Find A Grave

Robert Lieber

BIRTH	6 May 1926
DEATH	6 Jan 2008 (aged 81)
BURIAL	Body donated to medical science
MEMORIAL ID	23851216 ·

Burlington County Times - Medford, NJ resident
Robert Lieber, born May 6th, 1926 in Philadelphia, died January 6th, 2008. He served in the Army in WWII, Fighting from France to
Belgium to Luxembourg to Germany After the war, he earned a degree in Engineering from the University of Miami, and later a Masters Degree in Systems Engineering from Drexel University. He had a long and successful career at RCA, where he earned three Technical Excellence awards for his ground breaking role in developing a satellite tracking and fire-control radars at their Moorestown plant. Bob also received a patent for the early design of circuit boards, which helped revolutionize the manufacture of electrical equipment, contributed to a radar textbook, and at the pinnacle of his career, was awarded the General Sarnoff gold medal for excellence of achievement for all of RCA.
Above all, Bob was the most caring, devoted, and loving husband, father, friend, and brother-in-law of Marc and Carolyn Shuman He served as a wonderful role model for his children, Lee, Charles, and Ellen and his beloved grandchildren, Alex and Sara. To him, there was no such thing as a stupid question. He always had a patient and clear response to every query.
He was noted for his sharp, dry, self deprecating wit and readiness to give credit to
others When he became ill, those who had worked with him (he never said for him) called and visited to tell him that he was the best "boss" they ever had, and that they loved him.
Throughout the fifty-four years of marriage to Matsy (Marlene), he gave 100% of his love and devotion. Their marriage was one "made in heaven." It was love at first sight from their initial blind date. Bob's other love, besides his family and a succession of dogs and cats, was designing, building, and flying model airplanes He started as a young teenager and was a national champion at 13. He and his sons continued this hobby, traveling across the country and to Europe to compete.
Bob retired early in order to spend more time with his family and his model planes. He, Matsy, and Ellen traveled to six continents and were planning a trip to the 7th when he became ill
Those wishing to honor his memory are requested to help someone in need. In keeping with Bob's giving nature, he had donated his body to science.
January 8, 2008 12:00 AM

Maintained by: Find a Grave
Originally Created by: Jo Bohony
Added: 8 Jan 2008
Find a Grave Memorial **23851216**

Robert Lieber

RESOURCES
More Obituaries for Robert Lieber
Looking for an obituary for a different person with this name?

LIEBER
ROBERT, born May 6th, 1926 in Philadelphia, died January 6th, 2008 He served in the Army in WWII, Fighting from France to Belgium to Luxemburg to Germany. After the war he earned a degree in Engineering from the University of Miami, and later a Masters Degree in Systems Engineering from Drexel University. He had a long and successful career at RCA, where he earned 3 Technical Excellence awards for his groundbreaking role in developing satellite tracking and fire-control radars at their Moorestown plant. Bob also received a patent for the early design of circuit boards which helped revolutionize the manufacture of electrical equipment, contributed to a radar textbook, and at the pinnacle of his career was awarded the General Sarnoff gold medal for excellence of achievement for all of RCA.
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Throughout the 54 years of his marriage to Matsy (Marlene) he gave 100% of his love and devotion. Their marriage was one "made in heaven". It was love at first sight from their initial blind date. Bob's other love besides his family and a succession of dogs and cats was designing, building, and flying model airplanes. He started as a young teenager and was a national champion at 13. He and his sons continued this hobby; traveling across this country and to Europe to compete.
Bob retired early in order to spend more time with his family and his model planes. He, Matsy and Ellen traveled to 6 continents and were planning a trip to the 7th when he became ill. Those wishing to honor his memory are requested to help someone in need. In keeping with Bob's giving nature, he has donated his body to science. There will be no funeral.

Published on inquirer.com on Jan. 9, 2008

Print

REMEMBER

Share memories or express condolences below.

THE GUEST BOOK IS EXPIRED

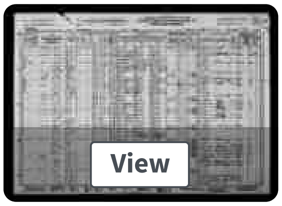
Please restore the Guest Book to share in the life story for ROBERT LIEBER

RESTORE THE GUEST BOOK

ancestry

Sophie Leiber

in the 1930 United States Federal Census



View blank form

Add alternate information

Report issue

Name:	Sophie Leiber [Sylvan Leiber]
Birth Year:	abt 1897
Gender:	Female
Race:	White
Birthplace:	Pennsylvania
Marital status:	Married
Relation to Head of House:	Wife
Homemaker?:	Yes
Home in 1930:	Philadelphia, Philadelphia, Pennsylvania, USA
Map of Home:	View Map
Street address:	Pine Street
Ward of City:	46
Block:	211
House Number:	6223
Family Number:	48
Age at first Marriage:	24
Attended School:	No
Able to Read and Write:	Yes
Father's Birthplace:	Pennsylvania
Mother's Birthplace:	Russia
Able to Speak English:	Yes

Household Members:

Name	Age
Leo Leiber	50
Sophie Leiber	33
Sylvon Leiber	21
Ruth Leiber	18
Robert Leiber	3

Neighbors: View others on page

Save & create tree Cancel

Source Citation

Year: *1930*; Census Place: *Philadelphia, Philadelphia, Pennsylvania*; Page: *10A*; Enumeration District: *0513*; FHL microfilm: *2341874*

Source Information

Ancestry.com. *1930 United States Federal Census* [database on-line]. Provo, UT, USA: Ancestry.com Operations Inc, 2002.

Original data: United States of America, Bureau of the Census. *Fifteenth Census of the United States, 1930*. Washington, D.C.: National Archives and Records Administration, 1930. T626, 2,667 rolls.

Description

The 1930 Census contains records for approximately 123 million Americans. The census gives us a glimpse into the lives of Americans in 1930, and contains information about a household's family members and occupants including: birthplaces, occupations, immigration, citizenship, and military service. The names of those listed in the census are linked to actual images of the 1930 Census. Learn more...

NATIONAL ARCHIVES

Provided in association with National Archives and Records Administration

Suggested Records

1900 United States Federal Census
Sophia Malason

1940 United States Federal Census
Sophia Lieber

1920 United States Federal Census
Sophie Moleson

U.S., Social Security Death Index, 1935-2014
Sophia Lieber

Philadelphia, Pennsylvania, Marriage Index, 1885-1951
Sophia Maleson

Pennsylvania, Marriages, 1852-1968
Maleson

New Jersey, Death Index, 1901-2017
Sophia Lieber

Pennsylvania, Federal Naturalization Records, 1795-1931
Fannie

Web: Burlington County, New Jersey, Death Index, 1814-2010
Sophia Lieber

1910 United States Federal Census
Sophia Muleson

U.S. City Directories, 1822-1995
Sophia Lieber

Write a comment.

Make a Connection

Form 15-6

DEPARTMENT OF COMMERCE—BUREAU OF THE CENSUS

FIFTEENTH CENSUS OF THE UNITED STATES: 1930

POPULATION SCHEDULE

State: Pennsylvania
County: Philadelphia
Township or other division of county:
Incorporated place: City of Philadelphia
Ward of city: 46 Block No. 211
Unincorporated place:
Institution:

Enumeration District No. 51-513
Supervisor's District No. 30
Sheet No. 10A 102
Enumerated by me on April 24, 1930, Morey Field, Enumerator.

2676

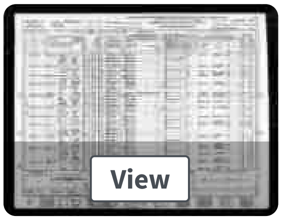
Line	Street (1)	House number (2)	Dwelling (3)	Family (4)	Name (5)	Relation (6)	Home owned or rented (7)	Value or rental (8)	Radio set (9)	Farm (10)	Sex (11)	Color or race (12)	Age (13)	Marital condition (14)	Age at first marriage (15)	Attended school (16)	Read and write (17)	Birthplace: Person (18)	Father (19)	Mother (20)	Mother tongue (21)	A	B	C	Year of immigration (22)	Naturalization (23)	Speak English (24)	Occupation (25)	Industry (26)	Code D	Class of worker (27)	Employed (28)	Unemployment line (29)	Veteran (30)	War (31)	Farm schedule (32)
1		6205			Goldberg, Henry	Head	O	9000	R		M	W	75	Wd		no	yes	Russia	Russia	Russia	Jewish	35	19	V	1895	Na	yes	Real estate	agent	8286	W	yes		no		
2					, Eve	daughter H					F	W	24	S		no	yes	Pennsylvania	Russia	Russia		58	19	0			yes	none								
3		6207			Naythons, Joseph	Head	O	9000	R		M	W	33	M	25	no	yes	Pennsylvania	Russia	Russia		58	19	0			yes	Clerk office	City tax office	7X93	W	yes		yes	WW	
4					, Pearl	Wife H					F	W	28	M	20	no	yes	Pennsylvania	Russia	Russia		58	19	0			yes	none								
5	Pine Street				, Bernice	daughter					F	W	6	S	—	yes	—	Pennsylvania	Pennsylvania	Pennsylvania		58					—	none								
6		6209			Klein, Samuel	Head	O	6000	R		M	W	36	M	23	no	yes	Delaware	Delaware	Delaware		71					yes	agent	life insurance	8885	W	yes		no		
7					, Lillian	Wife H					F	W	34	M	21	no	yes	Pennsylvania	Pennsylvania	Pennsylvania		58					yes	none								
8					, Betty	daughter					F	W	12	S	—	yes	yes	Pennsylvania	Delaware	Pennsylvania		58					yes	none								
9					, Shirley	daughter					F	W	5	S	—	no	—	Pennsylvania	Delaware	Pennsylvania		58					—	none								
10		6211			Shengold, Samuel	Head	O	6000	R		M	W	57	M	18	no	yes	Russia	Russia	Russia	Jewish	35	19	V	1891	Na	yes	tin smith	wholesale tinware	3790	W	yes		no		
11					, Esther	Wife H					F	W	57	M	18	no	yes	Russia	Russia	Russia	Jewish	35	19	V	1891	Na	yes	none								
12					Caplan, Daniel	boarder					M	W	25	S		no	yes	Pennsylvania	Russia	Pennsylvania		58	19	1			yes	salesman	retail gents furnishing	4590	W	yes		no		
13					, Joseph	boarder					M	W	23	S		no	yes	Pennsylvania	Russia	Pennsylvania		58	19	1			yes	salesman	insurance	8885	W			no		
14		6213			Swartz, Charles	Head	O	7500	R		M	W	37	M	24	no	yes	Poland	Poland	Poland	Jewish	35	14	V	1893	Na	yes	Jobber	wholesale shoes	9991	[illegible]	yes		no		
15					, Sadie	Wife H					F	W	33	M	20	no	yes	Pennsylvania	Russia	Russia		58	19	0			yes	none								
16					, Miriam	daughter					F	W	11	S	—	yes	yes	Pennsylvania	Poland	Pennsylvania		58	14	1			yes	none								
17					, Natalie	daughter					F	W	5	S	—	no		Pennsylvania	Poland	Pennsylvania		58	14	1			—	none								
18					Van Buskirk, Mary	servant					F	W	32	S		no	yes	Ohio	Ohio	Ohio		59					yes	servant	private family	9596	W	yes				
19		6215			Jaffe, Rebecca	Head H	M	Un			F	W	44	Wd		no	yes	Russia	Russia	Russia	Jewish	35	19	V	1906	Na	yes	none								
20					, Samuel	son					M	W	23	S		no	yes	Russia	Russia	Russia	Jewish	35	19	V	1906	Na	yes	salesman	retail cigars	4590	W	yes		no		
21					, Jacob	son					M	W	22	S		no	yes	Pennsylvania	Russia	Russia		58	19	0			yes	salesman	retail cigars	4590	W	yes		no		
22					, Charles	son					M	W	20	S		no	yes	Pennsylvania	Russia	Russia		58	19	0			yes	salesman	retail cigars	4590	W	yes		no		
23		6217			Rosenblum, David	Head	O	7500	R		M	W	50	M	28	no	yes	Russia	Russia	Russia	Jewish	35	19	V	1904	Na	yes	Jeweler	wholesale jewelry	8664	W	yes		no		
24					, Minnie	Wife H					F	W	45	M	23	no	yes	Russia	Russia	Russia	Jewish	35	19	V	1904	Na	yes	none								
25					, Irving	son					M	W	22	S		no	yes	Pennsylvania	Russia	Russia		58	19	0			yes	salesman	wholesale jewelry	4590	W	yes				
26					, Israel	son					M	W	20	S		no	yes	Pennsylvania	Russia	Russia		58	19	0			yes	salesman	wholesale jewelry	4590	W	yes				
27					, Ida	daughter					F	W	19	S		no	yes	Pennsylvania	Russia	Russia		58	19	0			yes	none								
28					, Gertrude	daughter					F	W	17	S		yes	yes	Pennsylvania	Russia	Russia		58	19	0			yes	none								
29		6219			Marmon, Isadore	Head	O	6000	R		M	W	41	M	19	no	yes	Russia	Russia	Russia	Jewish	35	19	V	1899	Na	yes	wholesaler	shoes mfg.	7239	[illegible]	yes		no		
30					, Ida	Wife H					F	W	40	M	19	no	yes	Russia	Russia	Russia	Jewish	35	19	V	1899	Na	yes	none								
31					, Betty	daughter					F	W	5	S	—	yes	—	Pennsylvania	Russia	Russia		58	19	0			—	none								
32					, Maurice	son					M	W	21	S		yes	yes	Pennsylvania	~~Pennsylvania~~ Russia	~~Pennsylvania~~ Russia		58	19	0			yes	none								
33					, Leon	son					M	W	15	S		yes	yes	Pennsylvania	~~Pennsylvania~~ Russia	~~Pennsylvania~~ Russia		58	19	0			yes	none								
34		6221			Savit, Joseph	Head	O	5500	R		M	W	60	M		no	yes	Russia	Russia	Russia	Jewish	35	19	V	1910	Na	yes	motor mechanic	motor brushes mfg.	7622	W	yes		no		
35					, Ida	Wife H					F	W	51	M		no	yes	Russia	Russia	Russia	Jewish	35	19	V	1910	Na	yes	none								
36					, David	son					M	W	29	S		no	yes	Pennsy	Russia	Russia	Jewish	35	19	V	1910	Na	yes	salesman	wholesale cheese	4590	W	yes		no		
37					, William	son					M	W	26	S		no	yes	Russia	Russia	Russia	Jewish	35	19	V	1910	Na	yes	salesman	shoe wholesale	4590	W	yes		no		
38					, Jay	son					M	W	27	S		no	yes	Russia	Russia	Russia	Jewish	35	19	V	1910	Na	yes	musician	Phila Orchestra	827V	W	yes		no		
39					, David	nephew					M	W	31	S		no	yes	Russia	Russia	Russia	Jewish	35	19	V	1910	Na	yes	salesman	shoe wholesale	4590	W	yes		no		
40		6223			Leolieber, Leo	Head	O	5500	R		M	W	50	M	20	no	yes	Russia	Russia	Russia	Jewish	35	19	V	1895	Na	yes	manufacturer	candy mfg	7213	[illegible]	yes		no		
41					Leiber, Sophie	Wife H					F	W	33	M	24	no	yes	Pennsylvania	Pennsylvania	Russia		58	19	2			yes	none								
42					, Sylvan	son					M	W	21	S		no	yes	Pennsylvania	~~Pennsylvania~~ Russia	Pennsylvania		58	19	1			yes	sheet metal mechanic	sheet metal shop	3735	W	yes		no		
43					, Ruth	daughter					F	W	18	S		no	yes	Pennsylvania	~~Pennsylvania~~ Russia	Pennsylvania		58	19	1			yes	Stenographer	pamphlet printing office	7149	W	yes				
44					, Robert	son					M	W	3	S	—	no	—	Pennsylvania	~~Pennsylvania~~ Russia	Pennsylvania		58	19	1			—	none								
45		6225			Forner, Max	Head	O	5500	R		M	W	57	M	32	no	yes	Russia	Russia	Russia	Jewish	35	19	V	1890	Na	yes	none								
46					, Esther	Wife H					F	W	54	M	19	no	yes	Russia	Russia	Russia	Jewish	35	19	V	1890	Na	yes	none								
47					, Frances	daughter					F	W	26	S		no	yes	Pennsylvania	~~Pennsylvania~~ Russia	~~Pennsylvania~~ Russia		58	19	0			yes	Stenographer	Real Estate	7186	W	yes				
48					, Goldie	daughter					F	W	22	S		no	yes	Pennsylvania	~~Pennsylvania~~ Russia	~~Pennsylvania~~ Russia		58	19	0			yes	Stenographer	Lawyers office	7194	W	yes				
49					, Anne	daughter					F	W	20	S		no	yes	Pennsylvania	~~Pennsylvania~~ Russia	~~Pennsylvania~~ Russia		58	19	0			yes	Stenographer	Lawyers Office	7194	W	yes				
50					, Joseph	son					M	W	16	S		yes	yes	Pennsylvania	~~Pennsylvania~~ Russia	~~Pennsylvania~~ Russia		58	19	0			yes	none								

ABBREVIATIONS TO BE USED IN COLUMNS INDICATED: [Use no abbreviations for State or country of birth or for mother tongue (Columns 18, 19, 20, and 21)]
Col. 6—Indicate the home-maker in each family by the letter "H," following the word which shows the relationship, as "Wife—H". Col. 7—Owned O, Rented R. Col. 9—Radio set R; Make no entry for families having no radio set. Col. 11—Male M, Female F. Col. 12—White W, Negro Neg, Mexican Mex, Indian In, Chinese Ch, Japanese Jp, Filipino Fil, Hindu Hin, Korean Kor; Other races, spell out in full. Col. 14—Single S, Married M, Widowed Wd, Divorced D. Col. 23—Naturalized Na, First papers Pa, Alien Al. Col. 27—Employer E, Wage or salary worker W, Working on own account O, Unpaid worker, member of the family NP. Col. 31—World War WW, Spanish-American War Sp, Civil War Civ, Philippine Insurrection Phil, Boxer Rebellion Box, Mexican Expedition Mex.

ENTRIES ARE REQUIRED IN THE SEVERAL COLUMNS AS FOLLOWS: Cols. 6, 11, 12, 13, 14, 16, 18, 19, 20, and 25—For all persons. Cols. 7, 8, 9, and 10—For heads of families only. (Col. 8 requires no entry for a farm family.) Col. 15—For married persons only. Col. 17—For all persons 10 years of age and over. Cols. 21, 22, and 23—For all foreign-born persons. Col. 24—For all persons 10 years of age and over. Cols. 26, 27, and 28—For all persons for whom an occupation is reported in Col. 25. Col. 30—For all males 21 years of age and over.

Robert Lieber

in the 1940 United States Federal Census



View blank form

Add alternate information

Report issue

Name:	Robert Lieber
Age:	13
Estimated birth year:	abt 1927
Gender:	Male
Race:	White
Birthplace:	Pennsylvania
Marital status:	Single
Relation to Head of House:	Son
Home in 1940:	Philadelphia, Philadelphia, Pennsylvania
Map of Home in 1940:	View Map
Street:	Pine Street
House Number:	6223
Inferred Residence in 1935:	Philadelphia, Philadelphia, Pennsylvania
Residence in 1935:	Same House
Sheet Number:	12B
Attended School or College:	No
Highest Grade Completed:	Elementary school, 8th grade
Neighbors:	View others on page
Household Members:	

Name	Age
Leo Lieber	59
Sophia Lieber	40
Ruth Lieber	28
Robert Lieber	13

Save & create tree Cancel

Source Citation

Year: *1940*; Census Place: *Philadelphia, Philadelphia, Pennsylvania*; Roll: *m-t0627-03748*; Page: *12B*; Enumeration District: *51-1963*

Source Information

Ancestry.com. *1940 United States Federal Census* [database on-line]. Provo, UT, USA: Ancestry.com Operations, Inc., 2012.

Original data: United States of America, Bureau of the Census. *Sixteenth Census of the United States, 1940*. Washington, D.C.: National Archives and Records Administration, 1940. T627, 4,643 rolls.

Description

The 1940 United States Federal Census is the largest census released to date and the most recent census available for public access. The census gives us a glimpse into the lives of Americans in 1940, with details about a household's occupants that include birthplaces, occupations, education, citizenship, and income. Learn more...

NATIONAL ARCHIVES

Provided in association with National Archives and Records Administration

Suggested Records

- U.S., Social Security Death Index, 1935-2014
  Robert Lieber
- New Jersey, Death Index, 1901-2017
  Robert I Lieber
- U.S., Obituary Collection, 1930-Current
  Robert Lieber
- 1930 United States Federal Census
  Robert Leiber
- Global, Find A Grave Index for Burials at Sea and other Select Burial Locations, 1300s-Current
  Robert Lieber
- U.S., Department of Veterans Affairs BIRLS Death File, 1850-2010
  Robert Lieber
- U.S. WWII Draft Cards Young Men, 1940-1947
  Robert Lieber
- Pennsylvania, Veteran Compensation Application Files, WWII, 1950-1966
  Robert Lieber
- Web: Burlington County, New Jersey, Death Index, 1814-2010
  Robert Lieber

Write a comment.

Make a Connection

Find others who are researching Robert Lieber in Public Member Trees

W-154-B

Single

1C Dec

FORM APPROVED
Budget Bureau No. 33-R012-42

REGISTRATION CARD (Men born on or after July 1, 1924, and on or before December 31, 1924)
(Also for the registration of men as they reach the 18th anniversary of the date of their birth on or after January 1, 1943.)

SERIAL NUMBER	1. NAME (Print)			ORDER NUMBER
W-154-B	ROBERT (First)	(None) (Middle)	LIEBER (Last)	13001B

2. PLACE OF RESIDENCE (Print)
1907 E. Marshall Rd., Drexel Plaza, Lansdowne P.O. Pa.
(Number and street) (Town, township, village, or city) (County) (State)

[THE PLACE OF RESIDENCE GIVEN ON LINE 2 ABOVE WILL DETERMINE LOCAL BOARD JURISDICTION; LINE 2 OF REGISTRATION CERTIFICATE WILL BE IDENTICAL]

3. MAILING ADDRESS
same
(Mailing address if other than place indicated on line 2. If same, insert word same)

4. TELEPHONE	5. AGE IN YEARS	6. PLACE OF BIRTH
Clearbrook 5044 J	20	Philadelphia (Town or county)
(Exchange) (Number)	DATE OF BIRTH: May 6, 1926 (Mo.) (Day) (Yr.)	Pa. (State or country)

7. NAME AND ADDRESS OF PERSON WHO WILL ALWAYS KNOW YOUR ADDRESS
Mr. Leo Lieber, 1907 E. Marshall Rd. Drexell Plaza, Pa. (Father)

8. EMPLOYER'S NAME AND ADDRESS
Unemployed veteran

9. PLACE OF EMPLOYMENT OR BUSINESS

(Number and street or R. F. D. number) (Town) (County) (State)

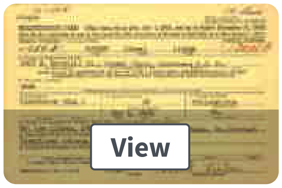
I AFFIRM THAT I HAVE VERIFIED ABOVE ANSWERS AND THAT THEY ARE TRUE.

Robert Lieber
(Registrant's signature)

DSS Form 1 (Rev. 11-16-42) 16—21630-4 (OVER) ancestry

Leo Lieber

in the U.S. WWII Draft Cards Young Men, 1940-1947



Add alternate information

Report issue

Name:	Leo Lieber
Gender:	Male
Relationship to Draftee:	Father
Registration Place:	Pennsylvania, USA
Next of Kin:	Robert Lieber

Household Members:

Name	Relationship
Robert Lieber	Self (Head)
Leo Lieber	Father

Save & create tree Cancel

Source Citation

The National Archives in St. Louis, Missouri; St. Louis, Missouri; *WWII Draft Registration Cards for Pennsylvania, 10/16/1940-03/31/1947*; Record Group: *Records of the Selective Service System, 147*; Box: *1477*

Source Information

Ancestry.com. *U.S. WWII Draft Cards Young Men, 1940-1947* [database on-line]. Lehi, UT, USA: Ancestry.com Operations, Inc., 2011.

Original data:

View Sources.

Description

This database contains World War II draft registration cards from multiple registrations filled out by men in select states aged 18–44.
Learn more...

NATIONAL ARCHIVES

Provided in association with National Archives and Records Administration

Suggested Records

1920 United States Federal Census
Leo Lieber

1930 United States Federal Census
Leo Leiber

1940 United States Federal Census

Leo Lieber

- Pennsylvania, Birth Certificates, 1906-1911
  Leo Lieber
- Pennsylvania, Death Certificates, 1906-1967
  Leo Lieber
- Pennsylvania, Birth Certificates, 1906-1911
  Geo Lieber
- Philadelphia, Pennsylvania, Marriage Index, 1885-1951
  Leo Lieber
- U.S., World War II Draft Registration Cards, 1942
  Leo Lieber
- Pennsylvania, Marriages, 1852-1968
  Leo Lieber
- 1910 United States Federal Census
  Leo Lieber
- U.S., Social Security Applications and Claims Index, 1936-2007
  Leo Lieber
- U.S., World War I Draft Registration Cards, 1917-1918
  Leo Leibers
- The Philadelphia Jewish Exponent Obituary Index, 1887-2006
  Leo Lieber
- Newspapers.com Obituary Index, 1800s-current
  Leo Lieber
- U.S. City Directories, 1822-1995
  Leo Lieber

Write a comment.

Make a Connection

Find others who are researching Leo Lieber in Public Member Trees

Form No. 1 -10

COMMONWEALTH OF PENNSYLVANIA
WORLD WAR II VETERANS' COMPENSATION BUREAU

APPLICATION FOR WORLD WAR II COMPENSATION—TO BE USED BY HONORABLY DISCHARGED VETERAN OR PERSON STILL IN SERVICE

IMPORTANT—Before Filling Out This Form Study it Carefully.
Read and Follow Instructions—Print Plainly in Ink or Use Typewriter. DO NOT Use Pencil—All Signatures Must Be in Ink.

1—Name of Applicant.
LIEBER ROBERT
Last / First / Middle or Initial

2—Address to Which CHECK and MAIL is to be Sent. 23
1907 E. MARSHALL RD. LANSDOWNE DEL. PA.
House No. St. R. D. P. O. Box / City or Town / County / State

3—Date and Place of Birth.
MAY 6 1926 PHILADELPHIA PENNA.
Month / Day / Year / City or Town / County / State

4—Name Under Which Applicant Served In World War II.
LIEBER ROBERT
Last / First / Middle or Initial

5—Date of Beginning and Date of Ending of Each Period of Service Between December 7, 1941 and March 2, 1946 (Both Dates Inclusive) During Which Applicant Was In DOMESTIC SERVICE.

18 JUNE 1944. 6m - 15da ~~3~~ 2 JANUARY 45
Date of Beginning / Date of Ending

6—Date of Beginning and Date of Ending of Each Period of Service Between December 7, 1941 and March 2, 1946 (Both Dates Inclusive) During Which Applicant Was In FOREIGN SERVICE.

3 JANUARY 45 13m - 31da 2 MAR. ~~12 MAY~~ 46
Date of Beginning / Date of Ending

7—Date and Place Applicant Entered Active Service.
JUNE 18 1944 PHILADELPHIA PA.
Month / Day / Year / Place

Applicant Must Not Write In Space Below

MAY 4 1950
Date Application Was Received

Batch Control Number
17096

Active Domestic Service
Months 7 $ 70.
Days $
Amount Due $ 70.

Active Foreign Service
Months 14 $ 210.
Days $
Amount Due $ 210.

Total Amt. Due $ 280.00

Audited By E. Jacoby
Service Computed By D. Bailey
Amounts Extended By C. Jasolt

Approved For Payment
Date MAY 15 1950
For A. G. Wassell
For Aud. G. [illegible]
For S. T. Diego

Application Disapproved
By

8—Service or Serial Numbers Assigned To Applicant.
Service No's.
Serial No's. 13201 601

9—Date and Place Where Applicant Was Separated From Active Service.
MAY 17 1946 FORT DIX NEW JERSEY
Month / Day / Year / Place

10—Is Applicant Now Serving In Armed Forces On Active Duty? Yes No ✓
If Answer is YES— Be Sure To Have Certificate Executed And Filed With Application—See Instruction Sheet.

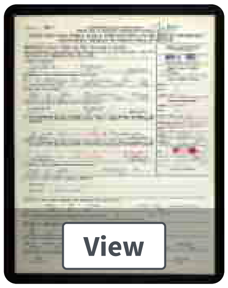
11—Mark "X" Above Name To Indicate Sex And Branch of Service.
X Male / Female / X Army / Navy / Marine Corps / Coast Guard / Other—Describe

12—Applicant's Residence At Time of Entry Into Active Service.
6223 PINE STREET PHILADELPHIA PENNA.
House No. / Street / R. D. / P. O. Box / City or Town / County / State

13—Applicant Was Registered Under Selective Service As Follows.
58 LANSDOWNE DELAWARE PENNA.
Draft Board No. / City or Town / County / State

Robert Lieber

in the Pennsylvania, Veteran Compensation Application Files, WWII, 1950-1966



Add alternate information

Report issue

Name:	Robert Lieber
Birth Date:	6 May 1926
Birth Place:	Philadelphia
Residence Date:	4 May 1950
Residence Place:	Lansdowne, Delaware, Pennsylvania, USA

Save & create tree   Cancel

Source Information

Ancestry.com. *Pennsylvania, Veteran Compensation Application Files, WWII, 1950-1966* [database on-line]. Provo, UT, USA: Ancestry.com Operations, Inc., 2015.

Original data: Pennsylvania (State). World War II Veterans Compensation Applications, circa 1950s. Records of the Department of Military and Veterans Affairs, Record Group 19, Series 19.92 (877 cartons). Pennsylvania Historical and Museum Commission, Harrisburg, Pennsylvania.

Description

Following World War II, the Commonwealth of Pennsylvania paid honorably discharged and veterans still in service bonus compensation. This collection includes Veterans Compensation Application Files. Learn more...

Pennsylvania Historical and Museum Commission

Suggested Records

U.S., Social Security Death Index, 1935-2014
Robert Lieber

New Jersey, Death Index, 1901-2017
Robert I Lieber

U.S., Obituary Collection, 1930-Current
Robert Lieber

1930 United States Federal Census
Robert Leiber

Global, Find A Grave Index for Burials at Sea and other Select Burial Locations, 1300s-Current
Robert Lieber

U.S., Department of Veterans Affairs BIRLS Death File, 1850-2010
Robert Lieber

1940 United States Federal Census
Robert Lieber

U.S. WWII Draft Cards Young Men, 1940-1947
Robert Lieber

Web: Burlington County, New Jersey, Death Index, 1814-2010
Robert Lieber

Write a comment.

Make a Connection

Find others who are researching Robert Lieber in Public Member Trees

LEO LIEBER

Leo Lieber, a candy manufacturer at 854 N. 8th st. for 50 years prior to his retirement two years ago, died Wednesday night at his home in the Parkway House, 2201 Parkway. He was 75. Funeral services will be held at 11 A. M. today in the Chapel of West Laurel Hill Cemetery.

CITATION:

Leo Lieber. (d. Jun. 08, 1955). Obit. Jun. 10, b. Apr. 08, 1879 in Botchane, Rumania, Russian father & mother, emig. to USA 1895, d. Jun. 08, 1955 Age 75, 50-yr. candy manufacturer, father of Robert I. Lieber, grandfather of Charles M. Lieber. *The Philadelphia Inquirer*.

NAME:	LEO LIEBER
GENDER:	Male
BIRTH DATE:	Apr. 08, 1879
BIRTHPLACE:	Botchane, Rumania
DIED:	Jun. 08, 1955
DEATH PLACE:	Parkway House, 2201 Parkway, Philadelphia, Pennsylvania USA
AGE:	75
BURIAL DATE:	Jun. 10, 1955
BURIAL PLACE:	West Laurel Hill Cemetery

Leo Lieber

in the Newspapers.com Obituary Index, 1800s-current

View original image on Newspapers.com. (May require an additional subscription).

Add alternate information

Report issue

Name:	Leo Lieber
Gender:	Male
Death Age:	75
Birth Date:	abt 1880
Death Date:	Abt 1955
Death Place:	2201 Park-wav
Obituary Date:	10 Jun 1955
Obituary Place:	Philadelphia, Pennsylvania, United States of America

These facts were pulled from a record by a computer and may not be accurate. Obituary records often include facts for family members of the deceased, some of whom may be living.

Save & create tree Cancel

Source Citation

The Philadelphia Inquirer; Publication Date: *10/ Jun/ 1955*; Publication Place: *Philadelphia, Pennsylvania, USA*; URL: *https://www.newspapers.com/image/174536596/?article=a6dea276-fef7-48fe-8cd2-4ca6e1b81a70&focus=0.26202095,0.23713797,0.37456667,0.2885229&xid=2378*

Source Information

Ancestry.com. *Newspapers.com Obituary Index, 1800s-current* [database on-line]. Lehi, UT, USA: Ancestry.com Operations Inc, 2019.

Original data: See newspaper information provided with each entry.

Description

This database consists of facts extracted from obituaries found on Newspapers.com™ dating from the early 1800's to current. Learn more...

Newspapers.com by ancestry

Provided in association with Newspapers.com (subscription required).

Suggested Records

1920 United States Federal Census
Leo Lieber

1930 United States Federal Census

Leo Leiber

1940 United States Federal Census
Leo Lieber

Pennsylvania, Birth Certificates, 1906-1911
Leo Lieber

Pennsylvania, Death Certificates, 1906-1967
Leo Lieber

Pennsylvania, Birth Certificates, 1906-1911
Geo Lieber

U.S. WWII Draft Cards Young Men, 1940-1947
Leo Lieber

Philadelphia, Pennsylvania, Marriage Index, 1885-1951
Leo Lieber

U.S., World War II Draft Registration Cards, 1942
Leo Lieber

Pennsylvania, Marriages, 1852-1968
Leo Lieber

1910 United States Federal Census
Leo Lieber

U.S., Social Security Applications and Claims Index, 1936-2007
Leo Lieber

U.S., World War I Draft Registration Cards, 1917-1918
Leo Leibers

The Philadelphia Jewish Exponent Obituary Index, 1887-2006
Leo Lieber

U.S. City Directories, 1822-1995
Leo Lieber

Write a comment.

Make a Connection

Find others who are researching Leo Lieber in Public Member Trees

P. J. Wunderle, Executive, Dies

Dr. George W. Hawk Dies; Active as Penna. Surgeon

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The David Sarnoff O

The 1962 Individual Awards for Science and Engineering

R. D. Kell

R. D. KELL, a Fellow of the Technical Staff, RCA Laboratories, Princeton, N.J., is recipient of the 1962 David Sarnoff Outstanding Achievement Award in Science . . . *"for many outstanding contributions which continue to lead to major innovations in the field of television."*

MR. KELL, as early at 1926-27, while doing graduate work, implemented a complete operating television system. Then, joining RCA in 1930, he directed development of components for the present television system, including the first high-power, high-frequency television transmitter, the first Iconoscope camera, and the first remote-pickup and radio-relay facility. After W.W. II, his continuing television work included image-orthicon cameras and improved transmission techniques, important contributions to the rapid commercialization of television. In the early 1950's, he contributed significantly to the establishment of compatible color television as a complete working system. He continues to challenge television frontiers: His more recent contributions have been in color video-tape recording and color-television reproducers.

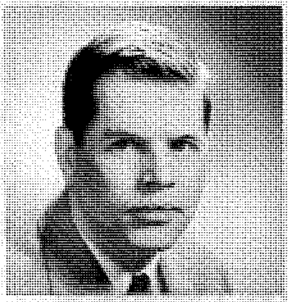
R. Lieber

R. LIEBER, Systems Engineering, Moorestown Missile and Surface Radar Division, Defense Electronic Products, Moorestown, N.J., is recipient of the 1962 David Sarnoff Outstanding Achievement Award in Engineering . . . *"for contributions to the field of high-precision space tracking and navigational systems."*

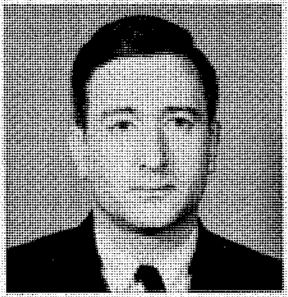
MR. LIEBER has contributed new and fundamental knowledge to high-accuracy prediction of satellite and missile position using surface-based tracking data, which opens new avenues to the solution of satellite tracking problems. He has made important advances in the integration of tracking, communication, and telemetry functions for support of space missions and has also pointed the way toward vehicle attitude determination from the earth. The applications for which he has developed solutions include ship, submarine, and aircraft navigation, and surveying of land locations. He has worked out commercial as well as military systems applications. As an Engineering Leader, he has demonstrated outstanding ability to plan the effort of and obtain maximum wholehearted support from the senior engineering personnel in his group.

The 1962 Tea

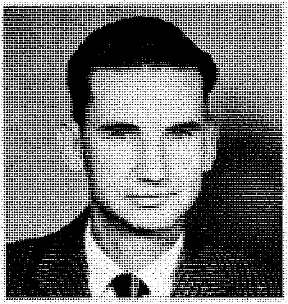
G. B. Herzog



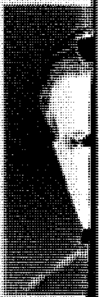
J. C. Miller

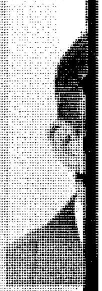


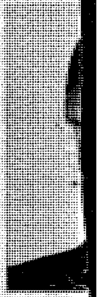
M. Berg



F. W. Peterson







utstanding Achievement Awards

h Awards for Science and Engineering

J. Lechner

M. H. Lewis

H. S. Miller

W. Mueller

H. Nelson

H. S. Sommers

G. B. HERZOG, R. J. LECHNER, M. H. LEWIN, H. S. MILLER, J. C. MILLER, C. W. MUELLER, H. NELSON, AND H. S. SOMMERS, of the RCA Laboratories, Princeton, N.J., are recipients of the 1962 David Sarnoff Outstanding Team Award in Science . . . *"for team performance in conceiving and developing devices, circuits, and memories for kilomegacycle computers."*

MESSRS. HERZOG, LECHNER, LEWIN, MILLER, MILLER, MUELLER, NELSON AND SOMMERS were members of a project team that undertook basic and exploratory research which has produced advances of great significance in high-speed (kilomegacycle) computers. Their work involved, among other things, a fundamental examination of phenomena and devices capable of extreme data-processing speeds. An important result of this work is basic knowledge about and circuit implementation of the tunnel diode; realization of tunnel-diode logic required the invention of entirely new concepts. The implications of this work for RCA's electronic-data-processing efforts in the future are considerable, for in addition to its significance on this project, their effort has produced a solid technological base upon which computers far beyond the present art can be built. Their work also has led to important basic knowledge and experience that may provide new commercial opportunities for tunnel and varactor diodes.

C. Block

B. Shrader

M. BERG, F. G. BLOCK, F. W. PETERSON, AND M. B. SHRADER, members of the Cermolox Power Tube Group, Electron Tube Division, Lancaster, Pa., are recipients of the 1962 David Sarnoff Outstanding Team Award in Engineering . . . *"for entirely new concepts in power tube construction which have resulted in compact, rugged, and more powerful ultra-high-frequency tubes."*

MESSRS. BERG, BLOCK, PETERSON, AND SHRADER were members of an engineering team that developed a new line of power tetrodes using ceramic envelopes and an internal construction permitting higher power dissipation, higher efficiency, and great ruggedness and compactness for space-age applications. The group achieved two important breakthroughs. The first was ceramic-to-metal seals of great strength which could be manufactured with ease and uniformity. This resulted in the desired compact and rugged external construction. The second was the conception and development of a revolutionary new method of making grids of precise alignment from materials with very high thermal conductivity, which gives the desired high efficiency at uhf and permits higher power output.

. . . About the Awards

RCA has chosen for its highest technical honors, the four *David Sarnoff Outstanding Achievement Awards* for 1962, a scientist, an engineer, a research team of eight scientists, and an engineering team of four engineers. The awards, to be formally announced by Dr. Elmer W. Engstrom, President of RCA, consist of a gold medal, a bronze replica citation, and a cash prize for each man.

The David Sarnoff Outstanding Achievement Awards for individual accomplishment in science and in engineering were established in 1956 to commemorate the fiftieth anniversary in radio, television, and electronics of Brigadier General David Sarnoff, RCA Chairman of the Board. These have been made annually since then to one scientist and one engineer.

The two awards for team performance were initiated in 1962.

All engineering activities of RCA divisions and subsidiary companies are eligible for the Engineering Awards. The Chief Engineers in each location may present nominations annually. Similarly, members of the research staff of the RCA Laboratories are eligible for the Science Awards. Nominations are made by the Research Directors.

The selection committee for both the individual and team awards in engineering includes: the Vice President, Research and Engineering, Chairman; the Staff Vice President, Product Engineering; the Director, Communications Engineering; the Vice President, RCA Laboratories; and the Vice President, Personnel.

The selection committee for both the individual and team awards in science consists of: the Vice President, Research and Engineering, Chairman; the Staff Vice President, Product Engineering; the Vice President, RCA Laboratories; the Associate Director, RCA Laboratories; and the Vice President, Personnel.

PARTIAL TRANSCRIPTION

R. LIEBER, Systems Engineering, Moorestown Missle and Surface Radar Division, Defense Electronic Products, Moorestown, N.J., is recipient of the 1962 David Sarnoff Outstanding Achievement Award in Engineering ... "for contributions to the field of high-precision space tracking and navigational systems.

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view RCA Engineer articles

by topic | by year | by author | by volume

Articles on Awards:

issue	page	authors	title	topics
Vol. 3 No. 4 Feb/Mar, 1958	2	Caulton, C. O.	Awards for engineers	Awards
Vol. 5 No. 5 Feb/Mar, 1960	30	RCA Engineer staff,	David Sarnoff outstanding achievement awards (1960)	Awards
Vol. 6 No. 5 Feb/Mar, 1961	28	RCA Engineer staff,	David Sarnoff outstanding achievement awards (1961)	Awards
Vol. 7 No. 6 Apr/May, 1962	32	RCA Engineer staff,	David Sarnoff outstanding achievement awards (1962)	Awards
Vol. 8 No. 6 Apr/May, 1963	40	RCA Engineer staff,	David Sarnoff outstanding achievement awards (1963)	Awards
Vol. 9 No. 6 Apr/May, 1964	44	RCA Engineer staff,	David Sarnoff outstanding achievement awards (1964)	Awards
Vol. 10 No. 6 Apr/May, 1965	42	RCA Engineer staff,	David Sarnoff outstanding achievement awards (1965)	Awards
Vol. 11 No. 6 Apr/May, 1966	48	RCA Engineer staff,	David Sarnoff outstanding achievement awards (1966)	Awards
Vol. 12 No. 6 Apr/May, 1967	50	RCA Engineer staff,	David Sarnoff outstanding achievement awards (1967)	Awards
Vol. 13 No. 6 Apr/May, 1968	48	RCA Engineer staff,	David Sarnoff outstanding achievement awards (1968)	Awards
Vol. 15 No. 6 Apr/May, 1970	48	RCA Engineer staff,	David Sarnoff outstanding achievement awards (1970)	Awards
Vol. 16 No. 6 Apr/May, 1971	56	RCA Engineer staff,	David Sarnoff outstanding achievement awards (1971)	Awards
Vol. 17 No. 6 Apr/May, 1972	56	RCA Engineer staff,	David Sarnoff outstanding achievement awards (1972)	Awards
Vol. 18 No. 6 Apr/May, 1973	48	RCA Engineer staff,	David Sarnoff outstanding achievement awards (1973)	Awards
Vol. 19 No. 6 Apr/May, 1974	48	RCA Engineer staff,	David Sarnoff outstanding achievement awards (1974)	Awards
Vol. 21 No. 1 June/July, 1975	48	RCA Engineer staff,	David Sarnoff outstanding technical achievement awards (1975)	Awards
Vol. 21 No. 6 Apr/May, 1976	46	RCA Engineer staff,	David Sarnoff outstanding technical achievement awards (1976)	Awards
Vol. 22 No. 6 Apr/May, 1977	40	RCA Engineer staff,	David Sarnoff outstanding technical achievement awards (1977)	Awards
Vol. 23 No. 5 Feb/Mar, 1978	100	RCA Engineer staff,	David Sarnoff outstanding technical achievement awards (1978)	Awards
Vol. 24 No. 5 Feb/Mar, 1979	4	RCA Engineer staff,	David Sarnoff outstanding technical achievement awards (1979)	Awards Engineer and the Corporation (Series)
Vol. 26 No. 1 July/Aug, 1980	4	RCA Engineer staff,	David Sarnoff Awards for Outstanding Technical Achievement (1980)	Awards
Vol. 26 No. 7 July/Aug, 1981	4	RCA Engineer staff,	David Sarnoff Awards for Outstanding Technical Achievement (1981)	Awards
Vol. 27 No. 1 Jan/Feb, 1982	4	RCA Engineer staff,	SelectaVision VideoDisc Awards	Awards VideoDisc, Capacitance electronic disc system
Vol. 27 No. 4 July/Aug, 1982	4	RCA Engineer staff,	David Sarnoff Awards for Outstanding Technical Achievement (1982)	Awards
Vol. 28 No. 4 July/Aug, 1983	4	RCA Engineer staff,	David Sarnoff Awards for Outstanding Technical Achievement, for 1983	Awards

RÉPUBLIQUE FRANÇAISE

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BREVET D'INVENTION

P.V. n° 894.097

N° 1.369.330

Classification internationale : G 06 *j* — G 06 *k*

Système d'exploitation de données. (Invention : Hans Karl FLESCH, Fredrick, Theodore GUTMANN et Robert LIEBER.)

Société dite : INTERNATIONAL STANDARD ELECTRIC CORPORATION résidant aux États-Unis d'Amérique.

Demandé le 11 avril 1962, à 14h 45m, à Paris.
Délivré par arrêté du 6 juillet 1964.
(*Bulletin officiel de la Propriété industrielle*, n° 33 de 1964.)

(*Demande de brevet déposée aux États-Unis d'Amérique le 27 avril 1961, sous le n° 106.090, aux noms de* MM. Hans Karl FLESCH, Fredrick Theodore GUTMANN *et* Robert LIEBER.)

La présente invention concerne les systèmes d'exploitation d'informations, et plus spécialement les systèmes où est effectuée l'inscription, sur des éléments d'affichage déterminés, d'informations concernant ou découlant d'éléments d'informations primaires. Bien qu'elle soit applicable à de nombreux systèmes d'exploitation d'informations, cette invention était à l'origine conçue et développée pour être utilisée dans le commerce et dans les banques pour la tenue à jour des comptes chèques. Dans ces systèmes, les éléments primaires sont des chèques et des feuilles de versement et les éléments secondaires des feuilles de registre tenues à jour en accord avec les indications de débit et de crédit portées sur un ou plusieurs éléments primaires qui leur sont associés. Les applications de cette invention à la comptabilité des services publics, à l'étude des statistiques, etc., et l'adaptation de l'appareil qui sera décrit, sont facilement réalisables grâce à la présente invention.

Trois opérations principales caractérisent et sont associées aux systèmes qui font l'objet de la présente invention. Ce sont, respectivement, une opération de tri dans lequel les éléments d'informations primaires sont groupés en accord avec une caractéristique commune, ici le nom du déposant, une opération de sélection dans laquelle un élément d'affichage ou élément secondaire, ici une feuille de registre, est associée à chaque groupe d'éléments primaires et une opération d'inscription par transfert dans laquelle les représentations des symboles d'informations découlant, directement ou indirectement, des éléments primaires, sont transférés sur les éléments secondaires associés. Ces opérations sont sujettes à trois sortes d'erreurs que l'on appelle erreurs de tri, de sélection et de transfert. La nature des deux premières sortes d'erreurs est indiquée dans leur désignation. La dernière erreur, erreur de transfert, peut être divisée en erreurs directes de transfert et erreurs indirectes, les premières caractérisant la mauvaise utilisation des symboles d'informations pendant une opération de transfert et les dernières l'omission ou la mauvaise utilisation d'un élément primaire qui ne permet pas l'opération de transfert ou aboutit à l'inscription d'un élément primaire sur plus d'un élément secondaire.

La présente invention concerne exclusivement la détection et la correction des erreurs de tri de sélection et des erreurs indirectes de transfert.

Si on considère les différentes sortes d'erreurs une par une, la technique utilisée jusqu'à présent pour éviter et corriger ces erreurs a été la suivante.

En premier lieu, en ce qui concerne les erreurs de tri, jusqu'à présent, la technique consistait à placer des symboles d'identification sur les éléments primaires avant de les donner à chaque déposant, ou bien, le déposant plaçait lui-même ces symboles avant toute chose. Ces symboles d'identification préalablement opposés sont ultérieurement utilisés pour grouper les éléments de chaque déposant, au moyen d'une opération manuelle ou automatique. De ce fait, les erreurs de tri se trouvent réduites. Il existe cependant des inconvénients, en particulier ces symboles préalablement opposés nécessitent une opération manuelle supplémentaire, qui est sujette à erreur. En outre, ces symboles n'ont aucune valeur lorsqu'une erreur non détectée a lieu, donc aucune valeur en ce qui concerne les erreurs de transfert indirect. De plus, ces symboles peuvent être altérés et effacés lorsque les éléments primaires sont relativement fragiles et fréquemment manipulés, comme dans le cas présent.

En second lieu, en ce qui concerne les erreurs de sélection, la technique jusqu'à présent consistait à comparer des symboles d'identification préalablement opposés sur les éléments secondaires avec ceux placés sur les éléments primaires pour voir s'ils sont semblables. Les critiques contre ce système ont été déjà formulées dans le paragraphe précédent, en outre ce système demande un dispositif supplémentaire capable de détecter les symboles d'identification primaires et secondaires, de conserver et de comparer ces symboles et de commander les opérations en accord avec ces résultats.

Finalement, en ce qui concerne les erreurs de transfert indirect, la technique jusqu'à maintenant consistait à pointer les opérations de transfert et les éléments primaires de manière à déterminer si chaque élément primaire avait été transféré. Mais ceci est coûteux en temps et en argent et ne suffit pas pour garantir qu'un élément primaire ne sera transféré qu'une fois et une seule.

La présente invention propose une solution économique et efficace aux problèmes exposés ci-dessus.

Une des caractéristiques de l'invention réside en un système d'exploitation d'informations comprenant des moyens d'inscription pour afficher sur un document secondaire des données figurant sur un document primaire, des moyens de détection pour extraire du document secondaire une information d'identité propre à ce dernier, des moyens associés auxdits moyens d'inscription et de détection pour transférer sur le document primaire ladite information d'identité afin d'identifier ledit document primaire en accord avec le document secondaire.

Une autre caractéristique de l'invention réside dans le fait que les moyens d'inscription comprennent des moyens de transfert pour porter sur un document secondaire sélectionné des informations extraites d'un document primaire, des moyens de positionnement pour placer ledit document secondaire en position nécessaire pour recevoir les informations primaires, des moyens de contrôle pour provoquer un mouvement relatif entre le document secondaire et les moyens de transfert corrélativement à la mise en place du document secondaire, d'autres moyens communiquant avec le document secondaire pour extraire ladite information d'identification, cette opération étant exécutée en association avec ledit mouvement.

Une autre caractéristique de l'invention réside dans le fait que le dispositif de détection servant à extraire l'identité du document secondaire comprend un ensemble de fil de transmission et des éléments opérant en liaison avec le document secondaire de manière à traduire électriquement l'information identifiant ledit document secondaire en faisant apparaître d'une façon appropriée une polarité sur certains desdits fils.

Une autre caractéristique de l'invention réside dans le fait qu'aux moyens de transfert et d'affichage sont associés des moyens pour empêcher l'inscription des informations primaires sur le document secondaire tant que l'information d'identité extraite dudit document secondaire n'a pas été transférée sur ledit document primaire.

Une autre caractéristique de l'invention consiste en un système d'exploitation d'informations comprenant des moyens de transcription pour afficher sur un document secondaire des informations extraites d'un document primaire, des moyens de détection pour extraire du document secondaire une information d'identité propre à ce dernier, des moyens de positionnement du document primaire et des moyens identificateurs en liaison avec lesdits moyens de positionnement pour afficher sur ledit document primaire l'information d'identité destinée à identifier le document primaire en concordance avec le document secondaire.

Une autre caractéristique de l'invention réside dans le fait que les moyens identificateurs servant à caractériser le document secondaire comprend des moyens de positionnement dudit document primaire pour que puisse y être effectuée l'inscription de l'information d'identité.

Une autre caractéristique de l'invention réside dans le fait que les moyens identificateurs comprennent des moyens de sélection de caractères en liaison avec les moyens de détection pour traduire l'information d'identité détectée, et des moyens de transfert communiquant avec lesdits moyens de sélection, de positionnement et d'inscription pour afficher sur ledit document primaire l'information d'identité extraite du document secondaire, ceci étant subordonné aux opérations de transfert des informations primaires sur le document secondaire et aux opérations de positionnement et du document primaire.

Une autre caractéristique de l'invention réside dans le fait que des moyens de commande sont adjoints aux éléments de sélection pour placer cesdits éléments de sélection dans une position prédéterminée pour opérer, corrélativement avec la mise en place du document secondaire.

Une autre caractéristique de l'invention réside dans le fait que des moyens de commande sont fournis aux éléments de sélection pour les rendre capables d'opérer ou les rendre inopérants corrélativement à la mise en place du document secondaire.

Une autre caractéristique de l'invention réside dans le fait que des moyens de blocage sont associés aux moyens de positionnement du document primaire pour empêcher l'accomplissement des opérations de transfert des informations primaires sur le document secondaire si le document primaire n'est pas convenablement placé dans le système de positionnement, des moyens de commande étant également associés au système d'inscription apposant l'information d'identification sur le document primaire pour autoriser leur fonctionnement en association avec les éléments d'inscription.

Une autre caractéristique de l'invention réside dans le fait que lesdits moyens de blocage comprennent des moyens de perception pour connaître la position du document primaire dans le système maintenant cedit document, et que lesdits moyens de commande comprennent des moyens de transmission pour transférer un signal de commande en accord avec le fonctionnement des moyens de transfert et en réponse à une information prédéterminée fournie par lesdits moyens de perception.

Une autre caractéristique de l'invention réside dans le fait que des moyens de blocage et de verrouillage sont fournis pour empêcher l'inscription sur le document secondaire des données extraites du document primaire si le transfert de l'information d'identification sur le document primaire ne peut s'effectuer.

Différentes autres caractéristiques ressortiront de la description qui va suivre, donnée à titre d'exemple non limitatif, en se reportant aux figures annexées qui représentent :

La figure 1, une vue d'ensemble qui explique le montage de l'ensemble et le fonctionnement des systèmes qui réalisent la présente invention;

La figure 2, une vue isométrique externe du dispositif d'exploitation et d'inscription des informations réalisé conformément à l'invention;

La figure 3, un schéma montrant le montage interne des composants du dispositif de la figure 2;

La figure 4, une vue isométrique de la face postérieure du système d'affichage 14*a* de la figure 2;

La figure 5, une vue isométrique de la partie supérieure gauche du couvercle 46 du système d'affichage de la figure 4, montrant un montage facultatif des pinces de guidage pour dévier le bras opérant du commutateur 181 pendant l'enlèvement d'une feuille de registre hors du système d'affichage 14*a*;

La figure 6 est une vue en coupe du dispositif de détection 16*a* et du système d'affichage 14*a* de la figure 2;

La figure 7 est une vue isométrique du support de came 88, montré schématiquement dans la figure 3 en relation avec le dispositif d'arrêt basculant 47;

Les figures 8A et 8B sont des vues en coupe de la touche de lecture 36 et d'une touche de commande 35, montrant les mécanismes de verrouillage et de déverrouillage qui leur sont associés;

La figure 9, une vue en coupe d'une roue des types et des mécanismes de mise en place et de remise en place du dispositif de transfert 17*a* de la figure 2;

La figure 10, une vue en élévation, le long de la ligne AA de la figure 9, avec les cliquets de détente selon la coupe le long de la ligne AA de la figure 9;

La figure 11, une vue le long de la ligne CC de la figure 10;

La figure 12, une vue le long de la ligne DD de la figure 10;

La figure 13, une vue isométrique des mécanismes d'impression dans le dispositif de transfert de la figure 2;

La figure 14, une vue partielle en coupe le long de la ligne 14-14 de la figure 13, montrant les détails des mécanismes de la figure 13;

La figure 15, un schéma en partie en élévation d'un dispositif auxiliaire, de détection du numéro du compte, réalisé conformément à la présente invention;

La figure 16, une vue de la plaque postérieure du système d'affichage dans le montage de la figure 15, comportant une coupe le long de la plateforme utilisée comme support vertical des feuilles de registre insérées;

La figure 17, une vue de la plaque antérieure du système d'affichage dans le montage de la figure 15;

La figure 18, une vue montrant l'association des cliquets avec les commutateurs et les roues des types à rochets conformément au mode de réalisation de la figure 15.

On va commencer la description en se reportant tout d'abord à la figure 1 qui représente un système de comptabilisation bancaire, désigné par le terme plus général de système d'inscription et d'exploitation d'informations. Ce système comprend des organes de commande qui font partie de l'ensemble portant la référence 1. On utilise l'ensemble 1 pour accomplir une opération d'inscription relative aux comptes chèques bancaires et une comptabilité complémentaire où se trouvent les renseignements sur le solde. Ces renseignements sont lus sur une feuille de registre 2, appelée dans l'invention élément secondaire; ils sont mis à jour conformément aux opérations de débit et de crédit principales lues sur les chèques et les feuilles de versement 3, appelés dans l'invention éléments primaires comme on l'a vu précédemment, les systèmes d'inscription et d'exploitation de données nécessitent des opérations de tri, de sélection et de transfert sujettes aux erreurs déjà citées. Dans l'exemple considéré, les chèques et les feuilles de versement sont groupés sous les noms des souscripteurs ou déposants. Les feuilles de registre correspondantes sont sélectionnées, pour la suite des opérations, et les informations de débit et de crédit principales dans chaque groupe de chèques et de feuilles de versement sont inscrites sur la feuille de registre correspondante et utilisées pour déduire de nouvelles informations sur le solde qui sont elles aussi inscrites. Ceci est représenté dans la figure 1 par les lignes en pointillé 4 et 5 qui représentent le transfert d'anciennes informations concernant le solde à partir des éléments 2 et 3. Une troisième ligne en pointillé 6, issue d'une source générale représentée schématiquement en 7, est utilisée pour représenter toutes les autres informations entrant dans l'ensemble 1 telles que la date d'inscription, la nature de la transaction et autres données du même genre. Comme il a été vu précédemment, la présente invention concerne les erreurs de groupement et de sélection, c'est-à-dire des erreurs de non-correspondance dans lesquelles les éléments primaires sont transcrits sur une feuille de registre qui n'est pas la bonne et les erreurs indirectes de transfert dans lesquelles les éléments primaires sont mal utilisés. L'originalité de l'invention est à l'inverse de l'ancienne technique qui consistait à détecter et empêcher ces erreurs, de laisser les erreurs se produire et aussi de transférer sur l'élément primaire une série de symboles d'identification propres à chaque élément pendant l'opération de transfert des données à inscrire. Lesdits symboles d'identification apparaissent immédiatement pour ceux qui plus tard examinent l'élément primaire pendant le cours normal des opérations bancaires. De ce fait l'absence de symboles d'identification ou la présence de plus d'un symbole d'identification indiquerait une erreur de transfert indirect, alors que la présence de symboles qui diffèrent des symboles d'identification de l'élément primaire sur le répertoire de dossiers indique une erreur de non-correspondance. Comme il a été indiqué précédemment la présente invention nécessite peu de procédures annexes et de ce fait est plus efficace que les techniques précédentes. Il est indiqué plus loin, et les banquiers en sont arrivés aux mêmes conclusions, que, malgré toutes les précautions prises dans les techniques précédentes, les erreurs de non-correspondance ont lieu, et lorsqu'une telle erreur survient, elle n'est découverte que lorsqu'un déposant mécontent vient signaler une erreur dans son relevé de solde. Même dans ce cas, une procédure difficile et longue est nécessaire pour localiser le compte du déposant victime de l'erreur.

La présente étude s'attache plus particulièrement aux dispositions de verrouillage, au moyen desquelles un élément primaire est associé avec un élément secondaire et un seul, que ce second élément soit approprié ou non.

Les dispositions de transfert et de verrouillage ci-dessous citées sont indiquées schématiquement dans la figure 1. L'ensemble 1 comprend un chariot 8, commandé et détecté par un dispositif de commande 9, comme l'indique la ligne 10. Le dispositif de commande 9 a été modifié et réalisé conformément à l'invention. Normalement, la feuille 2 serait directement placée entre les rouleaux du chariot 8, et déplacée latéralement par rapport à un dispositif d'impression non représenté dans la figure 1, l'information inscrite sur ce dispositif se trouvant transférée sur la feuille 2. Dans la présente invention, cette opération est précédée d'une opération de détection au cours de laquelle l'élément secondaire 2 est tout d'abord associé à un dispositif de transfert 11 comme l'indiquent les lignes en pointillé 12 et 13. L'élément 2 est placé dans un système d'affichage 14 à l'intérieur du dispositif 11 et, lorsqu'il est convenablement orienté, un signal « prêt » est envoyé à partir du système 14 vers le dispositif de commande 9, la voie de transmission étant indiquée en 15, lorsque ce signal est détecté, le dispositif de commande 9 actionne un système de détection, schématiquement indiqué en 16, qui détecte les symboles d'identification préalablement opposés sur l'élément secondaire, et transfère les signaux représentatifs à un dispositif d'enregistrement et de transfert 17 qui enregistre une représentation de ces signaux. L'association entre le dispositif de commande 9 et le système de détection 16 est illustrée en 18. Les lignes de communication entre le système d'affichage 14 et les systèmes 16 et 17 sont respectivement indiquées en 19 et 20. La sortie du dispositif 17 est indiquée en 21. Lorsque l'opération d'enregistrement est terminée, le dispositif de commande actionne le système d'affichage 14, cette association étant montrée en 22, ainsi la feuille 2 est libérée et glissée dans les rouleaux du chariot 8 pour l'opération suivante d'inscription. Pendant l'opération d'inscription, une opération inhabituelle a lieu. A chaque fois qu'une information est tirée d'un élément primaire 3, cet élément est inséré dans le système d'affichage 24 de manière à être associé avec le dispositif 17. On prévoit des commandes de verrouillage, représentées par la ligne 25, qui empêchent l'inscription de l'information tirée de l'élément primaire 3 jusqu'à ce que cet élément primaire soit convenablement placé dans le système d'affichage 24, et lorsque le transfert de l'information a lieu, le système 17 est actionné simultanément au moyen de l'envoi d'un signal sur la ligne 26, et transfère les symboles d'identification, concernant l'information enregistrée, à l'élément 3. L'élément 3 est alors manuellement ou automatiquement enlevé du système 24, ceci étant représenté par la ligne en pointillé 27.

Dans la figure 2, on trouve les différents attributs de l'ensemble 1 et le dispositif de transfert qui lui est associé. L'ensemble 1 comprend une base fixe 30, qui se prolonge en une partie 31 qui sert de support à un chariot 8 monté sur des rails non représentés. Le chariot a un mouvement de translation par rapport à la base fixe 30. La base fixe 30 comprend une pluralité de touches de 33 à 36. Les touches 33 servent à communiquer des renseignements secondaires tels que la date, la nature de la transaction et autres informations du même genre, à l'ensemble 1. Les touches 34 sont des touches au moyen desquelles les symboles des informations numériques sont sélectionnées pour être ensuite transférées dans l'ensemble 1. Les touches 35 sont des touches de commande qui permettent de transférer dans l'ensemble 1 les symboles sélectionnés par les touches 33 et 34. La touche 36 est une touche de lecture qui sera décrite ultérieurement. A l'intérieur de l'ensemble 30 se trouvent des organes enregistreurs et additionneurs non représentés, grâce auxquels on effectuera différents calculs sur les symboles sélectionnés par les touches 34 et transférés par les touches 35. A l'intérieur de la base fixe 30, schématiquement indiquées par le compartiment 37, se trouvent les roues ou barres des types 38 qui sont choisies en fonction des sélections effectuées par les touches 33 et 34, lorsque certaines des touches 35 sont actionnées. Les touches 35, en plus du transfert des symboles sélectionnés, dirigent le mouvement de translation latéral du chariot 8 par rapport à la base fixe 30 de manière à ce que les roues des types 38 soient placées en face de la partie appropriée du chariot, en vue d'imprimer le renseignement sélectionné ou calculé sur la feuille de registre insérée dans un rouleau 40 du chariot. Le rouleau 40 est actionné manuellement et sert à insérer verticalement un document, ici une feuille de registre 2 par rapport aux roues des types 38. La feuille 2, une fois mise en position par le rouleau 40 du chariot, est insérée dans une plaque de guidage 42 comprise normalement dans un tel appareil et qui peut faire contact ou non avec le rouleau 40. Cette plaque 42 comprend des rouleaux montés fous 43 qui s'opposent au rouleau 40 et de ce fait en tournant serrent la feuille 2 permettant ainsi son déplacement vertical. L'on voit d'après la figure 2 que pour insérer la feuille 2 entre les rouleaux 40 et 43, il est nécessaire, tout d'abord, d'insérer cette feuille dans un système d'affichage 14*a* qui se trouve juste au-dessus des rouleaux. L'indice *a* est utilisé lorsque l'on considère un mode de réalisation particulier du système 14. Le système d'affichage 14*a* est monté au moyen d'une applique 45 sur le chariot 8 et comprend une plaque transparente sur le devant et sur les côtés un système de guidage 46 qui permet de positionner une feuille 2 latéralement par rapport au système de détection 16*a* dont on a parlé dans la figure 1. Le système d'affichage 14*a* comprend un système d'arrêt basculeur qui peut prendre deux positions respectivement appelées position de blocage ou de déblocage, par rapport au système 14*a*. Dans la position de blocage, le système d'arrêt basculant 47 est intercalé sur le trajet vertical de la feuille 2 de manière à positionner verticalement cette feuille par rapport au système de détection précité 16*a*. Dans la position de non-blocage le système 47 est placé de manière à ne pas intervenir dans l'insertion verticale de cette feuille, de sorte que la feuille 2 peut continuer sa chute jusqu'aux rouleaux 40 et 43 du chariot 8. Le système de détection 16 tourne autour d'un pivot 50, fixé sur un support 51 qui prolonge la base fixe 30. Le système de détection 16*a* est normalement positionné de manière à ne pas être en contact avec le système d'affichage 14*a*, dans le but de protéger les éléments de détection et d'éviter un fonctionnement accidentel de ces éléments, entraînant un mauvais fonctionnement de la machine.

Comme on peut le voir dans la figure 2, le dispositif d'enregistrement et de transfert 17*a* comprend un compartiment séparé qui contient un système d'affichage 24*a* destiné à recevoir un élément primaire 3. Les roues des types 52, schématiquement représentées sont prévues pour transférer les symboles d'identification à chaque élément primaire 3 que l'on a glissé dans une fente 54 du système d'affichage 24*a*. Un plateau, 55 reçoit les éléments primaires qui s'empilent en 56 avant de subir les différentes opérations. Un réceptable 57 est prévu au bas du dispositif 17*a* pour récupérer les éléments primaires après que les opérations de transfert aient été réalisées. Il faut noter que ce réceptacle se détache facilement du dispositif 17*a*. Une feuille 2 attend dans le système d'affichage 14*a* d'être détectée par le système de détection 16*a*, ce dernier est montré au travail, dans cette position, il est basculé vers l'avant de manière à être contre la feuille 2. La feuille 2 comprend une partie du relevé du déposant 60 et une partie enregistrée 61, qui renseigne sur l'identité du déposant, c'est-à-dire donnent son nom, son adresse, son numéro de compte qui dans l'exempie considéré est 20 648. Ensuite cette feuille est subdivisée en 7 colonnes de 62 à 67, sur lesquelles s'impriment les indications reçues des roues des types 38 pendant l'opération d'inscription. Ces indications comportent respectivement un report du solde, le débit et le crédit, le solde actuel, des renseignements analytiques (tels que la date et la nature de la transaction) et en dernier lieu dans la colonne 67, le solde actuel est inscrit de nouveau pour être utilisé dans les écritures de la banque. La feuille 2 comporte des symboles d'identification préalablement apposés, dans la partie 68 qui se trouve dans le coin inférieur droit où est inscrit le numéro du compte, dans ce cas précis 20 648. Dans la présente invention, on a préféré traduire les données d'information sous forme de perforation comprenant des trous chacun étant placé dans une position déterminée choisie parmi les dix positions possibles d'une rangée horizontale située dans la région 68. Avec ce montage, lorsque le dispositif de détection est contre la feuille 2 et que le chariot se déplace vers la droite relativement au système de détection, l'aire perforée codée de la région 68 sert à établir une continuité électrique entre une plaque support conductrice du système d'affichage et les cinq balais du système

16*a*; de ce fait, elles transmettent cinq signaux qui sont envoyés à un temps déterminé en relation avec le nombre de chiffres du numéro de compte. L'appareil au moyen duquel s'effectuent les opérations de détection, d'avancement et de transfert avec l'aide des touches de commande 35, est décrit ci-dessous. Pour le moment, on notera que pendant l'opération de transfert ordinaire, la feuille 2 est placée verticalement dans le système d'affichage 14*a*, entre les rouleaux 40 et 43, jusqu'à l'endroit où l'information doit être inscrite, cette inscription se fait dans les colonnes 62 à 67 avec l'aide des touches de commande qui déterminent la position du chariot et le transfert des informations apportées manuellement; ces deux opérations peuvent être réparties entre les touches de tabulation qui font se déplacer le chariot et les touches de transfert qui commandent les différentes opérations relatives au solde, grâce auxquelles les nouveaux soldes sont déduits, enregistrés et inscrits.

En se référant à la figure 3, les opérations de transfert de la présente invention seront plus compréhensibles grâce aux schémas suivants dans lesquels le système d'affichage 14*a*, le dispositif de détection 16*a*, la base fixe 30 et le système de transfert 17*a* sont entourés par deux lignes en traits mixtes. Il faut mettre l'accent sur le fait que le chariot est le seul qui ait un mouvement de translation par rapport aux autres ensembles, et que le système de détection est le seul qui soit capable de tourner. Pour des raisons de référence, une partie du chariot 8 a été représentée par une double ligne de traits mixtes interrompue à la gauche du système 14*a*. A l'intérieur de la base fixe 30, les seuls organes nécessaires à une bonne compréhension de l'invention sont ceux inclus dans le système de commande 9*a*, étudiés déjà avec la figure 1. De ce fait, tous les autres organes à l'intérieur du système 30 sont omis, intentionnellement, afin de simplifier l'étude de l'invention.

En commençant par le système 16*a*, les mécanismes par lesquels ce système est amené à sa position de détection et de rappel sont les suivants, le système de détection comprend une bobine d'engagement 80 qui communique par une connexion 81, schématiquement représentée avec un support 51 qui prolonge la base fixe 30 selon un procédé qui sera décrit ultérieurement. Par le fonctionnement de la bobine 80, le système 16 pivote en position de détection au cours de laquelle l'aire codée du numéro du compte placée sur une feuille 2 peut être explorée. Le système 16*a*, ainsi positionné, est maintenu à l'aide d'un loquet 82 qui enclenche un levier de verrouillage 83. Le système de détection comprend aussi cinq balais 84 qui, au moment de la détection, s'appuient contre la feuille 2 qui se trouve dans le système d'affichage 14*a*. La feuille du grand livre est adossée contre une plaque conductrice 85 qui établit lorsque le chariot se déplace par rapport aux balais, une continuité électrique entre les balais 84 et une source d'électricité qui sera décrite plus tard. Les balais 84 se continuent chacun par un conducteur 86, ces conducteurs étant représentés schématiquement par un seul fil 87, de manière à simplifier le schéma. Le système d'affichage 14*a* comprend aussi une plaque de cames 88, dont les bossages servent à actionner un contact normalement ouvert 89, de manière à envoyer des signaux caractérisant la position, sur un conducteur 90 lorsque le chariot se déplace corrélativement au système de détection; ceci indiquant la position de l'aire codée de la feuille 2 relativement au système de détection. Les cinq conducteurs, représentés par la ligne 87 et le conducteur 90, sont associés comme il est indiqué en 91, à un dispositif de mise en place 92 faisant partie de l'ensemble 17*a*. Le dispositif de mise en place 92 comprend cinq mécanismes à cliquet représentés en 93 qui se complètent. Les mécanismes à cliquet fonctionnent, lorsque des signaux de référence sont émis sur le conducteur 90, en déplaçant les cinq roues des types associées d'un certain angle par rapport à leurs positions prédéterminées, suivant les références des symboles d'informations. Les signaux émis sur les conducteurs 87 sont appliqués à des mécanismes décrits ci-dessous, de manière à débrayer les mécanismes à cliquet des roues des types associées 52, de ce fait empêchant ces roues d'avancer plus loin, suivant le signal caractérisant le chiffre numéro de compte détecté par un des balais 84. De cette manière, les roues des types 52 sont finalement mises en place, de manière à permettre le transfert de la représentation du code du numéro de compte figurant sur la feuille 2 placée dans le système d'affichage 14*a*. Le fonctionnement des roues des types qui vient d'être décrit, commence généralement lorsqu'une feuille 2 est insérée dans le système d'affichage 14*a* contre le système d'arrêt basculant 47 qui est à ce moment-là dans sa position verticale de blocage due à toute une série d'opérations qui seront décrites ultérieurement; la feuille de registre 2 est maintenue par la barre 48, que l'on actionne manuellement lorsque l'on insère une feuille 2, les contacts 94 normalement ouverts sont fermés par la feuille. Les contacts 94 sont placés par rapport au système d'affichage 14*a* de manière à ce que, lorsque la feuille 2 est complètement insérée contre le système d'arrêt basculant 47, le contact reprenne sa position normale « ouvert ». En d'autres termes, dans la position indiquée, les contacts se trouvent au-dessus de la feuille 2 totalement introduite. Lorsque le commutateur 94 est fermé, une continuité électrique est établie entre une source d'électricité, indiquée schématiquement en 95 et un certain nombre de mécanismes actifs qui seront décrits ultérieurement. Cette continuité est établie à travers un conducteur 96, un curseur 97 extérieur à la base 30, une bande conductrice 98 sur le chariot 8, la plaque conductrice 85, le commutateur 94, une bande conductrice 99 sur le chariot 8, un curseur 100 extérieur à la base fixe 30 et un conducteur 101 terminé par une jonction 102. Les éléments du circuit, actionnés par l'établissement de cette continuité électrique, sont une bobine à arrêt basculant 103, un mécanisme de remise en place 104 et un relais 105 qui est excité par les contacts normalement fermés 106. Le commutateur 106 est commandé par le mécanisme de remise en place 104, selon un procédé qui sera décrit ultérieurement. La bobine 103 est utilisée pour actionner le système d'arrêt basculant 47 dans sa position de blocage, lorsque la feuille 2 passe devant le commutateur 94, la connexion entre la bobine et le système 47 étant schématiquement indiquée par la ligne en pointillé 107. Lorsque le système 47 est mis en position de blocage, il est maintenu par un loquet 108 placé dans le système d'affichage 14*a*. Le relais 105 comporte deux contacts associés 109 normalement ouverts, qui, lorsqu'ils sont fermés, établissent une continuité électrique entre la source 95 et le relais 105, grâce à laquelle le relais 105 se maintient de lui-même, cette continuité étant établie par les contacts 106 normalement fermés et commandés par le mécanisme 104. Comme les lignes en pointillé 110 l'indiquent, le mécanisme de remise en place 104 est actionné en association avec le dispositif de mise en place 92 et les roues des types 52. Quand il fonctionne, le mécanisme de remise en place 104 dispose les roues 52 selon la position angulaire définie précédemment de manière à préparer l'opération de mise en place et met en position les cliquets associés aux lignes en pointillé 93, afin qu'ils s'enclenchent dans les roues des types comme l'opération de mise en place le demande. Comme la ligne en pointillé 111 l'indique, pendant l'opération de remise en place, les contacts 106, normalement fermés, sont ouverts de manière à interrompre la continuité entre la source d'électricité 95 et le relais 105 qui se maintient de lui-même, de ce fait, le relais 109 retombe et la source 95 est déconnectée de la bobine 103 et du mécanisme 104. Donc lorsqu'une feuille 2 est insérée dans le système d'affichage 14*a*, elle actionne temporairement un contact 94, dans sa progression depuis la partie haute du système d'affichage jusqu'au mécanisme d'arrêt basculant 47, manœuvrant ainsi le relais 105 et la bobine d'arrêt basculant 103; le mécanisme d'arrêt basculant est donc amené à sa position de blocage de manière à retenir verticalement la feuille 2 au fur et à mesure qu'elle descend dans le système d'affichage. En même temps, le mécanisme de remise en place 104 est actionné de manière à permettre aux roues des types 52 et au dispositif de mise en place 92 de recevoir les signaux qui doivent être détectés à partir de la feuille 2. Finalement lorsque l'opération de remise en place est terminée le contact 106 est ouvert, le relais 105 hors-circuit, le solénoïde 103 n'est plus excité et le mécanisme 47 se maintient par le loquet 108. Il faut noter que le numéro de compte que l'on a détecté dans l'exemple présent est un nombre décimal de cinq chiffres, de ce fait les roues des types 52 ont chacune dix positions angulaires discrètes, chacune d'elles caractérisant un chiffre de 0 à 9.

A le moment-là, la feuille 2 est dans la position requise pour être lue.

Dans cette position la feuille s'appuie contre les lames de deux contacteurs sensibles 112 et 113 placés en série et normalement ouverts. Ces commutateurs sont de type connu, et identiques au contacteur 94. Ces contacteurs viennent au travail sans la moindre pression par exemple sous le poids d'un morceau de papier relativement rigide ou son équivalent. Lorsque la feuille 2 est convenablement placée dans une position verticale, la barre de blocage 48 est manuellement appuyée contre la feuille, de manière à la maintenir fermement pour pouvoir être détectée. La barre de blocage est associée avec une série de contacts de commutateurs 114 normalement en position ouverte, en série avec les commutateurs 112 et 113 et aussi avec une paire de contacts 115 et 116, l'un étant situé sur le chariot 8, ayant un mouvement de translation par rapport à l'autre situé sur la base 30. Dans la figure les contacts 115 et 116 sont fermés de manière à ce que si les commutateurs 112, 113 et 114 sont fermés, une continuité électrique est établie entre un conducteur 117 et la source d'électricité 95, par le conducteur 96, le curseur 97, la bande conductrice 98, la plaque conductrice 85, les commutateurs 112 et 114 et les contacts 115 et 116. Quand cela se produit, un signal est envoyé par un commutateur 118, dont la position normale est celle représentée, jusqu'à une bobine de verrouillage 119, une bobine de déverrouillage 120 et une bobine d'engagement 80, provoquant leur excitation. La bobine de verrouillage sert à bloquer les touches de commande 35 de manière à empêcher toute entrée ou sortie d'informations de l'ensemble 1 empêchant, de ce fait, le mouvement du chariot 8 par rapport au système de détection 16*a*, la détérioration des balais 84 ou un fonctionnement fortuit du dispositif de mise en place 92. La bobine de déverrouillage 120 libère la touche de lecture 36, de manière à permettre à un opérateur de manœuvrer cette touche et de ce fait, de commencer la manœuvre du chariot en vue de la détection et, finalement, la bobine d'engagement 80, selon sa fonction précédemment décrite, commande le mouvement du dispositif de détection 16*a* dans la position nécessaire à la lecture, le fonctionnement de la bobine de verrouillage a lieu de concert avec cette mise en position de manière à ne pas détériorer par le dispositif 16*a*. La touche de lecture 36 est associée au dispositif de commande du chariot, schématiquement indiqué en 121, cette connexion est indiquée par la ligne en pointillé 122. Lorsqu'on actionne la touche de lecture, le mécanisme de commande du chariot 121 entre en action, et le chariot est tabulé vers la droite par rapport aux balais 84; de ce fait les signaux de transfert du numéro de compte sont envoyés au dispositif de mise en place 92. La connexion entre le chariot 8 et le mécanisme de commande 121 est représentée par la ligne en pointillé 10. Il faut noter que tous les systèmes d'inscription et d'exploitation d'informations actuels comprennent des mécanismes de commande du type 121, grâce auxquels le chariot est à la fois mis dans une position déterminée au moyen de la touche de sélection de commande, et contrôlé en fonction des contacts qui permettent la sélection des différentes positions du chariot. Ce système de commande est connu et notamment employé dans les calculatrices.

En résumé, quand les contacts 115 et 116 se touchent et, lorsqu'une feuille 2 est convenablement placée dans le système d'affichage 14*a*, les touches de commande sont verrouillées en position de repos, le dispositif de détection 16*a* est en position de détection et la touche de lecture est déverrouillée, de ce fait permettant le mouvement transversal du chariot. Pendant ce mouvement, lorsque le chariot passe devant une position prédéterminée, un bossage de came 124 de la base 30 vient frapper le loquet 108 et, de ce fait, le système d'arrêt basculant 47 revient à sa position de repos. Ce système est en connexion avec la barre de blocage comme l'indique la ligne en pointillé 125, si bien que lorsque le système d'arrêt basculant est en position de repos, la barre de blocage se trouve dans sa position de rappel, permettant ainsi à la feuille 2 de tomber entre les rouleaux du chariot 40 et 43, qui ont été étudiés avec la figure 2.

Le support de plaque 88 a en plus des bossages qui actionnent le commutateur 89, un autre bossage qui actionne le commutateur 126, approximativement en même temps que la came 124, frappe le loquet 108. Lorsque le commutateur 126 est fermé, il connecte une bobine 127 de libération avec la source 95. Cette bobine 127 est reliée au moyen de son plongeur indiqué en 128 au loquet 82, grâce auquel le système 16*a* se maintient dans la position de détection. De ce fait, lorsque la bobine 127 est au travail le système 16*a* revient à sa position de rappel dans laquelle les balais 84 ne sont plus en contact avec la feuille 2, l'opération de détection est terminée.

Après l'opération de détection, les opérations d'inscription ont lieu. La feuille 2 est insérée verticalement dans une position déterminée, sur elles seront portées de nouvelles informations, le chariot 8 et les roues des types 38, de la figure 2, sont convenablement actionnés pour effectuer les transferts voulus. Cependant dans cette invention, comme pour chaque débit et crédit, le report est fait dans les colonnes 63 où 64 d'une feuille de registre. Le chariot est mis en position de manière à faire fonctionner un levier, non représenté, à l'intérieur du mécanisme de commande 121, ce levier est relié, comme l'indique la ligne en pointillé 131, au bras mobile 132 du commutateur 118. En l'occurrence, le bras 132 est actionné dans le sens contraire des aiguilles d'une montre pour venir se placer contre un contact fixe 134. Ainsi la bobine de verrouillage 119 se trouve reliée à la source 95 par un circuit électrique où nous trouvons en série un conducteur 135 et deux contacts de relais 136 normalement en position « fermée ». Dans ces conditions, la bobine de verrouillage est excitée et empêche l'action des touches de commande jusqu'à ce que les contacts 136 s'ouvrent. Les contacts 136 sont reliés à un organe photoélectrique qui se trouve à l'intérieur du système d'affichage 24*a*, ils sont actionnés lorsqu'un élément primaire est convenablement mis en position, ceci étant la condition nécessaire pour la libération des touches de commande 35. Après qu'un élément primaire ait été inséré dans le système d'affichage 24*a* et une touche de commande 35 sélectionnée, un jeu de contacts 138, relié par les lignes en pointillé 139 aux touches 35, est alors fermé. Les contacts formant l'ensemble 140, ouverts en position normale, et associés avec les contacts de la bobine de verrouillage 136, sont fermés lorsque les contacts 136 sont ouverts. Il s'ensuit que, lorsqu'une touche de commande 35 est sélectionnée dans ces conditions, une continuité électrique est établie à partir de la source 95, par le conducteur 135 et les commutateurs 138 et 140 jusqu'au dispositif de transfert indiqué en 141; de ce fait ce dernier est actionné. Ce dispositif comprend un marteau imprimeur qui, lorsqu'il vient au travail, presse l'élément primaire inséré dans le système d'affichage 24*a* contre les roues des types 52; de ce fait, la représentation du numéro de compte mémorisée dans les roues de type pendant l'opération de mise en place se trouve inscrit à l'aide du ruban encreur de la machine, sur l'élément primaire. Le dispositif 141 comprend aussi un dispositif d'avance qui, après le marteau imprimeur, délivre l'élément primaire ou réceptable 57 placé en bas du système 17*a*. Le réceptacle 57 sert à recevoir les éléments primaire ainsi traités et à éviter de ne pas les traiter plusieurs fois par erreur.

En se reportant maintenant à la figure 4, le système d'affichage 14*a* est monté sur la console du chariot 45 qui est renforcée par une paire de tiges transversales 145 fixées dans les bagues 146 montées dans la console. Ces tiges donnent sa rigidité à la console 45 et servent de support de montage pour les flasques 147 et 148 dans lesquelles un arbre de transmission de commande 149 est tourillonné. Cet arbre 149 est relié aux bras de levier 150 et 151, ce dernier étant caché derrière le support 148. Les bras 150 et 151 sont respectivement reliés aux bras supérieurs 152 et 153 dont la fonction sera décrite ci-dessous. Le bras de levier 150 est relié d'un côté au bras de levier 152 et de l'autre côté, attaché à un ergot 154 associé à une tige poussoir 155. La tigep-oussoir 155 est montée de manière à glisser dans une ouverture verticale de forme allongée 156, située dans le support 157 placé en équerre sur le flasque 147; ladite tige, coulisse à l'aide de son ouverture 160, sur un ergot 159 fixé au flasque 147. La tige-poussoir 155 est reliée par un ergot 161 à un support en forme de L, 162, qui est lui-même solidaire du système d'arrêt basculant 47. Le support 162 tourne autour d'un support charnière 163, l'autre extrémité du système d'arrêt basculant 47 étant pareillement associée au support charnière 164. Dans cette figure, le système 47 et la tige-poussoir 155 sont avancés, le plus loin possible, dans la direction indiquée par la flèche 165. Dans cette position, le système d'arrêt basculant se trouve dans sa position de blocage dans laquelle, comme il l'a été dit auparavant, il se trouve engagé sous le système d'affichage 14*a* servant de support vertical pour une feuille 2 insérée lors de la détection des numéros de compte codés. Le système d'arrêt basculant est maintenu dans la position indiquée contre un ressort comprimé 166, au moyen d'un bras de loquet 167 qui enclenche une saillie associée dans la face inférieure de la tige-poussoir 155. Le bras de loquet 167 est monté sur un ergot 168 fixé sur le support 147 et le point d'enclenchement de la tige-poussoir sur le loquet est sollicité vers le haut par un ressort plat 169, lui aussi fixé sur le flasque 147. Il faut donc noter que, si le loquet 167 tournait en sens contraire des aiguilles d'une montre autour de son pivot 168, la tige 155 et le système 47 seraient sollicités par le ressort 166 dans la direction opposée à celle indiquée par la flèche 165, donc, le système, d'arrêt basculant serait débrayé du système d'affichage 14*a*. Les dispositifs nécessaires pour le fonctionnement du loquet 167 et de la tige poussoir dans la direction de la flèche 165 vont maintenant être décrits. Les bras 152 et 153 sont pourvus de trous 170 à l'intérieur desquels la barre de blocage 48 pénètre tout en se déplaçant librement vers le haut en s'éloignant du système d'affichage, indépendamment du mouvement des bras 152 et 153. Dans la position indiquée, la barre de blocage s'appuie contre le système d'affichage dans la position nécessaire pour bloquer une feuille de registre en vue de la détection. Il faut noter d'après les différentes connexions indiquées, que la barre de blocage s'écarte du système d'affichage lorsque le loquet 167 tourne de manière à libérer la tige 155, la barre de blocage étant attachée à un bras 171 pivotant autour d'un axa 172, qui prolonge le système d'affichage 14*a* et associée, par levier 152, à la tige 155. Le bras 171 comprend des encoches 173 et 174 dans lesquelles s'engage un cliquet 175, ce qui permet d'obtenir deux positions possibles de la barre 48, l'encoche 174 servant à l'embrayage et l'encoche 175 au débrayage de la barre de déblocage. Le bras 171 est pourvu d'une came 176 qui dans la figure actionne le bras de commande 177 du commutateur 114 dont il a été question dans la figure 3, de ce fait les contacts sont fermés. L'autre extrémité de la barre de blocage, qui n'est pas visible sur la figure 4, est attachée à un bras 178, tournant autour d'un axe, non représenté, relié au système d'affichage. Ce bras comprend aussi des encoches dans lesquelles s'engage un cliquet 180, dont l'action est similaire à celle du cliquet 175.

En haut et à droite, le commutateur 94, monté au dos du couvercle 46, comprend un bras de commande sensible 181 qui s'engage dans une ou plusieurs fentes 182 du couvercle. De même les commutateurs 112 et 113, étudiées dans la figure 3, ont des bras de commande 183 et 184 qui s'engagent respectivement dans les trous 185 et 186 de la console 45. La console est évidée, comme indiqué en 187, pour faciliter l'insertion et l'enlèvement des feuilles par rapport au rouleau d'avancement 40 du chariot 8. A la gauche de la console 45 figure la plaque conductrice 85 du système d'affichage. Adjacents à cette plaque, se trouvent les montants 188 et 189 généralement en métal. Le support de came 88, décrit ci-dessous est fixé aux montants 188 et 189 et comprend des bossages qui actionnent les commutateurs 89 et 126 comme on l'a déjà vu avec la figure 3. Le système 47 ne se trouve pas bloqué lorsque l'on actionne comme suit. Dans la figure 4, la tige poussoir 155 est libérée lorsque le loquet 167 tourne dans le sens contraire des aiguilles d'une montre. Ceci a lieu lorsqu'un bossage de came 195 d'un support 196 est attaché à la base 30, de l'ensemble 1, sollicite l'extrémité du loquet vers le haut lorsque le chariot 8 a un mouvement latéral par rapport à la base 30 au cours d'une opération de détection. Le loquet 167 est pourvu d'un galet 198 à son extrémité qui permet de réduire la friction entre la came 195 et le loquet 167 pendant l'entraînement du chariot. La came 195 est d'une longueur telle, que lorsque le chariot se trouve le plus à gauche comme l'indique la flèche 197, le galet 198 repose sur la saillie 195. Le système 47 est dans sa position de blocage lorsque la bobine d'arrêt basculant 103, montée sur le prolongement 200 du support 196, s'excite, le plongeur de la bobine étant actionné contrairement au ressort 202, et se continuant par une jonction 203 reliée à une came 204 qui pivote sur un axe 205 fixé sur le prolongement 200 du support. La came 204 est pourvue d'un bossage 206 qui fait contact avec un prolongement 207 de la tige-poussoir 155 lorsque le plongeur de la bobine 103 vient au travail; de ce fait, la tige poussoir se déplace dans la direction 165. Pour parachever cette figure, les fils de la bobine 103 sont indiqués en 208, un de ces fils étant connecté à la jonction 102 étudiée avec la figure 3.

En se reportant à la figure 5 on voit que pour éviter la manœuvre superflue du bras de commande 181 du commutateur 94 lors de l'extraction d'une feuille, on a envisagé deux lames incurvées de ressort 211 et 212, solidaires d'un téton 213 fixé au couvercle 46. Ces lames déterminent le chemin suivi par la feuille lors de l'insertion et de l'extraction, ce chemin permettant au bras 184 d'être respectivement enclenché et débrayé de manière à ce que le commutateur 94 ne soit au travail qu'au moment de l'insertion.

En se reportant à la figure 6, on voit que la plaque conductrice 85 est isolée par un isolant 215, des autres parties du système d'affichage 14*a* et des montants 188. Le support de came comprend trois rangs de bossages, un des bossages du rang du milieu est indiqué en 217, les bossages des deux autres rangs étant cachés par les touches de commande 218 et 219. Le bossage 217, dans la figure, actionne une touche de commande 220 d'un commutateur. Les touches précédentes 218, 219 et 220, sont associées respectivement aux comutateurs 89*a*, 126 et 89*b*. Les sorties des commutateurs 89*a* et 89*b* sont combinées et corespondent à la sortie du commutateur 89 décrit dans la figure 3; il a été jugé pratique dans cet exemple de prévoir deux commutateurs avec des bossages de cames décalés les uns par rapport aux autres, de manière à éviter le chevauchement des signaux de sortie, dû à l'inertie des bras du commutateur. Les commutateurs 89*a* et 89*b* et 126 sont rattachés au coffret 221 du dispositif de détection 16*a* montré dans sa position d'enclenchement lorsque les balais de détection 84 sont contre une feuille de registre placée dans le système 14*a*, les touches de commande 89, 89*b* et 126 étant en même temps alignées avec les rangs correspondants des bossages du support de came 88. Les bossages apparaissent plus clairement dans la vue isométrique de la figure 7, dans laquelle deux des rangées de bossages caractérisant le temps, sont indiquées en 222 et 223, elles communiquent avec les commutateurs 89*a* et 89*b*. Un troisième rang indiqué en 224, comprend un seul bossage de came 225 qui envoie le signal de « fin de lecture » commandant la libération du système de détection 16*a*.

En se reportant à la figure 6 on voit que les rouleaux 40 et 43 sont montés conventionnellement. Le rouleau 40 est un grand tambour d'entraînement alors que le rouleau 43 est un petit tambour entraîné qui tourne dans la direction indiquée par la flèche 226. Le rouleau 43 est fixé à une plaquette de guidage 42 qui tourne et sert de guide à une feuille insérée. D'après la figure 6, l'on peut voir que lorsque le système de détection 16*a* tourne dans le sens des aiguilles d'une montre et s'éloigne du système d'affichage 14*a* et que le système d'arrêt basculant 47 va vers la gauche s'éloignant de l'extrémité du système d'affichage, la feuille 2 peut tomber verticalement contre la plaque de guidage 42 et être ensuite insérée entre les rouleaux 40 et 43.

Le système de détection 16*a* tourne de la manière suivante. Le système 16*a* est monté sur un axe 50 tourillonné dans le support 227 qui prolonge le support 51. Les bobines 80 et 127 respectivement d'engagement et de libération du système de détection sont respectivement fixées au supports 230 et 231, qui prolongent le coffret 221. Pour parachever la figure, les fils d'excitation de ces bobine; sont indiqués en 232 et 233. Un ressort 234, interposé entre la base du support 230 et le support 227, exerce une force qui tend à faire tourner dans le sens des aiguilles d'une montre le système 16*a* et l'axe 50 par rapport au support 227. Tel qu'il est montré le système de détection ne peut entreprendre un mouvement de rotation dans le sens des aiguilles d'une montre grâce au verrou 82 maintenu par une barre de verrouillage 83, qui prolonge le support 51. Le verrou 82 pivote sur un axe 236 au moyen d'une tige de verrouillage 237 qui relie l'extrémité droite du verrou à un bras 238 qui pivote sur un axe 239, extérieur au support 230. Le bras 238 est relié au moyen d'une jonction indiquée en 240, au bras du plongeur 241 de la bobine de libération 127 qui lorsqu'elle est excitée exerce une force contraire au ressort 242 qui tend à faire tourner le bras 238 autour de l'axe 239 dans le sens des aiguilles d'une montre, quand ceci a lieu la tige 237 est déplacée faisant tourner le verrou 82 autour de l'axe 236 dans le sens contraire des aiguilles d'une montre, s'opposant ainsi à la force exercée par le ressort 242, débrayant le verrou de la barre de verrouillage 83 et permettant au ressort 234 de faire tourner le système 16*a* dans le sens des aiguilles d'une montre par rapport au support 227 et donc de le débrayer. Réciproquement, la bobine d'enclenchement 80 est pourvue d'un plongeur connecté, par un bras 244 au support 227 qui prolonge le support 51. Lorsque la bobine 80 est excitée, une force est exercée sur le plongeur 243. Le plongeur 243 étant relié par le bras 244 au support fixe 227 et la bobine 80 étant montée sur le système 16*a* susceptible de tourner, lorsque la bobine s'excite, elle se déplace par rapport au plongeur 243, faisant tourner tout le système 16*a* et de ce fait engageant le verrou 82 dans la barre de verrouillage 83. Les fils électriques d'entrée et de sortie du système 16*a* sont alimentés par le câble 20*a*, les jonctions de câble étant faites à certains points appropriés à l'intérieur du coffret 221. En ces points, le reste des conducteurs du câble est attaché à l'aide de liens indiqués en 246.

En se reportant aux figures 8A et 8B, on voit les détails du montage des bobines de verrouillage et de déverrouillage de la figure 3. La bobine 120 est reliée à un plongeur 259 comportant un support de touche 260 connecté au moyen d'une goupille 261. Le support de touche 260 copmrend deux parties séparées par un espace vide 262, la vue en coupe ayant été prise à travers la fente 262. Le support de touche se déplace, en glissant dans le support 263 dans la direction de la flèche 264 lorsque la bobine 120 s'excite. La touche de lecture 36 comprend une tige 265 qui présente un évidement 266 dans lequel le support de touche 260 s'enfonce empêchant l'opération de la touche 36, sauf lorsque l'espace 262 se trouve devant l'évidement 266 lorsque la bobine 120 s'excite. Dans ce dernier cas, la touche 36 peut être actionnée librement, la tige 265 passant à travers la fente 262 du support de touche 260. De la même manière, la bobine de verrouillage 119 comprend un plongeur 267 comprenant un support de touche 268 connecté au moyen d'une goupille 269 et se déplaçant en glissant dans un support 263 dans la direction de la flèche 264 lorsque la bobine 119 s'excite. Une touche de commande classique 35 comprend une tige 270. La tige 270 et le support de touche 268 sont pourvus d'évidements 271, qui permettent le passage vertical de la tige 270 lorsque la bobine 119 n'est pas excitée, la tige 270 étant autrement, bloquée par le support de touche 268. Dans les figures 9, 10, 11, 12, qui décrivent la mise en place de la représentation du numéro d'un compte dans les roues des types 52 du dispositif de transfert 17*a*, les détails sont les suivants. Les cinq roues des types 52, représentées par les lettres *a*, *b*, *c*, *d* et *e* sont à l'intérieur d'un coffret 273, et montées sur un arbre décrit ci-dessous dont le tourillon se trouve dans le coffret. Les roues sont montées au moyen d'un électro d'avancement 274, fixé sur un support 275, et comprenant un plongeur associé 276. La bobine 274 est associée avec cinq bobines à loquets 277 de *a* à *e* qui sont chacune associée avec les cinq roues des types 52 de *a* à *e*. Les bobines 277 sont individuellement montées sur le coffret 273 au moyen de supports respectifs 278, de *a* à *e*, et ont des plongeurs associés respectifs 279 de *a* à *e*. Le bras 276 de la bobine 274, est relié à un levier coudé 280 dont le tourillon est monté au moyen d'un axe 281 sur un support 282′, prolongement du coffret 273. Une barre 282 montrée dans la coupe de la figure 9, est attachée au levier 280 et traverse le coffret 273, elle est parallèle à l'arbre sur lequel les cinq roues des types sont montées. La largeur du levier coudé 280 et les moyens de fixation sont tels que la barre 282 est solidement maintenue parallèle à l'arbre des roues des types. La barre 282 aboutit à cinq plongeurs 283, de *a* à *e*, qui mettent en position les roues des types 52 de *a* à *e* comme le montre la description qui suit. Les plongeurs 283 coulissent dans des trous à l'intérieur du support 284, prolongement du coffret 273. Ces plongeurs portent des joues à leur extrémité, ce qui limite leur course relativement au support 284. Les plongeurs 283 s'écartent des roues des types qui leur sont associées sous l'effet de ressorts 287, de *a* à *e* placés entre un prolongement du coffret 284 et les joues 286, de *a* à *e*,.et ils se rapprochent de ces roues lorsque le bras de levier 280 tourne sous l'effet de l'électro d'avancement 274 excité. Les plongeurs 283 sont reliés à des cliquets 288, de *a* à *e*, au moyen des goupilles 289, de *a* à *e*, qui sont fixées aux cliquets et passent par les trous respectifs 290, de *a* à *e*, des plongeurs. Les cliquets comprennent de longues fentes horizontales 291, de *a* à *e*, à travers lesquelles passent les goupilles 292, de *a* à *e* et 293, de *a* à *e*. Ces goupilles servant de supports aux cliquets. Les goupilles 292, sont fixées au coffret 273, alors que les goupilles 293 sont fixées à des tiges poussoirs verticales 294, de *a* à *e*, qui ont des fentes verticales à travers lesquelles les cliquets associés se déplacent latéralement et tournent verticalement. Les cliquets sont sollicités vers le bas dans ces fentes au moyen de ressorts 295, de *a* à *e*. La fonction des tiges poussoirs sera décrite ultérieurement. Les cliquets 288, de *a* à *e*, enclenchent les roues à rochets 296, de *a* à *e*, qui sont attachés aux roues des types 52, de *a* à *e*. Chaque roue des types comprend dix saillies également réparties, une saillie de type étant indiquée en 297*a*. Ces saillies représentent les chiffres de 0 à 9. Les combinaisons des roues des types tournent sur l'arbre 298 qui comprend des encoches 299, de *a* à *e*, qui enclenchent des rochets de remise en place 300, de *a* à *e*, qui pivotent au moyen d'axes 301, de *a* à *e*, fixés aux roues à rochets correspondantes 296, de *a* à *e*. Les rochets de remise en place sont sollicités vers le centre et les encoches 299 au moyen de ressorts 302, de *a* à *e*. Pendant les opérations de mise en place, l'arbre 298 est maintenu dans une position fixe, les roues des types tournant dans le sens des aiguilles d'une montre au moyen de cliquets 288, de *a* à *e*, qui leur sont associés. Comme on l'a vu précédemment, les cliquets se déplacent vers les roues des types lorsque la bobine 274 s'excite, et font tourner le levier coudé 280 autour de l'axe 281, de ce fait déplaçant les plongeurs 283, de *a* à *e*. Quand ceci a lieu, les roues à rochets 296, de *a* à *e*, tournent d'un angle discret équivalent à 1/10 de tour, les roues des types étant dans une position telle, qu'un chiffre décimal différent représenté par la saillie 297 se présente dans l'espace de marquage 54 chaque fois que la roue tourne. Les cliquets de blocage 303, de *a* à *e*, qui enclenchent les dents des roues à rochets 296, de *a* à *e*, maintiennent les roues dans leurs positions, les rochets 303 étant sollicités dans le sens des aiguilles d'une montre par les ressorts 304, de *a* à *e*, attachés aux montants 305, de *a* à *e*.

Comme on l'a vu précédemment, les cliquets 288, de a à e, sont sollicités vers le bas dans les fentes des tiges-poussoirs par les ressorts 295, de a à e, qui agissent aussi sur les tiges-poussoirs 294, de a à e; la force étant transmise par les goupilles respectives 293, de a à e. Cette force maintient les cliquets alignés par rapport à la périphérie des roues à rochets 296 de manière à ce que ces roues opèrent à chaque poussée horizontale du cliquet. Cependant les tiges-poussoirs 294 peuvent aller vers le haut au moyen de jonction 307, de a à e, et de leviers associés 308, de a à e, qui tournent autour d'axes 309, de a à e, fixés au coffret 273. Ainsi lorsqu'un des plongeurs 279, de a à e, des bobines 277, de a à e, sont sollicités vers le bas, la jonction correspondante 307 actionne, par l'intermédiaire du levier correspondant 308, la tige-poussoir correspondante vers le haut; de ce fait, par l'intermédiaire de la goupille 293, le cliquet correspondant est déplacé vers le haut et tourne autour du pivot correspondant 292 fixé au coffret 273, le trou vertical 290 à l'extrémité du plongeur 283 permettant cette rotation. Les tiges-poussoirs 294, de a à e, lorsqu'elles ont un mouvement ascendant s'engagent individuellement dans les loquets 310, de a à e, qui peuvent pivoter autour des axes 311, de a à e, montés sur une saillie 312 du coffret 273. La figure montre que le loquet 310a s'accouple avec une encoche 313a de la tige-poussoir 294a. Lorsque le cliquet qui lui est associé est maintenu vers le haut par un loquet 310, il n'est plus aligné par rapport à la périphérie de la roue à rochet associée 296, et de ce fait, ne peut enclencher les dents. La roue des types associée ne bouge donc pas de la position qu'elle a avant le dégagement du cliquet par l'intermédiaire de la tige-poussoir quand la bobine 277 s'excite.

Avant une opération de mise en place au cours de laquelle les électros d'avancement actionnent les roues de types dans le sens des aiguilles d'une montre (fig. 9), toutes les roues des types 52 sont replacées dans une position de référence de manière à permettre leur mise en place grâce à un nombre donné de signaux d'avancement. La remise en place des roues des types se fait de la manière suivante, il faut noter que dans la figure 9, ces roues sont remises en place. En supposant que les roues des types ont été mises en place, et qu'il faut les remettre dans leur position initiale pour qu'elles puissent recevoir un nouveau numéro de compte, un arbre 314, comprenant plusieurs cames 315 de a à e, tourne d'un angle discret au moyen d'un engrenage 316 tournant autour d'un arbre principal 317 indiqué sur la figure 10. Pendant la rotation de cet arbre, les cames tournent légèrement dans le sens des aiguilles d'une montre (fig. 9), désenclenchant les loquets associés 310, donc permettant aux cliquets d'assurer la rotation des roues à rochets 296. L'engrenage 316 est couplé avec l'arbre 298 de manière à ce qu'il fasse une révolution complète lorsque l'arbre 314 en accomplit une.

Ceci peut être clairement compris dans la figure 12. Comme on peut le voir, un engrenage 316a tournant autour de l'arbre principal 317 comprend un téton 318 qui, pendant une rotation dans le sens des aiguilles d'une montre de l'arbre 317, frappe une partie saillante 319 d'un dispositif de commande 320 fixé à l'arbre de cames 314, et le faisant tourner dans le sens contraire des aiguilles d'une montre, en opposition à la force exercée par un ressort 321 (fig. 12); ceci correspond, dans la figure 9, à faire tourner l'arbre dans le sens des aiguilles d'une montre. Lorsque le dispositif de commande 320 de l'arbre est frappé, le mouvement de l'arbre 314 et des cames 315, de a à e, fait que les loquets associés 310 s'éloigenent vers l'extérieur, de ce fait libérant les tiges-poussoirs et les cliquets associés. De plus, si l'arbre 317 tourne de 90°, l'arbre des roues des types 298 tourne de 360° ceci étant dû à l'association de l'engrenage 316a sur l'arbre 317, avec l'engrenage 316b sur l'arbre 298. L'arbre 317 tourne de 90° et revient à sa position initiale grâce à une bobine de rappel indiquée en 323, et l'arbre 298 est relié à l'arbre 317 au moyen de l'engrenage 316 et un embrayage 324 en roue libre qui enclenche l'arbre 298 dans un seul sens de manière à ce qu'il effectue un seul tour; ainsi les roues des types et à rochets reviennent à leur position initiale. En se reportant de nouveau à la figure 9, on voit que l'arbre 298 pendant son tour complet déclenche les rochets 300, de a à e, entraînant avec lui les roues des types et à rochets associées jusqu'à ce qu'elles se trouvent dans la position de la figure 9. Lorsque l'arbre 317 a tourné de 90° dans le sens des aiguilles d'une montre (fig. 12), il revient à sa position initiale, libérant l'arbre à came 314, qui revient à sa position de repos grâce à un ressort 321; de ce fait, les loquets 310, de a à e, se placent dans l'encoche des tiges poussoirs associées.

Un autre fait caractéristique de l'invention est à noter, au sujet de la rotation de 90° de l'arbre 317. En plus du téton 318 de l'engrenage 316a, il est prévu un autre téton 325 fixé à cet engrenage qui frappe un bras de commande 326 du commutateur 106 qui a été vu avec la figure 3, de ce fait ouvrant ses contacts, donc libérant le relais 105, par lequel la bobine de rappel 323 est maintenue au travail après qu'une feuille ait été insérée au-delà du commutateur 94. Donc, lorsque le téton 325 vient frapper le commutateur 106, la bobine de rappel 323 se trouve décollée et l'opération de remise en place des roues des types ainsi que la libération de la bobine d'arrêt basculant 103 se trouvent réalisées.

On voit donc que l'opération de l'ensemble, nécessite la manœuvre du bras de levier 280 qui produit l'avancement de chaque cliquet associé 288, donc par conséquence, des roues des types correspondants 52 qui n'ont pas été débrayées des cliquets par les tiges-poussoirs associées 294, et les loquets 310. Le bras de levier 280 et les tiges-poussoirs 294 sont respectivement commandés par la bobine 274, et les bobines 279, de *a* à *e*. Si l'on passe en revue l'opération de remise en place, on voit qu'elle comprend le fonctionnement d'une bobine de rappel 323 associée à un axe 317 et le faisant tourner d'un quart de cercle, ce dernier comporte un engrenage 316*a* et des tétons 318 et 325. Le téton 318 sert à actionner un dispositif de commande qui fait tourner un arbre à cames 314, libérant ainsi les tiges-poussoirs utilisées précédemment pour découpler les cliquets 288, de *a* à *e*, des roues des types qui leurs sont associées; le téton 325 est utilisé pour ouvrir le commutateur 106 lorsque l'arbre 317 a terminé son quart de cercle, de manière à mettre hors-circuit le relais 105 à l'intérieur du système de commande 9*a*, les électros 323 se trouvant donc libérés. De plus, l'arbre 317 en tournant de 90° grâce à l'association des engrenages 316*b* avec l'embrayage en roue libre 324, fait tourner l'arbre 298 dans un sens déterminé pendant une révolution et de ce fait met en position les roues des types 52 dans la position qu'elles ont dans la figure 9. Pour assurer la stabilité et l'exactitude de la remise en place par l'arbre 298, on a ajouté un cliquet à ressort 328 comme le montre la figure 11, ce cliquet étant associé avec un cran d'arrêt 329 de l'arbre 298.

Les figures 13 et 14 montrent le détail des mécanismes de commande utilisés pour transférer un numéro de compte enregistré, des roues des types 52 (fig. 9) à un chèque ou une feuille de versement insérée dans une fente 54, du dispositif 17*a*.

En se reportant tout d'abord à la figure 14, dans cette vue en coupe, les chèques sont initialement empilés (56) sur le plateau 55 situé près de l'opérateur. A l'intérieur de la fente 54 le coffret comprend deux ouvertures face à face 342 et 343, par lesquelles les roues des types 52 et un marteau imprimeur 344 leur faisant face peuvent être mis en relation. Un ruban encreur 345 passe autour des roues des types par l'ouverture 342 permettant ainsi l'impression sur le chèque du numéro donné par les roues des types grâce à la pression du marteau 344. Le ruban 345 est entraîné au moyen d'un système classique de poulies, indiqué en 346. Un chèque ou une feuille de versement inséré dans la fente 54 est maintenu à la verticale par une plate-forme 347, qui prolonge une pièce pivotante 348, que la figure isométrique 13 montre plus clairement. Cette pièce 348 comprend deux bras latéraux et une barre de connexion 349 en plus d'une plate-forme de connexion 347 appelée, commodément, « plate-forme d'arrêt ». Le dispositif 348 pivote autour d'un arbre 350, cette rotation sera décrite ci-dessous.

En se reportant à la figure 14, une roue 351, tourne autour d'un arbre 350, cette roue d'entraînement est associée à une roue 352 associée à un système de courroies 353 passant sur des poulies du type classique. La roue 352 est montée sur un arbre 354, se prolongeant par les bras latéraux de la pièce pivotante 348, la courroie 353 touche la surface de la roue 355, montée sur l'arbre 356, dont le tourillon est monté sur un support 357 fixé au coffre 340. La roue 352, si la pièce 348 pivote dans le sens contraire des aiguilles d'une montre autour de l'arbre 350, passe à travers une ouverture du coffret, mettant en contact la courroie 353 avec la surface d'une poulie de guidage 358 montée sur l'arbre 359, tourillonné dans le support 360 qui prolonge le coffret. En même temps, la plate-forme 347 est déplacée vers la gauche permettant ainsi le libre passage d'un chèque ou d'une feuille de versement inséré dans la fente 54 qui est saisi et transporté ensuite par les roues 352, 358, 351 et 355 au moyen de l'ouverture entre la plateforme 347 et l'arbre 354 jusqu'au réceptacle 57. De manière à faire tourner la pièce 348 autour de l'arbre 350, un prolongement 361 de ce châssis est associé au moyen d'une goupille 362 et d'une jonction 363 à un plongeur 364 qui est actionné au moyen de la bobine 366, (fig. 13). Lorsque cette bobine s'excite, le plongeur 364 se déplace et fait tourner le châssis 348 autour de l'arbre 350, de ce fait la courroie 353 se trouve en contact avec la poulie de guidage 358 et la plate-forme 347 n'obstrue plus la fente 54. Ainsi un chèque ou une feuille de versement parvient jusqu'au réceptacle 57, au bas du coffret et y est conservé.

On voit que, en se reportant aux figures 3, 13 et 14 la bobine 366 s'excite de la manière suivante. Lorsqu'un chèque est mis dans la fente 54, la plate-forme 347 étant placée comme dans la figure 14, il interrompt le faisceau de lumière entre une source 367 et une cellule photo-électrique 368. Ce faisceau lumineux normalement provoque l'excitation d'un courant électrique dans les fils de sortie 369. Ces fils conduisent à un relais 370 relié par les lignes en pointillé 137 aux contacts 136 et 140 de la figure 3. De ce fait, lorsque le relais 370 s'excite, les contacts 136 et 140 sont respectivement ouverts et fermés. Pour plus de sécurité, le courant qui alimente la cellule 368 est connecté avec le courant qui alimente la source électrique, si bien qu'une défaillance de la source de lumière empêche la manœuvre du relais 370, ainsi il n'est pas possible de confondre une défaillance de la source de lumière avec une interruption du faisceau lumineux. Ce procédé n'est pas indispensable pour l'étude considérée et, de plus, est connu dans la technique de la commutation, c'est pourquoi les détails ont été omis dans un but de simplification. Le fonctionnement du relais 370 (ouverture du commutateur 136 et fermeture du commutateur 140 de la figure 3) est utilisé de la manière suivante.

L'arbre 350 est entraîné par un engrenage 371, lui-même entraîné par un engrenage 372 tournant sur un arbre 373 entraîné par un moteur 374. Comme la figure 13 l'indique un second système de poulies est prévu à la droite de la pièce pivotante 348; il comprend deux poulies 376 et 377 montées sur les arbres 350 et 354 et reliées par une courroie d'entraînement 378. Les poulies 376 et 377 tournent respectivement sur les arbres 350 et 354. Il faut donc noter que le transport des éléments primaires, de la fente 54 au réceptable 57, se fait au moyen de deux systèmes de poulies, permettant ainsi un transport plus régulier.

Un arbre, portant un dispositif d'embrayage et de débrayage 379, tourne autour de l'arbre pivotant 373. Cet arbre comprend une petite came 380 et une grande came 381 qui tournent toutes les deux. Le dispositif 379 est freiné par un cliquet 382 qui prolonge un plongeur de bobine 383, sollicité par la bobine 384 lorsqu'elle s'excite. La bobine 384 s'excite lorsque les contacts 140 sont fermés par l'interruption du faisceau lumineux entre la source 367 et la cellule 368 due à l'insertion d'un chèque ou d'une feuille de versement.

Le fonctionnement de la bobine est donc dû au débrayage du cliquet, donc à la rotation du dispositif 379, jusqu'à ce que le faisceau lumineux ne soit plus interrompu. Lorsque le dispositif 379 tourne, l'arbre 373 et ses cames 380 et 381, tournent aussi; la came 380 actionne un commutateur 385 associé à une bobine 366 par les contacts du relais 386; de ce fait le transport du chèque jusqu'au réceptacle 57 a lieu. La came 380 est associée avec la came 381 de manière à ce que, lorsque le dispositif 379 tourne dans le sens des aiguilles d'une montre, la came 380 n'actionne pas le contact du commutateur 385 avant que l'ergot 387 ait été libéré par le bossage 388 de la came 381. L'ergot 387 est relié à un bras 389 du marteau imprimeur 344 qui tourne autour d'un arbre 390 et auquel le marteau imprimeur 344 est associé. Lorsque l'ergot 387 est libéré par le bossage de came 388, le ressort 391 pousse le marteau 344 vers les roues des types 52; ainsi le numéro de compte qui se trouvait sur ces roues se trouve imprimé sur le chèque ou la feuille de versement, avant tout mouvement du châssis pivotant 348.

En résumé, le fonctionnement de l'ensemble (fig. 3) comporte la sélection d'un compte débit ou crédit à partir de chaque élément primaire et leur transfert à la fois sur l'additionneur de l'ensemble et sur une feuille de registre. L'opportunité de cette association est par la suite véritable de la manière suivante. On empêche le transfert d'une information primaire et celui d'un numéro de compte tant qu'un élément primaire n'a pas été correctement placé dans le système d'affichage 24*a* (voir commutateur 136 de la figure 3) et que le numéro de compte transféré n'a pas permis une vérification visuelle de l'identité de la feuille de registre sur laquelle l'information primaire a été transférée.

Un certain nombre de principes généraux seront maintenant examinés en relation avec ce qui précède. Auparavant il a été question du transfert d'informations secondaires, dans lequel les informations secondaires sont transférés sur les éléments primaires (chèques ou feuilles de versement) en même temps qu'a lieu le transfert des comptes débit et crédit des éléments primaires, sur les éléments secondaires (feuilles de registre). Il a été montré qu'il est nécessaire pour effectuer cette opération, de disposer les indications concernant les numéros de compte, sur les éléments secondaires, de manière à ce qu'elles soient enregistrées et détectées avant d'être inscrites. En outre, le numéro de compte d'un élément secondaire ainsi enregistré peut être directement transféré, sous la forme d'indications visuelles permanentes ou d'un système équivalent, sur les chèques ou les feuilles de versement associés. Nous avons montré un dispositif d'enregistrement dans lequel l'information dépend de la position de roues de types et le transfert des éléments primaires se fait par impression, mais ceci ne doit en aucun cas être interprété comme une limite à la présente invention. Tout autre dispositif qui modifie uniquement la disposition des éléments primaires de manière à les associer avec les éléments secondaires peut être également applicable à l'exemple considéré. Par exemple, on peut automatiquement classer les éléments primaires conformément aux indications enregistrées concernant le numéro du compte.

En ce qui concerne le dispositif de détection, il a été décrit un système dynamique, dans lequel le chariot de la machine d'inscription est modifié, de manière à permettre la détection des indications concernant un numéro de compte, qui se trouvent sur une feuille de registre, et se déplaçant d'un mouvement latéral par rapport à la base fixe de la machine. D'autres techniques peuvent être utilisées. Par exemple, l'on connaît des montages pour mettre en position la feuille de registre tels que les chercheurs automatiques de lignes verticales qui permettent un mouvement vertical de la feuille de registre relativement à la base fixe de la machine pendant l'insertion de la feuille entre les tambours 40 et 43. De tels chercheurs de lignes nécessitent la perforation des bords droits et gauches de la feuille de manière à ce que la feuille soit déplacée verticalement et soit arrêtée à l'emplacement de la ligne sur laquelle se fera ensuite l'inscription. Pour utiliser un tel montage, il suffit de faire tourner la partie perforée 28 de la feuille de registre ainsi que les balais à l'intérieur du système de lecture, de manière à produire le mouvement de l'aire codée permettant l'exploration par des balais identiques à ceux cités dans le mode de réalisation précédent.

En fait, avec un dispositif avec chercheurs de lignes verticales, on n'a pas besoin des dispositifs donnant l'indication de l'avance et de la position, déjà citées, puisque ces indications sont fonction du dispositif des chercheurs verticaux eux-mêmes. En outre ce système élimine le dispositif d'arrêt basculant 33 et tous les organes associés avec le système d'affichage 31, considéré précédemment, puisque la mise en position qui dépend de ces organes n'est pas nécessaire dans ce cas. Un exemple de chercheur de lignes automatiques est le mécanisme de chercheur de lignes automatiques associé avec une machine à calculer de type connu.

De même, il n'est pas nécessaire que la feuille de registre se déplace par rapport au système de détection, il est même préférable, dans certains cas, de choisir un système de détection statique. Un exemple en est donné par les figures 15 à 18 comprise. En se reportant à la figure 15, il est bon de se rappeler que les touches de commande 35, décrites avec la figure 1, étaient pourvues d'une bobine de verrouillage. Dans le cas d'un système de détection statique cette bobine de verrouillage 119 interviendra de la manière suivante. Le dispositif de commande 121 (de la figure 3), sensible à la manœuvre de la touche de lecture 36 et des touches de commande 35 ainsi qu'au déplacement du chariot 8 (fig. 3), est utilisé pour actionner, à intervalles répétés, un commutateur 400 pendant la mise en position finale du chariot qui suit la fin de l'impression d'un nouveau solde. Cette mise en position finale comporte la mise en position du chariot, le plus loin possible vers la droite, sans arrêt intermédiaire comme dans le mode de réalisation précédent. Ce mouvement du chariot est le mouvement classique de la plupart des machines à calculer.

En actionnant le commutateur 400, un mécanisme bistable 401, de préférence un relais à loquet de type connu, est mis dans une première position stable, dans laquelle un jeu de contacts associés 402 est fermé, établissant ainsi une continuité électrique entre la source 95 et la bobine de verrouillage 119, donc empêchant les touches de commande 35 d'opérer.

Les opérations nécessaires pour manœuvrer le relais 401 de manière à libérer les touches de commande sont décrites ci-dessous.

Il faut noter que la fente 54, par laquelle sont insérés les chèques et les feuilles de versement ainsi que le système de transfert 17*a* au moyen duquel un numéro de compte est imprimé et un élément inséré transporté, sont en substance identiques aux organes décrits auparavant dans les figures 9 à 14. En outre, la mise en place des roues des types est accomplie au moyen des mêmes cliquets et roues à rochets, les cliquets étant indiqués en 288 de *a* à *e*, et les roues des types associées en 52, de *a* à *e* près de la fente 54. Les cliquets 288 sont actionnés par l'électro d'avancement 274 comme dans la figure 9, les signaux étant aiguillés différemment en rapport avec le dispositif de détection considéré. Il faut mettre en évidence un changement concernant le dispositif de détection relativement au précédent. Dans le mode de réalisation considéré, il n'est pas nécessaire de remettre les roues des types en place; en d'autres termes, les roues des types peuvent rester dans la position qu'elles avaient précédemment au moment où a lieu une nouvelle mise en place, il suffit simplement de libérer les loquets associés 310 de *a* à *e*, qui commandent les tiges-poussoirs 294, de *a* à *e* (montrées dans la figure 9); de ce fait, les tiges-poussoirs et les cliquets associés sont libérés. Pour cela, il est prévu une bobine de relâchement 403, reliée aux contacts 400 et qui s'excite à leur fermeture. Lorsque les touches de commande 35 sont bloquées et les cliquets 288 libérés de manière à s'enclencher dans les roues des types 52, le dispositif se trouve dans la condition « prêt pour la lecture »; pour libérer les touches de commande une opération de détection est nécessaire. Pour lire, ou détecter, les indices codés d'une feuille de registre il est prévu un système d'affichage 14*b* qui reçoit cette feuille destinée à être détectée. En se référant aux figures 15 à 17 on voit que le système 14*b* comprend une fente 405 entre deux plaques diélectriques 406 et 407. La plaque 406 comprend des prolongements latéraux 408 et 409 qui servent de guides latéraux pour l'insertion d'une feuille de registre. Deux bobines 410 et 411 sont montées sur des supports, non représentés, de manière à permettre aux plongeurs 412 et 413 de passer à travers les cavités 414 et 415 (fig. 16) de la plaque 406 et les cavités 416 et 417 (fig. 17) de la plaque 407. Les plaques 406 et 407 sont séparées par deux ressorts associés, non représentés, de manière à préserver un espace entre elles, lorsque les bobines 410 et 411 s'excitent. Les plongeurs 412 et 413 sont divisés en deux parties, désignées par A et B, que l'on a recourbées sur la face postérieure de la plaque 407, de manière à obtenir une force uniforme lorsque les bobines sont actionnées pour mettre en contact les plaques 406 et 407. La plaque antérieure 406 est pourvue de cinq rangées de contacts électriques 420, de *a* à *e* (fig. 16), comprenant chacune dix contacts. Les contacts 420 pénètrent légèrement à l'intérieur de la fente 405. De l'autre côté des rangées 420, sur la plaque postérieure 407, se trouvent des bandes conductrices associées 421, de *a* à *e* (fig. 17). Les plaques 406 et 407 sont en matière isolante et les bandes conductrices 421, de *a* à *e*, sont légèrement enfoncées dans la plaque 407, de manière à servir d'encastrement aux saillies 420 et à donner une prise supplémentaire à une feuille de registre pour qu'elle se maintienne dans une position fixe lorsque les deux plaques sont en contact. Les bandes 421 se trouvent sur le devant de la plaque postérieure 407 et sont de ce fait représentées par une ligne en pointillé, la vue de la figure 17 étant une vue de derrière. Les bandes 421 sont associées aux conducteurs 422, de *a* à *e*, par des connexions appropriées. Ces fils électriques conduisent à des relais 423, de *a* à *e* (fig. 15) et aux bobines de verrouillage 277, de *a* à *e*, qui, comme il l'a été dit pour la figure 9, servent à débrayer les cliquets associés 288, de *a* à *e*, des roues des types 52, de *a* à *e*, lorsque la position désirée a été atteinte. Les relais 423 ont des contacts 424 de *a* à *e*, ouverts, et en série en position normale, de manière à connecter électriquement la source 95 lorsque tous ces relais opèrent simultanément. Les cliquets 288 sont pourvus de mécanismes 425, de *a* à *e* (fig. 18), au moyen desquels, à chaque mouvement des roues des types, découle un mouvement correspondant des bras de contacts 426, de *a* à *e*, chaque bras pouvant être associé à dix contacts fixes (correspondant aux positions des roues des types associées). Ces contacts fixes sont reliés aux conducteurs 428 groupés par cinq, 428 de *a* à *e*, comprenant chacun dix contacts. Les conducteurs de chaque groupe 428 sont représentés schématiquement par une ligne en pointillé 430, de *a* à *e*, chacune d'elle étant reliée (fig. 16) à une rangée de contacts 420 de la plaque 406.

En se reportant aux figures 15 et 16 on voit que, si une feuille de registre est glissée dans la fente 405, deux jeux de contacts 431 et 432 sont actionnés. Cette feuille est appuyée contre une plate-forme 433 qui peut être tout simplement le rebord extérieur du coffret 14*b* ou une série de tiges saillantes ou tout autre organe vertical susceptible d'arrêter la feuille. A la fermeture des contacts 431 et 432, très sensibles, du type décrit avec la plate-forme 47 de la figure 3, une continuité électrique est établie entre la source 95 et le relais de verrouillage 401, ce relais étant ramené dans la position correspondant à l'ouverture des contacts 402. Le circuit électrique entre la source 95 et le relais 401 comprend deux contacts 434 d'un relais 435 en position normale fermés. Le relais 435 est actionné seulement lorsque tous les cinq contacts 424, de *a* à *e*, sont fermés. Donc lorsque la feuille de registre est maintenue correctement dans le système d'affichage 14*b*, les contacts 402 sont ouverts, déverrouillant ainsi les touches de commande 35. Simultanément, une continuité électrique est établie entre la source 95 et la bobine du relais 437, par les contacts 431, 432 et 434, les contacts 438 du relais 437 se trouvant ainsi fermés. Lorsque ces contacts sont fermés, une continuité est établie entre la source 95 et les bobines 410, les plongeurs 412 et 413 mettent donc en contact les deux plaques 406 et 407 et de ce fait établissent une continuité électrique, par la feuille de registre, entre un contact déterminé parmi les rangées 420, et une des bandes conductrices 421. De ce fait, une continuité électrique s'établit entre un conducteur sélectionné pris dans chacun des groupes 428, de *a* à *e*, et les bobines 423 et 277, de *a* à *e*, qui leur sont associées.

Aussi, lorsque les contacts 438 sont fermés, la source 95 est associée avec un contact repos-travail 439 du relais 440, ce contact étant maintenu contre un contact fixe 441 « auto-interrupteur » par lequel le relais est excité, en mettant en contact le contact mobile 439 avec le contact fixe 442. Le contact 442 est relié à l'électro d'avancement 274 qui actionne les cliquets 288, de *a* à *e*, l'association entre les cliquets et les roues des types 52 étant indiquée schématiquement par les lignes en pointillé 443, de *a* à *e*, associées aussi aux bras mobiles des contacts 426, de *a* à *e*, des commutateurs à dix positions reliés à la plaque 406.

Lorsqu'il s'excite, le relais 440 envoie des impulsions à l'électro 274 qui fait avancer les cliquets 288, et de ce fait, entraînent les roues des types et les bras mobiles associés 426 (voir fig. 15 et 18). Les bras 426, les uns après les autres, connectent la source 95 avec les conducteurs 428; ainsi, lorsque le conducteur correspondant à la perforation de la feuille de registre est relié au bras 426 qui lui est associé, les bobines 423 et 277 s'excitent, la dernière actionnant une tige-poussoir 274, non représentée (mais décrite dans la figure 9), qui se maintient par un loquet 310 qui débraye le cliquet 288 du bras 426 et de la roue des types 52 qui lui sont associés. Ceci est en partie montré dans la figure 18, dans laquelle le cliquet 288*a* s'engage, non seulement dans la roue à rochets 296*a*, mais aussi dans la roue à rochets 446 qui tourne sur un arbre fixe 447, de préférence parallèle à l'arbre 298 et bloquée par un cliquet 448. Les roues 446 et l'arbre 447 sont conducteurs, le dernier est directement connecté à la source 95 (fig. 3), alors que le premier comporte un balai représentant le bras du contact 426*a*.

De ce fait, les roues des types 52 sont finalement mises en position en accord avec le chiffre du numéro de compte. Il faut noter que puisque le dispositif considéré est un système de détection statique, l'aire codée peut se répartir sur toute la feuille, ceci étant en quelque sorte profitable puisqu'on recherche une séparation la plus grande possible entre les contacts 420 et entre les bandes conductrices 421, de manière à empêcher un couplage capacitif entre les conducteurs parallèles.

Finalement, il faut noter que l'on n'a pas besoin de mécanisme de remise en place des roues des types. Avant chaque opération de mise en place, le commutateur 400 étant fermé, la bobine 403 s'excite et débraye les loquets 310 de *a* à *e*, aucun autre mécanisme de remise en place n'étant nécessaire.

Jusqu'à ce point il n'a pas été spécifié où se trouve exactement le système d'affichage 14*b*. En pratique, il est préférable de mettre ce système 14*b* le plus près possible des contacts fixes explorés par les bras 426, de manière à minimiser l'importance des fils nécessaires et la capacité existant entre ceux-ci. Cependant, si on le désire, la fente 405 peut être placée immédiatement au-dessus des tambours 40 et 43 (fig. 2) au moyen d'un support qui prolonge, non pas le chariot, mais la base fixe de la machine. Dans ce but, il suffit de prévoir la plateforme 433 sous la forme d'une barre mobile qui s'étend entièrement sous la fente 405, ou sous la forme de deux tiges perpendiculaire à la fente, sous les plaques antérieure et postérieure 406 et 407. Dans ce dernier cas, les tiges peuvent être retirées en les incorporant aux plongeurs des bobines; ainsi, lorsque l'on doit les retirer pour permettre à la feuille de passer, il suffit d'actionner les plongeurs et d'enclencher les tiges. Inversement, lorsqu'il faut introduire les tiges, il suffit de libérer ces plongeurs. Cet embrayage doit évidemment avoir lieu lorsque l'opération de lecture est terminée, c'est-à-dire lorsque la feuille est engagée entre les deux plaques 406 et 407, ceci étant indiqué par l'envoi d'un signal sur le conducteur 450 (fig. 15). Alors, la plateforme ou les tiges peuvent être retirées. D'autre part, lorsque l'opération d'inscription antérieure est terminée, comme l'indique la fermeture des contacts 400, il est préférable de laisser la plateforme ou les tiges 433 de manière à servir de support de montage pour la détection des aires codées de la feuille de registre. Le dispositif des figures 15 à 18 montre les avantages de ce système relativement aux dispositifs précédents. Premièrement, il n'y a pas de mouvement intermédiaire du chariot, ce qui réduit le temps de détection. En second lieu, la suppression du mouvement de l'appareil de détection par rapport à la feuille diminue les possibilités d'usure contre cet appareil, les contacts de la plaque antérieure 406 étant plus rugueux que les balais 84 (fig. 3). Finalement, si la fente 405 est placée juste au-dessus du chariot, on obtient un gain de temps encore plus grand lors de la détection puisque la feuille est insérée, détectée et immédiatement après tombe entre les tambours du chariot. En outre, la suppression de l'opération de remise en place des roues 52 offre un gain de temps et une économie de matériel. Dans le cas où l'on a 50 fils conducteurs représentés par les fils 430, il sera bon, si la fente 405 est loin des organes d'exploration associés aux bras des contacts 406, d'utiliser un code intermédiaire dans lequel un code binaire à quatre chiffres 8-4-2-1 serait utilisé pour représenter chaque chiffre du code, 20 fils étant alors suffisants pour transmettre les cinq chiffres du numéro de compte, un dispositif de conversion de code étant associé au système d'exploration pour fournir une traduction du code 1 parmi 4 en code 1 parmi 10. Comme dernière remarque, il faut noter que, bien que les systèmes jusque-là analysés comprennent des relais de type classique et des organes à détection par perforations, il est évident que dans les techniques anciennes et nouvelles de commutation on pourrait trouver des équivalents à ces organes, en particulier le système à détection par perforations est l'équivalent des systèmes à enregistrement et détection magnétique. Dans ce dernier cas, de l'encre magnétique, par exemple, peut être utilisée pour inscrire le symbole d'un numéro de compte, un code ou des données sur une feuille de grand livre et des détecteurs magnétiques peuvent être associés en vue d'obtenir le transfert d'une information. Il est évident que dans cet exemple, comme dans les autres, il n'est pas nécessaire de mentionner tous les équivalents possibles du fait qu'ils sont connus.

Il reste bien entendu que la description qui précède n'a été donnée qu'à titre d'exemple non limitatif et que de nombreuses variantes sont susceptibles d'être réalisées sans sortir pour autant du cadre de l'invention.

RÉSUMÉ

Système d'exploitation de données. Le dispositif comprend des moyens d'inscription permettant d'afficher sur un document secondaire des données figurant sur un document primaire. Des moyens de détection permettent d'extraire du document secondaire une information d'identité particulière à ce document secondaire et de la transférer sur l'élément primaire. Des moyens sont fournis au dispositif pour que les données à porter sur le document secondaire ne puissent y figurer si l'information d'identité n'a pas été transférée sur le document primaire.

Société dite : INTERNATIONAL STANDARD ELECTRIC CORPORATION

Par procuration :

Y. Goupil

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Fig. 1.

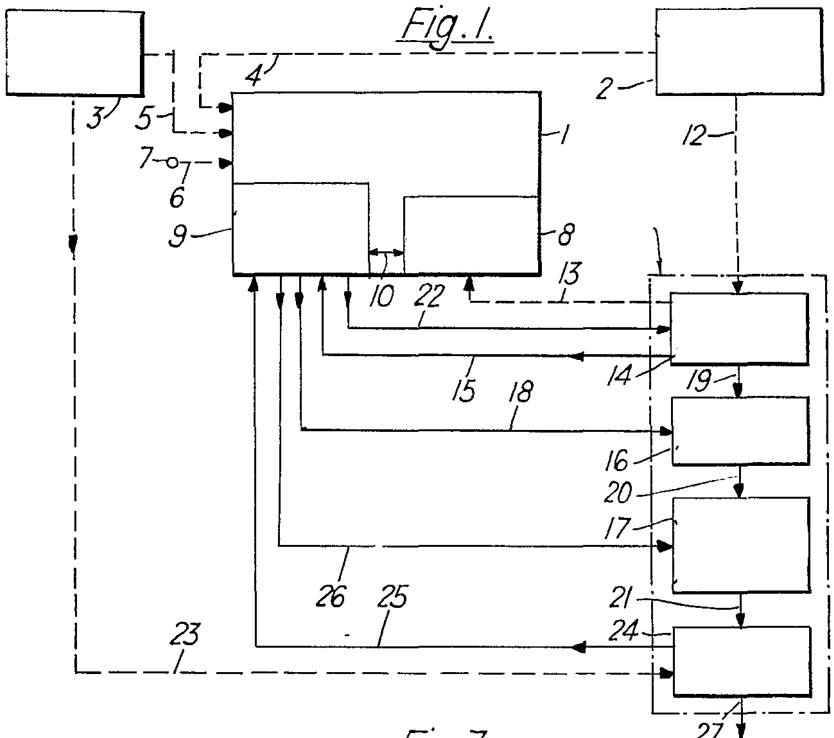

Fig. 7.

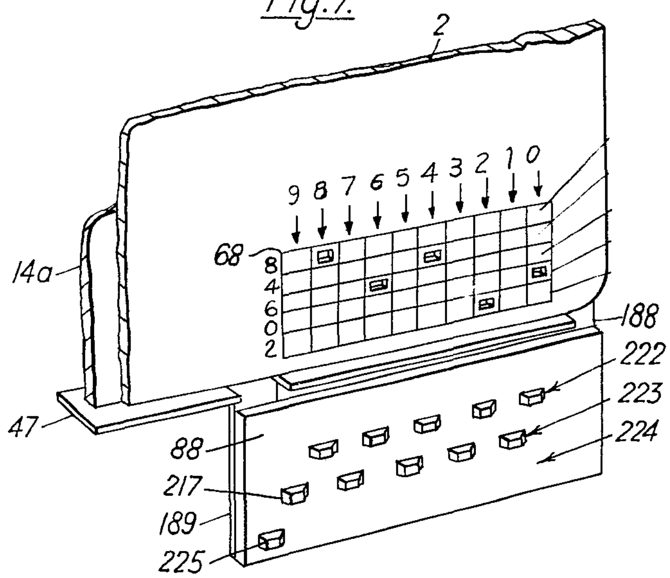

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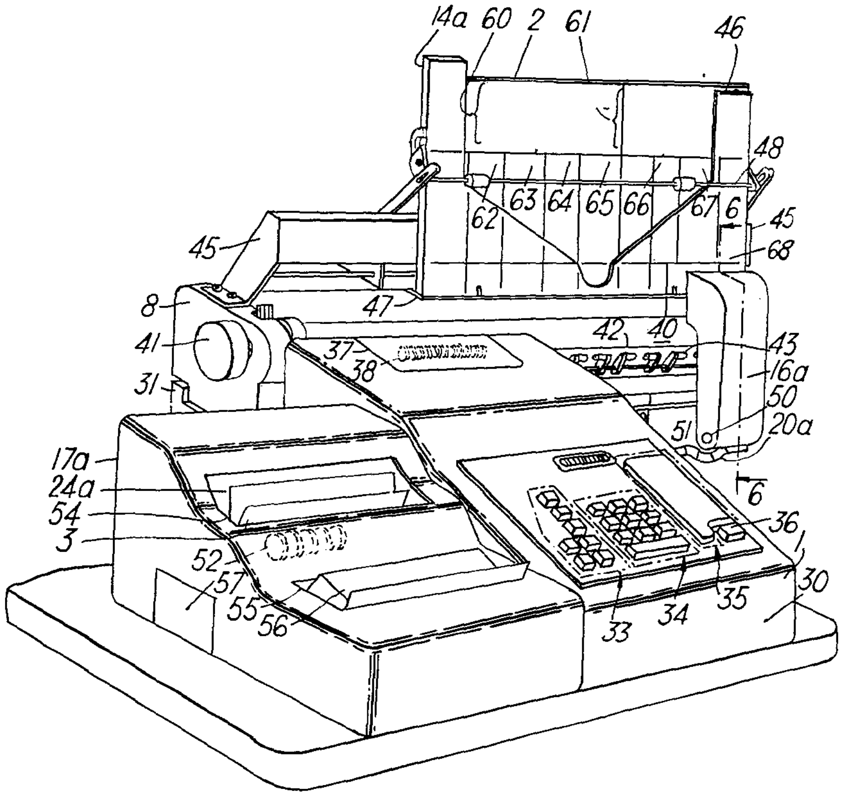
Fig. 2.



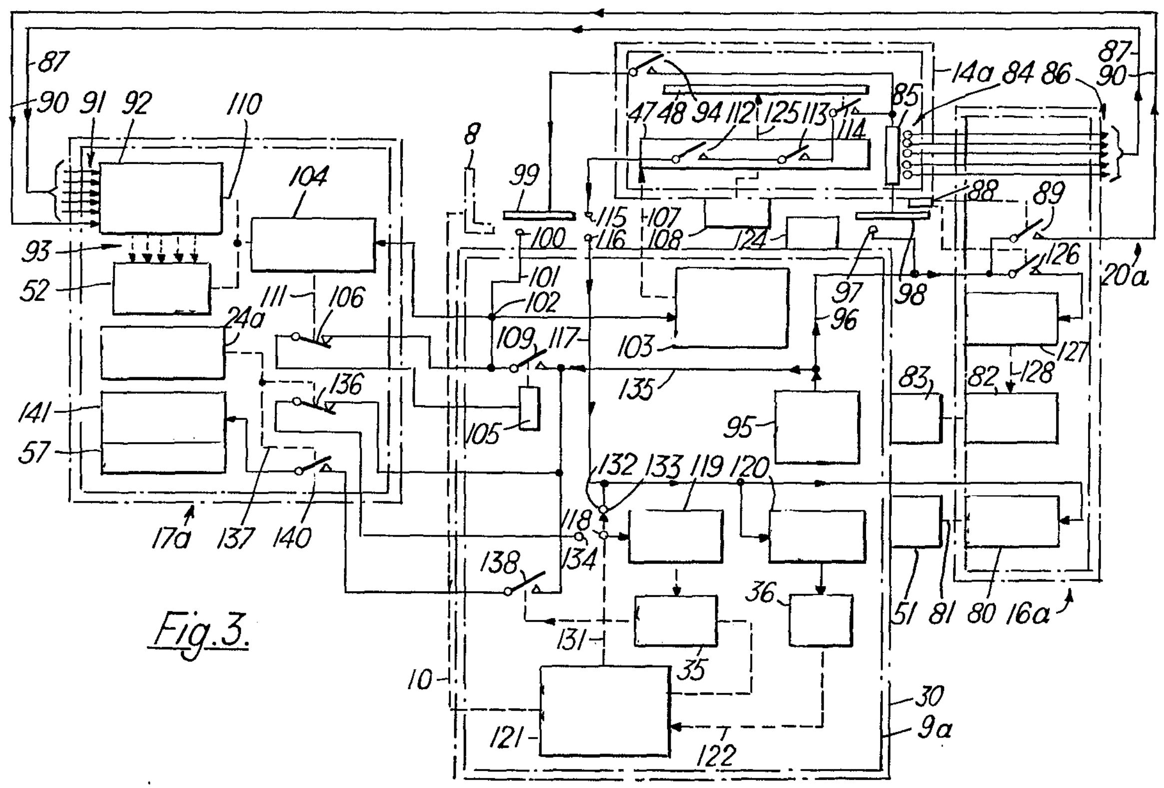

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Fig.3.

Fig. 4.

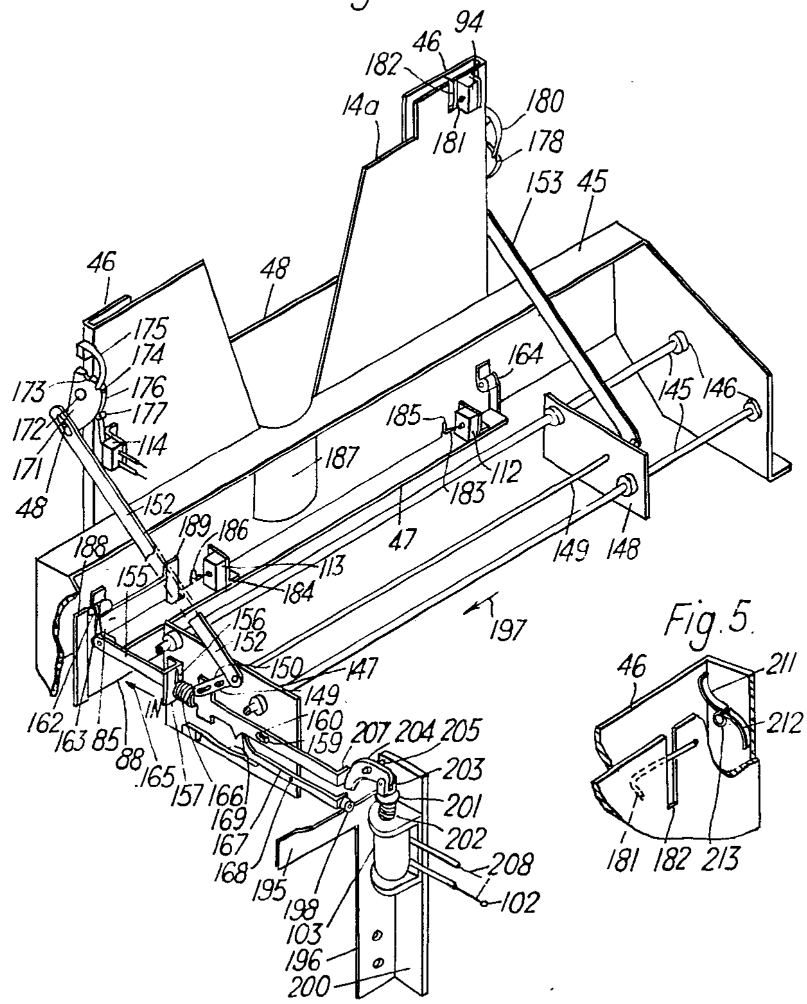
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Fig. 5.
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Fig. 6.

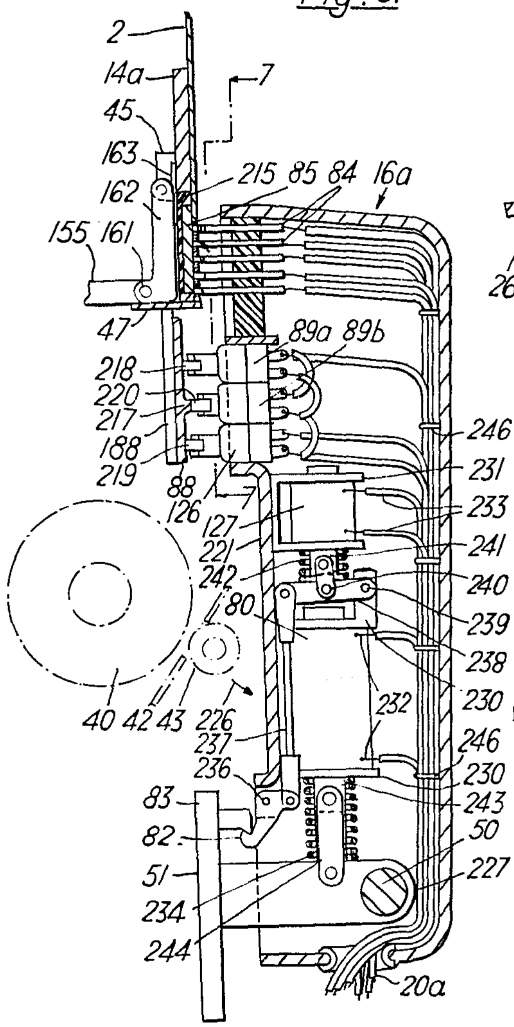

Fig. 8A.

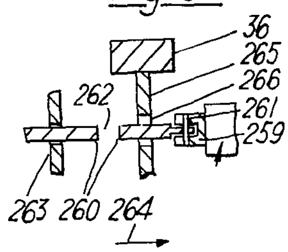

Fig. 8B.

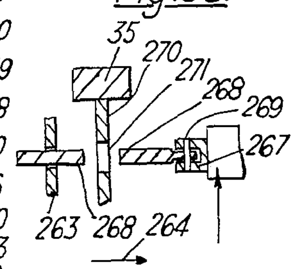

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Fig. 9.

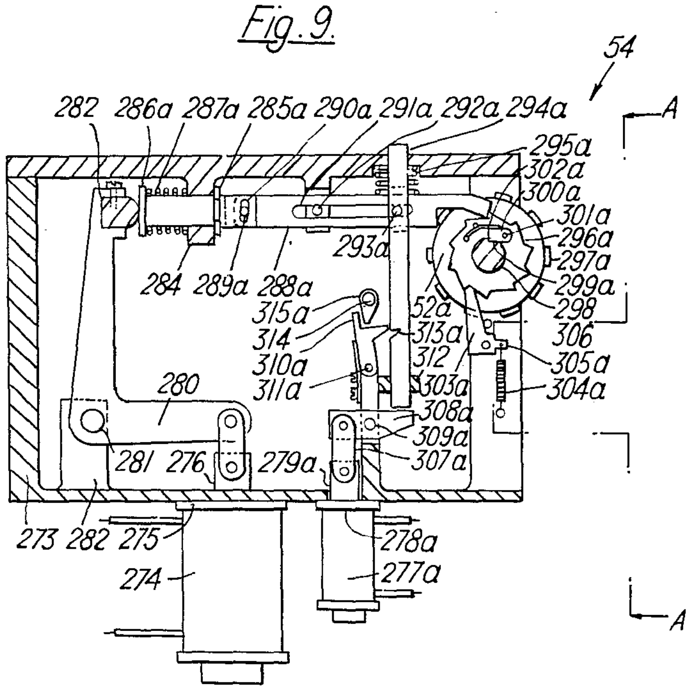

Fig. 16.

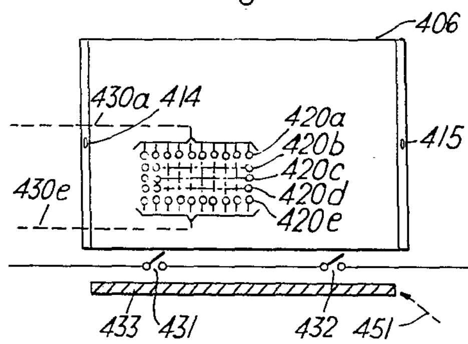

Fig. 10.

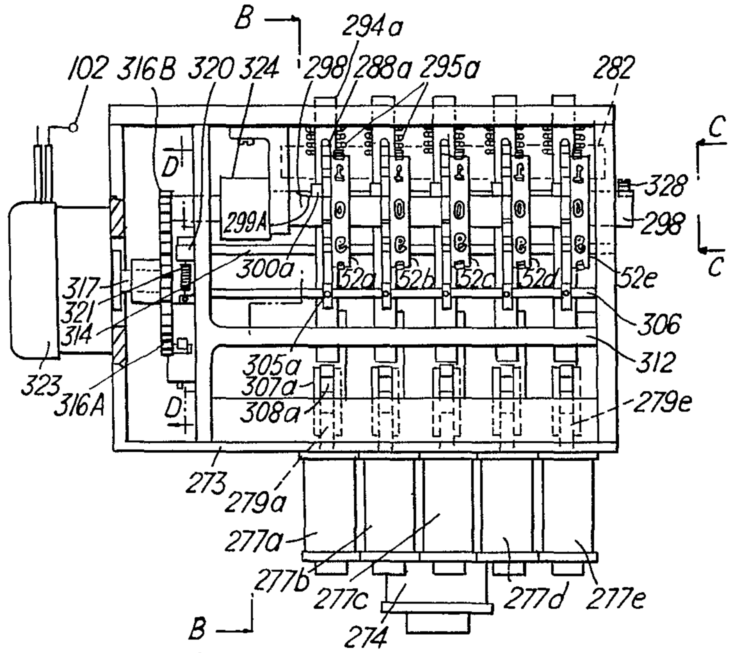

Fig. 12.

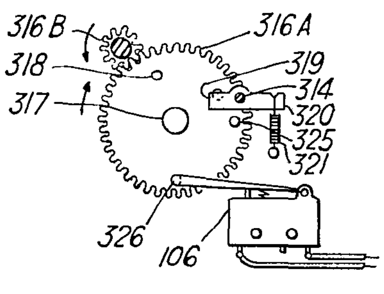

Fig. 11.

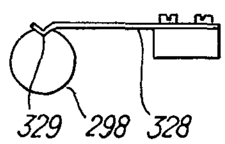

Fig. 13.

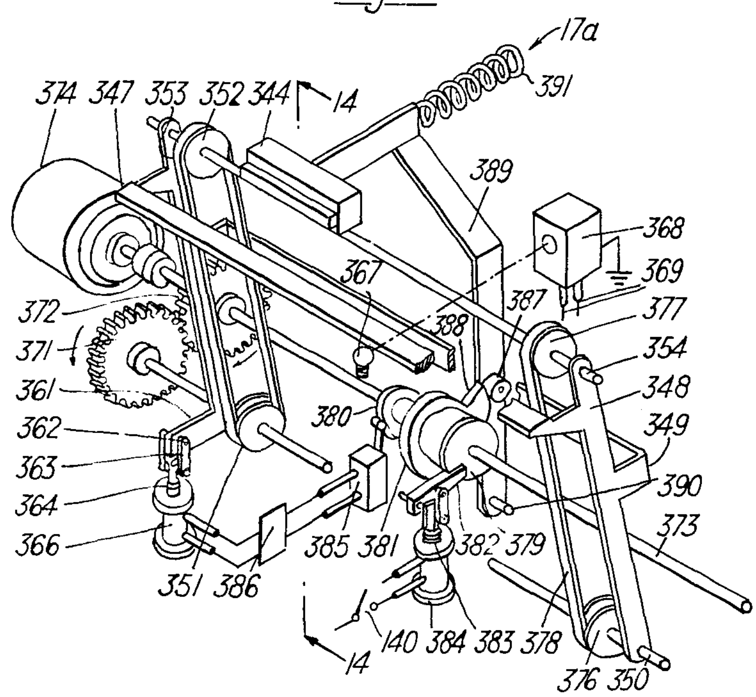
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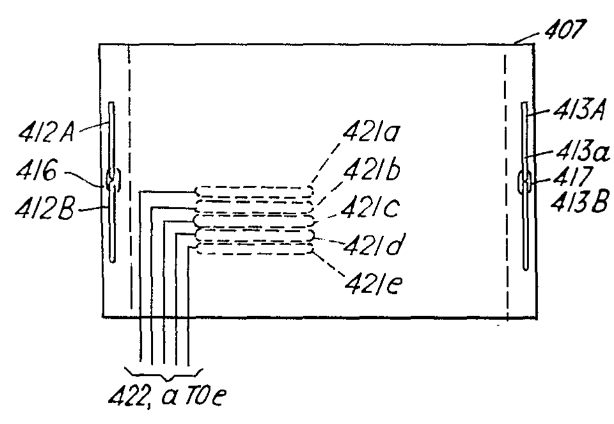
Fig. 17.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412B
421c
413B
421d
421e
422, a TO e

Fig. 14.

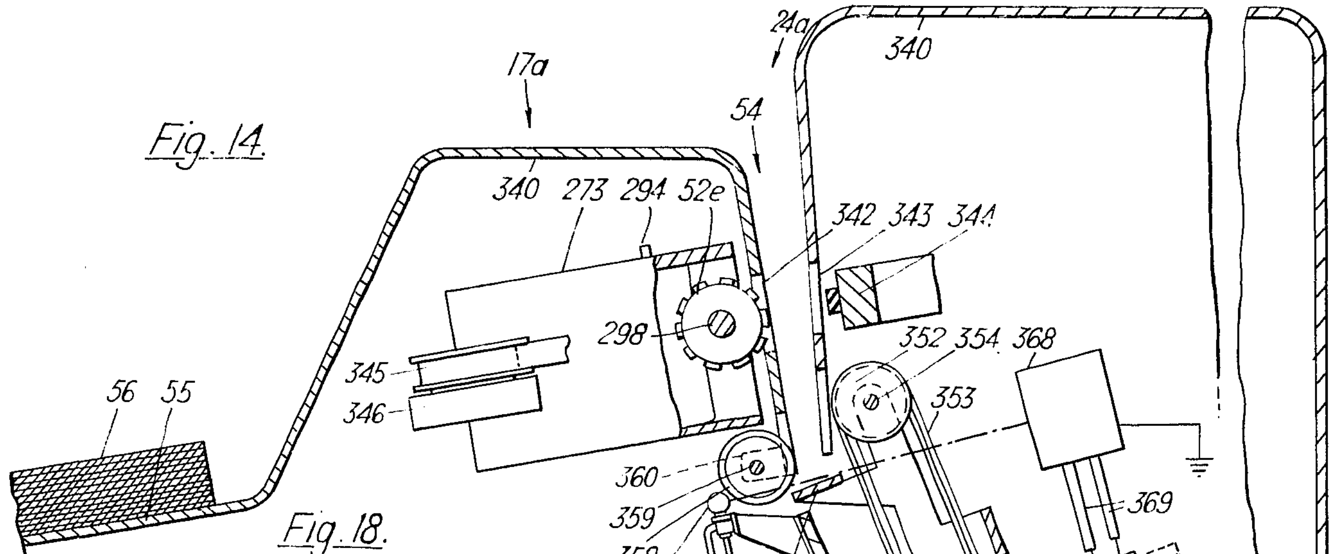
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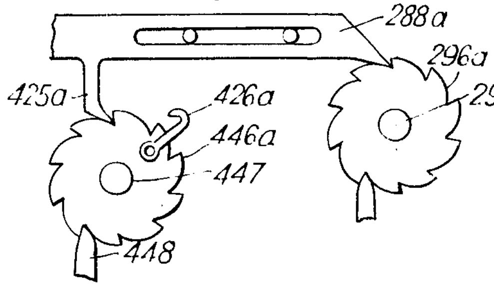
Fig. 18.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446a
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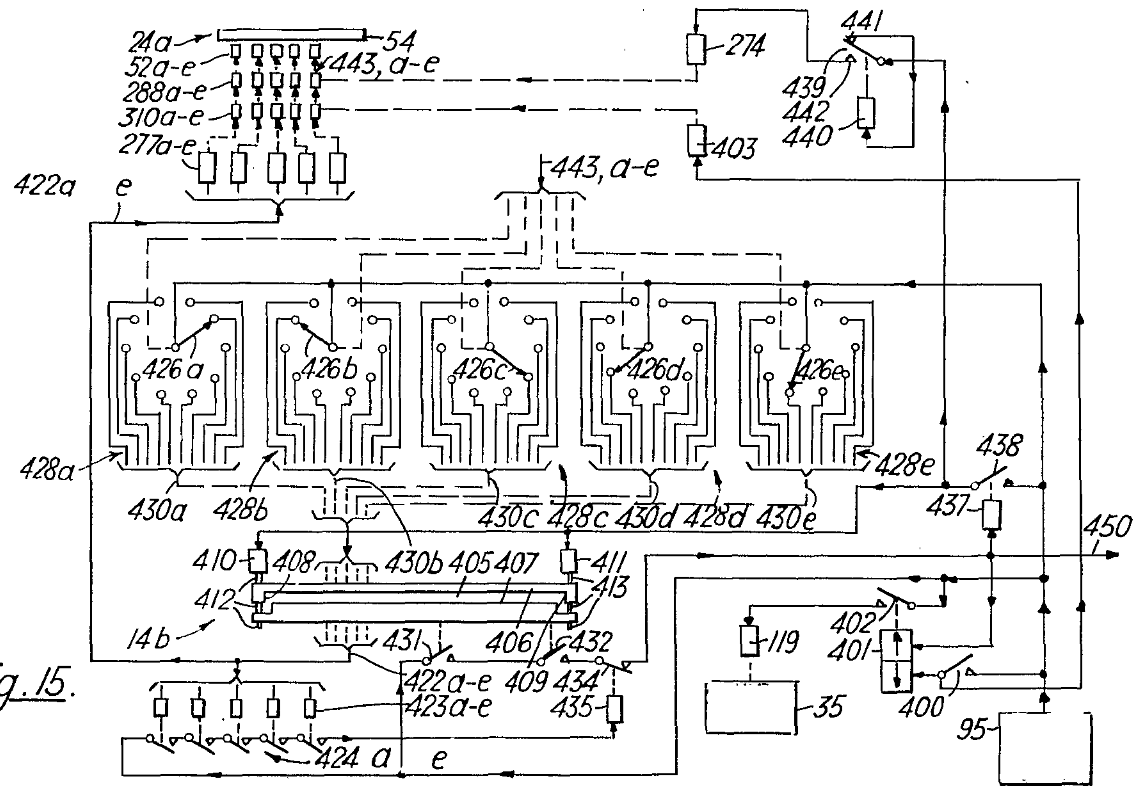

Fig. 15.

United States Patent Office 3,204,086 Patented Aug. 31, 1965

3,204,086

DATA PROCESSING SYSTEMS

Hans K. Flesch, Glen Cove, N.Y., and Fredrick T. Gutmann, Caldwell, and Robert Lieber, West Orange, N.J., assignors to International Telephone and Telegraph Corporation, Nutley, N.J., a corporation of Maryland

Filed Apr. 27, 1961, Ser. No. 106,090
16 Claims. (Cl. 235—61.9)

This invention relates generally to data processing systems, and particularly to such systems which require the posting, on selected display elements, of selectively grouped items of data relating to, or derived from, corresponding primary data elements. Although it is applicable to many data processing situations within the above definition, the invention was originally conceived and developed for use in connection with commercial checking account posting systems, wherein the primary elements are checks and deposit slips, and the selected display elements are account ledger sheets updated in accordance with debit and credit indications on one or more associated primary elements. The application of the invention to utility accounts, statistical surveys, and other large scale data processing operations, are too numerous to mention, and the adaptation of the presently disclosed apparatus thereto may be readily made by those skilled in the associated arts, without further experimentation or exercise of the inventive faculty, merely by reading the present disclosure.

As the above implies three basic procedures are generally associated with, and characteristic of, systems to which this invention may be applied. These are, respectively, a sorting procedure—wherein primary data elements are grouped in accordance with a common characteristic, in the present instance, the depositor's name, a selection procedure—wherein a display, or secondary element, a ledger sheet in the present instance, is associated with each group of primary elements, and a transfer posting procedure—wherein representations of intelligence symbols, derived, directly or indirectly, from the primary elements, are transferred to the associated secondary elements. These procedures are characteristically subject to three associated classes of errors which are respectively designated sorting, selection, and transfer posting errors. The nature of each of the first two classes of error is obvious from the designation. The last-mentioned class, transfer posting errors, may be further characterized in terms of direct and indirect transfer posting errors, the former involving mishandling of intelligence symbols during a transfer operation, and the latter relating to the omission, or mishandling of a primary element whereby no posting transfer is made, or whereby the primary element intelligence is posted to more than one secondary element. The present invention relates exclusively to the detection and correction of sorting, selection, and indirect transfer posting errors; apparatus for the detection and correction of direct transfer errors in association with the presently disclosed apparatus being shown and described in a co-pending patent application Serial No. 102,692, filed April 13, 1961, by K. J. Staller, and a system cooperatively employing the two error detection and correction systems, in a unique manner, and with improved efficiency being shown and discussed in a co-pending patent application Serial No. 125,769, filed July 21, 1961, by F. McKennett et al.

Considering the above classes of error individually, the prior art preventive or corrective approaches thereto have been as follows:

First, with respect to sorting errors, one prior art approach has been to place account number identifying symbols on the primary elements (checks and deposit slips) prior to the issuance of the elements to the depositor, or other party, executing the same, or to have the depositor place the identifying symbols thereon prior to the execution thereof. These "pre-placed markings" are subsequently used to efficiently group the elements of each depositor, by means of either automatic or manual operations, and thereby to reduce the possibility of sorting errors. The disadvantages, however, are that the pre-placement of identifying markings introduces an additional manual procedure, which is still subject to error, into the previously required operations. Further, the pre-placed markings are of no value after an undetected error has occurred, and therefore of no value with respect to indirect transfer errors. Also, the preplaced markings are subject to distortion, or obliteration where, as in the present instance, the primary elements are relatively fragile, frequently handled, objects.

Secondly, with respect to selection errors, the prior art approaches generally involve a comparison operation in which pre-placed account number identifying markings on the secondary display elements (ledger sheets) are compared to pre-placed identifying markings on the primary elements (checks, deposit slips), to determine a mis-association of the two. This is subject to the criticisms cited in the preceding paragraph, and requires additional apparatus, for sensing primary and secondary markings, for storing and comparing the sensed markings, as required, and for the control of system operations in accordance with the comparison results.

Finally, with respect to indirect transfer posting errors, the prior art approach is generally to provide for the tallying of transfer posting operations and primary elements, to determine whether a posting operation has been performed for each primary element. This, again, is costly in terms of auxiliary time consuming procedures and apparatus, and does not guarantee that each primary element will be involved in one, and only one, posting operation.

It is thus the primary object of this invention to provide a data processing system including provision for the efficient detection of sorting, selection, and indirect transfer posting errors, in a single auxiliary system operation.

Another object is to provide a data posting system which does not require preplacement of markings, and associated auxiliary manual operations, for the detection of sorting or selection errors.

Still another object is to provide a data posting system wherein primary elements are provided with correlating markings derived from secondary elements associated therewith in transfer posting operations.

Another object is to provide a data posting system wherein the disposition of any primary element, subsequent to a data posting operation, is determined in accordance with markings derived from a secondary element on which the primary element intelligence has been posted.

Yet another object is to provide, in a data posting system, an efficient and economical arrangement for conditioning a remote printing unit for the subsequent transfer of a correlating account number indication to a group of primary elements in accordance with account number signals derived from, and uniquely characteristic of, a secondary element on which data taken from said primary elements is to be posted.

These and other objects are achieved, in an exemplary arrangement disclosed herewith, by means of a correlating transfer unit which is readily adapted to, and operative in association with, commercially available posting transfer apparatus (e.g. accounting machines), to perform a correlating account number transfer operation by means of which all errors within the above classifications are discoverable during the ordinary course of business with no further manual, or other time-consuming auxiliary operations. The specific correlating transfer operation disclosed herein involves an auxiliary printing operation wherein a representation of account number signals derived automatically from a secondary posting element (e.g. a ledger sheet), is stored, and wherein an indication of the stored representation is later transferred to primary elements (e.g. checks, deposit slips), in association with manual or other operating procedures ordinarily required for posting data, taken from said primary elements, on said secondary element. As the primary elements are thereafter filed, during the ordinary course of business, errors may be readily detected in terms of discrepancies between the transferred account number indications on the primary elements, and indications on the selected file repository. It is again noted that the present account number transfer is a by-product of the associated posting operations and therefore requires no pre-placement of account number identifying markings on the primary elements, as well as the associated time consuming operations required for setting up such pre-placement. Thus, the cost of the present account number transfer may be somewhat offset by savings made in relation to hitherto required pre-placement operations. It is also noted that any indirect transfer posting error involving a failure to post, is accompanied by the absence of an account number transfer, this being also readily noticed during filing.

The foregoing, and other objects and features of the present invention may be more fully appreciated and understood from the following detailed description to be read in association with the accompanying drawings wherein:

FIG. 1 is a block diagram useful in explaining the overall arrangement and operation of a system embodying the present invention;

FIG. 2 is an isometric external view of a data processing and posting machine modified in accordance herewith;

FIG. 3 is a schematic drawing illustrating the internal arrangement of components in the modified machine of FIG. 2;

FIG. 4 is a rear isometric view of the holding fixture **14***a* of FIG. 2;

FIG. 5 is an isometric view of the upper left hand portion of the holding fixture cover **46** of FIG. 4, illustrating an optional arrangement of guide spring clips for bypassing the switch actuating arm **181** during removal of a ledger sheet from the holding fixture **14***a*;

FIG. 6 is a view in section through the sensing assembly **16***a* and holding fixture **14***a* of FIG. 2;

FIG. 7 is an isometric view of the cam plate **88**, shown schematically in FIG. 3, in relation to the tilt stop assembly **47**;

FIGS. 8A and B are respective views in section through read key **36** and a typical control key **35** illustrating the respective lock and unlock mechanisms associated therewith;

FIG. 9 is a view in section of a print wheel and associated setting and resetting mechanisms employed in the transfer assembly **17***a* of FIG. 2;

FIG. 10 is a view in elevation, with detent retaining pins shown in section, taken along line A—A of FIG. 9;

FIG. 11 is a view taken along line C—C of FIG. 10;

FIG. 12 is a view taken along line D—D of FIG. 10;

FIG. 13 is an isometric view of the printing and feed-off mechanisms in the transfer assembly of FIG. 2;

FIG. 14 is a partial view in section along line **14—14** of FIG. 13 illustrating further details of the mechanisms shown in FIG. 13;

FIG. 15 is a drawing partly schematic and partly in elevation of an alternative account number sensing arrangement in accordance with the present invention;

FIG. 16 is a view of the holding fixture backing plate in the arrangement of FIG. 15, including a section through the platform member used as a vertical support for ledger sheets inserted in the fixture;

FIG. 17 is a view of the holding fixture front plate in the arrangement of FIG. 15; and

FIG. 18 is a view illustrating the coupling of pawls to switch and printwheel ratchets in accordance with the embodiment of FIG. 15.

Referring to FIG. 1, a bank accounting machine system, generally termed a data processing and posting machine system, including controls modified in accordance herewith, is generally designated by the numeral **1**. System **1** is used to perform a posting operation in relation to bank checking accounts, and related accounting situations wherein balance information previously posted on a selected ledger card, or sheet, **2**, generally termed a secondary element, is brought up to date in accordance with primary debit and credit intelligence taken respectively from associated checks and deposit slips, **3**, generally termed primary elements. As indicated above, processing and posting systems of this type require the performance of associated sorting, selection and transfer posting operations which are subject to the corresponding errors associated with the present invention. Specifically, in the present instance, checks and deposit slips are grouped in accordance with the names of the associated makers or depositors prior to posting, corresponding account ledger sheets are selected for processing, and the primary debit and credit intelligence, for each group of checks and deposit slips belonging to the same account, is posted on the corresponding ledger sheet, while new balance information is accumulated, and thereafter posted on the same ledger sheet. This is schematically indicated in FIG. 1 by the dotted lines **4** and **5** which represent the transfer of old balance information and primary intelligence from the respective elements **2** and **3**. A third dotted input line **6** from a general source schematically indicated at **7**, is used to represent all other intelligence inputs to the system **1**, such as the date of posting, the nature of the transaction, and the like. As indicated above, the present invention relates to grouping and selection errors, or equivalently, to non-correspondence errors in which primary intelligence is posted on a non-corresponding ledger sheet, and to indirect transfer posting errors where primary elements are fortuitously mishandled so that the information thereon is not posted at all. The novel approach herein is, in lieu of the prior art immediate detection, or prevention of the errors, to allow the errors to occur, and also to transfer an account number indication to each primary element, in association with the corresponding posting operation, whereby the disposition of the primary intelligence is made immediately apparent to all who subsequently examine the primary element during the ordinary course of business. Thus, the absence of such a transferred account number indication, or the presence of more than one such indication would be indicative of an indirect posting transfer error, while the presence of a transferred indication which differs from the account number indication on the file repository of the primary element selected e.g. in accordance with other information on the primary element, such as the depositor's name, is indicative of a non-correspondence error. As noted above, the present invention requires fewer auxiliary procedures and is therefore more efficient than prior art systems. It is further noted, and bankers have so indicated, that despite all prior art precautionary measures, non-correspondence errors can, and do, occur, and once such an error has occurred, it is usually not discovered until a disgruntled depositor reports an incorrect balance statement. Even then, a difficult and time consuming procedure is required to locate the account of the depositor benefiting from the error.

The present approach further includes the provision of interlock precautions by means of which the association of each primary element with one, and only one, secondary element, whether or not the secondary element is correctly associated therewith, is further ensured.

The above account number transfer and interlock precautions are also schematically indicated in FIG. 1 as noted below. The system **1** includes a carriage mechanism **8** the position of which is controlled and sensed by a control unit **9**, as indicated by the connecting line **10**, therebetween. Control unit **9** has been modified in accordance with the present invention in a manner to be described. In conventional operations, the ledger sheet **2** would be directly inserted into rollers on the carriage **8**, and transported laterally in relation to a printing assembly, shown at **38** in FIG. 2, but, for convenience, not shown in FIG. 1, with the required posting intelligence being transferred via the printing assembly to selected positions on the ledger sheet, as required. In the present arrangement, this operation is preceded by a sensing operation wherein the secondary element **2** is first associated with a correlating account number transfer unit **11**, as indicated by the dotted lines **12** and **13**. The sheet **2** is inserted into a holding fixture **14** within the unit **11** and, when properly oriented in relation to this fixture, a "ready" signal is transferred from the fixture to the control unit **9**, the signal transfer channel being schematically indicated at **15**. When the "ready" signal is sensed, the control unit **9** actuates a sensing assembly, schematically indicated at **16**, to sense coded account number markings which have been previously placed on the sheet **2**, and to transfer signals representative thereof to a store and transfer assembly **17** which stores a representation of the transferred signals. The line of control between control unit **9** and sensing assembly **16** is shown at **18**. The lines of communication, from holding fixture **14**, to sensing assembly **16**, to store and transfer assembly **17**, are respectively indicated at **19** and **20**. The output of assembly **17** which actually represents the positions of a set of printing wheels **52** as explained below in connection with FIG. 3 is schematically indicated at **21**. When the storage operation of assembly **17** is completed, the control unit operates the holding fixture **14**, the control link being indicated schematically at **22**, releasing the ledger sheet **2** for insertion into conventional vertical line-feed rollers on carriage **8** in accordance with standard posting procedures.

During the subsequent posting procedure, another unconventional operation is provided herein. Specifically, whenever intelligence is taken from a primary element **3**, the associated element **3** is inserted into a holding fixture **24** so as to communicate with the assembly **17**. Interlock controls are provided, these being partially represented by the line **25**, which prevent the posting of the intelligence taken from the primary element **3** until the primary element is properly situated in the fixture **24**, and when the required posting transfer of primary data is made, the assembly **17** is simultaneously actuated, by means of a signal on line **26**, to transfer account number markings, corresponding to the intelligence stored therein, to the element **3**, and the element **3** is then either manually, or automatically, removed from the fixture **24**, the removal being characterized by the dotted line **27**.

Referring to FIGURE 2, the superficial attributes of the machine **1** and the associated correlating transfer unit **11** of this invention are indicated therein. The machine **1** includes a stationary base assembly **30**, having an extending portion **31** which supports the carriage assembly **8** on a railing not shown, the carriage assembly **8** being thereby translatable in relation to the stationary assembly **30**. The base assembly **30** includes a plurality of indexing members, or keys, **33** through **36**. Keys **33** are used to introduce auxiliary intelligence such as the date, the nature of a transaction, and the like into the machine **1**. Keys **34** are numerical indexing keys by means of which data is entered into the machine. The keys **35** are control keys by means of which the quantities, or other symbols, selected by the keys **33** and **34** are transferred into the machine. Key **36** is a read, or sensing key which is further considered below. Within the assembly **30**, there are conventional storage and accumulating units, not shown, by means of which various arithmetical operations may be performed, on quantities which are selected by the keys **34** and transferred by the keys **35**. Also included within the base assembly **30**, and schematically indicated within the compartment **37** therein, is an assembly of print wheels **38** or printing bars, which are conditioned, in accordance with the selections made by the keys **33** and **34**, when given ones of the keys **35** are depressed. The keys **35**, in addition to transferring key-selected symbol representations, are also used to direct the lateral movement, and positioning, of the carriage assembly **8**, in relation to the base assembly **30**, so that the printing assembly **38** may be positioned opposite any desired region of the carriage, for purposes of printing the selected intelligence, or numerical totals derived therefrom, on the ledger sheet which, for this purpose, is held by a conventional line-feed roller indicated at **40**. The roller **40** is manually operable to vertically position an inserted ledger sheet **2**, in relation to the printing assembly **38**. The ledger sheet **2** when positioned by the carriage roller **40** is inserted through a guide plate indicated at **42** which is normally included in such apparatus and which is movable into and out of contact with the roller **40**. The guide plate **42** is provided with idler rollers **43** which oppose the roller **40**, and thereby rotatably grip an inserted ledger sheet for vertical transportation thereof. It is clear in FIGURE 2, that in order to insert the ledger sheet **2** between the rollers **40** and **43**, it is necessary to first insert the ledger sheet into a holding fixture **14*a*** which is located immediately above the roller **40**. The subscript "*a*" is used to indicate that a specific example, of the item generally designated **14** in FIG. 1, is under consideration. The holding fixture **14*a*** is mounted, by means of the bracket **45**, on the carriage **8**, and includes a transparent front cover and lateral guide assembly **46** for positioning a ledger sheet laterally in relation to the sensing assembly **16*a*** corresponding to assembly **16** shown generally in FIGURE 1. The fixture **14*a*** is provided with a tilt-stop assembly **47** (FIGS. 2, 4, and 6), which is variably positionable, in relation to the fixture, in two associated positions, respectively termed the blocking, and non-blocking, positions thereof. In the blocking position, the assembly **47** is interposed in the vertical path of an inserted ledger sheet, so as to vertically position the ledger sheet in relation to the aforementioned sensing assembly **16*a***. In the non-blocking position, the assembly **47** is positioned so as not to interfere with the vertical insertion of a ledger sheet, thereby allowing the ledger sheet to be further inserted vertically between the rollers **40** and **43** of the carriage **8**. The sensing assembly **16** is pivotally supported by means of a pivot pin **50**, on a bracket extension **51** extending from the base assembly **30**. The assembly **16*a*** is normally positioned, or pivoted, away from the holding fixture **14*a***, in order to protect the sensing components therein, and also to prevent accidental operation of the sensing apparatus, and resultant malfunction of the machine, as modified in accordance herewith.

As indicated in FIGURE 2, the store and transfer assembly **17*a***, is provided with a separate housing containing a holding fixture **24*a*** for receiving a primary element **3**. Schematically indicated print wheels, **52**, are provided, for transferring correlating account number markings to each primary element **3** inserted into a feed slot **54** in the fixture **24*a***. A tray, **55**, is provided for holding the primary elements in a stack, **56**, prior to the processing thereof, and a schematically indicated receptacle, **57**, is provided, at the bottom of the assembly **17*a*** for receiving the primary elements after the associated account number transfers have been made thereto. It is noted that receptacle **57** is readily detachable from assembly **17*a***.

A ledger sheet **2**, is shown in the sensing position within the holding fixture **14*a***, awaiting sensing by sensing assembly **16*a***, the latter being also shown in the sensing position wherein it is tilted forward adjacent the ledger sheet **2**. The ledger sheet **2** comprises a depositor's statement portion **60** and a record portion **61** which are provided with identifying information, as indicated, this information comprising the depositor's name, address, and associated account number which, in the illustrated situation, is the number 20648. The ledger sheet 2 is further subdivided into columns **62** through **67** inclusive, which respectively receive printed indications, during the posting operation, from the printing assembly **38**, these indications respectively comprising a carried forward balance indication, debit indications, credit indications, new balance indications, analysis information (such as the date and nature of the transaction), and finally, in the last column **67**, the new balance indication is repeated for use as part of the bank records. The ledger sheet is also provided with pre-placed markings, in the region **68** in the lower right hand corner thereof (FIGS. 2 and 7), which represent the account number, such as the number 20648. For the present arrangement, we prefer to use a set of markings comprising a punched hole field consisting of 5 punched holes each selectively placed in one of ten associated positions in a corresponding horizontal row in the region **68**. With this arrangement, when the sensing assembly is positioned adjacent the inserted ledger sheet, and when the carriage assembly is moved to the right relative to the sensing assembly, the coded field of punched holes in the region **68** serves to establish electrical continuity between a conductive backing plate on the holding fixture, as described below, and five brushes in assembly **16*a***, thereby transmitting five signals which are selectively positioned, in time, in accordance with the associated account number digits. The apparatus by means of which the operations of the sensing assembly, the tilt-stop assembly, and the transfer assembly **17*a***, are accomplished in association with the indicated control keys, **35**, is discussed below. For the present, it is noted that during the ordinary posting procedures, the ledger sheet **2** is vertically inserted through fixture **14*a***, between the rollers **40** and **43**, to the line position at which posting entries are required to be made, and the desired entries are made, in the columns **62** through **67**, in association with the control keys, which control the carriage position and the transfer of the manually indexed intelligence, or tabulating keys specifically provided for moving the carriage, the transfer keys also controlling the associated balance accumulating operations whereby new balances are derived, stored, and posted.

Referring now to FIGURES 3–14, the correlating account number transfer operation of the present invention may be further understood with particular reference to the schematic drawing of FIGURE 3, in which the holding fixture **14*a***, the sensing assembly **16*a***, the base assembly **30**, and the transfer assembly **17*a*** are distinguished by double framed outlines. It is emphasized that the carriage assembly is the only assembly which is capable of translating with respect to the other assemblies, and the sensing assembly is capable only of pivoting with respect to the other assemblies. For purposes of reference, a portion of the carriage assembly **8** is shown in a "broken away," double-framed outline to the left of the holding fixture **14*a***. Within the stationary base **30**, the only items required for an understanding of the present invention are those included within the modified control unit, **9*a***, previously considered in connection with FIGURE 1. Hence, all other items within assembly **30**, are presently omitted in order to simplify the present discussion.

Beginning with assembly **16*a***, and referring to FIGURES 3, 6, and 7, the mechanisms by means of which this assembly is actuated into its sensing, and retracted, positions are as follows. The sensing assembly includes an engage solenoid **80** which communicates, through a schematically indicated linkage **81**, with a bracket extension, **51**, of the base assembly, **30**, in a manner to be described, whereby upon operation of the solenoid **80**, the assembly **16*a*** is rotated into the sensing position in which an account number code field, on a ledger sheet in fixture **14*a***, may be sensed. The assembly **16*a***, when so positioned, is held thus by means of a latch **82** which engages a latch strike **83**. The sensing assembly further includes a set of five brushes indicated generally at **84** which, in the sensing position, are pressed against the ledger sheet in fixture **14*a***. The ledger sheet is backed by an electrically conductive plate **85** which serves to establish electrical continuity between the brushes **84** and a source of electricity **95**, as discussed below, while the carriage assembly is translated in relation to the brushes. The brushes **84** are individually brought out in conductors **86**, which are schematically combined into a single line, at **87**, to simplify the drawing. The holding fixture **14*a*** is also provided with a cam plate **88** (FIG. 7), having projections thereon which are used to actuate a normally open switch **89**, so as to produce reference position signals, on a conductor **90**, as the carriage assembly moves in relation to the sensing assembly, this being thereby indicative of the position of the ledger sheet code field in relation to the sensing assembly. The five conductors represented by line **87**, and the single conductor **90** are coupled, as indicated at **91**, to a set mechanism **92**, included within the assembly **17*a***. Set mechanism **92** includes a set of five mechanisms having associated lines of action schematically indicated at **93**. The pawl mechanisms operate in response to the reference signals on conductor **90** to displace five associated print wheels from predetermined reference positions thereof through angular position increments associated with the positions of intelligence symbols thereon, and the signals on the conductors **87** are applied to mechanisms, discussed below, so as to selectively disengage the pawl mechanisms from the associated print wheels **52**, preventing further movement of the print wheels, in accordance with the account number digit signal sensed by an associated one of the brushes **84**. In this manner then, the print wheels **52** are ultimately positioned so as to enable the subsequent transfer therefrom, of a representation of the account number code on the ledger sheet **2** in the holding fixture **14*a***.

The foregoing print wheel setting procedure is generally initiated when a ledger sheet is inserted into the holding fixture **14*a*** against the tilt-stop assembly **47** which is, at the time, in the vertical blocking position as a result of operations discussed below. The ledger sheet is held by the clamping bar **48** which has been manually operated against the inserted ledger sheet. As a ledger sheet is inserted, normally open switch contacts **94** are closed by the ledger sheet. The switch **94** is so positioned in relation to the holding fixture **14*a*** that when the ledger sheet is fully inserted against the tilt-stop assembly **47**, the switch resumes its normally opened condition. In other words, in the indicated position, the switch is above the top of a fully inserted ledger sheet (see FIGURE 2). When switch **94** is closed, electrical continuity is established between a source of electrical power, indicated schematically at **95**, and a number of actuating mechanisms discussed below. This continuity is established through a conductor **96**, a sliding contact **97** extending from base **30**, a conductive strip **98** on the carriage **8**, the conductive backing plate **85**, the switch **94**, a conductive strip **99** on the carriage **8**, a sliding contact **100** extending from the base assembly **30**, and a conductor **101**, terminated in a junction **102**. The circuit elements actuated by the establishment of the aforementioned continuity are a tilt-stop solenoid **103**, a resetting mechanism **104**, and a relay **105**, which is energized through the normally closed contacts of a switch **106**. Switch **106** is controlled by the reset mechanism **104** in a manner to be described. The solenoid **103** is used to actuate the tilt-stop assembly **47** into its operated or blocking position as the ledger sheet passes the switch **94**, the linkage between the solenoid and the assembly **47** being indicated schematically by the dotted line **107**. When actuated into the blocking position, assembly **47** is engaged and held by a latch **108** located on the holding fixture **14*a***. The relay **105** includes a pair of normally open associated contacts indicated at **109** which when closed, establish continuity between the source 95 and the relay 105 whereby the relay 105 is self-held, this continuity being established through the aforementioned normally closed contacts 106 controlled by the mechanism 104.

As indicated by the dotted lines 110, the reset mechanism 104 is operatively associated with the setting mechanism 92 and the print wheels 52. When operated, the resetting mechanism 104 conditions the print wheels 52 to the abovementioned reference angular positions in preparation for a setting operation and also conditions the pawl mechanisms associated with the dotted lines 93 so that they engage with the associated print wheels as required for setting the print wheels. As indicated by the dotted line 111, during the operation of the reset mechanism, the normally closed switch contacts 106 are operated, specifically they are opened, so as to interrupt the continuity between electrical power source 95 and the self-held relay 105, thereby dropping out the relay contacts 109, and also thereby disconnecting the source 95 from the solenoid 103 and the mechanism 104.

Therefore, when a ledger sheet is inserted through the holding fixture 14*a*, the ledger sheet temporarily actuates a switch 94, as it proceeds from the top of the holding fixture to the tilt-stop assembly 47, operating the self-held relay 105 and the tilt-stop solenoid 103. The tilt-stop assembly is thereby brought into the blocking position so as to vertically retain the ledger sheet as it progresses downward through the holding fixture, and at the same time the resetting mechanism 104 is operated so as to condition the print wheels 52 and the associated setting mechanisms 92 to receive the signals which are to be sensed from the inserted ledger sheet. Finally, as the reset mechanism operation is completed, the switch 106 is operated, disabling relay 105, thereby terminating the resetting operation, and also thereby interrupting the energizing circuit to solenoid 103, the assembly 47 remaining held by the latch 108.

It is noted that the sensed account number, in the present instance is a five digit decimal number, and therefore the print wheels 52 each have ten discrete angular positions at which representations of the digit symbols 0 through 9 are located.

The ledger sheet at this time is in the position required for reading. In this position, the ledger sheet is resting against the actuating arms of two very sensitive switches, 112 and 113, having normally-open associated contacts. These switches are known as "feather touch" switches, and are preferably of the type designated E051–00D manufactured by Cherry Electronic Products Company, Island Park, Illinois, and the switch 94 is a similar switch of the type designated E51–00A, manufactured by the same company. These switches are of the type that are actuatable upon light contact, with a fairly rigid piece of paper or the equivalent.

When the ledger sheet is properly seated vertically, the clamping bar 48 is manually depressed against the ledger sheet so as to hold the ledger sheet firmly in the position required for sensing. The clamping bar is coupled to a set of normally open switch contacts 114 which are in series electrical circuit with the switches 112 and 113, and also with a pair of relatively translatable contacts 115 and 116 which are respectively situated on the carriage 8, and base 30. In the position shown, the contacts 115 and 116 are touching, so that if the switches 112, 113, and 114 are closed, electrical continuity is established, between a conductor 117 and the power source 95, through the conductor 96, sliding contact 97, conductive strip 98, conductive backing plate 85, the switches 112 to 114, and the contacts 115 and 116. When this occurs, a signal is delivered through a switch 118 which is normally in the position shown, to a lock solenoid 119, an unlock solenoid 120, and the engage solenoid 80, actuating all three solenoids. The lock solenoid serves to lock the control keys 35 so as to prevent the transfer

of any intelligence into or out of the machine 1, thereby preventing movement of carriage 8 in relation to the sensing assembly 16*a*, thus preventing damage to the brushes 84, or accidental operation of the setting mechanisms 92. The unlock solenoid 120 releases read key 36 so as to allow an operator to depress this key and thereby initiate the carriage motion required for sensing and finally, the engage solenoid 80 performs its abovementioned function of moving the sensing assembly 16*a* into the position required for reading, the operation of the lock solenoid being provided in conjunction with this positioning so as to protect the assembly 16*a* from damage. The read key 36 is linked to mechanisms included within the carriage controls schematically indicated at 121, the linkage being schematically indicated by the dotted lines at 122. When depressed, the read key actuates the carriage position controls 121 so as to tabulate the carriage to the right in relation to the brushes 84, thereby providing the required account number transfer signals to the setting mechanisms indicated at 92. The linkage between the carriage 8 and the control mechanisms 121 is again designated 10. It is noted that all presently available data processing and posting systems include control mechanisms, of the type designated 121 herein, by means of which the carriage may not only be positioned to any desired position following the operation of a selected control key, but also by means of which the position of the carriage is sensed in terms of carriage actuated switch contacts which enable selection of successive carriage positions. An illustrative carriage control arrangement of this type is shown in an article in Design News, February 13, 1961, entitled "Rotating Drum Supersedes Linear Tabulator To Ease Program Changes," by C. O. Lubatti, editor. This article is cited merely to show that there are known carriage control arrangements, for programming carriage displacement sequences in a calculating machine which are also versatile switching arrangements of the type useful herein to generally establish variable switching conditions in accordance with the position of the tabulating carriage, as is required in the discussion below.

Hence, in review, when contacts 115 and 116 are touching, and a ledger sheet is properly positioned in fixture 14*a*, the control keys are locked in their unoperated positions, the sensing assembly 16*a* is engaged in the sensing position, and the read key is unlocked allowing the depression thereof, and thereby enabling the movement of the carriage through the required sensing displacement. During the sensing movement, as the carriage passes a predetermined position, a cam projection 124 on the base 30 strikes the latch 108, relasing the tilt-stop assembly 47 to its non-blocking position. The tilt-stop assembly is so linked with the clamping bar assembly, as indicated by the dotted lines 125, that as the tilt-stop assembly assumes its non-blocking position, the clamping bar is released to its retracted position, allowing the ledger sheet to fall between the carriage rollers 40 and 43 previously considered in connection with FIGURE 2.

In addition to the projections which actuate switch 89, cam plate 88 is provided with another projection which serves to actuate a switch 126, at approximately the time at which cam 124 strikes latch 108. Upon closure, switch 126 connects a release solenoid 127 to the source 95, operating the solenoid. The release solenoid 127 is linked by means of the solenoid plunger indicated schematically at 128 to the latch 82 by means of which the assembly 16*a* is held in the sensing position. Thus, when solenoid 127 is operated, the assembly 16*a* is released to its retracted position wherein the brushes 84 are pivoted out of contact with the ledger sheet 2, and the sensing operation is completed.

Following the sensing operation, the previously required conventional posting operations are performed. Namely, the ledger sheet is inserted to the appropriate vertical line position where new entries are to be made, and the carriage **8** and printing mechanism **38**, of FIGURE 2, are suitably operated to perform the required transfers. In connection with the present invention, however, as each debit, or credit, transfer is made in the respective column positions, **63** or **64**, of a ledger sheet, the carriage is so positioned as to operate a lever, not shown, within the control mechanism **121**, this lever being linked, as indicated by the dotted lines **131**, to the movable contact arm **132** of switch **118**. Under these circumstances arm **132** is actuated counterclockwise into position against a stationary contact **134**, connecting the control key lock solenoid **119** to source **95**, through a series electrical circuit comprising a conductor **135** and a normally closed pair of switch contacts indicated at **136**. In this condition, the lock solenoid is energized preventing operation of the associated control keys unless, and until, contacts **136** are opened. The contacts **136** are linked to an actuating photoelectric element within the holding fixture **24***a* so as to be operated when a primary element is suitably positioned therein, this then being the condition required for the release of the control keys **35**. After a primary element has been so inserted into the fixture **24***a*, and a control key **35** has been selected, a set of contacts **138**, which, as indicated by the schematic dotted lines **139**, are coupled to the keys **35**, is then closed. Also, a set of normally opened contacts **140**, which are ganged with the lock solenoid circuit contacts **136**, are closed in association with the opening of the contacts **136**. It follows, that when a suitable control key **35** is selected under these conditions, continuity is established from source **95** through the conductor **135**, and the switches **138** and **140**, to the transfer mechanism indicated at **141**, thereby actuating the transfer mechanism. This mechanism includes a printing hammer which, when actuated, presses the inserted primary element in the fixture **24***a* against the print wheels **52**, causing the transfer, from an intermediate inked ribbon to the primary element, of a representation of the account number symbols stored in the print wheels during the previous setting operation. Mechanism **141** also includes a feeding mechanism which, following operation of the printing hammer, delivers the primary element which has been so processed to the receptacle **57** at the bottom of the assembly **17***a*. The receptacle **57** thereby serves to accumulate processed primary elements, preventing the inadvertent failure to process any of these elements, and also tending to prevent the multiple processing of a single element in connection with more than one ledger sheet.

Referring now to FIGURE 4, fixture **14***a* is suspended from the carriage bridging bracket **45**, which is structurally strengthened by a pair of tie rods **145**, seated in bushings **146** fitted into the bracket. The tie rods provide structural rigidity for the bracket **45**, and also provide a mounting support for vertical bracket members **147** and **148** in which an actuator link shaft **149** is journalled. The actuator link shaft **149** is connected to lever arms **150** and **151**, the latter being hidden from view behind vertical bracket **148**. The arms **150** and **151** are respectively linked to upwardly directed lever arms **152** and **153**, which function in a manner described below.

Lever arm **150**, is linked at one end to the lever arm **152**, and yoked, at the opposite end thereof, around a pin **154** which is connected to a push-rod **155**. Push-rod **155** is slidably mounted in a vertically elongated hole **156** in a bracket **157** extending from bracket **147**, and on a pin **159** extending from the bracket **147** through a hole **160** in the rod. The push-rod **155** is connected by means of a pin **161**, to an L-shaped bracket **162**, which is connected to the tilt-stop platform assembly **47**. The bracket **162** is also pivotally connected to a pivot bracket **163**, the other end of the tilt-stop assembly **47** being similarly pivotally suspended from a pivot bracket **164**. In the illustration, the assembly **47** and push-rod **155** are extended to a maximum forward position in the direction indicated by arrow **165**. In this position, the tilt-stop is in its so-called blocking position, wherein as previously stated, it extends beneath the holding fixture **14***a* providing a vertical support for an inserted ledger sheet, for purposes of sensing coded account number indicia thereon. The tilt-stop assembly is held in the indicated position, against the action of a compressed spring **166**, by means of a latch arm **167**, which engages a mating projection on the underside of the push-rod **155**. Latch arm **167** is pivotally suspended from a pin **168** attached to the bracket member **147**, and the push-rod engaging point on the latch is urged upwards by a flat spring **169**, also attached to bracket **147**. It may thus be appreciated that if latch **167** were rotated counter clockwise around latch pivot **168**, rod **155** and tilt-stop **47** would be urged by spring **166** in the direction opposite to that indicated by arrow **165**, and therefore, the tilt-stop assembly would be pivoted out of communication with the holding fixture **14***a*. The mechanisms required to operate the latch **167** and those required to push the push-rod in direction **165** are discussed below. Arms **152** and **153** are provided with holes **170** through which the clamping bar **48** projects, leaving the clamping bar free to rotate upwardly in a direction away from the holding fixture independently of the motion of the arms **152** and **153**. In the position shown, the clamping bar is pressed against the holding fixture in the position required to clamp an inserted ledger sheet securely for sensing. From the linking connections shown, it may be appreciated that the clamping bar is forced away from the holding fixture when latch **167** is rotated so as to release the rod **155**, the clamping bar being attached to an arm **171** pivotally mounted on a pin **172** extending from the fixture **14***a*, and also coupled, through lever **152**, to rod **155**. Arm **171** is fitted with notched detent recesses, **173** and **174**, which engage a detent spring **175** so as to provide two bistable operating positions for the clamping bar, the recess **174** being associated with the illustrated position and the recess **173** with the retracted, or disengaged, position. The clamping bar arm **171** is also provided with a cam projection **176**, which, in the position shown, operates actuating arm **177** of switch **114** previously considered in the discussion of FIGURE 3, closing the contacts thereof. The other end of the clamping bar, not visible in FIGURE 4, is attached to a clamping bar arm **178** pivotally mounted on a pin, not shown, which is connected to the holding fixture. The arm **178** also includes detent recesses which receive a detent spring **180** in correspondence with the action of recesses **173** and **174**.

At the upper right hand corner, the switch **94**, mounted on the back of cover **46**, includes a sensitive actuating arm **181** projecting through one or more slits **182** in the cover. Similarly, switches **112** and **113**, considered in connection with FIGURE 3, have sensitive actuating arms **183** and **184** projecting through respective openings **185** and **186** in the bracket **45**. The bracket **45** is recessed, as indicated at **187** to facilitate the manual insertion and removal of ledger sheets with respect to the feed roller **40** of the carriage **8**. At the left of bracket **45**, the conductive backing plate **85** of the holding fixture is shown. Adjacent to plate **85** are strap extensions **188** and **189**, preferably of sheet metal construction. Cam plate **88**, described below, is attached to the straps **188** and **189**, and includes projections for actuating switches **89** and **126** as considered in the discussion of FIG. 3.

Assembly **47** is operated to the non-blocking position as follows. From the position shown, the push-rod **155** is released by a counter clockwise rotation of the latching arm **167**. This occurs when a cam projection **195**, of a bracket **196**, attached to the base **30**, of machine **1**, urges the end of the latching arm upward, as the carriage **8** moves laterally relative to base **30**, during a sensing operation. The latching arm **167** is provided with an extending roller **198** which serves as a cam follower, riding along the upper surface of the cam **195**, and thereby minimizing friction between the latch arm **167** and the cam **195** during the traverse of the carriage. The cam

195 is of a length such that when the carriage is at an extreme position in the direction **197**, the roller **198** rests on the raised portion of cam **195**. Assembly **47** is operated to the blocking position when tilt-stop solenoid **103**, which is mounted on extension **200** of the base mounted bracket **196**, is energized, the solenoid plunger being operated, in opposition to a spring **202**, carrying with it a link **203** connected to a cam **204**, which is pivoted on a pin **205**, attached to the bracket extension **200**. Cam **204** is provided with a cam projection **206** which contacts an extension **207** of push-rod **155** when the plunger of solenoid **103** is operated, pushing the push-rod in direction **165**. For the sake of completeness, the actuating leads of solenoid **103** are indicated at **208**, one of these leads being connected to the junction **102** considered in the discussion of FIGURE 3.

Referring to FIG. 5, to avoid a redundant operation of actuating arm **181** of switch **94** during removal of a ledger sheet from fixture **14***a*, a pair of spring clips **211** and **212**—extending from, and attached to, a pin **213** connected to cover **46**—may be used to define respective ledger insertion and removal paths, which respectively include and bypass, the arm **181** so that switch **94** is actuated only during insertion of a ledger sheet.

Referring to FIG. 6, the conducting plate **85** is shown as being isolated, by a border **215** of insulating material, from other portions of the holding fixture **14***a* and from the strap **188** suspended therefrom. The cam plate includes three rows of cam projections, a projection in the middle row being indicated at **217**, the projections in the other two rows being obscured by extended switch actuating arms **218** and **219**. The projection **217**, is shown operating a switch actuating arm **220**. The foregoing switch actuating arm **218** to **220** are coupled to respective switches **89***a*, **126** and **89***b*. The outputs of switches **89***a* and *b* are combined and correspond to the output of the single switch **89** discussed in connection with FIGURE 3, it being deemed expedient in this instance to provide two switches with staggered corresponding cam plate projections, so as to avoid the overlapping of output signals therefrom due to switch arm inertia. Switches **89***a* and *b*, and switch **126** are all attached to the housing **221**, of the sensing assembly **16***a*, which is shown in the actuated position wherein the sensing brushes **84** are positioned adjacent a ledger sheet in fixture **14***a*, the actuating arms of the switches **89***a*, **89***b*, and **126** being simultaneously aligned with the corresponding rows of projections on the cam plate **88**.

The details of the cam plate projections may be more fully appreciated from the isometric view in FIGURE 7 wherein two of the rows of "strobe," or reference timing cams, are indicated at **222** and **223** respectively, these communicating with the switches **89***a* and **89***b* respectively. A third row, indicated at **224**, is provided with the single cam projection **225** which initiates the "end of reading" signal used to retract assembly **16***a*.

Referring again to FIG. 6, rollers **40** and **43** are indicated as being a relatively separable conventional arrangement. Roller **40** is a large driving roller, while roller **43** is a small driven roller which is pivotally movable in the direction indicated by arrow **226**. Roller **43** is attached to a guide plate **42** which pivots therewith and serves to guide an inserted ledger sheet. From the view in FIGURE 6, it may be appreciated that if sensing assembly **16***a* is pivoted clockwise away from fixture **14***a* and if the tilt-stop assembly **47** is moved to the left, away from the bottom of the holding fixture, the ledger sheet **2** is free to fall vertically against the guide plate **42** for insertion between the rollers **40** and **43**.

The pivoting of the sensing assembly **16***a* occurs as follows. Assembly **16***a* is mounted on a pin **50** journalled in a bracket **227**, extending from base extension **51**. The engage and release solenoids **80** and **127**, which are used to respectively engage and retract the sensing assembly are respectively attached to brackets **230** and **231**, extending from housing **221**. For the sake of completeness, the energizing leads of these solenoids are respectively indicated at **232** and **233**. A spring **234**, interposed between the bottom of bracket **230** and the bracket extension **227**, exerts a force tending to produce a clockwise movement of the assembly **16***a* and pin **50** relative to bracket **227**. In the position shown, the sensing assembly is prevented from undergoing clockwise rotation by means of the latch **82**, which is held by a latch strike **83** extending from the base bracket **51**. The latch **82** is rotatably mounted on a pin **236**, and rotatable relative thereto by means of a latch rod **237** which connects the right extremity of the latch to an arm **238** which is rotatably mounted on a pin **239** extending from the bracket **230**. Pin **238** is coupled by means of a linkage indicated at **240** to the plunger arm **241** of release solenoid **127**, which, when energized, exerts a force, in opposition to a spring **242** which tends to pivot arm **238** in a clockwise sense around the pin **239**. When this occurs, rod **237** is displaced, rotating latch **82** around pin **236** in a counter clockwise sense, in opposition to the force exerted by a spring **242** disengaging the latch from the strike **83**, and thereby allowing spring **234** to pivot the assembly **16***a* in the clockwise sense relative to bracket **227**, retracting the assembly. Conversely, engage solenoid **80** is provided with a plunger **243** which is connected through a linking arm **244** to the bracket extension **227** of base extension bracket **51**. When solenoid **80** is energized, a force is exerted on plunger **243**. Plunger **243** being linked by arm **244** to the fixed bracket **227**, and solenoid **80** being mounted on the rotatable assembly **16***a*, when the solenoid is actuated, it moves relative to the plunger **243** rotating the entire assembly **16***a* and thereby engaging latch **82** with latch strike **83**. The input and output electrical conductors of assembly **16***a* are fed through the cable **20***a*, the cable connections being made at suitably located points within the housing **221**. At these points, the remaining conductors of the cable are tied by means of tie wires indicated at **246**.

Referring to FIGURES 8A and B, the details of the lock and unlock solenoid arrangements of FIG. 3, are illustrated in respective sections therein. The solenoid **120** is linked to a plunger arm **259**, having a key plate **260** extending therefrom and connected thereto by means of a pin **261**. The key plate **260** in the view of FIGURE 8 include two sections separated by an empty region **262**, the section view having been taken through a keyway, or slot, occupying the region **262**. The key plate is slidably supported in a bracket **263**, and moves in the direction indicated by the arrow **264** when solenoid **120** is energized. The read key **36** includes a stem portion **265** having a key recess **266** through which the key plate **260** extends, preventing operation of the key **36**, except when the region **262** is adjacent the recess **266**, as when solenoid **120** is operated. In the latter instance, key **36** may be freely operated, with stem **265** passing freely through the slot **262** in the key plate **260**.

Similarly, lock solenoid **119** includes a plunger **267** having an extending key plate **268** connected thereto by means of a pin **269**, and slidably supported in an extension of bracket **263** so as to be able to move freely in direction **264** upon energization of solenoid **119**. A typical control key shown at **35**, includes a stem **270** extending downwardly therefrom. Both the stem **270** and the key plate **268** are provided with complementary key recesses, in the region **271**, which enable the free vertical passage of the stem **270** in relation to the plate **268**, when solenoid **119** is unenergized, stem **270** being otherwise locked by key plate **268**.

Referring to FIGURES 9 to 12, in connection with the setting up of an account number representation in the print wheels **52** of the transfer assembly **17***a*, the details thereof are as follows. The five print wheels **52**, individually identified by means of the associated letters *a, b, c, d,* and *e*, are enclosed within a housing **273**, and mounted on a shaft, described below, journalled in the housing. The print wheels are set by means of a stepping solenoid **274**, attached to mounting bracket **275**, and including an associated plunger arm **276**. Solenoid **274** is cooperatively associated with five latching solenoids **277**, *a* to *e*, which are individually associated with the five print wheels **52**, *a* to *e*. The solenoids **277**, *a* to *e*, are individually attached to the housing **273** by means of respective mounting brackets **278**, *a* to *e*, and have associated respective plunger arms **279**, *a* to *e*. Arm **276**, of solenoid **274**, is linked to a rocker crank **280** which is journalled, by means of a pin **281**, on a bracket **282** extending from housing **273**. A plunger bar **282**, shown in section in FIGURE 9, is attached to crank **280**, and extends across the housing **273** parallel to the shaft on which the five print wheels are mounted. The width of the rocker crank **280** and the indicated attaching screw and fitting are such that the plunger bar **282** is securely held in parallel relationship to the print wheel shaft. The bar **282** abuts five plungers **283**, *a* to *e*, which are used to position the respective print wheels **52**, *a* to *e*, as described below. The plungers **283** are slidably seated in holes within a bracket **284**, extending from housing **273**. The plungers are fitted with end flanges **285** and **286**, *a* to *e*, which limit the strokes of the associated plungers in relation to the bracket **284** in either direction of plunger travel. The plungers **283**, are urged away from their associated print wheels by means of springs **287**, *a* to *e*, interposed between the housing projection **284** and the respective plunger flanges **286**, *a* to *e*, and the plungers are actuated towards the associated print wheels when rocker crank **280** is rotated, upon energization of stepping solenoid **274**. The plungers **283** are linked to respective pawls **288**, *a* to *e*, by means of pins **289**, *a* to *e*, which are attached to the pawls and extend through respective holes **290**, *a* to *e*, in the plungers. The pawls include respective horizontally extending slits **291**, *a* to *e*, through which pins **292**, *a* to *e*, and **293**, *a* to *e*, are extended, these pins slidably supporting the respective pawls. Pins **292**, *a* to *e*, are fastened to the housing **273**, while pins **293**, *a* to *e*, are fastened to vertical push rods **294**, *a* to *e*, having vertical slots therein through which the associated pawls are free to move laterally and pivot vertically. The pawls are urged downward in these slots by means of springs **295**, *a* to *e*. The function of the push-rods is further explained below. The pawls **288**, *a* to *e*, engage respective ratchet wheels **296**, *a* to *e*, which are attached to the respective print wheels **52**, *a* to *e*. Each print wheel includes 10 uniformly distributed print projections, a print projection on the print wheel **52*a*** being indicated at **297*a***. These projections are representations of the digits 0 through 9. The print ratchet wheel combinations are rotatably mounted on shaft **298** which includes respective notches, **299**, *a* to *e*, which engage reset ratchets **300**, *a* to *e*, these being rotatably mounted, by means of respective pins **301**, *a* to *e*, attached to the corresponding ratchet wheels **296**, *a* to *e*. The reset ratchets are urged radially inwards towards the respective notches **299**, *a* to *e*, by means of flat springs **302**, *a* to *e*. During setting operations, the shaft **298** is held in a fixed position, the print wheel assemblies being rotated in the clockwise sense with respect thereto, by means of the pawls **288**, *a* to *e*, associated therewith. As previously noted, the pawls are pushed towards the print wheels when solenoid **274** is operated, rotating rocker crank **280** relative to pivot pin **281** and thereby extending the plungers **283**, *a* to *e*. As this is done, the corresponding ratchet wheels **296**, *a* to *e*, are rotated through discrete clockwise angular displacements of $\frac{1}{10}$ of a revolution, the associated print wheel positions being such that a different decimal digit symbol projection **297** is directed towards feed slot **54**, for each incremental movement Ratchet detents **303**, *a* to *e*, which respectively engage the teeth of ratchet wheels **296**, *a* to *e*, are used to maintain the discrete positions of the wheels, the ratchet **303** being urged in a clockwise direction by springs **304**, *a* to *e*, attached to posts **305**, *a* to *e*.

As previously stated, the pawls **288**, *a* to *e*, are urged downward in their respective push-rod slots by springs **295**, *a* to *e*, which also act on the push-rods **294**, *a* to *e*, the force being transmitted through the respective pins **293**, *a* to *e*. This force maintains the pawls in alignment with the periphery of the associated ratchet wheels **296** so that the ratchet wheels are operated during each horizontal thrust of the pawl. The push-rods **294**, however, may be moved upward by means of corresponding rocker arm linkages **307**, *a* to *e*, and associated rocker arms **308**, *a* to *e*, which are pivotally mounted on pins **309**, *a* to *e*, fastened to the housing **273**. Thus, when any of the plungers **279**, *a* to *e*, of solenoids **277**, *a* to *e*, are pulled downward, the corresponding linkage **307** acts through the corresponding rocker arm **308** to displace the corresponding push-rod thereby exerting an upward force, through the corresponding pin **293**, on the corresponding pawl, causing the pawl to pivot upward around the corresponding pin **292** which is fastened to the housing **273**, the freedom for such pivotal motion being afforded by the corresponding vertical hole **290** at the end of the corresponding plunger **283**. When pushed in the upward direction, push-rods **294**, *a* to *e*, are individually engaged by latches **310**, *a* to *e*, pivotally suspended by means of pins **311**, *a* to *e*, from a projection **312**, of the housing **273**. As indicated, latch **310*a*** mates with a notch **313*a*** in the push rod **294*a***. When held in the upward position by a latch **310**, the associated pawl is no longer aligned with the periphery of the associated ratchet wheel **296**, and therefore cannot engage the teeth thereof. The associated print wheel is thereby fixed in the angular position immediately preceding the upward stroke of the push-rod, this being determined by the energization of the associated latching solenoid **277**.

Prior to a setting operation in which the stepping solenoids operate the print wheels in the clockwise sense (FIG. 9), all of the print wheels **52** are positioned at a reference, or reset position, so as to enable the setting thereof with a predetermined number of stepping signals. The establishment of the print wheels in the reset position is accomplished as follows, it being noted that the position indicated in FIGURE 9 is the desired reset position. Assuming that the print wheels have been set, and that it is desired to reset them in preparation for a new account number setting operation, a shaft **314** carrying a plurality of cams **315**, *a* to *e*, is rotated though a small angular displacement by means of gears **316** which are all operated from a main shaft **317** indicated in FIGURE 10. Thus the cams, during the rotation of the main shaft **317** undergo small clockwise (FIG. 9) displacements, disengaging the associated latches **310**, allowing the pawls to assume operative positions in alignment with the peripheries of the associated ratchet wheels **296**. The gears **316** are so coupled to the shaft **298** as to rotate the shaft through exactly one revolution in association with the displacement of shaft **314**.

The foregoing may be more clearly understood from the view in FIGURE 12. As indicated, a gear **316*a*** on the main shaft **317** includes a projecting pin **318** attached thereto. This pin, during a clockwise rotation of shaft **317** strikes a projecting surface **319**, on a shaft actuating attachment **320**, which is attached to the latch release cam shaft **314**, rotating the latch release cam shaft **314** counterclockwise, in opposition to the force of an opposing spring **321** (FIGURE 12), this corresponding to the clockwise sense in the view of FIGURE 9. When shaft actuator **320** is struck, the resultant movement of shaft **314** and the cams **315**, *a* to *e*, attached thereto, causes an outward movement of the associated latches **310** releasing the associated push-rods and pawls. Further, if shaft **317** is rotated through a 90° angular displacement, the print wheel shaft **298** is caused to rotate through a complete 360° displacement due to the coupling between the gear **316*a***, on shaft **317**, and gear **316*b*** coupled to shaft **298**. Shaft **317** is rotated through a 90° displacement, and back, in association with the operation of a spring-biased 90° rotary solenoid indicated at **323**, and shaft **298** is coupled to shaft **317** by means of the gears **316** and a free wheeling clutch **324** which provides unidirectional engagement thereto, for unidirectionally displacing shaft **298** through exactly one revolution, whereby the associated ratchet and print wheel mechanisms are restored to the associated reference positions. Referring again to FIGURE 9, shaft **298** picks up the ratchets **300**, *a* to *e*, during its 360° rotation, carrying with it the associated print and ratchet wheel assemblies until they are in the reference position of FIGURE 9. When shaft **317** has completed its 90° movement in the clockwise sense in FIGURE 12, it rotates back to its initial position through a 90° counterclockwise rotation, releasing the latch release cam shaft which is restored to an unoperated position by the spring **321**, allowing the latches **310**, *a* to *e*, to rest against the associated push rods.

One additional feature should be noted, in connection with the preceding discussion, relating to the 90° rotation of shaft **317**. In addition to the pin **318**, affixed to the large gear **316***a*, there is another pin **325**, affixed to that gear, which strikes an actuating arm **326** of the switch **106**, previously considered in connection with FIG. 3, opening the contacts of the switch, and thereby deenergizing the relay **105**, through which actuating power to the 90° rotary solenoid **323** is maintained after a ledger sheet is inserted beyond the switch **94**. Hence, pin **325** operates switch **106**, deenergizing rotary solenoid **323**, and thereby terminating the print wheel resetting operation and also deenergizing tilt-stop solenoid **103**.

It should thus be understood that the over-all operation involves the actuation of rocker arm **280** to produce the individual stepping of the associated pawl members **288** and thereby to produce an associated stepping of those of the corresponding print wheels **52** which have not been disconnected from the pawls by means of the associated push rods **294**, and latches **310**. The operations of the rocker arm **280** and the push rods **294** are respectively controlled by the solenoid **274**, and solenoids **279**, *a* to *e*. Still further, the resetting operation, in review, involves the operation of a 90° rotary solenoid **323** coupled to a shaft **317** which is thereby rotated through 90°, carrying with it a gear **316***a*, having fastened thereto projecting pins **318** and **325**. The pin **318** is used to strike a latch release cam shaft actuator which rotates a latch release cam shaft **314**, releasing the latched push rods which were previously used to decouple the associated pawls **288**, *a* to *e*, from their respective print wheels, and the extending pin **325** is used to open switch **106** at the end of the 90° movement of shaft **317** so as to disable relay **105** within control assembly **9***a*, thereby de-energizing the solenoids **323**. Further, in rotating through its 90° displacement, shaft **317**, through the coupling between the gears **316***a* and **316***b*, and that between gear **316***b* and free-wheeling clutch **324**, unidirectionally rotates shaft **298** through a single revolution, positioning the print wheels **52** in their associated reference positions, as shown in FIGURE 9. In order to insure the stability and accuracy of the positioning of the reset shaft **298**, an additional detent spring **328** is provided, as indicated in the view of FIGURE 11, the detent spring mating with a detent notch **329** in the shaft **298** to further stabilize the incremental positions thereof.

Referring now to FIGURES 13 and 14, details are shown of the actuating mechanisms which are used to transfer a stored account number representation, from print wheels **52** (FIGURE 9), to a check, or deposit slip, inserted into the slot **54**, of assembly **17***a*. Referring first to FIGURE 14, in the sectional view therein, checks are initially arranged in a stack **56** on the tray **55** which is situated near the front of the assembly housing designated **340**. Within feed slot **54**, housing **340** includes respective opposed openings **342** and **343**, through which the print wheels **52**, and an opposed print hammer **344**, communicate. An inked ribbon **345**, shown in broken detail, is passed around the print wheels through the opening **342**, so as to enable the transfer, of an inked impression of the selectable symbol indications on the five print wheels, to any paper interposed between the hammer **344** and the print wheels, when the hammer is actuated towards the print wheels. The ribbon **345** is transported by means of a conventional pulley assembly, part of which is indicated at **346**.

A check or deposit slip inserted into the feed slot **54** is vertically supported on a platform **347**, extending from a pivot frame assembly **348** which is more comprehensively illustrated in the isometric view of FIGURE 13. The assembly **348** comprises two side arms and a connecting bar **349**, in addition to the connecting platform **347**, the latter being conveniently termed a "stop shelf." The entire pivot frame assembly is rotatably mounted on a shaft **350** and is rotated relative thereto by means described below.

Referring again to FIGURE 14, a wheel **351**, attached to shaft **350**, rotates therewith, the wheel constituting a drive wheel which is coupled to a driven wheel **352**, through a pulley belt linkage **353**, which is preferably of the conventional type. The wheel **352** is mounted on a shaft **354**, extending through, and attached to, the side arms of the pivot frame assembly **348**. The belt **353** abuts the surface of a wheel **355**, mounted on a shaft **356** which is journalled in a bracket **357**, attached to the housing **340**. The wheel **352** is so situated, in relation to frame **348**, that if the frame were pivoted counterclockwise around the supporting shaft **350**, wheel **352** would pass through a corresponding opening in the housing bringing belt **353** into contact with the periphery of an idler wheel **358** mounted on a shaft **359** journalled in a bracket **360** extending from the housing. Simultaneously, the platform extension **347** would be moved to the left in FIGURE 14 clearing the feed slot **54**, so that an inserted check or deposit slip may be vertically grasped and transported, by the wheels **352**, **358**, **351** and **355**, through the gap between the platform **347**, and the shaft **354**, into the receptacle **57**. In order to pivot the pivot frame assembly around shaft **350**, an extension of the pivot frame at **361** is coupled, by means of a pin **362**, and a linkage **363**, to a solenoid plunger **364** which is operated (FIGURE 13), by means of a solenoid **366**. When solenoid **366** is energized, plunger **364** is displaced, rotating assembly **348** around shaft **350**, and thereby bringing pulley belt **353** into contact with the idler wheel **358**, while removing the obstructing platform **347** from beneath the feed slot **54**, enabling the feeding of an inserted check or deposit slip into the storage receptacle **57** at the bottom of the housing. Solenoid **366** is energized as follows, referring to FIGURES 3, 13, and 14. When a check or deposit slip is inserted into the feed slot **54** with the obstructing platform **347** positioned as in FIGURE 14, the inserted element, when properly positioned, interrupts the communication between a source of light **367** and a light responsive photocell assembly **368**, energizing the output leads **369** thereof. The output of the photocell assembly, on the leads **369**, is applied to a relay **370** which is linked, as indicated by the dotted line **137**, to the switch contacts **136** and **140** of FIGURE 3. Hence, when relay **370** is energized, contacts **136** and **140** are respectively opened and closed. As a safety measure, the supply of power to photocell assembly **368** is preferably so related to the electric current supply feeding light source **367** that failure of the light source prevents further operation of the relay **370**, this condition distinguishing interruption of the light source from failure thereof. This not being essential to the present operation, and also well known as a safety measure in the switching arts, the details thereof have been omitted so as to simplify the present discussion. The output of relay **370** (opening of switch **136**, and closure of switch **140** of FIGURE 3) is used in the following manner.

The shaft **350** is continuously driven by a gear **371**, driven by a gear **372**, attached to a shaft **373**, which is continuously rotated by means of a motor **374**. As indicated in FIGURE 13, a second pulley assembly is provided at the right side of the pivot frame assembly **348**, the second pulley assembly comprising a pair of pulley wheels **376** and **377** respectively mounted on the shafts **350** and **354** and coupled by means of a drive belt **378**. The wheel **376** is connected to the shaft **350** and rotatable therewith, while the wheel **377** is rotatably mounted on the shaft **354**. It may thus be appreciated that the feeding of primary elements through the feed slot **54** into the storage receptacle **57** at the bottom of the housing **340** is accomplished by two pulley assemblies, more uniform feeding being thereby achieved.

A shaft carrying a clutch assembly **379**, is rotatably supported on the continuously rotating shaft **373**. The clutch assembly shaft includes a small cam extension **380** and a large cam **381** which rotate therewith. The assembly **379** is normally restrained by a dog projection **382** extending from a spring restrained solenoid plunger **383** which is pulled in by a solenoid **384** when the solenoid is energized. Solenoid **384** is energized when switch contacts **140** are closed during interruption of light continuity between source **367** and photocell **368** by an inserted check or deposit slip. The operation of the solenoid is therefore a pulsed operation resulting in disengagement of the dog and, therefore, rotation of assembly **379**, until the light interruption ceases. As the clutch revolves, the shaft **378** and its associated cams **380** and **381**, are rotated, cam **380** operating a switch **385**, which is coupled to the solenoid **366** through the contacts of a relay **386**, thereby feeding the light source interrupting element into the receptacle **57**. The cam **380** is so arranged in relation to the cam **381** that as the clutch assembly **379** revolves in the clockwise sense, the cam **380** does not actuate the contact of the switch **385** until after a pin **387** has been released by the abutting projection **388**, of the cam **381**. Pin **387** is connected to a print hammer lever arm **389**, which is rotatably mounted on a shaft **390**, and to which the print hammer **344** is connected. Accordingly, when the pin **387** is released by cam projection **388**, the spring **391** impels the hammer **344** towards the print wheels **52**, thereby transferring a printed impression of the account number stored in the print wheels, to the inserted check or deposit slip, just prior to the movement of the pivot frame assembly.

In review, the overall operation (referring to FIGURE 3) involves the selection of a representation of a debit or credit amount from each processed primary element and the transfer thereof to both the machine accumulator and an associated ledger sheet. The propriety of this association is subsequently ascertainble by means of the present cross-correlation operation wherein both the primary intelligence transfer, and the account number transfer are prevented unless a primary element is correctly seated in fixture **24***a* (see switch **136** of FIGURE 3) and the transferred correlating account number indications permit visual verification of the identity of the ledger sheet to which the associated primary intelligence was transferred.

A number of general principles may now be considered in relation to the foregoing. In all of the foregoing, we have discussed a secondary transfer arrangement wherein stored secondary indications are transferred to the primary elements (checks and deposit slips), in association with the transfer of primary debit and credit amounts from the primary elements to associated secondary elements (account ledger sheets). We have shown that it is necessary, in order to carry out this operation, to so arrange the secondary account number indications on the secondary elements, that they may be sensed and stored prior to any posting operations involving the secondary elements. We have further shown that the stored account number secondary indications may be directly transferred, in the form of permanent visual indications, or the equivalent, to checks or deposit slips associated with the secondary element. While we have shown a storage arrangement wherein the intelligence is stored in terms of print wheel positions, and the resultant transfer to the primary elements is in the form of a printed indication, this should by no means be construed as a limitation on the present system. Any other arrangement for uniquely modifying the appearance or status of the primary elements so as to uniquely correlate them with the associated secondary elements, is considered equally applicable in the present instance. For example, it is permissible to automatically file the primary elements in accordance with the stored account number indications.

As for the sensing arrangement, we have shown a dynamic sensing arrangement wherein the carriages of commercially available posting machines are modified so as to enable the sensing of secondary account number indications, on a ledger sheet, by means of the relative lateral movement between the machine carriage and the stationary machine frame or base. Other techniques may be used to accomplish the same purpose. For example, there are a number of well known ledger positioning arrangements known as automatic vertical line finders, by means of which relative vertical motion is produced between the ledger sheet and the machine base during the insertion thereof between the machine rollers **40** and **43**. Such line finders require the perforation of the left and right edges of the ledger sheet so as to enable the ledger sheet to be transported vertically, and also so as to indicate the proper line position at which the sheet is to be stopped for the successive posting operation. To use such an arrangement it is merely required to rotate the present punched field **28** on the ledger sheets and also to rotate the brushes within the read head assembly so as to provide the same relative movement between the code field and the brushes as in the previously described embodiment. In fact, with a vertical line finding arrangement, there is no necessity for additional timing or reference indexing devices and/or position indicating switches, since such signals are generally available from within the line finding apparatus as part of the ordinary operation thereof. Further, an automatic line finding arrangement would eliminate the necessity for the use of the tilt-stop platform assembly **33** and all other elements associated with the holding fixture **31** previously considered, since the positioning function of these elements is not required when the automatic line finding apparatus is used. An example of an automatic line finder, suitable for use in providing contemporaneous vertical positioning and sensing operations relative to a ledger sheet, is the optional automatic line finder attachment associated with the Monroe President Accounting Machine.

Alternatively, it is not necessary that there be any relative motion between the ledger sheet and the sensing apparatus, a static sensing arrangement being equally feasible and, in some cases, preferable. A static arrangement, suitable for this purpose, is disclosed in FIGURES 15 to 18, inclusive. Referring to FIGURE 15, it may be recalled that the control key members **35**, previously considered in connection with FIGURE 1, were provided with an interlock solenoid operated mechanism. In the present static arrangement, we prefer to have the interlock solenoid **119** operate as follows. The control assembly **121** (of FIG. 3) responsive to the operation of the read key **36** and the control keys **35**, and to the movement of the carriage **8** (FIG. 3) is used to pulse, or briefly actuate, a switch **400** during the final positioning of the carriage following the completion of a new balance printing operation; the final operation required during the previous posting. The final positioning movement, in the present instance, involves the positioning of the carriage to its furthermost right position with no intermediate stops as in the preceding embodiment. This then is the conventional carriage movement which is automatically provided on several commercially available accounting machines as part of the ordinary accounting operation cycle. Upon operation of switch 400, a bistable mechanism 401, which is preferably a latching relay, such as the series LL type manufactured by Filtors, Inc. is set in a first stable condition wherein an associated set of switch contacts 402 is closed, establishing continuity between power source 95 and lock solenoid 119, and thereby locking the control keys 35, preventing operation thereof. The operations required to reset the latching relay 401 so as to release the control keys are described below. For purposes of the present disclosure, it is noted that the feed slot 54 into which checks and deposit slips are inserted, and the associated transfer apparatus, 17*a*, by means of which an account number is printed out thereon, and also by means of which the inserted element is transported, are all substantially identical to the disclosed apparatus considered in the preceding discussion of FIGS. 9–14. Further, the setting of the print wheels is accomplished by means of the same pawl and ratchet members, the pawls being indicated at 288*a* to *e*, and the associated print wheels 52, *a* to *e*, are shown abutting the feed slot 54. The pawls 288 are actuated by the stepping solenoid 274 as in FIG. 9, the signals being derived differently in accordance with the present different sensing arrangement. One change relative to the previous setting arrangement should be noted. In the present embodiment, it is not necessary to reset the print wheels to any reference position. In other words, it is permissible to allow the print wheels to remain in whatever position they happen to be in at the time of initiation of a new setting operation, and merely to release the associated latches 310, *a* to *e*, which latch the push-rods 294, *a* to *e*, (shown in FIG. 9), thereby releasing both the push-rods and the associated pawls. For this, we provide an unlatch solenoid 403, which is connected to switch contacts 400, and energized upon closure thereof. With the control keys 35 locked and the pawls 288 released so as to engage with the respective print wheels 52, the system is in a "ready-to-read" condition, and a sensing operation is then required to release the control keys. In order to read, or to sense, the coded indicia on a ledger sheet, a holding fixture 14*b* is provided, to receive the ledger sheet for sensing. Referring to FIGS. 15 through 17, fixture 14*b* includes a slot 405, bounded by a front dielectric plate assembly 406 and a rear dielectric plate assembly 407. Plate 406 is provided with side projections, or extensions, 408 and 409, which provide lateral positioning guides for the insertion of a ledger sheet. A pair of solenoids 410 and 411, are mounted on brackets, not shown, in such a position as to enable the extension of respective solenoid plungers 412 and 413 through respective holes 414 and 415 (FIG. 16) in the front plate 406, and also through respective holes 416 and 417 (FIG. 17) in the rear plate. The plates 406 and 407 are separated by an associated pair of springs, not shown, so as to maintain a predetermined separation between the plates, when the solenoids 410 and 411 are energized. The plungers 412 and 413 are bifurcated into portions respectively designated A and B which are bent at the rear of plate 407 so as to enable a uniform application of force to the rear plate when the respective solenoids are operated to bring the rear plate into contact with the front plate. The front plate 406 is provided with a series of five rows of electrical contacts 420, *a* to *e* (FIG. 16), with ten contacts in each row. The contacts 420 extend slightly towards the interior of the slot 405. Opposite the rows 420 associated conductive strips 421, *a* to *e* (FIG. 17), are provided on the rear plate 407. It is repeated that the plates 406 and 407 are non-conductive plates, and it is noted that the conductive strips 421, *a* through *e*, are slightly recessed within the rear plate 407 so as to provide mating recesses for the projections 420, and additional gripping friction to retain an inserted ledger sheet in a fixed position, when the two plates are brought together by the solenoids. The strips 421 are located on the front of the rear plate 407 and are therefore shown in dotted outline, the view in FIG. 17 being taken from the rear. The strips 421 are connected to associated conductors designated 422, *a* to *e*, through suitable connections running through the rear of the plate 407 to the respective conductive strips. The leads are brought out to corresponding relays, 423, *a* to *e* (FIG. 15), and also to corresponding latching solenoids 277, *a* to *e*, which, as previously indicated in connection with FIGURE 9, are used to individually disengage the associated pawls 288, *a* to *e*, from the corresponding print wheels 52, *a* to *e*, when the desired position thereof has been attained. The relays 423 are provided with associated normally opened contacts 424, *a* to *e*, arranged in series circuit so as to transfer an electrical connection from source 95 only upon the coincident actuation of all of the relays. The pawls 288 are provided with associated attachments 425, *a* to *e* (FIG. 18), by means of which, in conjunction with each incremental movement of the associated print wheels, corresponding movements of movable switch contact arms 426, *a* to *e*, are derived, each arm being thus successively connectable to ten stationary contacts (corresponding to association print wheel positions). These stationary contacts are connected to conductors 428 which are accordingly arranged in five groups 428, *a* to *e*, of ten contacts each. The conductors of each group 428 are schematically represented by an associated dotted line 430, each of which is connected (FIG. 16) to an associated row of contacts 420 on plate 4 to 6.

Referring to FIGURES 15 and 16, when a ledger sheet is fully inserted into slot 405, two sets of switch contacts, respectively located at the lower left and right corners of the fixture 14*b*, are actuated. These switches are indicated at 431 and 432, respectively. The ledger sheet is inserted against a platform 433 which may either be a simple flange extension from the main housing of fixture 14*b*, or a set of pins projecting therefrom, or any other suitable vertical interruption member. Upon closure of the contacts of switches 431 and 432, which are preferably of the feather touch type previously discussed in connection with the platform assembly 47 of FIGURE 3, continuity is established between source 95 and latching relay 401, the latching relay being thereby reset in the condition wherein switch contacts 402 are opened. The electrical path between source 95 and relay 401, includes a normally closed pair of contacts 434 of a relay 435. Relay 435 is operated only when all five of the contacts 424, *a* to *e*, are closed. Thus, when the ledger sheet is properly seated in fixture 14*b*, switch contacts 402 are interrupted, unlocking the control keys 35. Simultaneously, electrical continuity is established between source 95 and the operating coil of a relay 437, through the switches 431, 432, and 434, closing associated relay contacts 438. When contacts 438 close, continuity is established between source 95 and the solenoids 410, actuating the associated plunger arms 412 and 413, to press the plate 407 against plate 406, thereby establishing continuity, through the inserted ledger sheet, beween a selected contact in each of the rows 420, and the opposing conductive strips 421. As a result, an electrical circuit path is established between a selected conductor in each of the groups 428, *a* to *e*, and the associated one of the solenoids 423, *a* to *e*, and solenoids 277, *a* to *e*.

Also, when contacts 438 close, source 95 is coupled to movable contact 439 of relay 440, the movable contact being spring restrained in the indicated position against a stationary "self-interrupt" contact 441 through which the relay is excited, moving contact 439 into contact with the stationary contact 442. Contact 442 is connected to the step solenoid 274, which serves to operate the pawls 288, *a* to *e*, through their respective strokes, the coupling between the pawls and the print wheels 52 being indicated schematically by dotted lines 443, *a* to *e*, which are also coupled to the respective movable contact arms 426, *a* to *e*, of the ten-position switch assemblies coupled to plate 406.

In operation therefore "self-interrupt" relay 440 supplies pulses to solenoid 274 advancing the pawls 288 which individually advance the associated print wheels 52 and the associated movable arms 426 (see FIGS. 15 and 18). The arms 426 successively connect source 95 to the associated conductors 428, and, when the conductor corresponding to the punched hole on the ledger sheet, is contacted by the associated arm 426, the associated solenoids 423 and 277 are excited, the latter solenoid operating a push-rod 274, not shown herein (but described in FIG. 9) which is held by an associated latch 310, which thus disengages the pawl 288 from both the associated contact arm 426, and the associated print wheel 52. This is partially illustrated in FIG. 18 wherein the pawl 288*a* is seen to engage not only the detented ratchet wheel 296*a*, but also a ratchet wheel 446, rotatably mounted on a stationary shaft 447, preferably parallel to shaft 298, and detented by a detent 448. The wheels 446 and shaft 447 are both conductive, the latter being directly connected to source 95, considered in FIG. 3, while the former is provided with an extending brush 426*a* representing the contact arm 426*a*.

Thus, the print wheels 52 are ultimately positioned in accordance with the corresponding account number digit. It is noted that since the present arrangement is a static sensing arrangement, the coded field may be distributed all over the ledger sheet, this being in fact a somewhat beneficial condition since it is also desirable to maintain maximal separation between the contacts 420 and also between the conductive strips 421, so as to prevent undesired capacitive coupling between translating conductors.

Finally, it is noted that no reset mechanism is required in relation to the print wheels. Prior to each setting operation, as switch 400 is closed, solenoid 403 is actuated to disengage the latches 310, *a* to *e*; no other mechanical resetting movement being required.

Thus far, the exact location of fixture 14*b* has not been specified. In practicing this invention, we prefer to place the fixture as close as possible to the stationary contacts scanned by the arms 426 so as to minimize the amount of wiring required and the relative capacitance therebetween. However, if desired, the slot 405 may be remotely positioned immediately over the carriage rollers 40 and 43 (FIG. 2) by means of a bracket extending, not from the carriage, but from the stationary base of the machine, and following the sensing operation, the obstructing platform 433 may be automatically displaced, the ledger sheet thus falling vertically between the rollers 40 and 43, through the slot 405. For this it is sufficient to provide the platform 433 in the form of either a movable bar which extends entirely underneath the slot 405 or in the form of a pair of pins which project underneath and across the slot beneath the front and rear plates 406 and 407. In the latter instance, the pins may be withdrawn from the path of the ledger sheet by having the pins form part of corresponding solenoid plungers, and by actuating the plungers and latching the pins when it is required to withdraw them. Conversely, when it is required to insert the pins, it is sufficient to unlatch the the aforementioned plungers. The latching operation should, of course, be performed when the reading operation is certain to be completed. That is, when the ledger sheet is engaged by the front and rear plates, as indicated by the presence of a signal on conductor 450 in FIGURE 15, the platform or the pins may be withdrawn. On the other hand, when the prior posting operation has been completed, as indicated by the closure of switch contacts 400, it is desirable to extend the platform or pins 433 so as to provide a mounting base for sensing the ledger sheet coded fields. The arrangement of FIGS. 15 to 18 affords a number of advantages over the previously considered arrangements. First, no intermediate carriage movements are required, the sensing time being thereby decreased. Secondly, elimination of the relative movement between the sensing mechanism and the ledger sheet reduces the possibility of wear and tear on the sensing apparatus, the indicated conductive contacts on the front plate 406 being more rugged in structure than the brushes 84. Finally, if the slot 405 is positioned directly over the carriage, a still further decrease in the time required for sensing is achieved since the ledger sheet is inserted, sensed, and immediately thereafter directly dropped into the carriage rollers. Further, the elimination of the previously required resetting operation wherein the print wheels 52 are reset to reference positions provides an additional time saving feature, and an additional economy in terms of hardware. Should it be found objectionable to provide 50 conductive leads as represented by the leads 430, it may be convenient, if the slot 405 is remote from the scanning assemblies associated with contact arms 426, to utilize an alternative code arrangement wherein an 8–4–2–1 four digit binary code is used to represent each digit of the code, 20 wires then sufficing to transmit the five account number digits, with a code conversion unit employed adjacent the scanning assemblies to provide a conventional translation of the four wire code signal combination to a one of ten wire signal selection.

As a final remark, it is noted that while the systems thus far analyzed are comprised to straightforward relay and punched hole sensing elements, it should of course be appreciated that the indicated elements have many full equivalents in terms of newly developed and also old switching components, and it is believed that no mention need be made of these equivalents since they are obvious to all of reasonable skill in the art. It is further believed that it is fairly obvious that punched hole sensing apparatus is the full system equivalent of magnetic code sensors employing representations placed on magnetic media and sensed by magnetically responsive elements. In the latter instance, magnetic ink, for example, may be used to provide account number symbol, or code, representations on the ledger sheets and magnetic sensors may be coupled thereto, with a resultant transfer of magnetic continuity, as distinguished from the indicated transfer of electrical continuity. It is believed that in this instance also, no further explanation or mention of the full equivalents is required in view of their obviousness.

While we have described above the principles of our invention in connection with specific apparatus, it is to be clearly understood that this description is made only by way of example and not as a limitation to the scope of our invention as set forth in the objects thereof and in the accompanying claims.

We claim:

1. A data processing system comprising means for posting, on a selected secondary element, a primary data representation derived from a selected primary element, means associated with said positing means for deriving and storing a secondary representation corresponding to account number identifying indicia on said selected secondary element, and means operatively associated with said posting and said deriving and storing means for transferring an indication of said stored representation to said selected primary element in association with said primary data posting.

2. A data processing system according to claim 1 wherein said posting means includes means for transferring primary intelligence indications, and means for variably displacing said secondary element to variably position said transferred intelligence indications thereon and wherein said deriving and storing means includes secondary element holding means mounted on said variably displacing means, sensing means, and means coupled

to said variably displacing means for inducing a predetermined relative movement between said secondary element holding means and said sensing means in association with the insertion of said secondary element into said holding means to thereby activate said sensing means to emit electrical signals corresponding to said indicia on said secondary element.

3. A system according to claim 1 wherein said secondary representation deriving and storing means includes a plurality of signal channels, and sensing means displaceable relative to said selected secondary element for producing electrical signals corresponding to said identifying indicia in selected ones of said channels.

4. A system according to claim 1 including means associated with said posting means and said deriving and storing means for preventing posting of said primary data until said corresponding secondary representation has been derived and stored.

5. A data processing system comprising means for posting on a selected secondary element, a primary data representation derived from a selected primary element, means associated with said posting means for deriving and storing a secondary representation corresponding to said selected secondary element, means for holding said selected primary element, and means communicating with said holding means for transferring an indication of said stored secondary representation to said selected primary element in association with said posting of said primary data.

6. A system according to claim 5 including means associated with said holding and said posting means for automatically discharging said selected primary element from said holding means subsequent to said primary data posting, and means coupled to said discharging and said posting means for inhibiting the respective operations thereof until said primary element is positioned in said holding means to receive said indication in a given region thereof.

7. A system according to claim 5 wherein said deriving and storing means includes means for selectively producing intelligence indications, and means for setting said indication producing means in accordance with said derived secondary representation, and wherein said indication transferring means includes means coupled to said indication producing means, said primary element holding means, and said posting means, for transferring said set indication from said producing means to said selected primary element if and only if said primary data is posted after the deposition of said primary element in said holding means.

8. A system according to claim 7 including means for resetting said indication producing means to a predetermined reference condition in association with the selection of said secondary element.

9. A system according to claim 7 including means for enabling said setting means in association with the selection of said secondary element and means for disabling said setting means after the setting up of said derived secondary representation in said producing means.

10. A system according to claim 5 including means coupled to said holding means for blocking the completion of said primary data posting operation until said selected primary element is situated in a predetermined position relative to said holding means, and means coupled to said posting and said indication transferring means for enabling said indication transferring means in association with said primary data posting.

11. A system according to claim 10 wherein said blocking means includes means for sensing the position of said selected primary element in relation to said holding means, and said enabling means includes means for transferring an enabling signal in association with the operation of said posting means and in response to a predetermined output condition of said position sensing means.

12. A system according to claim 10 including an enclosed receptacle and means coupled to said indication transferring means for discharging said selected primary element into said receptacle in association with the operation of said indication transferring means.

13. A data processing system comprising respective means for holding primary and secondary elements, said secondary elements having identifying indicia thereon, means for posting on a selected secondary element primary data derived from a selected primary element, means coupled to said secondary element holding means for producing a predetermined relative movement between said selected secondary element and said posting means in association with the insertion of said selected secondary element into said secondary element holding means, a plurality of signal channels, means operative in association with the operation of said relative movement producing means for producing a variably timed signal in each said channel, each said signal representing a corresponding intelligence unit included in said indicia on said secondary element, a plurality of variable indication producing elements individually corresponding to said signal channels, means coupled to said secondary element holding means for operating said indication producing elements to predetermined reference conditions in association with the insertion of said selected secondary element into said secondary element holding means, a corresponding plurality of setting elements variably coupled to said indication producing elements for discretely varying said indication producing elements in synchronism with corresponding increments of said predetermined movement of said secondary element, means for effecting coupling between said corresponding setting and indication producing elements in association with the insertion of said selected secondary element into said secondary element holding means, means coupled to each said channel for disjoining said corresponding setting and indication producing elements in response to said variably timed signals in said channel, means mounted on said posting means for discharging said secondary element into said posting means from said secondary element holding means at the conclusion of said predetermined relative movement of said secondary element, transfer means for operating said indication producing elements relative to a primary element in said primary element holding means for transferring a representation of said set indication thereto, means coupled to said primary element holding means for preventing operation of said posting means until said selected primary element is properly deposited in said primary element holding means, means coupled to said posting means for operating said transfer means in association with the operation of said posting means, a storage receptacle, and means coupled to said posting means for discharging said selected primary element into said receptacle at a predetermined time following operation of said transfer means.

14. A data processing system comprising respective means for holding primary and secondary elements, said secondary elements having identifying indicia thereon, means for posting on a selected secondary element primary data derived from a selected primary element, a plurality of signal channels, means coupled to said secondary element holding means for varying electrical conditions in selected ones of said channels in association with the deposition of said selected secondary element in said secondary element holding means and in accordance with said indicia on said secondary element, means for scanning said channels in predetermined groups, each said group including a different one of said selected channels, a plurality of variable indication producing elements corresponding to said plurality of groups of channels, setting means variably coupled to said indication producing elements for incrementally varying the indications thereof, means coupled to said secondary element holding means, said scanning means, and said setting means, for

synchronously operating said setting and scanning means in association with the deposition of said selected secondary element in said holding means, means for disabling said last-mentioned means when said indication setting means are all in conditions correlated to said indicia on said secondary element, means for disjoining said setting means from each said indication producing element when said scanning means is coupled to said selected channel in said corresponding group of channels, means for retaining said secondary element in said secondary element holding means until said indication setting means are all in conditions correlated to said indicia on said secondary element, transfer means for operating said indication producing elements relative to said primary element holding means for transferring a representation of said set indications to a primary element held therein, means associated with said posting and primary element holding means for preventing operation of said posting means until said selected primary element is suitably deposited in said primary element holding means, means coupled to said posting means for operating said transfer means in association with operations of said posting means, a storage receptacle, and means associated with said transfer means for discharging said selected primary element into said receptacle at a predetermined time following operation of said transfer means.

15. An account number verifying system for use in association with an accounting machine—of the type containing adding and printing mechanisms, and a movable carriage for transversely displacing a ledger sheet in relation to said printing mechanism, said carriage including rollers for holding and vertically displacing said ledger sheet relative to said printing mechanism—comprising a first holding fixture mounted on said movable carriage of said accounting machine and adapted to releasably engage a ledger sheet inserted therein, means displaceable relative to said first holding fixture for producing electrical signals representative of account number markings on a ledger sheet held in said first holding fixture during a predetermined displacement of said carriage, said fixture including means for automatically releasing said ledger sheet for vertical transport by said rollers following said predetermined carriage displacement, means coupled to said signal producing means for storing a representation of said account number signals,

a second holding fixture for holding a document bearing data which is to be transferred to said ledger sheet released from said first holding fixture and held by said carriage rollers, and means disposed adjacent said second holding fixture and coupled to said storing means for transferring to said document an indication corresponding to said stored representation of said account number signals in association with a transfer of said data to said ledger sheet via said accounting machine.

16. An account number verifying system for use in association with an accounting machine—of the type containing adding and printing mechanisms, and a movable carriage for transversely displacing a ledger sheet in relation to said printing mechanism, said carriage including rollers for holding and vertically displacing said ledger sheet relative to said mechanism—comprising a first holding fixture adapted to releasably engage a ledger sheet inserted therein, means displaceable relative to said first holding fixture for producing electrical signals representative of account number markings on a ledger sheet held in said first holding fixture during a predetermined displacement of said carriage, said fixture including means for automatically releasing said ledger sheet for vertical transport by said rollers following said predetermined carriage displacement, means coupled to said signal producing means for storing a representation of said account number signals, a second holding fixture for holding a document bearing data which is to be transferred to said ledger sheet released from said first holding fixture and held by said carriage rollers, and means disposed adjacent said second holding fixture and coupled to said storing means for transferring to said document an indication corresponding to said stored representation of said account number signals in association with a transfer of said data to said ledger sheet via said accounting machine.

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MALCOLM A. MORRISON, *Primary Examiner.*

WALTER W. BURNS, JR., *Examiner.*

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Fig. 1

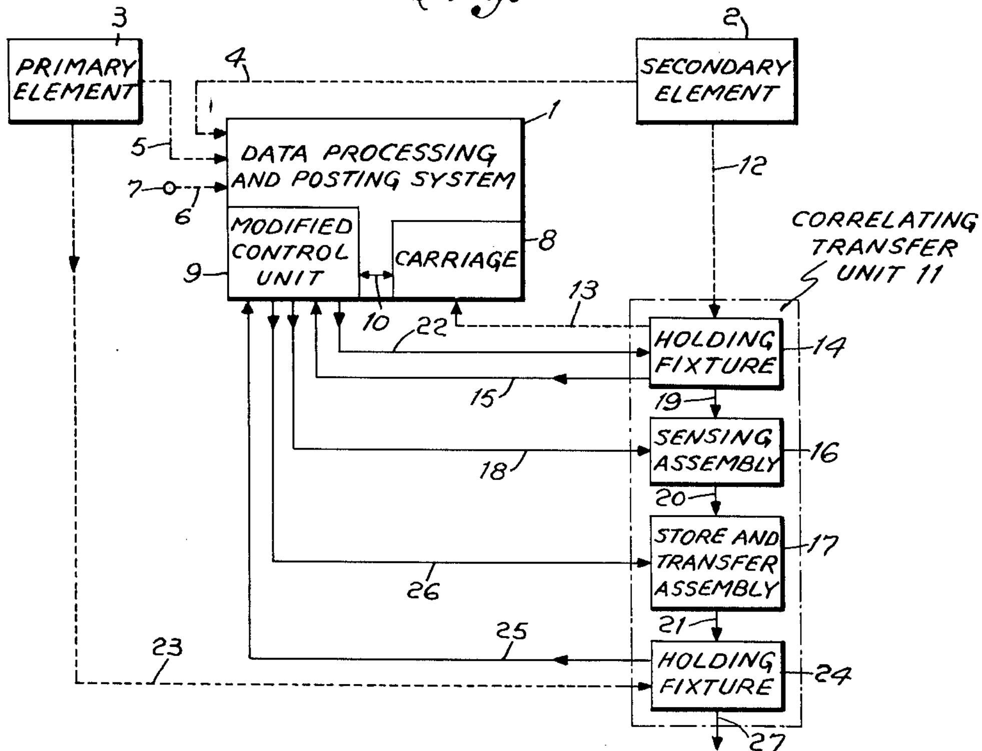
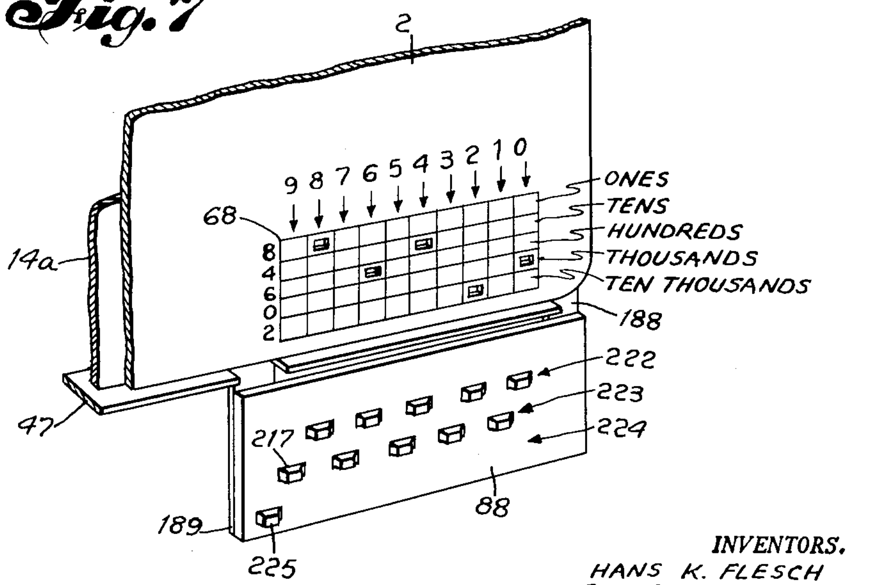


Fig. 7



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Robert Lieber
ATTORNEY

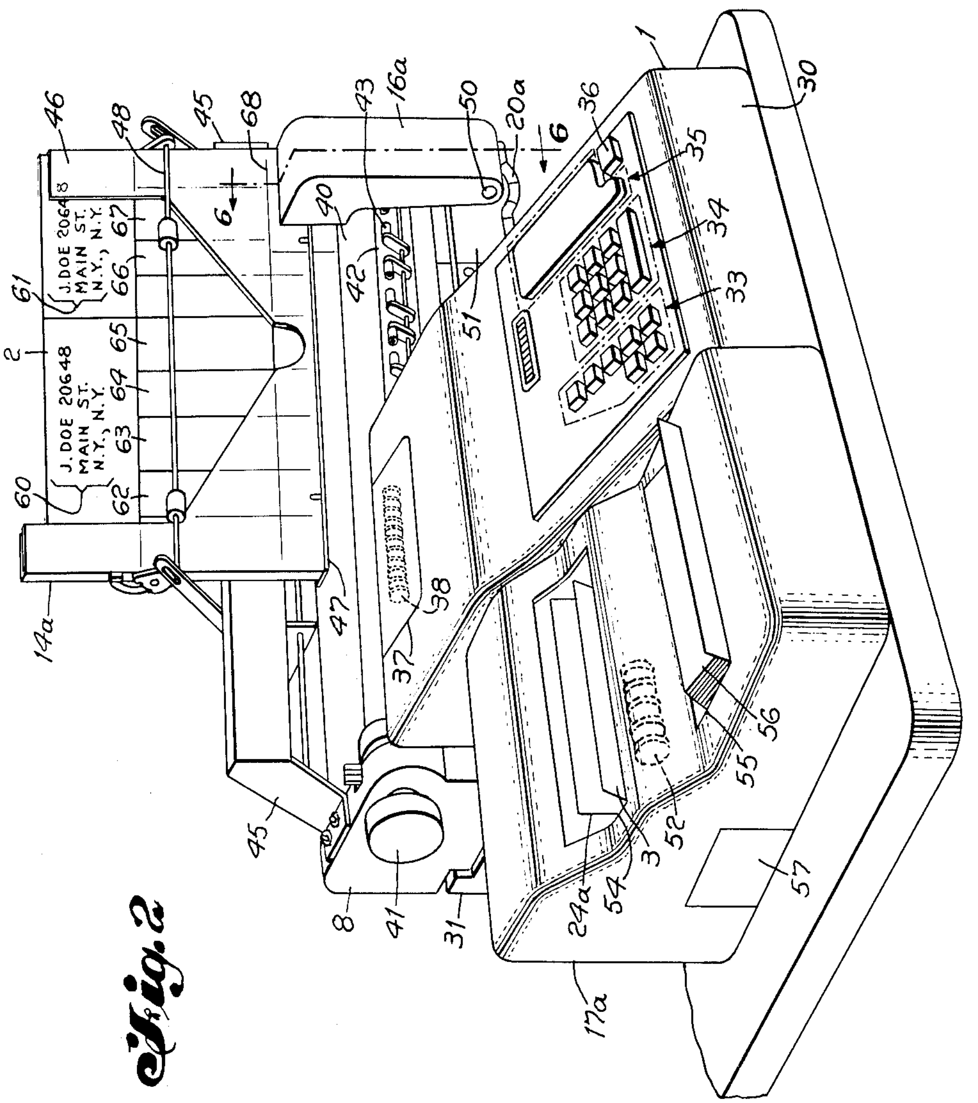

Fig. 2

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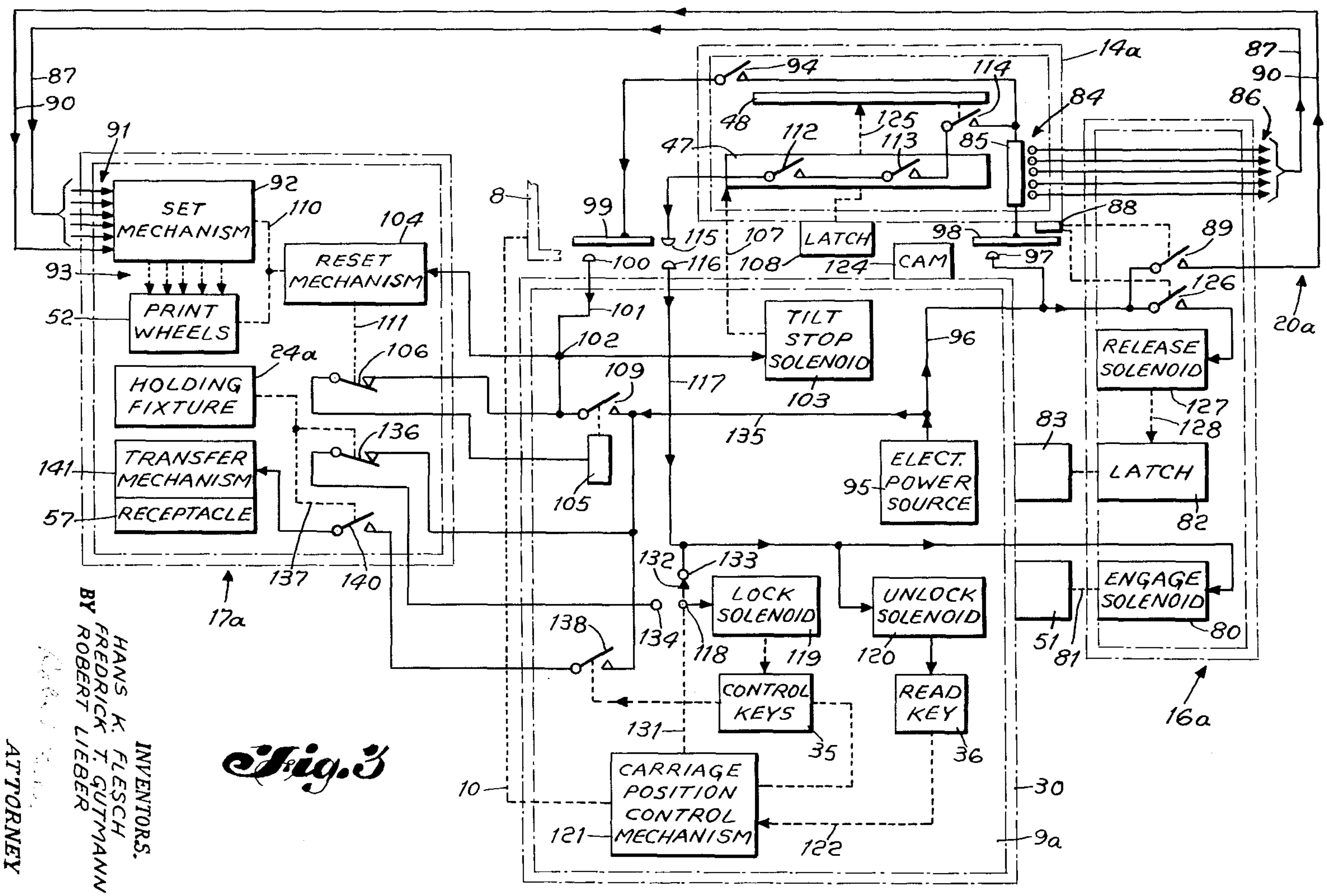

Fig. 3

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Fig. 4

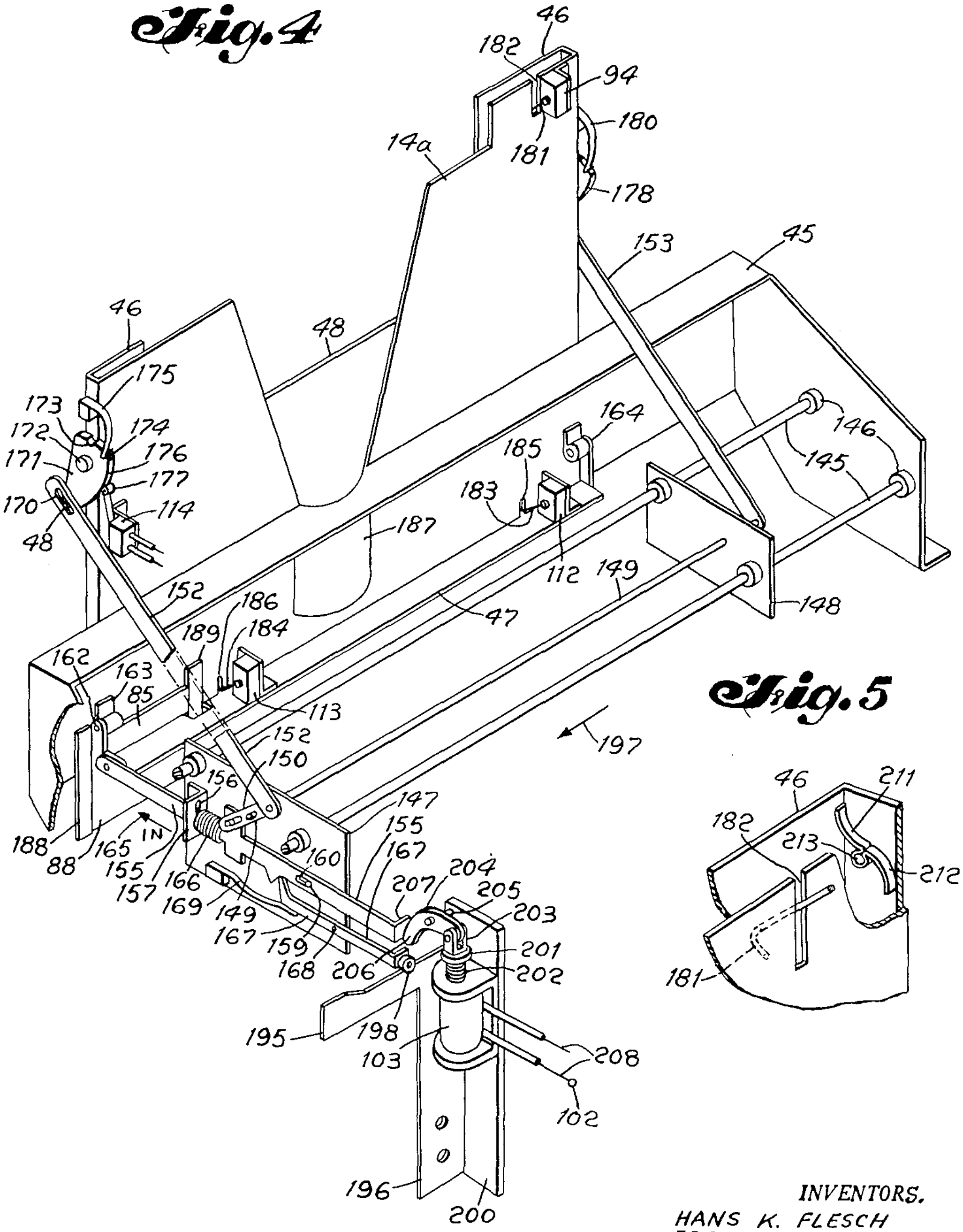

Fig. 5

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Fig. 6

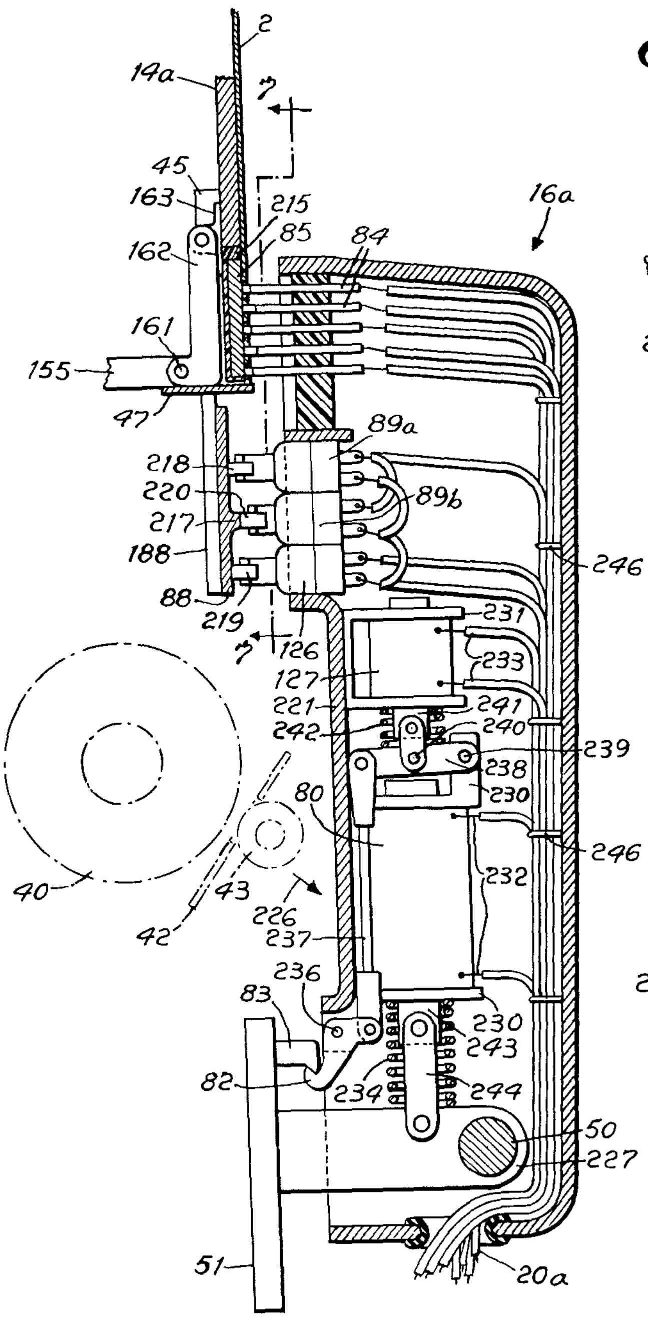

Fig. 8A

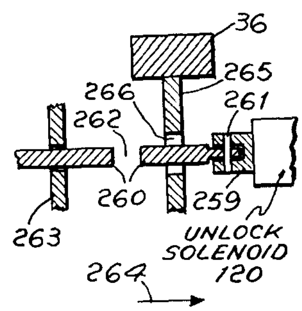

Fig. 8B

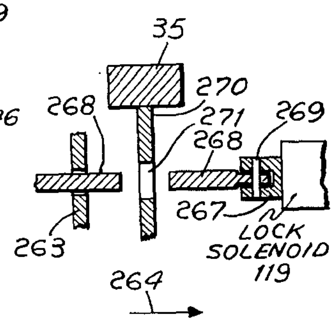

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Fig. 9

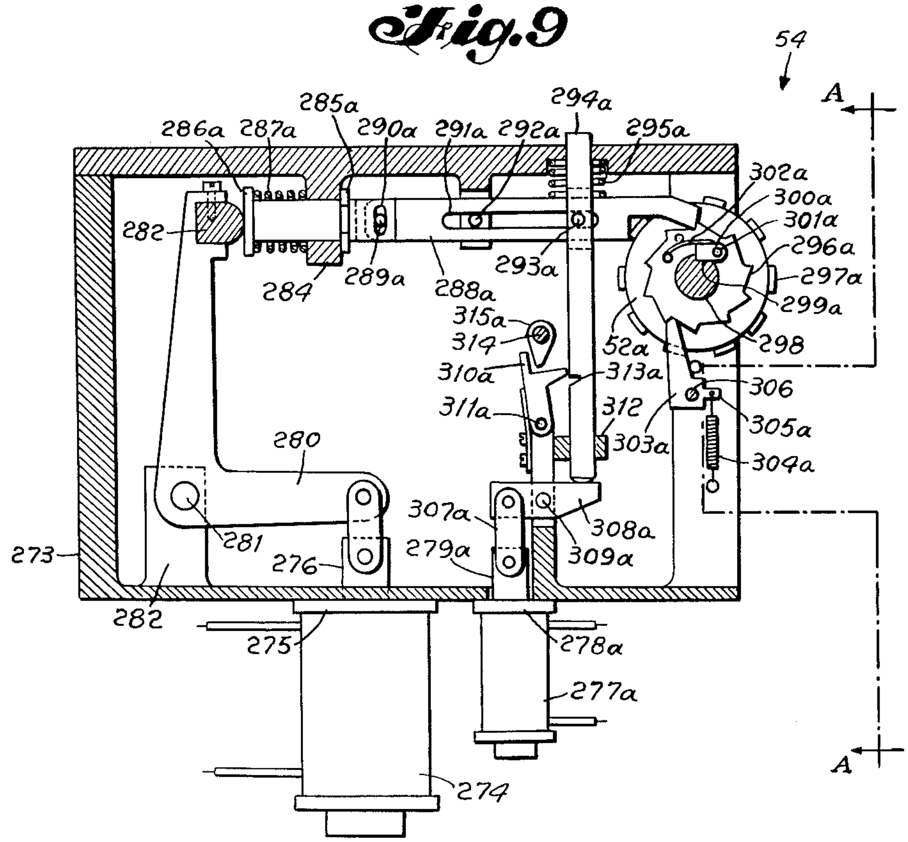

Fig. 16

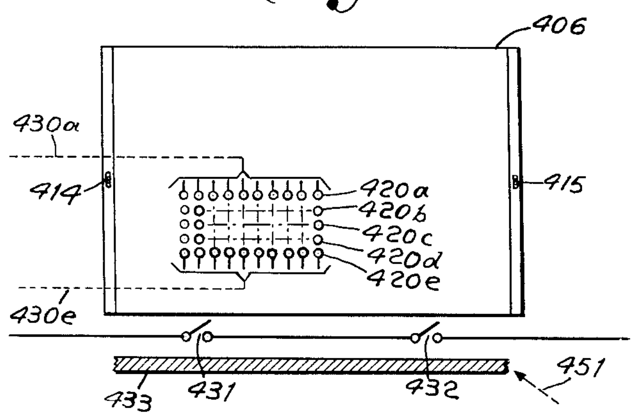

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Fig. 10

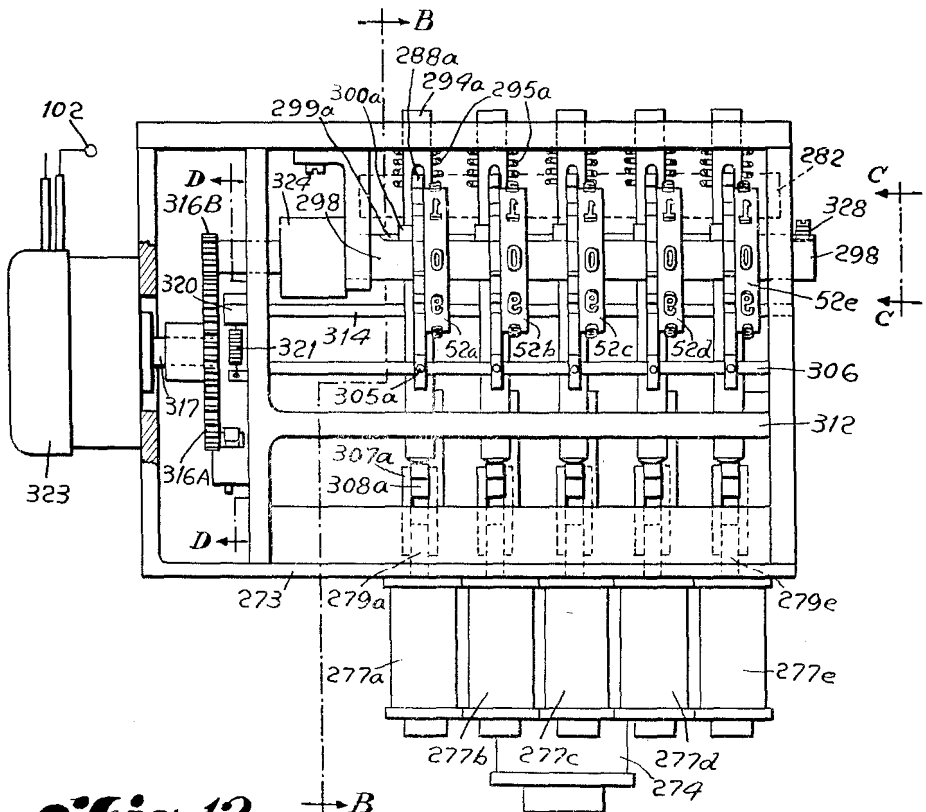

Fig. 12

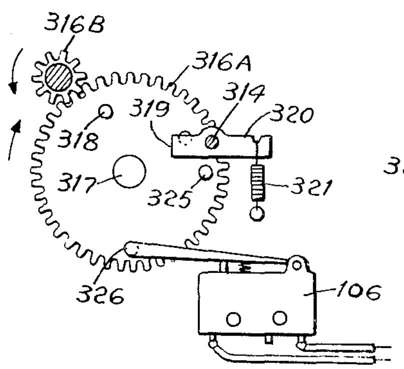

Fig. 11

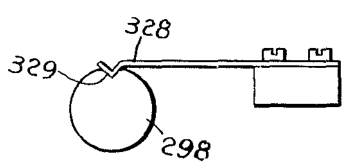

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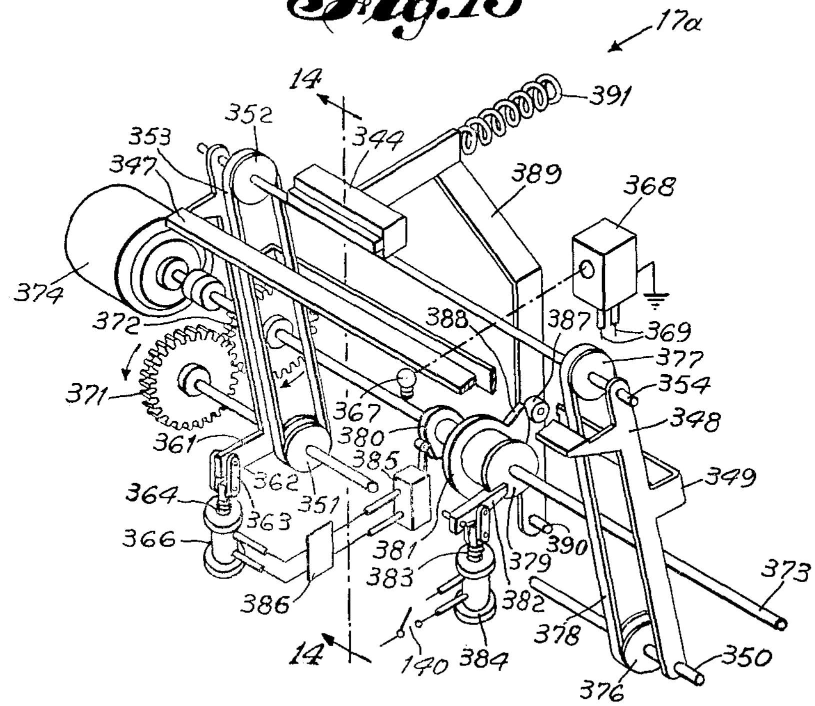
Fig. 13



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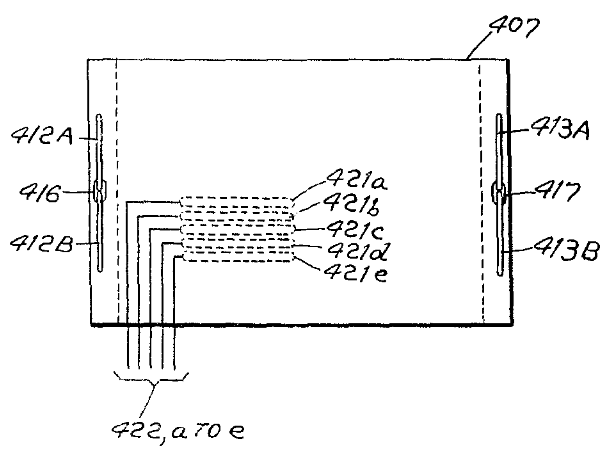

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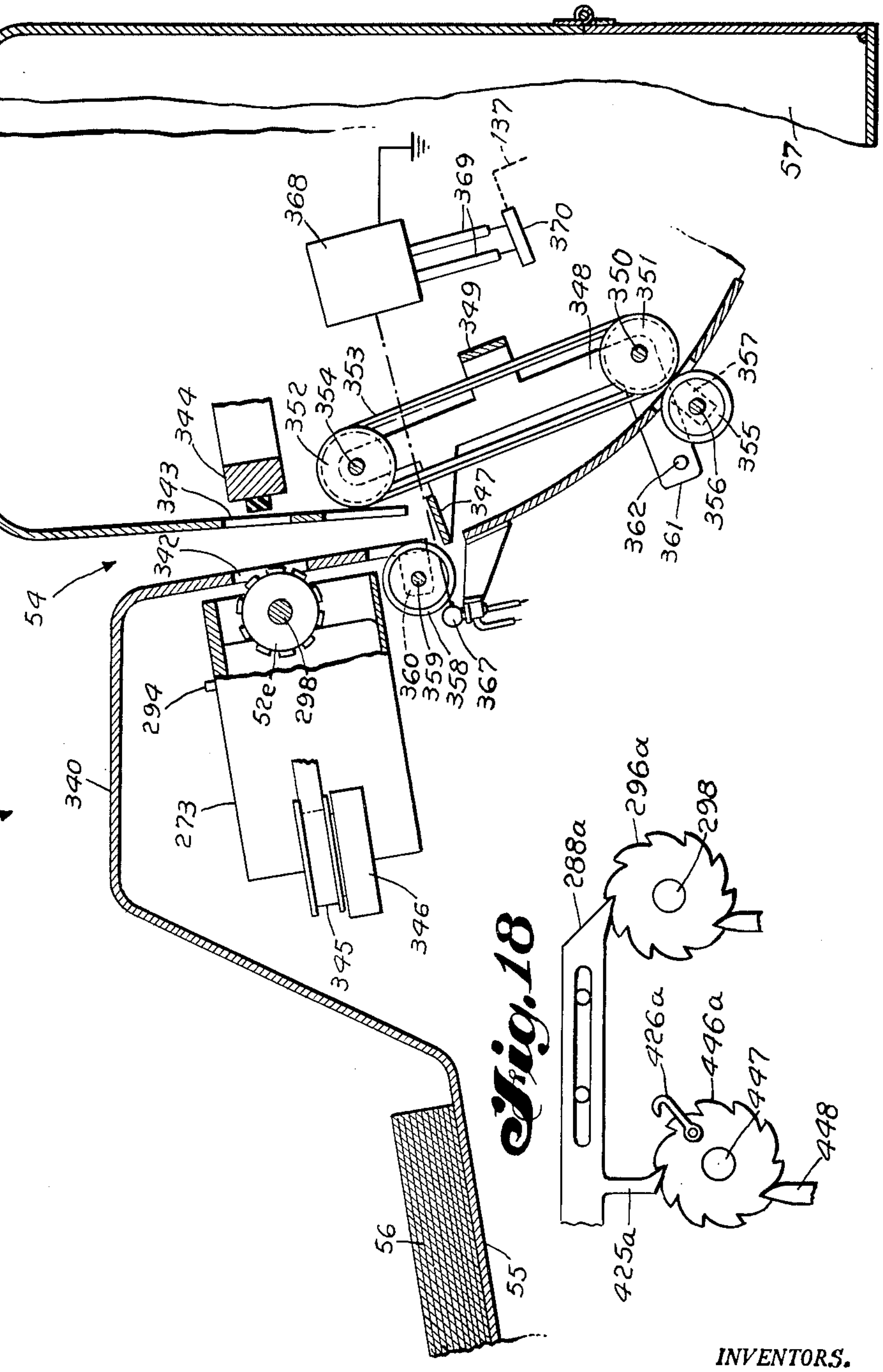

Fig. 14

Fig. 18

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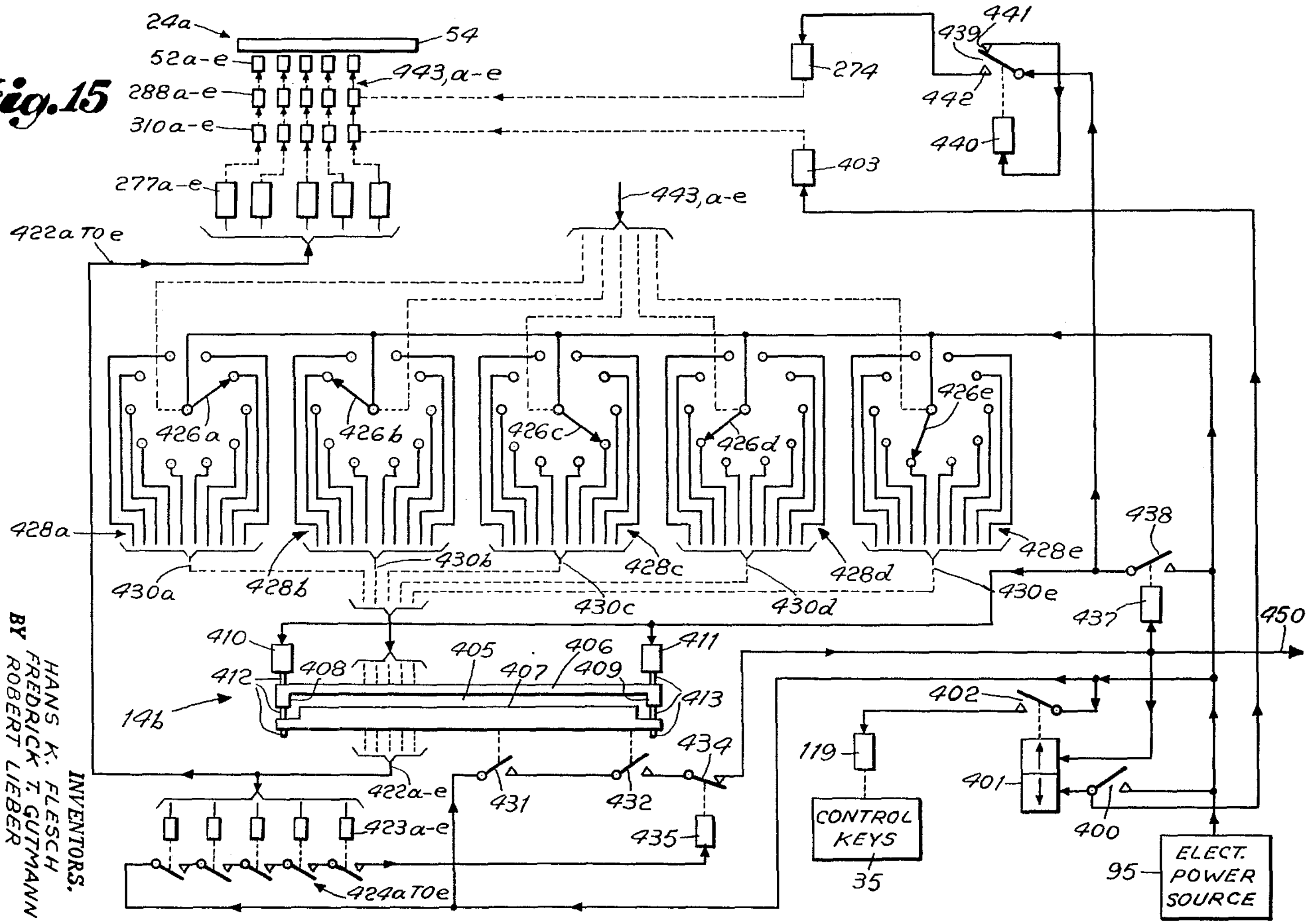
Fig. 15



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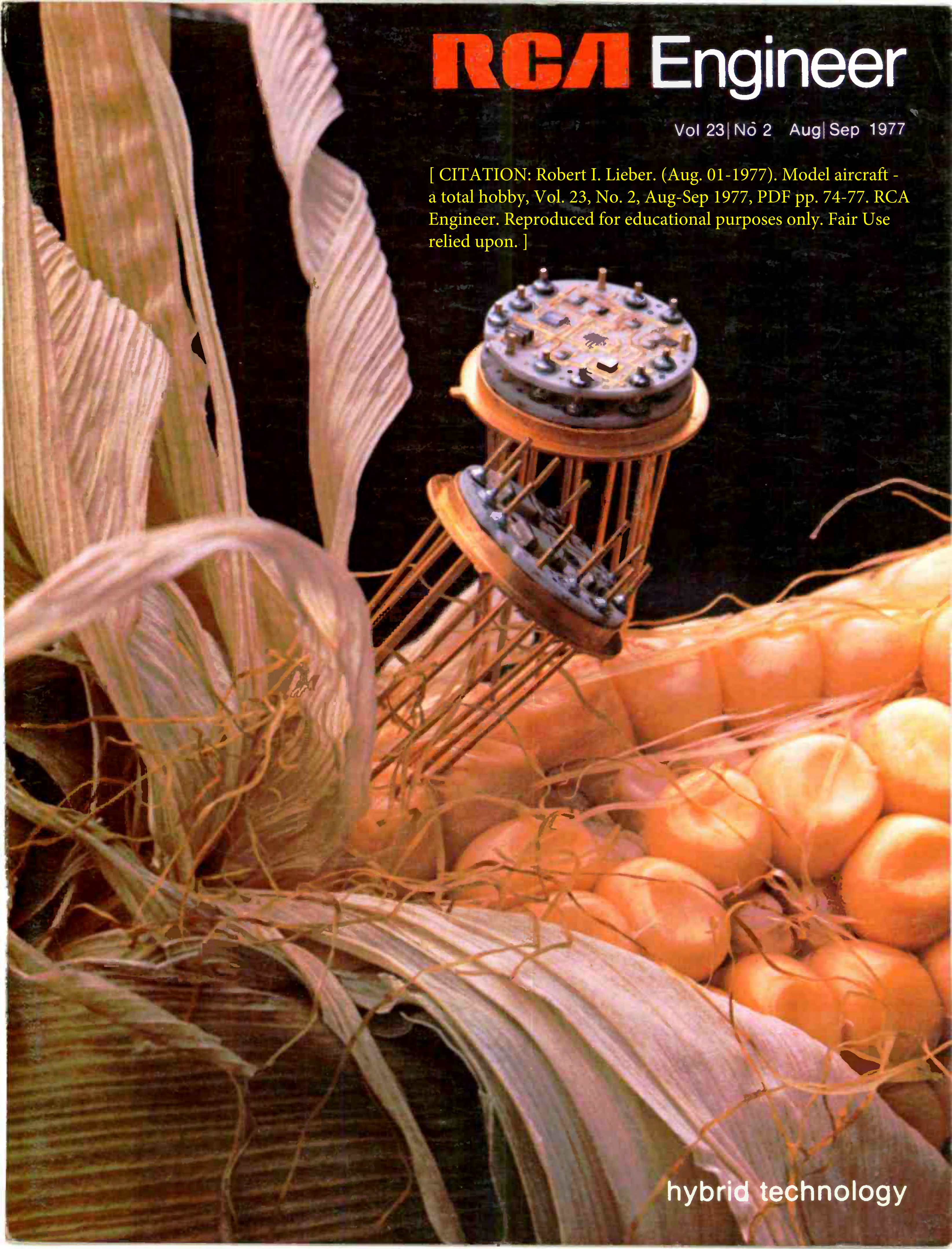
RCA Engineer

Vol 23 | No 2   Aug | Sep 1977



hybrid technology

RCA Engineer

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- To disseminate to RCA engineers technical information of professional value
- To publish in an appropriate manner important technical developments at RCA, and the role of the engineer
- To serve as a medium of interchange of technical information between various groups at RCA
- To create a community of engineering interest within the company by stressing the interrelated nature of all technical contributions
- To help publicize engineering achievements in a manner that will promote the interests and reputation of RCA in the engineering field
- To provide a convenient means by which the RCA engineer may review his professional work before associates and engineering management
- To announce outstanding and unusual achievements of RCA engineers in a manner most likely to enhance their prestige and professional status.

Our cover shows two kinds of hybrids. Electronically, we have multi-layer thick-film conductors, insulators, and resistors mounting and interconnecting beam-leaded and wire-bonded integrated circuits and chip capacitors. Agriculturally, we have the Golden Beauty version of *Zea Mays rugosa*.

Photo: Andy Whiting, MSR, Moorestown, N.J.

There've been some changes made

We recently charted a new course for the *RCA Engineer*.

For more than 22 years, the journal has kept engineers informed and has provided a vehicle for publicizing their work. We felt we could build on that traditional value by publishing articles that would interest larger numbers of engineers and help them stay up to date in their profession.

As a result, we are now seeking out and publishing articles that review or survey fields affecting a broad cross-section of the corporation's engineers—"LSI" by Hilibrand (Jun/Jul) and "electro-optic systems" by Seeley (Apr/May) are two examples.

We are also emphasizing tutorial material: "digital electronics," a four-part series by Shapiro (Aug/Sep 1976 through Feb/Mar 1977); "color tv" by Pritchard and "electronic displays" by Johnson (Jul/Jul); and the dialog on "hybrids" by Joyce in this issue.

We have continued to seek out and publish papers that review the business environment: Jacoby on "solid state" (Jun/Jul); Winder on "microprocessors" (Feb/Mar); Bouchard on "hybrids" in this issue.

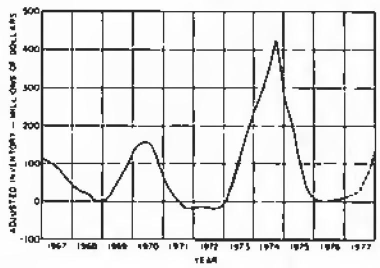
Graphically, our illustrations are now larger, more relevant to the text, and more fully explained. Editorially, we have opted to eliminate mathematical derivations, detailed supporting data, and lengthy descriptions in favor of presenting broader concepts. (The author of a paper is, generally, a phone call away for the details.)

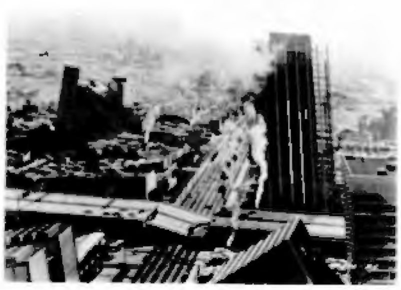
Our experience and that of our advisors told us that these changes were desirable—so we made them. Then, through the recently completed Engineering Information Survey, which elicited opinion from more than 3000 RCA engineers, you reaffirmed our decision to move in this direction. Let me cite a few general findings to make the point. About 80% felt that the *Engineer* should publish more state-of-the-art reviews; 64% wanted more information about competitive technologies; and 52% wanted more educational material. A complete report on the survey will be published in a later issue.

The *RCA Engineer* improvements are due, in large measure, to the diligent efforts of the competent, creative staff that works with me to produce the journal. But our small staff could not do it alone. A major share of the credit belongs to the editorial representatives who work inside RCA's various engineering activities and represent the journal's primary sensory network. The *Engineer* is fundamentally what you and these representatives make it; they are your contact with the journal and our contact with you.

In this issue, we have dedicated two pages to the editorial representatives (pp. 42-43) in the hope you will get to know them better, and through them help to further improve the contents and policies of *your* journal—the *RCA Engineer*.

John Phillips, Editor





Coming up

Our next two issues are on **advanced communications.** The Oct/Nov issue will center on **common carrier and satellite communications**, while the Dec/Jan issue will cover new developments in **broadcast communications**, such as **digital** tv and **circular polarization.**

Later issues will have **radar, software**, and **space technology** themes.

RCA Engineer

Vol. 23 | No. 2 Aug | Sep 1977

Hybrid technology—best supporting actor

For nearly three decades, hybrid microcircuits have not quite lived up to their advanced star billings. But in the past decade, the directors of the show business called electronics have recognized the role hybrids were meant to play—to support the stars of the industry, monolithic microcircuit technology and semiconductor technology in general.

J. G. Bouchard

What is a hybrid? I'm sure you've already said "I know what a hybrid is. It's a small circuit combining active elements and deposited resistors." Most hybrid experts, however, would rather relate their definition to interconnection and packaging technology:

> *Hybrids are a class of microelectronic circuits fabricated by a complete technology that is very dynamic, constantly evolving and expanding—a technology continually being augmented by the emerging semiconductor techniques in combination with innovative thick- and thin-film technologies.*

Thus, hybrid technology is essentially an advanced method of combining, assembling, and packaging newer components into a more effective, larger part of an electronic system. With such a definition, it becomes obvious that the nature of progress in hybrid technology must be evolutionary—governed by the development of techniques considered as basic and essential to hybrids, but also tracking developments of new components to be added to the ever-growing list of hybrid ingredients, and developments and applications of more effective semiconductor assembly techniques.

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Final manuscript received June 17, 1977.

Originally, hybrid microcircuits were simply the combination of deposited resistors with attached discrete packaged active elements. The very first hybrids were made using screen-printed resistors and vacuum tubes for a military fuze program in the early 1950s. When the transistor was introduced in 1955, it was a much more compatible hybrid element and greatly increased the effectiveness of hybrid technology of the late 50s and early 60s. Many hybrids were fabricated, and in fact, are still being fabricated consisting of packaged transistors in combination with deposited resistors and conductors on ceramic plates (Fig. 1). Early, uncased transistors were very fragile, very susceptible to damage during hybrid processing, and the potential size reduction by their use was realized only at extreme cost. It was not until *planar* transistors became available that the "chip-and-wire" hybrid technology became practical.

When monolithic microcircuit chips became available, they added significantly to the capacity and range of hybrid technology. Examples of hybrids incorporating ICs are illustrated in other articles of this issue.

Throughout its history, the *proper* application of hybrid technology has made available to the circuit designer the best of the microcircuit world—smaller size, better performance, higher reliability, and closer performance tolerance. The word *proper* was emphasized because too often hybrid microcircuits have been used to disadvantage.

Hybrids vs. monolithics

This controversy has been the subject of countless papers and many panel discussions at various technical meetings. Well, the battle is over, and in fact, those who always

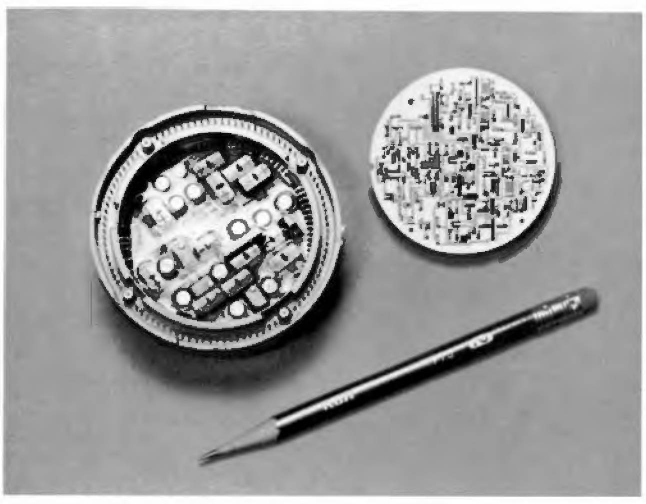

Fig. 1
Discrete device hybrid. This first form of hybrid technology is still being used in low-packing-density, low-volume applications.

recognized hybrids as a packaging technology will claim that there never was a battle—it has always been a big fuss about a nonexisting conflict. These two technologies do not perform parallel functions, but additive ones. Hybrid and monolithic technologies do not compete; they complement each other. One might say that monolithic microcircuit and general semiconductor technologies produce the stars of the microcircuit show, and hybrid technology produces the supporting cast. The monolithic stars can perform many simple and very entertaining acts on a solo basis, but a real production usually requires several stars and the assistance of an able supporting cast. For example, a monolithic IC operational amplifier is perfectly adequate for many ordinary applications, but an instrumentation amplifier requiring high performance is better realized by a hybrid microcircuit that will typically consist of three monolithic operational amplifier chips, precision and dynamically-trimmed resistors, and compensating capacitors.

Quite often, in show business, a supporting actor entertains and keeps the audience interested, while the star is preparing for the next act. Hybrid technology occasionally performs in this capacity, achieving the necessary small size using simple IC chips until the monolithic star is ready to perform. There have been, are now, and will be, many instances where a hybrid circuit consisting of a number of IC chips is used in a socket until the monolithic equivalent is available. The monolithic equivalent may not be available initially, simply because of its long development time, or may not be practical because the volume has not yet developed to justify its higher development cost. For a while, this monolithic performs a one-man show, but then the cycle starts again. Several such monolithic chips are utilized along with an appropriate hybrid cast to create a real spectacular.

Hybrids—what volume?

Enough of show business. How about the real hybrid business. How big is it? Where does it come from? The true magnitude of the current hybrid business is not available in conventional market forecasts. For example, *Electronics* magazine, which annually publishes a forecast of electronic markets, estimated the 1977 market of *Multi-components and Hybrids* to be $281.1 million and projects a market of $403 millon for 1980. However, this is only a small fraction of the true hybrid market, since these numbers represent *only* the hybrids that get to the market as hybrids. Since the hybrid business is largely captive, the true volume of the hybrid market does not show up as hybrids but as a hidden part of the end-item market. Most hybrid microcircuits do not get sold but are produced by the end-equipment manufacturers. It is safe to say that the total value of hybrids used in such equipment as computers, automobiles, telephones, military electronics, digital watches, and mobile radios far exceeds the $281.1 million estimate.

IBM, for example, has been using thick-film hybrid technology for nearly two decades, beginning with simple RC networks. Currently, this manufacturer has the highest known level of automation,[1] producing very complex hybrid circuits. IBM's annual volume is, of course, not publicized, but is known to exceed 10 million circuits per year.

Gerry Boucharc worked for a major semiconductor manufacturer as a transistor process and desigr engineer from 1957 through 1963. In 1963, he was appointed engineering manager responsible for both monolithic and thin-film hybrid development. Since 1968, when he joined RCA, he has been responsible for Burlington's Microelectronics Facility.

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Delco, the leading automotive electronic manufacturer, has invested over $12 million in hybrid automation[2] and currently produces upwards of 200,000 hybrids a week.

Western Electric has been using hybrid technology very extensively for many years. As part of the NIKE-X program, Western Electric developed and produced multichip wire-bonded hybrids (Fig. 2). This program led to the development of the beam-lead technology.[3] The oscillators for all Touch-Tone telephones are produced using tantalum (thin-film) hybrid circuit technology.[4]

These three companies are currently the largest producers of hybrid microcircuits, and none of them sell hybrid microcircuits.

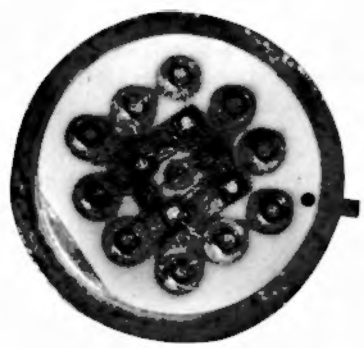

Fig. 2
Multichip wire-bonded hybrid deve.oped for the NIKE-X program. This type of hybrid was the precursor of beam-lead technology.

Why hybrids and when?

Early hybrid technology and many current applications were motivated by the need for small size. This issue contains several examples, and I'm certain you've seen many more. Thus,

Axiom I— Hybrids for small size

However, such manufacturers as IBM, Western Electric, and Delco did not adopt hybrid technology because of the available size reduction, but to take advantage of automation, which has led to *lower cost*. The major manufacturers realized early that hybrid technology lends itself very well to a high level of automation and thus greatly reduces the manufacturing labor costs. In hybrid production lines, the operators never have to move the individual pieces from station to station; they move magazines or trays containing many thousands of pieces. Within a main block of operations, the work is moved automatically by indexing-type conveyors. But the cost for this automation is very high and cannot be justified except for high-volume requirements. These companies saw the opportunity, had the volume requirements, invested in automation, and now reap the benefits. Thus,

Axiom II—Hybrids for high volume

But, hundreds of other companies are producing hybrids, none in quantities even approaching those described above. What is their motivation? In many cases, Axiom I applies: small size is important. Nevertheless, in some low volume applications, size is relatively unimportant and again, cost is the driving factor. In this issue, Brad Joyce[5] discusses the cost effectiveness of hybrids from a different perspective. Too often the hybrid-vs-discrete cost comparison is done at the component level with little or no consideration for the savings made possible at higher levels of assembly. In general, you can expect that hybrid technology can reduce system cost when a specific circuit is used many times in a system, e.g., as computer memories, test systems, multi-channel communication systems, Thus,

Axiom III—Hybrids for repetitive circuitry

It is important also to recognize the deficiencies, the drawbacks of hybrids, and where they should not be used. Too often people enamoured by the technology have insisted on applying hybrids where they were not needed, where they could not effectively compete. If your application does not need small size, there is no repetitive circuitry, and the volume is not large, hybrids most likely should *not* be used. Thus,

Axiom IV—Hybrids are not a cure-all.

Hybrids today

As we established at the the outset, "hybrid" is a *packaging* technology. Thus, the application dictates the package—it can be hermetic or not, it can be standard or custom, it can use discretes or chips—it is designed to do the job the best way possible.

Hybrid circuits currently being manufactured are the result of the proliferation of substrate-fabrication, packaging, and semiconductor-assembly technologies. The heart of all hybrids, the substrate, is produced using thick- or thin-film technology (occasionally, thick *and* thin film). Because of its lower cost, thick-film technology is used more extensively; thin-film is used when very close tolerance resistors or accurate geometries are required.

Although a large number of hybrid circuits are manufactured using pre-packaged semiconductor devices, the most universally used assembly technique is *chip-and-wire*. This technique has low-cost capability for high volume manufacture, as it is readily automated. The full range of device types is available in chip form, which allows for versatility in design and optimum size reduction with high reliability.

Even before IBM announced their Solid Logic Technology, *flip-chips* were touted as the ideal semiconductor form for hybrid manufacture. Thus far, they certainly have proven so for IBM, which has vertically integrated and now produces such chips for the millions of hybrids they manufacture. But for those hybrid manufacturers who have to buy chips, and have neither the money nor the volume to justify internal chip production, the limited availability of flip-chips, both in quantity and chip type, has principally limited their use to a very-high-volume company like IBM.

When *beam-lead* devices were first announced, many of us in the hybrid industry said, "This is it. This is the ideal form of semiconductors for hybrid manufacture." It was, and is still, the ideal form for hybrid manufacture; but it did not turn out to be a form that was cost effective for the assembly of discrete devices. Thus, the projected high volume for beam leads did not materialize, their costs continued high, only limited types were available, and their promise in the hybrid field, like the flip-chip, has for the most part, been realized in one company—in this case, Western Electric.

The future

Recently, Dr. C. Thornton, Director of the Electronics Technology and Devices Lab, USA-ECOM Fort Monmouth, New Jersey stated, "Over half the Army's (electronic) equipment to be built from here on out will use hybrid circuitry, both thin and thick-film."[6] As mentioned, hybrid technology is also firmly entrenched in computers, automotive electronics, and the telephone industry. And there is no doubt that hybrid applications will continue to proliferate.

Thick-film or screen-printed technology will continue to dominate: ceramic plates will become larger, substrate complexity will increase through more multilayers, and printing costs will be decreased by the use of multi-image printing and non-noble metal inks. The relationship of thick and thin film will continue as each meets a unique need.

Chip-and-wire will continue to dominate as the major non-captive-market assembly technology, and its effectiveness

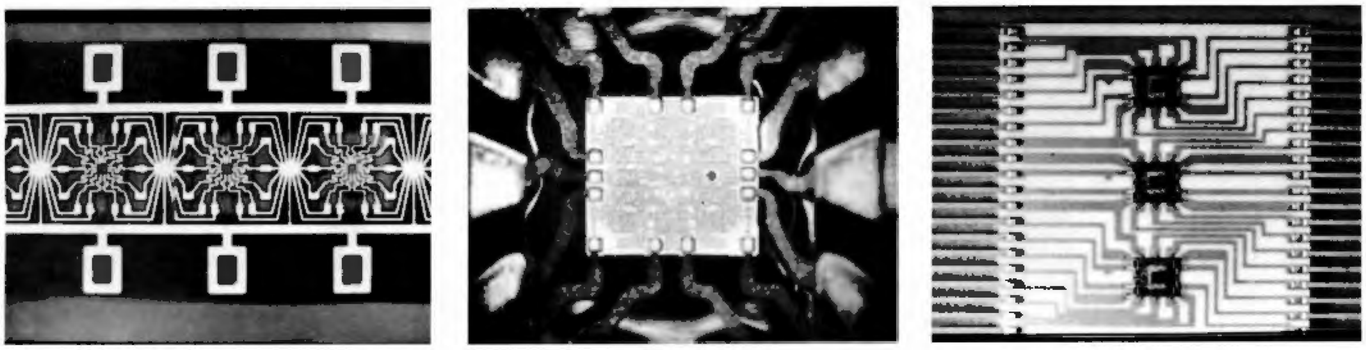

Fig. 3
Tape bonding has outstanding automation potential. Left, IC chips bonded to polyimide tape; center, close-up of chip bonding; right, tape-bonded hybrid.

will be further increased by automatic wire bonding. The discrete-device hybrid volume will decrease, but at a very slow rate. Very few new beam-lead and flip-chip hybrids will be designed.

These preceding predictions are almost obvious and should evoke few disputes, but it is much more difficult to predict the future of two new techniques: tape-bonding and leadless ceramic carriers.

Tape-bonding[7] (Fig. 3) offers some of the advantages of beam leads without some of its drawbacks—and some unique advantages. Like beam leads, it is gang-bonded, i.e., all leads are bonded in a single operation. But unlike beam-leads, tape-bonding makes practical both automated testing and burn-in after the chip is attached to the polyimide film. For very complex, high-reliability circuits, this is a most significant advantage. On the negative side, tape bonding, as currently practiced, requires specially "bumped" chips. It appears to have outstanding automation potential, and several semiconductor manufacturers are using this technique for assembling some of their packaged devices. A hybrid manufactured with tape-bonded devices could be the same size and use the same packaging techniques as a chip-and-wire hybrid. Because of gang-bonding and the higher assembly yield made possible by testing at the tape level, tape bonding offers potentially lower manufacturing cost. It is also expected that gang-bonded tape terminations would be more reliable than individual wires.

Another hybrid technology that is in its trial period utilizes leadless ceramic chip carriers,[8] which are essentially flat-packs with solder terminations instead of flat ribbon leads. The main advantage of this technology lies in the ease of testing and burn-in in the sealed package. It does not provide the size reduction of chip-and-wire or tape-bonded hybrids (2 to 4 times larger) and is only about one-fourth the size of a DIL circuit on a PC board.

The critics are still reviewing both of these technologies. The extent of their application in general hybrid production depends almost exclusively on the extent to which the semiconductor manufacturers utilize these technologies for the manufacture of their discrete families. The automatability, and thus low-cost potential, of tape-bonding may stir vertical integration and singular, high-volume, captive application somewhat similar to flip-chip at IBM and beam-leads at Western Electric. Wide-scale acceptance, however, will depend on the semiconductor manufacturers' acceptance of this bonding technology. Ceramic carriers cannot be automated as easily and thus do not offer the cost advantage that tape bonding does; furthermore, ceramic carriers must overcome the drawback of larger size. A leading semiconductor executive recently predicted that the ceramic carrier would eventually become the major hybrid component.[9] He pointed out that although tape-bonding has lower cost potential, the high volume required to realize these low costs would never materialize, as he predicts will occur for the ceramic-carrier devices. For these predictions to come true, a major portion of the DIL discrete semiconductor market must shift to ceramic carriers. In my opinion, the four-to-one size reduction is hardly enough justification for this major shift in discrete assembly packaging.

I expect that ceramic carriers will continue to be used for large hybrids requiring complex monolithic chips. But it is very doubtful that the volume of this form of active device will ever be significant.

Evolution will continue; a major revolution is unlikely. Tape-bonding has the potential of creating such a revolution—but it must first get the financial and moral support of the major semiconductor manufacturers. Otherwise it will be the beam-lead story all over again.

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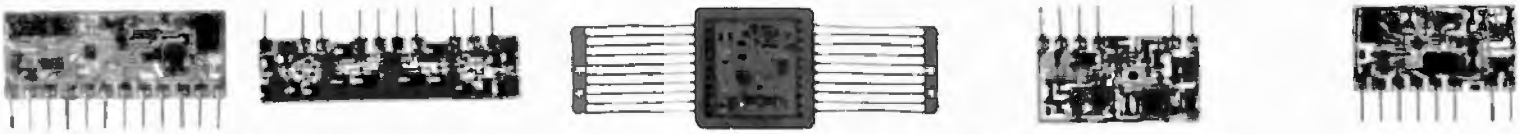
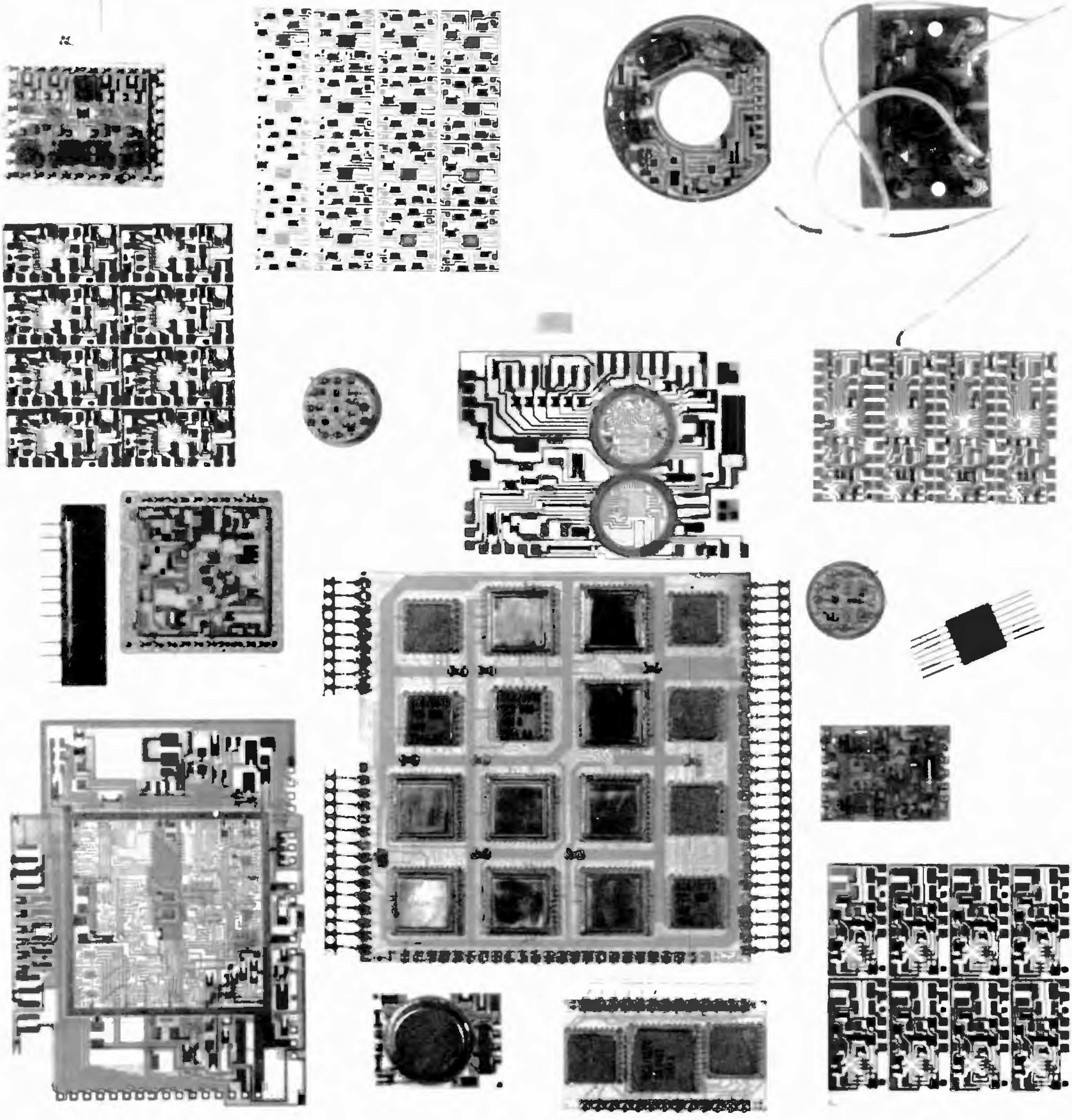


A circuit designer meets hybrid technology

B.T. Joyce

This dialog between a design engineer and a hybrid products engineer presents hybrid circuit design problems and the solutions in an informal, desk-side encounter, along with typical sketches, notes, and photographs



This paper about hybrids is directed specifically at design engineers who are held responsible for the technical integrity of the products they start on the way toward profitable production. It bypasses the technical sales pitch about the benefits of hybrids, all those good words written many times before in many different ways about many applications. Instead, we get down to the nitty-gritty technical concerns of the engineer who has an unproved circuit design and faces the prospects of committing it to unfamiliar packaging methods which (to him) seem totally unforgiving of error and frozen against change. The dialog starts in the hybrid production area.

Dsn eng: Thanks for showing me around the hybrid lab.

Hyb eng: Glad to. But we are really not a lab any more.

Dsn eng: Yes, I guess that's true. I'm impressed. Some day when I have a proven circuit design, I'd like to convert it to hybrids.

Hyb eng: You don't have to have a proven design before considering hybrid packaging.

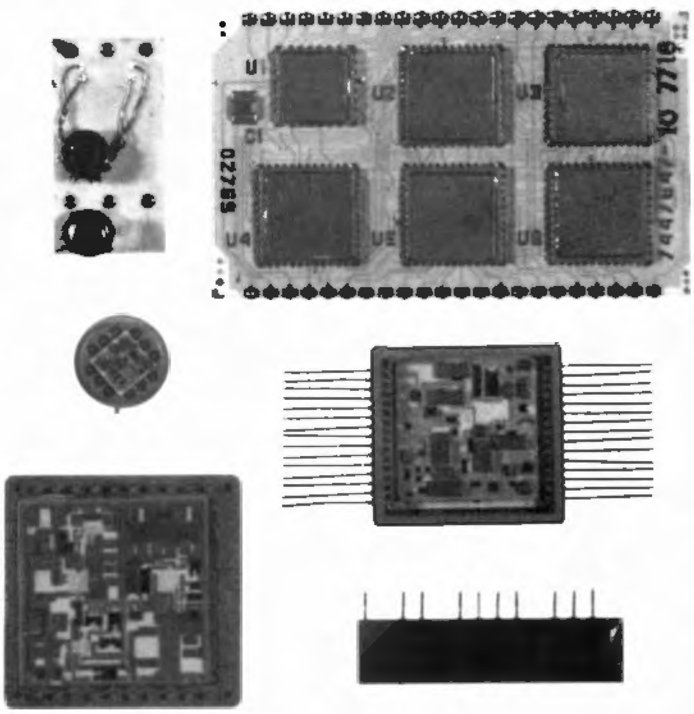
Dsn eng: Then I'd have to have a lot more time for the development—time, believe me, I never seem to get on the projects I'm always put on.

Hyb eng: Have you got a few minutes? I think you and I should sit down and get into some of the nitty-gritty details of hybrid design. No sales pitch. Honest! I'm sure you have heard about all the good things hybrids can do for you many times.

Dsn eng: True. In fact you were coming on pretty strong during the mini-tour you just gave me!

Hyb eng: Yes, I suppose I was. Instinct, I guess. But, how about it; can we chat for awhile?

Dsn eng: Sure, why not?



The two engineers settle down at a conference table in the engineering office area of the hybrid engineer. The hybrid engineer has near him drawing and photograph files and a desk loaded with what he calls "show and tell" hybrids, bits and pieces (literally "pieces," in some cases) of hybrids accumulated over years of product activity. Both have pads of paper to make notes and sketches to accompany their words.

Hyb eng: If hybrid packaging makes sense for your design, you should be considering that approach right from the beginning, designing and partitioning your circuit to take advantage of the fact.

Dsn eng: I thought I wasn't going to get a sales pitch. That sounds like motherhood. Lock—when I commit a circuit to a PC board, I've got a fighting chance, after the board is put together, to make the thing work. Let's face it, the first time through, errors *do* occur—not all the time, but often enough to make a few grey hairs. And you expect me to get locked into hybrids where the only way I can get a good look at my circuit is through a microscope? No way!

Hyb eng: What makes you think we can't do a reasonable job of fixing up problems?

Dsn eng: Can I change the value of some of the components?

Hyb eng: That depends upon what kind of components you're talking about. We actually have a lot of flexibility in the design of the hybrid, especially if we can anticipate specific areas that might change.

Dsn eng: How about resistors? Sometimes by changing a resistor value after the circuit is put together, I can improve its performance.

Hyb eng: How much of a change are you talking about? And which way?

Editor's note: For this dialog, the author draws upon his experiences as a circuit designer and a hybrid products engineer. Brad Joyce's biography and photo appear in his other article in this issue.

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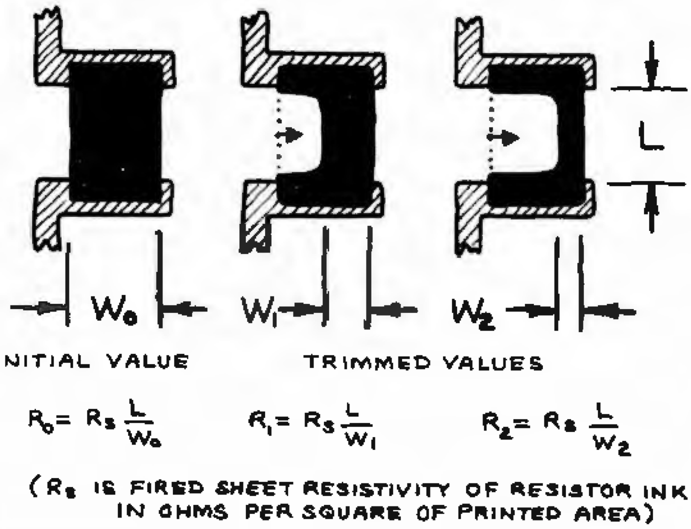
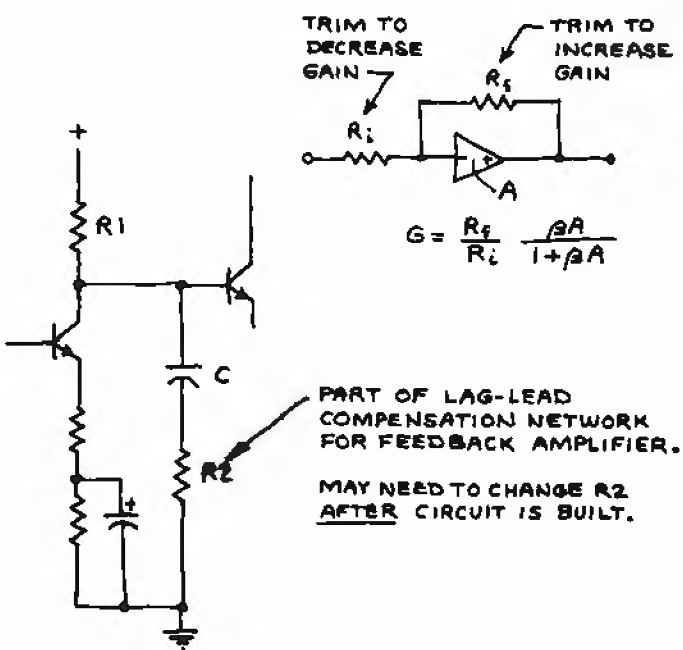
Dsn eng: Which way?

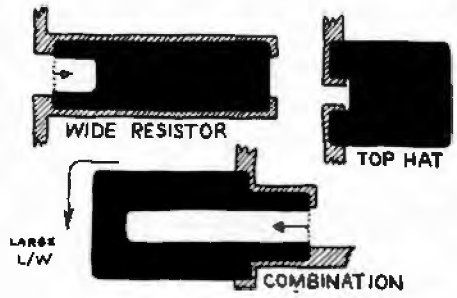
Hyb eng: Yes. Up or down? You see, we usually trim a thick-film resistor to the value you specify on the schematic, trimming before putting any chip parts down on the substrate. But, see, it's usually possible to trim the resistor more after the circuit is built by removing more resistor material. This drives the resistance up—but it's a one-way street. Without any special attention, a resistor can usually be doubled this way.



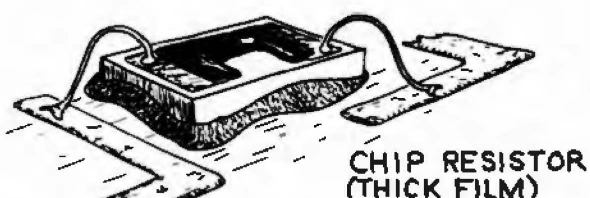
Dsn eng: Great! But what if I want to lower the resistor value? The resistor value could go either way. To improve the ac stability of a feedback amplifier, I might want to reduce or increase a resistor in a lag-lead compensation network. For that matter, I might want to change the basic gain of an op amp by altering R_f or R_i. Of course, here we might actually have a choice. If when you trim a resistor it always goes up, then we can trim one resistor to increase the gain or trim the other resistor to decrease the gain. But in general, I may have to make a resistor lower. What do you suggest?

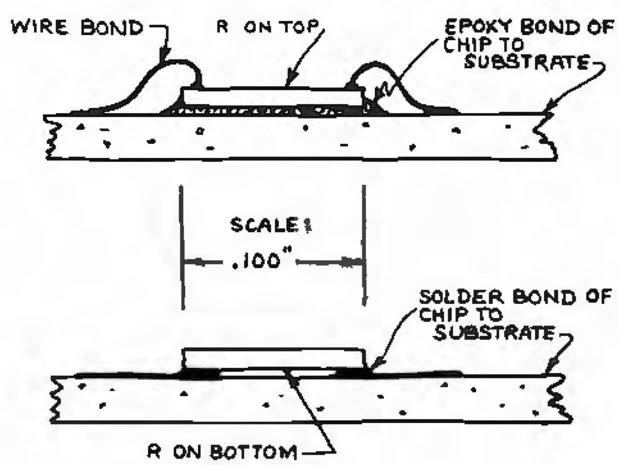


Hyb eng: Then we need to plan ahead, identify any uncertain resistor and start with a value you know is small enough, and actually plan to trim it again, say during the initial engineering sample run of hybrids. We can deliberately design such a resistor in a form that favors a wide range of final trimmed values such as by making it very wide or in a top-hat shape.



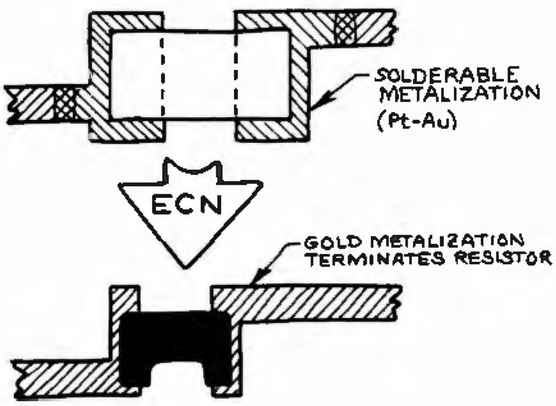
We have an alternative approach to make it easy to change resistors—somewhat more expensive to the hybrid product, though. We can use a chip resistor instead of a thick-film resistor. Chip resistors come in thick-film or thin-film types. With the thick-film type, we pay someone else to print, dry, and fire resistors. He cuts them into individual dice to sell to us. The thick-film types can be mounted face up or face down. One type is connected by wire bonds to the substrate





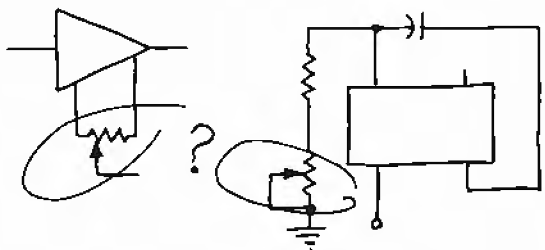
metalization; the other by solder. So we get lots of flexibility simply be leaving room for a chip resistor in the hybrid layout. A good general-purpose resistor configuration covers the resistor range of 1 ohm to 10 megohms, handles 100 mW, and comes in one size, 75 mils long by 50 mils wide.

The resistor can be changed very simply by trained operators or technicians. Downstream when the product gets into quantity production, we may decide that it is economical to get rid of the chip resistor and substitute a regular thick-film type.



TRIMMED THICK-FILM RESISTOR IS LESS EXPENSIVE THAN CHIP.

Dsn eng: What if I have to adjust a resistor after the hybrid is built? Can you give me a pot to adjust dc offset of an amplifier or one to set the frequency of a free-running multivibrator?

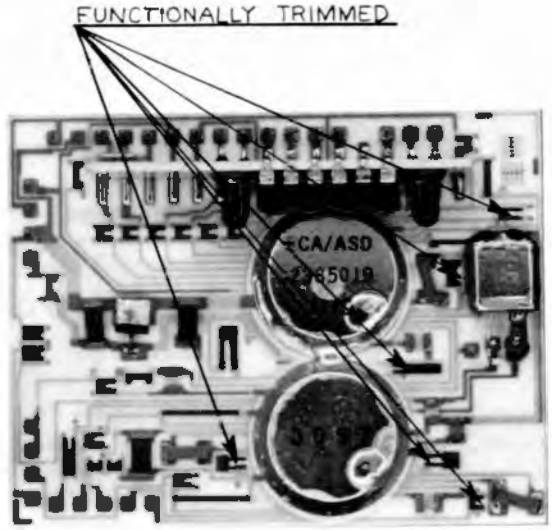


Hyb eng: Giving you a direct answer, yes! In certain complex hybrids, where we treat the ceramic substrate much like a PC board, we can mount conventional discrete parts on the ceramic "board" and thus make room for your potentiometers.

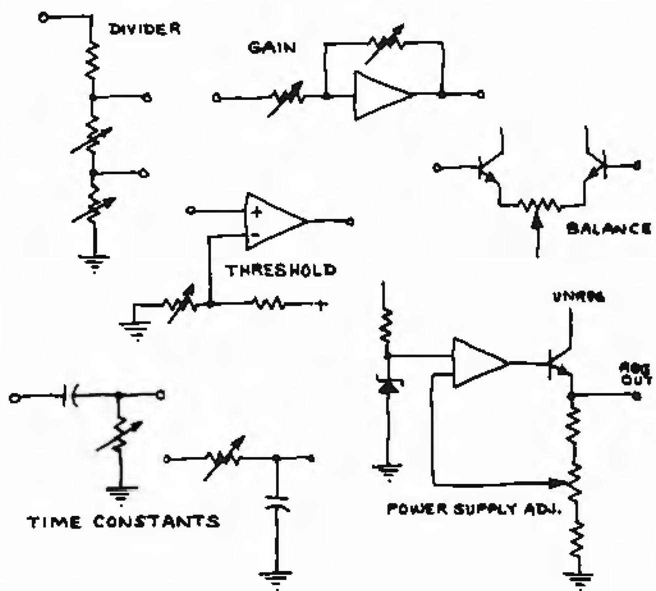
Here's a photo of the Range Counter/Display hybrid from the AN/GVS-5 Laser Rangefinder. Although it doesn't happen to have any potentiometers, it does offer space for large parts like a crystal and LED display devices. The semiconductor chips are all hermetically sealed and protected under the two round covers. Clearly, there is space for pots too. This circuit actually did have a requirement for some variable resistors, which we took care of by functional trimming.

Dsn eng: "Functional trimming." What's that?

THESE 5 RESISTORS ARE FUNCTIONALLY TRIMMED



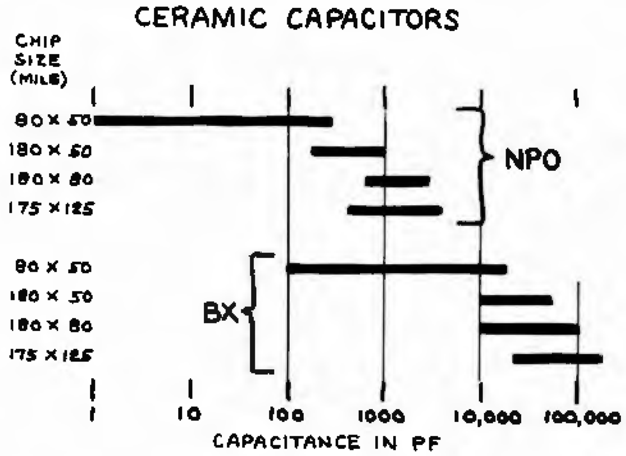
Hyb eng: "Functional trim," "active trim," dynamic trim"—these are all terms used to identify a resistor-trimming operation that takes place while the circuit is under power. We can actually trim a resistor while monitoring a specific circuit function such as your dc offset or your multivibrator frequency and then stop the trimming precisely when the correct value is reached. This range-counter hybrid actually has five functional trims on it. There are all sorts of circuit functions that can take advantage of functional trimming.



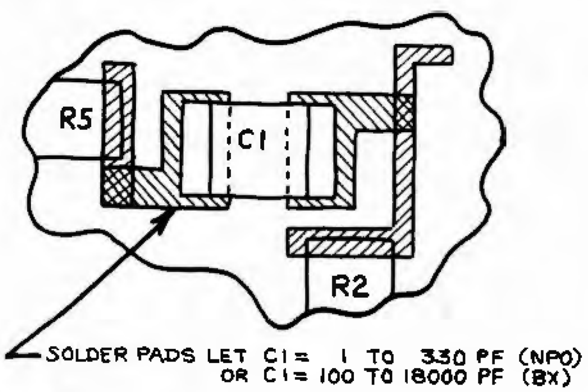
FUNCTIONAL TRIM

Dsn eng: I like that. OK, I've got a pretty good picture on how you can handle resistors. Suppose I need to change a capacitor?

Hyb eng: No problem, especially with some advanced planning. If we know, for example, that the value of a particular capacitor is a little uncertain, then we will make it a point to make sure its value falls well within a range of capacitance available for one specific size of chip capacitor. Capacitor ranges generally overlap for various chip dimensions. The hybrid can then be laid out with the metalization pattern appropriate for that size chip capacitor.



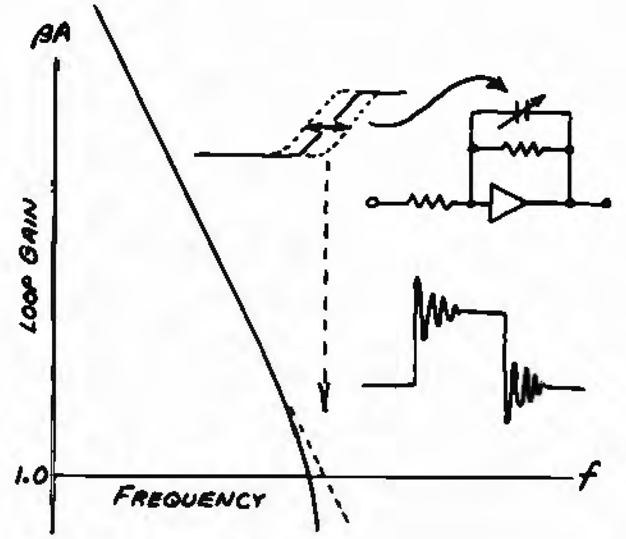
For example, one pattern is totally suitable for receiving a solder-mounted capacitor ranging from 1 pF to 330 pF if it is an NPO class-1 ceramic or from 100 pF to 18,000 pF if it is a BX class 2 ceramic.



Dsn eng: Can you give me a variable capacitor that I can adjust after the circuit is built?

Hyb eng: Depends on what you are trying to do. Just like the case of the pot, we could find room on a ceramic board for a fairly large variable capacitor, the sort of miniature component that you might have put on a PC board. But what do you have in mind? I have some options that may really intrigue you.

Dsn eng: Well, for one thing, I'm designing a video amplifier that is right on the ragged edge of not meeting spec at high frequencies, and my analysis shows that no way am I going to make it unless I either select parts or trim up the loop gain and adjust phase for each individual circuit. A little trimmer capacitor across the feedback resistor to the summing point will do the trick. It will give me some lead at the frequencies where I'm getting into trouble.



Hyb eng: What range of capacitance must you cover?

Dsn eng: Well, I know what I need on my breadboard and have a pretty good idea what I need on a PC board. But I haven't the foggiest notion about what I may need on a hybrid! In fact, that's a real problem, and one I'm not too anxious to fool around with.

Hyb eng: You're sure you can't find one value of capacitance which will do the trick for each circuit built?

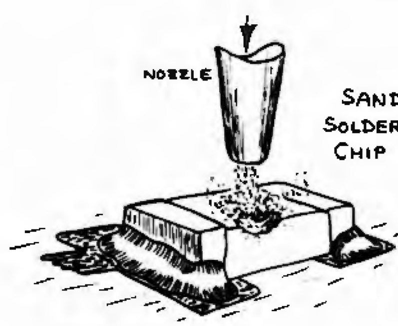
Dsn eng: Absolutely! There are some lags in the loop over which I have no control.

Hyb eng: Back to my question about the range of adjustment you need. What would you use if you put the circuit on a PC board?

Dsn eng: Oh, something between 3 and . . . 10 puffs, to play it safe.

Hyb eng: No sweat! We'll functionally trim the capacitor.

Dsn eng: Here we go again! You mean functionally trim it like the resistors?



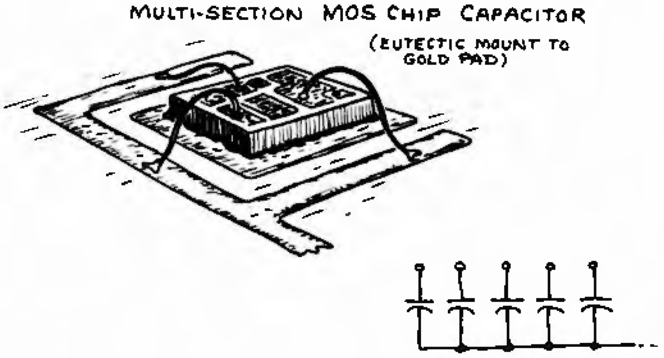
Hyb eng: Essentially. With resistors we abrade away material to make the resistance go up; with capacitors we abrade away material to make the capacitance go down. The ceramic chip capacitors are parallel plate capacitors with a high-K ceramic dielectric between them. The trimming operation cuts away the plates and dielectric material. So, we can power up your circuit and trim a capacitor for the high-freqency performance you are looking for.

Dsn eng: Sounds good. But can you choose the right capacitor in the first place, one that can be trimmed to the value we really need in the hybridized circuit? You sort of ducked around that point.

Hyb eng: Sorry! As a matter of fact, with hybrid packaging, all conductor runs are obviously very short. Compared with your breadboard or PC board, stray capacitance and inductance are significantly reduced, making it possible to get better frequency performance from any particular paper design. Your circuit in hybrid form will probably work better than ever because some of the lags you used to get from strays will be reduced, thus pushing out the frequency response. We can make a good guess at what capacitance value to put across the feedback resistor and then try trimming . And, if we pick the wrong starting value, it is no big deal to change the capacitor to another value—just a soldering operation by one of our assembly workers.

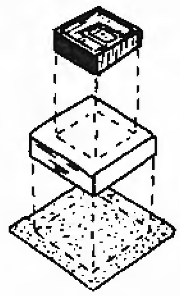
Incidentally, for small values of capacitance, the low "puffs" or even tenths of "puffs," we can make use of monolithic chip capacitors that use silicon dioxide as the dielectric—basically an adaptation of the MOS transistor technology. One electrode is the aluminum metalization pad on top of the chip; the other electrode is the bulk silicon body of the chip. Such capacitors are quite stable, like 35 ppm/°C.

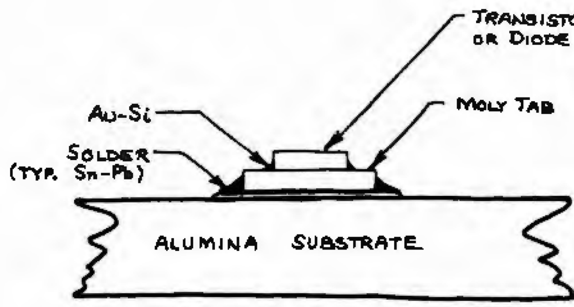
There are some single-chip, multi-capacitance MOS devices on the market which let you pick the capacitor value just by specifying which wire-bond pads you want connected up to your circuit.



Dsn eng: Well, I assume from what you've been telling me about resistors and capacitors that I shouldn't be particularly worried about changing semiconductor devices if I needed to.

Hyb eng: Up to a point, you are right. Diodes and transistors of one type can usually be easily changed to another type. The main reason this is true is because we have standardized on the area allocated and on the way we attach these devices to a substrate.





First, we eutectically mount the silicon chip to a gold-plated molybdenum (or kovar) tab. Then later, we solder the chip-tab assembly to the thick-film metalization on the substrate. A 35-mil square metal tab is a standard size we have picked to take care of most transistors and diodes. Thus, a change of type is easy. (Obviously, we'd better make sure we order any alternative chips that might be candidates for use in order to avoid purchasing delays.) But really, the possibility that you may need to make such a change is small if you have done a reasonably thorough design analysis and breadboard test of your circuit. Actually, we have had cases where selected transistor parts were needed instead of the standard catalog items. In such cases, the basic hybrid design remained unchanged by the use of selected parts. Selected part drawings were generated, of course, so that the appropriate parameters could be controlled, and the parts list had to be ECN'd.

Dsn eng: Selected parts? I thought with chips you had to take what you could get; that unless you packaged the chips and properly tested them, you didn't really have any guarantee of performance.

Hyb eng: Not too many years ago, your comment would have been right on. The semiconductor manufacturers, especially the big boys, really could care less about the hybrid people. Just buying chips could be a hassle if they weren't garden-variety types. Not so nowadays! The hybrid business has really come of age, enough to represent significant chip volume to the semiconductor people. And a number of speciality houses have gone into business just to serve the hybrid manufacturers and have set themselves up to meet requirements such as providing the selected parts.

Dsn eng: But I still thought you had to package a chip before you could really tell how it was going to perform. And then, what good is the chip to you?

Hyb eng: No good! At least that chip or any other chips that the vendor may check out in a final package. His trick is to use sampling techniques. He can pull samples from a specific wafer that contains hundreds of transistors or, for that matter, pull appropriate samples from an entire wafer lot. His tests on packaged samples pretty well spell out the performance characteristics of the lot so that he can sell to us chips guaranteed to meet our spec, even where we call out something special. But let's face it, selected parts cost more money than standard parts. And just as you try to avoid selected parts when designing circuits for PC boards, you also try to avoid selected chips for circuits that will be built as hybrids. But the flexibility to select is nevertheless still there.

Dsn eng: You know something? I think I have a right to feel a bit paranoid. So far in our conversation, we've been talking about all the things that might be questionable about my circuit design and the mistakes *I* might make. But let's face it, I'm really worried about the mistakes that *you guys* make. I've heard some real horror stories! You have no monopoly on geniuses.

Hyb eng: Amen! But we can get awfully creative when we have to fix a goof and when all the bosses are trying to help us.

Dsn eng: Yup, I known what you mean! But at least on a PC board when you have an unwanted conductor shorting two signal runs together, it's not too hard to cut away copper on the outside or even drill out the etch on a buried layer. What do *you* do?

Hyb eng: Same sort of thing. Sometimes we break an unwanted conductor run with a diamond-pointed scribe; other times we sand blast it out.

Dsn eng: Sand blast? You mean like trimming resistors?

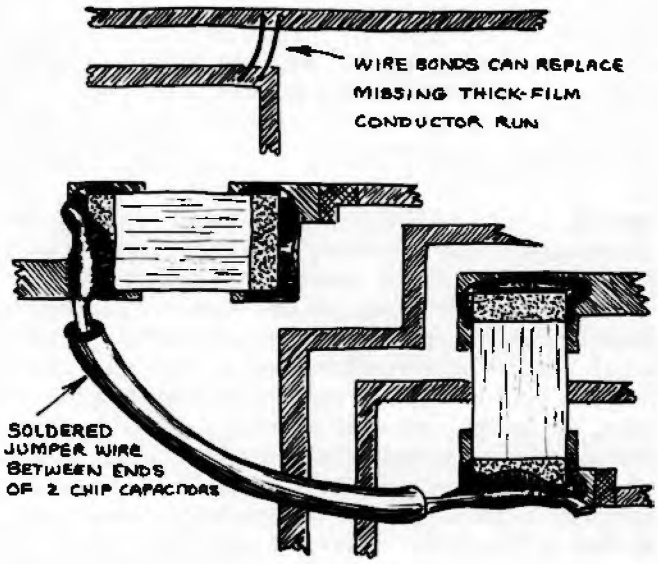
Hyb eng: Exactly. But we have to be careful not to damage anything in the local area around the line being cut. After all, if a resistor gets hit by an overspray of sand, its value may go up and go out of spec. Overspray on the face of a semiconductor can cause damage also. Let's face it, we have plenty of motivation to try to avoid having to cut away metal. We don't need that kind of problem, and we check the basic layouts very carefully for that reason.

Actually, it is usually easier to open shorts then to short opens.

Dsn eng: Come again?

Hyb eng: You know—replace a missing conductor run after the hybrid is made.

Dsn eng: On a PC board, we just solder in a jumper wire between a couple of convenient points.



Hyb eng: Sometimes we do the same sort of thing. In certain cases, we jump an open with gold wire bonds. Wherever there are soldered capacitors around, there are some good places to solder in a jumper. But the approach falls apart if the nice, solderable capacitor locations just don't happen to be associated with the missing conductor run. And unlike the PC board, where any exposed copper conductor is a good candidate for soldering, the metalized hybrid substrate has many gold conductor runs that can be soldered safely only with some of the more exotic solder alloys. Regular tin-lead solders leach away the contacted gold.

Dsn eng: Sounds hairy, but I suppose no worse than some of the fixes I've had to put on a PC board the first time through manufacturing.

Hyb eng: That's the real point I have been trying to make. Sure, everything is scaled down to a smaller size; but we have a whole bag of tricks (reasonable ones, believe me) that we use to get around problems if they occur—tricks that are no more special to us in building hybrids than the ones you are familiar with.

Dsn eng: How much of a circuit can I get into a hybrid?

Hyb eng: Hey! Great! You're ready to take a serious look at hybrid packaging?

Dsn eng: Well, let's say I'm listening. But I really don't have any feel for how much circuitry I can expect to shrink to a practical hybrid—you know, one that isn't going to cost a mint and cause a lot of grief. I could care less about "pushing the state of the art."

Hyb eng: You are asking a question that doesn't have a clean answer. Exactly how many parts you cram into a hybrid (in effect, how complex you make it) depends very much on the application and the product interests you are trying to serve. But let me throw some thoughts out—ones loaded with personal bias.

You can at least get a ball-park feel for what the hybrid can do for you. For instance, I can make one sweeping generalization: If you have a circuit function using discrete parts that are packaged tightly together on a PC board, we can package that same circuit function into one or more hybrids that will use only about one-tenth of the board area. Without qualms, we can take a digital logic circuit with twelve ICs and even a couple of capacitors and put them together in a single, hermetically-sealed one-by-one-inch package. And many hybrid houses (including ours) are doing a lot better than that!

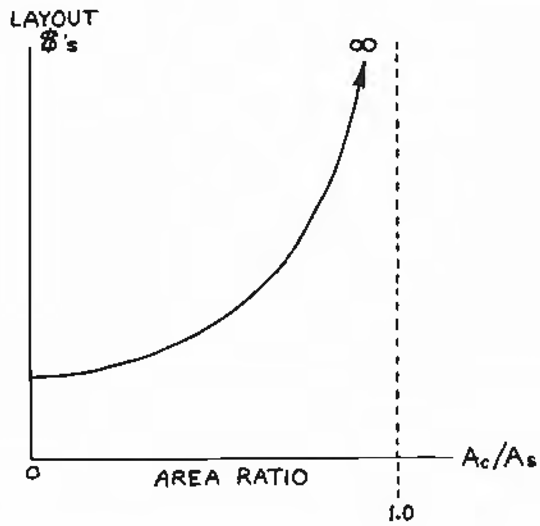
There is one thing that you really must be careful about when you start to move into hybrid packaging.

Dsn eng: What's that?

Hyb eng: That you and the hybrid engineer don't get carried away with the idea of packaging as much as possible into the hybrid package.

Dsn eng: How do I keep out of trouble?

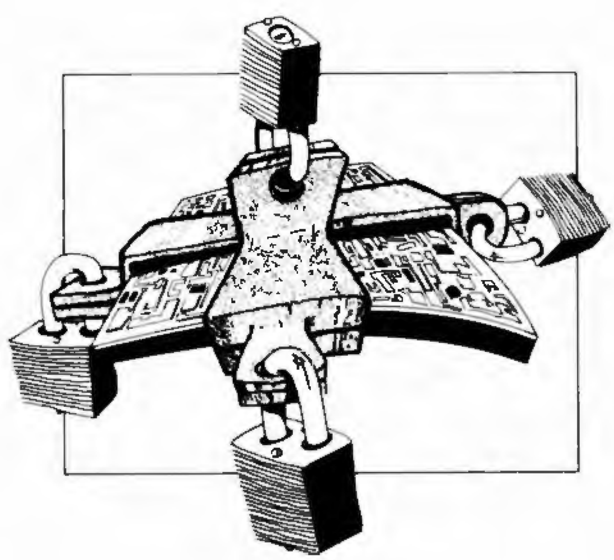
Hyb eng: Make sure some sort of decent area survey is done that makes an effective comparison of the area of the substrate with the area of all the chip parts and thick-film resistors. As a simple rule of thumb, I like to hold the area of the components to about one-half the substrate area. Let's face it, as the component area approaches the area of the substrate, the costs for just trying to lay out the circuit approach infinity.



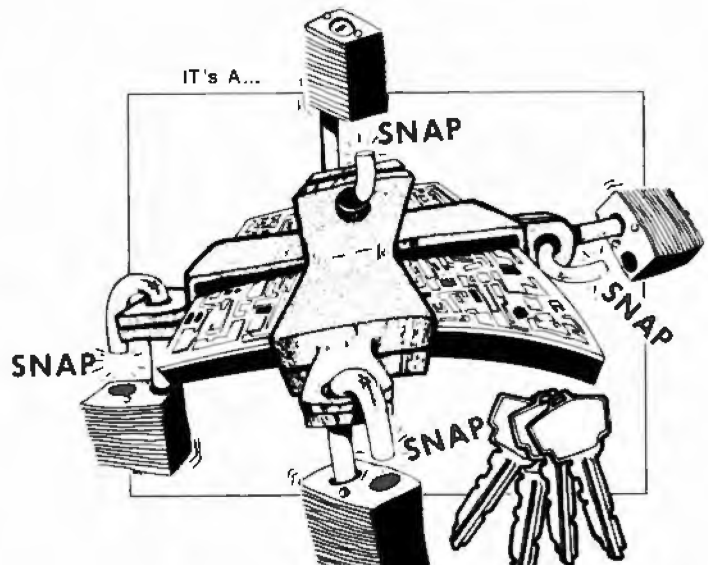
Dsn eng: A truism! But I've got the message.

Thanks for taking the time with me. I've got to get going. I have a meeting to get to in five minutes. But I'll be back later to get into details on a design I'm working on now. Say, have you ever considered writing down some of the stuff you've been telling me about?

Hyb eng: Who'd read it?



If I'm LOCKED Into Hybrids,
Are My Design Changes LOCKED OUT?



The changing role of hybrids in modern electronics systems

J.A. Bauer

Hybrid technology has improved to keep pace with the developments in monolithic ICs. Here's what one RCA facility is capable of doing in hybrid design and production.

Hybrid technology has generally replaced all other techniques of interconnecting and mounting multiple-chip components for high-density packaging. It has surpassed "cordwood" mini-mods and other techniques because the hybrid can use smaller uncased components and because direct connections to both active and passive components improve performance and reliability. The hybrid can achieve low cost by reducing volume and cabling. It also offers improved high-speed performance in digital circuits and analog circuits, and gives better adherence to design specifications by "hot trimming"—circuit trimming to match desired characteristics while the circuit is under electrical test.

Limitations to earlier technology

Before the availability of monolithic integrated-circuit components, the hybrid was recognized as a way to provide multilithic LSI within a single package by using special mounting and interconnecting techniques. Major efforts were devoted to treating of the semiconductor chips to improve the bonding process. Competing techniques of flip-chips, beam-leaded chips, and leadless inverted devices were developed. All of these have been, and are still being, used with success on specific products. However, several factors have reduced their utility in general-purpose applications. These are:

- Limited chip selection;
- Geometry variations between different sources of the same chip type;
- Limitations in substrate design;
- Nonuniform materials and processes for chip attachment;
- More costly components; and
- Growth of LSI into larger chips with more contacts than the specialized bonding process can accommodate.

For example, the hybrid facility at MSR in Moorestown has implemented successful designs with available beam-leaded components and mixes of beam-leaded components and chip-and-wire components, but currently plans no major developments in these older chip techniques.

Hybrids and LSI—competing and working together

As integrated circuits have progressed through the artificial designations of MSI, LSI, and VLSI to the availability of both commercial LSI and custom VLSI with thousands of components per chip, some of the earlier-designed hybrids have been replaced. However, hybrids have also

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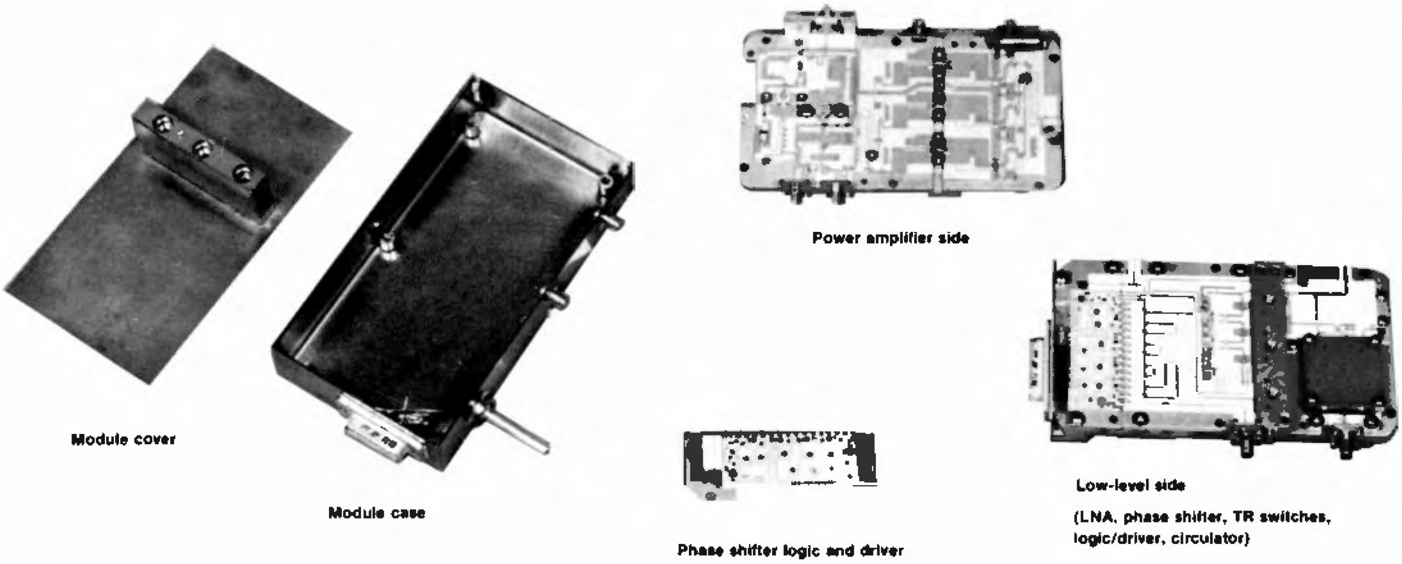

Fig. 1
Microwave assembly is made with thin-film sputtering, has connections of thermocompression gold ribbon.

progressed to higher complexity and larger sizes. The hybrid is an ideal mounting and interconnection mechanism for the larger custom/LSI chips using single-diffusion technology. The hybrid also has significant advantages when the requirements are:

- Very-high-frequency operation;
- Adjustment of circuit parameters in production;
- Very high or low power;
- Combination of monolithic types; and
- Combination of monolithics and passive elements.

Hybrid status at MSR

Hybrids can be made using either thick-film or thin-film technology.

The basic thick-film process in current use at Moorestown uses rf-sputtered thin-film molybdenum on a 99.5%-alumina substrate, with an overlayer of sputtered gold that is then electroplated with gold to an 0.4-mil metal thickness. A photoresist is applied and developed with the desired artwork patterns and the metal is etched to the substrate, leaving conductor where desired. This process provides excellent control of materials and dimensions for single-layer microwave circuits. It has the advantage of direct use of artwork on the substrate without an intermediate screen, as required for thick film, and thereby provides fast turnaround for engineering small quantities of circuits.

Both engineering and production sputtering equipments are installed at Moorestown. Although many substances can be deposited by sputtering, we have selected the moly-gold materials set to provide optimum characteristics of adhesion, bondability, and conductance for microwave circuits. Substrate-to-component connections and connections between substrates are made by thermocompression gold wire or ribbon welding. Fig. 1 shows a typical microwave assembly made by this process.

The basic thick-film substrate processes have not changed, although advances in design techniques, materials, and machinery have contributed to an order-of-magnitude increase in complexity and size.

Combining thick- and thin-film processes on the same substrate provides the advantages of each. For example, the wide range of resistor values and high power capability of thick-film inks combined with the high accuracy of thin-film conductors provides an improved means of constructing microwave and high-speed digital circuits.

Design automation aids hybrid design and production.

The practical implementation of very large and complex hybrids has been aided significantly by the design automation facilities and programs for hybrid designs[1,2] that use the CUTTER and AUTODRAFT programs developed at Moorestown. When experienced people use these facilities and programs, it is possible to cut design time by a factor of three. Also, the design review, manufacturing review, and modifications, plus accurate artwork, assembly drawings, and documentation can all be done from a single data base.

Examples of hybrid circuits

Very-high-speed circuits are possible with hybrids.

High-frequency digital circuit tests using microwave design techniques have compared packaged components on printed circuit boards with unpackaged components mounted and connected by thick-film hybrids. The typical maximum clocking speed for the hybrid in a pseudo-random code logic configuration was 800 MHz, whereas the printed-circuit board configuration was inoperable above 500 MHz. This has made it practical to deliver equipment capable of performing logical functions at 640 MHz. The thick-film hybrid shown in Fig. 2a operates at 640 MHz with good tolerance to variations of power supply and drive levels. It is constructed of micro-strip conductors between the top and bottom of the substrate, with gold ribbon bonding through laser-drilled holes in the substrate to make short ground

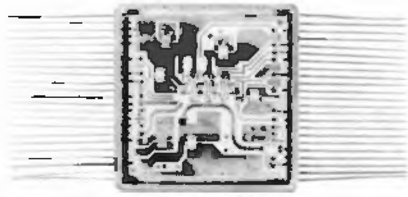

Fig. 2a
Higher-frequency digital operation is possible with hybrid circuits than with packaged components on pc boards. Thick-film hybrid here is capable of 640-MHz operation. Package is 1.25" square.

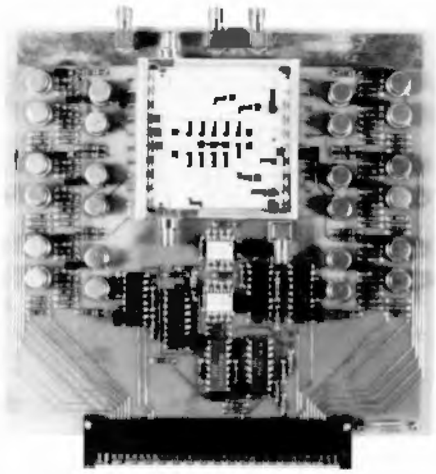

Fig. 2b
Companion delay-line hybrid to the one in Fig. 2a uses both thick- and thin-film technology. Board is roughly 6½" square.

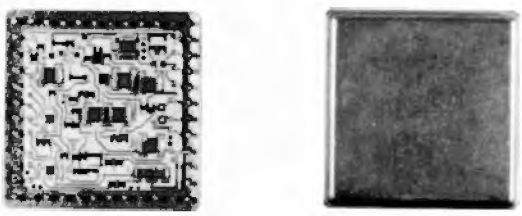

Fig. 3
"Hot-trimmed" video amplifier has its circuit characteristics adjusted while it is operating and undergoing test. This method gives performance characteristics that could not be obtained otherwise. Substrate is 1.25" square.

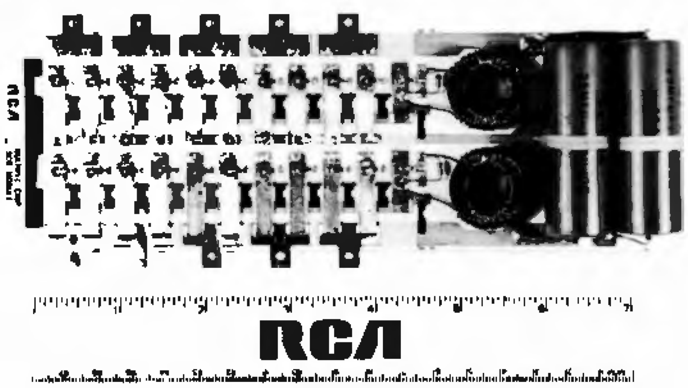

Fig. 4
Largest single-substrate hybrid produced at Moorestown, this 8-by-3-inch modulator circuit can accommodate 1000 V at 500 A.

connections from bottom to top. Two-layer gold thick-film conductors plus resistors and insulators are on top, and a thick-film ground is on the bottom.

Fig. 2b illustrates a companion hybrid, which is a 6-bit electrically-controlled delay line constructed with both thick-film resistors and conductors and alternatively with thick-film resistors and thin-film conductors, with no discernible difference in performance. Delays of 25 to 1675 picoseconds of the 640-MHz digital pulse train are provided by PIN-diode switching within the 2"×2" module.[3]

"Hot trimming" improves analog circuits.

The video amplifier[4] shown in Fig. 3 is an example of a circuit set that is adjusted in production by "hot trimming" to match characteristics from circuit to circuit. It has provided improved gain tracking, dynamic range, bandwidth and temperature sensitivity, none of which could be achieved by other construction techniques.

High-power hybrid circuits are possible.

High-power microwave circuits and high-power modulator circuits have been and are being produced at Moorestown. The high-power modulator circuit shown in Fig. 4 is the largest single-substrate hybrid produced at Moorestown; it measures 8"×3". Capable of switching 500 A at 1000 V, its calculated dissipation is 750 W. The unit is fabricated with thick-film conductors and resistors on an 0.1" beryllia substrate and can be either air- or liquid-cooled.[5] The 22 active devices are SCRs.

Module families standarize product lines, improve reliability, and lower cost.

The MSR main product line of high-performance tracking radars has required large numbers of active components. Over the past twenty years, a remarkable improvement in component packaging density has been made, by a factor of 2000 to 1, in progressing from vacuum tubes to discrete solid-state devices to integrated circuits. Simultaneously, performance requirements have increased so that the number of integrated circuits now contained in a modern phased-array radar (AN-SPY-1) has reached 50,000. In order to reduce cost and increase productivity and reliability, MSR has developed standard modules that can be used within a product and from product to product. The standard module families include comprehensive circuit rules, including wiring rules from module to backplane to rack.

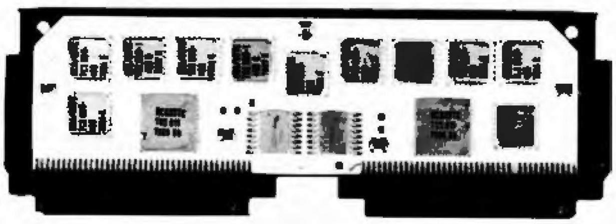

Fig. 5a
Leadless hermetic packages (LHPs) used on this hybrid make 100% automated testing possible. High yields are possible because individual LHPs can be fully tested before assembly. Standard plug-in module shown measures 1.4 by 5 inches.

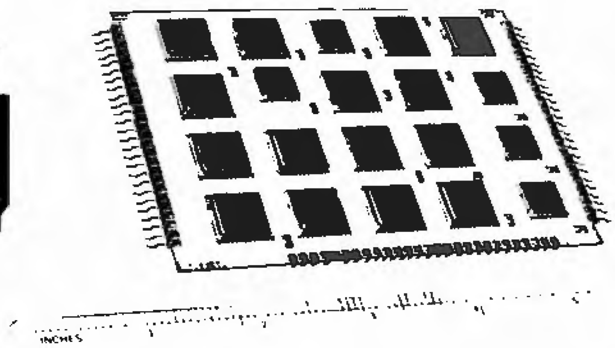

Fig. 5b
Forty active chips are on this complex hybrid, which measures 3 by 4 inches. LHPs make such complex substrates possible.

Complex high-yield hybrids

With the introduction of higher-speed circuits and LSI in standard dual-in-line and flat packs, it became evident that the area occupied by the hermetic package was the limiting factor in achieving packaging density and speed. Although hybrid packaging with uncased components would provide full performance and density advantages, the size of the hybrids was limited by yield.

Low yields were basically caused by the inability of assuring complete performance capabilities of chips before assembly and the cost of repairing large hermetic packages. Three major requirements must be met for producing complex high-yield hybrids:

1) 100% burn-in and test of semiconductors
2) 100% test of substrates
3) Simultaneous assembly of components to substrate.

All three of these advances have been made practical by assembling components in ceramic leadless hermetic packages (LHPs), in which active components are mounted, sealed, burned in, screened, and tested, thereby providing performance assurance before assembly. Multiple LHPs are mounted to multiple-layer thick-film substrates by simultaneous reflow soldering, which subjects components to minimum temperature-time stresses and provides excellent mechanical, thermal, and electrical connection to the substrate. Since mounting pads are constrained to the fixed dimensions of the LHP, it is cost-effective to implement fixtures to contact all mounting/interconnection pads on the substrate. These pads are spaced to accommodate individual "Pogopin" fixtures, which can provide interconnections for 100%-automated conductor-continuity and short-circuit tests before assembly with active devices.

By combining 100% component test, 100% substrate test, and simultaneous assembly, it has been possible to achieve 95% yield at initial assembly of production hybrids, even when using dozens of very complex LSI chips.

Assuming some devices will fail during assembly or in use, the ceramic substrate, with its multiplicity of small LHPs, offers advantages in fault isolation and repair over large hermetic packages. All pads are available at the junction between LHP and substrate, and each LHP can be individually heated and removed, then replaced by resoldering.

This technology has been used to design and build a set of standard plug-in modules with substrates measuring 1.4"×5" (Fig. 5a). It also leads to successful implementations of very complex hybrids, such as the 3"×4" unit shown in Fig. 5b, which contains 40 active chips of many types of LSI.

The future for hybrids

Printed circuit boards may eventually be replaced.

The basic hybrid technology has matured to a firm standing in providing performance and packaging-density advantages that can be achieved in no other way. In many cases, cost advantages are also shown as indicated by the availability of many commercially available assemblies in hybrid form. Substantial improvements in materials, processes, and machinery are being implemented in the industry. Among the most notable are the introduction of fine-line non-noble metal systems and automated equipment, both of which will further reduce cost, improve yield, and increase the maximum area available to the hybrid designer. With concurrent advances in the semiconductor art to larger chips, it should become practical to produce complete functional systems economically on hybrid substrates and replace printed circuit boards in many applications.

Automated testing and assembly will make hybrids more economical.

The availability of hermetically sealed chips on film that can be tested and screened before assembly to the substrate promises to provide high assembly yield and long life without hermetic package sealing. Also, enhancement of design automation programs with direct interfaces to numerically controlled assembly and test machinery will improve system economics and increase the economic use of hybrid techniques.

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2. Ramondetta, P.W., and Smiley, J.W.; "Design automation for complex CMOS/SOS LSI hybrid substrates," *RCA Engineer*, Vol. 22, No. 1 (Jun/Jul 1976) p. 35.
3. Designed by D.D. Freedman.
4. Designed by D.J. Demsey and E.L. Henderson.
5. Designed by D. Pruitt.

Hybrids—a look at the total cost

B.T. Joyce

Size, weight, performance, volume—these have been the traditional hybrid microcircuit driving requirements. But hybrids can also be cost savers, even in low volume applications, if total system cost is the basis.

The AN/USM-410 Automatic Test System provides an interesting opportunity to make cost comparisons between hardware produced using conventional discrete parts and hardware produced using equivalent hybrid microcircuit packages. Actual equipment has been built both ways so that historical data and factory cost estimates were available to make such comparisons on a total-build basis.

AN/USM-410 Automatic Test System

The AN/USM-410 is a third-generation, computer-controlled automatic test system. Typical of such equipment is the packaging arrangement of consoles and rack-mounted chassis suitable for depot, van, and shelter installations. Size and weight are not generally driving forces to the design.

Hybrid microcircuits found a very important place in this rack-mounted equipment, providing performance improvements. In addition, the hybrids were cost effective, a result primarily from the size reductions in the attendant equipment. There were fewer circuit boards, less chassis, a smaller rack, less labor in putting things together and getting them working—all acting to offset the higher initial cost of completed hybrids compared with the piece parts they replace. The reasons for using hybrids in the test system in the first place are presented in the remaining part of this paper along with the results of some cost comparisons of the discrete-part circuits and the substituted hybrid microcircuits.

A major problem that has plagued automatic test systems for years has been the interface between the tester and the unit-under-test (UUT). Whenever a test system serves a variety of different UUTs, special adapter cables and test-adapter boxes would proliferate. Such interface hardware makes the unique interconnections to the UUT and augments the test system with special loads and interface circuits. The procurement, logistics support, and change control of such adapters for fielded UUTs become very cumbersome and a major expense to the user. In the AN/USM-410 Automatic Test System, RCA introduced a Programmable Interface Unit as a viable solution to this problem. The Programmable Interface Unit (Fig. 1) provides 128 identical universal-test-point circuits, each of which can, under program control, be connected to a UUT interface line for measurement purposes or for excitation from a selected dc, ac, or pulse stimulus. The number of universal test points that can be provided in a given system is flexible because of the modular construction of the unit. Fig. 2 shows one of the dual-universal-test-point boards used in the Programmable Interface Unit.

Even though the Programmable Interface Unit simplifies interface adapters and eases test programming and test

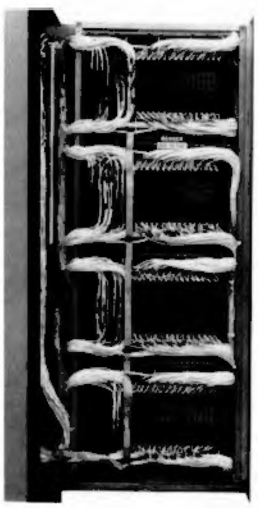

Fig. 1
Programmable interface unit replaces the myriad special adapters and cables of previous systems by placing universal test points under program control.

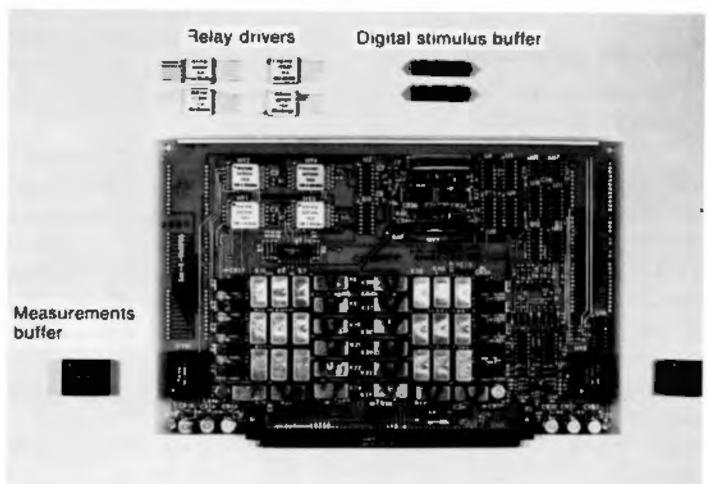

Fig. 2
Dual-universal-test-point board. Sixty-four such boards are used in the programmable interface unit. The hybrid microcircuits used on this board are arranged around the periphery of the board.

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Final manuscript received August 5, 1976.

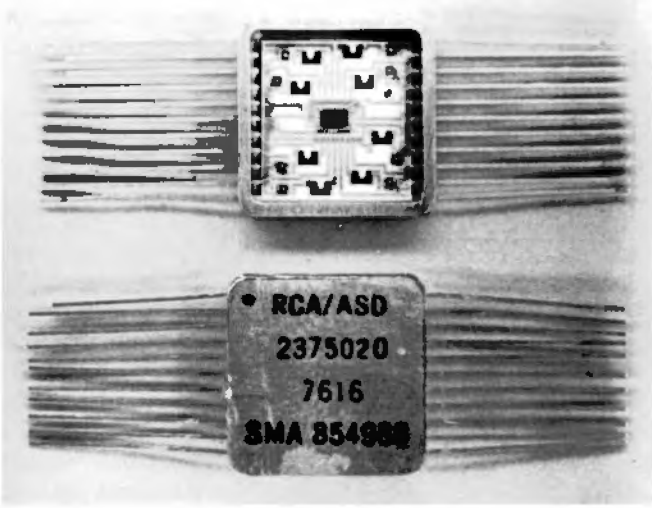

Fig. 3
8-channel, latching relay driver was the first circuit to be partitioned for hybridizing because it could be used on other boards of the main test system as well as on the universal test point board. A relatively uncomplicated hybrid, the circuit involves a dual, quad-latch integrated circuit, eight chip transistors and eight identical resistors. The thick-film substrate is solder mounted with gold-germanium in a 22-lead flat pack. The package is hermetically sealed with gold-tin solder. Substrates are printed on a multiple-image plate, sixteen circuits at a time. The circuit itself provides eight latched outputs, each of which can sink up to 100 mA of load current to ground.

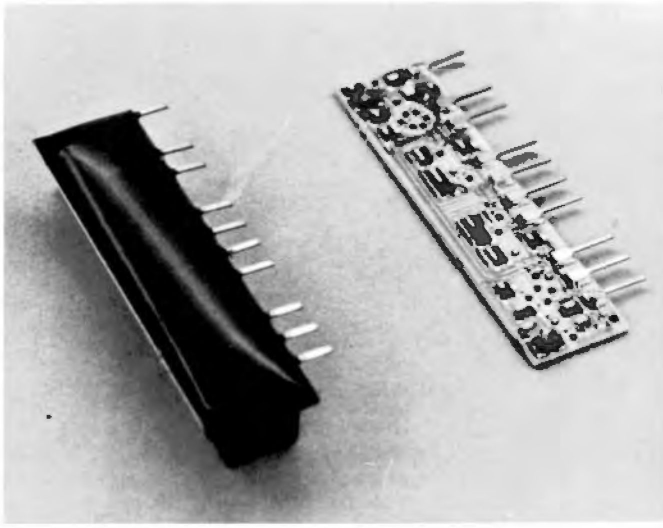

Fig. 4
Digital stimulus buffer hybrid is made up of 10 beam-lead diodes, 12 beam-lead transistors, 2 chip capacitors and 18 thick-film resistors. The package has leads for edge-type connection to a PC board. The conformally-coated circuit is provided with a heat sink to permit power dissipation of 2 W under maximum specified load conditions. In the test system, the digital stimulus/buffer is used to drive a unit-under-test with signals whose *high* and *low* voltage levels are programmable over a range of -20 V to + 20 V. The pulse width and pulse repetition rate are also controllable from programmable switching signals.

program maintenance, the unit itself is clearly complex and represents an increase in the cost to the test system hardware. Thus, the designers had to drive these costs down. Furthermore, the unit presented potential technical problems because of possible large physical size. Conventional discrete-circuit packaging methods would lead to a physically large unit that would be more susceptible to system noise problems and performance degradation from line capacitance and resistance. The designers were motivated, therefore, to use hybrids to reduce the physical size of the unit to manageable levels. Cost/performance tradeoffs studies revealed that despite the low production quantity, three circuits of the universal test point board could be converted to hybrid packages without cost penalty. These circuits are:

1) 8-channel, latching relay driver (Fig. 3).
2) Digital stimulus buffer (Fig. 4).
3) Measurements buffer (Fig. 5).

Hybrids vs discretes—cost comparison

The case for using hybrids has often been lost in the past by a superficial comparison of so-called parts costs. Fig. 6 dramatizes how such comparisons of "parts" costs can be misleading. Here the cost of each AN/USM-410 hybrid microcircuit, treated as a purchased part, is compared with the cost of the discrete piece-parts it replaces. The costs shown here, and at all other places in this paper, have been adjusted to reflect a factory-sell level appropriate to deliverable equipment. Note that, in the simple comparison of parts costs, these particular hybrids run from two times to three times more expensive than the piece-part equivalents.

Clearly, the cost study must penetrate beyond the basic costs of parts.

The hybrid, indeed, is more expensive than the piece parts it replaces simply because of the labor content added to produce a completely functioning circuit. Permitting objective cost comparisons, the AN/USM-410 provides two good baseline configurations of printed circuit boards, one associated exclusively with the relay driver circuit function

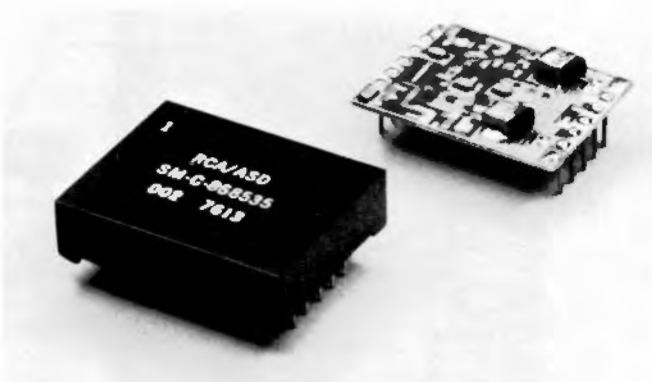

Fig. 5
Measurements buffer hybrid is a high-performance, unity-gain video amplifier used from dc to 10 MHz as a buffer between input signals from a unit-under-test and the measurements electronics of the test system. The hybrid packaging uses chip-and-wire construction. Chips are protected by encapsulation from the relatively benign environment seen by this class of equipment. In the manufacture of this hybrid, functional trimming techniques are used to optimize the gain and frequency response of the circuit.

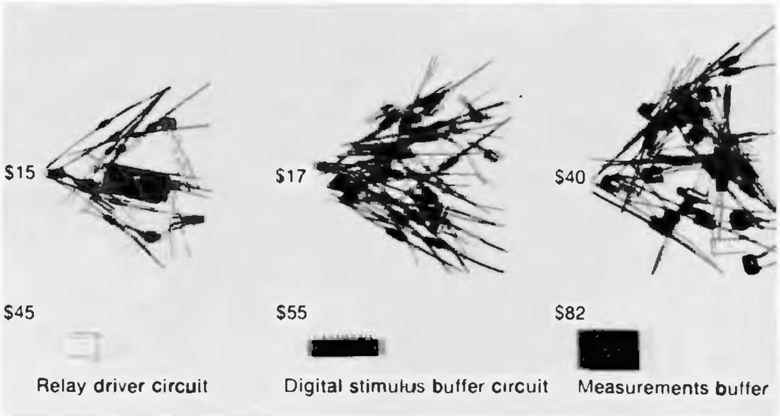

Fig. 6
Comparison of parts cost (hybrid vs. discrete) can be very misleading, mainly because the labor content involved in assembling the discretes has been ignored.

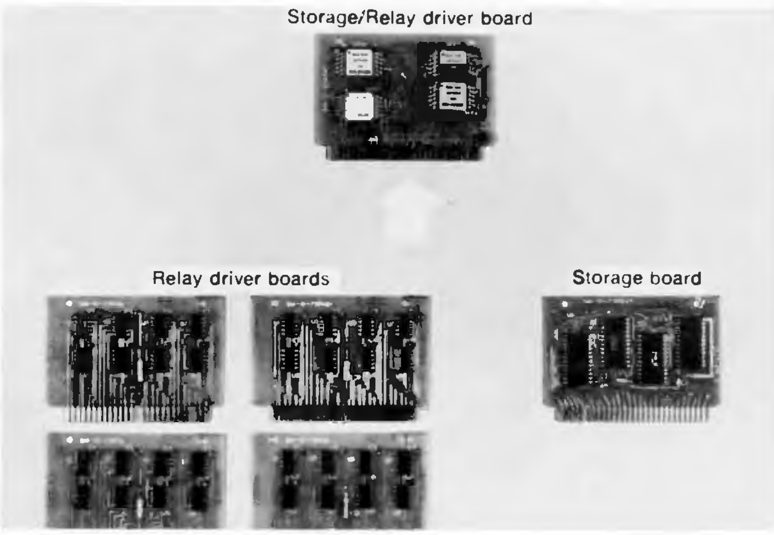

Fig. 7
Hardware reduction from the use of a hybrid relay driver with obvious savings in board fabrication, assembly, and test

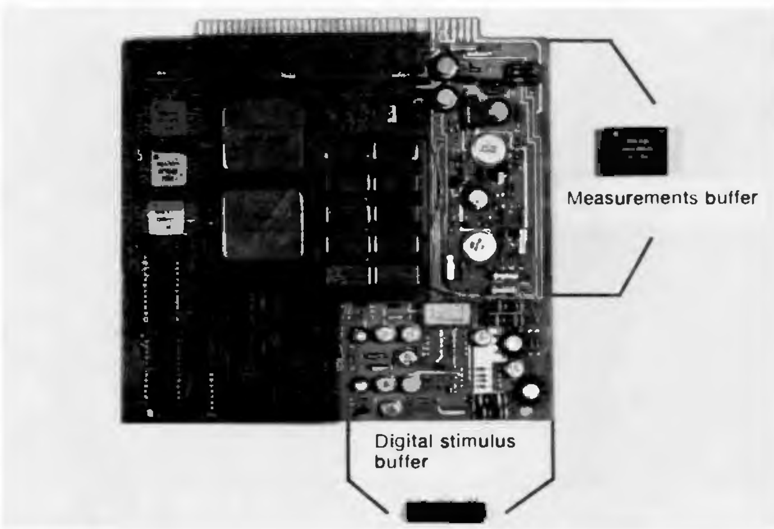

Fig. 8
Universal test point board (early version) shows another dramatic hardware (thus cost) reduction.

and the other associated primarily with the digital stimulus buffer and measurements buffer circuits. Fig. 7 shows the evolution of a combination of four 8-channel, latching relay driver circuits first configured with discrete parts (integrated monolithic circuits) spread out on four identical relay driver boards and one storage board. The hybrid packaging allowed these five boards to be replaced functionally by one board with obvious cost savings in board fabrication, assembly, and test. Similarly, the Automatic Test System has provided an opportunity to get a thorough comparison of costs for the two versions of the digital stimulus buffer and the measurements buffer. Fig. 8 shows an earlier circuit board configuration of a single universal test point for the programmable interface unit. Unlike the dual universal test point board shown in Fig. 2, this board used discrete parts to implement the functions of the two buffer circuits. But again, the two different arrangements provide good sources for cost comparisons.

The basic elements of recurring cost must be reviewed for an objective comparison of the cost of each circuit function in discrete form and in hybrid form. These recurring costs are:

- Electrical material (parts)
- Printed-circuit-board fabrication
- Assembly labor of PC board
- Test labor of PC board
- Labor and material associated with next level of assembly
- Manufacturing engineering and support labor

There are, of course, non-recurring costs that can be considered but will not be included in any detail in this paper. In general, most of the differences in non-recurring costs for the subject hybrids and their discrete-part equivalents were associated with the design layouts. The hybrid microcircuit layouts were indeed more difficult to perform and ranged in cost between $1500 and $4000 apiece.

Results of cost comparison: each hybrid microcircuit comes out looking better than the discrete parts it replaced.

Table I summarizes each element of cost allocated to the hybrid version and the discrete-part version of each of the three circuits. The table is divided into three groups of two colums each—one group for each of the circuit functions. Starting with the cost of the basic parts and treating the hybrid itself as a finished part, costs are compared for each major element.

After "basic parts" costs, the next element of cost examined is that for "PC-board fabrication." Here, actual (unpopulated) board costs for the finished products in both discrete and hybrid form were compared. Thus, in the case of the relay driver, the total cost for the five boards using discrete parts (see Fig. 7) was divided by four to allocate $36

Table I
Cost comparison of discrete vs hybrid circuits. The costs are based on circuit functions in quantities of 500 to 1000. The costs (at factory sell) are rounded-off to the nearest dollar.

	Costs per circuit function					
	Relay driver		*Digital stimulus buffer*		*Measurements buffer*	
	DIS	HYB	DIS	HYB	DIS	HYB
Basic parts (material)	$15	$45	$17	$55	$40	$82
PC-board fabrication	36	7	16	1	19	2
Assembly to PC board	15	2	17	1	16	1
Circuit test	1	—	2	—	2	—
Chassis mat'l/ass'y	12	7	12	7	12	7
Mfg. eng'g & support	6	1	9	1	10	1
Total costs	$85	$62	$73	$65	$99	$93
Relative costs	100%	93%	100%	89%	100%	94%

DIS: circuit using discrete parts
HYB: circuit using hybrid technology

to the PC-board cost for a single 8-channel relay driver function in discrete form; and the cost of the single board using hybrids was divided by four to allocate $7 to that same function in the hybrid version. Similarly, costs for PC-board fabrication were allocated to the discrete and hybrid circuit functions for the digital stimulus buffer and the measurements buffer making use of cost records associated with these boards and taking into account the relative area utilization of the circuits on the boards.

The cost figures shown for "assembly to PC board" are derived simply. The large differences here are a fundamental result of the substantially different number of parts being handled for the discrete versions compared with the hybrid versions. Although the dollars associated with PC-board "circuit test" are small compared with other cost elements, a parenthetical note is worth making. The discrete-part versions of the circuit functions in general are still very much subject to failure at board test and costly diagnostic testing and rework must follow with potential degradation of an entire board. The cost for comparable testing, malfunction finding, and rework in the hybrid microcircuit is already built into the so-called piece-part cost of the completed hybrid.

The next cost element, "chassis mat'l/ass'y," is concerned with carrying the circuit function costs to the next level of assembly. Thus, if the number of boards in a system is reduced, so too are the number of connectors that have to be assembled and wired in a chassis and the number (or size) of chassis and racks to handle the boards for a given system-level complement of circuit functions. For the universal-test-point configuration of the AN/USM-410 Test System, a half-rack of hardware with hybrids does the same job that two half-racks of hardware do with discrete parts. Thus, costs for the two versions, apportioned to single circuit functions, are shown.

Brad Joyce has been directly involved with the product design and application of hybrid microcircuits since 1971. He has previous experience as a design manager for signal processing electronics, digital computers, and automatic test equipment.

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The last cost element, "mfg eng'g & support," compares the support costs per circuit function for manufacturing methods engineers, test methods engineers, and material control people.

The last line provides the total factory costs in the manufactured equipment for each of the three circuit functions. Each hybrid microcircuit comes out looking better than the discrete parts it replaced.

Conclusions

Hybrid microcircuit packaging has long answered a need where size, weight, and performance have been driving requirements. Hybrids may now seriously be considered as cost effective even in relatively low production quantities if the total costs of manufacture in the end-item equipment are accounted for and, in particular, if the beneficial effects of miniaturization are recognized.

Acknowledgments

I want to give special recognition to the engineers who designed the electrical circuits for the hybrids so successfully used in the AN/USM-410; to B.A. Bendel for the 8-channel Latching Relay Driver, to R.P. Percoski for the Digital Stimulus Buffer; and to D.F. Dion for the Measurement Buffer. Both Mr. Bendel and Mr. Percoski designed the Programmable Interface Unit with its universal test point approach and performed the initial cost analyses supporting use of hybrids in the AN/USM-410.

PRICE applied

F.R. Freiman

The PRICE model estimates costs accurately and inexpensively; comparable conventional estimates now average 40 to 50 times the cost of a PRICE estimate.

PRICE, or, as *Business Week*[1] called it, "RCA's uncanny system for estimating costs," is a computerized parametric modeling system for estimating hardware development and production costs. It has been under almost continuous development at RCA since about 1962. For the past five or six years it has been used extensively by RCA, and under contract to NASA since 1971 and the Air Force since 1972. PRICE was first offered commercially to industry in August of 1975. By the end of 1976, more than twenty-five major industrial organizations and government agencies had contracted to use PRICE.

Top-down extrapolation approach

As described in detail in the Jun/Jul 1976 issue of the *RCA Engineer*,[2] PRICE was formulated as a universal system to generate cost-estimating relationships for a range of products or systems. In essence, it extrapolates past experience to predict costs. It predicts equipment development and production costs for a wide variety of products, both electronic and mechanical, when provided with proper experience factors and new-product descriptions.

An attractive feature of the PRICE system is the ease and speed with which these cost predictions are obtained. The trained PRICE user gathers data about a proposed product, asking a few simple but cogent questions of the engineers planning the equipment. He enters these data on PRICE input forms, one for each different equipment in the system.

He then accesses the time-shared computer in which the PRICE model resides, using a local terminal connected to the computer by telephone line. Using this real-time terminal, after giving his user password, he enters the PRICE data, line by line, into an input file and instructs the computer to "run PRICE," specifying the output format desired. Within minutes, the terminal prints the output sheet (Fig. 1), giving the development, production, and total costs for each equipment, including the costs of integrating and testing the equipments as a complete system. Provisions are made to rapidly modify or correct any or all of the inputs and just as rapidly see the effects of these changes on costs. Using the method just described, it is possible to thoroughly cost out a multimillion dollar system in as little as two hours.

Since the PRICE model predicts from a "macro-" or top-down, rather than the "micro-" or bottoms-up, parts-cost approach of conventional estimating, it is not as sensitive to missing input data as is the latter. Obviously, the more you know about the physical charactersitics of the end product being considered, and the more basic descriptors you can supply, the more precisely PRICE can predict costs. But because the model uses basic hardware descriptors such as weight, volume,

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                AIRBORNE RADAR  MIL-SPEC  DEC 1,1976

                INPUT DATA
                QTY      200. PROTOS   10.0 WT      45.000 VOL      0.760 MODE      1.
                QTYSYS     1. INTEGE  1.000 INTEGS  1.000 AMULTE 125.000 AMULTM 125.000

                MECH/STRUCT
                WS     10.000 MCPLXS  0.0   PRODS   4.200 NEWST    0.900 DESRPS   2.000

                ELECTRONICS
INPUT           USEVOL  1.000 MCPLXE  0.0   PRODE   4.300 NEWEL    0.000 DESRPE   2.000
DATA            PWR     0.0   CMPNTS     0. CMPID   0.0   PWRFAC   1.000 CMPEFF   1.000

                ENGINEERING
                ENMTHS    6.0 ENMTHP    5.0 ENMTHT    0.0 ECMPLX   1.200 PRNF     0.200

                PRODUCTION
                PRMTHS   25.0 PRMTHF    0.0 LCURVE  0.0   ECNE     0.0   ECNS     0.0

                GLOBAL
                YEAR    1976. ESC     0.300 PROJCT  1.000 DATA     1.000 TLGTST   1.000
                PLATFM  1.000 SYSTEM  1.000 PPROJ   1.000 PDATA    1.000 PTLGTS    1.00

                PROGRAM COST          DEVELOPMENT       PRODUCTION       TOTAL COST
                ENGINEERING
                 DRAFTING                    252.              24.             276.
                 DESIGN                      937.              73.            1010.
                 SYSTEMS                     150.               0.             150.
                 PROJ MGMT                   194.             328.             522.
COST             DATA                         61.              16.              77.
                  SUBTOTAL(ENG)             1594.             441.            2036.

                MANUFACTURING
                 PRODUCTION                    0.            6707.            6707.
                 PROTOTYPE                   734.               0.             734.
                 TOOL-TEST EQ                 97.             199.             296.
                  SUBTOTAL(MFC)              831.            6906.            7737.

                  TOTAL COST                2426.            7347.            9773.

                VOL     0.760 AVCUST   33.54 TOTAL AV PROD COST   36.74 LCURVE   0.097
                WT     45.000 ECNE    0.072 ECNS     0.021 DESRPE 0.494 DESRPS   0.210

CHECK           MECH/STRUCT
VALUES          WS     10.060 WSCF   12.021 MECID   0.0    PRODS  4.200 MCPLXS   5.602
                ELECTRONICS
                WE     35.000 WECF   44.872 CMPID   0.0    PRODE  4.300 MCPLXE   7.903
                PWR   162.399 CMPNTS  4053.                PWRFAC 1.000 CMPEFF   1.000

                SCHEDULES
SCHEDULES       ENMTHS  6.000 ENMTHP 14.074 ENMTHT 24.679 ECMPLX 1.200 PRNF     0.200
                PRMTHS 25.000 PRMTHF 50.229 AVER. PROD RATE PER MONTH           7.927

COST            COST RANGES           DEVELOPMENT       PRODUCTION       TOTAL COST
RANGES                FROM                  2122.            6121.            8242.
                      CENTER                2426.            7347.            9773.
                      TO                    2874.            9162.           12036.
```

Fig. 1
Typical PRICE estimate starts with input data, such as size, weight, and quantity of the system under evaluation (an airborne radar in this example). Outputs include a range of cost estimates and production rate.

technology, percentage of existing designs, and the planned engineering and production schedules, unknown factors can be omitted and the model will calculate them.

When the PRICE model is calibrated with empirical values that represent an organization's way of doing business and their product line, the PRICE estimates become a reflection of the history of that organization and provide an indication of how the organization will perform on the new project under consideration for bidding. Since PRICE can be operated with a minimum of inputs, the manpower required to generate early estimates is significantly reduced. Thus, only a minimum investment need be made prior to the bid/no-bid decision.

PRICE is being used effectively in early configuration trade-off studies. As already mentioned, alternate configurations can be entered and virtually instant economic impact assessments made. Highly sophisticated and costly technical approaches can be quickly identified, and perhaps modified to a cleaner, simpler, and more cost-effective approach.

Although PRICE can be used to advantage throughout the various stages in the evolution of an equipment or system, perhaps its greatest value has only begun to be appreciated. Because of its universality and the way it handles the effects of both technology and economic changes, PRICE has been able to predict the future costs for a proposed system or product. Because of the rigor of its algorithms and structure, it has proven many times to be more accurate in forecasting a system's costs than the technologists who have proposed or evolved the new system.

Decisions to invest in a new product depend not only on market forecasts of consumer demand, but also hinge upon the profitable selling price of that new product. That depends upon development, design, and production costs—the investment an organization must make to bring the product to the market. Industrial history is replete with examples of mistakes made as a result of poor cost predictions based on intuitive and conventional methods. Mistakes can be made in both directions. Underestimating costs can lead to resource-draining expenditures in bringing the product to market, and manufacturing costs that preclude a marketable price. On the other hand, many products have been left undeveloped or postponed because of inflated cost estimates, only to be scooped later by the competition.

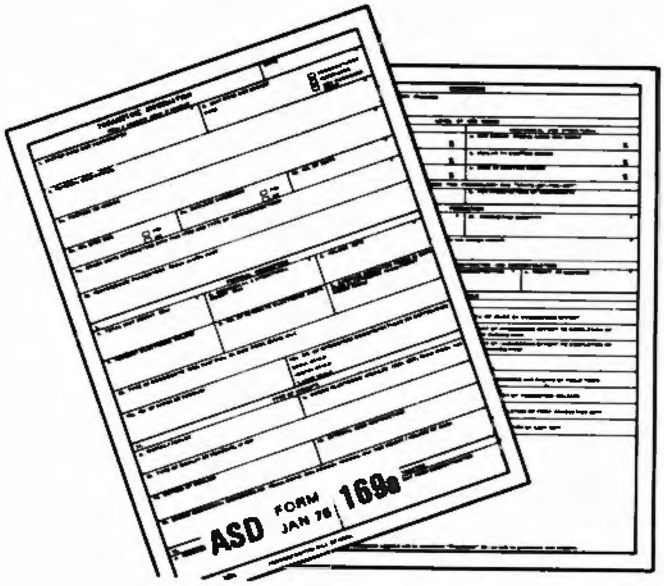

Fig. 2
PRICE is an input for source selection at some government agencies; Air Force Form ASD-169 is one example.

Where to use PRICE

The universality of the PRICE model and its adaptability to the ideosyncracies of various organizations have led to its widespread acceptance. Applications through the entire sequence of a product's history are described below.

The single most profitable time to use PRICE is during the concept stage of a program.

Using PRICE here allows meaningful decisions to be made before configurations are frozen. Many users are applying PRICE during the concept period to trade off configurations and schedules, and in general to assist in establishing a basic program concept that they will propose to their customers. Many PRICE customers are using PRICE to assist them in making bid/no-bid decisions.

Another common application is to establish cost targets at the proposal stage for bottoms-up estimating.

PRICE not only will provide an estimate of overall system costs, but also will provide a breakdown of the costs for the constituent equipments in that system. Done early enough in the proposal cycle, this breakdown will provide planning budgets to the specialty design groups.

The most obvious use of PRICE is to review the finished proposal pricing before it is sent to the customer.

Several years ago, Irving K. Kessler, RCA Group Vice President, mandated that all proposals to the government in excess of $1 million be run through PRICE to check the reasonableness of the proposed costs to the customer. When the PRICE output differs significantly from the detailed estimate, there must be a valid reason, since PRICE follows the organization's experience trend.

Some government agencies use PRICE as one of their many tools in the source-selection process. Indeed, the Air Force often requests that data for direct input to PRICE be submitted with proposals, on Form ASD-169 (Fig. 2). The use of PRICE in the source-selection process should not be limited to government source selection of contractors, for it is also an applicable tool in selecting subcontractors.

PRICE can also be used to establish Work Breakdown Structure (WBS) budgets after the job is won.

If PRICE was used properly in the proposal stage, a good start has already been made in allocating funding via the WBS.

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Because of its methodology, PRICE can be applied anywhere along the product development cycle.

It will predict future costs whether it is used at the start of a program or part way through. If an accurate definition of the work yet to be done can be made, PRICE will create an estimate to complete a project far more accurately than that obtained by subtracting the amount of money spent from the original estimate.

What some users are doing

A major west coast aerospace company has set up a central PRICE activity that coordinates seven different locations and sixteen trained PRICE users. They use PRICE in all phases of a program. Their electronics division uses PRICE as the principal ingredient of their bid/no-bid decisions. Additionally, all budgetary estimates going to corporate headquarters for review and approval are supplied on the basis of PRICE outputs, with no other supporting documentation provided.

Frank Freiman, as Director, PRICE Systems, is responsible for developing and using parametric modeling systems for engineering and management planning and decision-making purposes. He invented the PRICE methodology described here. His latest invention is the PRICE software model, a universal parametric model that predicts costs for design of an extended variety of computer programs.

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At RCA Automated Systems in Burlington, the STE/ICE (automated engine testing) program equipment was processed through PRICE very early in a design-to-cost program. Prototype hardware parameters and production schedules were input to PRICE to provide a comparison with the very challenging design-to-cost goal. Estimates of the hardware parameters expected to result from the planned design approach were also input at that time. The design team then got under way with confidence based on PRICE results that the goal of reducing production cost by one-half was achievable and that the planned design approach would yield the required cost reduction. During the system design phase, PRICE was employed to check vendor estimates for a critical subassembly as well as to characterize the design parameters of this subassembly when configured to meet the assigned cost target. The current estimate (1977) of both the STE/ICE system production cost and the cost of the purchased subassembly remain well below the established cost targets.

Another major west coast aerospace facility has a senior scientist who routinely evaluates every program in the concept stage and helps scientists and engineers make early trade-off studies in both hardware and schedules. He is functioning virtually as a one-man design review team, devoting all of his time to early-concept evaluations.

He made a recent study on two airborne digital processor assemblies. The existing processor design primarily uses integrated circuits. The engineering department felt that the production cost could be reduced if both assemblies were redesigned, to be functionally the same, but using LSI. Management imposed the constraint that the redesigned LSI version of the processor must cost 20% less in production than the present model; otherwise, it would not be cost-effective to bother with the redesign. This figure, with the quantities involved, would determine the breakeven point to recover the cost of redesign.

Both assemblies were entered into the PRICE design-to-cost mode, the target cost established for each assembly set at a value 20% lower than its present integrated-circuit version's cost, and the PRICE model was run. The output of the PRICE model in the design-to-cost mode is the design geometry required to meet the specified target average unit cost in production. Moreover, the estimated cost of the engineering redesign program is contained in the PRICE outputs being used for the decision. Using this, the reasonableness of the 20% breakdown point could also be verified.

In the case of the first assembly, engineering judged that they would be able to meet the indicated specifications. In the case of the second assembly, they decided that the requirements were, at this time, too severe. The decisions were made: Assembly No. 1—proceed with the redesign; Assembly No. 2—do not proceed with the redesign.

An east coast space operation recently used PRICE to measure the reasonableness of bottoms-up estimating on a major satellite proposal. They did that by running the ECIRP (PRICE spelled backwards) procedure on some recent satellites. ECIRP is a procedure that allows the derivation of empirical factors such as electronic and structural complexity from product history. The derived empirical factors were used as inputs to PRICE, giving a high degree of confidence that the established cost targets for the new project were empirically credible. The same operation also uses PRICE routinely for budgetary estimates and applies it on a regular basis to check out subcontractor cost proposals.

How can an RCA engineer use PRICE?

Engineers who plan new products or systems must be concerned with the economics of the development and production costs.

Configuring a new project with an unrewarding result is not good business. It also does not pay to produce a system whose cost exceeds that of other devices with equivalent performance. Moreover, a new product usually has many alternative design arrangements involving varying technologies, a mix of purchased items, or advancing the state of the art. Each variation will have an associated cost picture. Therefore, knowing the economics of each approach is important in determining the best technological direction to take.

An engineer can also use PRICE to determine the time needed to develop and design, as well as produce, the new systems. PRICE provides outputs that are credible indications of the times required. With this knowledge, an engineer can more wisely select the technology scheme or concept that is most economically feasible.

PRICE has its limits.

It requires the ability to estimate the weight and size of the design being considered. PRICE's philosophy is that the physical make-up of the equipment required to make a system perform generates its cost, rather than the performance itself. For example, one can design and build a computer using tubes, but it would require many racks of equipment with their inherent cost. The same computer requirements can be met by a design using an LSI technology. This advanced computer would be smaller and probably outperform the tube system, and moreover would be far more economical.

The average cost of processing a PRICE study to complete a "black box" is about $50. This includes the engineer's preparation and PRICE Systems costs. There are procedures within PRICE that will render production and development costs with minimal ancillary output information, which would reduce the cost to about $20 per "black box." Conventional estimates to the same level of detail now average 40 to 50 times the cost of using PRICE.

Getting aboard PRICE.

To get started with PRICE, a contract must be given to RCA PRICE Systems for a year's use of the model. One unlimited access to the model for one year's use will cost $30,000. In addition, there is a computer charge, which averages about $5 per study. To use the model, an engineer must be trained. This involves a two-week PRICE course given at Moorestown or Hollywood every month. Fig. 3 shows a typical PRICE class. After successfully completing the course, the engineer user is given the privilege of exercising the model. The two-week course is an intensive "hands-on" program, in addition to a thorough education in the computing procedures of the PRICE model. Trainees are instructed to correctly determine and prepare input information. Specialized instruction is given toward identifying and correcting erratic, distorted, or otherwise impossible descriptive information. There are many data checks built into the model that limit the processing of faulty parametric inputs.

More detailed information regarding the character of the model, its processing, and variable operating procedures is available through the PRICE Operations group in Moorestown.

Fig. 3
Learning to use PRICE: Two-week "hands-on" courses on using the PRICE model are given each month.

PRICE stands the test.

On face value, the PRICE model appears to be an overwhelming and impossible tool. Because of the claims made for PRICE, it initially generated more skepticism than positive response. To establish the model's credibility and confirm the claims that are made for it, interested engineers would have to test the model. This procedure involves inputting descriptive information about a concept that has been developed and produced. Based on the limited input data, the model will generate a "predicted" cost. The calculated costs can be compared to the actual expenditures. If they agree reasonably, the test has confirmed the model's predictability and claims of its capabilities.

This testing procedure is possible because there is a PRICE procedure that causes its mathematical regressions to revert to the economic and technological conditions of any past point in time to 1946. For example, if 1965 is used as an input, the user can enter design information that was known in 1965 and the model will process it from that point. Literally hundreds of such tests performed over the last five years have proved the claims made for PRICE. Virtually every PRICE customer has tested the model in this manner to assure that the PRICE method is appropriate to his products and organizational procedures.

Conclusion— PRICE is right

From the applications described, the advantages of using PRICE are manifest. Its universal applicability, its varied modes, and the speed with which its estimates are obtained, combined with the cost savings over conventional estimating, make PRICE invaluable as a management tool. Indeed, as confidence in PRICE grows within an organization, conventional cost estimating may be used less and less frequently. Readers within the RCA engineering community will recognize the advantage obtained by competitors who use PRICE, and will want to use one of the many RCA personnel who are trained in PRICE to assist in costing their proposals.

The PRICE system is being continually updated and improved by the RCA PRICE staff, and tested by both customers and staff. New models are under development to cover life-cycle cost and software estimating. As these and other improvements go "on line," PRICE becomes increasingly valuable to users and to RCA as an expanding "product line."

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Economic modeling: how Solid State Division predicts business trends

L.O. Brown

The Solid State Division is using several economic forecasting models to predict business turns, positive and negative, that affect near-term operations and profitability.

Four factors characterize the solid state industry:
- Extreme volatility to economic swings.
- Rapid technological advancement.
- Proliferation of applications.
- Changing customer requirements.
- Continued price erosion despite inflation.

Under these conditions, successful performance cannot be based on "gut feeling" entrepreneurship alone. The solid-state supplier must also have a good insight into the immediate marketplace and reasonable forecasts of both the micro and the macro spheres of the economy.

In the past, as part of the planning process, Solid State Division has tracked trends in end-equipment development and production and has qualitatively assessed the effects of changes in the macro economy on sales and operations. Lacking, however, were the tools and methods required to allow quantitative analysis of such change, so that realistic long range plans could be produced and undesirable bottom-line impacts minimized.

Following the sharp business decline in the third quarter of 1974, the Solid State Division embarked on a program to select and develop improved methods of economic tracking and modeling to fulfill these needs. This program was aimed at defining indicators that would forecast the probability of turns in business, both positive and negative, that would affect near-term (one to six quarters) operations and profitability. Through this program, it was hoped that pending economic change could be identified in sufficient time to develop and activate contigency plans.

From the myriad concepts explored to date, a handful have emerged that appear to fulfill the objectives of the project. In retrospect, if such concepts were available eight years ago, they would have provided a nine to twelve month "early warning" of both the 1970 and 1974 downturns and would have signaled the end of recession and return to a more normal business state three to six months earlier. Thus, in both recession and recovery, sufficient warning could be provided to allow retrenchment or expansion to meet future conditions and minimize the "bottom-line trauma."

In this paper, some of the concepts and methods of economic modeling currently being used by the divison are briefly examined as to: the insights they may provide into the nature of the business under study, their value as leading indicators of change, and their capabilities of producing realistic near-term forecasts of sales. Mathematical details of the techniques used are not given in the paper, but can be furnished to others who may need similar programs to supplement their planning.

Consumption/inventory model

The consumption of components (semiconductors) in sales of end-use equipment was one of the first models investigated and developed. The value of such a consumption model to a component manufacturer supplying parts to the end-equipment industry could be threefold:

- When compared with component shipments, it can show component inventory status at the end-equipment manufacturers' level, and signal turns in component sales when large inventory accumulations are evident (downturns) or when previously accumulated inventories are being eliminated (upturns).
- When compared to new orders and the total orderboard, it can provide insight into the "reality" of the orderboard and indicate the possibility of "double ordering" (because of product scarcity) by the user industries.
- Through a correlation of the component inventory status with general economic trends, changes in an equipment manufacturer's policy regarding inventory turnovers may be identified and the effect of such policy changes on near-term component sales can be anticipated.

In developing the consumption model, an "input/output" coefficient is developed for the specific component under consideration. This coefficient represents the value of the component in the "average" end-equipment unit. The I/O coefficient is then multiplied by the value of the shipments

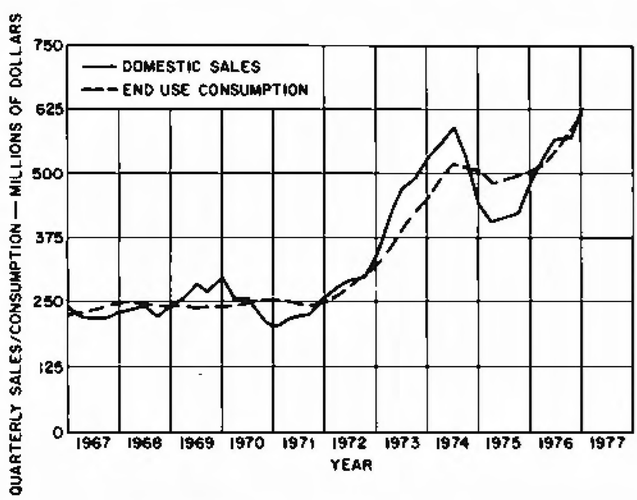

Fig. 1
Consumption vs sales for solid-state components. The difference between estimated end use of semiconductor devices and solid state domestic sales shows change in inventory.

of end-equipment to obtain the consumption of the component under study.

Results of the procedure, as applied to the domestic sale of semiconductors, are shown in Fig. 1. In this figure, the estimated domestic consumption of semiconductors (semiconductor use in end-equipment shipments) is compared with semiconductor sales to the equipment manufacturers. The change in inventory in any given quarter will, of course, be the difference between the components received in that quarter and the component content of the end equipment shipped in that quarter. This is change in total, or "pipeline," inventory, and includes unused components in stock and components in work-in-process and in unshipped finished equipment. Total inventory is then calculated as the integral of inventory change plus the inventory that existed at the "zero time" of the model.

A plot of the inventory for semiconductors derived from the consumption model described above is shown in Fig. 2.

Every manufacturing industry maintains a certain "desired" inventory level to support continued operation. The actual level of this desired inventory may be influenced by several factors, such as length of time to restock, current level of production and sales, and cost of maintaining the inventory. In the model, only the current business level is taken into consideration, and thus the desired level of inventory in any given quarter is entered as a constant times the component content of the end-equipment shipments of the previous quarter. An estimate of excess inventory is then made by subtracting the desired level from the total, (Fig. 3).

A comparison of Figs. 1 and 3 shows that downturns in semiconductor sales occurred during the first quarter of 1970 and third quarter of 1974, respectively. Inventory accumulation, however, began in the first quarter of 1969 and 1973 and progressed sufficiently to indicate a future turn in sales by the third quarter of 1969 and 1973.

Since the onset of inventory accumulation is a good indicator of future downturn in sales, the Solid State Division revises and updates this model on a quarterly basis. Further, even longer lead time in predicting slowdowns is obtained through the use of econometric forecasting models for both consumption and sales of solid-state devices.

Econometric forecasting models

As used in SSD, econometric modeling is the generation of mathematical functions representing factors in the micro economy (e.g., sale of semiconductor devices) in terms of macro economic factors as independent variables. In developing such equations, a linear relationship between variables is assumed and coefficients for each independent variable assigned through the use of least-square-deviation techniques over a historical base. Multiplicative models may be developed using the same techniques by relating the logarithms of the dependent and independent variables. Confidence in the derived model(s) may be gained through correlation with the original dependent variable, calculation of the standard error of the model, and through other statistical tests.

Such models are of value in the business planning cycle to:

- Produce forecasts.
- Gain insight as to product demand in various segments of the macro-economy through a study of the coefficients of the model.
- Investigate the effect of pricing and other competitive actions on sales.

While the generation of a micro model, such as product sales, is relatively straightforward, forecasting with the models usually requires the availability of a viable forecast of the accounts in the macro economy. Since the process of generating good macro economic forecasts on which to base micro forecasts is both complicated and costly, services such as Data Resources Inc., Chase Econometrics, or Wharton Econometrics are often used. The Solid State Division uses Data Resources, Inc., and results presented in this discussion are based on their macro forecasts.

Two statistically viable micro-econometric models have been generated using these methods: the first, total domestic sales of solid-state devices; and the second, the consumption of solid-state components in end-equipment shipped by the equipment manufacturer. Both models have been projected forward through 1977 using the December forecast of the general United States economy as seen by Data Resources, Inc. Model results are shown in Fig. 4. Major differences between these curves and those of Fig. 1 are the result of seasonal adjustment of dependent

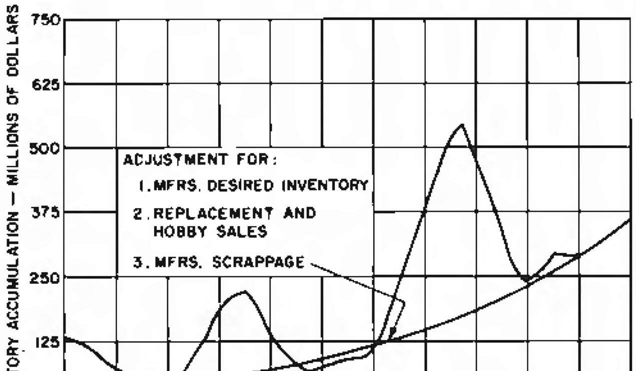

Fig. 2
Inventory for semiconductors derived from the consumption model of Fig. 1.

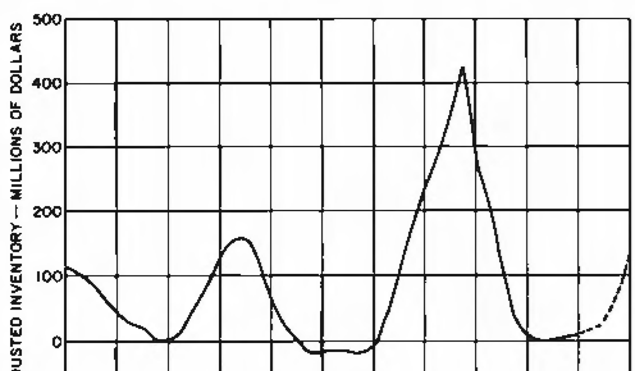

Fig. 3
Excess inventory is estimated by subtracting the "desired" inventory level from the total given in Fig. 2.

variables prior to modeling, the small errors inherent in the models and, of course, the forecast for 1977. The excessive growth noted in the forecast of solid-state sales in the third and fourth quarter of 1977 (over the growth of end-use consumption) indicates the potential of an excess inventory accumulation in late 1977.

The least-square regression techniques used in the definition of the models not only aid in the selection of economic accounts explaining the dependent variables (solid-state sales or end-use consumption) but covertly build into the model the consumer's, merchant's, and manufacturer's behavioral patterns inherent in the history of the independent variables. Further, each point in time of the solid-state series can be considered, in an economic sense, as the equilibrium point (or intersection) of the product supply and demand function, other parameters being equal. Thus, a solid-state price variable was introduced into the model. Since the model form used is multiplicative, the coefficient of regression of this price variable can be considered as the average elasticity of demand for solid-state devices, with respect to price. From this coefficient, the industry elasticity of demand is estimated to be (with respect to price) approximately -0.48. This figure indicates that a 10% decrease in price will increase total sales volume by less than 5%.

Other techniques

While the two models described briefly above constitute a significant portion of the effort underway in the Solid State Division, several other important techniques are used in the process of economic analysis and planning.

Consensus forecasting is simple, relatively inexpensive, and reasonably accurate.

In consensus forecasting, a trade organization requests marketing research people from a number of companies to simply estimate the total dollar volume of sales of various semiconductor products for the industry over a number of years. The statistical report produced is an effort to average the various estimates. There is no discussion or reporting of individual company sales prices, market shares, or any other such matter. The report is available to anyone who wants it. While simple in concept and relatively inexpensive to carry out, the method is valuable (and has relatively good accuracy) in producing both short- and long-range forecasts on which to base long-range planning.

Cahners method compares industry growth against a selected indicator.

The Cahners Method of forecasting, developed by the Research Department of Cahners Publishing Company, is basically a method of comparing the moving annual growth (sales) of an industry with the moving annual growth of a selected indicator that has been found to correlate with, and lead, the industry under consideration. By relating history of the turning points of the indicator to turning points of the industry under study, and slope relations between turns, an estimate of future industry turning points and growth can be made. Typical indicators that may be used are: Housing Starts, Dow-Jones Industrial Average, Free Reserves, or composites of several individual series, such as the composite of 12 leading indicators published by the Department of Commerce. While conceptually and mathematically unsophisticated and lacking in accuracy, this procedure is relatively inexpensive and will produce fairly reliable trend information as to business turning points and the approach (or continuance) of growth or recessional modes in the short-term future.

The indicator tracking method allows visual correlation between the industry and related economic series.

Least expensive of the techniques discussed, but probably of equal importance to techniques such as the Cahners Method discussed above, is the tracking of economic series related to the industry under consideration. Such series may be chosen either from the vast number of series published regularly by the Department of Commerce and the Federal Reserve Board, or may be obtained as a mathematical combination of such series. Such indicators are readily interpreted (as to their relationship to the industry) through graphical display over history. The advantage of this type of display is that trends of the economic series can be visually established and related to the trend of the industry series. Published series found to have high correlation with Solid State Industry sales and used within the Division include: Consumer Durables, Manufacturer's Durables, Consumer Sentiment Index, Private Housing Starts, and Gross National Product. Derived series used are a measure of discretionary income (disposable income less non-discretionary items such as food, clothing, household expense, transportation expense, and consumer debt liquidation), and an inventory index generated as a ratio of quarterly growth of manufacturing and trade inventories to the quarterly growth of expenditures for goods capable of being inventories. All series used to generate these indicators are published on a regular basis and are in the public domain.

The inventory index is shown in Fig. 5. Economic recessions, as defined by the Department of Commerce, are shaded areas in the Figure. As shown, each period in which the ratio has exceeded a value of one has been followed by a recessionary period, with the exception of the period from 66:1 through 67:3. While most components in the GNP showed marked decline in this period, large increases in military spending resulting from Vietnam war buildup

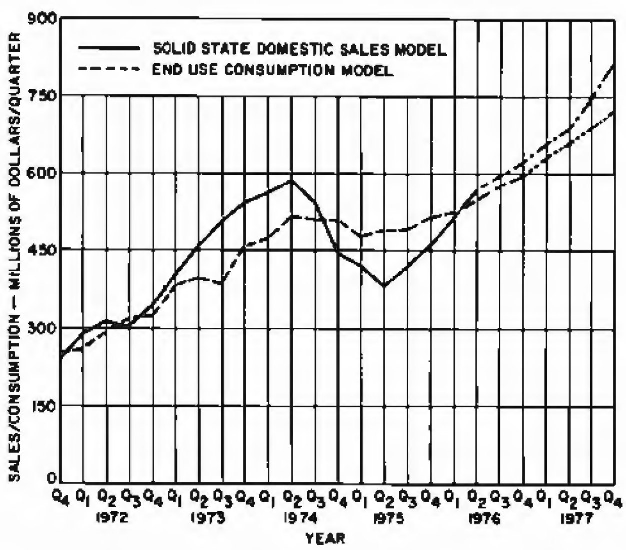

Fig. 4
Domestic sales/consumption model for the solid state industry.

prevented the total real GNP from the decline required (by the Department of Commerce) to define recession. A projection of the index, using the December forecast from the Data Resources, Inc., indicates the possibility of "excessive" inventory growth beginning in the first quarter of 1978.

Simple least-square methods involve modeling of an industry series with a single economic variable.

The econometric models discussed above are frequently referred to us as least-square multiple regression analysis since the technique involves the modeling of an industry series with several economic series simultaneously. This process is relatively expensive since it requires a large computerized data base as well as considerable computer analysis time. With the relatively inexpensive programmable and statistical calculators presently available, a simple, one-variable regression model may be generated at relatively low cost. While not yielding the accuracy or business insight of the multiple regression models, business trends and turning points can be more accurately predicted than with the two methods just described, particularly if the independent variable exhibits a good lead time over the industry-dependent variable. Further, most of the time series that may be considered as independent variables for such models are available as "hard copy" in journals such as *Business Conditions Digest* and *Economic Indicators*. An example of this technique is shown in Fig. 6. In this figure, annual growth in solid-state domestic sales is shown as a function of the annual growth of the U.S. GNP (current dollars) slipped by one quarter. All major turns in the growth of the industry are clearly matched with turns in the growth of the GNP.

Conclusions

Economic modeling is valuable in providing a better insight into the solid-state business. The program has further been of value in the development of long-range strategies and plans.

In developing the program, a reasonable balance has been maintained between program cost and value obtained. The program is not completed: new models must continue to be generated and added to those already in place, old models must be continually modified and updated to conform to the latest data and forecasts of the macro economy, and analysis and interpretation of model results must be provided to generate the economic scenario against which logical long- and short-term plans can be made. Only through such well-based planning can advantage be taken of available opportunities, and contingencies met, for the best interest of the Division and the Corporation. Since no major recession has occurred since the initiation of the program, the true value of it to the Division has yet to be tested and proven. Through the technique of "forecasting history," however, reasonable confidence has been established in the ability of the program to fulfill its objectives.

Lloyd Brown joined the Market Research Staff of the Solid State Division in 1973. Since the downturn in 1974, Dr. Brown has devoted his major effort to developing a better understanding of the interrelationship between solid state sales and the general economy.

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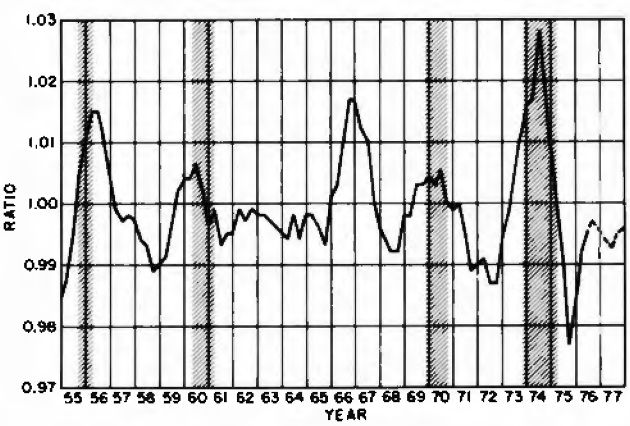

Fig. 5
Inventory index as derived from the indicator method of economic modeling.

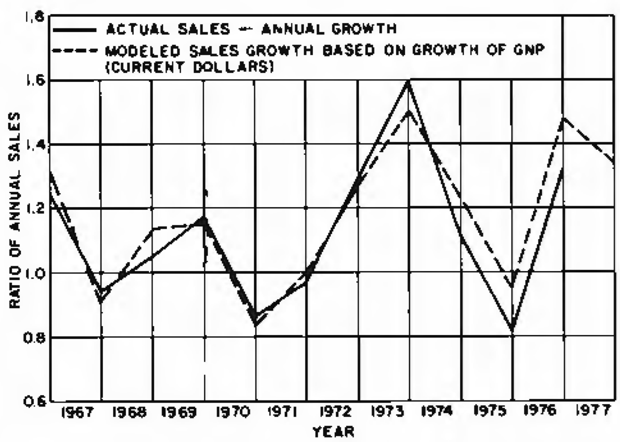

Fig. 6
Least-square method showing growth in solid-state domestic sales as a function of annual growth of U.S. GNP.

NBC Engineering—a fifty-year history

W.A. Howard

Part II: NBC's engineering "firsts" continue, from the beginnings of color tv up to today's computerized stations.

The beginnings of color television

Work on color television began as early as 1930 in the RCA Laboratories. As in the development of black-and-white television, there was a very close working relationship between NBC and RCA engineers, since NBC studios and transmitting facilities were the proving grounds for color television.

As early as 1940, RCA demonstrated the first color television system to the FCC, and on March 20, 1941, NBC used a field-sequential mechanical system to broadcast the first color signals from the Empire State Building. This system required a rotating color disc on both the camera and receiver.

Compatible color replaced the mechanical system.

Color television developed very slowly during the war years, but in 1946 RCA Laboratories presented the first public demonstration of an all-electronic color television system. The following year, members of the FCC witnessed a demonstration of "compatible color," a color picture that could be received not only on a color receiver, but also on any standard black-and-white set. Compatibility was very important to the success of color television, since so many homes already had black-and-white receivers.

In 1951, NBC and RCA engineers began an intensive schedule for field-testing all-electronic, compatible color television. NBC engineers had developed and installed a complete color facility at the Colonial Theatre, New York, using the most modern lighting, switching, and technical developments available at that time. This installation was America's first large-scale color television production studio and became the proving ground for the country's present color television system.

Again, the NTSC was called upon to formulate standards for a new television system in the United States. The NTSC worked from January 1950 to July 1953, undertaking the most comprehensive examination ever made into the principles and practice of a color television system. NBC engineers played an important role in this committee, with representation on all of its task forces. The final report totaled 18 volumes, 4100 pages.

Early in 1953, an NBC/RCA Liaison Committee on Color Television was formed to get ready to meet the demands for color equipment that were certain to arise after the approval of the proposed NTSC standards. On June 25, 1953, NBC and RCA engineers petitioned the FCC to adopt the compatible technical signal specifications demonstrated by NBC and RCA and approved by the NTSC.

On December 17, 1953, the FCC gave its long-awaited approval to compatible color television standards and authorized NBC to transmit using them. On the day of the FCC approval, NBC used the new compatible-color standards to broadcast programs to its entire television network.

This historic event in television was followed immediately by many more color firsts for NBC. The Tournament of Roses Parade, in Pasadena, Cal., was carried in full color by the entire NBC television network on January 1, 1954, making it the first major event televised on the new standards from a location outside the studios. The pickup was made with a new NBC color mobile unit that had been engineered and fabricated by NBC Engineering. This event also marked the first west-to-east color transmission on the new color standards.

Color television meant major changes in equipment, studios, and techniques.

The year 1954 saw the beginning of a major program for NBC Engineering to supply color facilities for the NBC network and owned stations. Studios, transmitters, switching systems, and all distribution equipment had to be colorized. New techniques had to be developed for testing transmission facilities, including the NBC network.

The first large color studio completed was the Brooklyn I studio in New York, which provided approximately 15,000 square feet of staging area. This was followed in 1955 with the Center Theatre, Ambassador Theatre, and large studios on 67th Street, New York. The Ziegfield and Hudson Theatres were added in 1956. For color film, the Radio City 4G/J film studio complex, with six RCA TK-26 color film cameras, went on the air in 1954. The 5H film facilities, with six additional cameras, were added in 1955.

"Color City," in Burbank, Cal., a $7 million project, went on the air on March 27, 1955, completing a major project by NBC engineers. This scored another first for NBC, as Color City was the first studio facility in the United States built from the ground up for color television. The most modern

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Bill Howard's photo and biography appeared with the first part of this article. (Vol. 23-2 Jun/Jul) and finest color facility in existence at that time, it originated many of NBC's early color shows and earned a reputation in the industry as the ultimate in technical quality.

The year of 1955 marked many milestones in color broadcasting. A full Broadway production of *Peter Pan* was done in color with the original stars, Mary Martin and Cyril Ritchard. This show attracted a then-record audience estimated at 65 million viewers. The first color broadcast of a President—Eisenhower's commencement address at West Point—was telecast using the new NBC color mobile units. The first color coverage of a World Series (Yankees vs. Dodgers) was distributed to the entire NBC network. Another first for NBC and the NBC engineers was on April 15, 1956, when WMAQ in Chicago went on the air with its all-color facilities, making it the first station in the United States to offer 100% color programming.

The 1950s and early 1960s were years of pioneering for color television, and NBC Engineering made important contributions to its growth. NBC Laboratories developed many of the techniques and signals that are used industry-wide today for testing amplifiers, switching systems, and network facilities, (e.g., multi-burst, stair steps, and window test signals). The sine-squared pulse, also used industry-wide, was introduced in this country from Europe by an NBC engineer, Ralph Kennedy.

Other developments originating in the NBC Laboratories prior to 1960 included all types of video effects such as chroma key, a color television effect in which a foreground scene can be electronically placed in a still or moving background scene without having the background show through the foreground. These developments were the forerunners of the highly specialized video-effect systems used in all modern-day switching systems.

By 1965, color television had mushroomed to an annual retail sales level of more than $3 billion in the United States, and NBC had converted a major part of its facilities to color. In announcing their 1965-66 programming, NBC offered 95.8% of its schedule in color, thus making NBC the first "Full Color Network."

1 Jimmy Durante rehearsing at Color City, Burbank, the first studio facility built for color television from the ground up. 2 Charles Schadel operating one of the first RCA color video tape recorders (TRT-1) in the late 1950s. 3 The color chimes logo, used from the 1950s through the early 1960s. 4 TK-41 color cameras during rehearsal at the Colonial Theatre in New York, where field testing of the NTSC color standards was done. 5 Color film equipment installed at WRCV, Philadelphia, as part of the big changeover to color.

Engineering leadership at NBC

O.B. Hanson, an outstanding engineer and administrator, served as Chief Engineer of NBC from its formation in 1926 until 1954, a span encompassing major technological developments in both radio and television. Robert E. Shelby followed Hanson as Vice-President of Engineering and Operations until his death in 1955. Andrew L. Hammerschmidt then held that position until 1961, and was followed by William H. Trevarthen, who served until his retirement in 1973. John R. Kennedy then became Vice-President, Operations and Engineering, a post that he presently holds. Frank L. Flemming has been Vice-President, Engineering, NBC Television Network, since 1969.

Contributions by NBC engineers

In viewing the many contributions made by NBC engineers over the past 50 years in the broadcast field, it is evident that the rapid expansion of technology has made many of them now obsolete. However, at the time of their development, these contributions served important functions to NBC and the broadcasting industry. It is impossible in this article to name all of the engineers who made major contributions; however, there are a few whose accomplishments have been extremely important to the growth and development of NBC.

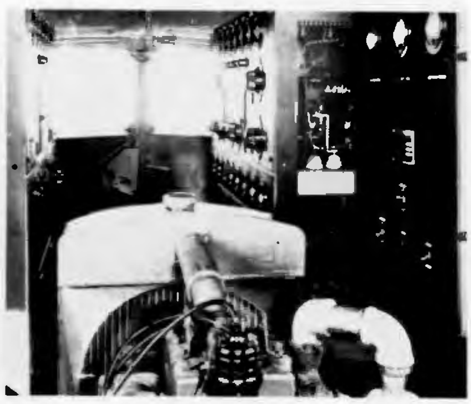
One such engineer, Lew Hathaway, served in the NBC Engineering Department from 1929 to 1972, a span of 43 years, during which radio and television grew from its infancy to a multi-billion dollar industry. He was granted 37 U.S. patents in radio and television, won three major awards from professional societies, and received two Emmy nominations.

In 1972 the National Academy of Television Arts and Sciences awarded NBC Engineering a "Citation for Oustanding Engineering Development" of the "hum bucker," a video transformer developed by Mr. Hathaway that is used industry-wide today by broadcasters and telephone companies on remote pickups. Another of his developments was interleaved sound, an emergency audio-transmission facility for television that uses gaps in the frequency spectrum of the video signal. This system is still in use today on the NBC network between New York and Burbank.

Vernon Duke, a veteran of 37 years with NBC Engineering, was granted over 20 U.S. patents and made major contributions to the development of studio and film cameras, kinescope recording, video tape, and film processing. He also served on many industry committees and authored several industry standards in the area of television film.

Television tape

The first quadruplex video-tape recorder was demonstrated to American broadcasters in March of 1956. This system of recording and playing back television signals became universally accepted by the broadcast industry; using tape as a method of delayed broadcast and show syndication revolutionized television.



However, the first quadruplex tape recorders could not record and play back color signals. NBC was well on its way to becoming all-color, so color tape was necessary. NBC and RCA engineers developed a color heterodyne system for recording color on magnetic tape, and the following year (1957), NBC began the first delayed broadcast of color shows out of its Hollywood studios. A year later the operation was transferred to the new NBC Burbank studio, where eight color recorders served the entire NBC network. By 1961 there were sixteen recorders in Burbank, twenty in New York, and all the owned stations were using color video-tape machines.

NBC made other contributions to video tape by developing remote start-stop and mode selection for all of their recorders. By 1960, the NBC Burbank engineers had developed a double system for recording and editing with video tape using a 16-mm magnetic sound recorder and a 16-mm kinescope recorder. A number of the NBC specials were edited with this system. Today, large video tape complexes with modern electronic editing systems have been installed in Burbank and New York, with approximately 30 color tape recorders at each location.

Remotes and mobile units

Over the span of radio and television broadcasting, a large part of NBC's programs have originated from "remotes," or locations outside the studios. In order to have the best coverage for sports, news, and entertainment originating at these "remote" locations, NBC Engineering has been responsible for engineering custom mobile units providing the same production facilities as the fixed studios.

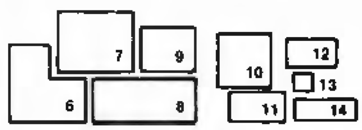
The network's inaugural radio program on the evening of November 15, 1926 was a remote originating from the Grand Ballroom of the old Waldorf-Astoria Hotel on 5th Avenue, the present site of the Empire State Building. A four-hour program featuring some of the finest talent available originated from this remote and was transmitted by telephone lines to the NBC control room at the AT&T Building for distribution to the network's 21 radio stations.

Mobile units date back to the early days of radio.

In the early years of radio, NBC's large fleet of mobile units using rf microphones and radio relay equipment covered many historic events, including the Hindenburg tragedy at Lakehurst, New Jersey in 1937. NBC engineers also used shortwave radio to bring news from outside the United States. A good example was the 1938 Munich crisis. Atmospheric conditions cut off the American broadcasters from immediate access to the event in Munich, Germany, so NBC engineers set up a shortwave circuit by way of Africa and South America to New York. Thus, on NBC exclusively, Americans heard the words of Prime Minister Chamberlain telling how Hitler would "come half way to meet me" in Munich.

Television's first mobile unit, engineered and designed by NBC, appeared on the New York streets on December 12, 1937. This unit was used for experimenting with and field-testing black-and-white television. When television was introduced to the American public in 1940, it was also via a remote, this time originating from a mobile unit at the New York World's Fair. And when NBC transmitted the first major network program on the newly adopted NTSC color standards, a remote of the 1954 Tournament of Roses Parade, it was done with new NBC color mobile units.

NBC Engineering also pioneered with "crash" television units equipped to operate on their own power while in



6 NBC's first mobile unit used a balloon-hoisted antenna. Engineer is Milton Kitchen. **7** NBC mobile units covered the *Hindenberg* tragedy, May 6, 1937. Cortney Snell, extreme left, was the engineer doing the pickup. **8** Mobile unit and *Hindenberg* a year earlier. **9** Interior of early mobile unit, showing generator in foreground and relay transmitter at rear. **10** Color mobile units field-tested NTSC standards in the early 1950s, later toured the country when standards were approved. **11** Black-and-white unit of the early 1950s. **12** America's first mobile television station as it appeared on its delivery to NBC on December 12, 1937. One unit was for pickup, the other for transmission. **13** NBC's logo from the 1960s until 1976. **14** Color mobile unit used in the 1960s and 1970s.

motion, maintaining continuity of sound and picture. On July 12, 1952, the first crash unit appeared on the streets of Chicago with its own power generator and microwave transmitter, transmitting sound and pictures back to the studio. In order to meet the requirements for participating in the presidential inaugural parade that year, a Cadillac limousine was outfitted to follow the full length of the parade without losing picture or sound. These units were the predecessors of the more modern units now used daily in today's "electronic journalism" operations.

Mobile television vans eventually became as well-equipped as the studios.

The first of the large multi-van remote units were designed and constructed by NBC Engineering and began operating in 1966 for sporting events. These units are also used for the Apollo launchings and pickups and the Miss America pageant. The first NBC unit of this type consisted of three forty-foot trailers—one each for camera equipment, production, and carryall.

The technical equipment supplied with these trailers was the same as supplied with any of NBC's fixed studios in New York or Burbank. It consisted of up to six color cameras, solid-state switching and effects equipment, quadruplex video tape recorders, instant replay and "slo-mo" equipment, and an audio console providing at least 30 microphone inputs. The units have been updated periodically to include newly developed equipment, such as character generators and slide storage equipment.

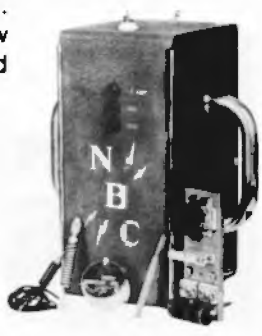
The mobile units designed later used more modern and compact equipment and so reduced the size and number of vans, but still provided the same production facilities. NBC today operates four of these large units out of New York and Burbank, with several smaller units at the owned stations in Chicago, Washington and Cleveland.

Portable cameras and electronic journalism

From the "walkie-talkie" to the "walkie-lookie."

NBC has been a pioneer and leader in developing and using wireless or rf microphones over a period of many years. The first use of an rf microphone system was in the 1936 Easter Parade on 5th Avenue, New York, with the transmitter and antenna concealed in a top hat. This was followed by later developments in the laboratory—in 1937, NBC's "beer mug" miniature transmitter operated in the 30-37 MHz band with a transmitter power output of 0.15 watt. The following year, a 2-watt uhf backpack transmitter was developed. These units, which were used extensively by the NBC news and sports departments for many years, were the predecessors of the complex systems used today that have two-way communication provided by a cue channel and a high-quality program channel. NBC's coverage of political conventions by radio began in 1928. The rf microphones used in these conventions were developed in the NBC Laboratories and soon became famous as "walkie-talkies."

NBC's television coverage of political conventions began on an experimental basis in 1940. At the 1952 political conventions in Chicago, NBC unveiled a portable rf-connected camera developed by NBC and RCA engineers. It was soon labeled the "walkie-lookie," as a companion to



15 Three-watt backpack remote radio transmitter of the late forties. **16** The famous uhf "beer mug" remote radio transmitter, developed in 1937. **17** NBC's first rf microphone system, used at the 1932 New York Easter Parade, was hidden in the top hat, with antenna projecting out. **18** Harry Truman being interviewed via NBC rf microphone during one of his famous strolls. **19** Engineer John Crampton demonstrates the "walking tv station" at the 1964 Democratic Convention. **20** RF-connected camera and beer mug radio microphone being used at 1956 convention. **21** NBC's peacock logo, used from the beginnings of the "Full Color Network" until 1976. **22** Correspondent Nancy Dickerson holding the ultraviolet-beam sound transmitter used at the 1964 conventions. Receiver is at left. **23** Modern TK-76 electronic journalism camera.

the "walkie-talkie." At that convention, NBC engineers also introduced the "crash truck," a tv newsroom on wheels, equipped with self-powered electronic and film cameras and its own darkroom. It was capable of preparing film for projection on the air in less than 10 minutes.

The 1956 and 1960 conventions saw increasing use of portable black-and-white cameras. Although the cameras themselves were small and lightweight, the control packs, microwave transmitters, and antennas were still heavy and bulky for maneuvering on the crowded convention floor. There were also problems with rf interference in the crowded 7-GHz microwave bands.

Two developments from the NBC Laboratories were used for the first time at the 1964 conventions. The first, the "black-beam" sound system, used a transmitter that sent out voice-modulated ultraviolet light. A receiver picked up the light, amplified it, and converted it to a standard audio signal. This system was used extensively from the convention floor and required no FCC license. The other new introduction was the electronic long-lens system developed by Fred Himelfarb. This system could increase the effective focal length of the standard camera lens electronically up to twice its normal magnifying power, so cameras were used extensively for close-ups from the convention floor.

Portable cameras became truly portable with the "walking tv station."

At the 1964 conventions in Atlantic City and San Francisco, NBC introduced a new rf-connected portable camera developed by NBC and RCA engineers expressly for these conventions. Soon labeled the "walking tv station," the system used camera and control units that were smaller and much lighter than for previous camera systems. For the first time, the camera's microwave equipment operated in the 13-GHz band, eliminating most of the noise and interference that had plagued previous microwave-link cameras. The complete package weighed less than 50 pounds and could be carried by one man.

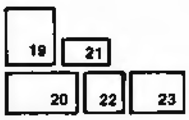
A new "crash" unit developed by NBC engineers was also introduced at these conventions. It was entirely self-contained, using a 5-kW gasoline generator to supply the power to operate all its equipment—two portable cameras, (walking tv stations), a portable video-tape recorder, microwave transmitting and receiving equipment, a video switching unit, and the necessary audio and communications equipment. While the vehicle was traveling at speeds up to 40 miles per hour, pictures taken by a cameraman on the roof could be transmitted via microwave to the main control center or taped for future use.

Between the 1964 and 1968 conventions, NBC and RCA Astro-Electronics engineers developed a portable color back-pack camera that transmitted video information in the 13-GHz band. This camera was used at the 1968 Miami convention for the first time. NBC Engineering has also worked with North American Philips on color rf-connected cameras.

Automation

Early automation used relay logic and steppers.

NBC pioneered the automation of radio and television operations. As the television facilities at Radio City and Television Master Control expanded in the 1950s, a form of automation using relay logic and steppers timed from precision clocks was installed in network switching, so that six channels could be individually preset and switched on a



real-time basis to eliminate human errors. Later this was expanded to the studio 5H control room, which controlled the local television station and provided network break-in. In this system, a complete station break could be preset and switched along with automatic roll-on projectors and tape recorders.

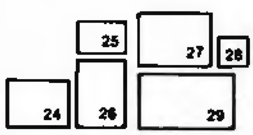
In April of 1958, NBC Burbank went on the air with 12 color video tape recorders, which recorded programs from the eastern NBC network and played them back to the Central Time network one hour later, and the Pacific Coast network three hours later. This automated system used relay logic and sequence-stepping switches electrically pulsed from precision clock impulses. It permitted preset recorders to record or play from specific recordings or playback lines at particular times and for particular intervals. Automatic rewind and cue-up were provided. For further automation, automatic gain control (AGC) amplifiers were used in both the audio and video program path. The color video AGC amplifiers had just recently been developed in the NBC Laboratories.

The first completely automatic station to be engineered by NBC was WBUF-TV in Buffalo, NBC's experimental uhf station, which went on the air in 1956. Again, relay logic, sequence steppers, and AGC audio and video amplifiers were used. A paper-tape system controlled the switching and pre-roll of film equipment and tape recorders. A full day's operation could be made up on punched tape and operators were needed only to load film and slide projectors. In 1959, WRC in Washington moved into a new television plant that was also completely automated using basically the same type of system that had been installed in Buffalo.

Computer control became a reality in the mid-sixties.

In the spring of 1962, a new switching central was placed in operation in Burbank, controlling KNBC and the Pacific network. The output switching at that time was done manually by loading information for each channel into preset relays, then putting the preset event on the air by using an enable pulse. The system anticipated, however, the eventual use of a computer for these functions, including storage of a full day's operation. The design of such a system, which was NBC Engineering's first experience with a computerized television system, was already underway. In March of 1966, the computer-controlled switching system was placed in operation in Burbank. A Daystrom Model 636 computer, which has a self-contained core memory of 20,480 words, stores, retrieves, and processes program information for switching three television channels. The programs for each day are fed from a variety of sources, including live studios, film chains, and video-tape recorders. Since the principal interface of the computer is through the keyboard and relay switching system, only three pieces of peripheral hardware are necessary: a tape punch and reader mounted in the main computer cabinet, and an electric typewriter through which the computer writes a log of the operation. Computer control for NBC Burbank has been in use for over eleven years and has been a very successful operation.

In 1969, the NBC Engineering Department began the automation and computer control of the entire NBC network in New York, a seven and one half million dollar project supervised by Frank L. Flemming, Vice-President of Engineering, NBC Network. After many planning sessions with operating personnel and extensive software contributions by the RCA Laboratories, the complex system began to take form. Many features of the system had to be developed, including machine control, a large routing switcher, and video source identification. The system was put into operation in October 1974, on a limited schedule,



24 Bob Lopez using the computer-controlled switching central at Burbank. **25** First automated tv station, WBUF in Buffalo, used paper tape readers to control film projectors and tape recorders. **26** Stepper-switch controllers at WBUF. **27** NBC's old television master control at New York. Originally engineered in the early 1950s, it was in constant use until 1974. **28** NBC's new "N" logo began use January 1, 1976. **29** Bob Post and Robert Waring at NBC's new switching central in 1976. Six separate channels can be controlled by minicomputer for an entire 24-hour day of automatic operation.

since this new system of operations involved changes in many NBC departments. By gradually increasing use of the system, it reached full-time operation (24 hours/day, 7 days a week) during July 1975. This modern and complex system is described in eight articles by NBC engineers in the Apr/May 1976 issue of the *RCA Engineer* (Vol. 21 No. 6).

Conclusion

The 50 years of NBC Engineering has spanned a period of major technological developments in communications that has permitted the nation's 620 low-powered radio stations in 1926 to expand into a multi-billion dollar annual business with over 700 television and 6000 radio stations. NBC engineers have made a major contribution to this development and expansion.

The challenge for NBC engineers in the future is equally as great as it was 50 years ago, with new technological applications and demands now on the horizon—digital television, microprocessors, image sensors, lasers and fiber-optics transmission, and the urgent need for a transparent international interchange system for television.

Acknowledgements

I gratefully acknowledge the helpful suggestions and information supplied by my colleagues in the NBC Engineering Department and thank the personnel in NBC Technical Operations and retirees who have supplied valuable documents and photographs. I would also like to express appreciation to my wife, an English major, for her invaluable contribution.

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The 1977 MIT-RCA Research Review Conference

What's new at MIT?

Computer education at MIT

just what does that young kid after your job know?

As an example of how the field of computer technology has grown, what was once a two-semester MIT graduate course on switching theory has now been squeezed into half a semester of an undergraduate course.

Today, the introductory course at MIT, called Switching Circuits, Logic, and Digital Designs, introduces the basic concepts of combinational logic, sequential circuits, flow diagramming, control modules, A-to-D and D-to-A conversion, microprogramming, and minicomputers. Each student in the course receives a portable laboratory in the form of a briefcase containing superstrips, switches, lights, power supplies, all the components needed for the lab exercises, and tools for assembling circuits. This course is followed by Digital Systems Project Laboratory, in which students use hardware/software tradeoffs, integrated circuits at the SSI/MSI level, and some LSI.

The coursework then broadens out into Minicomputers, Microprocessors, and Advanced Digital Systems, in which students pursue detailed studies of machine architecture, I/O organizations, memories, display terminals, and data communications. Projects in this course require the students to use MSI and LSI hardware and assembly-language programming on various micro- or mini-computers. There is also an undergraduate thesis option available for students with a further interest in the field.

The projects that students demonstrated at the conference were impressive. One, a game called MAZE, used a tv monitor to simulate the sensation of walking in a three-dimensional maze. The object of the game is to move through the maze and avoid being electronically "shot" by its robot inhabitants.

Electronic mail

the question is no longer "if?," but "how?"

Information handling is rapidly dominating the U.S. economy. More than 50% of the nation's workers are now involved with banking, finance, education, purchasing, personnel, accounting, research, etc., rather than the direct manufacturing of goods. The capital investment behind each manufacturing employee is now about $300,000, but only about $2,000 for a typical white-collar worker. This system is changing, though—technology is making its way to the office.

Presently, three different technologies—facsimile, word processing, and computer-based message systems—each with its own particular advantages and characteristics, are competing for the information-transfer market. The eventual winner will depend upon both advances in technology and decisions from the regulatory agencies.

There are presently about 100,000 facsimile machines in the United States; their popularity is based on their ease of use compared to, say, a Telex machine. Most of the communication done on them is alphanumeric, even though they can handle all kinds of graphical inputs. The second type of system, the word processor, now numbers about 110,000 in this country. Most of them do not have any communication capacity, but since the information in them is machine-readable, it could be easily and instantaneously sent electrically, rather than going through the trouble of typing a message out, putting it in a letter, and waiting for the Post Office to deliver it. As a result, the idea of communicating word processors is becoming a standard notion. The third type, computer message systems, provide a number of additional functions besides switching messages back and forth. In them, terminals at a number of locations, perhaps connected through a telecommunications network, contact a central computer that can receive messages, file them, forward them, search for past messages, retrieve data asked for in messages, or perform any number of other services.

Which type of electronic mail eventually dominates the market will depend on how the different systems meet certain performance criteria. For example, terminals must be everywhere, as ubiquitous as telephones, and should be able to be used by untrained operators. Users must be able to maintain privacy for their messages and also be able to authenticate that messages do indeed come from their supposed senders.

Computer-managed parts manufacturing

approaching mass-production economy for job-shop quantities

Machining a complete V-8 engine block in mass production costs roughly about $15, but machining only 100 of the same block would cost about $1500 per assembly. This 100:1 ratio is typical of what it costs to do low-volume manufacturing—a few hundred or few thousand parts per year. Considering that something like 90% of the world's total dollar volume of manufacturing involves items manufactured in quantities under a million per year,

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Ed. Note: Forty engineers representing most RCA divisions recently spent a day at MIT, attending a one-day seminar to learn what's new in the 2000 research projects under way there. Four of the presentations from that seminar are presented here in the form of notes taken by Hans Jenny, Manager of Technical Information Programs for RCA.

productivity increases in this area will bring about tremendous savings.

Several automated systems attacking this problem already exist. Computer control of all the operations in the manufacturing cycle, including transport, can bring mass-production transfer-line economies into discrete manufacturing operations that have traditionally been handled by job shops. Most of the computer-managed systems include a conveyor on which the fixtured parts move to machining stations that have their own complements of cutting tools (anywhere from 10 to 150) somehow arranged into tool banks for automatic insertion into the machines. One Japanese system takes a variety of bar stock as input, machines it, heat-treats it, and grinds it to produce a number of different parts. Another Japanese company has been quite successful in using a group of eight computer-managed lathes to produce parts for stepping motors (rotational parts, housing, cages, etc.) in batches of 30 to 50 per run. This system even uses a robot to put the parts into the machines precisely. These systems often are designed to run wholly unassisted for long periods. In fact, West Germany's Heidelberg Press Co., the world's largest printing press manufacturer, runs its computer-managed system for five days, twenty-four hours a day. The remaining two days are used to prepare for the next week's production.

Note that most of the examples mentioned here are from out of the United States. Computer-managed machining has not really progressed that far in this country. The MIT program is attempting to produce cost-benefit analyses to determine the cost sensitivity of the system inputs, and simulate actual systems so that cost-effective computer-managed systems could be designed rapidly from manufacturing requirements.

Inverse seniority

a layoff can be a good thing

In a cyclical economy, layoffs are inevitable. Here in the United States, unions and management have generally agreed that when layoffs are necessary, workers with seniority will stay on the job and the most recently hired will be out of work. Sometimes, however, as in the automotive industry, laid-off workers receive a very high proportion of their normal salaries (up to 95%). This trend is spreading, and these high benefits are producing a natural reaction in the senior workers—"Why can't *we* get this pay for no work?" At the same time, the low-seniority workers laid off tend to consist largely of minorities and women who have just recently entered the work force and are usually the people who most need the assurance of a steady job.

Inverse seniority reverses this situation, giving the senior workers a well-deserved (and compensated) vacation, while keeping the junior workers on the job. To be workable and equitable, the concept requires that the option for layoff be voluntary with the senior worker, with a right to recall at his or her option, and that there be a reasonable fund giving compensation for the laid-off workers.

Such a system has benefits to both the workers directly affected and society as a whole. For the workers, senior people have the opportunity for longer periods of time away from the job—time for education, travel, fixing up the house, or even trying out new careers, knowing their old jobs are protected. The junior people stay on the job, maintaining a steady income and increasing their job skills. Society benefits because junior workers are kept from being continually laid off after working only a few months and eventually winding up in the welfare system. The senior worker, though, when laid off from a job he is assured of returning to, imposes little or no burden on society.

There has been little experimentation with inverse seniority in the United States, although the basic idea has been used at such companies as International Harvester and John Deere. The Japanese, however, have successfully followed a similar approach for a long time.

What is RCA's connection with MIT?

The worlds of academia and industry are indeed often worlds apart. In an attempt to bring them closer together, MIT established its Industrial Liaison Program, which sets up contacts between MIT scientists and engineers and their counterparts at RCA and a number of other corporations. The MIT-RCA Research Review Conference described here is only one part of this liaison program—RCA engineers also have access to reports from all of MIT's 2000 research projects. For information on how to obtain research reports or more about the subjects covered here, get in touch with **Doris Hutchison,** RCA contact for the Industrial Liaison Program, **Building 204-2, Cherry Hill, N.J., extension PY-5412.**

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Meet your Editorial Representatives

You, as an engineer, have valuable information in your files or in your head. Editorial contacts at your location are available to help you share that information with the rest of the engineering community.

These Editorial Representatives (Ed Reps) can help you present that pet project or idea to a very important group—engineers and engineering management at RCA. Editorial Representatives (for each major activity) are appointed, usually by the chief engineer. Basically, their objectives are to assist authors by stimulating, planning, and coordinating appropriate papers for the *RCA Engineer* and to keep the editors informed of new developments. In addition, they inform the editors of professional activities, awards, publications, and promotions. Somewhere on these two pages, you will find a picture of your Ed Rep and his or her location and phone number. Use the contact to find out more on developing your own contribution to the professional literature.

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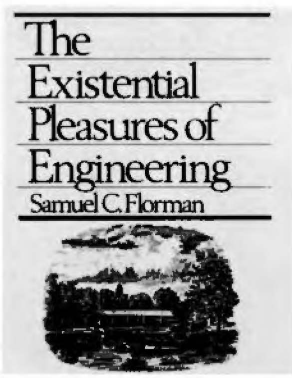
Zen, existentialism, and engineering

H. Kleinberg

The public's lack of understanding of the engineer's work is slowly turning to suspicion and hostility. This growing barrier makes two books "must" reading for engineers.



The Existential Pleasures of Engineering,
by Samuel C. Florman
160 pp. New York
St. Martins Press, $7.95.

Zen and the Art of Motorcycle Maintenance
by Robert M. Pirsig
406 pp. New York
Bantam Books, $2.50.

Strange titles. They seem more satirical than serious, promise to link topics that have nothing obvious in common, and they certainly don't sound like the names of technical books. In the narrowest sense they aren't technical, yet both books have direct and immediate relevance to every engineer.

They are thoroughly serious and deliver exactly what the titles promise, a strong connection between their seemingly unrelated components. And, while they are poles apart in style and approach, both books deal with the same subject—technology, or more precisely, a response to the strong anti-technology mood that pervades the atmosphere today.

The barriers that always exist between the specialist and the public have become increasingly more impenetrable in the past few decades. The natural lack of general understanding of what goes on behind that barrier is slowly becoming suspicion and hostility. It has become vital that the nature of technology and those who practice it be understood by the layman, so these books are especially timely. It is even more to the credit of the authors that they are neither defensively apologetic nor simply satisfied with platitudes about the contribution of technology to the good of mankind. Instead, they actively press the case that engineering and technical work are vigorous expressions of the highest human goals and aspirations.

Despite the common theme, the differences between the two books cover the entire range of writing. Florman, a civil engineer, wrote *Existential* as a direct exposition of the problem—a clear statement of the anti-technology ideas and a point-by-point response; Pirsig, a technical writer, wrote *Zen* as a novel centered around a motorcycle trip, with his thoughts about technology delivered as a series of Chautauquas* composed by the narrator as he and his young son travel. Florman deals primarily with engineering, with the reduction of scientific principles to practical ends; Pirsig treats technology from the angle of peoples' relationship to "things," using as his specific case the problems of fixing a motorcyle. Florman builds his position through copious references from his obviously wide reading on the subject; Pirsig reviews the entire history of Western philosophy and a bit of the Oriental as background to his conclusions. Florman attempts to build a philosophy of engineering that will refute the ideas of the other side; Pirsig undertakes the greatly more ambitious task of showing that both sides can be unified, can be looked at as two different manifestations of the essence of all experience—what he calles Quality.

Of the two, Florman's book is the more easily readable, and if you feel up to tackling only one of them, this should be it. *Zen* is a much more comprehensive treatment of the

*For those of you who are part of the postwar baby boom, a word about Chautauquas is in order. They were cultural and educational programs named after the resort area in New York State where they started, and date back to the days, a century ago, when it was believed that even vacation time should be partly spent in improving one's mind. To that end, series of informative lectures, often held in tents, were organized to bring enlightenment to small towns and outlying areas. While the original resort is still functioning in good health, the touring lecture series have gradually faded with the advent of radio and television, although they have apparently not yet completely died out.

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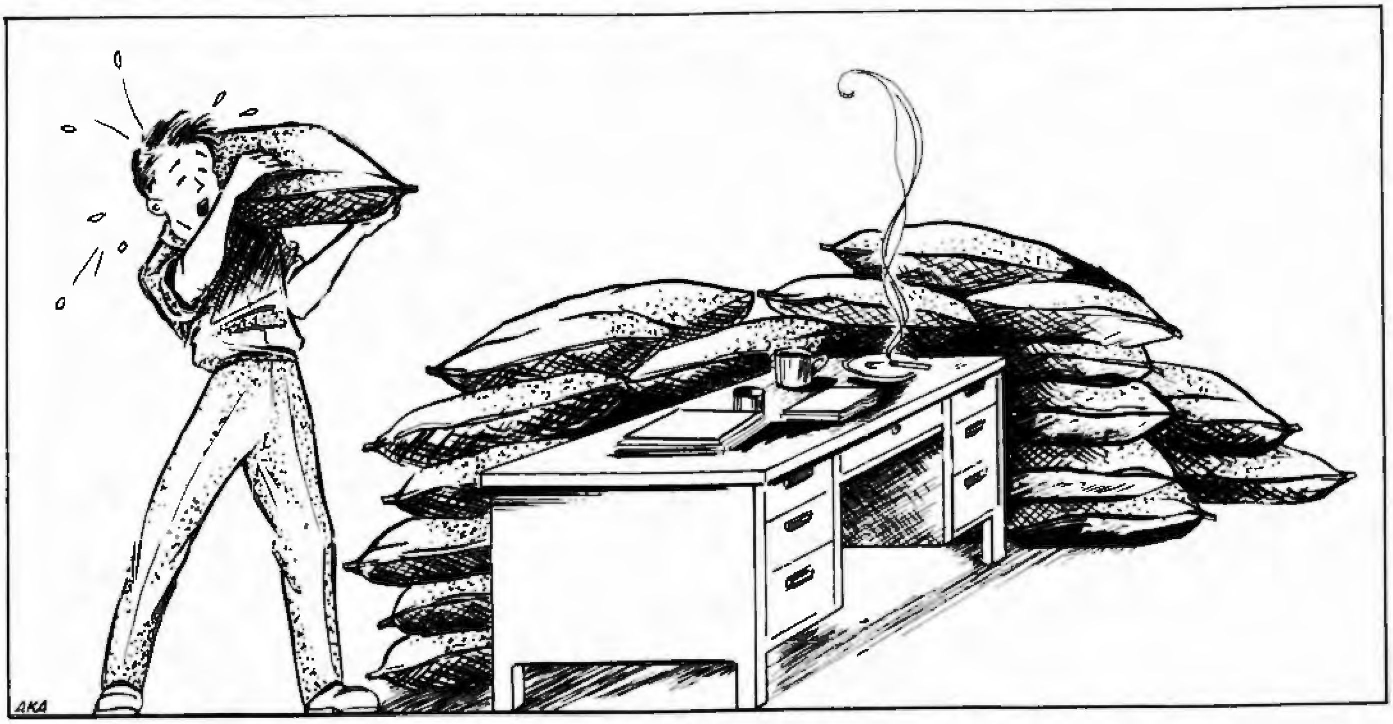

"... **while it would be premature** to pile sandbags around your desk, ... your work as an engineer is under attack."

subject, ranging widely over the history of philosophy and its interaction with the development of science. Judging from my own very limited knowledge of the subject, Pirsig's presentation of the classical ideas is remarkably concise and accurate. His own conclusions are simply that ... his own conclusions, and you may or may not agree with them. Nor are the books's merits as a novel of concern here, except to comment that despite a happy ending, it has the downbeat, slightly depressing mood so characteristic of today's fiction.

But one or both of these books should be required reading for every engineer because, while it would be premature to pile sandbags around your desk or to put bullet-proof glass around your lab bench, it is not too early to recognize the theme of these books—that your work as an engineer is under attack.

The opposition comes not merely from the confused flower children of the 1960s or a small band of extremists of the 1970s; it comes instead from the elite of today's intellectual leadership. If you are even a casual observer of current cultural trends you have probably picked up the message already. It comes through in today's movies, novels, and theater, in the explosion of interest in the mystical and the occult, in the recurrent theme of "dropping out of the system."

Both authors point out that what is under fire here is not merely nuclear energy or computers or supersonic aircraft or any other specific technology. What is being questioned is best expressed in the authors' words:

> "An even more serious indictment of engineering is to be found in a curious new philosophy that has been gaining currency since the mid-1960s. It is the doctrine that holds technology to be *the root of all evil.* The proponents of this view are not satisfied to say that technologists have been careless, foolish, or immoral. They see the source of society's problems and men's miseries as lying in the concept of technology itself."
>
> Florman, p. 45

> "But now I see that the it was mainly, if not entirely, technology. But, that doesn't sound right either. The 'it' is a kind of force that gives rise to technology, something undefined, but inhuman, mechanical, lifeless, a blind monster, a death force. Something hideous they are running from but know they can never escape."
>
> Pirsig, p. 46

> "The founding father of the contemporary anti-technological movement is Jacques Ellul, a theological philospher...(whose) thesis is that technique has run amok, has become a Frankenstein monster than cannot be controlled. By technique he means not just the use of machines, but all deliberate and rational behavior, all efficiency and organization."
>
> Florman, p. 46

It takes a while for an engineer to believe what he is hearing. How can anyone question something so obviously valid as the scientific system? And even when you come to accept the fact that such an idea can be seriously considered by any modern thinker, your first reaction is to point out how much our society depends on technology. The authors are ready with answers.

> "There's kind of a glaring inconsistency here, that's almost too obvious to dwell on. If they can't stand

physical discomfort and they can't stand technology, they've got a little compromising to do. They depend on technology and condemn it at at the same time. I'm sure they know that and that just contributes to their dislike of the whole situation."

Pirsig, p. 44

"If we are to build a new philosophy of engineering, we must start with a rebuttal of anti-technology. Conceivably we could let the argument go unanswered, except to respond that technology is a necessary evil. But that would not be very satisfying. Besides, it would not give expression to what we know in our hearts; that technology is not evil except when falsely described by dyspeptic philosophers."

Florman, p. 57

If you want a more specific example of the attitudes that the authors are responding to, go see the movie "Logan's Run." It is set in some unidentified future, in an enclosed city in which every human need is catered to by hidden, totally self-contained machinery. The population live their entire lives with no need to do anything but enjoy themselves. The only catch in this Utopia is the system used to control the size of the population—destruction of everyone at age 30. A couple escape from the city, discover the natural world outside, and like what they see. They return to the artificial city and, after performing the mandatory deeds of strength, endurance, and heroism, destroy the machinery. The film closes with what is apparently considered a happy ending as the populace emerges from the ruined prison of technology to live freely ever after in harmony with a benevolent nature.

Without doubt, every engineer who sees the movie will immediately wonder how such a group of totally unskilled and helpless people will cope with what is, in reality, a not very benevolent nature. How will they feed and shelter themselves? How will they deal with such natural phenomena as bacteria and viruses? If any of them survive the first winter, how will they then feel about technology? The questions seem obvious, but not to the film-makers who see life neatly divided into two categories—the oppressive world of machine and logic on the one hand, and the liberating world of nature and feelings on the other.

Both authors attack what they consider the basic fallacy of this negative view—the position that technology is essentially dehumanizing, not only to its helpless victims (the general public), but also to its practitioners (that's you). They respond that technology is not something that has been artificially or subversively grafted onto an otherwise innocent and passive mankind, but instead reflects a fundamental human drive. Designing a tool is as uniquely human an act as writing a poem, because humanity is differentiated from other species as much by its hand as by its brain. Using one is no less creative than using the other, and using both together represents the very best of the human mind and spirit. Far from being dehumanizing, science and technology and working with material things are rewarding and satisfying at a deep emotional level.

Harry Kleinberg is, by nights, the author of *How You Can Learn to Live with Computers*, published by Lippincott this fall. Weekdays, from eight to five, he is Manager of Corporate Standards Engineering in Cherry Hill, N.J.

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In the course of reaching his conclusions, Florman, for all his defense of engineers, gives us hell for refusing to admit that we find our work satisfying, and sometimes even fun. Pirsig makes his essential point that much of the peace of mind so sought after by the mystics can be found in doing good and careful work on something as mundane as an old motorcycle. It would be unfair to more fully summarize their conclusions without adequately developing their reasoning. Such a summary would sound maudlin and, taken out of context, would inevitably collide with the stubborn unwillingness of engineers to think about such "emotional" matters. I would suggest that you read one or both of these books to see whether they express something that you have always known, but have never thought much about.

Ed Note: Is the anti-techology attitude as pervasive as these authors indicate? Has it affected you, your work, or your social life? We'd be interested in hearing readers' views on this problem, which affects us all as engineers. Address correspondence to Editor, *RCA Engineer*, Bldg. 204-2, Cherry Hill, N.J. 08101.

Current modulation of laser diodes gives direct fiber-optic baseband tv

Standard methods for modulating laser diodes are not suitable for the low-frequency requirements of baseband tv. This method provides an economical means of putting closed-circuit tv on a fiber-optic link.

D.R. Patterson

Many wideband fiber-optic communication systems employing laser diodes as light sources use conventional constant-current power supplies. In these systems, a coupling capacitor supplies the ac modulation to the diode and an rf choke arrangement provides power-supply isolation (Fig. 1). This method of modulation has been useful for a wide variety of applications, including flying-spot scanners, document readers, and fiber-optic transmission of wideband rf-type carriers such as the vhf television spectrum from approximately 50 MHz to over 200 MHz.

There are applications, however, that may require the high power density and narrow beamwidth of laser diodes, but do not fully use the wide bandwidth capabilities of the diodes. These applications include baseband television (the 30-Hz to 4.5-MHz signal from a closed-circuit tv camera, video tape recorder, etc.) and its associated pulse distribution, audio, low-frequency facsimile, and digital and remote-control transmissions in optical cables. Here bandwidth requirements are of the order of 10 Hz to 8 MHz. The above-mentioned rf coupling capacitor and choke arrangement are not suitable at these low frequencies.

RCA Laboratories has designed a modulator that allows the necessary low-frequency modulation of the laser diode in a manner that retains the constant-current nature of the basic bias supply. This method allows the low-frequency signal to be transmitted directly without first putting it in the form of an rf carrier before modulating the laser diode.

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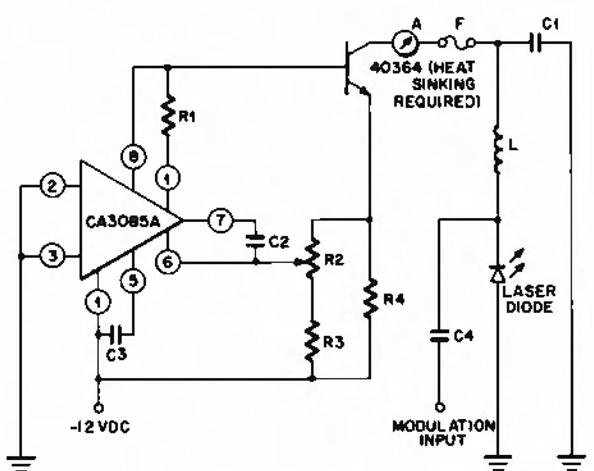

Fig. 1
Laser modulation in typical system is coupled in through capacitor C4, with rf-choke isolation from the power supply. Method shown here, which is for the RCA C30125 cw injection laser system, is not suitable for low-frequency (and thus baseband tv) applications.

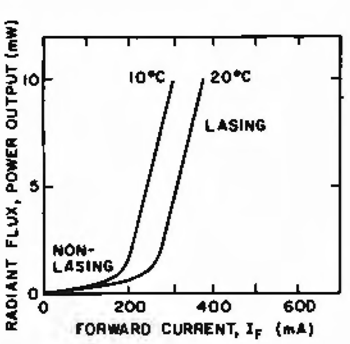

Fig. 2
Transfer curve for typical laser diode (RCA C30127) is steep, requiring a stable power supply; and temperature-sensitive, requiring a feedback cooling system.

Laser device characteristics

Fig. 2 shows a typical transfer curve (optical power output vs. operating current) for an RCA C30127 laser diode as a function of temperature. Two features of the figure are important from a design consideration: 1) above a threshold point, typically 300 mA, the slope of the transfer curve is steep, requiring good power-supply stability; and 2) the operating threshold point is temperature-sensitive.

To stabilize the operating temperature, a small thermoelectric cooler module has been incorporated in a feedback system using a temperature-sensing thermistor located in the base of the laser-diode heat sink. This temperature stabilization system[1] maintains the laser operating temperature to within a few tenths of a degree C.

Constant-current modulator

Fig. 3 shows a conventional current-feedback operational amplifier circuit with an added modulation source, V_{mod}, in series with the reference supply, V_{ref}. Using the concept of virtual grounds at the input of the amplifier, the load current, I_L is given by the expression

$$I_L = (E_r + V_{mod}) / R_s$$

where E_r is an adjustable dc bias voltage (operating or Q point), V_{mod} is the ac modulation voltage, and R_s is the value of a current-sampling resistor.[2] The graph in the upper corner of Fig. 3 shows the constant-current nature of the output for varying load lines.

System design considerations

From a practical standpoint, a number of areas must be considered in designing a suitable modulator power-supply system. The steepness of the transfer curve requires components with good temperature stability to minimize thermal drifts associated with the operating-point bias. Dissipation overrating on the pass devices and current-sampling components is therefore necessary.

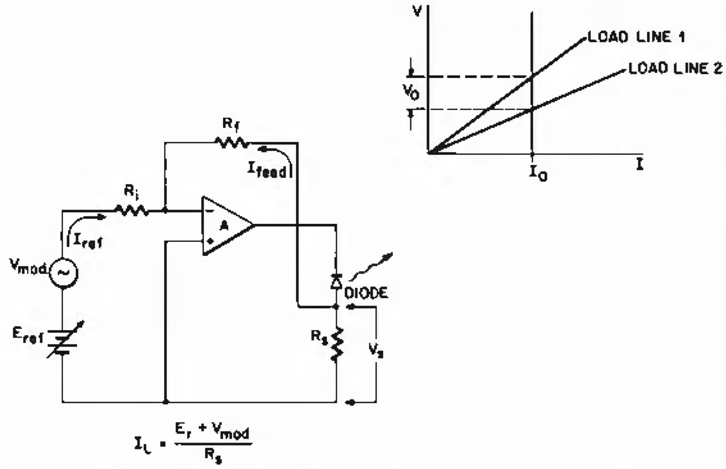

Fig. 3
Constant-current output (right) is a result of op-amp circuit in current-feedback configuration.

David Patterson is now working on electronic circuitry support in the areas of LED and semiconductor laser stabilization and modulation, as used in developmental fiber-optics systems and test facilities. His previous experience at RCA Laboratories includes work on infrared television camera systems.

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Transients are probably the most notorious sources of failures of solid-state laser diodes. These include power-supply turn-on and turn-off transients, in addition to transients supplied by external modulating sources. Cost considerations are likewise important in the design of a suitable commercial system.

The modulator shown in Fig. 4 was constructed with the above design considerations in mind. The CA3085A voltage regulator integrated circuit was found to perform the desired modulation at modest cost, compared to other wideband operational amplifiers, with only a minor change in circuit configuration. A modulation input amplifier and a voltage pre-regulator with current limiting were provided to complete the modulator. To meet present laser-diode operating-current ranges, the modulator has an adjustable operating-point bias range of 120-350 mA and an adjustable modulation capability of 90 mA peak-to-peak.

The circled numbers in Fig. 4 refer to the waveforms shown in Fig. 5. The effects of

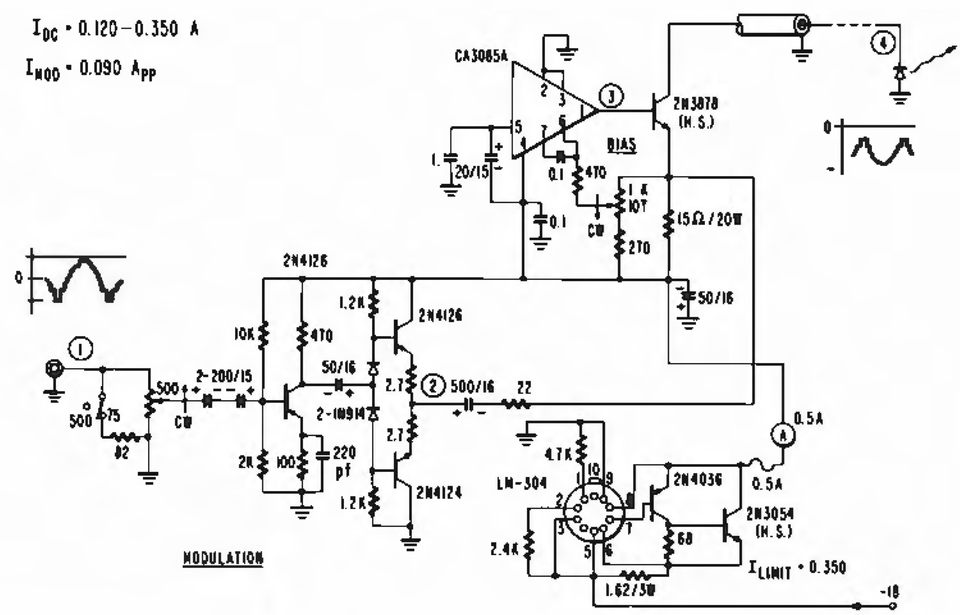
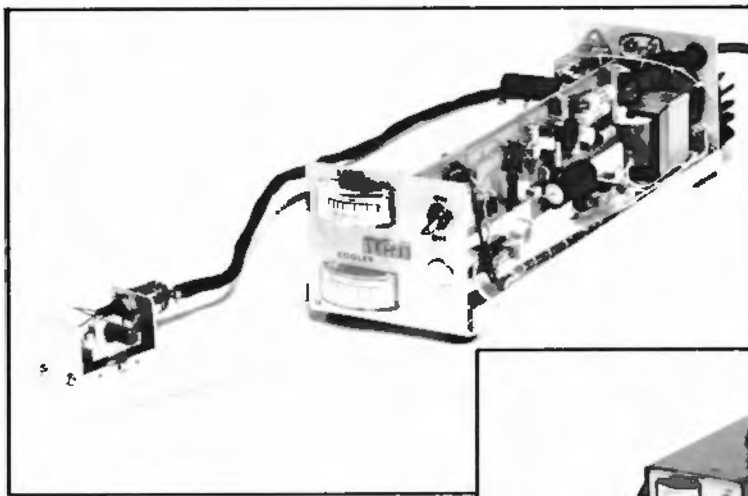


Fig. 4
Modulator circuit uses CA3085A voltage-regulator IC, modulation-input amplifier, and pre-regulator with current limiting. Operating point and modulation capability are adjustable.

feedback on the bandwidth of the system can be noted by comparing the input video sweep signals (10 MHz at a 60-Hz rate) with the voltage drive to the pass transistor and the final constant-current output signal. As the high-frequency information becomes attenuated by the circuit effects, the negative feedback compensates by allowing the gain for the high-frequency information to increase.

The complete unit consists of two pieces. The laser diode, thermoelectric cooler, and thermistor are in one detachable package, and a common power supply, the temperature control, and modulating circuitry are in the second. Fig. 6 shows the finished system with "pig-tailed" optical fiber attached to the removable laser-diode assembly.



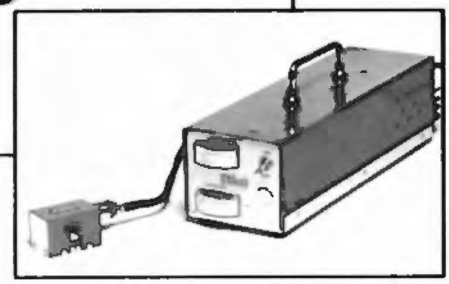


Fig. 6
Finished system with and without covers. Power supply, temperature control, and modulating circuitry are in unit at right; laser diode, thermoelectric cooler, thermistor, and coupling to optical fiber are in unit at left.

Conclusion

A semiconductor laser modulator allows low-frequency (10 Hz to 8 MHz) signals to be inserted within the feedback loop of a conventional constant-current power supply, thereby providing low-frequency capabilities to the present laser power-supply system. The system allows direct modulation of baseband television signals, and an associated audio subcarrier could easily be added.

Acknowledgments

The laser diodes were fabricated under the direction of Ivan Ladany. The demonstrator unit pictured in Fig. 6 uses a laser diode package developed by James Wittke; it incorporates an optical fiber coupled to the diode mount.

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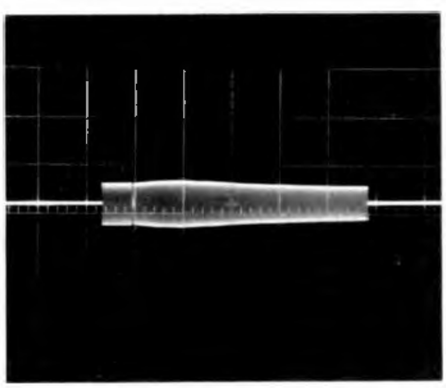
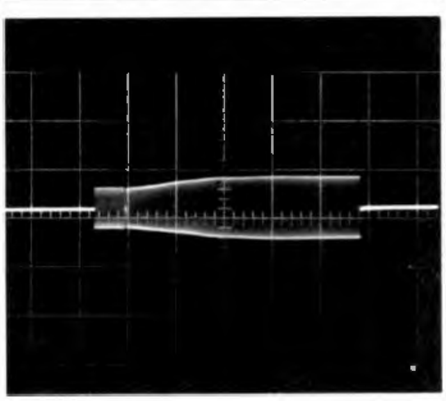
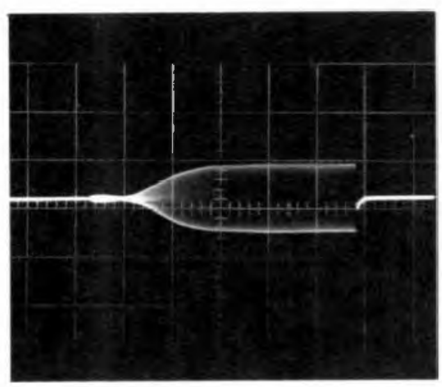
1. Wittke, J.P., Patterson, D.R.; and Ladany, I.; "Stabilization of cw injection lasers," RCA Technical Note TN 1005 or Data Sheet RCA Developmental Laser Types C30127.
2. See for example, Millman, J. and Taub, H.; *Pulse, Digital and Switching Waveforms*, New York, McGraw-Hill, Sections 1-8 and 1-9.



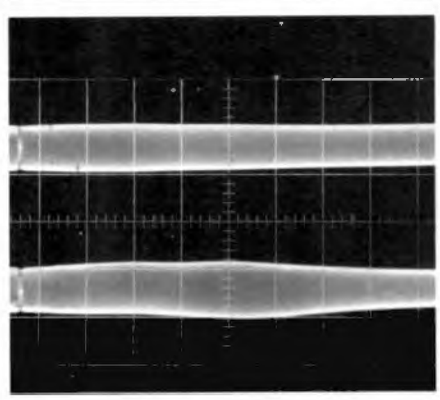
1 Video input signal
10-MHz sweep
1 V/vertical division



2 Amplifier output
10-MHz sweep
0.5 V/vertical division



3 CA3085 IC output
10-MHz sweep
0.1 V/vertical division



4 Top:
Video sweep input
10-MHz sweep
1 V/vertical division

Bottom:
Output current
10-MHz sweep
20 mA/vertical division

Fig. 5
Waveforms from circuit of Fig. 4 show the effect of feedback on system bandwidth. As the high-frequency information becomes attenuated, feedback has high-frequency gain increase.

The tokamak approach to controlled thermonuclear fusion

H. W. Hendel

As a power source, fusion has a number of potential advantages over fission. Fusion power has yet to be shown as feasible, but second-generation devices now under development should approach the power break-even point.

Power generation by controlled fusion holds the promise of unlimited, inexpensive fuel, and greater safety and negligible environmental hazard relative to fission reactors. Fusion has thus become one of the preferred approaches to solving the world's long-term energy problems, although its feasibility must still be demonstrated. Research towards producing fusion power based on synthesizing the heavy hydrogen isotopes deuterium and tritium into helium has progressed, despite many difficulties, to the point where reaction rates similar to those required for fusion reactors now appear to be within immediate reach. Following up on these recent achievements, next-generation fusion devices are being developed, some of which are designed to generate about 10 MW of fusion power (without conversion to electricity), comparable to the heating-power input, to demonstrate power break-even and scientific feasibility.

The Princeton University Plasma Physics Laboratory (PPPL), under contract to the U.S. Energy Research and Development Administration, has pioneered the development of fusion, with RCA one of its original industrial contractors in the early 1960s. PPPL's Tokamak Fusion Test Reactor (TFTR), now under construction and planned for operation in 1981, is expected to be the first fusion device to operate at reactor-like power densities. It will burn deuterium and tritium, the reference cycle for fusion-power reactors, with the highest reaction cross-section at conditons attainable now. Experimental power reactors are expected to be in operation and producing many tens of megawatts of electricity in about 1985.

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Theory behind the fusion reaction

Energy is liberated in fusion reactions because the binding energy per nucleus for the lightest elements is less than that for those with intermediate mass numbers. Thus, the sum of the masses of the initial, heavy-hydrogen isotopes is greater than the mass of the final reaction products (helium and neutrons), and the excess mass is converted to energy. However, fusion reactions do not occur spontaneously at room temperature. The reacting nuclei are positively charged, and the long-range Coulomb repulsion must be overcome before the short-range nuclear forces can give rise to fusion: the relative kinetic energy of the reacting nuclei must be raised either by acceleration (to $\geqslant$ 10 keV) or by temperature increase (to $\geqslant$ 100 million °C). At this temperature, the fusing isotopes will exist as a fully-ionized net-charge-neutralized ensemble of ions and electrons—a plasma.

Thermonuclear fusion, recognized in the 1930s as the stellar energy source (and thus the origin of solar and, indirectly, fossil power), was applied (uncontrolled) for the first time on earth in the (heavy-) hydrogen or fusion bomb. The large amount of energy released and the unlimited availability of deuterium fuel (tritium is not naturally abundant) in the oceans made controlled fusion-power reactors highly attractive. Each fusion reaction liberates about 20 MeV; the nuclear energy in the deuterium contained in one gallon of water is equivalent to the chemical energy in 300 gallons of gasoline, and the cost of this amount of deuterium is a few cents.

Practical problems and solutions

However, some of the scientific and engineering aspects of fusion reactors were immediately recognized as awesome. For prolific fusion of heavy hydrogen, a temperature of 10^8 °C, much higher than

Table I
Three fusion reactions are now used or projected for use in the next generation of fusion devices—deuteron-deuteron, deuteron-tritum, and deuteron-^{3}He.

d-d	$\rightarrow$ ^{3}He 0.82 MeV	+ n 2.45	First reaction used. d-supply unlimited.
	$\rightarrow$ t 1.01 MeV	+ H 3.02 MeV	
d-t	$\rightarrow$ ^{4}He 3.5 MeV	+ n + 14.1 MeV	Highest cross-section for present conditions. t is β-radioactive and so has handling difficulties.
d-^{3}He	$\rightarrow$ ^{4}He 3.6 MeV	+ H 14.7 MeV	No neutrons, only charged particles generated. Low cross section at low temperature.

ever previously achieved, must be attained. Thus, with the heat input per nucleus ~ 10 keV, close to one percent of the nuclei in the host plasma must be fused to produce the desired large power multiplication. This corresponds to a long, never-before-reached or even-considered particle confinement time of about one second. The hot plasma must be kept from interacting with the walls of its container, which acts as a heat and particle sink and a source of impurities; in addition, fuel must be replenished and burned-out reaction products must be removed.

One solution to the wall-interaction problem was the "Stellarator." A toroidal (doughnut-shaped) magnetic-confinement plasma device, it was proposed by L. Spitzer in 1951 at Princeton's Astrophysics Department. In the Stellarator, particle motion toward the wall is reduced by a confining magnetic field, directed parallel to the walls, so that the charged particles spiral around the field lines and move parallel to them, but do not connect with the walls easily. Today the tokamak, a Russian version of the toroidal device, has become the major approach, worldwide, to magnetic-confinement fusion and to fusion reactors in general. In tokamaks, plasma temperatures of 10^7 °C and (slowly) fusing plasmas are now produced routinely. This article concentrates on toroidal magnetic-confinement fusion as pursued at the Princeton University Plasma Physics Lab; similar work is carried on at Oak Ridge National Lab, Gulf-Atomic, MIT, and in Europe, Japan, and, with the biggest effort, the USSR.

Reaction characteristics and requirements

All fusion reactions are not created equal.

The characteristics of the fusion reaction chosen determine plasma properties and the device parameters necessary to attain an acceptable fusion reaction rate, the radiation effects, and the effects of the products on the device and its surroundings. The strength of the Coulomb barrier increases with the number of protons in the nucleus, so that the isotopes of hydrogen, having only one proton, have the highest cross-section. For low plasma temperatures, the cross-section rises rapidly with temperature, resulting in sufficiently high reaction rates at ~10 keV. Three reactions are now used or projected for use in the next generation of fusion devices: d-d, d-t, and d-^{3}He. See Table I for details.

Note, however, that even for carefully selected conditions, it may not be possible to favor one reaction and suppress others completely. In d-plasmas, about 50% of all reactions produce tritium, which in turn gives rise to d-t reactions; likewise, in a d-^{3}He mixture, d-d reactions producing neutrons will occur. The fusion power generated supplies both the useful power output and the plasma heating necessary for an ignited reactor to compensate heat losses. As a rule, fusion-reactor plasmas are transparent to neutrons, so the neutron energy must be absorbed outside the plasma and converted into heat. A major fraction of the charged fusion-reaction products is lost (at full energy) from currently available small plasmas, but large, ignited plasmas are expected to receive all heat-input from energetic charged particles. Charged fusion-reaction products must therefore be sufficiently confined so that most of their energy is dissipated into the plasma and the ignited plasma keeps burning without auxiliary heating.

What are the plasma conditions required for breakeven?

The plasma conditions required for a fusion reactor were derived by Lawson in 1959 from power-balance considerations. The fuel must be confined, at approximately the ignition temperature, for a sufficient time τ to generate energy beyond that invested to heat the fuel. Thus, at low density, the confinement time must be long; at high density, the reaction rate ($\sim n^2$ where n is plasma density) is high and confinement time can be short. Lawson's criterion can be expressed in terms of $n\tau$, with an $n\tau > 10^{14}$ s/cm^3 indicating reactor conditions for d-t plasmas. Table II lists approximate reactor conditions and current progress towards these goals.

Table II
Three conditions must be met to achieve a positive power balance in a fusion reactor. Table shows where tokamak-type fusion development stands today.

Condition	*Necessary value*	*Now attained in tokamaks*
temperature	$\geqslant 10^8$ °C $\cong$ 10 keV	~ 1.5 keV
density	$\geqslant 10^{14}$ cm^{-3}	$> 10^{14}$ cm^{-3}
confinement time	$\geqslant$ 1 s	~0.1 s

Hans Herdel has been RCA's consultant to Princeton Plasma Physics Laboratory since 1965. He pioneered in collisional drift (or universal) instabilities, their discovery, identification, mode stabilization, and evolution to turbulence; drift-wave-caused diffusion; feedback stabilization of instabilities; anomalous rf-absorption caused by parametric instabilities; and current-driven instabilities in isothermal plasmas.

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The implication of the one-second confinement time in Table II may be appreciated better by expressing it differently—the equivalent mean free path of the ions before fusing is comparable to a trip around the earth. Since the fusion reactor is necessarily limited in size, the confinement of the plasma away from the walls is one of the major problems in fusion research. Moreover, the wall is not only a sink of particles and energy, but it may also become a source of impurity atoms that will be ionized and will cool the plasma by radiation.

The Coulomb-collison cross section is generally a few orders of magnitude larger than the fusion cross section at the relevant conditions. Confinement of the hot plasma might be expected to improve as temperature is increased, because of the reduction of the Coulomb-collision cross-section, q. With increased particle energy, $q \sim 1/E^2$, which results in negligible binary-collision diffusion for fusion plasmas. However, the main contribution to losses from confinement is often caused by plasma instabilities; electric-field fluctuations, by interacting with the charged particles in the presence of the confining magnetic field, can transport plasma to the wall much faster than particle-particle collisions. Wave-particle effects also loom large because of the multitude of instabilities that may be present in plasmas.

A confined plasma is generally not in stable equilibrium; fluctuations and waves may be generated by perturbations from the equilibrium. In addition to unstable modes similar to those occurring in non-ionized gases and fluids, charge separation in plasmas may be restored by electrostatic forces, and displacement of the plasma may be counteracted by magnetic forces; additional eigenfrequencies and modes are related to the confining magnetic field. More than one hundred instabilities have been catalogued. In terms of the reservoirs of free energy available, instabilities can derive their energy from: 1) expansion energy; 2) directed kinetic energy of ions or electrons; 3) magnetic energy; and 4) deviations from the Maxwellian energy distribution. The effects of wave-particle interactions may produce an anomalous "effective" collision frequency, which in turn may generate undesirable (enhanced particle and heat losses) and desirable effects (anomalous resistivity and heating).

The tokamak

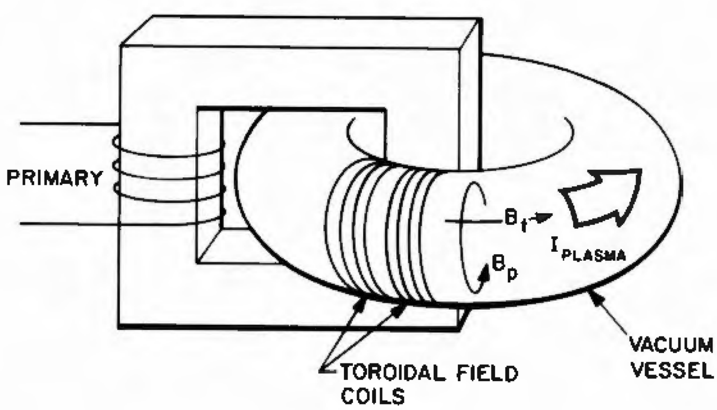
The tokamak, the Russian counterpart of the Stellarator, consists of a toroidal vacuum chamber and a toroidal ~ 5-T magnetic field (1 T (Tesla) = 10^4 gauss) generated by external coils. A transformer induces a current in the plasma contained in the vacuum vessel, so that the plasma doughnut becomes the secondary winding, Fig. 1. The (toroidal) plasma current (~ 10^6 amp) heats the plasma by electron-ion collisions, i.e., resistive, Ohmic dissipation. Moreover, this current also generates a poloidal magnetic field (~ 0.5 T), which, when superposed on the main toroidal field, forms helical field lines and improves plasma equilibrium. A third magnetic field, the vertical field, ~0.1 T, interacts with the plasma current to provide equilibrium by counteracting the major-radius expansion (which occurs in the absence of a poloidal field based on external conductors), and allows the plasma to be positioned inside the vacuum vessel, relative to the major radius, R.

The combination of magnetic fields produces particle orbits having banana-shaped projections.

The strength of the toroidal magnetic field increases towards the center of the torus, $B_t \sim 1/R$. Together with the helical field, this leads to a particle-transport mechanism not present in linear geometry. As a particle moves along a helical field line, starting on the outside of the torus, it spirals towards the inside, i.e., smaller R, where the magnetic field is stronger. The particle may then be magnetic-mirror reflected because of the tendency of strong-field regions to expel a fraction of the incoming charged particles. At the low collision frequencies of fusion plasmas, a small fraction of the particles will be trapped between such magnetic-field mirrors. The projection of the particle orbits into a poloidal cross section is banana-shaped (also shown Fig. 1); hence this type of diffusion is called *banana*, or neoclassical, transport. Expressing the diffusion coefficient as the square of the mean step size times the collision frequency, the step size (banana-width) is determined by the poloidal Larmor radius. Thus, neoclassical diffusion due to the poloidal ion Larmor radius is about two orders of magnitude larger than "classical" diffusion due to the toroidal-field Larmor radius.

High plasma temperatures require special heating methods.

As the plasma temperature increases, Ohmic heating becomes less effective, at about 1 to 3 keV temperature. Different heating methods are necessary for reaching higher plasma temperatures. The most promising and best developed supplementary heating method, beyond Ohmic heating, is neutral beam injection. (Ion beams cannot be used, since ions that penetrate into the magnetic field will also leave the confinement immediately.) Intense beams of energetic atoms (four to six 65-amp beams at 120 keV for the TFTR) are generated by charge-exchanging ion beams; the fast-atom beams penetrate into the plasma until they are ionized, and the beam velocity determines the penetration depth. The energetic ions thus created inside the plasma remain confined, transferring their excess energy to the plasma. Experiments in earlier tokamaks



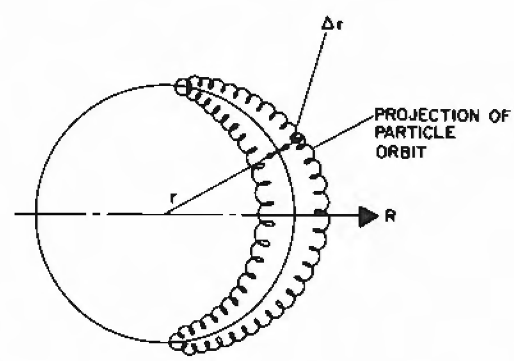


Fig. 1
Doughnut-shaped tokamak uses external coils to generate a strong toroidal magnetic field. The transformer-induced plasma current produces a weaker poloidal magnetic field, and the two combine to form helical field lines. (A third weaker field, the vertical field, is not shown here.)

Banana-shaped particle path results when particle orbit is projected onto poloidal cross section of torus. See text for explanation.

indicated efficient energy transfer of the neutral-beam power to the plasma.

Another heating method is adiabatic compression of the plasma by increasing the magnetic field strength, which was used during earlier experiments at PPPL and found to increase plasma temperature and density as predicted. A third method for auxiliary heating, not yet well documented in larger tokamaks, is rf heating. Generally, the heating frequency is chosen at or near one of the resonances of the plasma, the ion cyclotron and magnetosonic frequencies ($f \sim 50$ MHz), the lower hybrid frequency (~ 1 GHz), and the electron cyclotron and upper hybrid frequencies (~ 100 GHz). RF heating's principal problem is expected to be in operating the power-coupling structures in the hostile vicinity of the fusion plasma, where electrical breakdown may be facilitated by the presence of ions and electrons from the plasma and of secondaries from the nuclear radiation.

The two-component tokamak has some excellent advantages, but one major disadvantage.

Most previous plasma experiments and reactor designs were based on plasmas with Maxwellian energy distribution. The availability of intense, high-energy neutral beams and Ohmically heated tokamak plasmas slightly below the ignition temperature led to the proposal in 1971 at PPPL of a scheme that allows "break-even" attainment under less demanding plasma temperature conditions. In the two-(energy-) component tokamak (TCT), neutral-beam injection of deuterium can be used to generate a high-energy deuterium component, which interacts with the bulk plasma at the higher (nuclear) cross-section of the energetic beam. This increases the reaction rate by an order of magnitude over the Maxwellian-distribution reaction rate of a similar deuterium plasma heated by a (nonfusing) hydrogen beam, as was experimentally shown at PPPL.

Thus, with the TCT method, the fusion power density generated is raised by an order of magnitude, and the $n\tau$ values required by the Lawson criterion to achieve power break-even in a Maxwellian plasma are lowered by an order of magnitude: both the objectionably low power density and the large size of (Maxwellian) magnetic-confinement fusion reactors might be improved. However, an inherent limitation of the TCT is its low power amplification, which is small (2 to 3) relative to the arbitrarily large amplification factors of ignited reactors. In any case, since neutral-beam injection is now the preferred heating method, the two-energy-component regime will have to be traversed and studied as a preliminary to ignition by beam injection.

Tokamak scaling looks good.

Another highly promising result of recent tokamak work is the observed scaling of the energy confinement, τ_E, with plasma density, n, and plasma minor radius, a, which indicates the potential for large improvements of the operating conditions. Combining measurements from a variety of tokamaks now in operation, one finds that observed energy confinement scales as na^2 (Fig. 2). The scaling with plasma minor radius is important, since future reactors will necessarily be larger than present devices. The plasma-density scaling

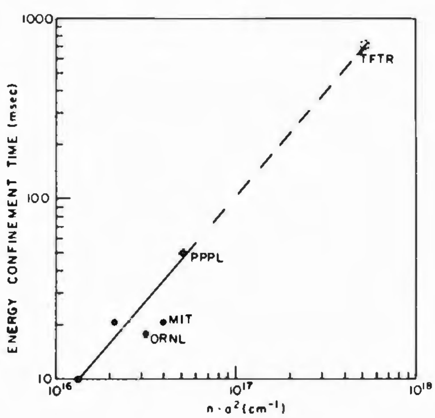


Fig. 2
Tokamaks show strong economy of scale— energy confinement time improves with na^2, the product of the plasma density and the square of the minor radius of the torus.

Where do tokamaks fit into the overall fusion picture?

The tokamak is only one of a number of approaches toward producing controlled fusion power. Each method has its proponents who want it to get the research (and research dollars). Presently, though, tokamaks are more highly developed and appear to have the highest probability of achieving fusion power. RCA's only connection with the tokamak today is the author of this paper, Hans Hendel, who has been a consultant to the Princeton Plasma Physics Laboratory since 1968, through RCA Laboratories.

The major differences among the various approaches lie in their methods of confining the plasma. Stars use gravity, which is cheap and reliable by anybody's standards, but that only works because of the stars' huge masses. Tokamaks use magnetic fields to confine the plasma, but they are not alone in doing so—magnetic-mirror and "theta-pinch" reactors are two more. Laser fusion uses a form of inertial confinement in which very small fuel pellets are heated and compressed by very large laser pulses to produce the fusion "burn." The resulting explosions are thus small enough to be handled by relatively standard systems. After a late start relative to the magnetic-confinement approaches, laser fusion has made considerable progress, but has yet to be shown feasible.

If the nuclear particles chosen are "advanced" fuels, the fusion products will all be charged particles and there will be less neutron-induced structural damage, radioactivity, or environmental problems associated with the neutron flux of other fusion power plants. Another potential advantage with advanced fuel reactions is that, with them, it may be possible to convert the kinetic energy of the charged fusion products directly into electric energy and avoid the steam/turbine/generator system and its problems. Such a fusion system would have to be classified as a "dream" system, however, since it is far from realization.

Good descriptions and explanations of these other fusion programs can be found in "The prospect for fusion power," *Technology Review*, (Dec 76) and "The future with fusion power," *Mechanical Engineering* (Apr 77). For a discussion of fusion power that includes an analysis of its drawbacks (large size and cost, potential differences between the ideal cycles and what the fusion program is likely to deliver), see "Fusion research" in *Science* (Jun 25, Jul 2, and Aug 20, 1976).

—*W.D.L.*

Table III

Toroidal confinement devices around the world. Experimental power reactors are planned for operation in about 1985.

Device	Location	Year	Major radius R (cm)	Minor radius a (cm)	Current J (10^6amp)	Magnetic field B (T)	Ion temperature T_i (keV)	Neutron density n ($10^{14}cm^{-3}$)	Confinement time τ (s)	Confinement criterion $n\tau$ (s/cm^3)
C-Stellerator	Princeton	1965	100	5		3.5	.04	0.1	10^{-3}	10^{10}
PLT	Princeton	1977	130	45	0.6	4.0	1.0	1	<0.1	$<10^{13}$
TFTR	Princeton	1981	265	110	2.5	6.0	10.0	1	0.1	10^{13}
JT-60	Japan		300	100	3.3	5.0				
T-20	USSR		500	200	6.0	3.5				
JET	Europe		300	125/210 D-shaped	4.8	3.4				

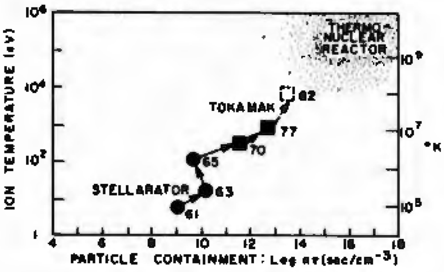


Fig. 3

Reactor conditions take place at log containment value of 14. Graph shows the extensive progress towards this goal that has been attained in a relatively short period of time.

observed is also highly advantageous (the Maxwellian fusion reaction rate is proportional to n^2) and different from classical transport phenomena, which would be expected to reduce τ_E with increasing n. The highest $n\tau$ values have been obtained in a high-magnetic-field tokamak at MIT, where high plasma density ($n=7\times10^{14}$ cm^{-3}) resulted in long energy-confinement times ($\sim 10^{-1}$s) and $n\tau$ values well above 10^{13}s/cm^3. The effect of plasma-temperature increase on energy confinement remains to be determined. Fig. 3 and Table III show the progress of toroidal confinement devices toward the fusion goal.

Problems remaining

Assuming that reactor-size plasmas can be confined at sufficient density and temperature to produce large amounts of fusion power, additional obstacles will need to be overcome.

Neutron radiation will affect the lifetime of the tokamak's structural parts.

The first wall adjacent to the plasma, and the neutron absorbing blanket next to it, will be exposed to the full intensity of the unattenuated neutron flux. Radiation damage will severely limit the operating life-time of these structural elements because of helium generation from (n, α) reactions and atomic dislocations. The expected first-wall replacement every 3 to 5 years will substantially affect operation and cost.

There is still radioactive waste, although less than in fission reactors.

A comparison of the radioactive wastes generated in fusion, fission, and liquid-metal fast-breeder reactors indicates that fusion reactor wastes may be less than one-tenth that of fission reactors, and less than one-hundredth of fast breeders. The use of advanced fusion reactions, which produce mainly charged reaction products, and of carefully selected structural materials, may improve the outlook for fusion even more. Fusion waste products generally appear to have a much shorter half-life than fission waste.

Tokamaks are not inherently steady-state power producers.

In reactor design studies, transformer-driven discharges of about one hour are envisaged. The maximum pulse length is determined by the necessity to provide a continuous change of magnetic flux in the plasma to preserve equilibrium. During the current shut-down interval (~3 minutes), the electric output power would be supplied by stored heat. Fuel injection of 300 one-millimeter-diameter frozen fuel pellets per second at a velocity of 5×10^6 cm/s (10 to 100 MeV acceleration voltage) has been proposed in one design.

Impurities must somehow be removed from the plasma.

The prevention of impurity influx or, alternatively, the removal of impurities to maintain an acceptable impurity-ion level, may turn out to be one of the most severe obstacles to fusion. Magnetic "divertors" are planned for some next-generation devices to direct the impure plasma adjacent to the walls into special absorption chambers.

Cost estimates

The cost of electricity from fusion has been estimated to be comparable to that of present power costs. Since fusion fuel costs are negligible, anticipated future price increases of fossil and fission fuels, coming from resource depletion and processing cost escalation, will work in favor of fusion.

The outlook

TFTR will produce reactor-like conditions in the early 1980s; experimental reactors should produce electrical power after 1985.

To assure the operation of fusion-power demonstration reactors in the 1990s, a series of increasingly complex devices is planned, both in this country and abroad (see Fig. 4). The Tokamak Fusion Test Reactor at PPPL (Fig. 5), which is expected to generate about ten megawatts of fusion power under reactor-like conditions (without producing electricity), will represent an intermediate level between today's small, zero-power experiments and the experimental power reactors anticipated to produce electrical power and to demonstrate ignition after about 1985.

The industrial contractor supporting PPPL consists of a team of Ebasco and Grumman engineers. TFTR costs are estimated to be 225 million dollars and initial d-d operation is expected by 1981. The design-operation span is eight years, with

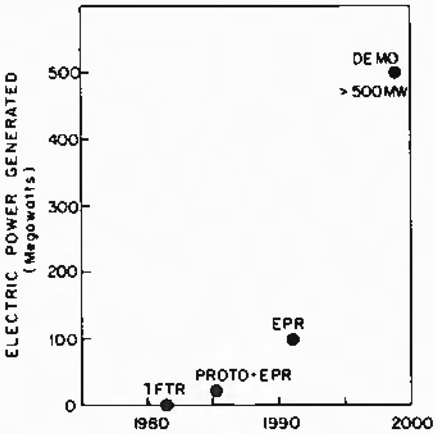


Fig. 4
Fusion power step by step. Tokamak Fusion Test Reactor is scheduled for operation at Princeton in the near future. Then come the prototype and actual experimental power plant in the later 1990s.

RCA's early involvement in the fusion effort

RCA engineers were working on fusion power at its very early stages of development with the C-Stellarator, the first toroidal magnetic-confinement fusion device. (The corporation's contribution to the C-Stellarator was summarized in a series of five articles in the Feb/Mar 1961 issue of the *RCA Engineer.*) Beginning in 1957 a group called C-Stellarator Associates managed the development, design, fabrication, installation, and testing of the C-Stellarator research facility specified by the scientists of Project Matterhorn (later renamed the Princeton Plasma Physics Laboratory), Princeton University, and the Atomic Energy Commission. The engineers and scientists of C-Stellarator Associates were drawn from various RCA product divisions, the RCA Laboratories, and the Allis-Chalmers Corp.

RCA Electron Tube Division engineers designed, developed, and built the ultra-high-vacuum system; Broadcast Division engineers, the rf power equipment; and Electronic Data Processing engineers, the control timer and data-handling system. Allis-Chalmers engineers concentrated on the motor-generator, mechanical structure, magnetic field coils, and controls for these subsystems. The C-Stellarator operated until about 1968 and then was modified into the first tokamak outside the USSR, the Princeton ST (Symmetric Tokamak). A summary of RCA's background in plasma and fusion research would be incomplete without mentioning supporting work, during and after the Stellarator effort, done at RCA Laboratories and the operating divisions.

four years of tritium use. Early experiments in hydrogen and deuterium will study confinement and scaling laws and will provide operational check-out before the more troublesome tritium is introduced. It is assumed that fusion power densities of $\sim 1\ W/cm^3$ will be attained, which is comparable to those of reactors.

The fusion power generated is predicted to equal the injected neutral-deuterium-beam power (tritium plasmas), so that breakeven conditions should be achieved. In the TFTR, the neutron power will be allowed to escape—there will be no attempt at conversion. The alpha-particle energy from the fusion reaction is expected (on the basis of computer simulation of the orbits) to be largely deposited in the plasma, and should exceed the Ohmic-heating power, resulting in measurable effects on the plasma. The magnetic field strength will be above 5 T and the maximum plasma current 2.5 million amps. The standard pulse length will be one second, but longer pulses are possible. Neutral-beam-injection pulse length will be 0.5 second, with a total of 20 MW of 120-keV neutral-deuterium power delivered to the plasma. The minor and major radii of the device will be 1.1, and 2.65 meters, respectively. Because of the activation resulting predominantly from the 14-MeV d-t neutrons ($10^{12}\ n/cm^2$-s at vacuum wall for 20-MW d-t power), remote handling for maintenance and repair will be necessary. An automatic system will handle the radioactive tritium and supply it to the TFTR. No divertor for impurity reduction is planned. Plasma behavior during operation will be diagnosed by some forty simultaneous methods; for example, six different microwave probes will be available—two 2-mm and 4-mm interferometers and two 4-mm scattering apparatus. All data relevant to TFTR performance and control will be collected by CICADA, the Central Instrumentation Control and Data Acquisition.

Conclusion

Our energy-hungry society is demanding stable solutions to its long-term energy-supply problems. Harnessing controlled thermonuclear fusion will tax all our inventiveness, but it promises reduced environmental hazards relative to fission, and low-cost, abundant, inexhaustible fuel not subject to future price escalation resulting from depletion.

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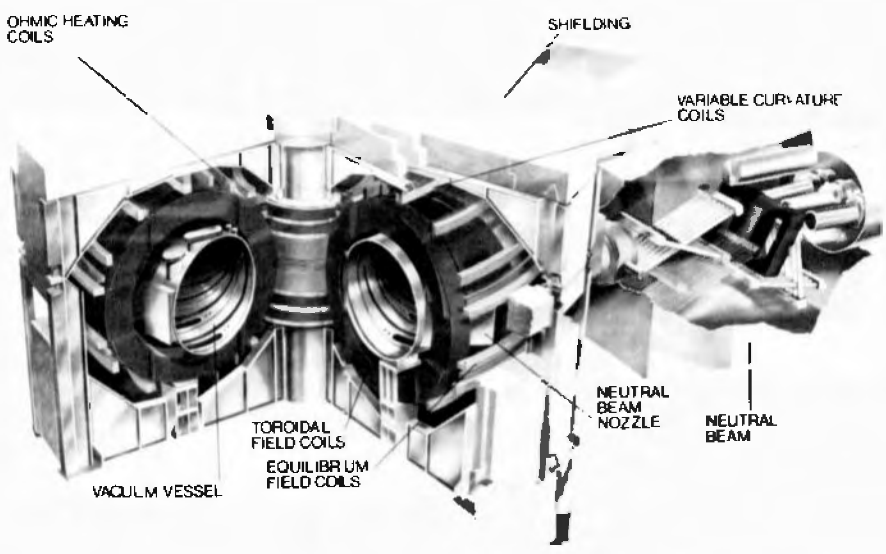

Fig. 5
Tokamak Test Fusion Reactor at PPPL is expected to generate about ten megawatts of fusion power under reactor-like conditions in 1981. It will not generate electricity, however.

Sensurround—building your own earthquake

RCA technicians knew they had a good special-effects system when the "Earthquake" audience asked, "How do they shake the floor?" Integrating Sensurround into theatre sound systems was no easy job, though.


"Earthquake"

E.G. Holub

For many years, Universal Studios felt that the public would have to be offered some sort of "event," not accessible on home tv, in order to attract large audiences into the threatres. People who make up audiences have a certain budget for outside-of-the-home entertainment, and Universal knew they had to provide something very special, so the potential audience would choose to spend their money in a movie theatre, rather than in the ball park or concert hall. One way to make films more attractive was to augment the normal theatre experience with special sound effects. Thus, Sensurround I was created to produce the auditorium-shaking sensations used in the movie "Earthquake."

RCA Technical Services' association with Universal's special-effects activity began in 1974, with the introduction of "Earthquake" and Sensurround I. RCA has now installed approximately 300 Sensurround sound-effects systems in theatres throughout the United States.

Low-frequency sound system

In Sensurround I, low-frequency sound was used to simulate earthquake rumbles and vibrations. The sound was so intense that it could be physically felt in the body as well as heard, so a special sound system had to be designed to augment the theatre's normal sound system. This special system had to be relatively portable and somewhat tailored to each theatre that would use it. Another important design consideration was that the system had to be self-operating after it was installed, so theatre personnel would not have to operate or maintain it.

Early in the project, it was realized that none of the existing standard film recording techniques could effectively record and reproduce sound below 40 Hz, where the frequencies could be physically felt in the body, so each installation was equipped with a low-frequency noise generator. Low-frequency control tones recorded on a special audio track regulated the timing and intensity of the earthquake rumble from the noise generator.

The early 15-Hz system produced good effects, but destroyed speaker after speaker.

Audio-equipment manufacturers were invited to participate in the Sensurround I conception and were asked for equipment designs. The outcome resulted in the use of stock concert-bass horns in the prototype system. For early demonstrations, a General Radio random-noise generator with a lowpass filter simulated the not-yet-designed system generator.

Even though early demonstrations used tuned cabinets (one cubic meter) that had a response tuned to 15 Hz, very low frequencies reproduced at sound pressure levels of about 120 dB (C scale, or flat response) did indeed give the illusion of actual physical vibration and movement. This sound was also physiologically effective when used with visuals depicting earthquake actions.

Therefore, design efforts began with the goal of a 15-Hz system. Many speakers were utterly destroyed while trying to attain the necessary sound pressure levels. Because of this, it was decided that the horn design had to be efficient at these low frequencies.

Designing a horn to operate with a cutoff frequency of 15 Hz theoretically requires a horn mount of about 300 square feet in area.

The low frequency also requires a slow taper rate, meaning the horn would have to be very long. Folding a horn to reduce its length usually degrades the frequency response, but only well above the cutoff frequency. Since the theatres' normal sound systems would handle the higher frequencies anyway, it was considered practical to fold the Sensurround horns.

The horn mouth area was reduced by locating the horn in a corner, so the walls and floor of the theatre formed boundaries and restricted the angle into which the horn radiated. If the horn operates into a small area, the mouth of the horn can be reduced. With a small mouth, some attentuation occurs just above cutoff and there is some frequency-response fluctuation. Since this system did not need to reproduce continuous tones, the uneven response was not important.

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"Rollercoaster"

"Earthquake"

Three horn configurations were developed for the Sensurround system.

Each type of horn used special 18" low-frequency drivers. All three designs (Fig. 1) prevented large cone excursions, which could be destructive to the reproducer.

The first horn is a "W" horn, with two fold-backs to increase the length. Because of its bulk, it is difficult to transport and cannot be used in theatres that require a low-profile horn. The second design, called the "C" horn, is a vertical corner horn that is used where height is a restriction. It uses two 18" drivers and, since it has no internal folds, must be operated into a corner. The third design, the modular "M" horn, is a widely applicable configuration that can be used in multiples by stacking. Each "M" horn contains one 18" driver and is operated into a corner or specially constructed baffling.

The horn driver units were originally standard dynamic speakers, but for Sensurround the *Bl* factor was modified and mechanical positive bias designed into the

"Midway"

moving mass. These drivers have voice coils capable of dissipating 1 kW without burning out. Combining high power with long excursions at the desired frequencies in these drivers was another problem, but experimentation produced a combination of cone suspension materials and polymer treatments that yielded the necessary excursion capability and low failure rate.

When the Sensurround activity began, there were only a very few amplifiers available that could deliver more than 300 watts.

As a result, Universal used those manufacturers' equipment that could produce this power. One problem with operating the drivers near resonance is that this makes them highly reactive and so effectively increases the loading on the driving amplifiers. Highly reactive currents are therefore driven back into the amplifier, which can falsely trip output protection circuits and cause loud chirps, squeaks, and buzzes. BGW and Cerwin-Vega amplifiers were found to operate well without these problems.

By limiting the bandwith of the amplifier it could have been manfuactured at a lower cost, but Universal wanted a full-range, general-purpose, high-powered amplifier for potential expansions to Sensurround.

The Sensurround interface

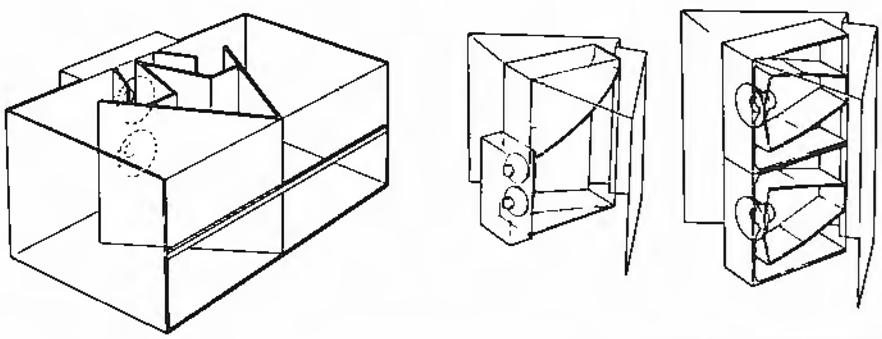
"Earthquake" was released in the three standard theatre film formats; 6-track magnetic sound on 70-mm film, 4-track magnetic sound on 35-mm film, and the old standard single-track optical sound on 35-mm film. The Sensurround effects had to interface with all of these formats.

In reality the term "standard" theatre sound equipment hardly has any meaning today. Some theatres have old subpar systems, others have been updated partially, and still others have new systems. It was thus difficult to design a system that could be quickly installed anywhere.

The final Sensurround I system configuration consisted of the horns required for a given theatre, the amplifiers to drive them, and a special control box integrated into the theatre sound system between the projector changeover switch and the audio power amplifier. See Figs. 2 and 3.

Two tones control the Sensurround effect.

The control electronics accommodates a wide variation in input and output levels and impedances. There are also a digital random-noise generator and filters that generated the earthquake rumble effect. The rumble was turned on and off and otherwise controlled by circuitry tuned to control tones recorded on the audio track of the feature. Sensurround I used two control tones, one at 25 Hz to control the



Recording engineer/producer

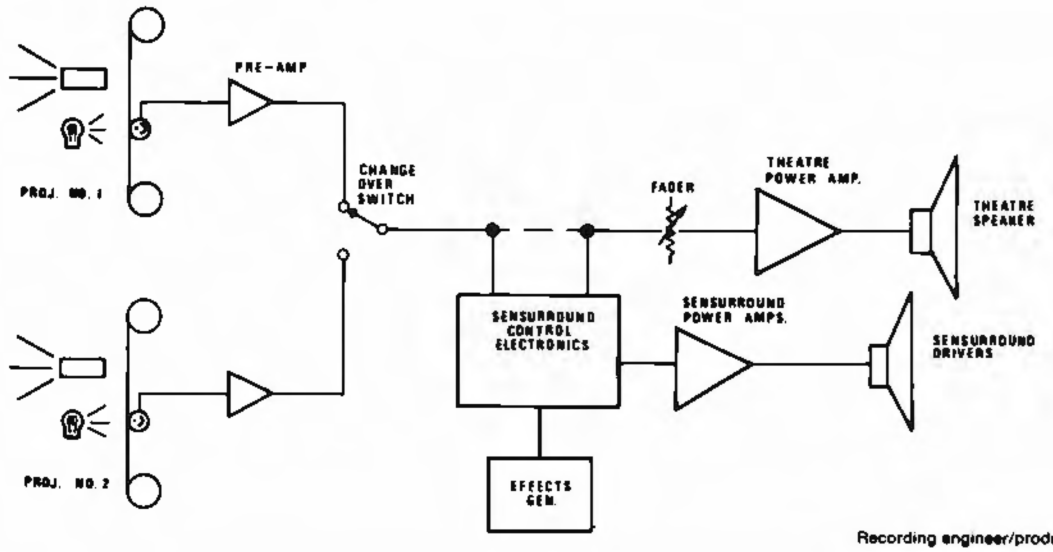
Fig. 1
Three speaker horn types are used in Sensurround. The *W* horn (left) is the largest, the *C* horn (center) is used in height-restricted areas, and the *M*, or modular, horn (right) can be stacked in multiples. Folded configurations are used to increase horn length; special low-frequency drivers are also used.

level of the rumble effect, and another at 35 Hz to combine certain normal soundtrack sounds with the Sensurround rumble for added impact. The control tones are recorded at a maximum level of 30 dB below 100% modulation, and have an analog control range of 10 dB. Tunable active filters separate the control tones.

Because of the closeness of the 25-Hz and 35-Hz tones, the detection filters had to have high Qs to enhance selectively. This, coupled with the low-level control signals, created a filter with a sluggish response time. The Q was therefore reduced and dip filters were added before each control circuit. Some time-constant lag remained, however, that had to be compensated for in the recording of the control tones. The dubbing mixers had to anticipate the action in the picture by turning the control on and off in advance of the screen action.

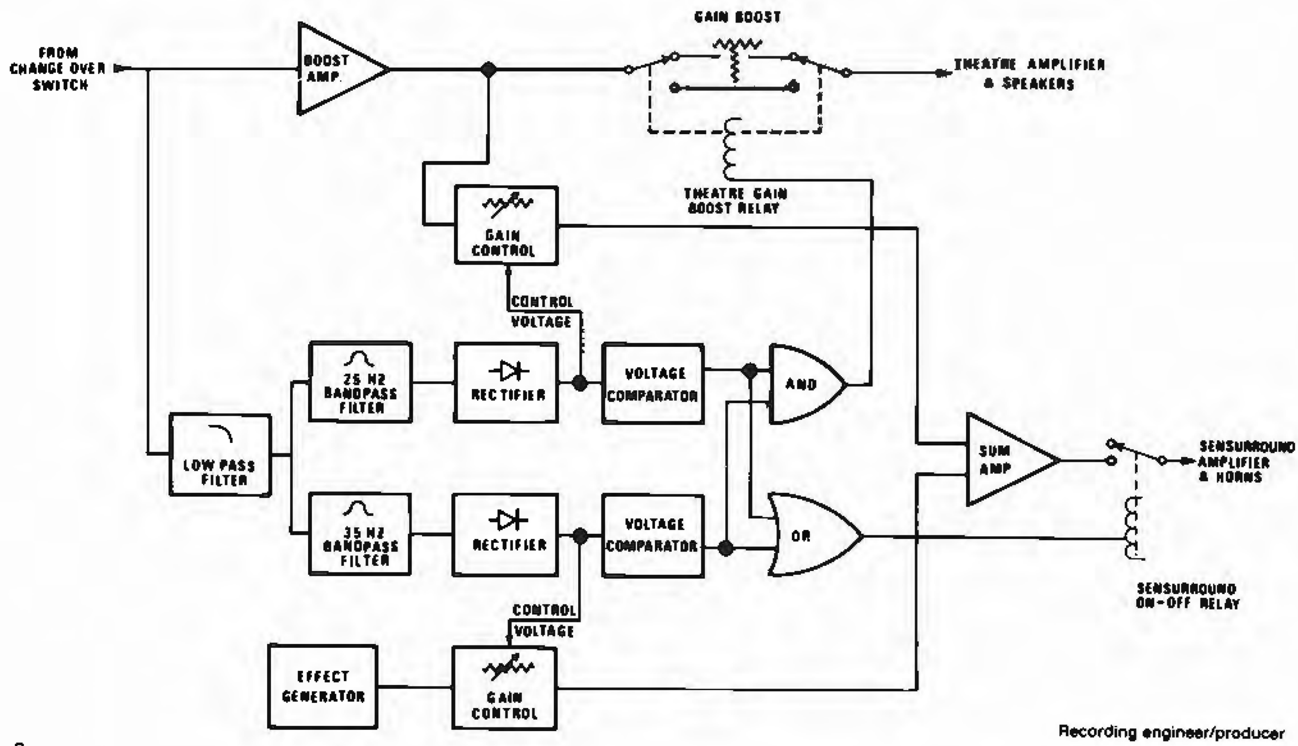
Optical and magnetic-optical sound systems required different formats.

For 35-mm optical sound formats, the control tones are recorded on the normal sound track at a reduced level. For 35-mm magnetic-optical formats, the control tones were recorded on the optical track. Since most magnetic projectors are also equipped for optical sound, the optical sound track was used for control-tone recovery, and, if necessary, an additional



Recording engineer/producer

Fig. 2
Sensurround system is an addition to, and works in parallel with, existing theatre sound systems.



Recording engineer/producer

Fig. 3
Two tones on the soundtrack control the Sensurround electronics. The 25-Hz tone controls the level of the rumble effect and the 35-Hz tone combines normal soundtrack sounds with the Sensurround rumble.

preamplifier was included in the Sensurround control electronics.

When "Earthquake" was recorded on 35-mm as an optical sound print, the control tones were mixed with the normal soundtrack material, which was rolled off below 35 Hz so that program sound would not trigger the effects. In the 70-mm format (not used in the United States) two of the six magnetic tracks were devoted to 100-Hz control tones used for effects gating and steering.

During development, Universal found that the normal sound appeared to diminish in intensity when the rumble was activated. To correct this, circuits were added to the control electronics to automatically increase the normal sound track level 6 dB when the effects were gated into operation. This created a good subjective audio balance.

RCA's involvement

The initial planning for "Earthquake" called for 17 theatres to be equipped with Sensurround by the end of the first year of operation. However, nearly 400 theatres showed "Earthquake" by using nonpermanent systems that could be moved to different theatres on demand. Installing and maintaining that amount of equipment in widely dispersed locations throughout the country required a nationwide service organization, and the contract was awarded to Technical Services of the RCA Service Company. Universal specialists trained regional RCA personnel, who in turn went into the field and trained other RCA people. RCA is now handling the installation and maintenance calls within the continental U.S. and has performed the installations in Mexico, South America, and the Caribbean. In addition, for the feature "Earthquake," RCA handled the transfer and installation of equipment into new locations.

The RCA service men work closely with the theatre managers and Universal in evaluating the theatres and installing the equipment. Upon completion of an installation, careful sound pressure level measurements are taken to assure high-quality performance of the system. The system is adjusted until an overall sound pressure level of 95 dB (A scale) is achieved at the center of the theatre, with no more than 110 dB (C scale) 4 feet in front of any horn. These levels are deemed safe for continuous human exposure for periods up to 8 hours.

Murphy's Law and nonstandard sound systems

The Simplex/Norelco XL20 optical sound system presented an interesting problem. The schematic of this one-unit hybrid amplifier is too complex to show here; it has a transistorized preamplifier and a vacuum-tube power amplifier, with transformer coupling between them.

The first attempt to connect this amp to the Sensurround I system was straightforward. The coupling capacitor was opened and the output of the preamp was fed to the Sensurround control electronics; the return from the control electronics went into a newly installed system gain control and then returned to the power amplifier. But, since there was no gain stage in the power amp, the new gain control had to be at maximum in order to obtain normal house levels. Of course, this was not tolerable, so a second attempt to break into the amplifier was made earlier at the coupling capacitor following the first stage of amplification after the photocells. However, at this point the control signals (25-Hz and 35-Hz) did not have enough gain for the Sensurround system.

Finally, the connection was made at the coupling capacitor between the two final transistor stages. Here, the preamp gain and the power amp gain were sufficient, but the frequency response could be affected at this point by the treble and bass controls. Therefore, the bass control setting had to be fixed, because if it were changed, the control-signal levels would be incorrect and the system would work improperly, if at all.

As a result of the experience gained in attempting to install Sensurround where a pickoff point had to be determined prior to disrupting the amplifier circuitry, preliminary measurements were made while running the test films to determine the point of adequate and desirable signal level.

Because of the problems created by systems like the Simplex XL20, in some cases, Universal supplied separate self-contained transistor preamplifiers that tied directly to the sound pickup device to give the necessary preamplification to the control electronics. When the signal was returned to the theatre's amp from the control electronics, it was attenuated down to the pickup input level to run through the sound system in the usual manner. This method avoided interrupting the circuitry of the original sound system and was especially helpful in systems using etched circuits.

Installing Sensurround—problems with nonstandard theatres

Even though Sensurround I was designed for versatility and ease of installation, there were difficulties in matching it to nonstandard theatre sound systems.

A standard theatre sound system historically consists of sound pickups, changeover switching mechanisms, an auditorium-equalization (compensation) panel, power amps, and the sound reproducers, consisting of a crossover network and high- and low-frequency speakers.

However, in the years since the concept of "standard theatre sound system" was conceived, the theatre business prospered, declined, then gradually improved again. During the declining years, many nonstandard economy sound systems were installed. These abbreviated systems used single amplifiers containing preamps and power amps. Changeover switching was done before the amplifier and auditorium equalization was done with simple bass and treble tone controls. Vacuum tubes were replaced with solid-state devices, and photocells were replaced by phototransistors and solar cells. Some older theatre systems were hybrids, with tube preamps and solid-state power amps or vice versa. In other systems the photocells were removed and replaced by higher-gain solar cells, necessitating amplifier circuit changes. Many of these modifications and circuit changes were never recorded.

Stereophonic magnetic sound was introduced in the late 40s, and again the hybriding of systems was compounded. Following the 4-track magnetic sound of the late 40s came the 6-track sound of 70-mm Todd-Ao. Again, newer equipment was added to the older equipment.

Today, a theatre sound system is more nonstandard than standard, so the problems the RCA Service Company theatre men encountered were many and varied.

For example, the Motiograph A7505 sound amplifier would not pass the 25-Hz and 35-Hz control signals at a usable level. This problem was easily corrected, though, by increasing the capacity of the preamps' coupling capacitors.

During the practical work of installation, problems were encountered that seemingly couldn't exist.

Universal had developed a Sensurround setup procedure using special test film that was performed by the RCA man. The final checkout was done with a short reel of the actual film. In some cases, after the setup procedure was performed, the effects from the test reel were intermittent or nonexistent. This problem was resolved and found to be caused by excessive output levels from the preamps at 25 Hz and 35 Hz into the Sensurround control unit.

On the control-tone test films, which were 400 Hz with either a 25-Hz or 35-Hz frequency imposed on the track, the Sensurround control unit would work fine. However, on the sound track of an actual reel many frequencies appeared at once and the control frequencies appeared as a modulation envelope on the normal sound. Since the basic level was too great within the preamp, the soundtrack signals were clipped in final preamp stage before reaching the control electronics. This clipping action destroyed the control tones, and so no effects were present. This problem established a maximum preamp control signal output of about −10 dBm from the preamps.

Some amplifiers did not clip the control tones on excessive sound track input to the control electronics because the low-frequency response was poor. In this case, if excessive signal output was fed to the control electronics, the normal low-freuqency theatre sound would pass through the control-electronics tone filters by brute force and activate the rumbles at the wrong time. Here again, a need was created for a maximum preamp output level to the control unit.

A theatre projection booth can be a high-noise environment.

Xenon arc lamps, high current switching, and brush motors can all cause problems. If the theatre's sound system was not installed with proper attention to grounding, noise could be a problem. Normally the Sensurround I system could work with control signal input levels as low as −40 dBm to the control unit. Experience showed, however, that in high-noise booths where the signal-to-noise ratio was poor, noise would trigger the rumbles. Switch clicks were particularly troublesome. From this experience, coupled with the lesson learned from the ill effects of excessive signal, an optimum level of −20 dBm was established. With this level at the output of the theatre's preamp, the control electronics functioned trouble-free, no matter what was encountered in the projection booth.

Specific installation instructions did not exist for the multitude of sound systems in existence.

The RCA men went to their installation locations, reviewed the system or system diagrams (if available), and determined where the tie-in points would be. Sometimes this turned out to be a complicated procedure—see the insert on the previous page. But the list of problems didn't stop there. Speaker placements sometimes produced acoustical cancellations and dead spots, projector-speed variations changed the control-tone frequencies, transducers and speakers failed, and there were some grounding problems.

Sensurround II

"Earthquake" was so successful—it brought two Academy Awards and good gross profits to Universal—that a second Sensurround picture followed, "Midway." To avoid the field problems that RCA Service Co. had encountered in installing the original system for "Earthquake," Universal developed Sensurround II.

Universal selected to use only the 35-mm optical format for "Midway." The random-noise generator was discarded and the effects sound was recorded directly on the optical track. In order to obtain an effective dynamic recording range of about 100 dB for the Sensurround effect, DBX expansion and noise reduction were introduced as part of the control electronics. To overcome the subpar sound in some systems, solar cells were installed as pickup devices for the "Midway" sound and the control electronics included an optical preamp compensatable to 10 kHz.

The 25- and 35-Hz control tones were retained. However, they no longer controlled the timing and intensity of the effects, but rather directed them through either the front, rear, or all the Sensurround horns.

The future

Universal recently released "Rollercoaster," the third Sensurround film. It looks as if low frequency may become a permanent part of the moviegoing sound spectrum.

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CMOS reliability

CMOS integrated circuits have been widely accepted because of their low power dissipation, high noise immunity, and wide operating voltage range. These circuit advantages would be worthless if CMOS were not reliable.

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Complementary metal-oxide-silicon (CMOS) integrated circuits have had a major impact on the electronics industry, and have created new areas of application for digital circuits. CMOS digital circuits, because of a number of very significant circuit advantages, including low power dissipation, high noise immunity, and wide operating-voltage range, have become a very widely used logic family.

The RCA series of CMOS devices, first introduced as the COS/MOS CD4000 series in 1968, has gained wide acceptance. The introduction, in 1971, of plastic-encapsulated CMOS integrated circuits was instrumental in achieving even wider acceptance of this popular series.

The COS/MOS product line today includes more than 100 standard parts in the CD4000A series, parts that are used worldwide in applications ranging from battery-operated watch circuits to many functions in the aerospace, computer, automotive, and consumer industries. In addition, a new product line has been introduced, the CD4000B series, which has improved features such as a higher operating-voltage range (3 to 20 V), standardized output drive, symmetrical transition time, and improved electostatic-discharge (ESD) protection networks.

Reliability of MOS integrated circuits

MOS (metal-oxide-silicon) integrated circuits have had a very great impact on the digital electronics industry. Not only have MOS integrated circuits displaced digital bipolar integrated circuits in many applications, but they have made possible a large number of totally new electronics applications. As a result, MOS integrated circuits are at present being produced in unit volumes comparable to those of bipolar integrated circuits.

Because bipolar integrated circuits were available earlier, more information has been published on their reliability than on MOS integrated-circuit reliability. In addition, initial bipolar circuit usage was largely in high-reliability military and aerospace applications; MOS integrated circuits have been used principally in consumer and commercial applications. While early MOS devices were primarily hermetically packaged, a very large portion of all MOS ICs produced today are encapsulated in plastic. Since plastic has also been widely used to encapsulate bipolar integrated circuits, including both digital and linear circuits, a discussion of the similarities and differences between MOS and bipolar ICs follows.

Plastic encapsulated ICs are significantly more reliable today than they were several years ago.

A large percentage of all MOS integrated circuits manufactured are encapsulated in plastic rather than in hermetic packages. Plastic encapsulation provides a number of significant advantages, including lower product cost, freedom from potential problems with loose particles (in molded devices), mechanically strong dual-in-line packages, good resistance to shock and vibration, a no-leak-test requirement, and the possibility of small packages.

A number of possible limitations of plastic-encapsulated integrated circuits have been identified in studies of early plastic encapsulation of both bipolar and MOS ICs. These limitations include moisture-penetration effects, effects resulting from a mismatch in coefficient of linear thermal expansion of plastic relative to silicon and interconnect metals, and the presence of ionic materials and other contaminants in certain plastics.

The knowledge of the potential limitations of certain plastics has led to the use, in recent years, of vastly improved materials and processes for fabrication of plastic-encapsulated devices. An example is the use of high-purity Novolac epoxy plastics with high glass transition temperatures. Modifications in assembly techniques have also been made. As a result of these changes, plastic-encapsulated devices, both bipolar and MOS, are significantly more reliable than devices fabricated a number of years ago.

Humid ambients, such as 85°C/85% relative humidity, constitute a means for greatly accelerating possible failure mechanisms in plastic-encapsulated silicon devices. Consequently, quality control tests, as well as high-humidity tests, particularly under bias conditions, have been used to quantitatively assess the integrity of IC passivation and encapsulation systems, and have been the basis for process improvements. The effect of high humidity conditions on the acceleration of device failure mechanisms has been the basis for a number of detailed studies.

MOS versus bipolar ICs:

There are a number of fundamental differences between MOS and bipolar silicon devices that affect integrated-circuit reliability. Digital MOS ICs differ from digital bipolar ICs principally in the higher substrate resistivity, the use of higher applied voltages, and in the importance of the properties of the gate oxide of MOS devices.

MOS fabrication technology differs from bipolar technology in that the process is simpler. Accordingly, it is easier to attain higher chip complexity with the MOS

Editor's note: Considerably more information was gathered by the authors than could be presented in this brief survey. Readers interested in more information should examine references 1 and 2, which contain further test data, background information, and bibliographic listings that could not be included here because of space limits.

technology and, thus, higher gate-to-pin ratios. Since wire-bond failures are a significant factor in limiting the reliability of small-scale integrated circuits, the MOS technology offers the possibility of significant improvements in equipment reliability by reducing the number of wire bonds and external interconnections. Moreover, the MOS technology offers the possibility of lower power dissipation per function, which in turn improves device reliability by assuring lower chip temperatures during operation. In typical bipolar ICs (TTL), device dissipation is significant. By contrast, dissipation in MOS devices such as CMOS and CMOS-SOS (silicon-on-sapphire) is very low.

The MOS technology has an advantage relative to bipolar devices in that the high current densities in the metal interconnections and, thus, electromigration (current-induced mass transport) is not a common problem. In addition, high current density problems at metal-silicon contacts are less frequent. The high impedance of MOS devices makes multi-level interconnections feasible in complex arrays without significantly compromising circuit properties. Diffused cross-unders in the single-crystal silicon are effective, and if another level of interconnections in addition to that provided by the metallization layer is required, polycrystalline silicon, deposited as part of the silicon-gate process, is very effective. By contrast, an additional level of interconnections in bipolar arrays requires the use of metal-over-metal crossovers, which requires additional technology and introduces possible new failure mechanisms.

Since localized defects in silicon affect integrated circuit reliability, one advantage of conventional monolithic MOS compared to bipolar circuits is that no expitaxial layer is required. Therefore, MOS devices can be fabricated in silicon of better crystallographic quality, with little possibility of stacking faults or of the epitaxial spikes that cause device problems and damage to the masks used for photolithography. Finally, since MOS processing is simpler than bipolar processing and requires less steps, the possibility of manufacturing errors that adversely affect reliability is lower.

Frequently, failure rates for devices of various complexities are lumped together and reported as a failure rate for a particular family. Because MOS devices tend to be more complex than bipolar devices, they would have to have a lower failure rate per gate to have a reported failure rate per packaged part equal to that of bipolar devices. However, for equal complexity, bipolar and MOS are equally reliable.

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MOS ICs make use of many of the same materials and processes as bipolar ICs and small-signal transistors. Accordingly, improvements in silicon materials, oxidation, photolithography, diffusion, metallization, passivation and plastic encapsulation, and in device physics, process control, and electrical characterization have resulted in substantial improvements in the reliability of both types of integrated circuits.

MOS failure modes and mechanisms: opens, shorts, degradations.

Since many processing steps, materials, and construction features are common to both MOS and bipolar ICs, many of the possible failure mechanisms that have been reported apply to both types of devcies. For example, passivation, chip-to-substrate bonding, wire bonding, and package sealing or molding procedures are similar for MOS and bipolar ICs.

MOS failure modes can be classified as shorts, opens, and degradations. Shorts are most commonly the result of dielectric failure of the gate (thin) oxide. Electrical opens may result from microcracks in the metallization at topographic steps, photolithography problems, corrosion of metallization, fusion of metal because of overstress, or open wire bonds. Degradation-type effects are attributable to the motion of ions (such as Na^+) in the SiO_2, or to surface-charge spreading effects and consequent inversion.

Considerable information is available on the distribution of failure mechanisms in devices that failed accelerated stress tests, or that failed during field usage. The principal MOS failure mechanisms are the result of motion of charge in or on oxides, and shorts through gate oxides. There is, however, a considerable variance in the distribution of mechanisms depending on the source issuing the information. Device users, who include electronic-equipment manufacturers, government agencies, and industrial organizations performing government-contract-supported reliability studies, tend to agree that there are large variations between products from different suppliers.

Gate-oxide breakdown may result from localized breakdown at defects, or from

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intrinsic breakdown of thin oxide at input circuits. Breakdown at inputs is principally attributable to overstress resulting from discharges of static electricity of sufficiently high energy. While virtually all MOS ICs contain an input-protection circuit, such circuits vary considerably in design, principle of operation, and effectiveness. Susceptibility of silicon devices to static-electricity effects is not unique to MOS circuits, and has been reported in bipolar integrated circuits.

Several forms of alkali ion migration are possible, including the commonly reported transverse Na^+ ion movement in an electric field at an elevated temperature, and lateral Na^+ ion movement followed by transverse movement. The net result of alkali ion migration is to increase the threshold voltage of p-channel transistors, decrease the threshold of n-channel transistors, or to decrease the field inversion voltage of n-type regions.

Because MOS structures have proven an excellent tool for the study of Si-SiO_2 interface properties, a vast amount of information has been made available for the improvement of the design and control of the device fabrication process.

Aluminum metal corrosion in integrated circuits has been the subject of considerable study in recent years. It has been shown that low-temperature-deposited glass-like inorganic passivation materials can be very effective in reducing the possibility of aluminum corrosion. Opens in aluminum have been shown to occur principally at cracks or pinholes in passivation-glass layers, and specific techniques for detecting and minimizing the occurrence of such localized defects in the integrity of passivation-glass layers have been developed. Specific factors that can result in chemical corrosion of aluminum and electrochemical corrosion at cathode and anode regions have been identified.

Failure rates under actual use (field) conditions are very much lower than failure rates under the accelerated stress conditions typically used by device manufacturers to evaluate reliability.

Some data is available on the reliability of similar devices in hermetic and plastic packages. In general, operating-life failure rates are reported to be several times as high for devices in plastic. It is generally not possible, however, to take the available data and make specific quantitative conclusions relative to the effect of plastic encapsulation on the reliability of a given type of MOS IC. One reason for this is that, even though the same wafer processing is applied to both types, there are many differences in the assembly and test sequences other than just plastic versus hermetic packaging. For example, devices intended for high-reliability applications may be subjected to a more stringent visual inspection criteria, may be assembled under very closely controlled conditions with considerable documentation, may be electrically tested at wide ranges of conditions such as −55°C and 125°C, and may be subjected to various screens, electrical tests, burn-ins and lot acceptance criteria. Obviously, such techniques, while more costly, are effective in eliminating a certain number of potentially less reliable (freak) devices from the main population.

The failure rate of plastic-encapsulated MOS devices can be considered to be the sum of the specific failure rates resulting from failure mechanisms occurring on the chip, in the interconnection system external to the chip, and in the package. While unsuitable plastics can adversely affect the reliability of susceptible chips, plastic encapsulation cannot provide a chip reliability in excess of that which would be encountered in a dry, inert ambient. Accordingly, the reliability of many plastic-encapsulated devices, particularly under lower humidity conditions, is limited by the reliability of the encapsulated chip rather than by any reliability limitations imposed by the plastic.

A failure rate on the order of 0.1%/1000 hours at 85°C at the 60% upper confidence level can be expected for high-quality plastic-encapsulated commercial-type MOS ICs prepared by a mature, well-controlled process. Field failure rates for plastic-encapsulated MOS ICs at operating temperatures up to 55°C can be considered to be on the order of 0.01%/1000 hours (60% upper confidence level). Obviously, variations will occur depending upon type, design, process, manufacturer, screens applied, voltage, and severity of ambient conditions and other specifics of the final application.

A number of manufacturers have shown increases in failure rates of MOS products as a result of increasing operating voltage at accelerated stress conditions, such as during operating-life tests. Possible effects of higher operating voltage on MOS ICs include increased susceptibility to surface-charge spreading and to field inversion, and increased incidence of oxide breakdown. Oxide breakdown in MOS structures has been considered by some to follow Peek's law in that the time to failure is inversely related to the fourth power of the applied voltage.

Generally, an increase in chip complexity will decrease the failure rate per gate or per

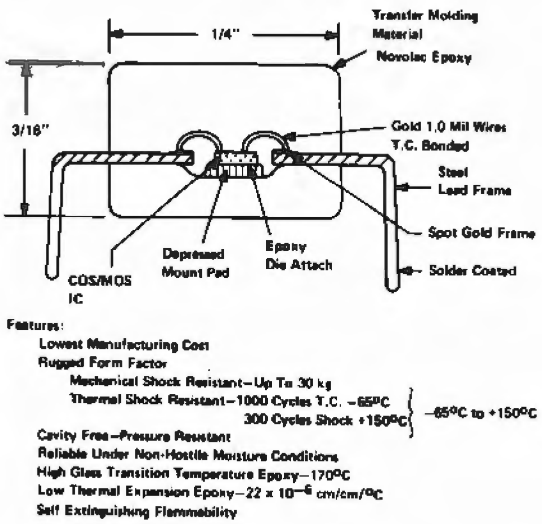

Fig. 1
Dual-in-line plastic (DIP) package, the 1976 system.

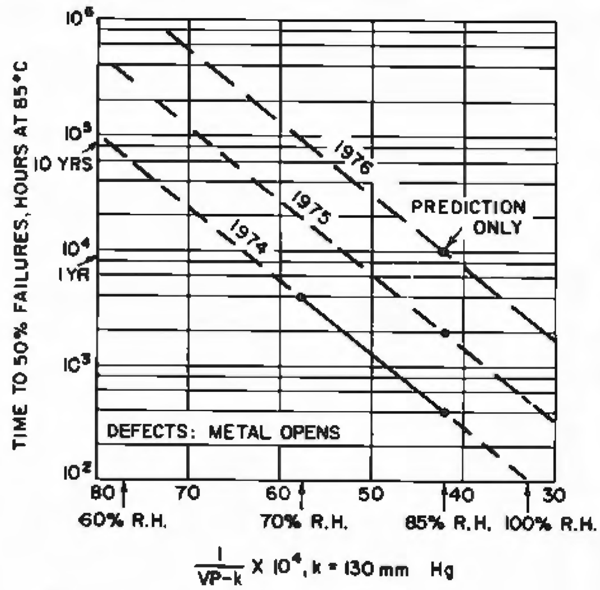

Fig. 3
Vapor pressure versus median-time-to-failure at 85°C. Published acceleration factors show that the 1975-76 plastic packaged product would survive the moisture level in their applications.

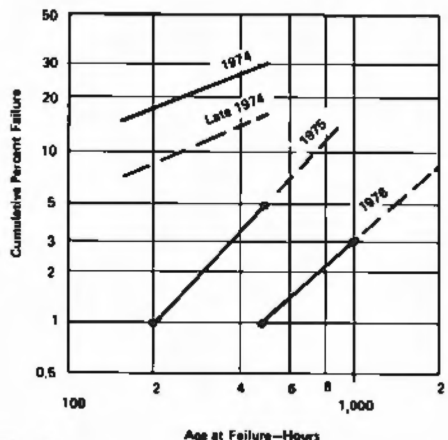

Fig. 2
Weibull plot of 85% relative humidity with temperature-humidity-bias characteristics of RCA CMOS product from 1974 to 1976. Failures plotted for catastrophics only (opens and multiple parameters).

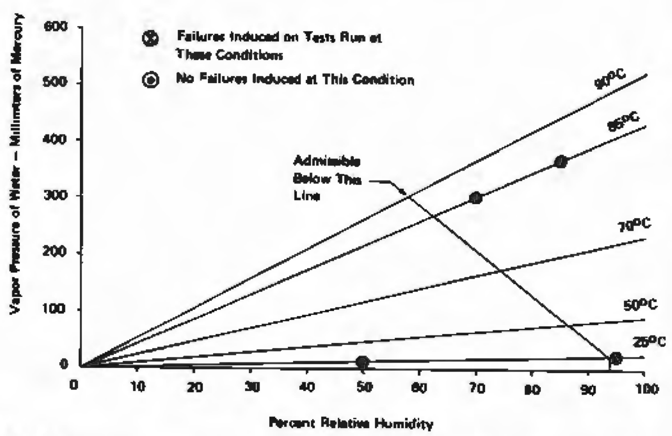

Fig. 4
Lower operating temperatures lower the vapor pressure. This plot is especially useful because it is based on experimental data and is related to water-vapor pressure.

function accomplished. The overall failure rate may be considered as the sum of the failure of wire bonds, failures that would occur with a chip of any size, and chip failures at localized defects, which is an area-dependent factor. The failure rate of wire bonds is simply the product of the failure rate per wire, such as 0.0001%/1000 hours, times the number of wires. The failure rate attributable to localized defects increases with increasing chip area, but is not linearly dependent on the area of the chip; it is considered to increase less rapidly than chip size, because of the tendency of localized defects to cluster rather than to occur at random. (The considerations here are somewhat similar to those which have been shown to apply to the effect of chip size or circuit complexity on IC yield.) Complex ICs are, thus, more reliable per gate, and the use of complex ICs in electronic equipment to perform the same functions as a number of less complex devices will, in general, result in substantially improved equipment reliability.

Reliability of MOS and bipolar ICs is about equal for equal complexity.

In general, reported failure rates of bipolar ICs have been approximately equal to those of MOS ICs of equal complexity prepared by means of mature, well-controlled processes, and operated at the same chip temperature. A number of researchers have reached the conclusion that there is no systematic difference between MOS and bipolar integrated circuit reliability.

The reliability of MOS ICs depends on the design, process, circuit manufacturer, degree of testing and screening, and on the application, as well as the packaging.

Plastic packages are satisfactory for the majority of all MOS IC applications. No major differences in reliability of products of equal functional complexity made by the major MOS technologies (PMOS, CMOS, or NMOS) or of products made with Al or Si gates are evident in the available reliability data. Furthermore, the reliability of MOS devices can be considered to be equal to that of bipolar digital circuits of equal complexity when each type is prepared by a well-controlled process and operated at the same temperature.

CMOS reliability data

Although higher-reliability commercial CMOS devices are being demanded by the industry, cost constraints are always in view. Plastic-packaged CMOS devices are used to satisfy these cost constraints. However, the substitution of lower-cost plastic packages for more expensive hermetic product raises some important issues for integrated circuits, both bipolar and MOS. These issues are usually relatively simple, but can be confusing to designers and component engineers because of the differences in data presentation from various manufacturers of MOS integrated circuits. The basic factors of package selection depend upon:

1) A thorough understanding of the final application environment with respect to temperature, temperature cycling, humidity, salinity, and corrosive chemical contamination.

2) Determination of the system life and, consequently, the component life required.

3) The potential for screening (burn-in, etc.) and the level of stress that can be used.

4) Mechanical requirements of packages in the system.

5) The electrical environment.

Plastic packages—moisture is a consideration.

The long-term reliability of plastic-encapsulated CMOS devices in humid environments is limited by the effects of moisture. Most applications can accept some degradation in device characteristics, but catastrophics (such as opens and shorts) are never acceptable. Moisture entry allows electrochemical corrosion or electroplating of metals to occur.

Externally applied potentials and potentials produced by dissimilar metals affect the metal on the semiconductor chip during operating and non-operating conditions. Extended life in plastic packages depends on choice of metal, plastic encapsulant, passivation layer over the metal system, and resistance to moisture entry into the package during system life.

The moisture that enters the package is often contaminated with soluble salts, such as sodium chloride; the water itself can dissolve some of the ionic species in the plastic and develop an electrolytic solution that will attack exposed metal, especially aluminum. However, aluminum is not the only metal subject to water corrosion. In the presence of water, ionic contaminants, and a potential, most metals will either electrodeposit or undergo electrode reactions that lead to corrosion.

The choice of plastic package, then, must take into account these effects of moisture, and appropriate testing must be performed to establish data that are meaningful in determining the reliability of the device in its application. CMOS devices will dissipate relatively little power; therefore, the silicon-chip temperature rise over the operating ambient will be negligible; consequently, the relative humidity at the surface of the device will not be affected. Increasing temperature at the device surface reduces the probability of moisture failure mechanisms.

The plastic package used by RCA is shown, schematically, in Fig. 1. The choice of materials minimizes both thermal mechanical deformation and moisture failure mechanisms. As plastic encapsulation materials for use with semiconductors improve, and with the maturing of the CMOS technology, greater reliability is found with the overstress tests used to characterize humidity capability. Fig. 2 is a Weibull plot of 85°C/85% relative humidity (R.H.) with temperature humidity bias (THB) characteristics of RCA CMOS product from 1974 to 1976. If the acceleration factors found in the literature are applied to the 1975-1976 product, it will be seen that moisture failures under most application conditions are not to be expected. A plot of vapor pressure versus median-time-to-failure at 85°C for this data (Fig. 3) shows this effect dramatically. The slope of the prediction line used for this data was derived from 1974 product.

Since most operating temperature conditions are less than 85°C, a plot of vapor pressure, temperature, and relative humidity was developed to indicate recommended conditions for plastic. As Fig. 4 shows, lower operating temperatures lower the vapor pressure and make possible operation at high humidity levels. Another factor that must be considered in using plastic-encapsulated product is whether the environmental conditions cause condensation of water vapor (dew point). If dewing occurs, the possible increased presence of water at the chip complicates the determination of the reliability of the plastic package. Moisture absorbed in the plastic at the chip interface provides moisture at the device surface and, if condensation takes place, especially where voids occur at the plastic-to-silicon interface, then more moisture is available for chemical reactions. Water molecules tend to displace the plastic from the device interface.

Table I
Package choice by moisture environment for temperatures between 20°C and 40°C.

Average R.H.	*Comments*	*Package*
100%	Permanent moisture	Frit
75% to 100%	Dewing	Frit
75%	Some dewing	Plastic (5-yr life)
≤75%	No dewing	Plastic (10-yr life)

With the above information, then, four classes of operation have been identified as to humidity, temperature, and dewpoint considerations. Table I shows these conditions and recommends the package type to be used under each set.

Although the classical method of testing product under controlled conditions has its place, very often in comparing materials one would like to look at the effects at the minimum, maximum, and "out-of-spec" conditions to determine the materials that provide the greatest margin of safety. A recent plastic-encapsulation study shows that the plastic material used in 1976 has a greater margin of safety under conditions of high humidity when the process is 2.5 times maximum limit. The testing of both plastic materials under controlled conditions gives only one part of the data in the total sample space.

Several other tests have been used to determine the reliability of the plastic package. One important test—the reliability-verification-sequence (RVS)—subjects devices to a pressure-cooker stress test (15 psig, 121°C, 24 hrs) followed by a bias operating-life test at 85°C (temperature is maintained below 100°C to prevent the vaporization of moisture forced into the package during the pressure-cooker stage). This test is better than the 85°C/85% R.H. test in calibrating device reliability under application conditions. A device that passes 2 or 3 cycles of this sequence test without a catastrophic failure is a device whose field-usage failure rate should be independent of moisture, if the application is proper. RVS tests were run on plastic package samples that incor-

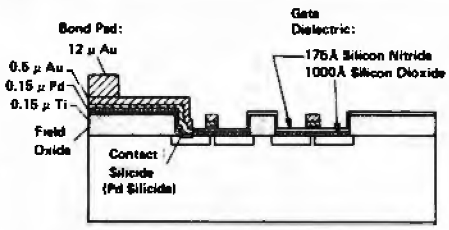

Fig. 5
Trimetal system. Nitride-passivated titanium, platinum, and gold metallization used instead of aluminum can produce reliability results comparable to hermetically sealed package.

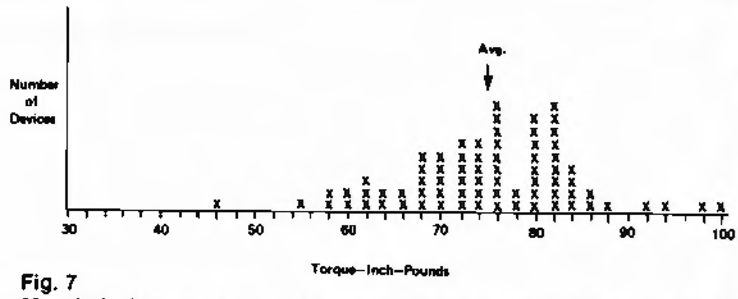

Fig. 7
Mecahnical-torque tests on frit-sealed packages. Normally, 15 in-lbs. of torque strength is sufficient to ensure package integrity under field conditions.

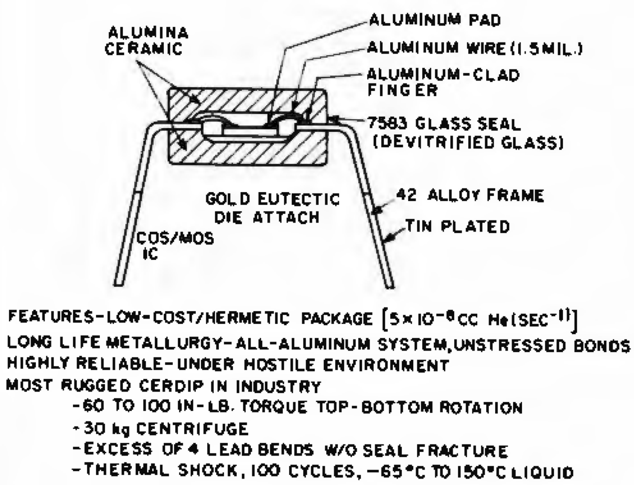

Fig. 6
Frit-sealed package construction. This is the dual in-line CERDIP system that provides low-cost moisture protection by hermetically sealing the package.

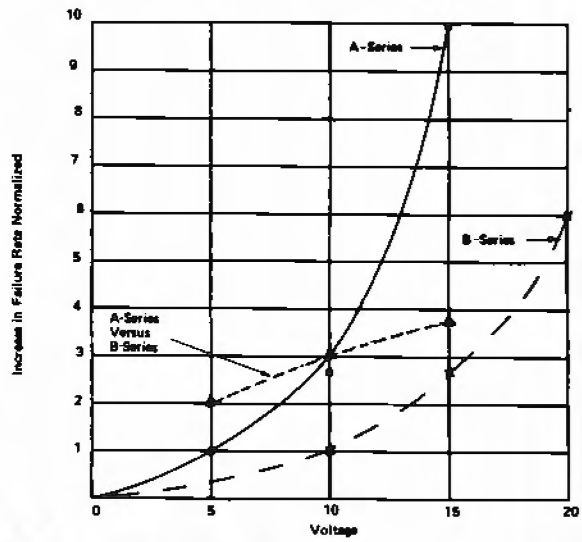

Fig. 8
Applied voltage versus failure rate. Data show how an increase in applied voltage increased the failure rate (at 125°C) for A- and B-series product.

porate the 1975 and 1976 molding systems; new production units were also tested. All the failures were degradational; none were catastrophic (open or short).

Gold chip—the trimetal system improves reliability.

No plastic materials known at this time can offer complete protection against moisture penetration when compared to hermetically-sealed packages. Thus, reliability can be increased substantially by making the chip more hermetic.

CMOS devices processed with gold in place of the aluminum metallization, in addition to a silicon nitride layer, can produce the desired reliability results. The basic construction of the nitride-passivated titanium, platinum, and gold metallization system is shown in Fig. 5.

The silicon nitride provides junction hermeticity while the titanium metal provides adherence to the dielectric and the platinum serves as a diffusion barrier for the gold. In addition to reducing the moisture problems, the use of the trimetal system also reduces effects of mechanisms associated with electromigration, Al-Si and Al-SiO_2 reactions. Because gold ions are soluble in water, gold can be electrodeposited, especially in the presence of the chloride ion. The glass passivation normally employed on the silicon chip prevents the formation of water directly on the gold metallization; the use of epoxy with low chloride content further minimizes the possibility of electrodeposition.

Reliability data for the gold chip in both plastic and hermetic packages shows that much higher stress levels will be obtainable with this chip design in both operating temperature and moisture environments, regardless of packages.

The frit package provides a hermetic seal.

When a hermetic package is desired, the most economical choice for high-volume commercial application is the frit package. Fig. 6 shows that the frit package is a cavity type. The key issues in determining the reliability of the frit package centers obviously around maintenance of hermeticity throughout the life cycle. If hermeticity is not maintained, the frit-package reliability could be worse than that of the plastic package with aluminum-metallized chip under severe moisture conditions. Hermeticity can be affected by severe mechanical or thermal shock; both of which can occur during PC board insertion and wave soldering. In monitoring the mechanical- and thermal-shock capability of a package, emphasis is placed on running highly accelerated tests, such as mechanical torque and liquid-immersion thermal shock. Fig. 7 shows typical mechanical-torque test results. Normally 15 in-lbs. of torque is sufficient to eliminate field problems resulting from loss of package integrity.

Life tests have no value unless the test conditions relate to quantities that can be measured and controlled in the final application.

Semiconductor junction temperature and operating voltage are available parameters that can be measured directly or indirectly. Both qualitative and quantitative descriptions are used to extrapolate the results of life tests to actual use conditions. The most frequently used model is the Arrhenius equation which, basically, states that a certain minimum amount of activation energy is required for reactions to take place.

Life tests of CMOS devices are usually conducted in two modes: static bias life and dynamic operating life. For logic devices, the static bias life test is generally the more severe. For CMOS devices, the activation energy required to predict life is 1.1 eV. With this information, accelerated tests can be conducted on both plastic and frit packages and then extrapolated to use conditions.

Voltage affects failure rate.

Although the life of CMOS devices, like other semiconductors, is considered to have basically an Arrhenius acceleration, voltage is another parameter that substantially affects the failure-rate equation. Electronic components are complex engineering systems, and one should not develop too many analytical equations that attempt to explain all the physical and chemical reactions in terms of failure rate. Good engineering data can be derived empirically for both temperature and voltage characteristics, and can be used to determine how parts will eventually behave in an application. Fig. 8 shows the voltage acceleration factor for both CD4000 A- and B-series product. The presence of a voltage accelerates the mobility of charges on the exterior of the SiO_2 or other surface dielectric, and results in charge accumulation with resultant increases in surface leakage currents. The B-series ICs show less sensitivity to voltage stress than the A-series ICs because B-series devices are operating at a much smaller percentage of actual device breakdown voltage (40% to 60%).

Summary of commercial CMOS package types: each has merits.

Table II is a summary of the main factors that determine the reliability of each package type discussed in this section. There are advantages and disadvantages to each system; no one package has all of the engineering and manufacturing merits

Table II
Plastic versus hermetic package. Main factors that determine reliability of each package type.

	Al, plastic	*Au, plastic*	*Frit*
Life maximum rating	125°C (85°C actual)	150°C	125°C
Acceleration factor over 100°C	10	100 to 400	10
Moisture resistance	Some failure mechanisms	Yes	Yes
Wire bond reliability problem	High temperature and high moisture environment	No	No
Electromigration	Fair	Excellent	Fair
Microcracks	Possible	No	Yes
Barrier quality	n/a	Very good	n/a
Metallurgy	Au-Al	Au-Au	Al-Al
Chip mounting	Low temperature (200°C)	Low temperature (200°C)	High temperature (450°C)
Hermeticity	n/a	Yes	Required
High rel. capability	No	Yes	Yes

Table III
Static discharge (input to V_{SS}) versus life. The CMOS frit package was used since higher temperature accelerated tests could be performed.

Test and conditions	*Control*	*One discharge* 100 V	*One discharge* 200 V	*One discharge* 300
Bias life; 12 V, 200°C, 24 hrs				
CD4013AF	1/13*	2/12	2/13	1/12
CD4016AF	3/13	0/12	3/13	1/12
Bias life; 12 V, 200°C, 24 hrs (second sample)				
CD4013AF	1/15	1/15	0/15	1/15
CD4016AF	0/15	0/15	0/15	0/15
CD4011AF	0/15	0/15	0/15	0/15
Bias life; 12 V, 125°C, 168 hrs				
CD4013AF	1/10	1/11	0/10	2/11
CD4016AF	0/10	0/10	0/11	0/11

**Number of failures/number in group tested.*

Table IV
Field-usage operating-life data on CD4000A family of high-reliability integrated circuits (MIL-STD-883 slash-series types)

Satellite	*Oscar-6*[6]	*ITOS D/F/G/H*[1,6]	*Atmosphere Explorer C/D/E/*[2,6]	*Satcom F1/F2*[7]
Time in orbit (months)[5]	32	85.5	49	16.5
Number of units	90	168	7200	1652
Device—hours	2,073,600	2,585,520	84,672,000	9,812,880
Number of failures	0	0	0	0
Failure rate (%/1000 hrs)[3,4]	0.045	0.035	0.001	0.0092
MTTF (hrs)[3]	2,360,000	2,900,000	96,000,000	10,750,000
Total device hours	99,144,000			
Total failure rate[3,4]	0.00092%/1000 hrs			
Total MTTF hrs[3]	108,000,000			

[1]Satellite D orbit time 23 months, F 36 months, G 24 months, H 2.5 months.
[2]AE/C orbit time 34 months, AE/D 4 months, AE/E 11 months.
[3]Failure rates and MTTF presented at 60 percent 1-sided s-confidence level.
[4]Operating temperature range 25°C to 125°C; no acceleration factor used.
[5]Data in table represents field usage through Oct 15, 1976.
[6]Reporting data stopped on OSCAR 6, ITOS D and AE/D
[7]Satcom orbit time; F1, 10 months; F2, 6.5 months.

Table V
MIL-STD-883, method 5005, qualification subgroup C5, 125°C testing.

Detail spec	*Device hrs*	*Device failures Degrad*	*Inop.*
50 gates	387,000	0	0
51 flip flop	258,000	1	0
52 gates	516,000	1	0
53 gates	258,000	0	0
55 buffers	563,000	4	0
56 counters	645,000	3	0
57 shift register	387,000	3	0
Total	3,014,000	12	0

Table VI
CMOS qualification testing—failure rates.

MIL-M-38510, class A	*MTTF (Hrs)*
3.014×10^6 device hrs at 125°C	
12 degradational rejects	
0.44%/1000 hrs @ 125°C	225,000
0.066%/1000 hrs @ 55°C	1,330,000
0.02%/1000 hrs @ 25°C	5,000,000
Zero functional rejects	
0.03%/1000 hrs @ 125°C	3,300,000
0.0045%/1000 hrs @35°C	22,000,000
0.0013%/1000 hrs @ 25°C	75,000,000

necessary to warrant elimination of the others.

Because there is a greater demand for plastic-encapsulated product than there is for any other package, the attractiveness of the gold chip in plastic increases. The gold chip in plastic offers some of the hermeticity advantages of the frit product and the ruggedness of the plastic-packaged product. In addition, reliability is improved by the presence of silicon nitride, which acts as a complete barrier to alkali-ion movement through the surface of the device. Higher operating temperatures can be achieved by gold-chip devices in plastic than by any other chip type in plastic, and the cost of the gold-chip product will be less than that of frit or Cerdip product.

Electrostatic discharge is becoming less of a reliability threat.

The breakdown of gate oxides because of the discharge of static electricity has been given considerable attention since MOS devices were first introduced. Although the mechanism of failure is well understood, two questions are continually asked, for which industry-wide data is not available.

1) If a device is subjected to static charge and does not fail, will it fail during its expected life under rated stress, i.e., is gate-oxide breakdown a life-related mechanism?

2) Can devices be screened for weak gate-oxide defects by the use of a static-discharge pulse?

Evaluations have been conducted on CMOS parts incorporating protection networks in an attempt to answer these questions. As more precautions are taken against electrostatic discharge by users of MOS devices, and as semiconductor manufacturers develop protection networks that are equal to worst-case electrostatic-discharge experience, this phenomenon will become less of a reliability threat.

The life-test matrix shown in Table III was designed to provide a preliminary insight into latent life-test failures. Devices were stressed at lower electrostatic levels (100 to 300 V) and then subjected to accelerated- and rated-life conditions. No statistical difference was noted between the stressed and control groups. Although more work is required, gate oxide shorts do not appear to be life-related defects.

High-reliability CMOS integrated circuits have operated in space for one hundred million hours with no failures.

A considerable amount of data on devices in ceramic packages has been generated during qualification and conformance testing of CD4000A series CMOS devices to MIL-M-38510, class A specifications. These data indicate excellent package integrity (one failure in a total of 729 devices tested to group B qualification tests), and excellent stability (only one failure in a total of 1504 devices tested to group C qualification tests). Conformance test data on over 2.3 million device-hours of accelerated-stress testing at 125°C on a wide variety of circuits, from gates to MSI devices, show only 5 degradational failures and 3 inoperable failures, which corresponds to a functional failure rate at 125°C of 0.14%/1000 hours, at 60% confidence level.

Accelerated stress type life tests on CD4000B series devices have indicated improved stability at various operating voltages, with relatively less senstitivity of devices to voltage stress than with CD4000A series devices. The higher reliability of B-series devices is attributed to ability to electrically test devices at higher voltages, and to operation at a small percentage of actual device avalanche breakdown voltage.

Functional and dc parameter testing on CD4000B-series parts is performed at 2.8 V and at 22 V, whereas CD4000A-series devices are tested at 2.8 V and at 17 V. An improved input-protection circuit is being incorporated in all new B-series devices.

Recent data on reliability of 9110 CMOS integrated circuits in satellites are given in Table IV. These data represent a total of over 100 million device-hours of operation of CD4000A-series devices with no failures, corresponding to a failure rate of 0.00092%/1000 hrs at a 60% confidence level.

Qualification test data submitted to the Defense Electronic Supply Center in 1976 for 23 CMOS part types shows excellent reliability (Tables V and VI). Test specifications require that 129 units be tested for 1000 hrs each; one failure is allowed. Only 12 degradational rejects were found in the testing and no inoperative failures were noted, indicating that the parts reliability at 25°C is approaching that of the satellite field data presented in Table IV.

Radiation hardening may allow future CMOS circuits to withstand 10^6 rads (Si).

Ionizing radiation constitutes a specific type of environmental stress that can produce severe degradation in the electrical properties of silicon integrated circuits. Early MOS devices were shown to be sensitive to ionizing radiation. Degradation of MOS devices, for example, was shown to occur at a level as low as 10^3 rads (Si).

Recent studies have generated a considerable amount of information concerning the effect of the thermally-grown oxide purity, growth conditions, and annealing conditions on susceptibility to radiation damage. As a result of these studies, it is now possible to modify the processing conditions to produce CMOS integrated circuits with considerably improved radiation hardness. CMOS ICs guaranteed (by testing) to withstand 1×10^5 rads (Si) are now commercially available with typical devices capable of withstanding 2 to 3×10^5 rads (Si), and with devices capable of withstanding 10^6 rads (Si) in several instances. Continuing research and development in this area is expected to produce further improvements, with production devices specified as capable of withstanding 10^6 rads (Si) a possibility in the near future.

Summary and new product trends

CMOS technology is now maturing to the degree that improved performance and reliability equaling and surpassing that of bipolar devices is a reality. The understanding of the basic failure mechanisms of CMOS devices has led to substantial process and material improvements that either eliminate or minimize the effects of these mechanisms in circuit applications. Improvements in plastic materials and process innovations, such as ion implantation, improved passivation layers, improved metallization, and improved designs are examples of the factors that have increased CMOS reliability.

The introduction of the higher voltage CD4000B-series product with improved electrostatic-discharge protection (equivalent to TTL) is an example of the innovations in CMOS processing that lead to improved reliability in circuit performance, especially as more application experience is gained.

Future CMOS improvements are likely to occur in the area of high-speed devices—for example, in devices employing the silicon-on-sapphire (SOS) technology.

Recent trends in CMOS fabrication technology include improved designs, use of ion implantation, improved photolithography, improved metallization, improved passivation, and the use of improved processes which permit very high chip complexity. Ion implantation provides a high purity, very closely controlled source of dopant atoms which permits tighter distributions of electrical characteristics of transistors (threshold voltages of n-channel and p-channel transistors), and thus improved reliability. High chip complexity makes possible higher gate-to-pin ratios, and thus decreases the probability of failure due to wire bonds, packages, or external interconnections of various types (such as soldered connections in electronic equipment). Moreover, with high-complexity chips, the failure rate per logic gate tends to be lower than that of gates on low-complexity chips. CMOS, because of low dissipation per gate, can be used to fabricate very complex chips without introducing reliability problems which result from excessively high chip temperatures. By contrast, TTL integrated circuits, and to some extent PMOS and NMOS circuits, have problems with power dissipation in large chips.

The above-described advantages, added to high noise immunity and other advantages, have resulted in very wide use of CMOS integrated circuits in electronic systems, with predictions of even wider usage in the next several years.

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Various sources of information on MOS IC reliability were used in the preparation of this article. In addition to the published literature, the sources include manufacturers' brochures, compilations by independent testing laboratories, releases by device users, reports by government agencies, and reports by organizations performing government-supported contracts.

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CMOS/SIS—a planar process that may improve on SOS

C.E. Weitzel

Silicon-on-sapphire technology holds great advantages for integrated circuits, but the silicon-in-sapphire process improves on SOS by allowing higher packing densities.

CMOS/SOS has been heralded as the next step in the evolution of CMOS integrated circuits. CMOS/SOS offers the advantages of CMOS—low power consumption and high noise immunity—along with higher speed and better isolation of SOS. A planar SOS technology, however, is needed to achieve higher packing density with this better isolation.

CMOS/SIS (silicon in sapphire) is distinct from other planar SOS processes in that the silicon islands are imbedded into the sapphire substrate. This is accomplished by creating holes in the sapphire substrate prior to epi growth. The silicon epi is then grown in the standard manner, and the silicon that is not in a hole is polished away. This results in a perfectly planar surface.

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The manufacturing process

The first step in the SIS process (Fig. 1) is to define the ion-beam milling mask on a polished sapphire substrate. Since sapphire mills at about one-third the rate of other readily available materials, the mask must be over 2.0 μm thick if 0.6-μm deep holes are to be milled. Deposited SiO_2 and p+ doped polysilicon have been used to define geometries as small as 0.20 mil. At a pressure of 8×10^{-5} torr, an accelerating potential of 900 V and beam current density of 0.60 mA/cm^2, the 0.6-μm-deep holes are milled in 60 minutes. Following the removal of any remaining masking material, the wafers are cleaned and then fired in H_2 at 1200°C for 30 minutes.

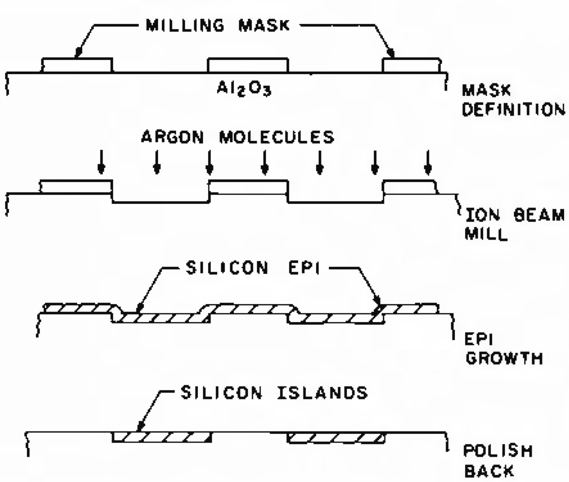

Fig. 1
Four-step process produces silicon islands in the sapphire substrate. From top, mask is placed on substrate, 0.6-micrometer-deep holes are milled out, silicon epitaxial film is grown over the entire substrate, and excess silicon is polished away by diamond.

After the silicon epitaxial film is grown in the standard manner by the pyrolysis of silane, the silicon that is not in the holes is polished away by using 1/4-μm diamond. Presently, this is a hand operation. The sapphire substrate acts as a very good polishing stop because of its hardness and chemical inertness. From this point on, any one of a number of standard SOS processes can be used to fabricate devices. In this work, the p+ polysilicon-gate deep-depletion process was used[1] to manufacture n-channel deep-depletion transistors and p-channel enhancement-mode transistors. Fig. 2 shows a cross-sectional view of an SIS transistor. If the silicon is polished perfectly flat with the surface of the sapphire substrate, the polysilicon gate will encounter a small step in traversing the silicon island because of the difference in density between SiO_2 and silicon.

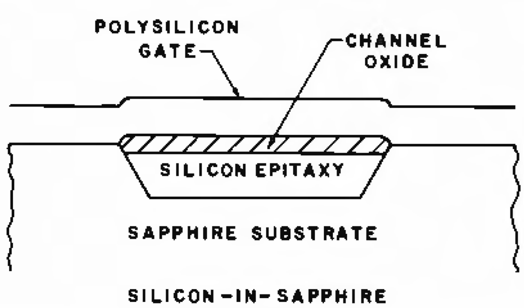

Fig. 2
SIS transistor is made with any standard SOS process, using the final step of Fig. 1 as the starting point.

SIS transistor characteristics

Electrical characterization of CMOS transistors fabricated using the SIS technology indicates that device parameters are almost identical to CMOS/SOS transistors fabricated in the conventional manner. FET mobilities of

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over 450 cm^2/V-s were measured on n-channel deep-depletion transistors and over 200 cm^2/V-s on p-channel enhancement-mode devices. The leakage current of fully turned-off devices approaches 100 pA per mil of channel width for a device with a source drain spacing of 0.4 mil at $V_{DS} = 5.0$ V, as shown in Fig. 3. Leakage current at $V_G = 0$ is somewhat higher because of low threshold voltages and parasitic n-channel edge transistors, which have even lower threshold voltages. Edgeless n-channel devices in which the channel region does not include the silicon island edge did not show the higher edge-leakage current. Parasitic edge transistors are also observed in conventionally processed SOS devices.[2] Also, both p-channel and n-channel devices have exhibited no bias-temperature instability problems (Fig. 4). The B-T stressing was done at 250°C for 15 minutes with +10.0 V applied to the n-channel gates and −10.0 V applied to the p-channel gates. In addition to test transistors, a small integrated circuit (71 mils by 79 mils) was fabricated with the SIS technology. At wafer probe, the SIS wafers showed slightly higher yield than the control wafers.

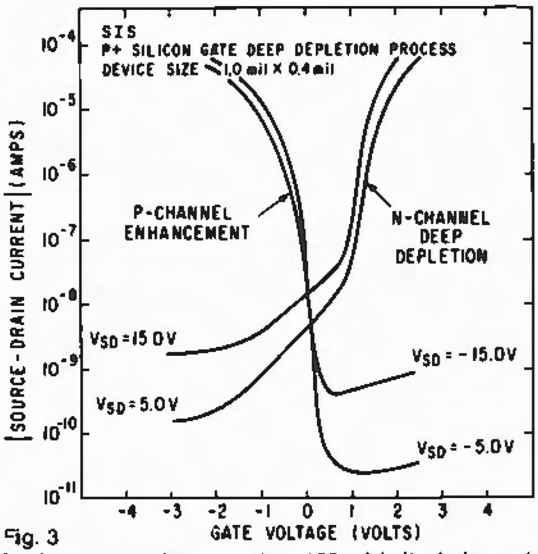

Fig. 3
Leakage current approaches 100 pA/mil of channel width on fully turned-off device. Curves are for p+ silicon-gate deep-depletion process for a 1.0 x 0.4-mil device.

Conclusions

These experimental results indicate that CMOS/SIS offers the advantages of conventional SOS with the addition of a planar surface. It should be possible to translate this planarity into tighter packing density and, at the same time, maintain the excellent isolation offered by an insulating substrate.

Acknowledgments

The author is indebted to Z. Turski, D. Capewell, T. Pawlicki, and L. Barlow for their technical assistance.

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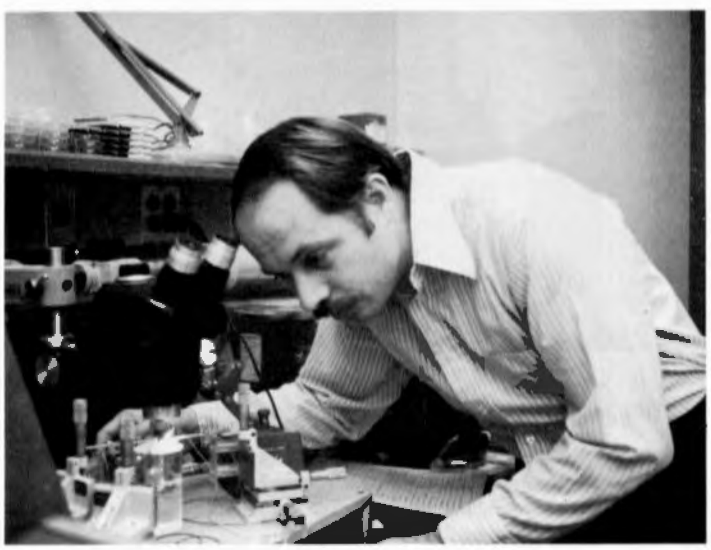
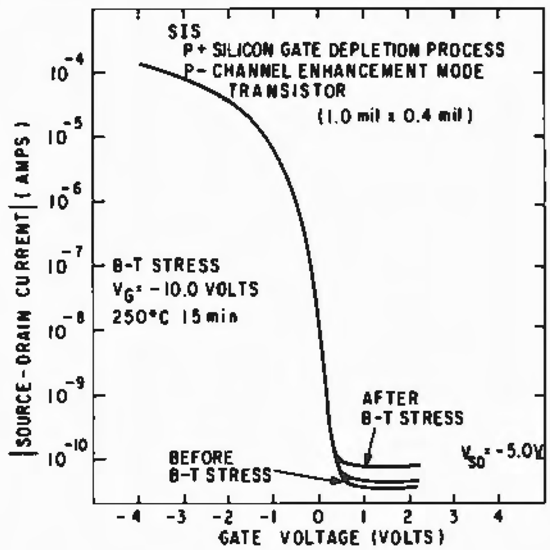
2. Flatley, D.W. and Ham, W.E.; "Electrical instabilities in SOS/MOS transistors," Electrochemical Soc. Fall Meeting, 1974, Abstract #198.

Charles Weitzel joined the Integrated Circuit Process Research group at RCA Laboratories in 1973. He has done research and development in many areas of SOS/MOS transistor processing. However, his main interest has been in studying the effect of sapphire substrate variables on MOS transistor characteristics.

Contact him at: **Integrated Circuit Technology, RCA Laboratories, Princeton, N.J. Ext. 3339**





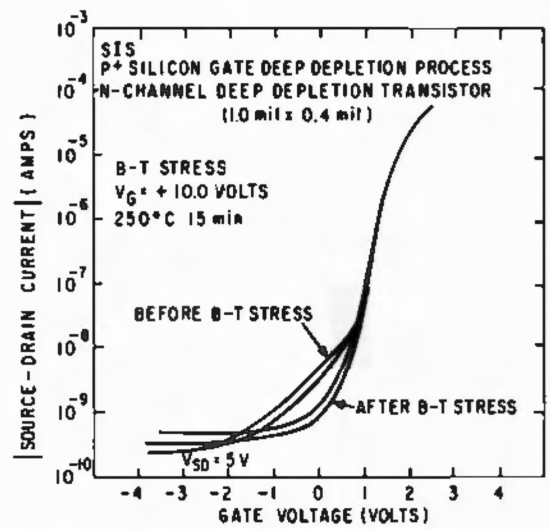


Fig. 4a (top) and 4b
Bias-temperature instability is not a problem with either p-channel (top) or n-channel (bottom) devices.

Model aircraft—a total hobby

R. Lieber

Model aircraft involves the hobbyist in the total cycle—concept, production, competition—thereby generating a sense of personal accomplishment and satisfaction.

In this age of specialization, model aircraft building and flying is a hobby that allows, indeed requires, the individual to be a generalist and assume all of the roles associated with the construction and use of an end product. The hobbyist is at once an entire corporation in miniature, and identity with his product is complete.

The model aircraft movement is at least 50 years old and has a well-developed organization at both the international and national levels. International competition is sponsored along the lines of the Olympic games, while other less formal meetings are carried out at the national and local levels. The organizational structure provides the forum for the free exchange of ideas and, as an important byproduct, an introduction to new friends from diverse walks of life and from many parts of the world.

Categories of model aircraft

Model aircraft fall into three broad categories: 1) free flight; 2) control line; and 3) radio control.

Free-flight models are those over which the modeler has no real-time control.

All basic adjustment of the flight path must be built into the aerodynamics of the model. Final trim to a desired trajectory is accomplished by a series of limited-duration test flights, each followed by small adjustments to the flight surfaces. Free-flight models range from delicate rubber-strand-powered indoor models to rugged engine-powered outdoor aircraft. Within this range is the towline glider, which is towed like a kite to the release altitude, and the hand-launch glider, whose launch motive power is the human arm.

Control-line models fly in a circular path at the end of thin constraining wires.

The wires provide the control link for the modeler, who stands at the center of the flight path. Model classes include replicas that duplicate both the form and flight characteristics of full-scale prototypes, as well as those designed for all-out speed or varying degrees of maneuverability. Models designed for moderate maneuverability perform precisely defined aerobatic patterns, while others proportioned for extreme response are used in a free style of flying in which two aircraft are pitted in a combat-like performance.

The radio-control category allows for the ground control of the model flight with only line-of-sight limitations.

This category includes scale versions of full-scale prototypes in which the details are taken down to the rivet

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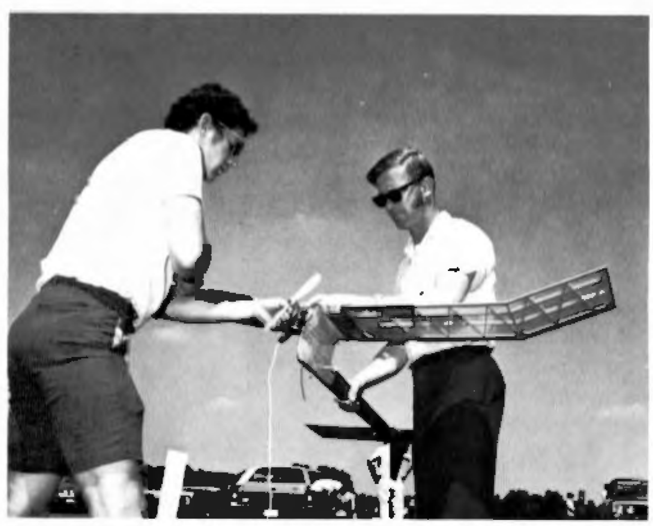
Indoor free-flight models are covered with condenser paper or very thin transparent film. The covering gives the structural framework a spider-web appearance. Complete models often weigh less than 1/100 ounce; flight durations as high as 50 minutes have been recorded.



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This engine-powered outdoor model is constructed of balsa wood covered with 1-mil mylar, and weighs 20 ounces. This model has engine thrust greater than model weight, allowing for very fast vertical ascent. Engine runs are limited to 10 seconds by an onboard mechanical timer that cuts off the engine fuel supply and initiates the glide portions of the flight.

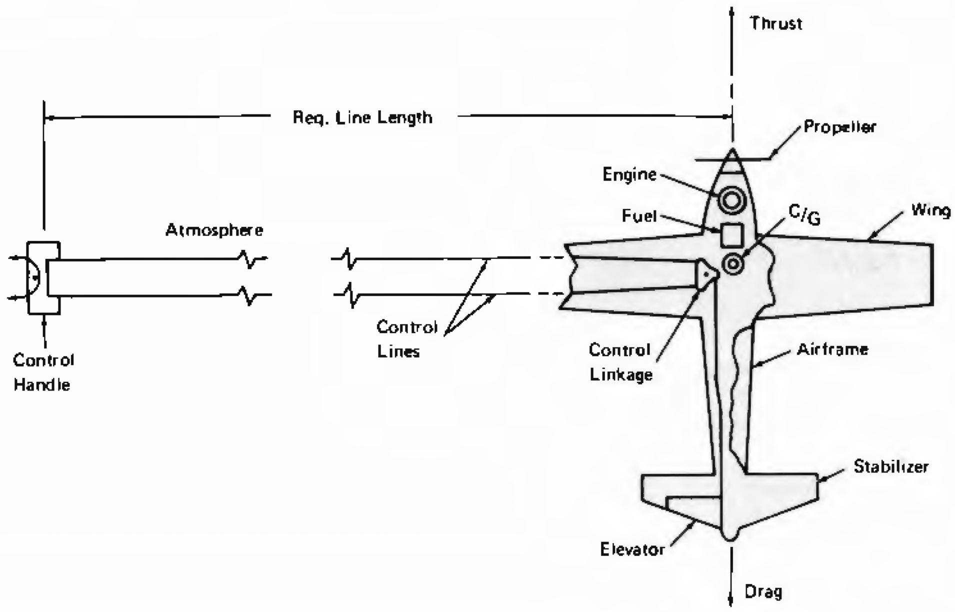

Fig. 1
Control-line system, showing how control lines, through linkage, operate the elevator for altitude control.

heads and weathered paint, as well as aircraft that specialize in precision aerobatics, pylon racing, and both slope and thermal soaring. Although the workmanship requirements in all model categories are high, the radio-control category also places a premium on the ability of the hobbyist as a pilot.

My interest is centered on free-flight power and control-line speed models. To give *RCA Engineer* readers some idea of what's involved in the model aircraft hobby, I would like to describe some of the design considerations and construction techniques that are applied to the all-out speed model.

The control-line speed model

A sketch of the control-line speed model as a system is shown in Fig. 1. The model is controlled in altitude by rotating the control handle. Handle motion is transmitted through the control lines and converted to elevator deflection by means of the control linkage in the airframe. The sensitivity of the model to control motion depends upon the

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Radio-control model scale replica of a two-place 1930's mail plane. It fully matches the original's scale measurements, finish, and interior details. The flight characteristics include realism of speed and control that match the real plane to an astonishing degree.

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Control-line stunt model class is designed for exceptionally smooth response through aerodynamic layout. This model weighs 3 pounds and flies about 50 mi/h. Construction is of balsa, foam, and hardwood, with a final paint finish.

location of the center of gravity, C/G, with respect to the wing and stabilizer, and C/G is chosen to provide a flight path at a desired altitude with a minimum elevator deflection.

In terms of Fig. 1, the speed performance, V, of the system is described by Eq. 1.

$$V = K\,[BHP(E)/(AS + BdL)]^{1/3} \qquad (1)$$

where

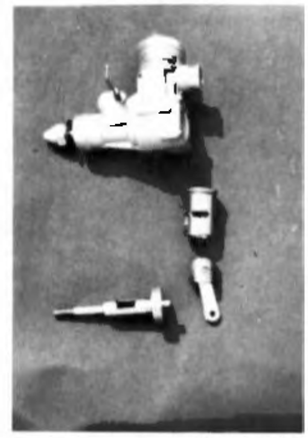
BHP is the engine/fuel system brake horsepower
E is the propeller efficiency
A is the model drag coefficient
S is the wing area
B is the control-line drag coefficient
d is the control-line diameter
L is the uncovered control line length (2 lines)
K is a constant including air density

The goal of the model aircraft hobbyist is to attempt to control the parameters of the performance equation within well-defined competition rules, in order to achieve maximum speed.

The engine

Top engine performance, BHP, is a paramount requirement for speed. Short of having a machine shop, the modeler must carefully purchase an engine by considering manufacturing specification sheets, manufacturer reputation, and any past performance data on the engine in question. After purchase, a break-in period of several hours is required to seat the rotating parts and to establish the piston-to-cylinder fit. A good racing engine with proper fuel system will output 1 BHP at 28,000 r/min. This is equivalent to your 150-cubic-inch Ford engine putting out 1000 BHP!

The racing engine is of two-cycle sleeve-valve design. The essential parts of the power train are shown to emphasize the design simplicity. Fuel is drawn in through the front intake, passed through the crank-shaft, and valved into the combustion chamber by the piston acting to uncover slots in the sleeve. Combustion products are exhausted from the rear by similar piston-sleeve action.



Charles Lieber

The propeller

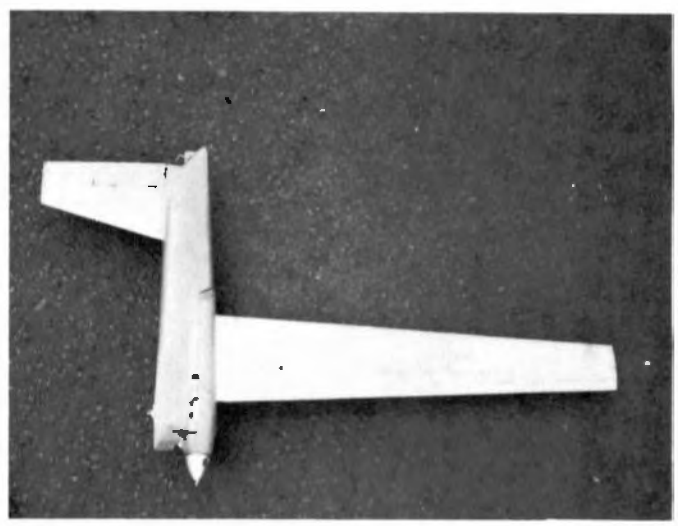
The BHP of the engine must be coupled to the plane through the propeller. The prop must absorb the engine output and convert it to thrust with maximum efficiency at the peak speed of the model. Prop choice is a flight-test procedure, but here the theory of propellers is used to establish the range of test to be carried out. Because of the high r/min operation, the props are molded of special fiber glass or carbon strands impregnated with epoxy.

The airframe

The drag of the model must be minimized while maintaining structural integrity under conditions of high vibration and air load. Structurally, this means that the airframe must have good damping characteristics as well as high tensile strength. Aerodynamically, this leads to enclosure of all operating parts in a smooth shell. Also, parts outboard of the engine thrust line need to be minimized because they are flying at speeds progressively faster than those closer to

Academy of Model Aeronautics

This 5-foot wing span, 7-pound radio-control model is propelled at 100 mi/h through a precision aerobatic pattern by a 2-hp engine. The radio-control system uses feedback position servos in the model to regulate engine speed, retract landing gear, and move at least three independent aerodynamic control surfaces.



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Control-line model of the international speed class. This model is constructed mainly of fiberglass and magnesium. It weighs 17 ounces ready to fly, and is capable of speeds in excess of 150 mi/h. The asymmetric design results from analysis of drag contributions by the airframe and control lines.

the center of the flight circle, and their drag force is increasing as the square of their speed. This in part leads to the asymmetric shape of the control-line model shown in the photo of the author.

The basic airframe is molded of fiberglass cloth and epoxy. This construction results in a very clean model of minimum wall thickness, yet possessing the required structural properties. The steps in this construction begin with the carving of a form whose outside dimensions are those of the required part. A urethane or silicone material is poured over the form, resulting in a semi-rigid mold that has good dimensional stability, high tolerance of undercuts, and no draft requirements, i.e., parts are easily removed from the mold. Fiberglass cloth, impregnated with epoxy, is then laid up in the mold and allowed to cure. The part is removed from the mold as a complete assembly after the excess material is trimmed.

The control lines

In the class of speed model I am describing, the line diameter and the total line length from the center of the flight circle to the engine thrust line are specified. One might expect that the line drag force would then be fixed. Not so! The drag coefficient, *B*, is a very strong function of the spacing between the lines during flight. This is shown in Fig. 2. Every effort must be made to minimize the line spacing. In addition, the line drag is proportional to the line length uncovered by the model wing. This latter point is another reason for the asymmetrical model shape. Here, within wing structural limits, an attempt is made to streamline the lines by enclosing them within the wing.

Conclusion

After all the theorizing, design, purchasing, construction, engine break-in, test, and competition flying are complete, I look back with a good deal of satisfaction on the labor that resulted in my personal creation. Regardless of whether the results are a success or failure, the important thing is that I can say, "I did the whole thing."

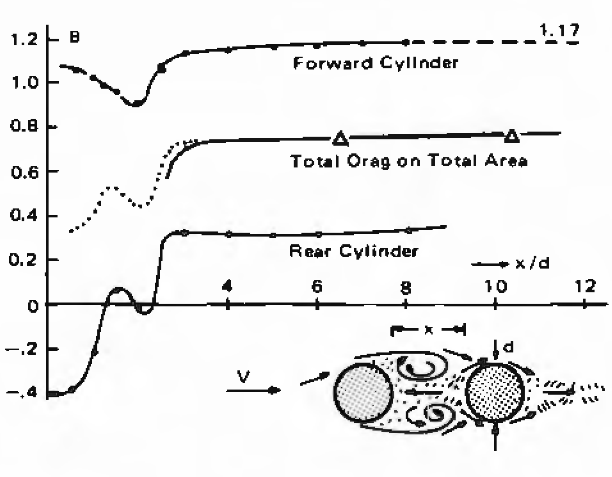

Fig. 2
Drag coefficients of two circular cylinders, one placed behind the other. The graphs show that as the lines get closer and closer, there is a reduction in drag coefficient.

Recommended reading

If you are interested in learning more about model aircraft, write to the Academy of Model Aeronautics, 815 15th Street, N.W., Washington, D.C. 20005. Also, three magazines that cover this hobby are available at newsstands and hobby shops. They are *Model Builder, Model Airplane News,* and *Flying Models.*

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Bob Lieber has been responsible for systems engineering of radar and guidance projects since coming to RCA in 1952. He has written papers in the fields of radar, satellite navigation, and missile guidance systems, and was a recipient of the 1962 David Sarnoff Outstanding Achievement Award. In the field of model aircraft he has contributed papers on speed performance factors and propeller theory. He has been an active aeromodeler since 1938.

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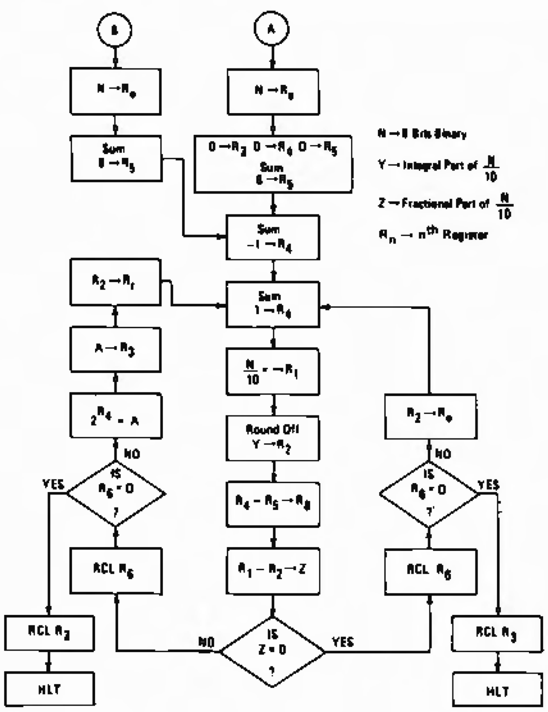
Engineering and Research Notes

Binary-to-decimal conversion program for a programmable calculator

A.R. Campbell
Missile and Surface Radar
Moorestown, N.J.
Ext. PM-2510

Binary-to-decimal number conversion, often needed when working with digital equipment, can require laborious raising to powers and addition. This program, designed for an SR-52 calculator, provides a convenient method of converting 8-, 16-, 24-, and 32-bit words to their decimal equivalents.

To use the program, binary words are entered into the calculator eight bits at a time, most significant bit first. (Since the SR-52 has a 10-digit mantissa, the program ignores the first two digits entered and only operates on the last eight binary digits.) The user then presses the SR-52's user-defined key A, and the program displays the decimal answer.



Here's a typical 8-bit conversion:

ignored

1 1 1 1 1 0 1 0 1 0 ← 1) Enter binary number in display.

8 bits

2) Press A key.

2 3 4 ← 3) Calculator displays decimal equivalent.

To obtain 16-, 24-, and 32-bit conversions, do the above operation for the first eight bits, but for each additional eight bits entered, press the user-defined key B, which will sum that 8-bit conversion with all previous conversions, to a maximum of 32 bits.

The conversion algorithm is shown here in flowchart and SR-52 program-listing form. It works by performing repeated divisions by 10, splitting the dividend into integral and fractional parts, and then looking to see if the fractional part is a 1 or 0. If it is a 1, the program raises 2 to appropriate power and sums it into register 03. After the program has looped through eight bits, it recalls register 03 and halts.

Location	*Codes*	*Keys*			
000 - 003	46 11 42 00	*LBL	A	STO	0
004 - 007	00 00 42 00	0	0	STO	0
008 - 011	03 42 00 04	3	STO	0	4
012 - 015	42 00 05 08	STO	0	5	8
016 - 019	44 00 05 01	SUM	0	5	1
020 - 023	94 44 00 04	+/−	SUM	0	4
024 - 027	46 79 01 44	*LBL	*6	1	SUM
028 - 031	00 04 43 00	0	4	RCL	0
032 - 035	00 55 01 00	0	÷	1	0
036 - 039	95 42 00 01	=	STO	0	1
040 - 043	51 78 43 00	SBR	*5	RCL	0
044 - 047	04 75 43 00	4	—	RCL	0
048 - 051	05 95 42 00	5	=	STO	0
052 - 055	06 43 00 01	6	RCL	0	1
056 - 059	75 43 00 02	—	RCL	0	2
060 - 063	95 90 68 43	=	**if0*	*8	RCL
064 - 067	00 06 90 67	0	6	**if0*	*7
068 - 071	02 45 43 00	2	y^x	RCL	0
072 - 075	04 95 44 00	4	=	SUM	0
076 - 079	03 43 00 02	3	RCL	0	2
080 - 083	42 00 00 41	STO	0	0	GTO
084 - 087	79 46 67 43	*6	*LBL	*7	RCL
088 - 091	00 03 81 46	0	3	HLT	*LBL
092 - 095	68 43 00 06	*8	RCL	0	6
096 - 099	90 67 43 00	**if0*	*7	RCL	0
100 - 103	02 42 00 00	2	STO	0	0
104 - 107	41 79 46 78	GTO	*6	*LBL	*5
108 - 111	75 93 05 54	−	.	5	)
112 - 115	57 00 52 22	**fix*	0	EE	INV
116 - 119	52 22 57 42	EE	INV	**fix*	STO
120 - 123	00 02 56 46	0	2	**rtn*	*LBL
124 - 127	12 42 00 00	B	STO	0	0
128 - 131	41 00 01 05	GTO	0	1	5

Reprint RE-23-2-18
Final manuscript received June 8, 1977.

COSMAC Applications Contest Winners

First place:

John Kowalchik
Solid State Division
Mountaintop, Pa.

A COSMAC-based autopatch control for amateur repeaters
First prize is a COSMAC Evaluation Kit and Microterminal.

Second place:

Thomas Lenihan
RCA Laboratories
Princeton, N.J.

A/D-based burglar alarm system
Second prize is a COSMAC Evaluation Kit.

Third place:

Victor Auerbach
Astro-Electronics
Princeton, N.J.

COSMAC Microtooter

Vince Battaglia
Mobile Communications Systems
Meadow Lands, Pa.

COSMAC-controlled battery-charger/efficiency-tester

Leonard Borkon
Solid State Division
Lancaster, Pa.

Microprocessor control of a CB radio antenna to minimize VSWR

Third prize is a choice of a Microtutor or a COSMAC VIP.

Future issues of the *Engineer* will have descriptions of the winning entries. Valid entries were also received from:

David Costello
Missile and Surface Radar
Moorestown, N.J.

Programmable audio waveform generator

Miguel Negri
NBC
New York, N.Y.

Remote control of NBC facilities

Frank Panzarino
Globcom
New York, N.Y.

Oscilloscope generator cartridge

Mark Riggle
Missile and Surface Radar
Kwajalein, Marshall Is.

Music synthesizer system

Patents

Automated Systems

R. Depierre| G.J. Forgays
H.H. Behling| W.C. Curtis
Airborne moving-target indicating radar system—4034373

R.C. Guyer
Optical adjustment device—4037942 (Assigned to U.S. Government.)

W.J. Hannan
Adaptor for inter-relating an external audio input device with a standard television receiver and an audio recording for use therewith—4040088

R.E. Hanson
Method for determining engine monent of inertia—4036049 (Assigned to U.S. Government.)

L.R. Hulls| S.C. Hadden
Filter which tracks changing frequency of input signal—4032852

J.A. McNamee
Vibrometer—4041775 (Assigned to U.S. Government.)

Avionics

C.A. Clark, Jr.
High voltage protection circuit—4041357

C.A. Clark, Jr.| R.A. Ito
Radar contour edge restore circuit—4038655

M.I. Hussain
Pulse stream identification circuit—4041486

Broadcast

L.J. Bazin
Apparatus for automatic gamma control of television color signals—4038685

D.M. Schneider| L.J. Bazin
Video blanking circuit—4038687

L.J. Thorpe| B.E. Nicholson
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L.A. Harwood
Complementary field effect transistor signal multiplier—4032967

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M.N. Norman
Brightness control apparatus—4044375

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Government Systems Division Staff

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Method of preparing portions of a semiconductor wafer surface for further processing—4035226

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Reduction of parasitic bipolar effects in integrated circuits employing insulated gate field effect transistors via the use of low resistance substrate contacts extending through source region—4035822

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A.A. Todd
Semiconductor integrated circuit device—4035828

M.B. Goldman| S.J. Niemiec
Protection circuit—4039869

L.F. Heckman, Jr.| J.B. Pickard
High power coaxial cavity resonator tunable over a broad band of frequencies—4034320

V.E. Hills| L. Wu
Selectively powered flip-flop—4042841

M.V. Hoover
Complementary symmetry FET mixer circuits—4032851

T.W. Kisor
Package for semiconductor components—4037267

Special Contracts

E.M. Ball
Vacuum tube gas test apparatus—4038616

Pen and Podium

Recent RCA technical papers and presentations

To obtain copies of papers, check your library or contact the author or his divisional Technical Publications Administrator (listed on back cover) for a reprint. For additional assistance in locating RCA technical literature, contact RCA Technical Communications, Bldg. 204-2, Cherry Hill, N.J., extension PY-4256.

Automated Systems

D.R. Bartlett
New-technology ATE in support of the YAH-64 advanced attack helicopter—AIAA, Orlando, FL (7/11-13/77)

M.J. Cantella
Application of the high-resolution return-beam vidicon—*Optical Engineer* (5-6/77)

R.F. Gerenz
A methodology for improving the strategic warning process—*J. of Defense*, Special Crises Management Issue (5/77)

R.F. Gerenz
Data fusion—Electronics in NORAD Symp., Air Force Academy, Colorado Springs, CO (9/13-14/77)

J.J. Klein
A high performance tv camera for multiplexing of parallel FLIR video—IRIS-25th National Infrared Information Symp., San Francisco, CA (6/15/77)

F.P. McGurk|R.A. Asmussen
Novel production engineering techniques used on the AN/GVS-5 hand held laser rangefinder—Advances in Laser Engineering Seminar, SPIE, Hughes Aircraft, Culver City, CA (8/26/77)

D.A. Priestley
New-technology automatic test system simplified interface with ARTADS—AFCEA Seminar, Ft. Monmouth, NJ (9/15/77)

N.B. Wamsley
Infrared techniques automate diagnostic test generation process—20th Midwest Symp. on Circuits and Systems, Lubbock, TX (8/15-16/77)

Government Communications Systems

G.J. Brucker
Transient test of a CMOS bulk microprocessor—IEEE Nuclear & Space Radiation Effects, Williamsburg, VA (7/12/77)

G.J. Brucker
Circumvention and interaction of CMOS/bulk peripherals with CMOS/SOS memory in transient environment—IEEE Nuclear & Space Radiation Effects, Williamsburg, VA (7/12/77)

G.J. Brucker
Characteristics of CMOS/bulk and SOS memories in a transient environment—IEEE Nuclear & Space Radiation Effects, Williamsburg, VA (7/12/77)

Dates and Deadlines

Upcoming meetings

Ed. Note: Meetings are listed chronologically. Listed after the meeting title (in bold type) are the sponsor(s), the location, and the person to contact for more information.

OCT 16-21, 1977—**119th Technical Conf. and Equipment Exhibit** (SMPTE) Century-Plaza Hotel, Los Angeles, CA **Prog Info:** SMPTE, 862 Scarsdale Ave., Scarsdale, NY 10583

OCT 25-27, 1977—**Electro-Optics/Laser '77 Conf. and Expo.**, Anaheim, CA **Prog Info:** Bill Ashman, Industrial & Scientific Conference Management, Inc., 222 W. Adams St., Chicago, IL 60606

OCT 25-27, 1977—**Semiconductor Test Symp.** (IEEE) Hyatt House, Cherry Hill, NJ **Prog Info:** John A. Bauer, Test Symp., PO Box 2340, Cherry Hill, NJ 08034

OCT 25-28, 1977—**Radar Intl.-RADAR 77** (IEEE *et al*) IEE, London, England **Prog Info:** IEE, Conf. Dept., Savoy Place, London, WC2R OBL England

OCT 26-28, 1977—**Ultrasonics Symp.** (IEEE) Del Webb's Towne House, Phoenix, AZ **Prog Info:** Fred S. Hickernell, Motorola, Inc., 8201 E. McDowell, Scottsdale, AZ 85252

OCT 31-Nov 1, 1977—**Joint Engineering Mgmt. Conf.** (IEEE *et al*) Stouffer's Inn, Cincinnati, OH **Prog Info:** Paul H. Bluestein, Paul H. Bluestein & Co., 3420 Section Rd., Cincinnati, OH 45237

NOV 2-4, 1977—**Automatic Support Systems for Advanced Maintainability (AUTOTESTCON)** (IEEE) Dunfey's Hyannis on Cape Cod, MA **Prog Info:** E.B. Galton, AUTOTESTCON 77 c/o RCA, PO Box 588, Burlington, MA 01801

NOV 6-10, 1977—**Engineering in Medicine and Biology Conf.** (IEEE) Hilton, Los Angeles, CA **Prog Info:** AEMB, Suite 404, 4405 East-West Hwy., Bethesda, MD 20014

NOV 8-10, 1977—**Mechanical Engineering in Radar** (IEEE) Sheraton Natl., Washington, DC **Prog Info:** Harry C. Moses, Naval Research Lab., Code 5307, 4555 Overlook Ave., Washington, DC 20375

NOV 8-10, 1977—**MIDCON** (IEEE) O'Hare Conv. Ctr., Hyatt Regency, Chicago, IL **Prog Info:** W.C. Weber, Jr., EEEI, 999 N. Sepulveda Blvd., El Segundo, CA 90245

NOV 8-11, 1977—**COMPSAC '77 (Computer Software & App. Conf.)** (IEEE) Sheraton-O'Hare, Chicago, IL **Prog Info:** Stephen S. Yau, Dept. Computer Sci., Northwestern Univ., Evanston, IL 60201

NOV 8-11, 1977—**Magnetism & Magnetic Materials Conf.** (IEEE) Raddison Hotel, Minneapolis, MN **Prog Info:** C.D. Graham, Jr., Univ. of Penn., Dept. of Metallurgy and Matls. Sci., Phila., PA 19174

NOV 13-17, 1977—**NAEB Convention**, Washington, DC **Prog Info:** James A. Fellows, NAEB, 1346 Connecticut Ave., N.W., Washington, DC 20036

NOV 14-16, 1977—**Second Annual Intl. Videodisc Programming Conf.** (IVDC) New York, NY **Prog Info:** IVDC, PO Box 102, Cooper Sta., New York, NY 10003

NOV 27-DEC 2, 1977—**ASME Winter Annual Mtg.** (ASME) Hyatt Regency, Atlanta Hilton, Atlanta, GA **Prog Info:** ASME, 345 E. 47th St., New York, NY 10017.

M. Nguyen|R. Pickholtz
Bounds for the queue in loop system—Computer Performance Modeling Symp., New York, NY (8/16/77)

Missile and Surface Radar

R.D. Bachinsky
Fragment wake modeling—AIAA/BMDSC, Stanford Research Institute, Menlo Park, CA (7/26-27/77)

M.W. Buckley
Project management—Co-Chairman, AMA Seminar, Montreal, Que. (6/8-9/77)

J.O. Neilson|W.J. Paterson|G.W. Suhy
Simulations for sizing large radar control computers—Modeling and Simulation Conf., U. of Pittsburgh, Pittsburgh, PA (4/22/77)

N. Rosenfeld
Development of microprocessors and microprocessor-based systems using an off-the-shelf microcomputer—IEEE workshop in microprocessors, U. of Penna., Phila. PA (6/10-12/77)

H. Urkowitz
Clarity in windows—*IEEE Spectrum*, Letter to the editor (7/77)

L. H. Yorinks
Large feed displacements in an offset reflector antenna—1977 Intl. IEEE/AP-S Symp. (6/21-24/77)

Laboratories

D.A. de Wolf
Optical coherence through turbid media—OSA Topical Mtg. on Optical Propagation through Turbulence, Rain, and Fog, Boulder, CO (8/9-11/77)

D.A. de Wolf
Light beams in turbulent air: diagram techniques—OSA Topical Mtg. on Optical Propagation through Turbulence, Rain, and Fog, Boulder, CO (8/9-11/77)

A.H. Firester|M.E. Heller|P. Sheng
Knife-edge scanning measurements of subwavelength focused light beams—*Appl. Optics*, Vol. 16 No. 7 (7/77) pp. 1971-74

W. Kern
Chemical etching of dielectrics—Electrochem. Soc. Symp. on Etching, Washington, DC (5/76). Also in "Etching for Pattern Definition," Electrochem Soc. (1976) pp. 1-18d

T. Takahashi|O. Yamada
Cathodoluminescent properties of yttrium aluminum borate—*J. Electrochem. Soc.*, Vol. 124 No. 6 (6/77) pp. 955-58

J.P. Wittke|I. Ladany
Lateral mode selection in semiconductor injection lasers—*J. Appl. Physics*, Vol. 48 No. 7 (7/77) pp. 3122-24

C.R. Wronski
Photovoltaic properties of discharge-produced amorphous Si—*Technical Digest*, 9th Solid State Devices Conf., Tokyo, Japan (8/30-31/77)

C.R. Wronski|D.E. Carlson
Surface states and barrier heights of metal amorphous silicon Schottky barriers—*Solid State Communications*, Vol. 23 (9/77) p. 421

DEC 1-3, 1977—**Semiconductor Interface Specialist Conf.** (IEEE) Carillon Hotel, Miami Beach, FL **Prog Info:** W.R. Hunter, IBM, Thomas Watson Res. Ctr., PO Box 218, Yorktown Hts., NY 10598

DEC 5-6, 1977—**Chicago Fall Conf. on Consumer Electronics** (IEEE) Ramada-O'Hare Inn, Des Plains, IL **Prog Info:** Richard Sudges, Rockwell Intl./The Admiral Group, 1925 N. Springfield Ave., Chicago, IL 60647

DEC 5-7, 1977—**Intl. Electron Devices Mtg.** (IEEE) Hilton, Washington, DC **Prog Info:** Courtesy Assoc./Susan Herman, 1629 "K" St., N.W., Washington, DC

DEC 5-7, 1977—**Natl. Telecommunications Conf.** (IEEE) Marriott Hotel, Los Angeles, CA **Prog Info:** Stanley A. Butman, 4800 Oak Grove Dr., Pasadena, CA 91103

JAN 16-18, 1978—**Integrated and Guided Wave Optics** (OSA) Salt Lake City, UT **Prog Info:** Optical Soc. of Am., 2000 L St., N.W., Washington, DC 20036

JAN 24-26, 1978—**Reliability & Maintainability Conf.** (IEEE *et al*) Biltmore, Los Angeles, CA **Prog Info:** D.F. Barber, POB 1401, Branch PO, Griffiss AFB, NY 13441

JAN 30-FEB 1, 1978—**Automated Testing for Electronics Manufacturing,** Marriott, Los Angeles, CA **Prog Info:** Sheila Goggin, ATE Seminar/Exhibit, 167 Corey Rd., Brookline, MA 02146

FEB 7-9, 1978—**Conf. on Laser and Electro-Optical Systems** (OSA) Town and Country Hotel, San Diego, CA **Prog Info:** Optical Soc. of Am., 2000 L St., N.W., Washington, DC 20036

FEB 15-17, 1978—**Intl. Solid State Circuits Conf.** (IEEE, U. of Penna.) Hilton, San Francisco, CA

MAR 21-23, 1978—**Industrial Applications of Microprocessors,** Sheraton, Phila., PA **Prog Info:** W.W. Koepsel, Dept. of E.E., Seaton Hall, Kansas State Univ., Manhattan, KS 66506

Calls for papers

Ed. Note: Calls are listed chronologically by meeting date. Listed after the meeting (in bold type) are the sponsor(s), the location, and deadline information for submittals.

JAN 16-18, 1978—**Integrated & Guided Wave Optics** (OSA) Salt Lake Hilton, Salt Lake City, UT **Deadline Info: 10/20/77 to** Amnon Yariv, Cal. Inst. of Tech., Pasadena, CA 91109

MAR 22-24, 1978—**Vehicular Technology Conf.** (IEEE) Regency, Denver, CO **Deadline Info: 10/15/77 to** John J. Tary, U.S. Dept. of Commerce, OT/ITS, 325 Broadway, Boulder, CO 80302

APR 24-26, 1978—**Electronic Components Conf.** (IEEE) Disneyland, Anaheim, CA **Deadline Info: 10/28/77 to** John Powers, Jr., IBM Corp. Hdqtrs, Dept. 836 IB, 43 Old Orchard Rd., Armonk, NY 10504

MAY 6-11, 1978—**American Ceramic Soc. 80th Annual Mtg., Electronics Div.** (ACS) Cobo Hall, Detroit, MI **Deadline Info: (Title and author) 11/15/77; (50-wd ab) 12/1/77 to** Henry M. O'Bryan, Bell Laboratories 6D-307, 600 Mountain Ave., Murray Hill, NJ 07974

MAY 9-12, 1978—**Intl. Magnetics Conf.** (Intermag) Florence, Italy **Deadline Info: (2-pg digest) 12/15/77 to** David A. Thompson, IBM, Thomas J. Watson Research Ctr., PO Box 218, Yorktown Heights, NY 10598

JUN 26-29, 1978—**Conf. on Precision Electromagnetic Measurements** Conf. Ctr., Ottawa, Ont. **Deadline Info: (ab) 1/15/78 to** Andrew F. Dunn, Natl. Research Council, Montreal Rd., Ottawa, Ont. KIN6N5

JUL 16-21, 1978—**Power Engineering Soc. Summer Meeting** (IEEE) Los Angeles, CA **Deadline Info: 2/1//78 to** G.A. Davis, Southern Calif. Edison Co., POB 800, Rosemead, CA 91770

Engineering News and Highlights

Hillier honored by Electron Microscopy Society

Dr. James Hillier, Executive Vice President and Senior Scientist, received the Electron Microscopy Society of America's Distinguished Award for his pioneering efforts in the development of early electron optical instrumentation on the North American continent. The award was presented to him at the EMSA's Awards Luncheon in Boston on August 24, 1977.

Dr. Hillier is well known in the field of electron microscopy and for his role in encouraging the growth of this instrument as a research technique of wide importance in biology, medicine, chemistry and other sciences.

Between 1937 and 1940, while a research assistant at the University of Toronto's Department of Physics and at the Banting Institute of the University's medical school, he and a colleague, Albert Prebus, designed and built the first successful high-resolution electron microscope in the Western Hemisphere.

New Products Laboratory formed

William M. Webster, Vice President, RCA Laboratories, and **D. Joseph Donahue,** Division Vice President, Operations, Consumer Electronics Division, recently made a joint announcement of the formation of a New Products Laboratory. Its purpose will be to facilitate the planning, project identification and the timely development of new products.

Jay J. Brandinger, Division Vice President, Engineering, Consumer Electronics Division, appointed **J. Peter Bingham** Chief Engineer of the New Products Laboratory.

This Laboratory will be responsible for introducing improvements into the current product line and for developing new electronics products. The New Products Laboratory will interface with RCA Laboratories as technical feasibility of new ideas is established and with the Consumer Electronics Product Design activity when economic and market feasibility have been determined. The function having this responsibility was formerly located at RCA Laboratories. It will now be centered in Indianapolis.

The Consumer Products Research effort will continue at the RCA Laboratories in Princeton and will interface with the New Products Laboratory.

To the Editors:

Because of the review nature of my article, [U.S. color television fundamentals," *RCA Engineer*, Vol. 23 No. 1, pp. 64-75], I obviously had to draw upon information originating from a very large group of individuals who contributed to the development of the NTSC Color Television System. I thereby express my thanks and appreciation to all concerned.

Accordingly, an additional reference inadvertently not cited, useful to those interested in more information regarding this topic, may be found in the book by John Wentworth, entitled *Color Television Engineering*, McGraw Hill, 1955. It contains much of the early background material used as a basis for the review article.

D.H. Pritchard

Promotions

Solid State Division

Joseph Banfield from Member, Technical Staff to Leader, Technical Staff, Metallurgical Technology group of the Materials and Processes Laboratory.

Missile and Surface Radar

Katharine Purdum from Senior Member, Engineering Staff to Member, Project Management Staff, AEGIS Computer Programs.

Charles Profera from Principal Member, Engineering Staff to Staff Administrator, IR&D Programs, Systems and Advanced Technology.

Staff announcements

Solid State Division

Thomas T. Lewis, Director, Electro-Optics Operations, announced the organization as follows: **Clarence H. Groah,** Manager, E/O Operations, Administration and Product Control; **Leonard W. Grove,** Manager, Manufacturing—E/O; **David L. Brubaker,** Manager, Manufacturing—Special Parts; **Leonard W. Grove,** Acting, Production Control; **William H. Hackman,** Manager, CAT Scanner; **Richard J. Miller,** Manager, E/O Fabrication; **Richard Phillips,** Manager, Photo Engineering; **Donald C. Reed,** Manager, Custom Tube Manufacturing; **Kenneth A. Thomas,** Manager, Finishing; **Fred A. Helvy,** Manager, E/O Engineering; **Ralph W. Engstrom,** Senior Member, Technical Staff; **Fred A. Helvy,** Acting, Applications Engineering—E/O; **Fred A. Helvy,** Acting, Process and Material Development; **Daniel L. Thoman,** Manager, Product Development; **Thomas T. Lewis,** Acting, Product Marketing; **Thaddeus J. Grabowski,** Manager, Market Planning; **N. Richard Hangen,** Manager, Market Planning; **Edward F. McDonough,**, Manager, Market Planning; **Carlton L. Rintz,** Manager, Market Planning; **Ronald G. Power,** Manager, Solid State Detectors—Canada; **Eugene D. Savoye,** Manager, E/O Solid State Technology; **Thomas W.**

Edwards, Leader, Silicon Engineering; **William H. Henry,** Manager, Silicon Manufacturing; and **Fred R. Hughes,** Manager, Solid State Emitters.

Philip R. Thomas, Division Vice President, Solid State MOS Integrated Circuits, announed the organization as follows: **Gerald K. Beckmann,** Manager, Operations Planning and Administration; **John A. Ekiss,** Director, MOS Manufacturing Operations; **Peter J. Jones,** Director, Product Marketing, MOS; **John P. McCarthy,** Manager, MOS Special Programs; **Norman C. Turner,** Director, MOS Engineering; and **Robert O. Winder,** Director, MOS Systems.

John A. Ekiss, Director, MOS Manufacturing Operations, appointed **David S. Jacobson** Manager, Photomask Operations.

Commercial Communications Systems Division

Joseph P. Ulasewicz, Division Vice President and General Manager, appointed **Donald L. Neff** Manager, Operations Control, Mobile Communications Systems, Meadow Lands, Pa.

Research and Engineering

Howard Rosenthal, Staff Vice President, Engineering, appointed **John D. Bowker** Manager, RCA Frequency Bureau.

John D. Bowker, Manager, RCA Frequency Bureau, announced the organization as follows: **Norman B. Mills,** Manager, New York Office Frequency Bureau; and **Edward E. Thomas,** Manager, Washington Office Frequency Bureau.

RCA Laboratories

James L. Miller, Director, Manufacturing Systems and Technology Research Laboratory, announced the organization as follows: **Istvan Gorog,** Head, Optical Electronics and Process Control Research; **Marvin A. Leedom,** Head, Mechanical and Instrumentation Technology; **James L. Miller,** Acting Head, Manufacturing Systems; and **D. Alex Ross,** Staff Engineer.

Fred Sterzer, Director, Microwave Technology Center, appointed **Ho-Chung Huang** Head, Microwave Processing Technology Research.

Marvin A. Leedom, Head, Mechanical and Instrumentation Technology, appointed **William G. McGuffin** Manager, Instrumentation.

David D. Holmes, Director, Television Research Laboratory, appointed **Ronald L. Hess** Head, Deflection and Power Supply Systems Research; **Stanley P. Knight** Head, Signal Conversion Systems Research; and **Robert M. Rast** Head, Systems Technology Research.

Nathan L. Gordon, Staff Vice President, Systems Research, appointed **Paul M. Russo** Head, TV Microsystems Research.

Government Systems Division

James Vollmer, Division Vice President and General Manager, appointed **Paul E. Wright** Division Vice President, Engineering.

Patent Operations

Harold Christoffersen, Director, Solid State and Electronic Systems, announced that **Donald S. Cohen,** Managing Patent Attorney, will assume the responsibility for Solid State Device and Processing Activities.

Consumer Electronics Division

Jay J. Brandinger, Division Vice President, Engineering, announced the organization as follows: **J. Peter Bingham,** Chief Engineer, New Products Laboratory; **J. Peter Bingham,** Acting Manager, Signal Systems and Components; **Cortland P. Hill,** Manager, Product Design and Test Technology; and **Eugene Lemke,** Manager, Display Systems.

Edmund W. Riedweg, Plant Manager, Bloomington, appointed **John M. Wright** Manager, Technical Coordination.

Obituaries

Charles M. Odorizzi, a retired Executive Vice President of RCA, died August 23. He was appointed to the staff of the President in 1969 and served on the staff of the Chairman of the Board until his retirement in 1973. Mr. Odorizzi served as a member of the RCA Board of Directors from 1957–1974.

Prior to joining RCA in 1949 as Vice President in charge of service for the RCA Victor Division, he held several top management positions outside the company. He became Senior Executive Vice President, Services, in 1968, with responsibility for over-all supervision of RCA Global Communications, Inc., RCA Service Company, Parts and Accessories, and The Hertz Corporation. At other times during his career he had responsibility for RCA Victor Record Division, RCA International Division, the Broadcast and Communications Products Division, Corporate Licensing activities, and RCA Magnetic Products Division.

Henry P. Lemaire, formerly Chief Engineer of Memory Products Division, Needham, Mass., died recently. He joined RCA in 1959 and after a brief time was in charge of Advanced Development for the Memory Products Division where he supervised the development of ferrites for new applications, high-temperature ferrites, and high-speed memories. Mr. Lemaire remained with that division when it was sold to Digital Equipment Corporation in 1972. He later became vice president, component manufacturing and engineering.

Recent books by RCA authors

Kleinberg

Blicher

How You Can Learn to Live with Computers

Harry Kleinberg
Published by J.B. Lippincott Company

The following description appears on the inside flap of Harry Kleinberg's book. Harry, Manager of Corporate Standards Engineering, Cherry Hill, N.J., and a former computer engineer, also has an article in this issue of the *RCA Engineer*, pages 44-46.

"You don't have to have a private lab at M.I.T. to understand the basics of the computer, according to computer expert Harry Kleinberg. Written in clear, jargon-free language for the layman, *How You Can Learn to Live with Computers* dispels the many myths and fears that surround computers and explains the remarkably simple principles on which they operate.

For some, the computer heralds a new age of liberation, where mental drudgery will be as outmoded as physical labor and social decisions will be made with speed and correctness. For others, it foreshadows an Orwellian world where humanity's every action and thought will be controlled by the Machine.

Harry Kleinberg argues that neither vision is true, and traces his own long acquaintance with this amazingly versatile invention to illustrate exactly what the computer can and cannot do. You may be surprised to learn that computers don't solve problems, make decisions, or think; that words like "intelligence" and "memory" assume entirely different meanings when applied to the computer; and that a computer possesses no oracular power beyond the limitations of the person who programs it. For anyone who fears that a computer may someday claim his job, *How You Can Learn to Live with Computers* tells you just how much of your work a computer might be expected to perform.

Humorous, sensible, insightful, *How You Can Learn to Live with Computers* presents both the comic and the serious sides of the machine—and concludes that it will indeed revolutionize your life, but in ways that you may not expect."

Thyristor Physics

Adolph Blicher
Published by Springer-Verlag

Thyristor Physics presents concisely the physical principles underlying the operation and performance characteristics of the class of p-n-p semiconductor switch known as the thyristor. The book is directed to semiconductor-device physicists and designers, students, and those electronic-circuit designers who wish to apply thyristors creatively without the limitation of considering them only as "black boxes." The book endeavors to present an up-to-date account of the advances in understanding the operation, potentialities, and limitations of thyristors as switching-circuit elements.

Following an introduction to basic device theory, the author discusses the static and dynamic properties of silicon controlled rectifiers, triacs, gate-turn-off thyristors, and reverse-conductivity thyristors. The final chapter of the book is devoted to thyristor-circuit basics.

This volume is the first in the English language devoted almost entirely to thyristor physics.

Dr. Adolph Blicher was manager, Advanced Devices and Applications, of the Solid State Technology Center, RCA Laboratories, Somerville, N.J. at the time of his retirement in 1972. He joined RCA Solid State Division, Somerville, N.J. in 1955 and was in charge, over a period of years, of the development of a very great variety of semiconductor devices such as low- and high-frequency transistors, thyristors, integrated circuits, solar cells, varactor and tunnel diodes, vidicon targets, light emitting diodes, etc.

Licensed engineers

When you receive a professional license, send your name, PE number (and state in which registered), RCA division, location, and telephone number to: *RCA Engineer*, Bldg. 204-2, RCA, Cherry Hill, N.J. New Listings (and corrections or changes to previous listings) will be published in each issue.

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William D. Lauffer, Jr., Cherry Hill, N.J.; Del.-5243.

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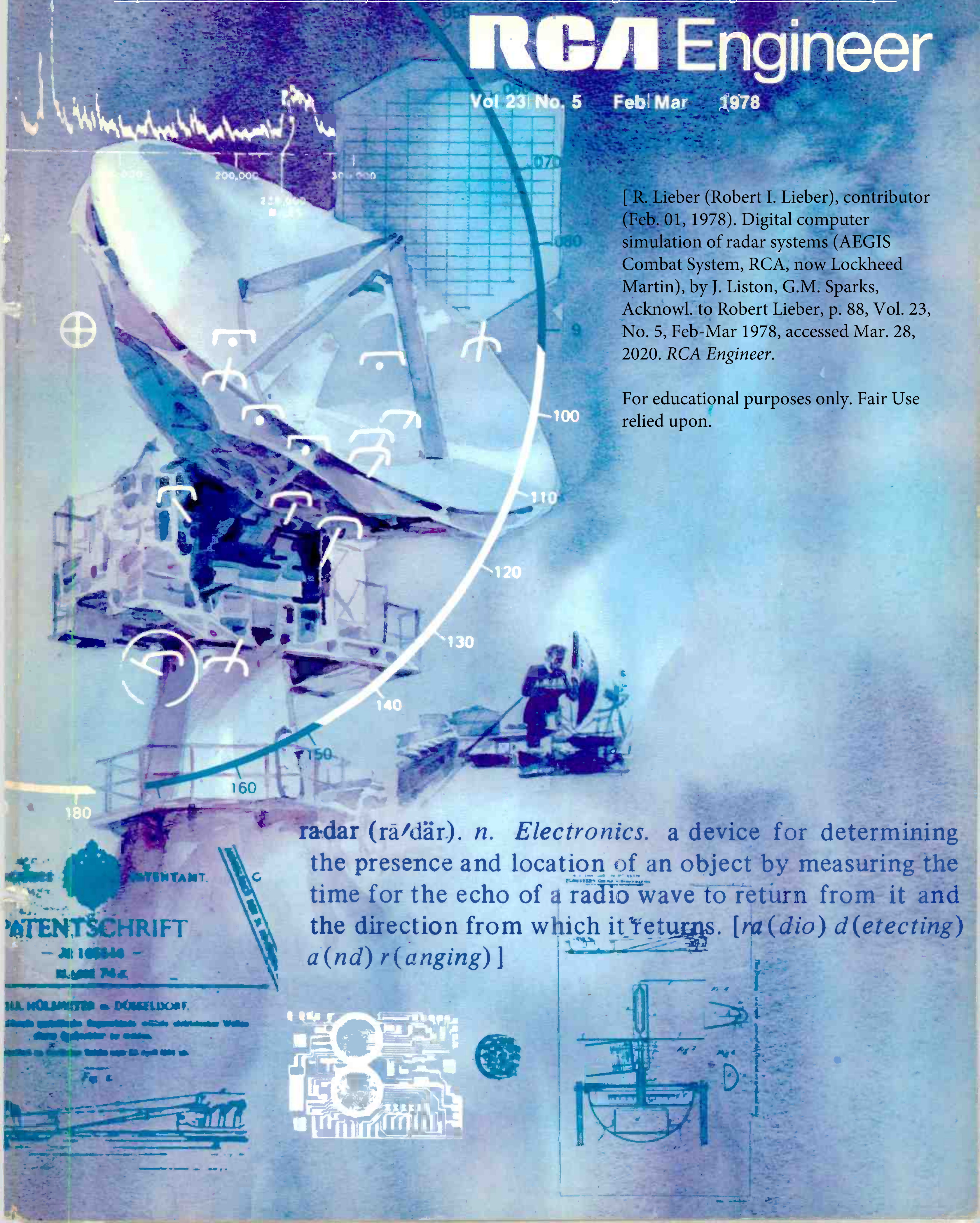
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PATENTSCHRIFT
ra·dar (rā′där). n. Electronics. a device for determining the presence and location of an object by measuring the time for the echo of a radio wave to return from it and the direction from which it returns. [ra(dio) d(etecting) a(nd) r(anging)]

RCA Engineer

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- To disseminate to RCA engineers technical information of professional value
- To publish in an appropriate manner important technical developments at RCA, and the role of the engineer
- To serve as a medium of interchange of technical information between various groups at RCA
- To create a community of engineering interest within the company by stressing the interrelated nature of all technical contributions
- To help publicize engineering achievements in a manner that will promote the interests and reputation of RCA in the engineering field
- To provide a convenient means by which the RCA engineer may review his professional work before associates and engineering management
- To announce outstanding and unusual achievements of RCA engineers in a manner most likely to enhance their prestige and professional status.

Our cover combines radar's past and present. The large circle is a plan-position indicator showing a number of targets. Starting at the top center of the cover, we have: the trace of the first radar echo bounced off the moon; a face of the AN/SPY-1 phased-array radar system; the AN/FPQ-6 instrumentation radar; Dr. Irving Wolff performing radar experiments at RCA's Camden plant in the 1930s; Hulsmeyer's German and British radar patents from the early 1900s (surrounding modern electronic hybrid microcircuits); Guglielmo Marconi, inventor of the "wireless," shown in two views; a three-dimensional plot of a radar antenna pattern; Heinrich Hertz, who showed that electromagnetic energy could be reflected; an integrated circuit; and Nicola Tesla, who first proposed the practical use of radio waves for detecting objects.

Cliff Winner, from Missile and Surface Radar, Moorestown, N.J., painted the watercolor for our cover.

The radar business—25 years later

Twenty-five years ago, RCA dedicated its new plant in Moorestown on what had formerly been a highly productive asparagus field. This expansion of facilities represented RCA management's long-term investment in the vital field of radar engineering. In his dedicating speech, W. Walter Watts, then Vice President, RCA Technical Products, stated:

> "Radar is but one fast-moving frontier in the amazing science of electronics, which daily brings us new wonders in such fields as television, 'electronic brain' computers, communications, industrial products and controls, and sound recording and reproduction. As in these other fields, we have only scratched the surface of radar's potential services."

That perception has proved to be well-founded. Initially, straightforward applications of traditional radar technology yielded a solid business base in neatly packaged user areas (e.g., the range instrumentation radar "product line"). With the passage of time, technological advances blurred the earlier distinctions between radars, computers, and communications. More importantly, the emphasis shifted from separate electronic "black boxes" to integrated electronic systems. In many cases, radar became the heart of such systems.

At the same time that our customers were demanding ever-increasing levels of performance from radar systems, they have had less money to spend. Thus, "Design to Price" has become a necessity rather than just a slogan.

Today we stand astride a radar technology with capabilities that were beyond conception when Moorestown opened its doors in 1953. Now we can cover the skies from horizon to horizon, detecting, tracking, identifying, and countering everything that moves. Non-military applications also abound, for we can measure ocean wind currents, predict crop yields, and measure soil conditions and potential drought areas all over the world—all with radar. Truly there is reason for pride in accomplishment among radar developers.

And uneasiness, as well. Radar users are becoming increasingly aware of how diverse technologies could converge to extend and expand radar's capabilities. We can be certain that some user, somewhere, is already making far-reaching assumptions on future radar applications. Almost as certainly, some industrial or academic laboratory is nurturing a germ of an idea that will ultimately make these assumptions a reality.

So today the business outlook for radar is as robust as it was 25 years ago. The pattern that has characterized radar development in recent years seems certain to continue. Our challenge is to assure that RCA remains a leader by stimulating and supporting the groundwork of today that will anticipate and satisfy the requirements of the future. Clearly it is a challenge of major proportions.

But it's more fun than growing asparagus.

Max Lehrer

Max Lehrer
Division Vice President and General Manager
Missile and Surface Radar
Moorestown, N.J.

Radar—it's changed

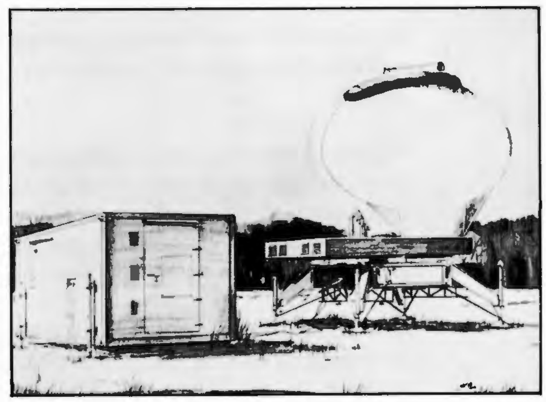
from this

6, 11

to this

25, 32

and this



61

Sarnoff Award winners 100

How do RCA's information sources rate?

46

coming up

Our next issue (Apr/May) covers the **software** explosion and how it is affecting the traditional hardware-oriented engineer. Our anniversary issue (Jun/Jul) traditionally covers the year's most significant technological events at RCA—**digital television, SOS technology, optical videodisc memory,** and more.

RCA Engineer

Vol. 23|No. 5 Feb|Mar 1978

about this issue...

Radar technology today—perplexity in Wonderland

Part of the wonder and fascination of radar is that it can *do* so much. In something like 40 years, defense establishments all over the world have come to depend on it more and more—originally as a sometimes-reliable sensor, and more recently as a key controlling element in major defensive systems. Today, space-age radars routinely identify, track, and analyze virtually everything in earth orbit.

But the non-military applications of radar are even more exciting. Radar is everywhere—as a bulwark of air traffic control, in marine navigation (including more and more pleasure boats), in assessing soil conditions and crop harvests on an international scale, measuring and plotting terrain features and sea states, and even (as detailed herein) as a tool in the basic steel-production process. Perhaps the best evidence of acceptance is the introduction of the word "radar" into the vocabulary of the consumer products market.

This kind of application explosion didn't just happen. It represents, instead, a studied and imaginative application of modern technology to exploit the intrinsic potential of radar. Practically everything has been tossed into the pot—a broader slice of the electromagnetic spectrum, the wonders of solid-state devices and circuit miniaturization, and the entire range of computer elements. In essence, the continuing growth of radar derives directly from technological diversity.

This kind of diversity, of course, begets *complexity*. And another name for complexity is *perplexity*—for the layman who is struggling to understand, and even to a degree for the trained engineer who knows the basics but is uncertain about how all the peripherals work. The pace of radar development in recent years has opened a very real chasm between the conceptual simplicity and elegance of radar technology and the ability of the average engineer to feel comfortable with it.

A stated goal of the *RCA Engineer* is to help bridge this gap. And this issue represents an honest, if modest, attempt to make some of the technology of modern radar understandable both to those who are interested but not directly involved and to those who are involved, but on the fringes.

Accordingly, the papers in this issue are *not* about RCA products for the most part. Neither do they describe everything that is new and good in the field, either in applications or in the technology.

What this issue *does* offer is a thorough-going primer on radar operation (Barry Fell, p. 14), some interesting historical background and personal reminiscences (Tom Greene, p. 6, and Irv Wolff, p. 11), a summary of where we stand today technologically (Art Robinson, p. 25), and a working-level treatise on the explosion in signal and data processing (Walt Weinstock, p. 32). The remaining papers form a montage of some of the work going on in RCA today—from feeds and antennas, to solid-state switching and amplification, to the dark arts of balancing analog and digital processing techniques, to a few special examples of radar applications.

In summary, although this issue is certainly not comprehensive, it gives a feeling for what radar is all about today. If you see something that interests you and would like to learn more about it, please call one of the authors. They are all articulate and enthusiastic. If you're looking for something and don't see it here, several of the papers include fairly extensive references on specific subjects. And if you're still curious, the following brief bibliography lists a number of recent papers on radar by RCA authors.

Don Higgs
Technical Publications Administrator
Missile and Surface Radar
Moorestown, NJ

Ed. Note: **Don Higgs** presented the idea for the radar issue to the *RCA Engineer* Planning Board in June 1976. He then guided it through several levels of planning and pushed it to its final steps—working personally with most of the authors through rough drafts, rewrites, and approvals. The quality of the result speaks for itself.

Ed Burke, our Consulting Editor at MSR, provided the graphic treatment for Don's Editorial Input.

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The early days of radar

T.G. Greene

Although the first radar patents were filed in the early 1900s and working systems existed in the 1920s, World War II was the real driving force behind radar development.

Ed. Note: This short history does not attempt to be all-inclusive; it is part of a more complete radar history, consisting of about fifty wall panels being prepared by Tom Greene for display in the corridors of RCA's Moorestown plant. Space constraints have excluded credit to many radar workers within and outside of RCA; we have also stopped our history just after the end of World War II, when large-scale radar-based defense systems entered the scene.

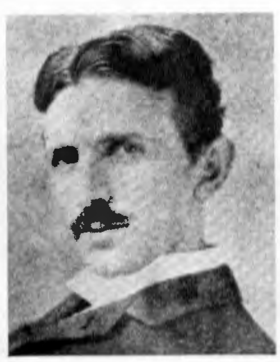
Tom Greene's role here has been that of a collector and editor, rather than as an author. He is deeply indebted to the good memories and collecting habits of the many GSD engineers who helped on this project, as well as those engineers who long ago had the foresight to write thorough final engineering reports on their projects.

1886 Heinrich Hertz

Professor Heinrich Hertz in Germany demonstrated experimentally in 1885 that 66-centimeter radio waves could be formed into beams and that solid objects would reflect them. When the identity between light and radio waves was established, it became clear that a radio wave reflected back on itself would create a wave-interference pattern, and that this pattern would in itself be evidence of the reflecting object.

This wave-interference detection method, the forerunner of the pulse method, was reported by various groups of workers in widely different applications, in the early 1920s, both in the United States and abroad.

1900 Nicola Tesla



When Hertz demonstrated that electromagnetic waves could be reflected by solid objects, he was far ahead of his time in the science of radio-location. It remained for Nicola Tesla to recognize and to point out the practical application of the radio "echo," so vital in the Second World War. Describing his 1889 method and transmission of wireless energy in *Century Magazine* (June, 1900) he wrote:

"Exactly as with sound, so an electrical wave is reflected, and the same evidence which is afforded by an echo is offered by an electrical phenomenon known as a "stationary" wave - that is, a wave with fixed nodal and ventral regions. Instead of sending sound-vibrations toward a distant wall, I have sent electrical vibrations toward the remote boundaries of the earth, and instead of the wall the earth has replied. In place of an echo I have obtained a stationary electrical wave - a wave reflected from afar.

Stationary waves . . . . mean something more than telegraphy without wires to any distance . . . For instance, by their use we may produce at will, from a sending station, an electrical effect in any particular region of the globe; we may determine the relative position or course of a moving object, such as a vessel at sea, the distance traversed by the same, or its speed."

1903 First practical application

KAISERLICHES PATENTAMT.

PATENTSCHRIFT

— № 165546 —

KLASSE 74d.

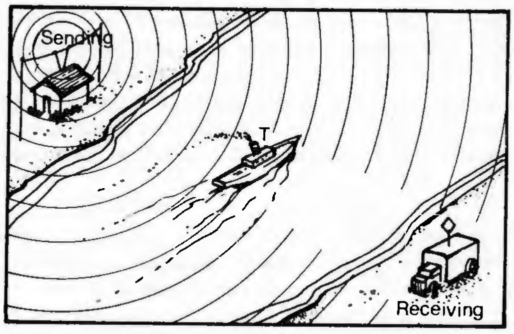
CHR. HÜLSMEYER in DÜSSELDORF.

Fig. 1

In 1903 Christian Hülsmeyer experimented with radio waves reflected from ships. He obtained patents in several countries the following year for his obstacle detector and ship navigational device. His scheme was demonstrated to the German Navy but failed to develop interest because the maximum range of detection was only about one mile using the technology available at the time.

Hülsmeyer recognized the problems of stabilizing a highly directional beam on a rolling, pitching naval vessel and provided some correction for this in his British patent entitled *"Hertzian-wave Projecting and Receiving Apparatus Adapted to Indicate or Give Warning of the Presence of a Metallic Body, such as a Ship or a Train, in the Line of Projection of such Waves."*

1922 Ship detection by interference



At the Naval Aircraft Radio Laboratory at Anacostia, D. C., Dr. A. Hoyt Taylor and Leo C. Young were conducting radio field strength measurements when they observed that a ship passing through a high-frequency field affected the performance of the receiver. In September 1922, they suggested the use of this interference effect for the detection of ships.

1924 Watson-Watt and the RAF

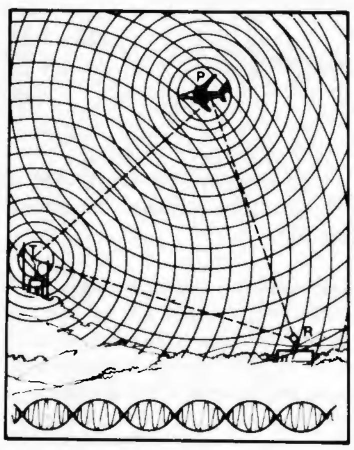
Beginning studies on mechanical direction finders in 1919, Robert Watson-Watt developed a cathode-ray direction finder in 1928 capable of locating thunderstorms out to 400 miles and in azimuth to 1°. With his wife Lady Margaret Robertson Watt as his principal laboratory assistant, he began major research on airplane radio-location in 1935. In 1940-41 the Germans, continually encountering concentrated RAF fighter opposition to their bombing raids, assumed the British had large numbers of fighter planes. At that time woefully weak in fighter craft, Britain was able to vector those they had to the German attackers by using Watson-Watt's equipment.

When Robert Watson-Watt was knighted on King George VI's birthday in 1942, he was identified merely as "a pioneer in radio location." When war security restrictions were later lifted, he finally received credit for his principal role in developing Britain's radar, credited equally with the RAF in winning the Battle of Britain.

1925 Measuring the ionosphere

The first reported use of pulsed radio energy to measure distance was that of Gregory Breit and Merle Tuve of the Carnegie Institute in Washington, D.C. Reporting on their basic scientific investigation in the *Physical Review* in 1926, they described successful efforts to measure the height of the conducting layers in the ionosphere, using interrupted trains of waves (ICW) and an oscillograph to record the echos. Several organizations and amateurs assisted in their experiment. Arrangements were made to transmit from NRL's station NKF, Bellevue, Anacostia, D.C., Westinghouse's station KDKA in Pittsburgh, RCA's station WSC in Tuckerton, NJ, and the Bureau of Standards' WWV in Washington, D.C. Their superheterodyne receiver, located at NRL, used type 201A tubes produced by RCA. The summary of the detailed 21-page paper cited above reported that the hypothesis of an ionized upper layer of the atmosphere was correct and that its height varies from 50 to 130 miles.

1930 Young and Hyland



Leo C. Young and L. A. Hyland, engineers at the Naval Research Laboratory (successor to the Naval Aircraft Radio Laboratory), were experimenting with short-wave direction finding. Hyland noted trouble with the performance of the equipment in the form of occasional violent signal fluctuations. He was ready to return his "balky" receiver to the laboratory for overhaul when he observed that the signal fluctuations occurred only when an airplane flew overhead. Hyland wrote a memo describing this method of detecting aircraft to Dr. Taylor (mentioned earlier), who reported it in a letter to the Chief, Bureau of Engineering, on November 5, 1930. A development program started immediately.

Taylor, Young and Hyland received a patent on a "System for Detecting Objects by Radio" for their NRL work on cw wave-interference radar.

1932 RCA enters the field

Radar research and development were carried on exclusively by the military services until RCA entered the field in 1932, when a group of engineers under the direction of Dr. Irving Wolff began work in the microwave field. Although RCA began radar research and development with marine and aircraft navigation and collision prevention applications in mind, the military applications of radar soon became evident and work with both the Army and Navy followed. (His accompanying article describes this early work more completely.)

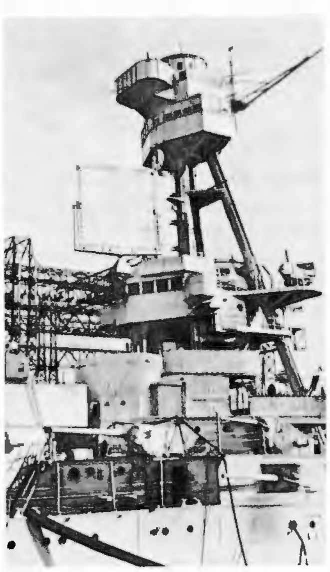
By 1937 RCA had developed pulse ranging equipment which could determine the range of a target with considerable accuracy over short distances and obtain reflections from targets at greater distances. A radio detection and ranging equipment installed on the roof of one of the RCA buildings in Camden, New Jersey, was the first microwave pulse radar system in the United States, and probably the world. The antenna was designed with directional characteristics and mounted so that it could be rotated. A cathode-ray tube was employed as an indicator in the receiver output circuit. One coordinate on the indicator tube screen showed distance and a second coordinate showed angle. The skyline of Philadelphia was plotted, and vessels plying the river about two miles distant were located.

1937 Col. Blair demonstrates radar

In 1937, the first equipment developed by the Signal Corps was demonstrated at Ft. Monmouth to the Army Chief of Staff. "General Malin Craig was sold when he saw we were able to keep a plane flying overhead in the beam of a searchlight directed by the radar position finder."

Colonel William Blair did not receive a patent covering the invention until 1957, after special legislation was passed permitting the filing after the legal time limit had expired. Col. Blair could not file until 1945 due to wartime secrecy. His pulse echo system used a single transmitter and receiver to determine distance and direction. The system credited to Sir Robert Watson-Watt of England required two receivers.

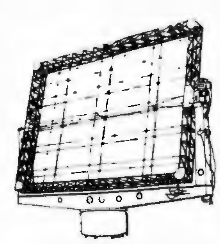
1937 Shipborne radar

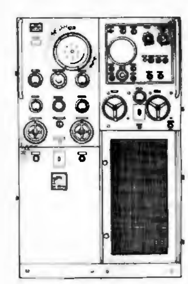


In 1937 RCA began work on the development of the CXZ, a shipborne equipment for detection and ranging, operating at 475 MHz. A single cabinet housed the transmitter, modulator, and pulse generator, and also served as a pedestal for the antenna array. This was the first shipborne radar designed by a commercial firm to be installed on a Navy ship, the *USS Texas*.

At the same time a radar operating at 200 MHz was developed at the Naval Research Laboratories and placed on the *USS New York*. Comparative tests of the two equipments showed that the RCA unit had superior definition, while the NRL version gave longer range. A model incorporating the best points of each was designed and RCA received a production contract for six units designated Model CXAM.

1939 Commercial radar for the Navy



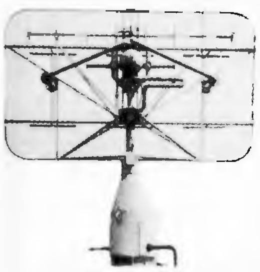


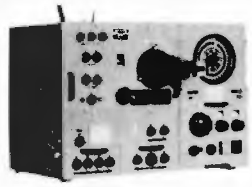
RCA's production contract for six CXAM radars was followed by a contract for fourteen additional equipments known as Model CXAM-1.

The Model CXAM was the first radar produced for the Navy by a commercial firm. It was an air search instrument providing range and bearing information, and was designed for installation on aircraft carriers, battleships, and cruisers. The first of these equipments was installed on the flagship *USS Augusta* in June, 1941. At the time of our entry into World War II, the twenty sets installed on the most important ships of the fleet were the only radars in use by the Navy.

An officer serving on the *USS California* reported using CXAM 1 equipment successfully for navigational purposes on a fogbound trip from Seattle to San Francisco.

1941 High-production shipborne radar





The SA (Shipborne, Surface and Air Search Radar) was developed to provide early warning and keep track of surface vessels and aircraft targets. It also proved useful as a navigation aid. The Model SA was intended for installation on destroyers and destroyer escorts. Development started in April 1941 and the first model was delivered in September. Production started immediately after the Pearl Harbor attack; 1565 sets of the Model SA series were produced by RCA at Camden. This was the largest quantity of this type of equipment produced by any one manufacturer during the war.

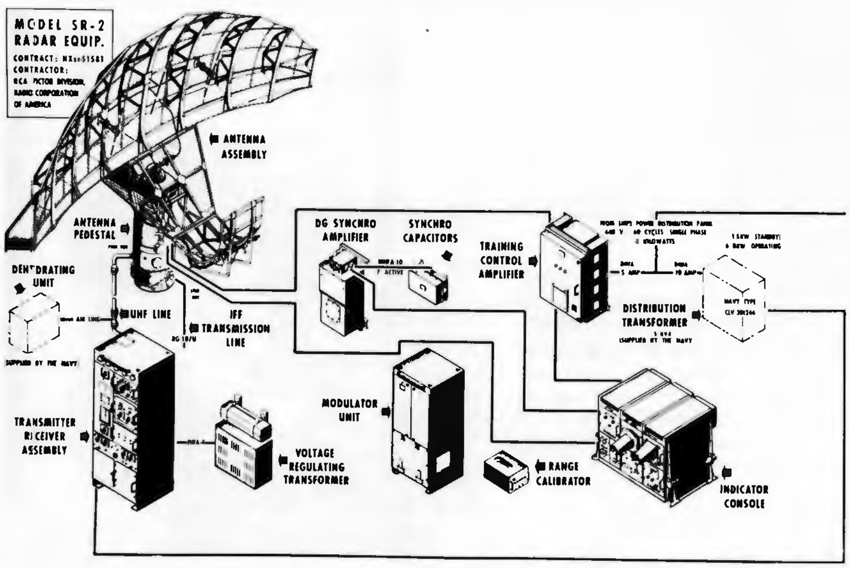
1942 Madam X — the proximity fuze

RCA engineers cooperated with the U.S. Navy's Bureau of Ordnance and the Office of Scientific Research and Development in the development of the proximity fuze for use in rotating projectiles such as field artillery or antiaircraft shells. This fuze was designed to burst in the vicinity of the target, within the fragmentation area of the shells, making it as effective as a direct hit.

Known officially as the VT fuze, it was unknown to all but a few military officials, scientists, and engineers until the war was over. To the factory workers, it was a mysterious project known as Madam X. Five and one-half million fuzes (more than half those supplied to the armed forces between October, 1942 and war's end) were assembled at RCA's Camden, New Jersey and Bloomington, Indiana plants.

The VT fuze was enclosed in the nose of the projectile. A conical metal cap on the tip acted as an antenna. It continuously radiated high-frequency energy in a beam roughly matching the fragmentation pattern of the projectile. When a portion of the radiated field encountered a target, the antenna loading varied, which in turn changed the plate current of the oscillator. This change was detected and amplified enough to start a thyratron tube conducting and so actuated the detonator in the projectile. A special wet battery, in which the electrolyte was contained in a glass ampule, supplied the electrical energy. The shock of firing broke the ampule and the spinning of the projectile distributed the electrolyte through the battery cells. The fuze required the designing of miniature tubes and associated parts sturdy enough to withstand not only the terrific impact when the gun was discharged, but also the centrifugal force of the shell's high-speed spinning.

1943 High-frequency radar



The Model SR-2 shipborne surface and air surveillance radar was designed to incorporate the experience gained on all previous search radars to provide long-range warning for large ships.

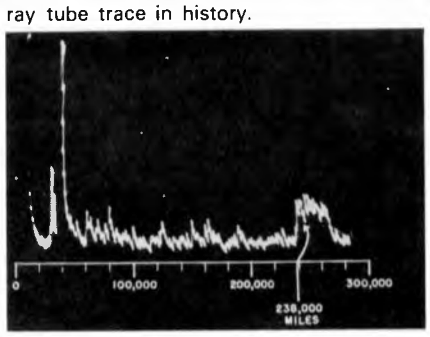
Coordinated design began in October 1943 and the first production model was shipped to NRL for test in April 1945. Two sets were delivered and installed aboard the *USS Midway* and the *USS Franklin D. Roosevelt* before World War II ended. A total of 18 sets were produced by RCA before the program was cancelled at war's end. Operating at a higher frequency than the SA, the SR-2 had a longer range and supplied more accurate range and bearing data than earlier shipborne search equipment. The antenna structure was made of stainless steel to avoid corrosion problems experienced with former search arrays.

1946 Radar echoes from the moon

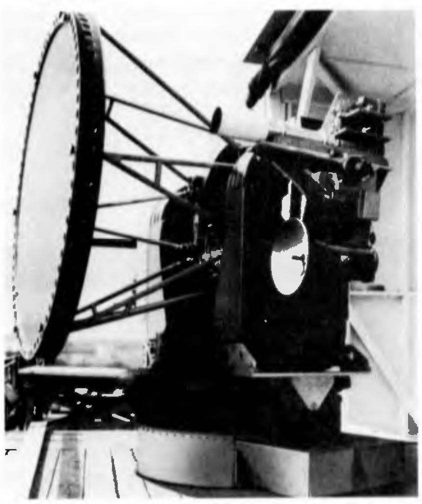
Late in 1945 the U.S. Army Signal Corps began a program to determine whether radar signals could be reflected from the moon and what use might be made of them.

Two antenna "mattresses" of the type used on the Army SCR-270-271 radar were assembled together at Evans Signal Laboratory in Belmar, NJ. The resulting array of 64 dipoles, about 40 feet square, was supported on a 100-foot tower. Because the antenna could rotate in azimuth only, observations were restricted to a relatively short time near moonset and moonrise.

On January 10, 1946, the first echoes from the moon were obtained at moonrise. One of the earliest photographs from these experiments, that of an echo at moonrise on January 22, 1946, is shown on the sweep of a conventional type-A radar oscilloscope. At about 2-1/2 seconds after the first pulse was transmitted, a vertical deflection of the trace occurred — the pulse returned from the moon had been received. This became the most widely published cathode-ray tube trace in history.



1946 Radar systems



The Bumblebee contract was one of the earliest examples of an integrated radar system. The system did far more than detect targets. The contract was initiated to have RCA support the U.S. Navy and their systems contractor, the Applied Physics Laboratory of the Johns Hopkins University. RCA's task included: "Research and development work . . . carried on in connection with electronic guidance equipment for guided missiles . . . . Special emphasis shall be placed on the development of radar equipment to track enemy targets and to guide these (Bumblebee) missiles to the targets."

The significant feature of this contract for RCA was that it led into the entire instrumentation radar business for the corporation: AN/FPS-16, AN/MPS-25, AN/FPQ-4, AN/FPQ-6, AN/TPQ-18, CAPRI, and AN/MPS-36.

Reprint RE-23-5-2
Final manuscript received January 18, 1978

Author Greene holding a prototype four-horn monopulse feed for the Apollo LM rendezvous radar.

Tom Greene's long association with radar began in 1942, when he tested SA, SD, and Mark 11 radars for RCA in Camden. He worked on the AN/FPS-16, Talos, BMEWS, and DAMP programs at MSR and later served as Manager of Proposals and Contract Reports there. He is now an instructor for PRICE, RCA's cost-predicting model, and is also responsible for PRICE documentation.

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Radio Vision—the early days of radar at RCA

RCA's involvement in radar started as an attempt to find an application for microwaves.

I. Wolff

Finding work for microwaves

When radar development was first undertaken, mostly by various military establishments, in the middle 1930s, the carrier frequency used for the transmission was several hundred MHz at the high end. It wasn't until compactness and greater directivity indicated the use of a basically higher carrier frequency, and a powerful pulsed magnetron was developed in England, that work on microwave radar started in the early 1940s at M.I.T. Radiation Laboratory.

Irving Wolff initiated the program of microwave research at RCA described in this article that eventually led to the production of radar equipment. He became Director of the Radio Tube Research Laboratory in 1946 and was Vice President, Research, RCA Laboratories from 1954 until his retirement in 1959.

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Princeton, N.J. 08540
609-924-3252

Author Wolff checking early radar equipment on the roof of Building 5 in Camden during the 1930s.

In RCA, one might say that we had the cart before the horse. In the early 1930s radar, we called it Radio Vision, was initially developed to find an application for microwaves some seven years before microwaves became the backbone of radar.

About 1932 publications were appearing, originating in Germany and Japan, relating to developments of microwave magnetrons. Research was also reported at the University of Michigan. This seemed to be a fruitful area for RCA research, and with the approval of Dr. E. W. Engstrom, Manager of Research, we initiated a program to develop a 3000-MHz system. Dr. E. G. Linder was recruited from Cornell to undertake a magnetron development. The receiver we used first was an old-style silicon-crystal type.

By 1934, work had progressed sufficiently to have an operating transmitter-receiver system and RCA demonstrated the equipment at several IRE meetings during that year. At that time, the possibility of reflecting sharp beams of microwaves from metal objects and ionized gases was shown.

The Signal Corps was excited by these demonstrations and invited us to bring the equipment to Navesink Light at Sandy Hook, N.J. to test the range of the apparatus as a communication set. We were very thankful for this invitation because the location for distance tests was much better than any we had in Camden. The transmitter site was at an altitude of 250 feet overlooking New York Bay and there was a clear range over New York harbor of more than 15 miles. The transmission tests were quite successful, giving a range as great as line-of-sight.

From our standpoint the most significant experiment was an attempt to obtain a reflection from a boat entering New York harbor. The channel was about one-half mile from the transmitting-receiving location and we were elated to receive reflected signals from a ship passing through the channel. Some water tanks on shore at about the same distance were also good targets.

Pulse radar

Our equipment at this stage used audio modulation of the transmitter; three-foot parabolic dishes on both transmitter and receiver obtained directivity. Thus, only the azimuth of the reflecting object was determined. The success of the reflection experiments at the Signal Corps Laboratory changed the orientation of our research from the possible application for radio relaying to use as a navigation instrument. For most effective application in navigation, however, distance as well as azimuth information would be required, leading us to start a project for pulse modulation of the transmitter and pulse amplification in the receiver. We aimed for a pulse of less than one microsecond duration to obtain satisfactory distance resolution.

RCA's Camden plant was the site of early radar experiments.

Apparatus with such pulse modulation was constructed in 1938 and the equipment was placed on the roof of Camden's Building 5 for tests. The receiving equipment was later modified to substitute a superregenerative magnetron for the crystal or detector. We were able to pick up and follow the ferry boats and other shipping in the Delaware River as well as the trains on the elevated line on the Philadelphia side of the river.

At first, we had only a distance trace on the scope with a vertical blip showing the distance of the reflecting object. It was not long, however, before we tied the position of the antenna to the horizontal trace, the time after pulsing of the transmitter to a vertical trace, and the pulse signal to the grid, giving what is now called B scan.

In considering this development, it is interesting to think about the debt we owed television in what we were doing. If it had not been for the television research it is doubtful that we would have had the tubes to amplify the short pulses and the cathode ray tubes on which to show the return signals. These pieces of equipment are so commonplace now that it is easy to forget that they were new developments at that time.

How our radio-vision equipment could have been developed to have a commercial application is anyone's guess. We had in mind using it as a navigation aid installed on ships, and with additional refinement it might well have gone in that direction.

A series of plane crashes gave radar development a push.

However, a seemingly more important commercial need took precedence and changed the direction of our research sharply. Shortly before the time when the successful tests described above were made, there had been a series of very bad airplane crashes into mountains. At a high-level meeting held to discuss the lack of progress that RCA had made toward securing leadership in aviation radio, it was suggested that adopting our radiovision equipment to airborne use as a collision preventive could give us a big boost with the airline industry. This was the kind of imaginative technological advance using radio techniques that appealed to General Sarnoff, and we were directed to see what we could do.

The project, initiated in the spring of 1937, was oriented to the development of airborne equipment which would warn pilots of the approach to mountains and other aircraft. Owing to the instability, research nature, and antenna bulk at that time, a practical airborne system seemed doubtful until microwave components had gone through a development phase. Hence, the highest frequency which could be used with existing commercially available components, 500 MHz, was chosen for the radio frequency of the airborne equipment. We did not have manpower available to continue research on both the existing 3000-MHz project and the new airborne unit, so the former was temporarily set aside.

In the latter part of 1937, the new equipment was installed in RCA's Ford Trimotor airplane and numerous flight tests were made during the ensuing year. Targets were the Catskill Mountains and the Alleghenies of Pennsylvania. Two antenna systems were employed. To get a signal from potential obstacles in front of the airplane, we used an inverted "V" type antenna installed along the length of the Ford airplane. A dipole antenna under the plane obtained the altitude signal. With the airplane in level flight at the height of the mountain top, signals were received at a distance of about 5 miles. If the airplane were 1500 to 2000 feet above the mountain no signal was visible. The signal picked up from the ground reflection on the dipole altitude antenna was always visible. Other airplanes flying up to one-half mile directly in front of our radar-equipped plane could be detected. This was probably the first successful airborne radar equipment flown anywhere.

It had been our intention to give public demonstrations of our apparatus, as well as a modification of it for shipboard use to guard against collisions with other ships and obstacles such as icebergs. But once more, our plans had to suddenly change. By the late 1930s, war clouds were thickening in Europe and the military personnel who were shown the equipment and results immediately clamped a lid of secrecy on it and gave us contracts to develop apparatus for their use. Thereafter we became essentially a government contractor.

In summary, some seven years after it had been first undertaken, our microwave research led indirectly to first development, and later manufacturing, contracts for various types of radar apparatus for the military. Directly related to the airborne equipment which was demonstrated was a search radar using a Yagi antenna mounted on the wing of PBR flying boats and a high-altitude altimeter to aid in accurate high-altitude bombing.

It was entirely fortuitous that we just happened to have something very much needed by the military at the right time and it is interesting to speculate as to what might have happened if war had not been on the horizon. Assuredly, military application had not been our objective when we started the microwave research, or even when "Radio Vision" was well along. One can certainly say that progress in development and manufacture would have been much slower without the impetus of R&D funds and the urgency of equipment for a war.

FM radar

This, so far, has been the story of our early pulse radar. However, "circumstance of location" led us into another use of reflected radio waves using frequency modulation of the carrier (now known as fm radar).

At about the time we were making the flight tests in the Ford Trimotor, a young man contacted our patent department and said that he had some equipment to demonstrate. C. D. Tuska and I went to look. This was the "circumstance of location" referred to above. If the young man, Royden Sanders, had not happened to live close to Camden, it is very doubtful that RCA would have undertaken any fm radar research at that time.

While a sophomore at engineering college, and unaware of the Bell Laboratories fm radar work, Sanders independently developed the concept of fm radar and left college to work on his idea. We were familiar with the Bell Laboratories work and noted that he appreciated some of the factors which limited accuracy and had taken steps to make needed improvements in his development. We were sufficiently impressed to offer to buy whatever improvement patents he might obtain and to give him a chance to proceed with his development in RCA. This proved to be a wise decision. Sanders turned out to be a prolific and determined inventor as well as a sound engineer with a great dedication to fm radar.

RCA's fm-radar altimeter was very accurate at low altitudes.

In due course, a development model of an altimeter was built and demonstrated to the military services. This altimeter was not competitive with our high-altitude bombing pulse altimeter, since the pulse unit was most useful at then high altitudes such as ten to twenty thousand feet, where the ambiguity caused by pulse length was not of primary importance. On the other hand, the fm unit was most useful at low altitudes even down to fifty feet or less. When the fm altimeter was put into production, some tens of thousands were produced and, most unusually, the same apparatus was standardized for the US Navy, the Air Force, and the British. The production demands and timing were too great for RCA to handle alone, so two additional manufacturers were recruited to build the same unit.

The fm-radar altimeter proved to be most useful over water, where its exceptional low-altitude performance could be well put to use. As a next step, the output was tied in with the aircraft altitude control to set the altitude automatically. Since the output of the fm altimeter is most readily a current proportional to altitude, this step was not too involved, at least to the extent of getting adequate control signal from the altimeter.

The next step was a single radar that provided altitude, distance, and speed of approach.

Although it was obvious that the fm radar signal contained the information for determining the distance to the reflecting object, it was not generally appreciated that it also contained information on the speed of approach to the reflector. Sanders appreciated that where there was relative motion between the radar and the reflector, the sum of the up-sweep and down-sweep output frequencies gave a signal proportional to distance, whereas the difference was proportional to speed of approach to the reflector. Thus, the information required to drop a bomb in level flight over water, namely altitude, distance, and speed of approach to target, were all available from one instrument. One antenna pointed forward to get the target information and a second antenna pointed downward to obtain altitude measurement.

Equipment for dropping bombs automatically was constructed and numerous flight tests were made dropping water bombs against the lighthouses in Delaware Bay. Fortunately, none of the numerous fishermen in small boats in the river was ever hit.

A final step was to adopt the equipment to automatic bomb release in other than level flight. Before the more sophisticated development could be completed and put into production, though, the war was over.

This completes the story of the early days of radar (Radio Vision) in RCA, a project which was initiated to develop equipment and study applications of microwaves, and ended by supplying search radar, radio altimeters, and automatic bomb-dropping research and apparatus to a military at war.

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An introduction to radar concepts

B. Fell

Radar is basically simple—transmitting a pulse of microwave energy at a target and timing the reflected return. But the radar designer must produce equipment that can also detect the valid signals in a noisy environment, separate target signals from clutter, and avoid antenna-induced errors.

The origins of radar (RAdio Detection And Ranging) science are obscure, since early attempts to detect objects with radio waves ended either in failure or uncertainty as to the usefulness of this phenomenon. As discussed in Skolnik,[1] although pulsed radar was used as early as 1925 to investigate the ionosphere,[2] the earliest radars used to detect aircraft were bistatic continuous wave (cw) systems.

Early radars were used to detect the presence of targets but, as pulsed radar techniques were developed, radars were able to determine target slant range, angle, and rate of change of slant range with respect to the radar.

With the advent of short-wavelength radar ($\approx$ 1 cm to 3 cm) and miniaturization of electronic components, radar was placed aboard aircraft. Present-day airborne radar is used for avoiding collisions with other aircraft, determining aircraft altitude, locating areas of extreme turbulence, such as weather fronts and thunderstorms, and controlling onboard weapon systems, such as guns or missiles.

The primary military use of radar during the 1950s was to detect and help identify aircraft. Two North American air-defense systems built at that time were the U.S.-Canadian DEW (distant early warning) Line along the arctic circle and the U.S. SAGE (semi-automatic ground environment) radar net within the continental United States.

The Soviet Union's launching of Sputnik I in October 1957 called for the development of high-power, land-based, long-range radar that could probe the environs of outer space. The U.S. Ballistic Missile Early Warning System (BMEWS) and the Space Detection and Tracking Network (SPADATS) were developed and deployed over the last 20 years to answer ballistic-missile and satellite-defense problems.

Pulsed-radar functions are also being performed by optical systems, made possible by the development of the pulsed laser over the past 15 years. Optical radar is sometime referred to as ladar (LAser Detection And Ranging).[3]

Table 1 indicates the standard frequency bands allocated to microwave radar. Long-range (greater than 100 nautical miles) radars normally operate within vhf, uhf, or L-band. S- and C-band radars operate over medium ranges (50 to 100 nautical miles). X- and K-band systems are usually limited to short ranges (less than 30 nautical miles) since their transmissions experience high attenuation as they propagate through the earth's atmosphere. The microwave absorption is mainly caused by oxygen and water vapor in the atmosphere.

Table I
Radar frequency bands are allocated internationally by the International Telecommunication Union (ITU). Atmospheric attenuation increases with frequency, so low-frequency radars are used for long-range operation and high-frequency radars for short-range missions.

Letter Designation	Frequency
VHF	137 – 144 MHz 216 – 225
UHF	420 – 450 MHz 890 – 940
L Band	1215 – 1400 MHz
S Band	2300 – 2550 MHz 2700 – 3700
C Band	5255 – 5925 MHz
X Band	8.5 – 10.7 GHz
K_u Band	13.4 – 14.4 GHz 15.7 – 17.7
K Band	23 – 24.25 GHz
K_a Band	33.4 – 36 GHz

This paper deals exclusively with radar that operates in the microwave region of the frequency spectrum. It should provide a brief answer to the questions:

1) What is a radar?

2) How does a radar work?

3) What are the analytical tools used in radar system design?

Types of radar

Radars perform two primary functions: surveillance and tracking.

Surveillance (or search) radars, such as the RCA AN/UPS-1 and the GE AN/FPS-24, search a volume of space and report the detection of targets within the volume. Most airport radars are of the surveillance type. Tracking radars determine a time-history of and Tracking System (SPADATS), in the late 1960s, doubled the United States space-tracking ability.

and the Sperry AN/SPG-55, must be provided with initial pointing data in order to acquire and lock onto a target. The target is tracked until it leaves the radar coverage, maneuvers out of the radar tracking "gate," or until the target is no longer of interest. Tracking radars have been used at such facilities as Cape Canaveral, Wallops Island, and the Pacific Missile Range.

Many radars perform both surveillance and tracking. Included in this group are: 1) track-while-scan radars; 2) track radars that have a search capability; and 3) agile-beam radars.

A track-while-scan radar produces track data by correlating detection reports as the radar scans continuously in angle. The correlation procedure can be accomplished by a sophisticated computer or an operator seated at a display.

Tracking radars, such as the RCA AN/FPS-49, which can open their tracking gates to detect targets over a wide range interval, are able to search a volume of space. Once a detection is made, the radar can position its antenna beam in the direction of the target and execute a tracking algorithm. This type of system is usually unable to track more than one target.

Agile-beam (or inertialess beam-steering) radars have been made possible with the introduction of electronic, as opposed to mechanical, beam steering. Although electronic beam-steering techniques were used to a limited extent during World War II, the full advantages of inertialess beam steering were not realized until the early 1960s. Agile-beam radars have the flexibility to schedule search or track functions in any direction as needed, since their antennas are not constrained to rotate at a fixed rate (if indeed they rotate at all).

The RCA shipboard AEGIS AN/SPY-1 radar system is an example of an agile-beam radar. AN/SPY-1 uses a two-dimensional array of phase shifters to steer the radar beam. Hence it is called a phased-array radar. The AN/SPY-1 maintains a volume search and, upon detecting a target, tracks that target while still maintaining the volume search. The AN/SPY-1 can thus track many targets anywhere in its detection volume and still perform surveillance of the radar coverage.

Since time is a fixed entity, an agile-beam radar must trade off available time between search and track functions. However, the data-handling capabilities associated with an agile-beam system can be enormous. For instance, the addition of one Bendix AN/FPS-85 phased-array radar to the USAF Space Detection and Tracking Systems (SPADATS), in the late 1960s, doubled the United States space-tracking capability.[4]

Radars can also be characterized by the types of data they collect. Five common types of radar are continuous-wave, pulsed, pulsed-doppler, multistatic, and synthetic-aperture systems.

The continuous-wave (cw) radar transmits a continuous signal. If this signal is transmitted at a fixed frequency, target doppler (a measure of the target speed along the line connecting the radar location with the target position) can be determined very accurately. Many police departments use this type of radar to monitor the speed of automobiles. In addition to target doppler, frequency modulation provides a method of determining target range with cw radars.

Pulsed radars transmit a fixed duration pulse of energy at repeated intervals called the pulse repetition interval (PRI). Pulsed radars measure target range and angle.

Pulsed doppler radars measure target position in the same manner as pulsed radars but, in addition, extract doppler information from a received train of pulses. The doppler and position information is used not only to detect and track targets, but also to discriminate between moving targets and radar clutter. The remainder of this paper concentrates on describing the properties of pulsed doppler systems unless stated otherwise.

Multistatic and synthetic aperture radar systems will be discussed briefly for the sake of completeness.

Multistatic radar uses one or more transmitters and a set of radar receivers over a long baseline to provide highly accurate angle, as well as range, information. If the elements of the multistatic system are coherent, a multistatic radar becomes a microwave interferometer. The multistatic concept has been used extensively in the field of radar-astronomy.

Synthetic-aperture systems provide high angular resolution with small antenna apertures. Interferometric in nature, these radars are placed on moving platforms such as aircraft or satellites and use the platform motion to simulate a set of receive antennas.

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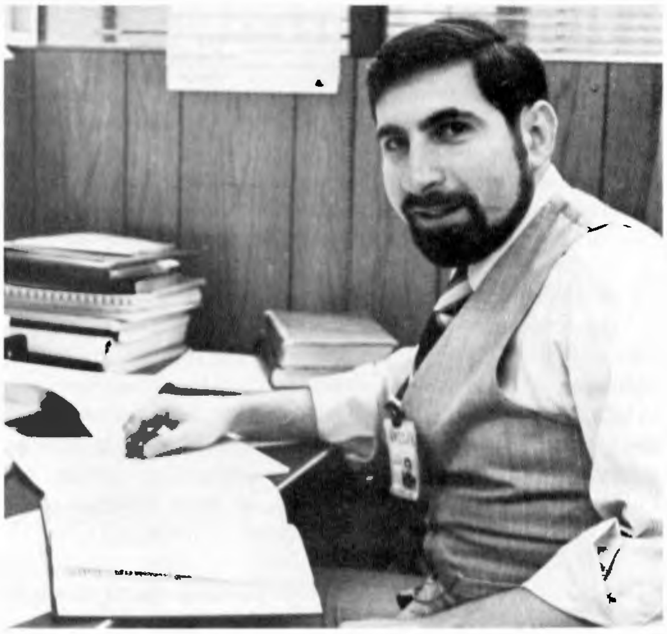

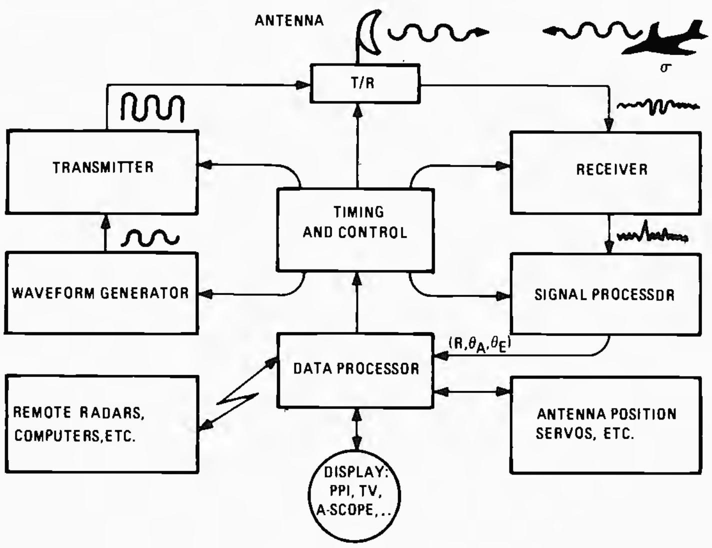

Fig. 1
A radar consists of a number of subsystems that affect overall system performance, but are all tied to a central timing/control subsystem. The waveform generator produces a pulse that is amplified by the transmitter and radiated by the antenna. If the pulse strikes a target, a return (dependent on the target's radar cross section) will be reflected back to the antenna. This signal is amplified in the radar receiver; the *S/N* is maximized by a technique known as matched filtering. The signal processor takes this information and filters out unwanted returns. A data processor provides for the radar's long-term timing and control, sending signals to display units, the antenna positioners, to other radars or computers, etc.

Radar functions

Radars can detect targets, estimate target position and velocity, and identify targets.

Target detection consists of searching a volume of space and reporting any targets which appear in that volume. Target position and velocity estimation includes the determination of range, angle (either azimuth, elevation, or both) and range rate (doppler) with respect to the radar. Target velocity cannot be measured instantaneously by a single radar, but must be derived from a time history of target position data.

Radars that measure target range, azimuth, and elevation are called three-dimensional; radars that measure range and only one angle are called two-dimensional. A two-dimensional system which measures range and elevation is sometimes called a height finder, since it provides an accurate determination of target altitude.

There are two general approaches to target identification: Selective Identification Friend/Identification Friend or Foe (SIF/IFF); and Space Object Identification (SOI). SIF/IFF is a technique in which a radar sends out a coded series of pulses that in turn trigger a transponder carried aboard the radar target. The transponder reply is directed toward the radar and contains target information such as target identification, range, and altitude. Air-traffic controllers at major airports use such systems to immediately identify aircraft in the vicinity of the airport.

SOI is a radar identification technique that uses the "skin return" from a radar target. Over the past 20 years, much progress has been made in identifying orbiting satellites by illuminating these radar targets at high data rates. The resulting amplitude vs time history of the target returns is analyzed to determine target characteristics such as size, shape, and tumbling rate.

Radar system operation

As shown in Fig. 1, a radar is composed of a series of subsystems: a waveform generator, a transmitter, an antenna, a receiver, a signal processor, a data processor, control equipment, and displays.

The waveform-generator produces a pulse of electromagnetic energy.

This pulse, the beginning of the radar cycle, can be a simple sinewave at a constant frequency or a complex waveform. Typically, complex radar waveforms may include a series of subpulses at the same or varying frequencies, a single phase-coded pulse, or a single frequency modulated (fm)-coded pulse.

The transmitter is an amplifier that increases the amplitude of the waveform generator output to the desired level.

This amplification is accomplished at radio frequencies (rf) by either a magnetron, klystron, traveling wave tube, conventional microwave tube, or solid-state power amplifier. The transmitter is characterized by its power amplification (gain), peak power output, pulsewidth, and duty factor (product of transmitted pulse duration and the pulse repetition frequency). The output of the transmitter is fed to the antenna subsystem.

The antenna matches the impedance between the guided-wave output of the radar transmitter and the free-space propagation of the radar pulse.

Antennas are of many types and sizes. The antenna determines the two-dimensional beamshape and beamwidth of the transmitter radar energy. Since the antenna concentrates the transmitted energy in a particular solid angle, passing energy through an antenna amplifies the total radar energy in a particular direction as opposed to transmitting radar energy equally in all directions. This characteristic of an antenna is called the directive gain. Antenna gain and beamshape are discussed below.

If a radar target is passive (i.e., if it does not actively produce radio transmissions that are directed back to the radar), the target merely acts as reflector that intercepts a portion of the transmitted radar power and reradiates it in various directions. These reflection characteristics are described by the target radar cross section (σ).

A radar target can modify the radio frequency of the transmitted radar waveform.

The component of target velocity along the propagation direction of the radar transmission (v_r) shifts the frequency of the transmitted pulse, because of the doppler effect, according to the relation

$$\Delta f = 2\, v_r / \lambda \quad (1)$$

where Δf is the magnitude of the frequency shift and λ is the wavelength of the transmitted pulse.

The radar mission determines the radar operation after transmission of a pulse. Surveillance radars continually scan a volume of space. The antenna beamwidth, antenna scan rate, and pulse-repetition frequency of such a radar determine the number of pulses transmitted and hence received by the radar. A typical search radar may transmit 20 pulses during the time it takes the antenna beam to sweep across a target. Tracking radars, on the other hand, know the target position relative to the beam axis, and by means of feedback they can continually steer the antenna so it is always directed towards the target.

The radar energy reflected from a target and captured by the radar antenna is sent to the radar receiver.

The receiver subsystem converts the frequency of received energy from radio frequency (rf) to an intermediate frequency (if), which is usually around 50 MHz. The receiver amplifies the received energy and maximizes the signal-to-noise ratio of individual pulses through a technique called matched filtering. This information is sent to the signal processor, which interprets the content of the received energy.

The signal-processing subsystem filters out unwanted returns.

Such unwanted "clutter," is typically energy reflected by obstacles on land, the land itself, the sea, or precipitation in the form of rain or snow. The signal processor can perform coherent or non-coherent pulse integration and presents its output to an indicator screen or an automatic target-detection subsystem.

A timing and control subsystem oversees overall operation of a radar during the period from pulse formation to pulse formation.

Overall radar operation is controlled by an operator or, in modern high-data-rate automatic systems, by a data processor. In addition, the data processor performs data smoothing and prediction for targets under track. The data processor also compensates for platform motion associated with radars located aboard aircraft or ships.

Radar output goes to a display or as control information for other systems.

The output of the radar can be presented in various ways, such as: 1) a plan position indicator (PPI) scope, which plots target range versus antenna azimuth position; 2) an "A"-scope, which displays receiver output amplitude as a function of time (i.e., range) for a particular azimuth or elevation direction; or 3) a cathode-ray tube (CRT) display updated by a data processor in real time. The radar system can use its output data to position its own antenna or drive also be sent to distant command and control posts, other computers, or to other radars. For example, a multistatic radar network requires communication among the related sensors to enable maximum use of the information obtained from the extended radar baseline.

Radar detection of targets

Detection can be broken down to transmitting a pulse, receiving a return, and separating signals from noise.

A radar determines the basic target-position parameters by producing a high-powered pulse of microwave energy (Fig. 2). This pulse energy is concentrated into a beam and directed by the radar antenna into a solid angle centered along a line in space. If a target lies in the general direction of this beam, the target will intercept and reradiate a portion of the transmitted radar energy.

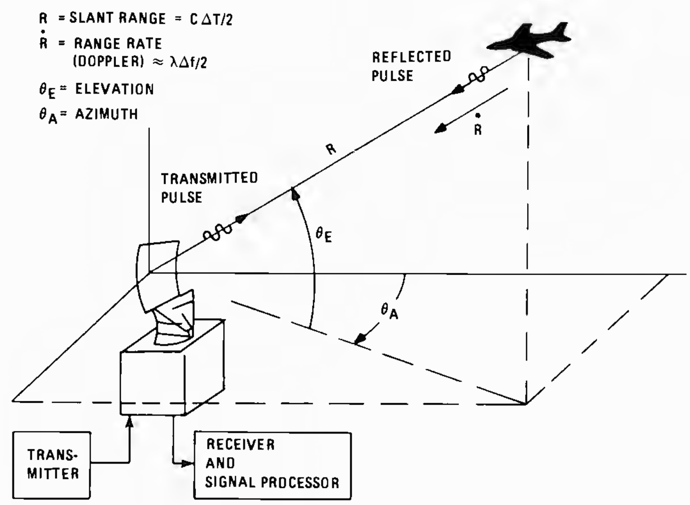

Fig. 2
Target positions can be determined in terms of slant range, azimuth, and elevation (for a "3-D" radar) or range and only one angle ("2-D" radar). Range is determined by timing the interval it takes for a pulse traveling at the speed of light to travel to the target and back. Range rate is derived from the doppler-induced frequency difference between the transmitted and received pulses. Coarse angle measurements are obtained from the antenna pointing direction.

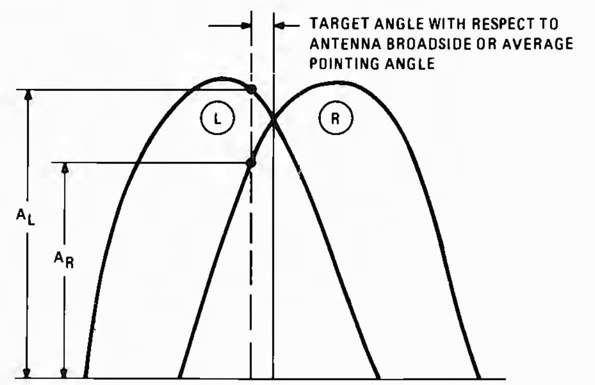

Fig. 3
Fine-angle measurements are obtained by comparing the returned target amplitude (and/or phase) in two adjacent beam positions. These beams are generated either electronically or by physical movement of the antenna. The ratio of the received target amplitudes in the left and right beams is used to measure the target position with respect to the antenna broadside or average steering angle.

The radar antenna captures a portion of this reradiated energy and sends it to the radar receiver/signal processor where the presence of the target is detected, assuming the returned signal strength can be differentiated from the system noise and clutter.

The slant range from the radar to the target is determined by measuring the time delay between the transmission of the pulse and the detection of the echo. The rate of change of this slant range with respect to time (which is called the range rate or doppler of the target) is determined by measuring the frequency difference betwen the transmitted and received pulse.

The target angular position is determined from the antenna pointing direction. Fine-angle information can be determined in many ways, all of which essentially compare the target amplitude and/or phase in two adjacent beam positions. These beam positions are generated either simultaneously (monopulse) or sequentially (sequential lobing). See Fig. 3.

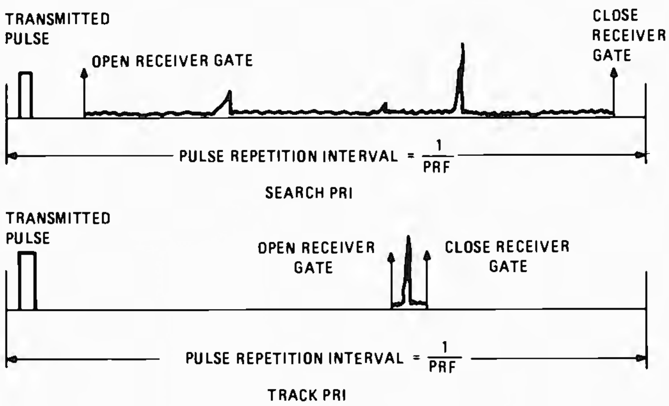

Fig. 4
Radar pulses are transmitted at a fixed rate—the pulse repetition interval (PRI); its reciprocal is the pulse repetition frequency (PRF). A search radar (top) is interested in the entire volume it is searching, and so monitors returns throughout the radar's entire range. A tracking radar (bottom), however, is interested only in the target it is tracking and so only monitors returns about the target's estimated position.

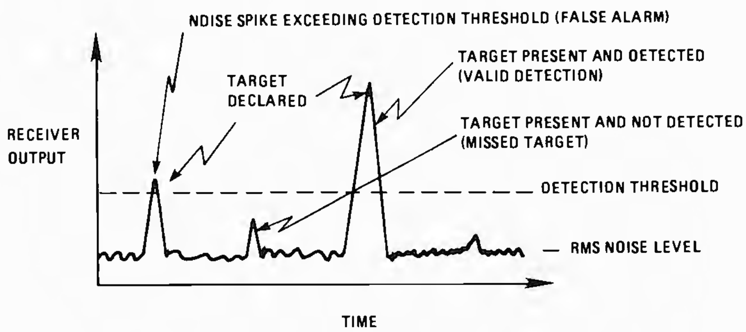

Fig. 5
Detection threshold is a variable. It is set to produce the best compromise between avoiding false alarms and avoiding missed targets.

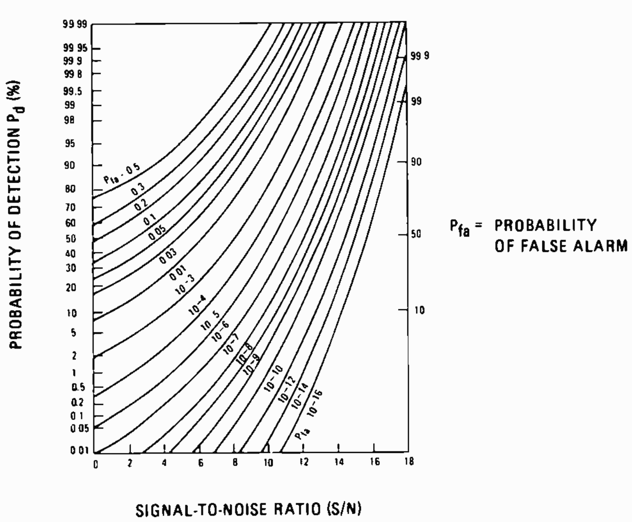

Fig. 6
Detection probability and false-alarm probability vary with *S/N*. Threshold setting must take this into account.

As mentioned previously, target detection is performed in the radar's receiver and signal-processor subsystems. The radar receiver must differentiate the reflected radar signal from the system noise background. The received signal strength depends on the target range and reflection characteristics, the radar transmitting power, and antenna gain. System noise is caused by unwanted electromagnetic energy that either enters the radar antenna from the radar environment or is produced by brownian motion of electrons within the radar receiver itself.

The radar transmits pulses of electromagnetic energy at a fixed rate called the pulse repetition frequency (PRF). As illustrated in Fig. 4, the time interval between two successive pulses is called the pulse repetition interval (PRI), which is the reciprocal of the PRF.

The receiver in a search radar monitors energy which has entered the radar receive antenna throughout the radar's entire range. See Fig. 4(top). The receiver in a tracking radar, however, monitors received energy only over the range extent which brackets the target's estimated position. See Fig. 4(bottom).

Target detection consists of establishing a threshold and declaring a target when a returned pulse of energy exceeds that threshold.

The detection threshold (Fig. 5) can be manually controlled from a gain control on the operator display, or it can be set automatically either at a fixed level or at a variable level based on a constant-false-alarm-rate (CFAR) logic network. The presence of noise makes target detection a statistical problem. The probabilities associated with target detection in a noise environment are:

1) *probability of false alarm*, which is the probability that a noise spike will exceed the preset threshold;

2) *probability of detection*, which is the probability that a target return, if present, will exceed the threshold; and

3) *probability of a missed target*, which is the probability that a target return will not exceed the threshold.

For a mathematical introduction to the detection of signals in noise, the reader is referred to section 2.5 of Ref. 5.

Fig. 6 plots detection probability versus signal-to-noise ratio for various detection threshold settings (i.e., for various probabilities of false alarm).[6] For a given threshold (probability of false alarm), the greater the signal-to-noise ratio, the greater the probability of detection. Similarly, for a given detection probability, the higher the threshold setting (i.e., the lower the probability of false alarm) the greater is the required signal-to-noise ratio.

The radar range equation

The signal-to-noise ratio (S/N) and system false-alarm probability (P_{fa}) determine the probabilty of detecting a radar target (P_D), i.e.,

$$P_D = P_D\,(S/N,\ P_{fa}) \tag{2}$$

In addition, the signal-to-noise ratio developed on a target along with an associated resolution factor determines the estimation accuracy for the target range, range rate (doppler), and angle with respect to the radar. The estimation accuracy standard deviations, σ_R, $\sigma_{\dot{R}}$, and σ_θ, are given by the relations:

$$\sigma_R = \Delta R/[k_R\,(S/N)^{1/2}] \tag{3a}$$

$$\sigma_{\dot{R}} = \Delta\dot{R}/[k_{\dot{R}}\,(S/N)^{1/2}] \quad (3b)$$

$$\sigma_{\theta} = \Delta\theta/[k_{\theta}\,(S/N)^{1/2}] \quad (3c)$$

ΔR, the radar range resolution, is determined by the reciprocal of the effective bandwidth of the transmitted pulse. $\Delta\dot{R}$, the radar doppler resolution, is determined by the reciprocal of the effective time the target is illuminated by the radar. $\Delta\theta$, the angle resolution, is determined by the antenna effective beamwidth. The constant factors k_R, $k_{\dot{R}}$, and k_θ are determined by the relation between the transmitted waveform, the filter response of the receiver, and the antenna beam characteristics.

The radar range equation represents the relationship between the received radar signal-to-noise power ratio and a series of parameters which characterize the radar, the target, and the environment.

The radar range equation can be written as

$$S/N = (P_{peak}/kT\,B\overline{NF})\,(G_T)\,(\sigma/4\pi R^2)\,(A_e/4\pi R^2)\,(1/L) \quad (4)$$

where
- (S/N) is the signal-to-noise ratio at the output of the radar signal processor;
- P_{peak} is the peak power transmitted by the radar;
- k is Boltzman's constant;
- T is the ambient temperature (degrees absolute);
- B is the bandwidth of the radar receiver;
- $\overline{NF}$ is the noise figure of the receiver;
- G_T is the transmit antenna gain;
- R is the slant range from the radar to the target;
- σ is the radar cross section of the target;
- A_e is the effective area of the receive antenna; and
- L is the total system losses.

The radar range equation provides an analytical tool for analyzing and predicting radar performance. As shown in Eq. 4, the radar range equation determines the instantaneous signal-to-average noise power as a function of the radar and target parameters.

As shown in Eq. 5, the signal power present at the output of the radar receiver (S_{out}) is determined by the peak power transmitted by the radar, the antenna gain provided by the radar upon transmission of the signal (G_T), the ratio of the effective target radar cross section area (σ) to the area over which the transmitted energy has spread ($4\pi R^2$), the ratio of the effective receive antenna aperture area (A_e) to the area over which the reflected energy has spread (also $4\pi R^2$), times the gain of the receiver (G_A), divided by the system losses (L).

$$S_{out} = P_{peak}\,G_T\,(\sigma/4\pi R^2)\,(A_e/4\pi R^2)\,G_A\,(1/L) \quad (5)$$

The environmentally-caused noise within the receiver bandwidth B at absolute temperature T is

$$P_N = kTB \quad (6)$$

where k is Boltzman's constant, a universal constant that relates temperature to energy. The noise figure of the receiver ($\overline{NF}$) is a measure of the noise produced by the receiver itself. It is defined by the relation

$$N_{out} = kTBG_A\,\overline{NF} \quad (7)$$

where N_{out} is the total noise output generated by the receiver and G_A is the gain of the receiver. Therefore, the signal-to-noise ratio present at the receiver output, the ratio of Eqs. 5 to 7, is described by Eq. 4 above.

The radar antenna receive power gain, G_R, is related to the effective area of the radar antenna, A_e, through Eq. 8,

$$G_R = 4\pi A_e/\lambda^2 \quad (8)$$

where λ is the free-space wavelength of the transmitted radar signal.[7]

The antenna effective area, A_e, is related to the physical area of the antenna, A, through the expression

$$A_e = \rho\,A \quad (9)$$

ρ is called the antenna efficiency factor. Its numerical value is between zero and one. The efficiency is a function of: 1) the efficiency with which the antenna aperture is illuminated; 2) the amount of energy which "spills over" the edges of the aperture (and is wasted); and 3) the efficiency of the antenna feed.

Solving Eq. 8 for A_e, substituting this result into Eq. 4, and combining terms gives the following form of the radar range equation:

$$S/N = P_{peak}\,G_T\,G_R\,\lambda^2/\,[(4\pi)^3\,R^4\,(kT)\,B\,(\overline{NF})L] \quad (10)$$

The radar range equation shows which system parameters the radar designer can control.

The peak transmit power (P_{peak}), antenna gain (G_T,G_R), transmit wavelength (λ) and receiver bandwidth (B) are parameters which are under the control of the radar systems designer.

The system designer has limited control over receiver noise figure ($\overline{NF}$) and system losses (L). Low noise figures can be achieved by using cryogenic techniques or, more practically, by using parametric amplifiers as the receiver first stage. Principal system losses include: 1) losses in the radar waveguide on transmit and receive; 2) propagation losses caused by atmospheric attenuation; and 3) signal-processing losses. The atmospheric noise temperature (T) is dictated by the radar environment. The radar cross section of the target (σ, which is not necessarily equal to the physical cross-sectional area of the target) is specified when stating the radar performance requirements for target detection. However, the actual radar cross section of a target depends on the target size, shape, and aspect angle with respect to the radar line of sight.

The peak power, P_{peak}, refers to the power produced when the transmitter is turned on for the duration of the pulse, τ. The average transmitter power during a pulse, P_{avg}, is given by the relation

$$P_{avg} = P_{peak}\,(\tau/T) \quad (11)$$

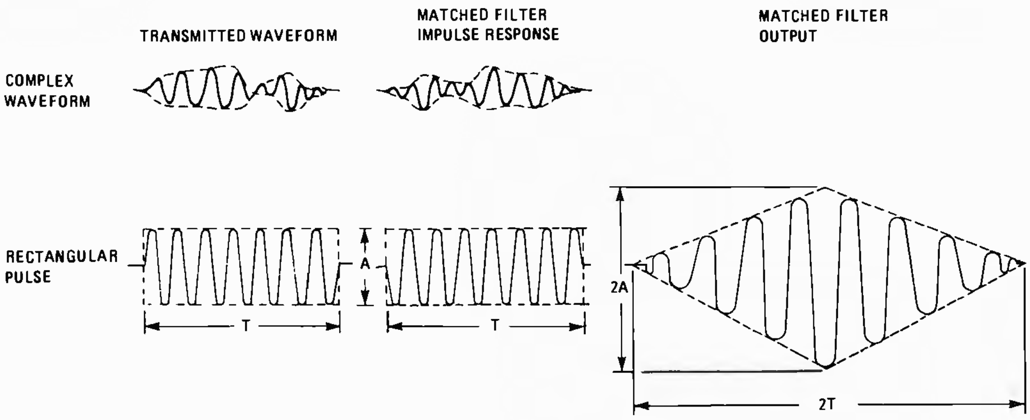

Fig. 7
Matched filtering between transmitted waveform and receiver output produces the maximum S/N. It does not preserve the shape of the original transmitted pulse as seen with the example of the rectangular pulse.

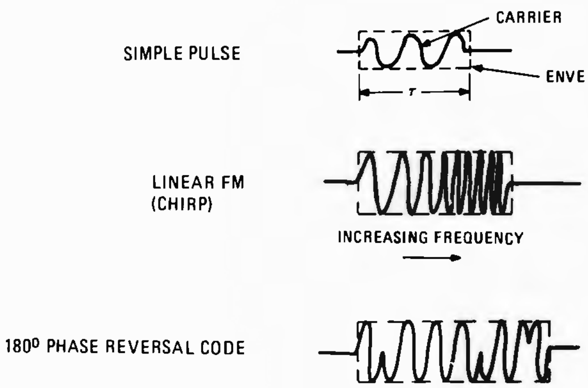

Fig. 8
Typical radar waveforms. Simple pulse is formed by rectangular modulation of the rf carrier. "Chirp" waveform, used to achieve high range resolution at moderate transmission power, is actually a long pulse generated by delaying different frequency components of a short pulse. Phase-reversal codes are used to obtain pulse compression for low as well as high time-bandwidth products.

where T is the pulse repetition period. Since $T = 1/PRF$, the relation between average and peak transmitter power can also be written as

$$P_{avg} = P_{peak}\,(\tau)\,(PRF) \qquad (12)$$

The transmitter duty factor (DF) is defined to be the quotient of the average transmitted power to the peak transmitted power, hence

$$DF = P_{avg}/\,P_{peak} = \tau\,(PRF) \qquad (13)$$

Continuous wave (cw) radars transmit a continuous "pulse" at a fixed frequency. Under these conditions $\tau \rightarrow \infty$, $PRF \rightarrow 0$, $P_{avg} = P_{peak}$, and thus $DF = 1$.

Signal-to-noise enhancement

The matched filter is the first step in S/N enhancement.

The signal-to-noise ratio at the receiver output is maximized when the receiver is a matched filter with respect to the transmitted radar waveform.[8] The impulse response of a matched filter is the time reversal of the transmitted waveform, as illustrated in Fig. 7. The matched-filter output is the convolution of the transmitted waveform with the matched-filter impulse response. Matched filtering does not preserve the original transmitted pulse shape. For example, the matched-filter output associated with a rectangular-pulse transmitted waveform is a triangular pulse, as shown in Fig. 7.

The selection of the transmitted waveform used by a radar system is based on factors such as required range and doppler resolution, peak power constraints, and clutter environment. Fig. 8 illustrates a few typical radar waveforms. A simple pulse transmitted by a radar is formed by rectangular modulation of the radio-frequency carrier. The pulse shown has a pulse length τ.

Transmitted waveforms can have internal codes. For example, a long pulse generated by delaying different frequency components of a short pulse (pulse expansion) before transmission and delaying the frequency components in an inverse manner upon reception (pulse compression) is called a "chirp" waveform. The chirp pulse provides the equivalent of a high-power illumination of the radar target using only a moderate peak transmission power because of the length of the transmitted waveform. At the same time, the chirp pulse provides high range resolution, which is determined by the effective bandwidth of the pulse.

Pulses can also be coded by periodically shifting the transmitted radio frequency phase 180 degrees, as illustrated in Fig. 8. The matched filter for this type of phase code has an impulse response equal to the time reversal of the transmitted phase code.

Pulse trains are used to determine target doppler as well as target range. Since doppler resolution is determined by the reciprocal of the effective time the target is illuminated by the radar, multiple pulses transmitted in a single pulse repetition interval can be used to make a gross doppler determination during that period. Fine doppler estimates can be made by processing a series of pulses transmitted over a sequence of pulse repetition intervals. A series of pulse repetition intervals that are processed as a group to enhance target detectability constitute a dwell of the radar beam. See Fig. 9.

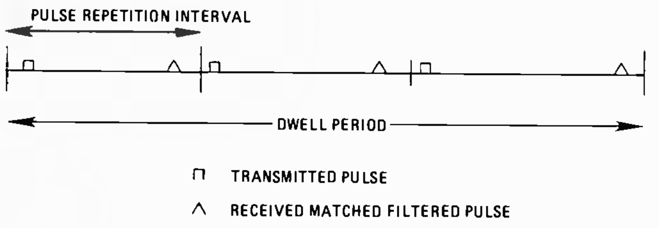

Fig. 9
Radar "dwell" enhances target detectability by processing a series of pulses.

Table II
Radar returns for a target usually vary from pulse to pulse because of the complicated reflection process taking place. The fluctuating radar cross section for different target types was initially categorized by Swerling. His Models I and III usually apply to jet aircraft or missiles, while Models II and IV apply to propeller-driven aircraft.

CROSS-SECTION DISTRIBUTION	SWERLING MODEL	PULSE-TO-PULSE
EXPONENTIAL – RANDOM ASSEMBLY OF REFLECTORS	I	COHERENT
	II	NON-COHERENT
RICE – ONE LARGE STEADY AND NUMEROUS RANDOM REFLECTORS	III	COHERENT
	IV	NON-COHERENT

The signal-to-noise output of a radar system can also be enchanced by integrating a series of radar returns.

The integration, which is performed in the signal processor or data processor, effectively multiplies the single-pulse signal-to-noise ratio by a factor n_e. Hence,

$$(S/N)_{integrated} = n_e\,(S/N)_{single\ pulse} \tag{14}$$

where n_e is equal to the number of pulses integrated (n) if the integration process is coherent over the integration period. If this coherence is disturbed or not present within the radar system, n_e is a number between $n^{1/2}$ and n, depending on the system factors that affect the integration process.

Coherent integration depends on the coherence of the radar transmitter, the target reflections, and the receiver characteristics from pulse to pulse over the duration of the beam dwell. The transmitted and received signals are both referred to a stable, and thus coherent, reference signal produced in a local oscillator.

Since a radar target is a complicated reflector or collection of reflectors, the signal-to-noise ratio returned by a target usually varies from pulse to pulse. This variation in target cross section was accounted for in a systematic manner by Swerling[9] in terms of four models summarized in Table II. Scan-to-scan fluctuation (Swerling Models I and III) usually applies to jet aircraft or missiles, whereas pulse-to-pulse fluctuation (Swerling Models II and IV) is representative of propeller-driven aircraft. A point target results in a constant or steady radar cross section and is called a Marcum target model.

The effect target cross section behavior has on the detectability of these various target models is illustrated in Fig. 10. These curves

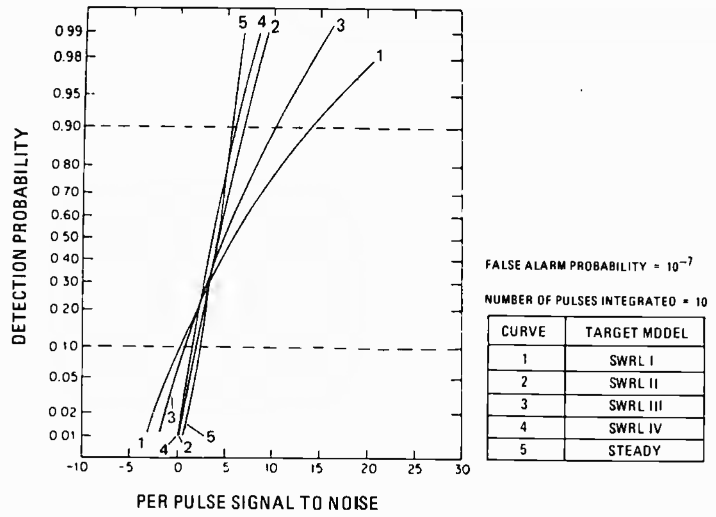

Fig. 10
Detectability varies with type of target model. Example here assumes false-alarm probability of one in ten million and that 10 successive pulses have been integrated. Note that detection-probability curves for fluctuating targets and steady targets cross as *S/N* increases.

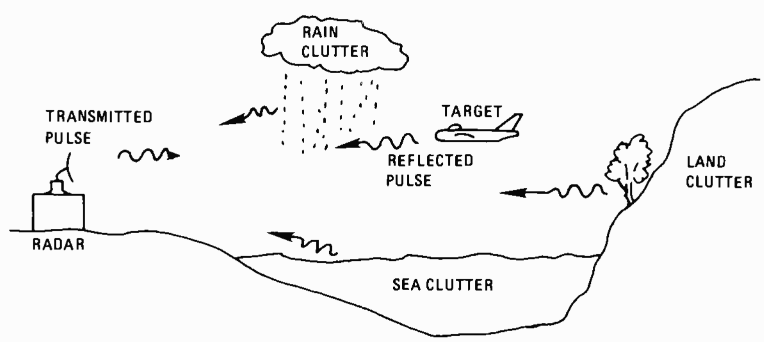

Fig. 11
Clutter is radar energy returned from objects other than the desired target.

represent the signal-to-noise ratio needed per pulse to achieve a specified detection probability, given a false alarm probability of 10^{-7} and assuming ten successive target returns have been integrated.[10]

Note that for large detection probabilities, a lower signal-to-noise ratio is required to detect steady targets than to detect fluctuating targets. On the other hand, for small detection probabilities, the reverse is true. Fluctuating targets require lower signal-to-noise ratios at small detection probabilities than constant targets, since fluctuating targets will occasionally scintillate in such a manner that a strong target signal will be returned to the radar.

Discriminating targets from clutter: signal processing

In addition to thermal noise, the detection of radar targets is complicated by the presence of clutter. As illustrated in Fig. 11, clutter is radar energy returned by objects in the radar environment other than radar targets. Sources of clutter are stationary objects, land, large bodies of water, and precipitation in the form of rain or snow.

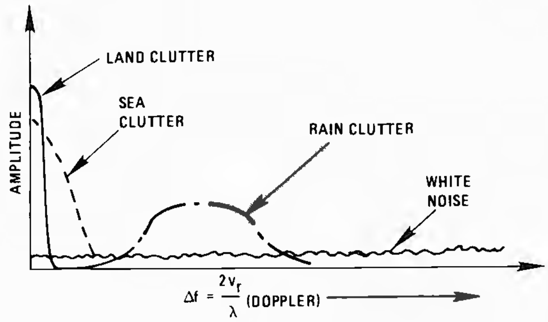

Fig. 12
Clutter can be identified by plotting return amplitude against the doppler frequency. Land is essentially stationary, but moving leaves, branches, etc. produce a spread centered around zero. The sea has more motion associated with it, and so has a wider spread, but is still centered close to zero. Rain, however, is associated with wind velocities, and so has a non-zero mean and a wide distribution.

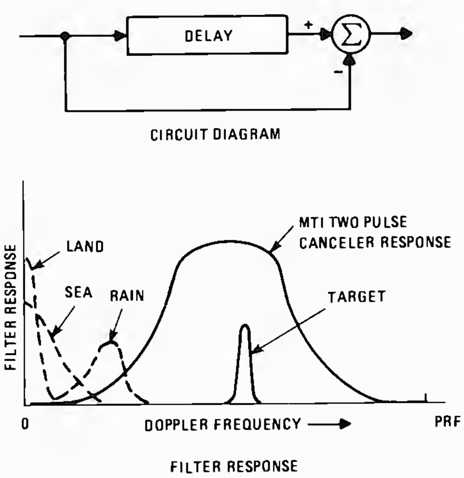

Fig. 13
Moving-target indicator canceler is one method of separating clutter from targets. It works by subtracting successive radar returns from one another and so attenuates signals that have doppler frequencies centered at zero (land and sea clutter) or at multiples of the system pulse-repetition frequency.

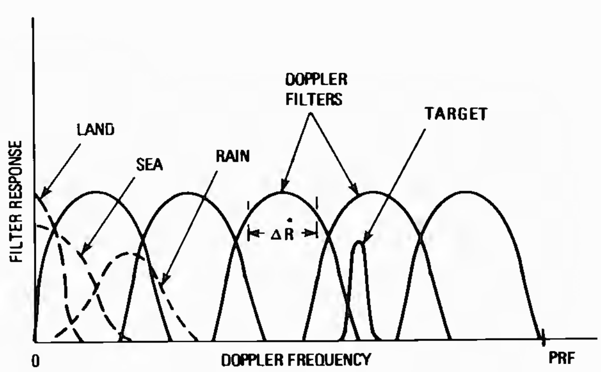

Fig. 14
Doppler filters can be used to separate target returns from clutter in frequency space. Each doppler filter is monitored by CFAR circuitry to differentiate targets from distributed clutter in range.

Unlike noise, clutter exhibits properties that are at least partially correlated from pulse to pulse. Target motion (doppler) can also be used to distinguish a target from clutter.

Land-clutter amplitude is characterized by a reflectivity per unit area. The total energy reflected by land back to the radar depends on the radar pulsewidth, antenna azimuth beamwidth, antenna pointing angle, and the type of terrain. The spectral (i.e., doppler) distribution of land clutter has a zero mean and a small spectral spread. The spread is caused by the rms velocity of the scattering elements such as bushes, tree limbs, and leaves.

Sea-clutter amplitude is similar to land-clutter amplitude in that its reflectivity is specified per unit area. The primary difference between land and sea clutter is the non-zero mean and greater spectral spread of sea clutter. The sea-clutter mean velocity and spectral spread depend on the wind velocity near sea level, water wave height, and water wave velocity.

Rain clutter is a volume effect; its reflectivity is specified per unit volume. The energy reflected by rain back to the radar depends on the radar pulsewidth and the antenna azimuth and elevation beamwidths. Because of high-altitude (up to 20,000 feet) wind shear, rain clutter exhibits a non-zero spectral mean and a large spectral spread.

Fig. 12 illustrates representative land, sea, and rain clutter amplitude as a function of doppler (clutter motion). As is shown, white noise is distributed uniformly over all doppler frequencies.

Targets can be separated from clutter with a Moving Target Indicator (MTI) canceler or a doppler filter bank.

As illustrated in Fig. 13, an MTI canceler subtracts successive radar returns from one another. This results in the synthesis of a doppler filter which, as shown in the figure, attenuates receiver signals that have doppler frequencies centered at zero or at multiples of the system pulse repetition frequency (PRF). Targets that have non-zero doppler will be detected at the signal processor output, whereas most clutter will be suppressed.

Another method of differentiating targets from clutter is to synthesize a doppler filter bank, shown in Fig. 14. This can be done by taking a fourier transform of a train of radar pulses or synthesizing a series of doppler filters from a train of radar pulses. Filter synthesis can take place in either the signal-processing subsystem hardware or in the data-processor subsystem software.

The output of each filter is monitored by CFAR (constant false-alarm rate) logic. The CFAR logic detects threshold crossings that occur over only a few adjacent range cells. This differentiates targets from clutter and suppresses clutter that is distributed in range.

The doppler resolution of a doppler filter bank is determined by the width of the individual doppler filters. Therefore, the filter width is inversely proportional to the effective time the radar illuminates the target.

Radar antenna theory

Most radar antennas are of two general types: reflector or array.

A reflector produces a radar beamshape from a continuous distribution of energy across the antenna aperture. Its optical analog is an aperture, which, when illuminated, results in a diffraction pattern. An array antenna consists of a discrete distribution of radiators across an aperture. Its optical analog would be a one- or two-dimensional diffraction grating.

A radar aperture can be sized and illuminated to produce different beamshapes.

A fan beam is narrow in one dimension and broad in the orthogonal direction. This type of beam can be shaped to concentrate radar energy near the radar horizon and gradually decrease the energy transmitted at higher elevations. Elliptical beams are two-dimensional beams that have an elliptical cross section. Pencil beams exhibit a circular cross section and are used to simultaneously determine target azimuth and elevation.

As mentioned earlier, antenna beam steering is accomplished either mechanically or electronically. A mechanical scan entails moving the pedestal that supports the antenna reflector. Electronic steering can be performed by varying the relative phase of adjacent radiators (either in the feed mechanism or on the face of the antenna). Some radars use a mixture of these two steering methods in which, for instance, the radar beam is steered mechanically in azimuth and electronically in elevation.

Fig. 15 illustrates the parameters that characterize antenna performance. The antenna aperture is the active area of the antenna surface. The power gain of the antenna is determined by the physical area of the antenna, the efficiency with which this area is illuminated, and the transmission wavelength. The half-power beamwidth of the antenna (in radians) is approximately equal to the ratio of transmission wavelength to the aperture dimension. Uniform illumination of the aperture shown would result in a beam that is narrow in azimuth and broad in elevation.

If the aperture shown in Fig. 15 is uniformly illuminated, the far-field antenna pattern in each coordinate would be a $(\sin x/x)^2$ power distribution consisting of a mainlobe and a series of sidelobes. The 3-dB beamwidth would be λ/a and λ/b in the horizontal and vertical coordinates, respectively. The first sidelobe amplitude would be 13 dB below the mainlobe, as shown in Fig. 16.

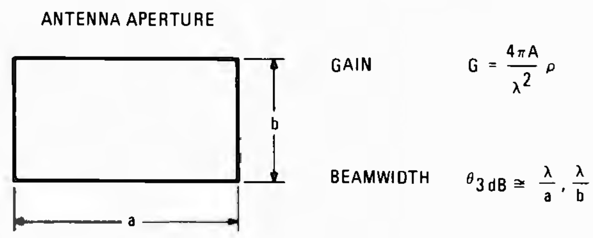

Fig. 15
Antenna parameters depend on surface area, physical dimensions, transmission wavelength, and antenna efficiency.

From a radar standpoint, these sidelobes are high. They could result in increased clutter entering the system through the antenna sidelobes and could also result in large-angle errors if the antenna sidelobes illuminate large targets.

The microwave antenna designer can control sidelobes by varying the illumination distribution across the antenna aperture.

Taylor[11,12] has shown that illumination of an antenna aperture with a series of functions that approximate Chebyshev polynomials decreases the antenna sidelobe level markedly—typical sidelobe levels of 30 dB below the mainlobe can be obtained. As shown in Fig. 17, these lower sidelobes are accompanied by a slight broadening of the antenna mainlobe with a slight loss in angular resolution. The antenna gain decreases

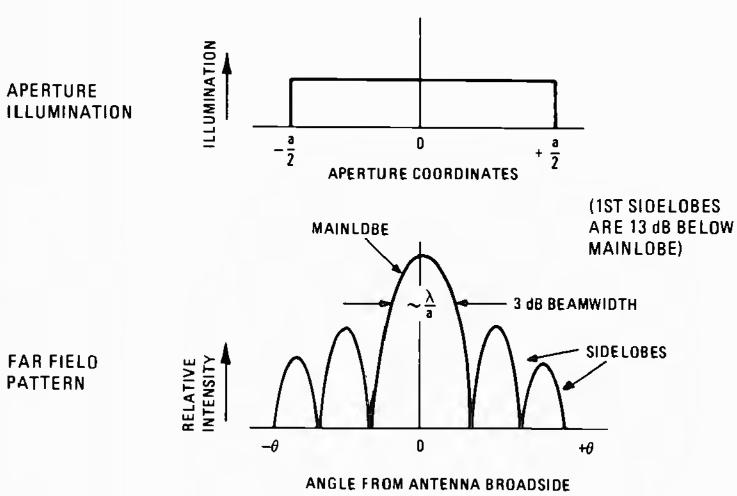

Fig. 16
Antenna pattern for uniform illumination produces a mainlobe and a series of sidelobes. Even though the sidelobes are 13 dB below the main lobe, they are undesirable. Fig. 17 shows one method of decreasing sidelobe amplitude.

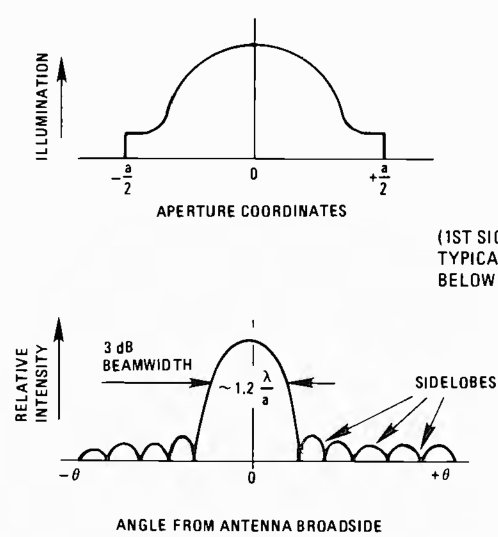

Fig. 17
Sidelobes are reduced by weighting the illumination across the antenna aperture. This weighting is accompanied by a slight broading of the main lobe and a subsequent decrease in antenna gain.

because of the decrease in the antenna illumination efficiency as compared to uniform aperture illumination (i.e., the antenna efficiency factor decreases). Taylor weightings are but one of a number of types of aperture illumination that have been used in radar design over the past thirty years.

Conclusions

Radars measure target echo characteristics (delay, amplitude, phase, etc.) to determine such parameters as target:

1) range;

2) range rate (doppler);

3) angle;

4) velocity (derived from a time history of range and angle measurements); and

5) signature (amplitude time history).

The probability of target detection and the accuracy of target range, range-rate, and angle determination depend on the signal-to-noise ratio returned by the target to the radar. Therefore, a matched-filter receiver is used to maximize the system signal-to-noise rate at the receiver output.

Since radar targets can be obscured by land, sea, and rain clutter, target doppler information is used to discriminate targets of interest from environmental clutter. This is accomplished through the use of MTI cancelers or doppler filter banks.

Radar antenna patterns are similar to the patterns developed by far-field optical diffraction theory. The sidelobes that a radar antenna produces can be controlled and reduced through proper aperture illumination weighting.

A thorough treatment of such an extensive subject as radar is difficult in such a short paper. It is hoped that this general discussion has set the stage for the informative papers that follow. For those interested in a deeper understanding of radar and detection theory, a short bibliography of significant books and papers devoted to radar is given below.

Acknowledgments

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a system/technology perspective—

Radar weapon system sensors

A.S. Robinson

Radar weapon system sensors have evolved from relatively simple electromechanically scanned search radars to multifunction electronic scanning designs that simultaneously search, discriminate, and track multiple targets and weapons in real time—all in an intense and growing radar countermeasures environment.

Early radar technology

Radar sensors have played a critical role in both offensive and defensive weapon systems since they first matured under fire during World War II. Driven by a pressing need for early warning of air attack and for effective deployment of their interceptor aircraft, British scientists and engineers, in a very short period of time, performed the prodigious feat of converting prewar laboratory research in electromagnetic propagation into a successful wartime operational air defense system. It is interesting to review the architecture of this system, and of the environment in which it operated, since it established the basic framework from which modern radar systems have grown.

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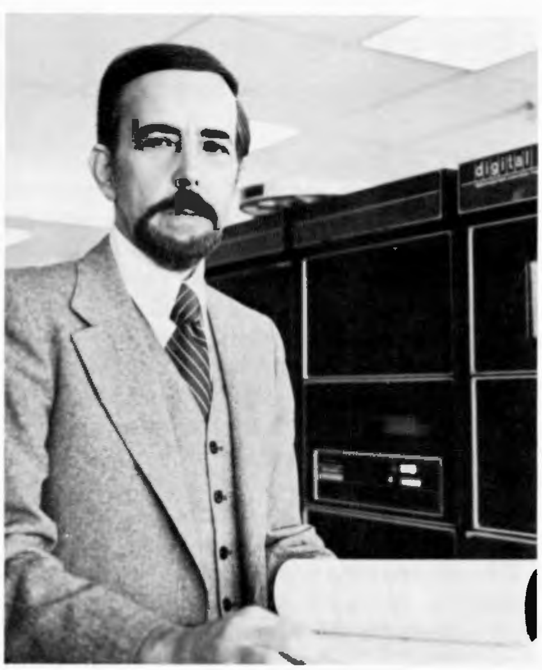


Several tactical factors, matched with radar's abilities, contributed to radar's early success.

First, the threat to be detected consisted of the buildup of large numbers of aircraft into attack formations, and was a time-consuming process, involving sequential takeoffs and climbing to loitering altitudes that were well within the field of view of defensive radars. Second, the radar-reflecting cross sections of individual aircraft were large, so that single aircraft could be detected, and the approximate sizes of assembling forces could be approximated from their net cross sections and distributions. Finally, once turned toward their targets, these formations were limited to the speed of their slowest aircraft, while the speed and climbing capabilities of defensive interceptors, the distribution of their airfields, and the speed of communication from the distributed radar network to centralized operations control, and then on to the interceptors themselves, was fast enough to make it possible to achieve initial interceptions well before target areas were reached.

From a technology perspective, communication equipment developments had already established a technology base for transmitters, receivers, and antennas which, while at lower than optimum frequencies for radar, could be used directly in radar designs of limited angular resolution that were nonetheless effective for their primary "trip-wire" function. This "trip-wire" mode was needed to conserve limited defensive interception resources, making it possible to initiate interceptions only when they were required, with centralized control of tactical reserves, and the ability to match the number of interceptor aircraft to the estimated number of attackers. Once interceptors were airborne, relative, rather than absolute, positions were of importance. Radar tracks of both offensive and defensive formations made it possible for ground controllers to vector interceptors into advantageous attack positions to local control by the interceptors based on visual (and, later, airborne radar) contact.

Initially, radar's critical role in air defense was a well kept secret.

Radar's outstanding success during the Battle of Britain resulted both from this fortuitous matching between air-defense needs and the performance that even early radar technology could provide, and from a lack of appreciation by the offense of the capabilities of these new sensors and of the degree to which they had been integrated into an overall defensive weapon system. As a result, attacks on both radars and command centers were limited, and while significant levels of initial damage were achieved, these attacks were not pursued, so that both radars and interceptor command links remained effective throughout the war. This was the first and last time that a radar-based defensive weapon system was in such a fortunate tactical position. Thereafter, all military commands have understood the major role that radar sensors play, and so have reflected this understanding in the design of both their offensive and defensive systems.

The basic scanning radar designs developed during World War II were based primarily on mechanical scanning.

They included *"2-D" search radars*—antennas rotating in azimuth, using "fan beam" patterns—narrow in azimuth and broad in elevation; *height-finding radars*—antennas slewable to a commanded azimuth position, with antenna patterns narrow in elevation and broad in azimuth so that they could be mechanically scanned in elevation ("nodded") to provide height data; and *tracking radars*—antennas with patterns narrow in both elevation and azimuth, forming a "pencil beam" that could track a target by nutating in a narrow circle around it ("conical scan").

Emergence of electronic scanning

Since these early pioneering developments, mechanically scanning, single-function radars have evolved through several generations of technology improvements and represent, today, the majority of deployed operational radars. Electronic scanning technology has matured during this same time period and is being used increasingly either to augment mechanical scanning or to completely replace it. High-precision, high-data-rate, single-target tracking radars continue to use mechanical scanning in both azimuth and elevation, but conical scanning of the pencil beam about the target has been largely replaced by "monopulse" designs. This approach is based on clusters of feeds that form multiple antenna beams, slightly skewed off the precision antenna pointing axis. (See the paper by Profera.) These beams are processed and subtracted to provide three signals—one proportional to target amplitude that is used to measure range, one proportional to elevation angular deviation, and the other proportional to azimuth angular deviation from the antenna pointing axis. The range measurement and the antenna pointing angle, corrected by the two deviation signals, provide a precise measurement of target position, obtainable during a single radar pulse transmission.

Search radars have evolved to "3-D" designs, with antenna beams narrowed in elevation as well as azimuth. These beams scan electronically in elevation as the antenna rotates mechanically in azimuth. For many applications this represents an effective approach. It provides hemispheric coverage with a single rotating antenna, detects all targets in the radar field of view, and, by processing the series of returns received from these targets as the beam scans past them ("track while scan"), obtains target positions in three dimensions on each rotation (range, azimuth, and elevation angle).

For applications such as unjammed air traffic control, the quality of the resultant target tracks is adequate to maintain required levels of air-space control. For many other applications, however, the data rate and beam-pointing flexibility obtainable with this approach is either marginal or inadequate. The problem arises from the lack of flexibility in the mechanical azimuth scanning technique. As the antenna sweeps by a target or groups of targets, the number of data samples obtained may not be adequate for target discrimination, particularly if the target is immersed in clutter or jamming. The number of returns obtained from a given target on each revolution can be increased by decreasing antenna rotation rate, but such a decrease increases the delay before a new set of samples is obtained on the next revolution. When targets are maneuvering rapidly, the quality of track data deteriorates rapidly between data samples, and is unsatisfactory for many applications. The expansion of electronic scanning in 3-D radars from elevation scanning alone to combined electronic scanning in elevation and azimuth greatly increases radar flexibility and is a clear trend for future 3-D radars. There are, however, many applications such as multiple-target discrimination combined with the control of interception weaponry, in which both search and continuous, precision, high-data-rate, track data is required. In these multi-function systems, a multiplicity of fixed antennas, in which all scanning is electronic, is necessary. This situation first arose after World War II, when ballistic intercontinental missiles were developed and deployed.

The first reaction to this ballistic-missile threat was to develop and deploy a radar network capable of providing early warning of a ballistic missile attack. This network, based on mechanical searching and tracking radar designs, was intended to provide early warning to both military retaliatory forces and to the civilian community. While relatively conventional radar technology was adequate for providing early warning, it proved to be totally inadequate for the problem of providing an active defense against ballistic missiles.

Active defense systems

Multifunction radar capabilities are necessary for active ballistic-missile defense.

The large number of missiles involved, the masses of accompanying decoys and jammers, and the reflecting wakes formed by the reentry of these bodies into the atmosphere combined to create a vast swarm of targets, immersed in noise and clutter, and to impose a new dimension on the radar performance required in search, discrimination, tracking, and fire control. The key problems were and are discrimination and fire control—searching through the target swarm using sophisticated waveforms and signal processing to separate out targets of potential interest, then tracking and performing further discrimination tests on each of these targets at a high data rate to provide precision inputs for fire-control computations. Conventional electromechanically scanned tracking radars can achieve the required data rates only by using one radar for each target, an approach that is not economically feasible for the large number of simultaneous target tracks involved. In response to this threat, phased-array radars

technology perspective 1

Phased-array antennas

Phased-array antenna principles are illustrated in Figs. 1 through 3. The antenna in Fig. 1 rotates mechanically in azimuth, while scanning electronically in elevation. The antenna face is divided into horizontal segments, with rf energy from the radar transmitter distributed to each row through individual phase shifters. The energy from each phase shifter is then distributed to all of the radiating elements in its row. When the phase shifters all receive identical settings, energy emanating from each row adds in phase only along the antenna axis, and a pencil beam is generated in a direction perpendicular to the antenna face. In all other directions, the energy adds with different phases and therefore tends to cancel, with the lack of perfect cancellation leading to antenna sidelobes. As in all antenna designs, the amount of energy lost to these sidelobes can be controlled by tapering the level of rf energy across the antenna aperture.

At the cost of a substantial increase in the number of phase shifters (e.g., to 4900 instead of 70), the antenna beam can be designed to scan electronically in both azimuth and elevation, as illustrated in Fig. 2. The rf energy from the transmitter now reaches each radiating element through an individual phase shifter. By introducing appropriate variations in phase in both the vertical and horizontal directions, the antenna beam can be scanned electronically, typically over angles of ±60°. Typical phase shifters use either magnetic materials or diodes in the rf path, with these devices, in turn, actuated by digital control registers. While the antenna is receiving returns from its last transmission, digital commands are distributed to buffer registers associated with each control register so that, at the end of the listening interval, a single command can transfer the contents of all buffer registers to all control registers, thereby immediately switching the antenna beam to its new pointing direction. A photograph of one face of modern four-face Navy phased array radar—the AN/SPY-1A—is shown in Fig. 3. The AN/SPY-1A phased-array antenna is comprised of approximately 4500 waveguide radiating elements and ferrite phase shifters, and is capable of electronically positioning its narrow beam anywhere within an octant of a sphere.

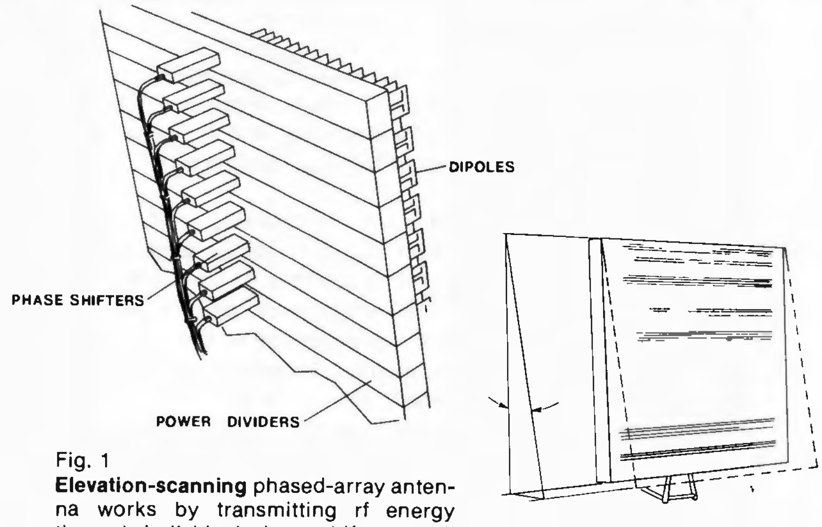


Fig. 1
Elevation-scanning phased-array antenna works by transmitting rf energy through individual phase shifters to all the radiating elements in a row.

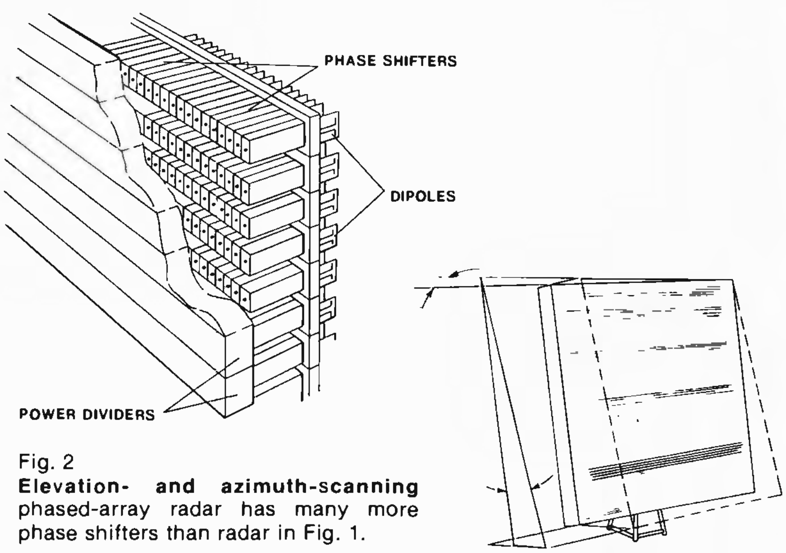


Fig. 2
Elevation- and azimuth-scanning phased-array radar has many more phase shifters than radar in Fig. 1.

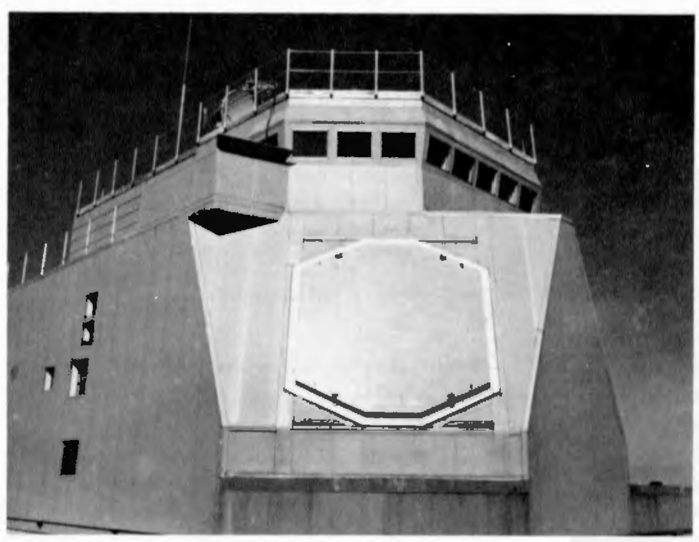


Fig. 3
Modern phased-array radar, the AN/SPY-1A, is used in air-defense system on Navy ships, four antenna faces per ship. This face is on the developmental site at Missile and Surface Radar, Moorestown.

began to come of age. While initial designs were large and expensive, they provided the first radar systems in which the pointing direction of antennas could be changed in a few millionths of a second, thereby making it possible to multiplex search, discrimination, tracking, and guidance functions at high speed. (See *technology perspective 1.*)

Under the impetus of ballistic-missile defense, phased-array radar concepts evolved over the years into increasingly effective hardware designs in a number of frequency bands. Simultaneously, major advances were made in the level of sophistication of radar waveform generation and associated signal processing, in the generation and distribution of high levels of coherent rf energy, and in both the hardware and software required for massive real-time digital data processing. These major radar advances were coordinated with the development of quick-reaction, high-speed interceptor missiles and their associated command, control, and guidance. (The paper by Liston and Sparks shows how radar engineers simulate these sysems as an aid to the design and checkout processes.) The net result of all of these efforts was the establishment of a technology base for ballistic-missile defense that would make possible deployment of a defensive system which, against a full-scale nuclear attack, would have a high probability of intercepting and destroying a significant number of offensive weapons, but a low probability of intercepting them all.

ABM defense deployment has arguments pro and con.

It is possible to reason that deploying such a system would reduce the probable level of attack damage. Alternatively, it can be argued that deploying a strong ABM defense would trigger the production and deployment of a more-than-offsetting number of offensive missiles and so increase the probable level of damage. Starting from these positions, more and more complex arguments for and against ABM defense have evolved. At present, ballistic-missile defense has halted short of full-scale deployment, with substantial ongoing funding directed toward probing the potential impact of new technologies that might upset the present state of nuclear offensive dominance. If current efforts fail to limit the number of nations with both nuclear weapons and the capability to deliver them, it is not unreasonable to envision the eventual deployment of some form of ballistic-missile defense as protection against the relatively small-scale (but highly damaging) attack that such nations will be able to mount.

Radar sensors must be designed as part of an overall system design process.

Lessons learned in attempting to solve the problems of ballistic missile defense are being translated rapidly into the design of offensive and defensive weapons systems for non-nuclear warfare. In the non-nuclear domain, offensive and defensive systems are continuously growing in capabilities in a state of "restless imbalance." The speed and maneuverability of both offensive and defensive weapons is steadily increasing, as is the sophistication of the sensing, guidance, and warhead options that they carry. World War II "time on target" tactics of multiple weapon firing, so timed that all weapons reach the target together, continue in this new weapon environment, so that defensive weapon systems have to be designed to cope with the simultaneous arrival of a large number of targets. Further, the time available between target detection and required weapon commitment has steadily decreased, to the point that time delays inherent in human intervention have had to be minimized and in some situations eliminated. *These and related factors have made it essential that effective weapon systems be designed as total entities, including the platform that carries them, the radar and electro-optical sensors that are their "eyes," the signal and data processing, command and control, and weapon guidance that are their "brains," and the weaponry that is their "striking arm."* The periodic exercising of elements of these systems in actual combat has taught system designers a number of important lessons, not the least of which is the central role to be played by systems countermeasures.

Growing importance of countermeasures

Offensive and defensive weapons system designers seek to design sensors that can see approaching weapons platforms (aircraft, ships, tanks, etc.), and the weapons that they launch (missiles, shells, etc.), determine their locations, velocities and accelerations, and assist in the guidance of weaponry against them. They also attempt to design into their systems techniques to blind, confuse, and destroy the sensors that will probably be deployed against them, and to overcome attempts to blind, confuse, and destroy their own sensors.

In essence, countermeasures has become the name of the game.

The crucial role of sensors—both radar and electro-optical—in modern warfare is now fully recognized, and any and all means for countering their effectiveness is receiving a high level of priority. A substantial percentage of the military intelligence efforts of all nations is directed toward evaluating the capabilities and limitations of opposition weapons and of the sensor/computing techniques that will be used to aim, launch, and guide them. Dual efforts tend to flow from these evaluations—the development and testing of tactics to take advantage of projected performance limitations in opposition systems, and the development of new and/or modernized countermeasure technologies and equipments to further enhance these tactics. Typical anti-radar techniques include low-altitude, terrain-masked attack trajectories; high-power noise jammers to radiate energy matched to radar transmissions, thereby masking intermediate- and long-range target returns; repeater jammers to receive radar interrogations and repeat back a multiplicity of false target returns; decoys designed to simulate high-threat targets in order to induce heavy weapon expenditures from limited weapon inventories; passive reflector dispensers capable of sowing masses of high radar cross section material over large areas, thereby generating large numbers of false targets and clutter; and Anti-Radiation Missiles (ARMs) to receive, home on, and destroy the radar itself, often requiring only radar sidelobe emanations to carry out their mission.

Technology implications

As these new tactics and equipments evolve, their degrees of effectiveness become known through the military intelligence process, and technologies, equipments, and tactics are further modified to counter them.

The impact of all of these factors on radar technology has been profound. One result has been increasing use of phased-array radars, with one radar taking on a number of functions, (e.g., search and multiple-target track), which in earlier systems required the time-consuming sequential use of a number of sensors. Radar bandwidths are being broadened and bandwidth diversity features, such as changing transmission frequency from pulse to pulse throughout this band, will be used to make the task of jammers and deception repeaters more difficult. Where feasible, individual radars will be designed to operate in multiple frequency bands, and within a given battle area, a multiplicity of radars, operating in concert, each in a different part of the frequency spectrum, will be used to improve the probability of discriminating true target from false, of defeating jamming, and of detecting missiles homing on the radiation of a given radar in time to turn that radar off before it is destroyed. Substantial efforts will be expended on reducing radar sidelobes, in order to reduce the signal levels received from radar jammers, as well as easing the task of designing deception transmitters as decoys for the ARMs designed to home on radar sidelobe energy. (See the paper by Scudder.) In general, the line between radar and electronic countermeasure subsystems can be expected to blend and possibly disappear as these subsystems unite in their common task of sensing incoming targets, overcoming jamming and deception, and jamming and confusing sensors deployed against them.

The computation speeds already required by weapons-systems phased-array radars far exceed the wildest blue-sky thinking of the World War II era.

Radars are now required to search volumes that may be hundreds of miles in diameter with resolutions in the order of tens of feet, and to discriminate and track large numbers of targets with still higher resolutions. Limitations in the peak power available with realistic transmitter designs make it necessary to code transmitter waveforms so that pulses of relatively long duration can be reduced by signal processing to the resolution dimension required by the system. (See the paper by Weinstock.) Rain, noise, fixed and movable clutter, chaff, noise jamming, repeater deception jamming, deception targets, and real targets all give rise to radar detections that have to be processed in real time in order to provide the discrimination and targeting information on which the entire system depends.

Pipeline processing, distributed data processing, and low-cost digital LSI make the high-speed computation possible.

Directly following the antenna, required computation rates are often so high that they can only be achieved by "pipeline" computing architectures (see *technology perspective* 2), in which signals are passed through a series of computing elements in a "pipeline" configuration, with all elements operating simultaneously at high speed to achieve the required overall signal-processing throughput rates. Typically, this part of the signal processing retains a limited, but important, level of programmability in terms of such factors as pipeline configuration control, weighting values to be applied to the signals, etc. (See the paper by Timken and Herold.) Typical competing implementation approaches in this area include high-speed digital LSI, surface acoustic wave (SAW) devices, and sampled analog charge-coupled device (CCD) processing. Only after initial detection processing do signal rates usually drop sufficiently to make the use of general-purpose digital data processing feasible. Digital data processing itself is going through an important era of transition. The use of large, high-speed machines with highly complex software, once the only practical design approach due to digital device costs, is giving way to distributed data-processing architectures, (see *technology perspective* 3) now made economically feasible by the advent of low-cost digital LSI devices (*technology perspective* 4). A strong drive is developing to use the opportunity presented by this new architectural flexibility to improve the entire process of system software design, development and test—an area that has proved to be a major cost and performance stumbling block in many recent system developments. The expectation is that substantial simplifications will result from distributing software with hardware in separately testable entities of limited program complexity, while retaining centralized "housekeeping" control of this array of processors, and of data-base functions that need to be shared between them. (See the paper by Buch, Clapper, and Smith.)

Two additional "drivers" underlie present trends in radar technology—one a matter of national style and policy, the second an economic overlay constraining all of the technologically possible alternatives.

Years ago U.S. scientists and engineers used to view the efforts of their U.S.S.R. counterparts with condescension. Each system designed by the Soviets has usually represented a relatively small incremental progression from the prior system designed for that function. The fact that each of these systems has usually been produced in quantity, and distributed to both their armed forces and their allies in a timely manner, wasn't considered in our thinking. U.S. programs have been characterized by use of the highest level of technology currently available, or soon to be available. Resulting systems have been substantially more sophisticated than their U.S.S.R. counterparts. However, these systems have taken longer and longer to develop and have been deployed in limited quantities over relatively long periods of time. The pattern now emerging is that U.S.S.R. systems, having gone through substantial improvements and upgradings over many years, now represent very significant levels of performance and are widely deployed. U.S. systems continue to demonstrate a technological edge, but the margin is simply not as great as before and, in terms of deployed systems, we are clearly behind in many situations.

Hand in hand with this problem is the issue of economic constraints. Our high-technology military systems are increasing in cost at a rate of approximately 400% per decade. As a nation, we simply cannot afford the substantial increase in defense expenditures and/or the decrease in fielded systems that this cost growth implies. In 1978, approximately $124 billion will be budgeted for defense and approximately 10% of these resources will be devoted to research, development, test, and evaluation. It is probable that in terms of constant dollars, the budget segment allocated to the design, development, and production of weapons systems will remain essentially constant. The clear challenge in the years ahead, in every area of defense, will be to identify the essential characteristics required of our weapons systems, and to then focus our technologies on *reducing the cost* of these systems, so that they can be deployed in the quantities required to establish a real defense in being, rather than a defensive potential. All signs point to the probability that, exclusive of guerrilla warfare, when non-nuclear wars occur, they will be of relatively short duration and will involve very substantial attrition. It is unlikely that there will be time to tool up, produce, and deploy systems that are still in research and development at the outbreak of hostilities.

Each of the papers presented in this issue addresses some aspect of this technology/cost balance problem, and the means for driving toward deployed technological excellence at a price that we can afford.

technology perspective 2

High-speed pipeline processing

Directly following the antenna, processes such as matched filtering, convolution, correlation, and spectrum analysis must be performed. Digital implementation of these functions combines the advantages of high performance, stability, noise immunity, and programmability. However, even the largest general-purpose digital computers cannot achieve the processing speeds required for real-time signal-processing applications.

Pipeline processing permits the designer to achieve the desired data throughput at the expense of signal time delay. As illustrated in Fig. 1, signals are passed through a series of computing elements, with all elements operating simultaneously at high speed, to achieve the overall throughput rates required.

Pipeline architectures simplify the control and data storage problems which would occur if the throughput were to be achieved by paralleling large numbers of processors. Furthermore, the Fast Fourier Transform, an algorithm which greatly reduces the number of computations associated with convolution, spectrum analysis, etc., can be easily configured to fit pipeline architecture.

Fig. 2 presents the block diagram of a high-speed digital pipeline pulse compressor developed under Air Force sponsorship using silicon-on-sapphire LSI technology. This processor performs 60 multiplications and 78 additions every 0.1 microseconds, for an effective computing speed of 600,000,000 multiplications plus 780,000,000 additions per second!

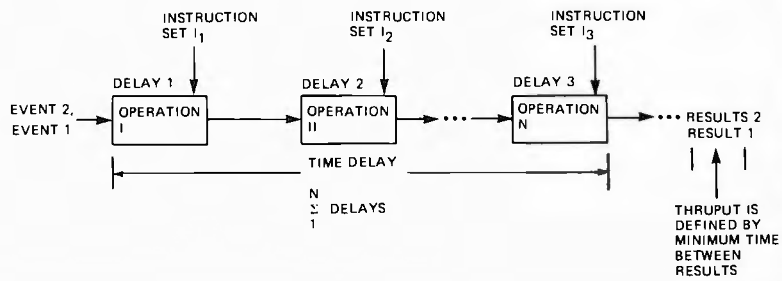


Fig. 1
Pipeline processing achieves high data throughput at the expense of time delay.

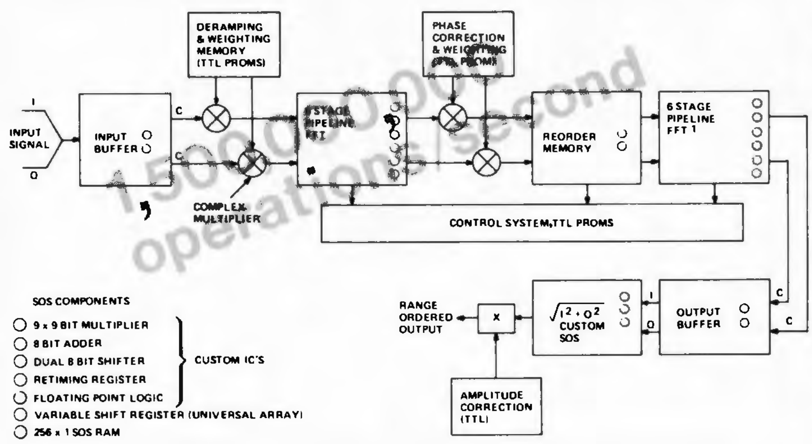
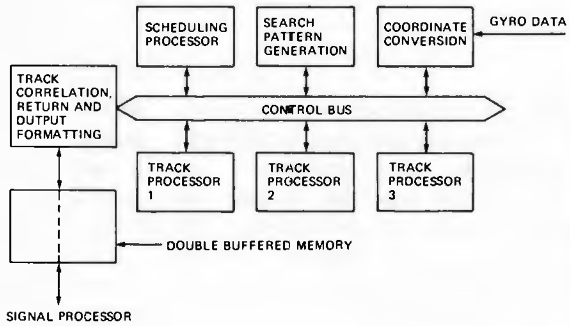


Fig. 2
High-speed pipeline processor performs 60 multiplications and 78 additions every 100 ns.

technology perspective 3

Distributed processing with microcomputers

The block diagram at the right illustrates one architectural approach to the design of a distributed microcomputer system for multifunction radar control. The control processor acts as a control distributor for radar data. Radar return data from the signal processor is correlated with track files residing in the memories of the distributed microcomputers. This is accomplished by the central microcomputer via direct memory access to the distributed microcomputer memories. After correlating old and new data, the control microcomputer provides new data to the appropriate microcomputers, and assigns any new tracks to one or more of the distributed microcomputers, with each microcomputer executing its tracking algorithms independently. Other functions such as scheduling, coordinate conversion and search-pattern generation are also updated concurrently. Depending on the particular radar design, all data-processing functions can be distributed in this manner, or the distributed microcomputers can be used to decrease the processing load of a centralized data processor.



In this approach to distributed microcomputing, the control processor acts as a control distributor for radar data.

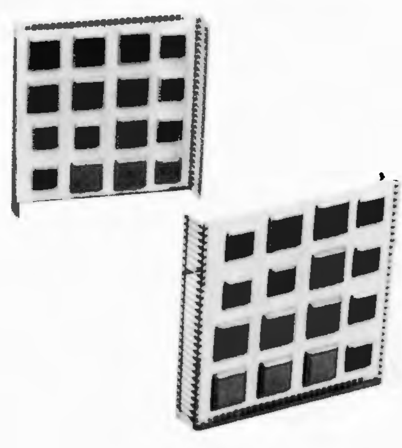
technology perspective 4

High-density electronic packaging

The increased speed and complexity of radar signal and data processing has been matched by major advances in digital logic circuits and packaging.

Following World War II, the invention of transistors provided active logic elements requiring two orders of magnitude less volume than tubes. Logic circuitry shrunk even more in size as numbers of interconnected transistors were placed on the same chip by a process known then as integration—today as small-scale integration. Over the years, we have passed through the development of medium-scale and large-scale integration and are now entering the era of very-large-scale integration (VLSI), with 10,000 to 100,000 active elements interconnected on a single chip—a further increase in packing density of 4-5 orders of magnitude.

The photograph at the right shows a multi-layer thick-film ceramic substrate interconnecting 16 chips on each side of a board that is approximately 3" by 4". Using VLSI technology, this packaging approach will provide circuit densities exceeding 80,000 gates per square inch.



Mirror photograph of thick-film substrate interconnecting 16 chips on each side of the board. VLSI packaging densities will exceed 80,000 gates per square inch.

Radar processing architectures

W.W. Weinstock

System requirements determine the processing structure; flexibility and cost drive the mechanization.

Contemporary radar systems use a wide range of minicomputers, microcomputers, programmable signal processors, and special purpose logic for flexible and reliable operations at reasonable cost. The radar system requirements actually determine which processing architecture to use for a given application.

This paper examines a relatively simple radar system that uses a wide range of typical processing functions. This example illustrates the types of processing requirements that must be handled in modern radars and provides the basis for evaluating the various architectural alternatives available.

A generic radar system example

A track-while-scan (TWS) radar is a search radar whose output data is used to develop tracks.* As a system, the TWS radar (Fig. 1) is relatively simple—a continuously rotating search beam gathers target azimuth and range data. Targets are illuminated on each scan, and their detections are used by the system to form target tracks. It is a good example because it uses a wide range of radar-processing operations: search, detection, acquisition, multiple-target tracking.

*Barry Fell describes the track-while-scan radar in his tutorial paper in this issue.

The signal processor extracts the target from noise and clutter.

To detect a target, the system must separate it from a background of noise and clutter. Noise may be due to external interference or the radar receiver itself. Clutter may be due to backscattering from the earth's surface, or from rain or clouds. The primary function of the signal processor is to reject noise and clutter by suitable filtering, so that the target will be detected every time the beam scans by it.

This calls for the examination of every range-azimuth cell where a target can be present. The total number of cells that must be processed is the number of range-azimuth cells viewed in a single scan. For example, a radar scanning 360° with a beamwidth of 1°, a pulse length of 1 μs (about 500 ft in range), and a maximum range of 500,000 ft, will look at 360,000 cells each scan. With a representative scan period of 3.6 seconds, this means that 100,000 cells must be processed each second.

The number of targets that can be seen during a scan depends on the traffic. A typical value for air-search applications is several hundred, or (nominally) one target per thousand cells. Consequently, the rate of information flow drops by three orders of magnitude after targets are extracted by threshold detection. For radars with better range resolution (say 0.1 μs pulse length, or 50 ft in range) the number of range cells can increase by an order of magnitude but the reduction in the rate of information flow can be four orders of magnitude or greater.

In summary then, the signal processor performs high speed filtering operations, repeated on a range-cell-by-range-cell basis, to extract the signal from a background of noise and clutter. This filtering is followed by amplitude detection and thresholding. To have real-time operation, the processing time must not exceed the time extent of the signal return. For the cases just cited, this is between 0.1 and 1 μs. As we shall see, an extensive sequence of operations may have to be performed during this very brief period.

The data processor correlates the signal processor outputs.

The signal processor *output* is an irregular flow of target-like returns. These can include occasional noise spikes and residual clutter in addition to the targets. The *data processor* now must correlate these returns on a scan-to-scan basis to develop target tracks.

This correlation process must do several things. First, it must associate successive returns from the same target under a variety of conditions. There must be no confusion because of target maneuver or the presence of other returns nearby. The identity of targets on crossing or merging flight paths must be retained. Clutter or interference in the vicinity of the flight path must not be confused with target return data.

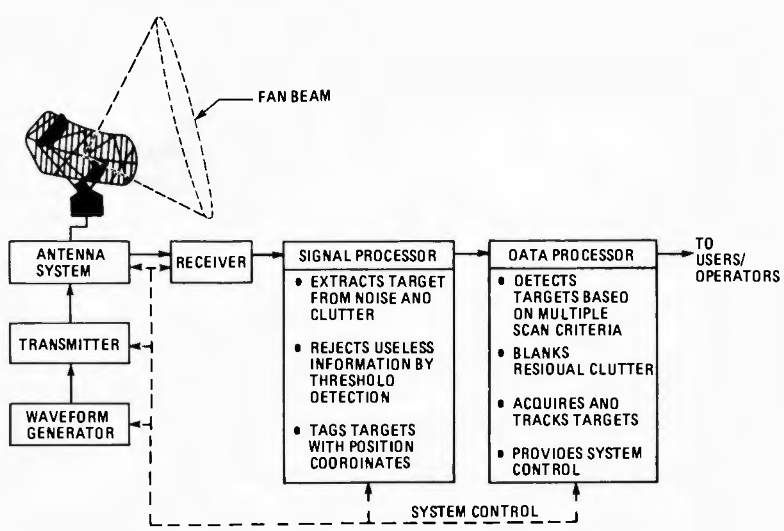


Fig. 1
Generic two-dimensional track-while-scan radar provides a point of departure for considering typical requirements of signal and data processing.

In additon to maintaining tracks, the system must be capable of recognizing a new target; i.e. one which is not currently under track. It must be able to do this without being confused by transient interference or environmental returns. Noise and clutter must also be excluded as soon as possible to lighten the processing load.

Different correlation methods are required to reject noise and clutter. Since noise is random, it will not correlate in position on a scan-to-scan basis. Consequently, some form of multiple-scan correlation process must be used to establish the presence of a new target. Clutter, on the other hand, is strongly correlated scan-to-scan. This fact can be used to map and blank out the residues of strong returns.

In addition to performing its target-handling functions, the data processor serves as the focal point for controlling the system and for disseminating target data. Using its target files, the processor drives operator displays and provides digital data for any higher level system processing required.

Radar system designers today can choose from a variety of processing approaches.

Many current radars employ primarily analog signal processing, while others digitize all processing functions after the the receiver (i.e., after baseband conversion). Although the two approaches exist side-by-side today, this paper addresses only digital implementations since these offer advantages in processing capacity and flexibility—clearly making them favored candidates for the radar system application.

Signal processing functions

The series of operations required to extract a target from a background of noise and clutter is shown in Fig. 2.

All of the returns reflected from the target during a single scan are used in making the detection decision. For the case of the radar with a 1° beamwidth, a 3.6 second scan period, and range of 80 nmi (i.e., 1 ms between pulses), about ten returns are received from a single target during the scan period. Numbers like a few dozen returns are typical. Processing starts on a single pulse with matched filtering. Subsequent operations involve multiple pulse returns.

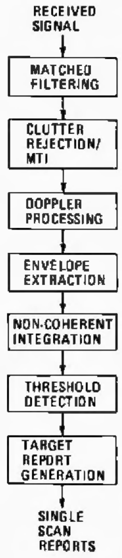


Fig. 2
Signal processing operations involved in extracting target information from a background of clutter and noise.

Extracting a signal from noise is a two-step process that makes use of the differences in spectra.

White noise has a flat spectrum, while the signal spectrum is dominated by that of the single pulse. The multiple-pulse (target) spectrum has a fine structure of narrow lines separated by the pulse-repetition frequency. The specific nature of these lines depends on the time that the target is illuminated by the radar beam and by the target's behavior during that time. For maximum signal-to-noise ratio, we need a filter whose transfer characteristic is matched to the target spectrum.

This matching can be achieved by cascading two filters—a single pulse-matched filter followed by a bank of narrowband (doppler processing) filters to coherently integrate a number of successive pulses from the target. The bandwidth of these filters is a measure of the coherent integration time. In cases where radar instabilities or target fluctuations produce decorrelating effects, it may not be advantageous to coherently integrate all the returns from one pass. In this case, the doppler processing integrates as many as feasible and non-coherent integration (using amplitude information only) completes the job.

Clutter rejection also takes place in two steps.

Since the received signal frequency shifts with target motion, the processor rejects targets whose frequency shift (doppler) is small—signifying small radial velocities typical of clutter. This process, called moving target indication (or MTI), is accomplished by comparing the phase change between successive returns. In practice, this usually involves from two to four successive samples.

The rejection characteristic of an MTI filter is limited by the number of pulses employed. In general, clutter may have some frequency-shift components due either to internal fluctuations (such as those caused by wind blowing the leaves of trees) or to radar instabilities. MTI will not reject these components completely. However, the doppler processing employed for coherent integration has a narrow bandpass which provides the second step of clutter rejection.

Non-linear operations eliminate unneeded phase and amplitude information.

The four filtering operations that were just discussed—matched filtering, MTI, doppler processing, and non-coherent integration—account for the bulk of the signal-processing burden and all involve linear filters. Two non-linear operations are present as well; they destroy information. Envelope detection discards phase information at the point where it is no longer useful. Threshold detection discards low amplitude targets.

The final step in signal processing is the consolidation of all the data into single-scan reports. This requires an estimate of target range and azimuth, and possibly amplitude as well. Such estimates involve computing weighted averages, and this computation is similar to that involved in linear filtering. Following parameter estimation, the data is formatted as needed for the data processing to follow.

In summary then, signal processing involves a sequence of linear filtering and non-linear operations, performed on every range cell of interest. These operations are basically arithmetic—multiplication, addition, and time delay. The computations are summarized in the appendix.

Data processing functions

Data processing involves operations on the signal processor output—a succession of single-scan reports of target position and amplitude. The purpose is to establish target tracks and to reject any remaining

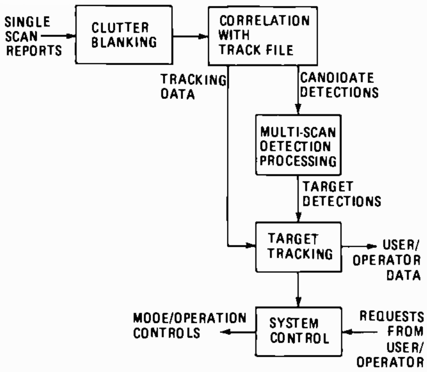


Fig. 3
Data processing involves operations on a succession of single scan reports from the signal processor to provide complete target track information.

undesirable returns. Fig. 3 shows the multiple-scan processing needed for detection, acquisition, tracking, noise and clutter rejection, and system control processes.

The processing burden caused by undesired returns is minimized if these signals are rejected early in the processing sequence.

Clutter blanking removes those residual clutter reports that were strong enough to pass the detection threshold—even after MTI and doppler processing. This makes use of a radar generated "map" of the environment. The map is, in effect, a file of stationary targets that appear on a repetitive basis. Correlation with the map rejects returns in regions where strong clutter will mask desired targets.

Rejection of noise, on the other hand, is based on its *non-repetitive* character. Noise reports are unlikely to correlate geometrically on a scan-to-scan basis. Accordingly, the data processor requires a series of single-scan reports before declaring a detection, thereby rejecting noise before the acquisition and tracking processes are started.

Target data are developed from several single-scan reports.

The only targets that are candidates for detection are those not currently in any active file. Consequently, all single-scan reports must be correlated with the system track file. A target that fails to correlate with an active track is a candidate for the multiple-scan detection processing.

After a succession of reports has been received on a new target, the system can establish velocity information that is good enough to localize the likely position on the next scan. This predicted position is then used as the standard against which the new scan data are correlated. The uncertainty in this position is a function of the quality of previous observations and deviations due to possible target maneuvers. The design of the tracking and prediction filter then becomes a compromise between the narrow bandwidth required for good noise rejection and the wide bandwidth needed to minimize lag errors in the presence of a target maneuver.

The uncertainty in predicted target position for the next scan is the basis for correlation problems in a multiple-target environment. Flight paths can cross; merging or splitting formations can be encountered; targets can fly near strong clutter regions. Each case can produce a problem of maintaining track continuity, and the problem is aggravated by the possibility of a target maneuver at any time.

In addition to track maintenance, the tracking function must also discontinue tracks that show a run of poor quality data or no data at all. If no returns have been received for the memory span of the track filter, then there is no basis for coasting and the track should be dropped. Failure to drop poor tracks will lead to unnecessary processing burdens and correlation problems.

The system control problem is one of changing waveforms and exercising options to match changes in the environment.

The false reporting rate, in particular, must be monitored and controlled so that spurious single-scan reports do not saturate the system. Sector adjustments of threshold levels and blanking may be required to control this situation.

The data processing functions center on the use and management of target files.

The key files hold the information on targets under track, the clutter map, and the list of candidate new detections. The file processing operations involve a series of correlations or data associations in order to make the basic decisions:

- Is the return clutter?
- Is it from a target already under track?
- Is it from a new detection which has not yet passed the multiple-scan detection criterion?

The number of possible branches in this logic is in marked contrast to the signal processing problem involving a fixed sequence of operations on every cell. The sequence of data processing operations on a single-scan report depends on the type of report. A fairly elaborate logic is required to ensure that all the possibilities are considered.

Another major difference between data processing and signal processing is in the degree of regularity of input data.

The data processor receives an input for every threshold detection by the signal processor. The time between reports depends on the geographic distribution of targets and the antenna scan period. In general, the inputs will be irregularly spaced in time. Concentrations of targets can produce peak rates considerably above the average. The signal processor, on the other hand, processes one resolution cell after the other, on a regular basis.

How it's done—implementing the processing functions

The basic processing requirements we have discussed are summarized in Table 1. The enormous differences in processing load and speed requirements, as well as in complexity of operations, clearly demonstrate the need for diversity in system development.

The evolving data processing technology has given rise to distributed processing systems whose architectures are tailored to the problem at hand.

Data processing requirements are typical of those imposed on general-purpose computers. In the 1950s and 1960s, data processor designs were based primarily on centralized, large-scale machines. This approach, of course, has been altered significantly with the advent of the minicomputer and the microcomputer, which are based on different technologies.

The impetus toward the use of smaller machines has come from a second direction as well—software development. Small machines mean distributed processing with dedicated software. Monolithic software developments are giving way to modular sets, offering a promise of easing the problems of software management and software change.

The architectural challenge of distributed systems is to partition the problem into

Table I
Comparison of processing requirements demonstrates the need for a wide variety of processing approaches.

Characteristic	*Representative capability required* *Signal processing*	*Data Processing*
Processing load	Millions of inputs/second	Hundreds of inputs/second
Types of processing required	Regular, well defined, arithmetically intense sequence	Variable sequences of logic, control, and arithmetic operations
Processing speeds	Tens of million of operations per second	Hundreds of thousands of of operations per second
Data span	Tens of milliseconds	seconds
Acceptable processing delays	Microseconds	Tens of milliseconds

elements with simple interface and communication requirements. Highly repetitive processing involving a limited number of different operations can be based in dedicated smaller machines. This is why operations such as "smart terminal" drivers and coordinate converters have become distributed elements. The midi/mini/microcomputer hierarchies that are appearing are one aspect of distributed operations.*

However, certain functions by their nature require a strong centralized processing system capability. For example, if a number of processing functions require the use of an extensive set of files, they should share them directly. The alternative to this is duplicating these files for each processor and communicating any changes as they occur. In our generic TWS system, the track files were used in detection, acquisition, and tracking. Since they might contain hundreds of targets whose coordinates are continuously changing, the file users must be tightly tied to the point where the files are generated.

The world of signal processing is evolving from the other direction, with highly structured requirements and extremely high arithmetic content.

The magnitude of the arithmetic processing problem is illustrated by digital matched filtering. A transmitted waveform can be internally coded so that a long pulse can be compressed into a narrow pulse with good range resolution. In this way, high energy can be achieved in a short pulse without exceeding the peak power limitations of the transmitter. Compression ratios of a few hundred to a few thousand are common. If the range resolution is on the order of a hundred feet, then independent cells will be separated by 0.2 μs after compression. This presents a formidable processing burden, as shown in the Appendix.

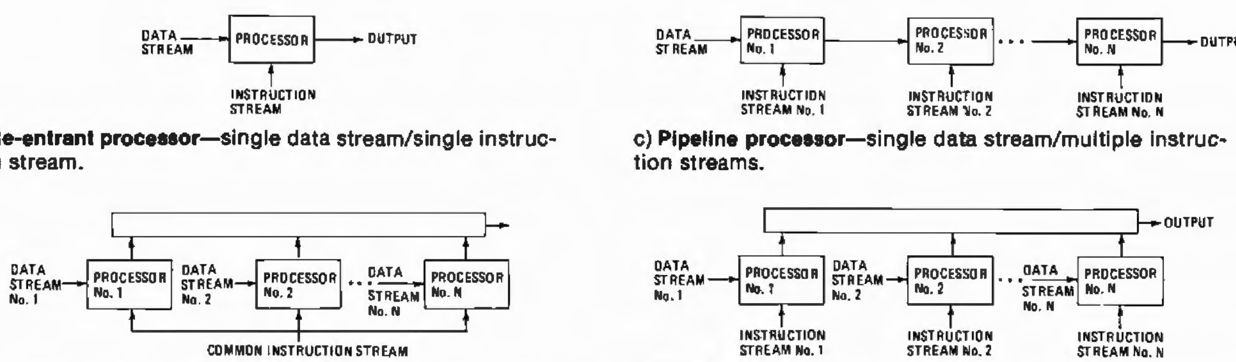
A time-domain form of matched filtering multiplies the received signal by a replica of the transmitted signal and then integrates the result.[2] For the case where the waveform coding has the form of a thousand subpulses, there are 1000 multiplications and additions required every 0.2 μs. This is an unacceptably high processing burden, even for the fastest of current machines. It can be reduced by two orders of magnitude if time-domain filtering is employed using the Fast Fourier Transform and inverse FFT. However, the arithmetic capability required is still very demanding.[3]

Processing requirements drop considerably after matched filtering has been completed. However, the complete sequence (MTI, doppler processing, envelope detection, and thresholding) must be accomplished every 0.2 μs if the processor is to keep up with the input data. Present-day systems commonly require signal processors to achieve 100 times the throughput of a minicomputer with only 10 times the parts count.[4,5] The signal processing implementation problem, then, is one of balancing processing speed and flexibility against cost.

Practical processors typically rely on some form of parallel architecture for high-speed operation.

Processing architectures can be categorized by the number of data streams and the number of instruction streams;[6,7] four typical approaches are shown in Fig. 4. With the exception of the re-entrant processor (Fig. 4a), each type has explicit parallelism in its structure. This parallelism is central to achieving high-speed operation. The array processor (4b) has been used where data is divided on a range basis and different processors perform identical

*Buch, Clapper, and Smith discuss distributed processing at the microprocessor level elsewhere in this issue.



a) **Re-entrant processor**—single data stream/single instruction stream.

c) **Pipeline processor**—single data stream/multiple instruction streams.

b) **Array processor**—multiple data streams/single instruction stream.

d) **Parallel processor/multiprocessor**—multiple data streams/multiple instruction streams.

Fig. 4
Basic processing architectures illustrate differences in approach for handling single and multiple instruction streams.

Table II
Parallelism, in many forms, must be integrated for high throughputs.

Form of parallelism	*Implementation*
Arithmetic	Four multipliers and adders will perform an FFT, butterfly, or second-order section
Memory	Separate instruction and data memories allow parallel instructions and data accesses Two operand memories allow simultaneous fetching of operands for signal processing computations Multiple buses (3) support simultaneous memory accesses
Overlap of instruction and data cycles	Separate logic/control, registers and buses for instruction execution and instruction and data accesses
Parallel control of units which must operate simultaneously	Long instruction word for parallel control Multiple address instructions (3) for data retrieval and storage of results.

processing on cells at different ranges.[8] The pipeline structure (4c) typifies most current hardwired processors. It is also applicable where special microprocessors are used for each processing function, and where the function is established by firmware. That is where processors are converted, for example, into an MTI processor, doppler processor, or non-coherent integrator by virtue of the program used in that element.[9,10] The parallel processor is the most generalized form of parallel configuration.

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Parallelism can also be implicit in the internal structure of each processing element. In fact, most high-performance reentrant signal processors are built using the techniques given in Table II. Current signal processing systems use both classes of parallelism. The specific choice for any particular application is a function of the problem and the amount of flexibility desired in the solution.

Flexibility can be achieved in a straightforward manner using digital techniques.

For example, in the case of pulse compression discussed earlier, long codes can be generated by simply adding more subpulses to the waveform. An analog mechanization would require a separate filter for each waveform. Where flexibility is required, the frequently higher cost of digital elements is offset by the multi-mode or multi-function capability of the digital hardware.

Many levels of flexibility are possible. At the lowest level, a hardwired processor may be capable of changing parameters (e.g., bandwidth) without altering its basic configuration. This amounts to changing stored constants within a specific configuration.

On the other hand, the processing system can be implemented using a programmable signal processor, which is a general-purpose re-entrant machine tailored to the signal-processing problem. All of the radar functions can be executed by sequential operations. Changes can be implemented by modifying the machine's program. This approach offers a high degree of flexibility, especially where system requirements are expected to evolve with time. Changes can be accommodated without a hardware redesign.*

But flexibility has its price. General-purpose devices must have capabilities that are not always used in each application. Furthermore, in the case of programmable machines of any kind, efficiency is lost when flexible, high-order languages are employed. The use of machine language yields greater efficiency but makes the software more difficult to change.

A third aspect of flexibility must be considered. This relates to cost as a function of quantity. A common design with wide application is required to obtain a cost advantage. This commonality can be achieved with general-purpose microprocessors as well as with programmable systems. The high-performance microprocessor is well suited to the array and pipeline architectures that were discussed earlier.

* Herold and Timken discuss programmable signal processors in this issue.

For further reading

Several papers in this issue illustrate a number of specific implementations of the architectures discussed here. They demonstrate some of the state-of-the-art alternatives that RCA is currently investigating. They also show the significance of programmability as applied to signal processing.

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Appendix
Signal processing operations that remove noise and clutter from the radar signal

Signal processing operations are primarily arithmetic in nature, involving a number of multiplications, additions, and time delays.

Linear processing

The linear filtering operations required in signal processing can be examined by considering the filter transfer function

$$H(z) = Y(z)/X(z), \tag{1}$$

where $X(z)$ is the transform of the input signal and $Y(z)$ is the transform of the output. The general transfer function of any system that can be described by linear difference equations with real coefficients (and this covers all the sampled data cases of interest) is of the form

$$\mathrm{H}(z) = \frac{Y(z)}{X(z)} = \frac{b_0 + b_1 z^{-1} + \cdots + b_N z^{-N}}{1 + a_1 z^{-1} + a_2 z^{-2} + \cdots + a_M z^{-M}} \tag{2}$$

The z^{-1} factor is associated with the delay between successive samples; the a's and b's are real coefficients. By cross-multiplying and taking the inverse transform, this becomes

$$\begin{aligned} y(n) &= b_o x(n) + b_1 x(n-1) + \cdots + b_N x(n-\mathrm{M}) \\ &\quad -a_1 y(n-1) - a_2 y(n-2) - \cdots - a_M y(n-\mathrm{M}). \end{aligned} \tag{3}$$

Thus the current output $y(n)$ is the weighted sum of the present input $x(n)$ and all past inputs to $x(n-M)$, together with past outputs $y(n-1)$ to $y(n-M)$. The general filter is recursive since the output feeds back into the input. This produces an infinite-duration response to any input. For the special case where the denominator of Eq. 2 is a constant, Eq. 3 reduces to a finite-duration impulsive response.

The mechanization of Eq. 3 requires a series of multiplications, additions, and time delays. A wide variety of implementations is available; the choice depends in part on practical considerations—the quantization effects associated with finite word length and the computational efficiency of the candidate architecture.

The computations can be decomposed into a series of simpler computations. Since the denominator in Eq. 2 is a polynomial with real coefficients, its roots are either real or complex conjugates. This means that Eq. 2 can be represented as the product of transfer functions, none of which is greater than second order. Thus, instead of computing Eq. 3 directly, a cascade of second-order operations can be used. This suggests mechanizations which sequentially employ simple second-order sections of the form:

$$y(n) = Ay(n-1) + By(n-2) + Cx(n-2) + Dx(n-1) + x(n). \tag{4}$$

Therefore, the capacity to do four real multiplications and four real additions per step is the basic capability required for time-domain filtering.

Eq. 1 suggests the frequency domain implementation of the linear filter. It requires that $X(z)$, the Fourier transform of the input signal, be computed and multiplied by $H(z)$, the filter transfer function. The inverse transform of the product $H(z)\,X(z)$ then gives the filtered output $y(n)$.

The use of the fast Fourier transform (FFT) algorithm allows the discrete Fourier transform and its inverse to be computed efficiently.[1] The computational burden of the frequency domain approach can be considerably less than the time domain equivalent, even though it involves both a transform and an inverse transform.

The FFT algorithm can be done in steps, by cascading computations of the following type

$$\begin{cases} u(m+1) = u(m) + W^l v(m) \\ v(m+1) = u(m) - W^l v(m) \end{cases} \tag{5}$$

where $u(m)$, $v(m)$ are complex representations of the inputs to the stage; $u(m+1)$, $v(m+1)$ are the outputs; and W^l is a fixed complex multiplication factor. Complex operations are performed by operating on the real and imaginary parts of the quantity of interest. Complex multiplication is equivalent to four real multiplications and two additions. Thus Eq. 5 calls for the same capability needed to do the time domain filtering in Eq. 4. *Therefore, linear filtering requires the capability to do four simultaneous multiplications and additions, regardless of the approach.*

Non-linear processing

The non-linear operations required in signal processing are envelope detection and threshold detection.

Envelope detection removes the phase information from the signal amplitude returns. Prior to envelope detection, the signal is coherent and is represented by two quadrature quantities—an in-phase component, I, and a quadrature component, Q. These are generated by phase detecting the received signals against a reference oscillator and a 90° phase-shifted version of this reference. The components (I,Q) are the elements of the complex signal discussed previously. Amplitude detection requires the computation of $(I^2 + Q^2)^{1/2}$. An exact value of amplitude is not required for the threshold detection that follows. The use of any monotonic function, such as $(I^2 + Q^2)$, will allow for rejection of signals below the critical amplitude level.

Threshold detection involves the simple comparison of the integrated amplitude in a cell with the critical threshold value. If the threshold is exceeded, the return has passed the single-scan detection criterion and is sent on for further processing. If the threshold is not exceeded, the return is irreversibly discarded. Thresholding is the primary branching operation in signal processing.

This brief summary confirms that signal processing operations are primarily arithmetic in nature, involving a number of multiplications, additions, and time delays. Although these operations are relatively straightforward, the number of operations required, in microseconds of time, makes high-speed arithmetic capability an absolute requirement for real-time processing.

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Solid state for super-power radars

The ideal high-speed switch for multi-megawatt pulsed radar modulators may be a thyristor.

D.L. Pruitt

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One trend seems inevitable in the continuing radar evolution—a constant demand for more power. In particular, pulsed radar (and laser) systems are already pushing modulator output pulse power levels of several *billion* watts peak—at relatively high (up to 0.5%) duty cycles.* Typical modulator requirements are for pulsewidths of 10 μs, with 2 μs risetime, at 200 to 300 pulses/s. Continuous or intermittent duty may be required, depending on the application.

The heart of any high-power pulse modulator is the pulse-switching device.

Hydrogen-thyratron, spark-gap, and mercury-pool devices—these have been the traditional choices for handling the power levels required. But their size and weight are usually as impressive as their power-handling capacity.

The ideal switch, of course, would be small and lightweight, with long life and high reliability—features that suggest a solid-state approach. This paper describes the five-year history of RCA's investigations of solid-state devices for high-power pulse switching. Several developmental switches are described, with performance ratings that show very real potential as practical switches for high-power pulse modulators.

Background of development

In a line-type pulse modulator, energy is transferred from a high voltage power supply to a "pulse-forming-network" (PFN) capacitance, via a charging inductance and a charging switch. This charge transfer takes place over a relatively long time called the interpulse period. The pulse switch is then triggered to discharge this energy into the load, producing a short, high-peak-power load pulse. The PFN configuration causes the energy to be delivered to the load as a rectangular pulse.

*Duty cycle is the ratio of pulsewidth to interpulse period.

After a short interval to allow the pulse switch to recover voltage blocking ability, the charging switch is triggered to initiate another cycle.

Power transistors generally make poor switches in super-power short-pulse modulators, mainly because the peak capability of a power transistor is little higher than its dc capability. This characteristic leads to an inefficient use of silicon, resulting in a large and unreasonably expensive switch. Also, transistors are more susceptible to damage from fault current than are thyristors.

Power thyristors tend to be limited by rms current rather than peak current, and are thus more appropriate for design of a relatively small, low-cost pulse switch. Power thyristors are limited in pulse-current risetime because of slow spread of current across the silicon chip after the gate is triggered. This characteristic (slow rate of current spreading) can cause localized chip overheat for rapidly rising current pulses—the well known *di/dt* limit. Large high-power thyristers are more susceptible. to *di/dt* limitations than are small, low-power thyristors. Several interdigitated and regenerative gate designs have been developed to enhance high frequency performance. However, at the present state of the art, it appears that relatively small chips (up to 0.1 in. diameter and 35 A rms rating) have a definite performance edge over larger devices for pulses with risetimes up to 2 μs.

Device selection

During the early study and investigation, arrangements were made with the RCA Solid State Division to make pulse dissipation tests on several thyristor-device families: RCA S3700M, RCA S2600M, and 2N3899. From these tests, tentative ratings were derived, thus allowing cost and size tradeoffs to be made in order to select the best device for further work. The tests were made using 20-μs pulses, with

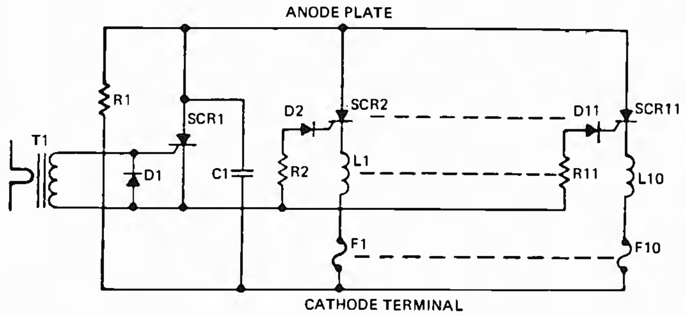

Fig. 1
Basic SCR switch "module" with 10 thyristors paralleled on a common anode plate. (Dotted lines indicate that the SCR circuit is repeated ten times.)

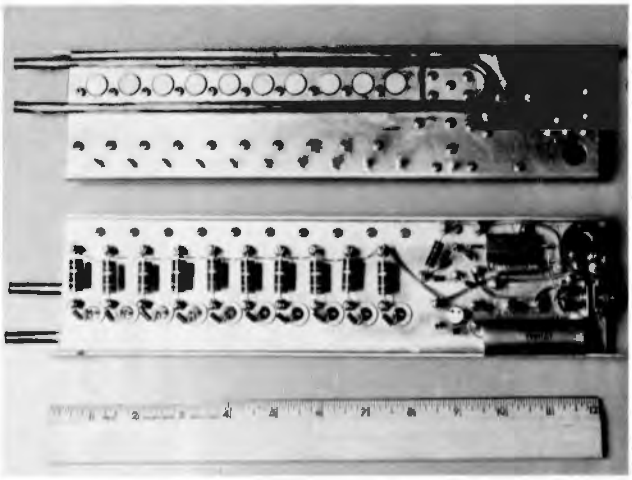

Fig. 2
Parallel SCR switch, showing press-fit thyristors on a water-cooled aluminum plate.

risetime up to 2 μs, and a low repetition rate.

The resulting data showed that one 2N3899 can replace four S3700Ms or three S2600Ms. The significantly higher parts count with the smaller devices seemed certain to make a S3700M or a S2600M modulator more expensive than a 2N3899 modulator. Further, a 2N3899 modulator would be smaller in overall size. Therefore, the 2N3899 (stud mount)/2N3873 (press fit) family was selected for further work.

Developing the switch

The switch was fabricated in two steps:

1) A "module" was constructed by paralleling a number of individual devices on a common anode plate.

2) A number of "modules" were connected in series to obtain the desired voltage capability.

A ten-thyristor module yielded 1.8 megawatts of peak power.

After an evolutionary period of many months, a module using ten type-2N3873 thyristors pressed into a common anode heat sink was developed. (Ten is an arbitrary number; any convenient number up to probably several dozen may be paralleled.) As shown in Fig. 1, a pilot thyristor (SCR1) provides gate drive to the ten main thyristors by switching the voltage on C1 onto the common gate bus. C1 is charged to the module anode-to-cathode voltage. Gate-isolating resistors R2 through R11 ensure a proper overdrive (2 A peak at the nominal 500 V operating level) into each of the main thyristor gates. Diodes D2 through D11 provide further gate isolation, preventing feedback from a leaky or shorted thyristor to the gate bus. Inductors L1 through L10 are straight No. 18 bus wires, each approximately 4 cm long, which connect the ten main cathodes to the next anode plate for a series stack. Fuses F1 through F10 provide automatic disconnect of an individual failed thyristor.

Pilot thyristor SCR1, an RCA S2600M, is normally triggered by a nominal 1-A (peak), 5-μs pulse from current transformer T1. The secondary of T1 has 50 turns of magnet wire on a small (CF111-Q1) ferrite toroid. In a series stack of modules, a 50-A (peak) primary pulse is conducted through a single-turn primary which links all of the toroids in series. The primary turn is a silicon rubber-insulated high-voltage wire.

Early versions of the module were constructed using the stud-mounted 2N3899 thyristors on a water-cooled copper plate. Later versions were constructed using press-fit 2N3873 thyristors on a water-cooled aluminum plate. Fig. 2 shows this latter version.

These switch modules were extensively tested in a conventional artificial line type modulator circuit at 6000 A peak. They yielded 1.8-MW peak power and 9 kW average power.

Using RCA2N3873 thyristors selected at random from a lot of 1000 units containing two different date codes, current sharing among ten paralleled thyristors typically fell within ±20% of the average value. Two continuous runs of 8 hrs each were made at the given conditions. In destructive tests, the devices exhibited remarkable toughness: at least four, and sometimes five of the ten devices had to be removed (by clipping the cathode leads) before failure occurred among the remainder in a 5-minute test. Typically, soft solder melted at the cathode connection before the device failed in these destructive tests.

Twenty modules were connected in series to produce a 30-megawatt switch.

On the basis of the encouraging early results, the Air Force in 1974 awarded RCA a contract to construct and test a 30-megawatt switch.

Twenty modules were constructed, using ten type 2N3873 press-fit thyristors in parallel in each module; the 20 units were connected in series to form a 10-kV peak-voltage, 6-kA peak-current switch (Fig. 3). A modulator was constructed to test this switch to 50 MW peak power and 150 kW average power.

This switch has been operated for short periods (up to 5 minutes) at the full design power levels. (The thermal constant of the thyristor switch is short compared to 5 minutes.) With water cooling provided, the switch heat sink temperature rise was only a few degrees Centigrade. Longer operational periods were precluded by the danger of overheating test set components,

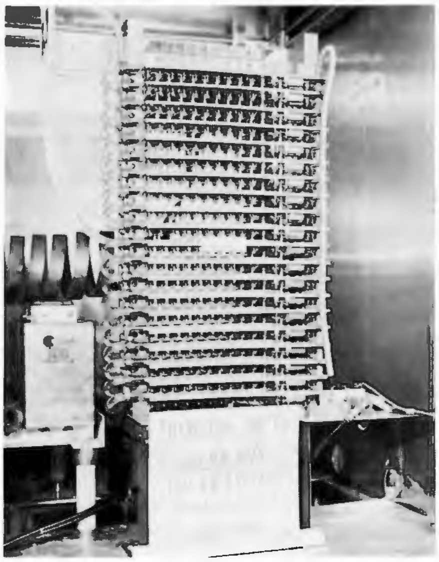

Fig. 3
30-megawatt switch shows 20 modules in breadboard configuration used to verify high-power switching performance.

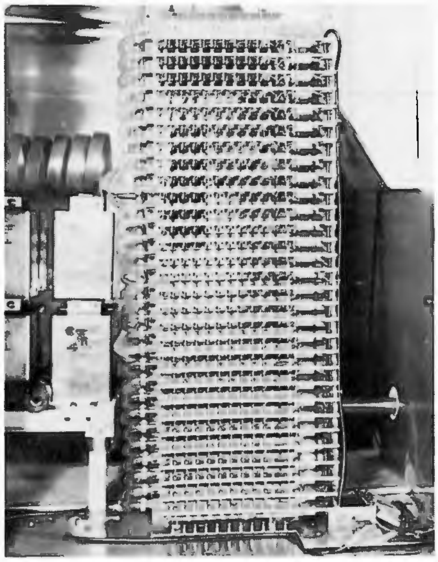

Fig. 4
Extension of switching voltage capability from 10 to 15 kV was demonstrated in this developmental switch.

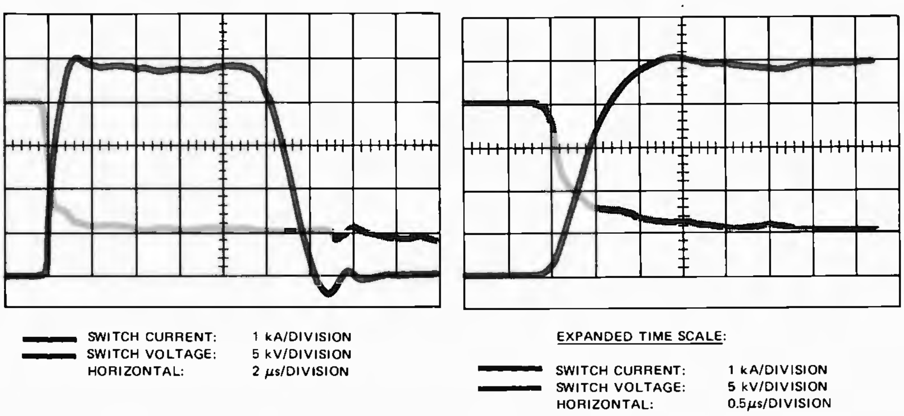

Fig. 5
15-kV switch current and voltage waveforms show instantaneous switching capability on normal 2 microsecond time scale (left) and on an expanded 0.5 microsecond time scale (right).

particularly the pulse-forming-network capacitors.

Levels achieved were:

Peak switch voltage	10 kV
Peak switch current	7000 A
Peak load power	32 MW
Average load power	160 kW
Pulsewidth	20 µs
Current risetime (10% to 90%)	1.7 µs
Repetition rate	250 pulses/s

Adding ten more modules produced an additional 15 megawatts of peak power.

Under a contract extension from the Air Force, the 10-kV, 30-MW switch described above was extended to a 15-kV switch by adding 10 additional modules in series for a total of 30 series modules. (See Fig. 4.)

Because of test-set limitations, this 15-kV switch could not be tested to its full inherent capabilities of 45-MW peak and 225-kW average power. Therefore, the switch was tested for the following parameters:

Pulsewidth	10 µs
Current risetime	0.8 µs
Peak PFN votage	15 kV
Peak load current	4700 A
Peak load power	30.9 MW
Repetition rate	285 pulses/s
Average load power	88.1 kW

The switch was repeatedly snapped on and off at full power, demonstrating instant full power availability without warmup. Continuous runs were again limited to about 5 minutes by component (PFN-capacitor) heating. Fig. 5 shows switch current and voltage waveforms during the pulse.

Hybrid circuit thyristor switch

Early in this program, the use of hybrid circuit techniques was recognized as offering a potential dramatic reduction in size and weight for the parallel SCR switch module. Glass-passivated chips of an appropriate size became available in 1975 (from Unitrode Corporation), and a hybrid circuit development program was started in 1976.

A 40-A (rms rating) 600-V chip (R044060) was chosen; this chip is 5-mm (0.2 in.) square. The concept involves attaching, by reflow soldering, 20 main switch SCR chips in a ten parallel/two series configuration, plus two trigger (or pilot) SCR chips, on a beryllia substrate. Beryllia was chosen for its excellent thermal properties—high conductivity and high specific heat.

The resulting circuit (Fig. 6) is essentially two series circuits, much like the configuration shown in Fig. 1, but with an important simplification. The electrical isolation of the SCR anodes, provided by the beryllia heat sink, allows placement of the fuses (F1 to F20) in the anode circuits; this, in turn, eliminates the requirement for gate-isolating diodes (D2 to D11 in Fig. 1). Otherwise, circuit operation is exactly as described earlier.

Several trial layouts were generated and discarded in arriving at the hybrid circuit layout. Because of the high rms currents involved (40 A rms/chip), the SCR chips are not soldered directly to the substrate metallization, but rather to copper contact pads which are in turn reflow soldered to the metallization pattern. The printed-circuit resistors (gate resistors and bleeder resistors) add negligible weight to the hybrid circuit. The trigger transformers (T1 and T2) and the circuit capacitors (C1 and C2) contribute significant (but not major) weight to the hybrid module.

The completed module weighs 190 grams without cooling fins, and 235 grams with cooling fins attached. Fig. 7 is a photograph of a completed hybrid-circuit thyristor-switch module.

The performance objective, as an air cooled switch, was as follows:

Peak voltage	1 kV
Peak current	3 kA
Pulsewidth	10 μs
Current risetime	1 μs
Repetition rate	100 pulses/s
Duty cycle	0.001
Peak power	1.5 MW
Average power	1.5 kW

Ten hybrid SCR modules were connected in series to obtain a 10 kV (nominal) air-cooled switch as shown in Fig. 8, and the switch was installed in the test modulator. In initial testing, some difficulty was experienced with module voltage sharing, resulting in loss of devices. After repairs, maximum voltage was limited, resulting in the following maximum operation:

Peak voltage	8.9 kV
Peak current	3 kA
Pulsewidth	10 μs
Current risetime	1 μs
Repetition rate	100 pulses/s
Duty cycle	0.001
Load resistance	1.2 Ω
Peak load power	10.8 MW
Average load power	10.8 kW

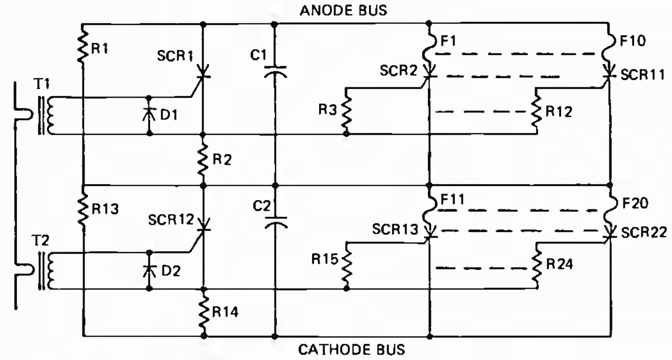

Fig. 6
Hybrid SCR chip switch circuit provides 20 switching chips without the requirement for gate-isolating diodes. (Dotted lines indicate that the SCR circuit is repeated ten times.)

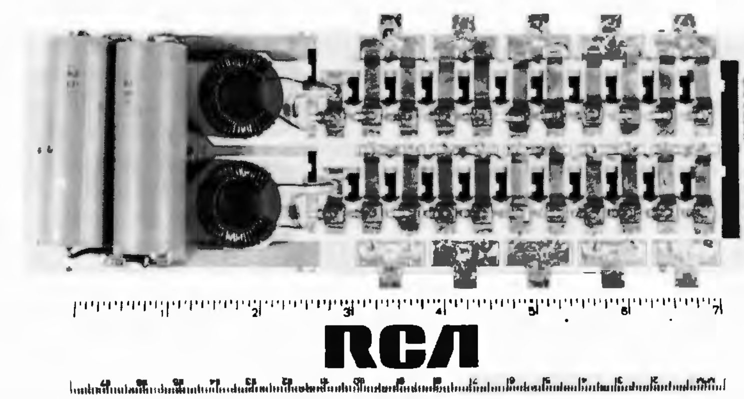

Fig. 7
Hybrid switch module in completed form shows compactness attainable in final design.

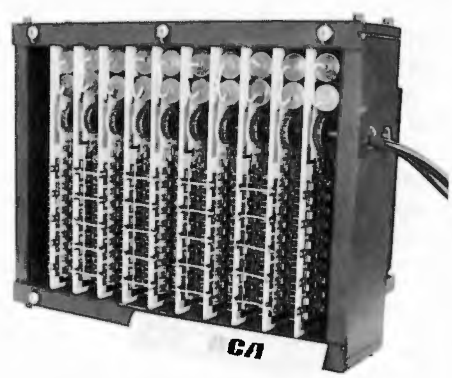

Fig. 8
Air-cooled hybrid switch incorporates ten SCR modules in series for high-voltage testing.

Conclusions

The work performed on thyristor switching has shown that series/parallel arrangements of relatively small thyristors can be used effectively in high-power artificial line-type pulse modulators. A 30-MW (peak) 150-kW (average) power modulator was demonstrated using packaged 2N3873 devices with water cooled heat sinks. A lightweight, compact, air-cooled hybrid SCR switch attained 10 MW peak and 10 kW average in an artificial line-type modulator. These results show that solid-state switching has arrived as a practical reality for advanced super-power pulsed modulator applications.

Acknowledgments

Part of the material contained in this paper was published in the *Record* of 1976 Twelfth Modulator Symposium sponsored by IEEE. Significant portions of this solid-state modulator development work were sponsored by the Air Force Systems Command's Rome Air Development Center, Griffiss AFB, N.Y. The following RCA personnel made significant contributions: E.O. Johnson, RCA Laboratories; E.M. Leyton (deceased) formerly of the RCA Laboratories; and G. Albrecht, formerly of the RCA Solid State Division.

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Pulsed GaAs FET microwave power amplifiers for phased-array radars

R.L. Camisa
J. Goel
H.J. Wolkstein
R.L. Ernst

Phased arrays require pulsed operation at high frequencies, but at the beginning of this project, nothing had been published on the pulse characteristics of GaAs FET amplifiers.

The successful realization of I-band (8-10 GHz) airborne phased-array radars depends upon the development of high-performance economical power-amplifier modules. IMPATT diode amplifiers and transistor amplifier-multiplier approaches have been unsuccessfully tried at these frequencies. At lower frequencies, three-terminal silicon bipolar transistors are used exclusively. Recent advancements in GaAs technology indicate that efficient power amplification is possible, with many researchers[1,2] achieving output power in excess of 1 W through 12 GHz.

This paper summarizes the performance of a 9-10 GHz, 0.5-W pulsed GaAs FET amplifier developed as part of an Air Force exploratory technology program.[3] The amplifier reported here is considered a driver for higher-power stages yet to be developed, with an eventual output power goal of 5 W. In array-radar applications, the amplifiers must be operated in a pulse mode such that the devices are activated only when a radar pulse is being transmitted.

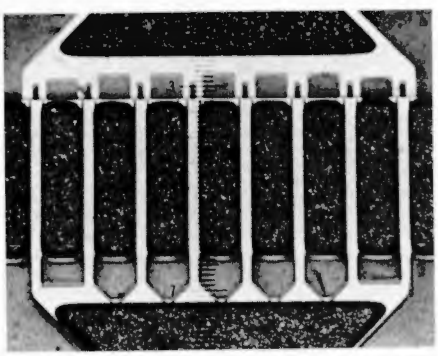

Fig. 1
Typical RCA GaAs FET chip before flip-chip mounting.

At the inception of this program, there was no published prior art concerning the pulse characteristics of GaAs FET amplifiers. Therefore, the major goal of this effort was to compare the cw and pulse performance of microwave amplifiers using these devices. The evaluation of phase variations within a pulse was of particular interest for this phased-array application, since low phase variations make amplifier-to-amplifier tracking problems less difficult.

The distinctive features of RCA GaAs FETs used in this amplifier program are briefly summarized below. Flip-chip bonding procedures, first applied to GaAs power FETs by RCA, presently differentiate our approach from others in the field and will be described. The amplifier design approach discussed here emphasizes pulse techniques and associated tradeoffs.

Device technology

Flip-chip devices have distinct advantages.

The distinctive features of RCA's GaAs FETs used in this amplifier program are: a) flip-chip bonding, for its heatsinking qualities and reduced source inductance; b) self-aligned gate processing, for its simplicity; and c) multiple-layer epitaxy, for its non-degrading ohmic contacts. The details of the device processing have been previously published[1,4] and only the highlights will be briefly reviewed here. Our fabrication processes use conventional photolithographic techniques and avoid difficult alignment problems. Modern microfabrication techniques such as ion beam milling are used, avoiding undercutting and resulting in an almost 1:1 ratio of photoresist pattern to actual device geometry.

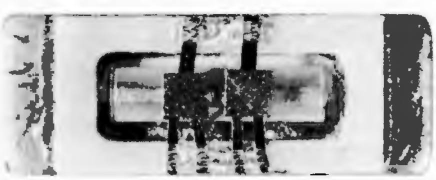

Fig. 2
"Flipped" device mounted on a gold-plated copper carrier. This technique provides good heatsinking and low source inductance.

Flip-chip bonding of devices allows optimal heatsinking of units in a common-source configuration, while at the same time optimizing gain by reducing source inductance to a minimum. This technology uniquely lends itself to high-performance, reliable devices which can ultimately be adapted to large-scale production. Fig. 1 shows a typical RCA GaAs FET chip with plated source posts. Fig. 2 is a photograph of a "flipped" device mounted on a gold-plated copper carrier. In the flip-chip bonding, ribbons or bond wires are attached on gate and drain pads and the device is then flipped down onto a copper carrier, thereby contacting all the sources at the same time. The gate and drain connections are then tacked down on a ceramic ring having metallization pads. Inductance is minimized by grounding all sources directly, without the use of wirebonds. The copper pedestals extract heat directly away from the surface of the device, where the heat is generated. The flip-chip technology appears difficult, but this technique has proved very practical with the advent of commercially-available flip-chip bonding machines.

Amplifier development

The overall multistage amplifier was designed in modular blocks.

This design allowed individual sections to be separately optimized and cascaded easily with other stages. A modular construction is also desirable because it is tractable—if an individual amplifier fails, it can be easily located, reworked, or replaced by an equivalent unit. The most common type of modular design is the quadrature-coupled balanced amplifier.[5] In this construction, each amplifier stage requires two quadrature couplers and two single-ended circuits. The main disadvantage of an all-balanced approach is that two devices per

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Why do we need high-frequency pulsed amplifiers?

Airborne radars are requiring higher and higher resolution, and high-frequency operation (up to 12 GHz) can provide it Higher frequencies also mean smaller antennas and less aircraft weight. However, standard amplifiers do not work well at such high frequencies, and GaAs MESFET amplifiers seem to fill this gap.

It is also efficient to have an airborne radar work in both the air-to-air and ground-to-ground modes. (The driving force here is for military tactical aircraft, but future commercial applications seem possible—collision avoidance with the air and ground are both important.) Thus, the radar must be able to "look" in a number of different directions in a very short time. Phased-array radars do this well, but they pulse beams in different directions by combining a large number of different-phased beams. By varying the individual phases, the combined beams will cancel each other out in different directions, resulting in a beam that can change its direction quite rapidly. The requirement for rapid pulsing is thus passed on to the amplifier.

Ray Camisa was project engineer for the GaAs amplifier described here. His work at the Microwave Technology Center has also included GaAs FET devices and linear amplifiers. He has also published papers on low-noise parametric amplifiers, microwave integrated circuits, and MIS varactors.

Contact him at:
Microwave Technology Center
RCA Laboratories
Princeton, N.J.
Ext. 3136

Jitendra Goel is presently working on GaAs MESFETs and amplifier circuit design. His work has included the first X-band amplifier with an output above 1 W and the first dual-gate high-gain octave-bandwidth (4-8 GHz) amplifier.

Contact him at:
Microwave Technology Center
RCA Laboratories
Princeton, N.J.
Ext. 3166

Herb Wolkstein is now concentrating on the development and applications of solid-state microwave devices. He was previously Manager of Advanced Programs and Application Engineering for RCA's microwave activity, where he made many contributions to TWT and solid-state technology.

Contact him at:
Microwave Technology Center
RCA Laboratories
Princeton, N.J.
Ext. 2710

Bob Ernst has developed and supervised the construction of hundreds of microwave integrated circuit modules operating at frequencies ranging from 70 MHz to 40 GHz. He is now working on power-combining techniques and the pulsed-microwave system described here.

Contact him at:
Microwave Technology Center
RCA Laboratories
Princeton, N.J.
Ext. 2510

Authors Wolkstein, Goel, Ernst, and Camisa, along with the microwave amplifier described in this article.

amplifier stage are required. An alternate approach uses directly cascaded amplifiers without couplers. The disadvantage of this amplifier type is that individual amplifier stages interact with each other, which makes tuning the complete amplifier difficult. The advantage of the directly cascaded amplifier, however, is that a minimum number of devices are used.

The final version of the driver amplifier used a mixed single-ended and balanced design as a compromise between the number of devices used, alignment difficulty, and overall volume. This was done by separating the amplifier into three distinct modules. The two output modules are balanced stages. The input module is a circulator-coupled, three-stage single-ended amplifier. Fig. 3 is a block diagran of the overall amplifier showing stage-by-stage performance. At band center, the output power of the overall amplifier was 500 mW with an associated gain of 30 dB. The small-signal gain was 33 dB and the noise figure was 12.5 dB.

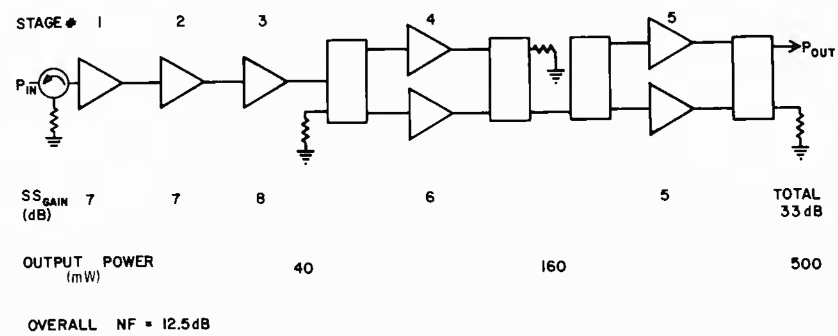

Fig. 3
Stage-by-stage performance of the GaAs FET amplifier. Pulsed operation takes place in the last two stages, where most of the power is dissipated.

The amplifier video circuitry design and rf-pulse operation differentiate this amplifier from all previous FET amplifier designs.

In an airborne-array application, in order to conserve power, the FET amplifiers should be off when no rf pulses are being transmitted. Two methods of pulsing the amplifiers were considered: pulsed-gate and pulsed-drain.

In a pulsed-gate configuration, the device is cut off by putting a reference voltage larger than the pinchoff voltage on the device. In order to turn the device on, a positive-going pulse decreases the effective negative gate-to-source voltage such that the FET can draw its normal operating current. In the second approach, the drain voltage is pulsed from 0 V to the normal operating drain potential and current. The drain-biasing scheme requires a fast current driver and the gate-biasing scheme does not. However, a disadvantage of the gate-pulsing scheme is that it puts heavy demands on the maximum voltage that the device must tolerate without damage—the device breakdown voltage must be greater than the algebraic sum of drain voltage, gate voltage, and rf voltages. Our amplifier used the gate-biasing scheme because of its simplicity and ultimate lower cost. Also, the amplifier was pulsed only in the last two balanced stages, where most of the power is being dissipated.

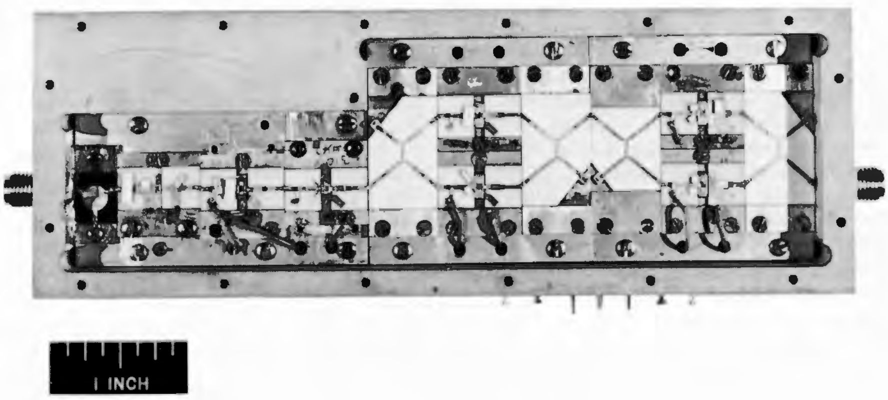

Fig. 4
Experimental amplifier was produced in a microwave integrated circuit format. Note the modular approach taken and compare the modules with the blocks of Fig. 3.

The amplifier performs well, especially in terms of its AM/PM conversion.

Fig. 4 is a top view of the amplifier delivered to the Air Force Avionics Laboratory. The overall package is approximately 15×6×2.9 cm. The input and output connectors are the hermetically sealable type with excellent rf performance through 18 GHz. The amplifier requires two dc inputs ($V_D = 8$ V, $V_{ref} = -4$ V) and one video pulse (0 to −4 V). With −4 V, the last two stages are cut off, and with 0 V, the amplifier is turned on. The amplifier package is divided into rf and dc (or video) compartments.

The amplifier rf circuits were fabricated in a microwave integrated circuit (MIC) format. All circuits were made on 0.635-mm (0.025-in.) Al_2O_3 microstrip transmission lines with chrome-copper-gold metallization. The substrate thickness is dictated mainly by the type of coupler used in the balanced design. Actually, at I-band, a thinner substrate is preferred to minimize dispersion and radiation effects.

Table I summarizes the design goals of the amplifier and the experimental results; Fig. 5 shows the amplifier in pulsed operation. The amplifier met all room-temperature design goals except power-added efficiency. The poor efficiency resulted from having to select devices with high breakdown voltages so that the FETs could be pulsed. This should not be a fundamental problem for the reasons stated in the article's conclusion. The AM/PM (amplitude-modulation/phase-modulation) conversion performance of this amplifier was excellent. At frequencies within the desired band, the AM/PM conversion was so low that it was hardly measurable. With further optimization, AM/PM could be further reduced over the entire band to approximately 2°/dB.

Conclusions

A five-stage GaAs FET amplifier with 29.7 ±0.4 dB gain at 500 mW output power over the 9-10 GHz band was designed, fabricated and tested. Extensive characterization of the amplifier performance was carried out under cw, pulsed-rf, and pulsed-rf pulsed-bias conditions to assess its suitability for airborne phased-array applications. The amplifier performance under cw and pulsed conditions was almost identical. To obtain pulsed amplifier stages not sensitive to the duty cycle, the gate of each FET was pulsed from pinchoff to its operating potential. This technique eliminated the need for fast current drivers, but put stringent constraints on the dc characteristics of the rf devices. If this gate-biasing technique is to be used, all the rf devices must have similar pinchoff values and their breakdown voltages must exceed the algebraic sum of pinchoff voltage, applied drain voltage, and the total rf voltage swing at maximum power output. In the limited time available for developing this amplifier, it was difficult to meet these dc requirements and simultaneously obtain good rf performance. This problem is not a fundamental one, but it underscores the need for further optimization of circuit and/or FET geometries specifically designed for pulsed-rf applications.

Acknowledgments

The authors gratefully acknowledge the support of the Air Force Avionics Laboratory, Wright-Patterson Air Force Base, for their encouragement and support of this work. All power devices used in this program were supplied as part of another X-band power FET program. Dr. H. Huang was the project scientist for the device-development effort. The cooperation of W. Reichert, P. Pelka and J. Klatskin in handling the devices is gratefully acknowledged. All the FET amplifier circuits were assembled and optimized by M. Kunz.

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Table I
Amplifier performance met all room-temperature design goals except power-added efficiency. Low efficiency came from having to select devices with high breakdown voltages so that the FETs could be pulsed.

	Design goal	*Experimental results*
Gain and frequency response	30 ± 0.3 dB over 9- to 10-GHz band at 500 mW output power	29.7 ± 0.4 dB at 500 mW output power
Output power	500 mW	500 mW
Efficiency	20%	8%
Pulsewidth Repetition rate	0.2 to 65 μs 300 to 0.3 kHz	Both requirements met
Rise/fall time	50 ns (max)	< 30 ns
AM/PM* conversion	3°/dB (max)	3.5°/dB (max)
Pulse-amplitude droop	5% (max)	⩽ 5%
Intrapulse phase shift	5° (max)	< 5°
Unit-unit gain/ phase tracking	0.6 dB in gain 7° in phase	No data obtained in program time frame

*AM/PM = amplitude-modulation/phase-modulation

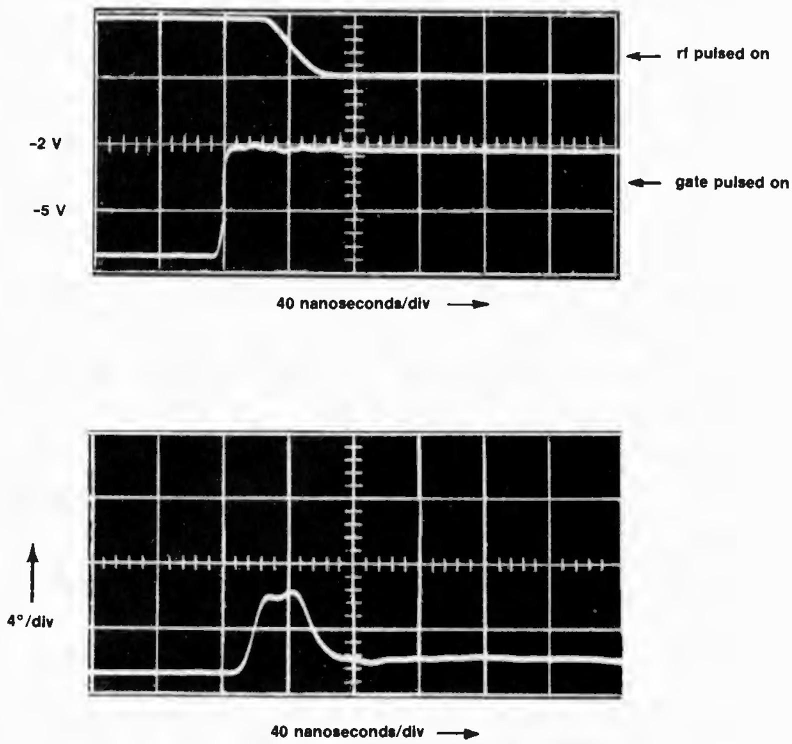

Fig. 5
In pulsed-gate operation (top) a positive-going pulse decreases the effective gate-to-source voltage and so allows the FET to draw its operating current and turn on. Resulting phase imbalance (bottom) is within specifications.

- **RCA Engineer—ranks second (after discussions with associates) as a source of technical information about RCA.**
- **TREND—ranks second (after the grapevine) as a source of non-technical information about RCA.**
- **RCA Libraries—rank fifth as a source of all information—rated right after: Your own files (some of which have been accumulated with the help of the library), the engineers in your own group, books, and handbooks (many provided by the library).**
- **RCA Technical Abstracts—ranks lowest of the four, partly because of its low visibility.**

Engineering Information Survey results Part 3

D.E. Hutchison | J.C. Phillips | F.J. Strobl

A closer look at four information sources—how important are they to you?

What value do RCA engineers place on the *RCA Engineer*? *TREND*? *RCA Technical Abstracts*? The RCA libraries? The recent Engineering Information survey answered these questions and several others* related to these four RCA-sponsored communication channels:

How accessible are they?
How are they used?
What should be done to improve them?

*An earlier paper focused on the general results of the Engineering Information Survey.[1] A second paper compared the information needs and use patterns of high and low achievers.[2] This paper reviews four specific technical information sources available to RCA engineers.

How accessible are they?

Most engineers follow the path of least resistance.

Research on the use of information sources shows that accessibility often determines frequency of use.** Engineers frequently turn first to the information source that is most accessible; perceived technical quality influences his decision to a lesser extent. This implies that improving the quality of an information source may not lead to increased use of that source—unless it is accessible.

**See, for example, Allen, T.; *Managing the flow of technology* (MIT Press; 1977) p. 184.

How accessible is the RCA Engineer? Trend? RCA Technical Abstracts?

% of respondents having access

	RCA Engineer	*TREND*	*RCA Technical Abstracts*
Direct access	73%	67%	9%
Indirect access	13%	23%	36%
No access	14%	10%	55%

Direct access means that the information is distributed directly to the engineer's office or home. Sources identified as *indirect access* are available through circulation or borrowing. *No access* means these sources are not available or not used.

RCA Engineer is distributed on a company-paid subscription basis and is generally sent to an engineer's home. According to the Survey, coverage varies substantially by location (100% in some to virtually none in others). Research and development engineers get the most complete coverage; manufacturing and service engineers, the least.

TREND is sent in bulk quantities to each engineering location within RCA. A distributor in the location routes sufficient copies to engineering groups for distribution to each engineer. The survey indicated that about 10% of the respondents did not receive TREND.

RCA Technical Abstracts is distributed to libraries, to engineering management, and to those who feel they have a need for direct access. Many survey respondents (55%) have no access (do not know what *RCA Technical Abstracts* is or have no access to it.)

What is your access to an RCA Library?

Library at my location	77%
Remotely located library	7%
No access	16%

Library services are available to most survey respondents; 77% have direct access and 7% can take advantage of the central library of their major operating unit.

How are they used?—a question of value

How would you rate RCA Engineer, TREND, RCA Technical Abstracts, and the RCA libraries as sources for the following types of information?

	RCA Engineer	*TREND*	*RCA Technical Abstracts*	Library
Tech. info—job related	60%	42%	37%	90%
Tech. info—other	90%	68%	37%	93%
Business info-RCA	70%	95%	N/A	82%
Business info—other	30%	47%	N/A	81%
Professional	61%	56%	N/A	85%

This table summarizes the percent of respondents who said these sources are valuable, very valuable, or somewhat valuable.

Do you use the RCA Engineer, TREND, and Technical Abstracts to find personal contacts with experts with whom you can discuss technical matters?

	RCA Engineer	TREND	*RCA Technical Abstracts*
Source has provided contacts with experts.	39%	28%	18%

Let's analyze what these data tell us about the value of each of these technical information sources.

RCA Engineer:

The above data confirmed:

—that the *RCA Engineer's* major value is as a source for general technical information. (Tech info—other.)
—that it is a valuable source of business information about RCA.
—that in some cases it can be very valuable as a source of job-related information, but
—that it has only moderate value as a source for industry-related business information.
—that another important measure of the *RCA Engineer's* usefulness is its value in fostering intracompany, interdivisional contacts.

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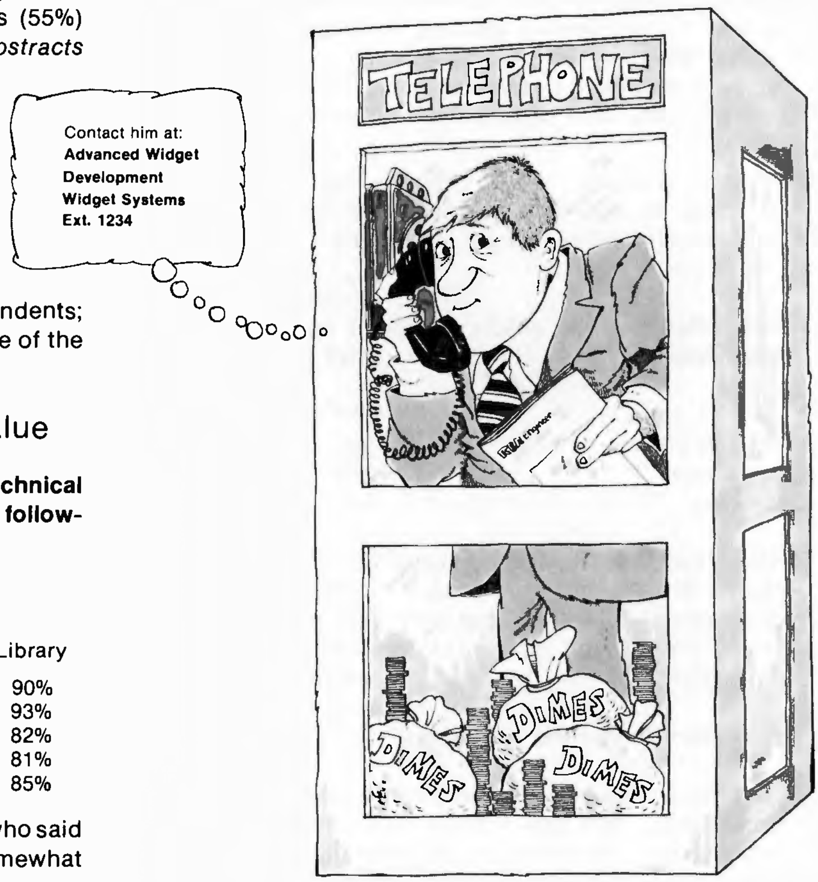

Thirty-nine percent of RCA Engineer readers have used the journal to locate experts on technical matters.

TREND

The **R**esearch and **E**ngineering **N**ews **D**igest, is valued as a primary source for business information about RCA, has fairly high value as a source of general technical information about RCA, and is of moderate value for the remaining three categories of information (professional, business-other, and technical-job related).

RCA Technical Abstracts

Although *Technical Abstracts* is valued by 37% of the respondents, this constitutes the lowest ranking of the four sources considered. One of the reasons for this low ranking is that 55% of the respondents did not have access to *RCA Technical Abstracts*.

Library

The libraries rate very high and maintain an image of providing material in all five areas of information to 81-93% of the respondents. There is little question that their value ranks highest among the sources covered here.

How much of most issues of the RCA Engineer and TREND do you read and scan?

	RCA Engineer	*TREND*
Read	20%	41%
Scan	52%	46%

The *RCA Engineer* publishes over 500 pages a year; thus, each year the average survey respondent reads over 100 pages—a considerable reading volume. An interesting finding was that the percentage read was similar for all types of engineers (research, design, manufacturing) but varied greatly with professional achievement (discussed later).

TREND presents short capsules of diverse items: respondents read what interests them and scan the rest. The almost 50/50 read/scan relationship suggests a good mix of content.

How often do you obtain copies of reports or papers referenced in RCA Technical Abstracts?

	RCA Technical Abstracts
Use more than twice a month	4%
Occasionally	29%
Never use	67%

RCA Technical Abstracts is used by 33% of the survey respondents, 4% at least once a month, and 29% use it occasionally. Recalling that only 45% have access (9% direct, 36% indirect), many of those who have access follow through by obtaining copies of the documents abstracted.

How often do you use the Library?

Libraries accessible at a location are used by 77% of the respondents; 48% use it more than twice a month; 29% occasionally. The heaviest use is for literature searches, followed by reading current journals and proceedings. Other uses of the library range from checking Military Specifications and vendor information to seeing what's new and finding a quiet place to work. 9% are too busy to use the library, and 4% say that their management discourages them from using the library.

How does achievement level relate to access and use of these sources?

An earlier paper on the Engineering Information Survey[2] compared the differences in information use between high and low achievers.* It showed that high achievers use appreciably more initiative in seeking out information and make the effort required to be well informed beyond the immediate job. Generally, the same pattern shows up in the data for the four information sources reported below.

	% of respondents answering positively	
Access	*High achiever*	*Low achiever*
Receive *RCA Engineer* at home	84	46
No access to *RCA Engineer*	5	33
Receive *TREND*	78	56
Direct receipt of *RCA Technical Abstracts*	63	28
Library at my location	86	60
Use (by those who have access)		
% of *RCA Engineer* read	21	16
% of *TREND* read	42	37
Use *RCA Technical Abstracts* twice a month	12	4
Never use *RCA Technical Abstracts*	20	44
Use library more than twice a month	70	45
Never use library	2	13

*Achievement was measured by six criteria: perceived technical currentness, effectiveness as an information source, and the number of papers, presentations, patents, and awards.

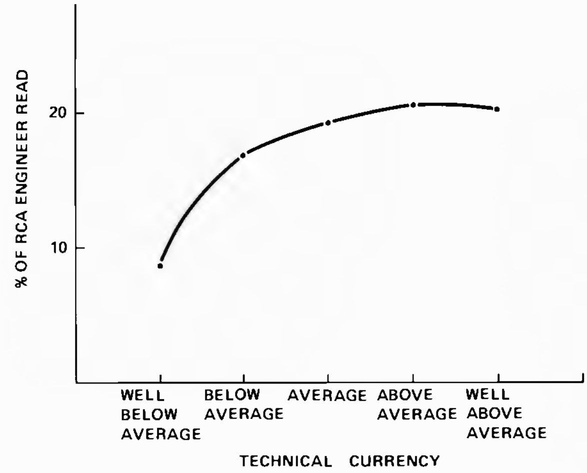

Fig. 1
RCA Engineer is read more by engineers who perceive themselves to be more up to date. Respondents were asked to rate themselves in terms of being up to date with the current state of the art in their technical field; these responses are plotted against percentage of the *RCA Engineer* that is read for each category.

We were able to derive several other interesting relationships from this comparison and other survey analyses:

RCA Engineer

- Engineers who read more of the *RCA Engineer* regard themselves as being more up to date (see Fig. 1).
- Engineers who have more access to the *RCA Engineer* perceive that their management places more emphasis on staying up to date.
- Engineers who have more access to the *RCA Engineer* are used more frequently as technical information sources.
- Engineers with more professional achievements have better access to the *RCA Engineer* and use it more to find personal contacts with whom they can discuss technical matters.

RCA Technical Abstracts

- Those who find *RCA Technical Abstracts* most useful are those who receive it directly.
- Those who regard their management as placing strong emphasis on keeping up to date had easy access to *RCA Technical Abstracts*.
- Those receiving *RCA Technical Abstracts* directly rated themselves near the top in keeping up to date.
- Engineers who have more access to *RCA Technical Abstracts* have more patents, papers, presentations, and awards (Fig. 2).

Library

- Those who put more emphasis on keeping technically current make more use of, and have better access to, libraries.
- Those who use the library more also publish more papers, make more presentations, file more patents, and win more awards (Fig. 3).
- Those who have used computer-assisted searching have more professional accomplishments.

What can we do to improve?

The survey results contained many recommendations for enhancing the value of the information sources covered.

What could make the RCA Engineer more important?

By far, the most common response to this open-ended question was for "more directly job-related material." Other write-in suggestions repeated most often were:

—include more tutorial or self-study material.

—include more state-of-the-art technology.

—make it easier to understand—less math, less technical.

—go into more technical depth.

—make it more applications oriented.

Following up on this open-ended question, the survey attempted to delve more specifically into recommendations for change.

When asked about state-of-the-art reviews, for example, more than 79% of the engineers responding (about 2100) considered it important to publish more of this type of article in the *RCA Engineer*.

Respondents were asked to write-in state-of-the-art topics and other topics that should be in the *Engineer*, along with

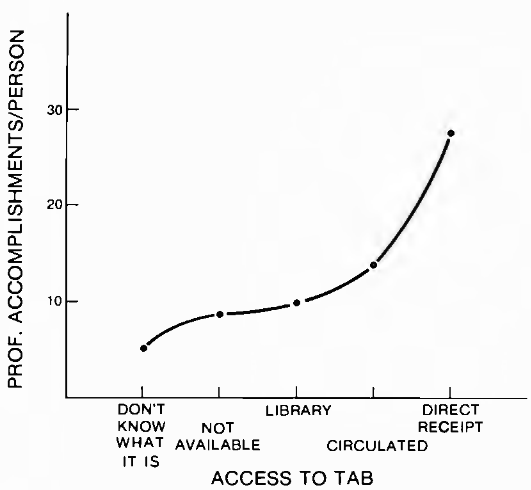

Fig. 2
Access to RCA Technical Abstracts relates to accomplishments (papers, patents, presentations, awards).

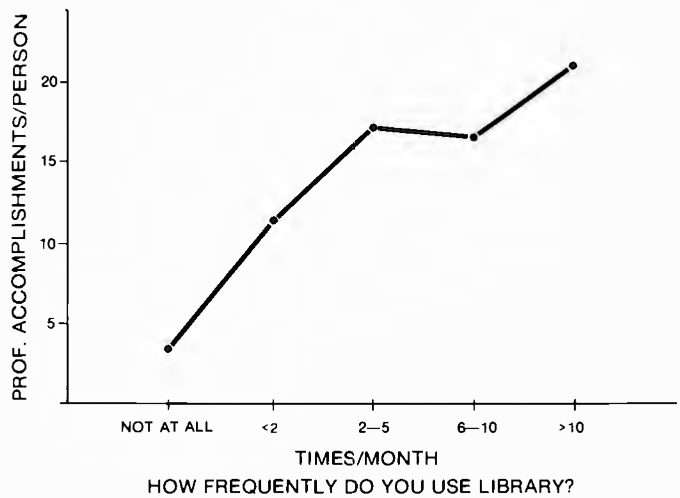

Fig. 3
Library use correlates strongly with professional accomplishments. Engineers who visit their libraries frequently are those who are writing more papers, making more presentations, obtaining more patents, and receiving more awards.

TREND is second only to the grapevine as a source of nontechnical information about RCA.

suggested possible sources or authors. Table I lists the most frequent recommendations by general topic.

The survey also provided a listing of types of information that might be useful and asked respondents to check as many as apply. The results are given in Table II.

Table I
General topics that survey respondents suggested for the *RCA Engineer.* (The list is in order of the popularity of the topics based on write-in answers to the question "What would you suggest as some of the more important topics to be covered in the *RCA Engineer*").

Computers/digital technology
Solid state technology and applications
Manufacturing
Communications
Business/policy
Profiles of other activities
Electro-optics
Circuits
Mechanical engineering and packaging
Television
Heat transfer
Career information
Devices
Materials

Table II
More information about competitive technology and more educational presentations were the two strongest survey requests. (These are responses to the statement "The *RCA Engineer* should have more information about.")

	% of respondents answering %
Competitive technology	64
Educational presentations—for self-study	52
Profiles of divisions and activities	40
Various aspects of engineering as a profession	33
Educational presentations—for career guidance	28
Technical reference file (technical bibliographies of various topics compiled by experts)	28
Blue-sky look into the future	27
Entertainment (electronics is fun and educational; hobbies, etc.)	23
Book reviews	20
Two-way communications/letters to editor	13
Profiles of engineers	12
Picture features (photo essays)	12
Interviews	10

What subjects would you like emphasized more in TREND? What are the subjects you would like emphasized less?

The results, in descending order of importance, show the percentage of readers desiring more information in a particular area, minus the percentage of those desiring less emphasis:

New products, developments	65%
New markets	52%
Business	51%
Scientific advances	48%
Policy	35%
Available services (Library, MIS, Information Services, etc.)	24%

What services could the library provide that would be helpful to you that it does not now provide?

In the answer to this question, there seemed to be a general feeling that our libraries are not being kept up to date because of budget limitations. Requests were made for more up-to-date books, broader coverage, more copies of popular books so there wouldn't be such a long wait for them, and a larger selection of journals and conference proceedings.

Library users would also like their libraries to have more space for older material, which now must be discarded. They would like on-line computer searching, audio-visual aids and materials, video tapes of RCA courses, catalogs of holdings in other RCA libraries, bulletins from their library listing new acquisitions, faster response time on documents requested, and better copying facilities.

Reactions to the survey— what are we doing with these results?

RCA Engineer
John Phillips, Editor
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As I reported in the August-September issue,[3] we have already started publishing more review and survey articles, more tutorial information, and more about RCA's businesses. We plan to continue these efforts. Further, we feel that most papers we publish—whether product-, technology-, or application-oriented—can teach, can make some mention of the business climate, and can review related developments. To that end, we have been encouraging authors to include additional broader-interest material in each paper. This may be a perspective statement added as a "box" to the article, or it may simply be an expanded introduction, further explanation of the theory, stronger conclusion, or clarifying illustration.

Most important, we are making the needs of our broad readership known to potential authors as we invite papers for future issues; we are also insisting that those needs be met as a condition of publication. Many engineers wanted more information on the competition and on competitive technologies. Here we hit a real obstacle. Including information on competition is difficult, partly because such information is difficult to get, and partly because the *RCA Engineer* is published by RCA. While we cannot evaluate our competitor's products in a company-sponsored journal, we will stress competing technologies in any technology review we publish. For example, in the August-September 1977 issue, the paper on CMOS Reliability, by Larry Gallace, *et al*, also treats bipolar device reliability. In the same issue, Jerry Bouchard and John Bauer reviewed the competing hybrid technologies, not just the ones used at their locations.

Because access and use of the *Engineer* relate so strongly to the survey's measures of engineering achievement, we are continually working with management to broaden the distribution, and have directed much of our editorial resources toward improving readability. Direct distribution to *all* engineers remains a primary objective.

We have also taken steps to build upon the journal's value as a source of personal contacts for technical information. This shows up in several ways:

- Direct statements within the body of each article, letting readers know where more information is available from the author or from others at RCA.
- Useful references and bibliographies.
- Specific contact information for each author.
- Reviews of work being done around the company (e.g., "Where the electro-optics action is at RCA" by Haynes, Apr - May 1977)

We plan, to use the many write-in suggestions for articles and features. As the mechanism for follow-up, all the suggestions from a location will be given to the Editorial Representative for that location. If we obtain half of them, we will fill the pages of the *Engineer* for at least the next decade.

When we come to the question of including material related directly to every engineer's job, we have a real problem. Many of us would like to solve our next major problem by simply picking up a piece of literature. But no information source is that good. And, although the request for directly job-related information was a major recurring theme of this survey, the best we, as information gatherers, can do is make it easier for readers to determine what is relevant to their jobs and provide them efficient tools and methods for further literature or expert searching. We are emphasizing the importance of useful references and bibliographies in each article; and, as reported, if an article has some bearing on a particular job, author contact is simple and straightforward.

In summary, then, the survey results set a major goal for the *RCA Engineer* staff, Editorial Representatives, and authors: to produce a journal that meets the needs of the readership—said another way, to produce a journal "by and

Many readers of RCA Technical Abstracts follow through by obtaining copies of the documents it abstracts.

for the RCA Engineer." This survey was a large step in a continuing process of trying to better understand our readers' needs and interests, recognizing, of course, that these needs and interests change continually. We will continue to solicit your ideas and try to be responsive to your needs.

TREND—The Research and Engineering News Digest
Frank Strobl, Editor
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The survey results have provided an additional perspective on what *TREND* readers want to see in RCA's technical news digest.

A main concern that generally underlies all the survey data is how *TREND* can be more useful to RCA engineers. One of *TREND's* purposes is to point out to engineers where useful information can be found—Continuing Engineering Education courses; valuable resource materials (such as RCA Library programs, RCA-MIT Industrial Liaison Symposia); RCA technical symposia; and engineering or marketing contacts who can provide in-depth information on technical work going on in other divisions.

This last item is receiving special emphasis because the Survey indicated that 59% of RCA engineers "never use *TREND* to find personal contacts with whom they can discuss technical matters." To remedy this, a contact name is being included in every story covering a technical achievement.

Business information about RCA fared well in the readers' ratings. *TREND* includes business information not only on RCA's technical operations but also on the contributions of its diverse companies. We constantly try to get articles looking at the business perspectives of a particular operation, and more of these will be published in the future.

In response to the Survey question on "technical information not directly related to job duties but important to keeping broadly abreast of the state of the engineering art and science in a particular field," *TREND* scored about average. *TREND*, as The Research and Engineering News Digest of RCA, has as another goal to make engineers and scientists aware of the latest technical achievements in the Corporation—the whole Corporation. We hope to include more of the technical work going on in the Corporation that is not highlighted elsewhere. How? By periodically asking our readers for "news tips" on developments they want to share with the total technical community at RCA, and by utilizing the Editorial Representative network to help get inputs.

As for supplying technical information that is directly relevant to the performance of present job duties, *TREND* scored below average and it should. We don't pretend to help an engineer do a specific job, but do attempt to point out where a colleague may be doing comparable work and how additional information can be obtained.

TREND was rated above average as an information source about professional achievements, i.e., society work, awards, honors. We will continue to concentrate on major technical honors and achievements, but leave coverage of the bulk of professional accomplishments to the *RCA Engineer* journal and other media such as Technical Excellence newsletters.

The survey showed that 10% of the respondents did not receive *TREND*. The news digest is not sent directly to each engineer but is disseminated via a distributor network. A person at each location is charged with the responsibility of breaking down a bulk shipment and forwarding copies to engineering departments at that location. As engineers move around in their divisions or change locations, they should advise the *TREND* office of their new addresses to ensure uninterrupted service. Distributors are asked to poll periodically the engineering departments they service to make sure *TREND* distribution is adequate.

Indications of unsatisfactory distribution uncovered in the Survey are being followed up. All Survey respondents should receive their own copy of *TREND*, as the engineering community is the prime audience for the news digest.

Although content of a digest is primary, its readability is enhanced by its look. *TREND* readers scan 46% of the digest and read 41%—not bad, but the ratio should be shifted to more "read." With Editorial Board and Staff help, we are attempting to make *TREND* more interesting and lively by improving its graphics (typography, photos, cartoons), content (shorter stories to gain more variety in coverage of all RCA's operations), and by running specials (technology quizzes, guest editorials). A highly valued feature in *TREND* is the organization chart. Readers are interested in following the progress of their colleagues. More charts are planned in upcoming issues.

In summary, then, these Survey results will serve as a guideline, along with suggestions from the *TREND* Editorial Board, to ensure that readers get balanced and adequate coverage of RCA's technical and related business activities in each issue. But perhaps more importantly, we can't publicize your achievements if we don't know about them. *TREND* is a "readers' digest" in the sense that it reflects its readers' work. Our output is your input. We look forward to hearing from you if you feel you have an achievement that can help others at RCA in their work.

RCA Technical Abstracts
Doris Hutchison, Editor
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Ext. PY-5412

The survey showed that many of those reading *RCA Technical Abstracts* do follow through by obtaining copies of documents abstracted therein. However, it was a surprise to find that 21% of those replying have encountered so much delay or difficulty in getting documents that they have given up trying. Copies of all documents abstracted in *RCA Technical Abstracts* are available, and there is no reason why you should not be able to obtain them. The best source, of course, is your librarian, who should be able to get any RCA document for you fairly quickly. If you experience any difficulty in obtaining documents, we would like to know about it.

RCA Technical Abstracts is of value to 37% of the respondents; this constitutes the lowest ranking of the four sources considered. One reason for the low ranking is that 55% of the respondents do not use *RCA Technical Abstracts* because they either do not know what it is (26%) or do not have access to it (29%). To help remedy this situation, a reprint of an *RCA Technical Abstracts* cover with a description of its purpose, coverage, how to use it, and where to find it was included with an *RCA Engineer* mailing. Hopefully, some of the 55% mentioned above will now look for *RCA Technical Abstracts* in their library, ask their engineering management to put them on their circulation list, or, if not otherwise available, request to be put on the distribution list. A number of such requests have been received and honored.

RCA Libraries
Contact your librarian, or
Doris Hutchison
Corporate Engineering, Cherry Hill, N.J.
Ext. PY-5412

The libraries rate very high in this survey and maintain an image of providing business, professional, and technical information to 81-93% of the respondents. There is little question that their value ranks highest among the information sources covered in the survey.

Why does RCA provide these technical information sources?

RCA Engineer—A bimonthly technical journal that publishes state-of-the-art reviews, tutorials, and other technical, and business-oriented papers. It provides an in depth look at what's going on at RCA and helps you update your knowledge of the electronics field. It also provides a forum in which you can publish to enhance your professional reputation. For more information, call John Phillips, Cherry Hill, Ext. PY-4254.

TREND—a monthly briefing of what's going on technically at RCA, what RCA's businesses are doing, and what services, products, and other aids are available to support your work. For more information, call Frank Strobl, Cherry Hill, Ext. PY-4220.

RCA Technical Abstracts—A monthly company-private abstract bulletin of RCA's proprietary technical reports and publications. It cites author, source, and document-number and includes RCA patent disclosures and MIT research reports as well as the RCA papers and reports. Annual cumulative indices are also available, starting with 1968. For more information, call Doris Hutchison, Cherry Hill, Ext. PY-5412.

RCA Libraries—The highly skilled librarians in RCA's technical libraries can get just about any piece of technical information you may need or desire. If your location doesn't have a library, your divisional library is willing to support you. For more information, call your librarian or Doris Hutchison, Cherry Hill, Ext. PY-5412.

All locations employing large numbers of engineers are serviced by an RCA technical library operated by a highly skilled professional librarian.[4] Many other locations have modest libraries or technical information collections staffed on a part-time basis. This type of information facility could also be useful at several additional locations. Engineers in locations lacking library facilities can use the major library of their operating unit; at present, about 7% of the survey respondents take advantage of a remote library.

Some of the needs expressed by survey respondents are now being provided at several locations. For example, on-line computer searching is now available at Moorestown, Princeton (Laboratories and Astro-Electronics), Lancaster, Indianapolis, and Burlington; soon to be available in Camden, with other libraries considering this service.

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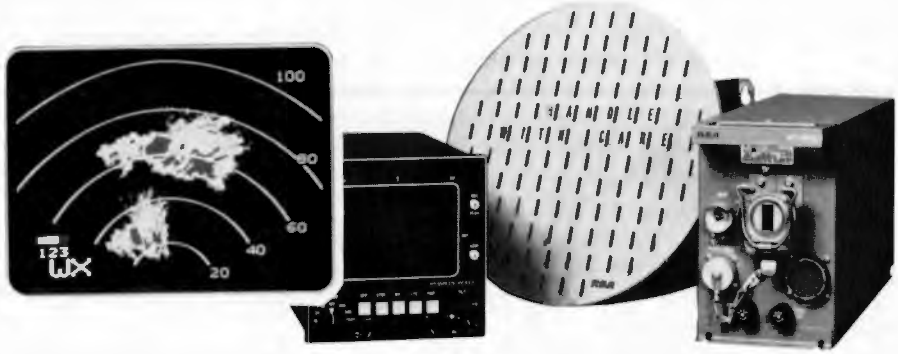
The color weather radar indicator—a 1978 David Sarnoff Award winner

Color displays for airborne weather radar

Pilots recognize potentially dangerous storms more readily when the storm locations are displayed in color.

R.H. Aires | G.A. Lucchi



In 1977 RCA introduced weather radar systems with color indicators for both commercial air carriers and general-aircraft users. The use of color has significantly improved the pilot's ability to recognize potentially dangerous storms. It has also improved the radar's usefulness in the ground-mapping mode, where the pilot looks at the terrain below instead of the weather ahead. But before describing this advance, some background on weather radar is necessary.

Relating rain density and turbulence

Weather-radar systems used in the air-carrier and general-aviation industry measure the rainfall density that exists within a storm cell—they are not able to assess turbulence directly.

Experience has shown, however, that storm cells containing rainfall rates of over 11.5 millimeters per hour quite often produce enough turbulence to cause aircraft structural damage or passenger injury. Therefore the FAA advises pilots to stay at least 20 miles away from storms with rainfall rates exceeding 11.5 mm/hr.

The radar return from a storm depends upon the backscatter from the raindrops.

Eq. 1 is the basic radar range equation used to calculate the detectability of a specific radar target.

$$P_r = P_t G^2 \lambda^2 \sigma / [(4\pi)^3 \; R^4 L] \qquad (1)$$

where

P_t = transmitter peak power
G = antenna gain used both for receiving and transmitting
λ = radar carrier wavelength
σ = target radar cross section area
R = one-way range between radar and target
P_r = received power from the target
L = system losses, correlation gain, etc.

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This equation is derived from the theoretical considerations with the radar target consisting of a solid, highly conducting surface of generally spherical shape. In order to apply this equation to meterological-type targets, it must be modified to reflect a three-dimensional fluid-impregnated volume representative of a storm cell core.

The radar backscatter coefficient Z for spherical raindrops has been empirically established. The coefficient is a function of the sixth power of the raindrop diameter and the number of raindrops in a specific volume. It is denoted by

$$Z = \sum_{i=1}^{N} D_i^6$$

and is inversely proportional to the fourth power of the radar carrier wavelength and proportional to the second power of absolute value of the dielectric constant, K, of water. Since the backscatter coefficient is also proportional to rainfall rate, the relationship* $Z = 200\, r^{1.6}$ is used to define the reflectivity, where Z is in mm^6/m^3 and r is the rainfall rate in mm/hr. For the pencil-shaped radar antenna beam generally used on airborne weather radar systems, the resultant pulse volume can be defined as $(\pi/8)R^2\theta^2 cT$, where R is the radar range, θ is the antenna beamwidth, c is the speed of light, and T is the transmitter pulsewidth. The resultant radar target backscatter cross section σ is the pulse volume times the factors which relate to the meteorological targets described below.

*This relationship pertains to Strataform-type storms; $Z = 55\, r^{1.6}$ is sometimes used for convective storms.

This backscatter coefficient is shown in Eq. 2.

$$\sigma = (\pi^5/\lambda^4)\; ZK^2(\pi/8)R^2\theta^2 cT \qquad (2)$$

By substituting σ from Eq. 2 into Eq. 1, converting the terms into appropriate values, and converting the equation into a dB format, the weather range equation for a beam-filling target is shown in Eq. 3. This format makes the equation suitable for relatively simple graphing and so assists tradeoff analyses in design.

$$P_r = 10\log P_t + 20\log\theta + 10\log T + 10\log Z - 20\log\lambda - 20\log R + 2G - L - 168.25 \quad \text{(dB)} \qquad (3)$$

where P_r is in dBm, θ is in degrees, Z is in mm^6/m^3, R is in nautical miles, P_t is in kW, T is in μs, λ is in cm, G is in dB, and L is in dB.

For a storm cell whose diameter does not fill the radar beam, Eq. 3 must be modified by substituting the non-beam-filling volume equation $(\pi/8)d^2cT$ for the beam-filling volume equation $(\pi/8)R^2\theta^2cT$ into Eq. 2, where d is the storm cell diameter. The same procedure used to establish Eq. 3 yields Eq. 4 for non-beam-filling storms.

$$P_r = 10\log P_t + 20\log d + 10\log T + 10\log Z - 20\log\lambda - 40\log R + 2G - L - 133.08 \quad \text{(dB)} \qquad (4)$$

All terms in Eq. 4 have the same units as in Eq. 3 except d, which is in nautical miles.

Eqs. 3 and 4 are used to calculate the received power which appears at the input to the receiver for the range and radar parameters selected for a specific storm cell density.

Both range equations are plotted in Fig. 1 using the system parameters for the RCA PriMUS-400 ColoRadar system with an 18-inch flat-plate antenna. It can be seen that the received power decreases at 6 dB per octave of range at distances up to the point where the 3-nautical-mile-diameter storm-cell model changes from beam-filling to non-beam-filling. At greater ranges the received power decreases at 12 dB per octave of range.

Pilots must avoid storms above a certain intensity, so radar displays must make these storms stand out.

The radar meteorology industry has related rainfall rates to the storm intensities (Table I). The table also gives the colors RCA uses to indicate these rainfall rates.

RCA's background in weather radar

RCA has been producing airborne weather radar systems for commercial air carriers and general-aircraft users since 1955. The first system produced was the well known C-band AVQ-10, which is still being used by many of the world's airlines. Since that time, most of the airborne weather radar systems have been designed to operate at X-band. So far, RCA has produced a total of eleven different types of X-band and two types of C-band radars; they are used in aircraft ranging from wide-bodied jets down to the smallest twin-engine aircraft. RCA's most recent weather-radar advancement is the PriMUS-400 ColoRadar described here.

Table I

Radar measures rainfall, which can be correlated to storm turbulence. (Radar cannot measure turbulence directly.) Radar meteorology industry has grouped rainfall rate (and thus turbulence) via this table. RCA has selected colors in the table to indicate the different storm levels.

Storm intensity	*Rainfall rate*	*Display color*	*Digital level*
Drizzle	0.25 mm/hr	black	0
Light	1.0 mm/hr	green	1
Moderate	4.0 mm/hr	yellow	2
Industry standard pilot alert	11.5 mm/hr	red	3
Heavy	16.0 mm/hr or greater	*	*

*Storm levels with rainfall rates greater than 11.5 mm/hr are shown as the number 3 level regardless of their intensity.

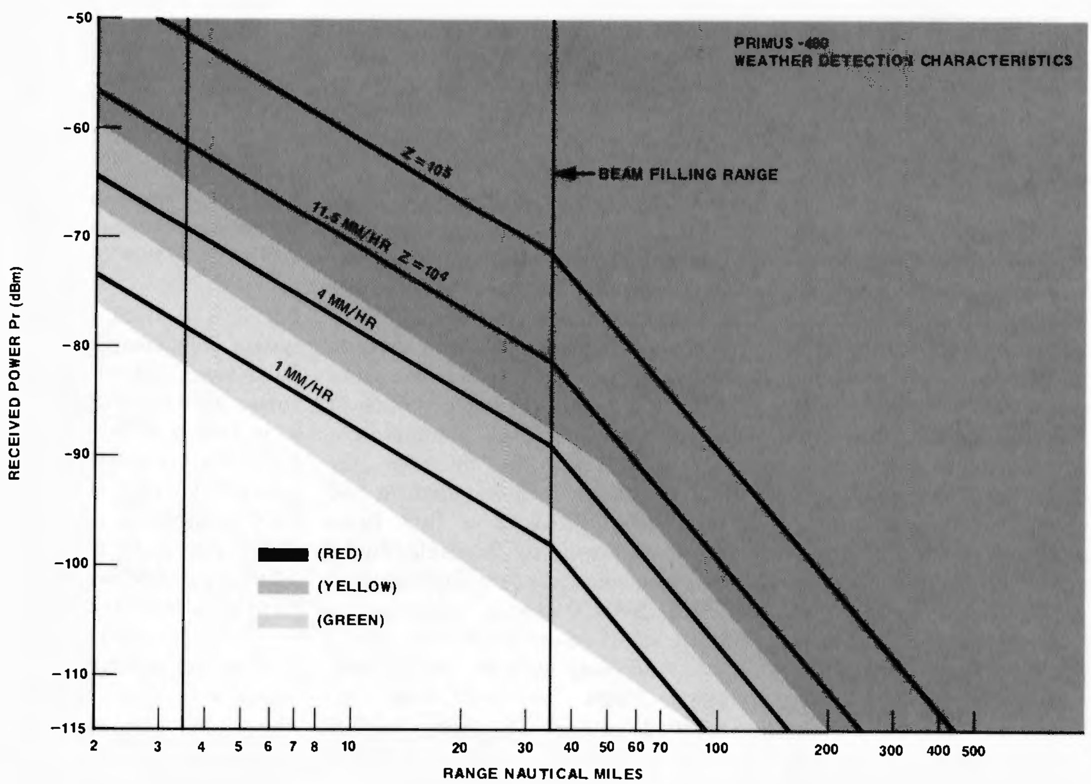


Fig. 1

Weather detection characteristics of the PriMUS-400 ColoRadar. The four solid lines show the returned power from storms with different rainfall rates. The 11.5 mm/hr. storm is potentially dangerous. System identifies levels of storm intensity by different colors on the display. The vertical "beam-filling" line, which defines 3-nautical-mile-wide storms that do or do not fill up the radar beam, also establishes the break point between the two radar range equations. The shaded areas show how the receiver gain is shaped.

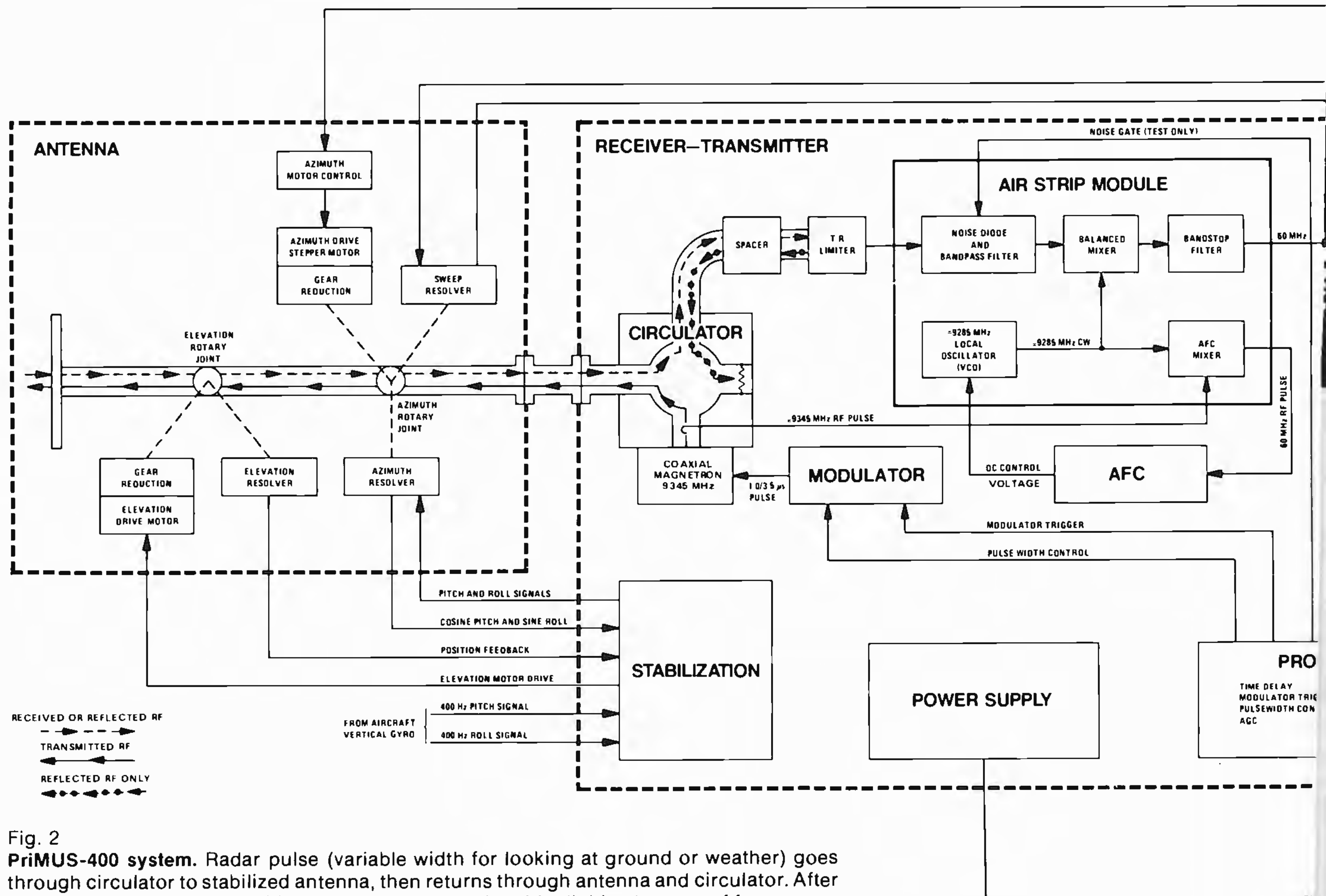


Fig. 2
PriMUS-400 system. Radar pulse (variable width for looking at ground or weather) goes through circulator to stabilized antenna, then returns through antenna and circulator. After signal processing and amplification, the returned signal is digitized to one of four storm-intensity levels, scan-converted from polar to x-y coordinates, and displayed on the color crt.

Meteorologists have established that storms whose rainfall rate equals or exceeds 11.5 mm/hr (a Z factor of 10^4) should be avoided by aircraft. As a result, in monochrome displays, areas with this Z level are blinked between the brightest level (number 3) and then off so that the pilot can easily distinguish the storm's position. In the color display system, this level appears as red, with a pilot option to have the area blinked between black and red. In order to determine where lesser rainfall rates are located in a storm cell, the 4 mm/hr signal level is detected and displayed as the 2nd from the brightest (number 2) in the monochrome indicator and in yellow for the color indicator. The 1 mm/hr storm is indicated as the lowest level (number 1) on the monochrome indicator and green on the color indicator. In this manner, the pilot can easily determine where to fly to avoid storms of varying intensity levels. The "drizzle" level is not shown on the display because its turbulence intensity is insufficient to be of concern.

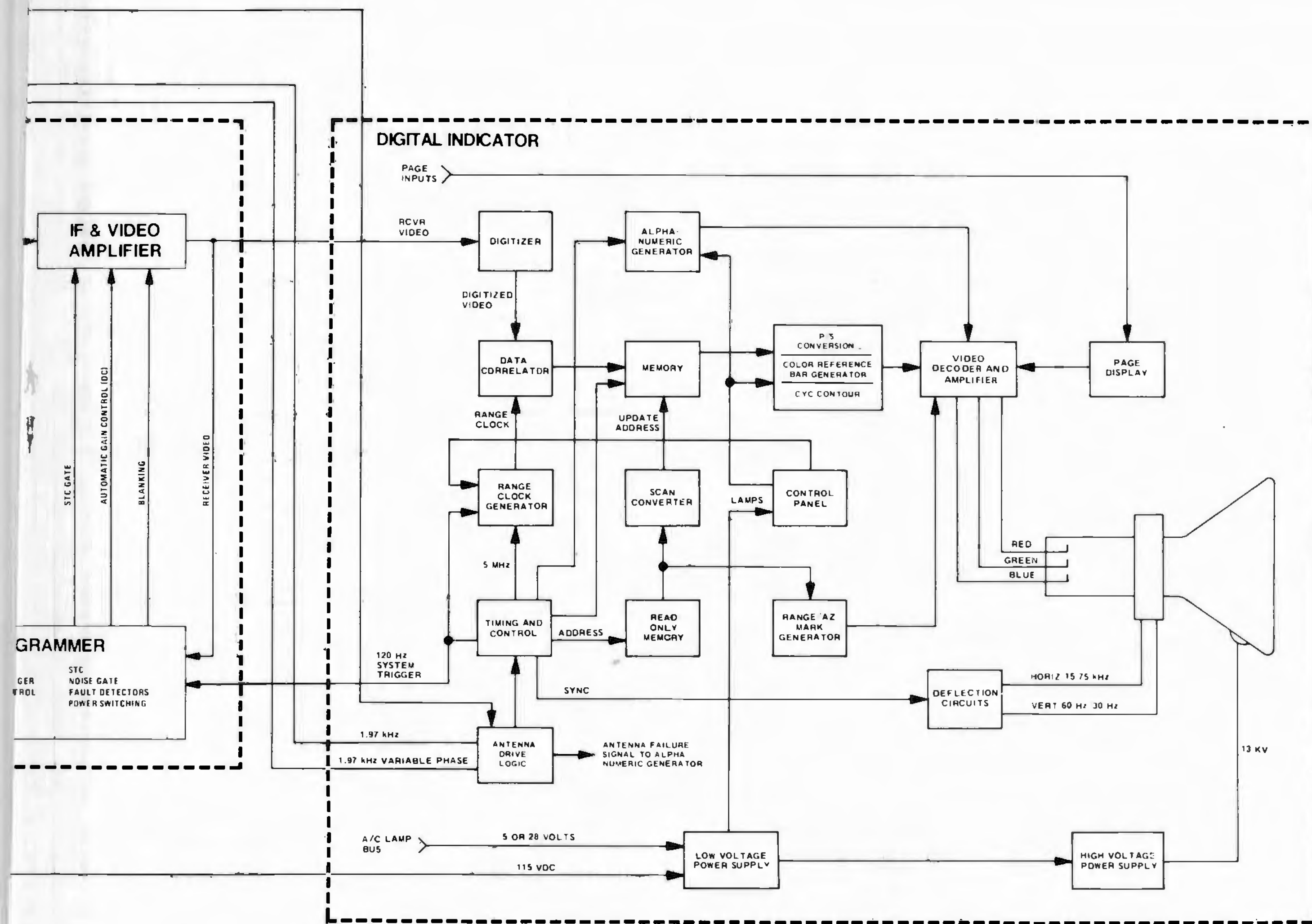
PriMUS-400 ColoRadar

On March 15, 1977 RCA announced the first general-aviation airborne weather radar system with a color indicator. The acceptance of this system by pilots has been overwhelming, primarily because the use of color greatly simplifies the recognition of displayed storm intensities. In addition to the advantages provided by color, the resolution of the display used in the PriMUS-400 ColoRadar is four times better than previously available digital storage type indicators. Another feature of the PriMUS-400 ColoRadar is the use of a different set of colors (cyan [blue-green], yellow, and magenta) in the ground-mapping mode. In this mode the transmitted pulsewidth and receiver bandwidth have been optimized to take full advantage of the increased display resolution. The overall result is much better ground-mapping than previously available. Major design considerations for the primary functions of the PriMUS-400 ColoRadar system will now be described.

The major elements of the PriMUS-400 system are the receiver/transmitter, the indicator, and the antenna.

Fig. 2 is a block diagram of the radar system. A magnetron generates microwave pulse energy at 9345 MHz and the circulator then directs it to the antenna, where it is radiated to illuminate the target. Reflected energy from the target is intercepted by the antenna and directed by the circulator to the microwave mixer. The mixer converts the microwave frequency to a first i.f. of 60 MHz. After amplification at 60 MHz, a second conversion to 10.7 MHz occurs within the i.f. amplifier to achieve the desired bandwidth prior to video detection. An AFC adjusts the receiver microwave local oscillator to track the magnetron frequency.

The detected video signal is digitized in the indicator to four discrete levels. After digital integration of the returns from four pulses, the data is scan-converted from polar-coordinate (rho-theta) format to tv



(x-y) format for storage in a RAM memory. Readout of the RAM memory is in standard tv format at a 60-Hz field rate. A decoder turns on the appropriate red, green, or blue gun of a color CRT, depending on whether the data represents a 0, 1, 2, or 3 level.

External video signals can be added to the radar data by video mixing at the video amplifier. Range and azimuth marks and even alphanumeric information can also be added to the display by video mixing. The indicator logic generates timing signals to trigger the transmitter and to drive the antenna azimuth stepper motor. The antenna elevation motor is driven from signals derived from the aircraft attitude reference (vertical gyro) to stabilize the antenna against pitch and roll maneuvers and permit manual control of the antenna elevation angle for ground mapping.

The transmitter has a variable pulsewidth.

A 10-kW coaxial magnetron has been selected for reliability and frequency-stability characteristics. This magnetron has been used in the top-of-the-line RCA general-aviation weather radars since the introduction of the AVQ-21 in 1970. It maintains nearly full power output until end-of-life because of its conservative cathode loading. The large coaxial cavity is much less subject to particle build-up than the older strap-vane design and therefore has less tendency to change frequency with age. A solid-state line-type modulator with an SCR switch provides the required 4.7-kV pulse for the magnetron.

In the weather mode, the transmitter pulsewidth is 3.5 μs. For optimum performance this pulsewidth requires an i.f. bandwidth of approximately 350 kHz. From Eqs. 3 and 4 it can be seen that the received power (P_r) is greater with a wider pulsewidth. A pulsewidth of 3.5 μs sacrifices little weather resolution, since the established model storm cell is 3 miles or 37 μs in diameter. The 3.5-μs pulsewidth is therefore a reasonable compromise between sensitivity and resolution.

In the ground-mapping mode, the resolution of small targets is limited by the pulsewidth and receiver bandwidth. The selection criteria here was a tradeoff with the display resolution, which is determined by the size of the digital memory. In the PriMUS-400 ColoRadar the digital memory consists of two planes of 64k bits each. The screen therefore can be divided into 256 × 256 cell locations, with the range resolution determined by dividing the selected range scale into 256 cells. On the 25-mile-range scale the smallest increment stored is 25/256 miles or approximately 0.1 mile, which is equivalent to 1.2 μs. A 1-μs pulsewidth is used in the ground-mapping mode for selected range scales of 50 miles or less. On the 100-, 200-, and 300-mile ranges the pulsewidth is increased to 3.5 μs for increased range performance and because the display is the limiting factor on resolution.

The pulse-repetition frequency (PRF) is determined by the desired display resolution and the antenna scan rate. The

Fig. 3
I.F. amplifier optimizes system sensitivity by generating a second i.f. center frequency of 10.7 MHz. Sensitivity time control (STC) adjusts gain with range; manual gain control allows pilot to vary color-level settings and see which part of storms are most intense.

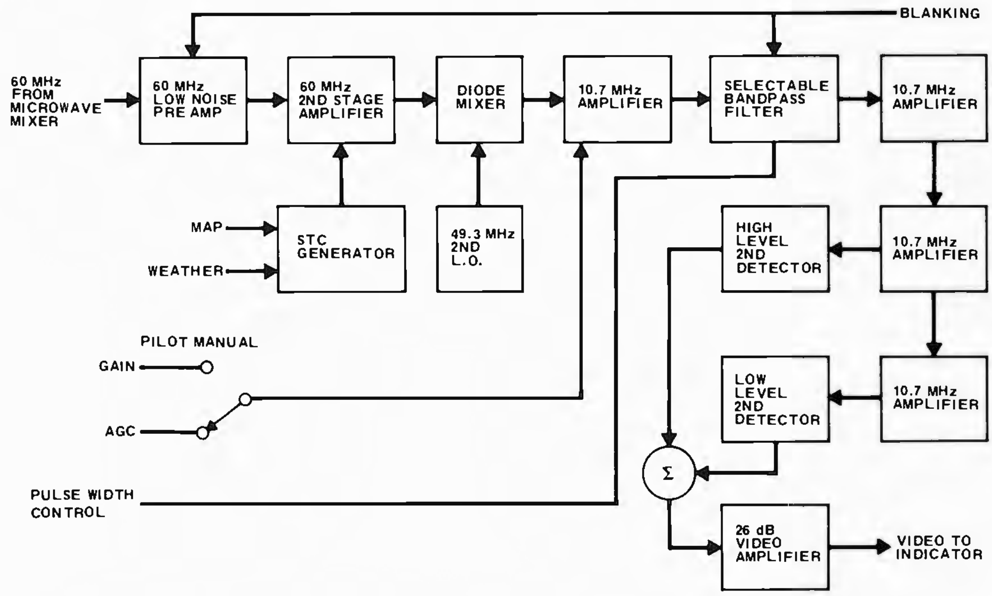


Fig. 4
AFC system essentially guarantees "lock-on."

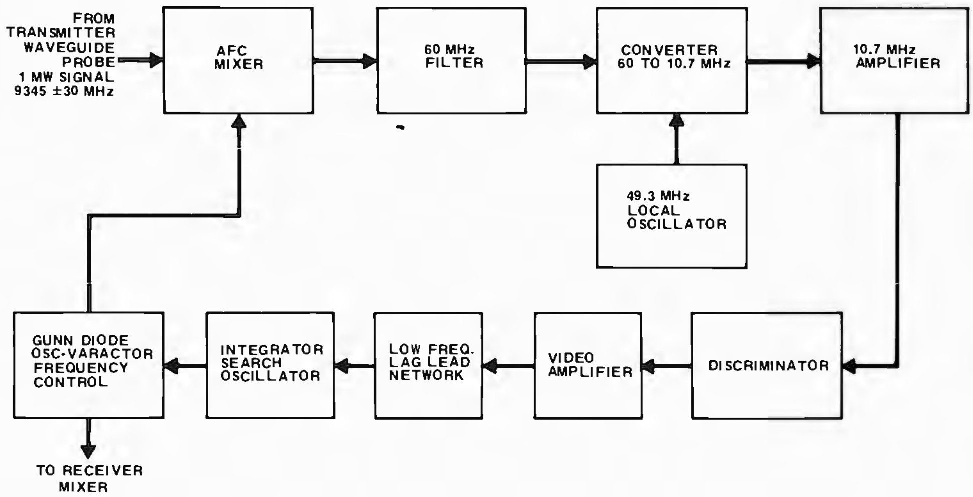
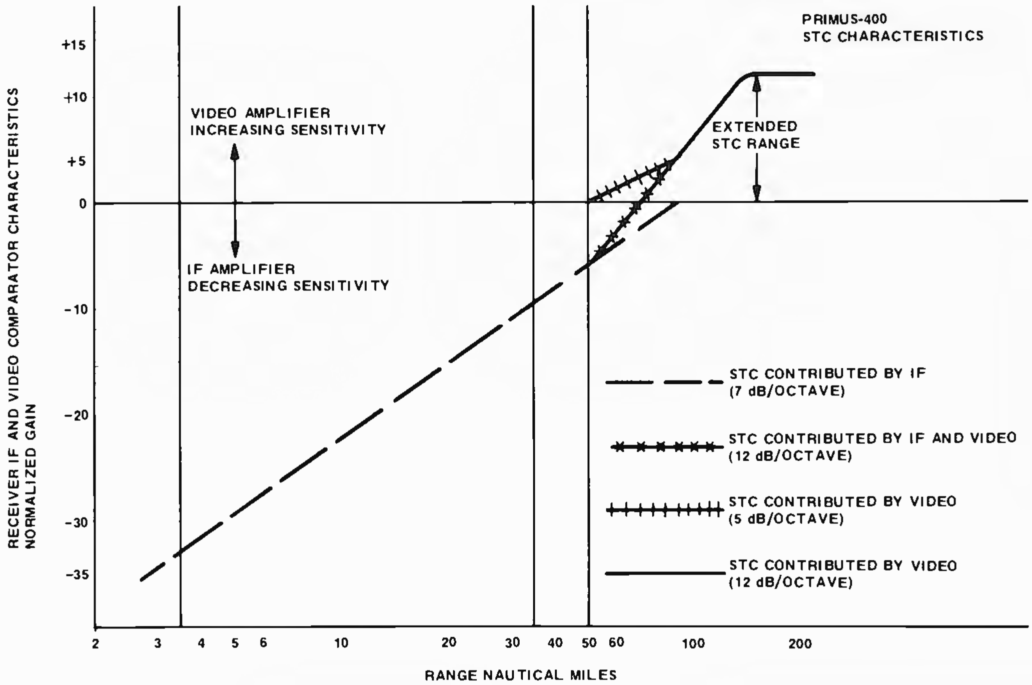


Fig. 5
Perceived-power/range slope can be varied at the i.f. amplifier or video amplifier. Beyond 50 nautical miles range, additional sensitivity comes from varying the reference voltages of the comparators.



PriMUS-400 antenna scans 120 degrees in 4.3 seconds. For an azimuth resolution of one quarter of a degree, a PRF of 120 Hz is required.

The receiver has a very good noise figure.

The PriMUS-400 achieves a 7-dB noise figure by using a bandpass filter to reduce the noise at the image frequency along with low-noise hot carrier diodes, a balanced mixer to reduce feedthrough of local oscillator noise, and a low-loss circulator and TR device. An isolator between the Gunn diode local oscillator and the mixer reduces frequency pulling. A separate AFC mixer permits accurate adjustment of the sampled magnetron frequency amplitude. This configuration provides a system noise figure at least 1 dB lower than competitive systems and provides 40-dB rejection of signals at the image frequency.

A 60-MHz first i.f. amplifier center frequency permits the practical design of the X-band bandpass filters used to reduce image-frequency noise mentioned in the previous section. In order to achieve the 350-kHz predetection receiver bandwidth, a second local oscillator and mixer generate a second i.f. center frequency of 10.7 MHz to optimize the system sensitivity when in the 3.5-μs-pulsewidth weather mode. Sensitivity time control (STC) is generated in the STC generator (Fig. 3) and injected into the second stage of the 60-MHz amplifier. The STC is adjusted for approximately 35-dB receiver gain attenuation at 3 nautical miles and has the gain increase at a rate of 7 dB per octave of range, reaching maximum gain at approximately 90 nautical miles. The adjustment allows for 3 dB of internal system degradation and 1 dB per octave of range to account for atmospheric attenuation from intervening rain up to 35 nautical miles, as shown in Fig. 1.

AGC, applied to the first 10.7-MHz amplifier, is established by sampling the video output signal at a range beyond the maximum range of expected radar signal returns. A pilot-operated manual gain-control voltage is applied in lieu of AGC when the gain is turned out of the calibrated preset position. The manual gain control can determine which of the 3-level (red) areas contain the most intense rain. While in this variable-gain position, an alphanumeric warning on the indicator reminds the pilot that the system is not calibrated for the standard rainfall rates. The gain control is also very useful for optimizing target recognition when in the ground-mapping mode.

A separate X-band mixer diode provides a sample from every magnetron pulse at 60 MHz, which is then down-converted to a 10.7-MHz amplifier and discriminator. When not "locked-on," the control voltage automatically sweeps the X-band local oscillator ±30 MHz until "lock-on" is established. The AFC servo loop is designed to achieve the highest stable gain possible with a 120-Hz sampling frequency. More than a 10:1 range of a "−2" gain vs. frequency slope is used in the AFC servo loop is achieve a high effective K_v. The average search sweep rate of 10 MHz/second is slow enough to essentially guarantee "lock-on" with this loop characteristic and a discriminator bandpass of 1.5 MHz. Fig. 4 is a block diagram of the AFC.

Three comparators determine the 0, 1, 2, and 3 levels corresponding to rainfall less than 1 mm/hr, 1 mm/hr, 4 mm/hr, and 11.5 mm/hr, respectively.

Fig. 1 shows that the power-received/range slope is 7 dB/octave at less than 50 nautical miles range and 12 dB/octave beyond 50 nautical miles range. Within the range of STC, 7 dB/octave is achieved by varying the i.f. gain, as shown in Fig. 5. Beyond 50 nautical miles range, additional sensitivity is provided by varying the reference voltages, and thus the sensitivity, of the 2- and 3-level comparators to achieve a total of 12 dB/octave of range up to 150 nautical miles. Since the PriMUS-400 displays red for a 3-level signal strength, the pilot is accurately warned of 3-level storms up to a range of approximatley 150 miles (18 minutes away at a jet speed of 500 knots).

A four-pulse digital integrator with a 3-out-of-4 algorithm reduces the false-alarm rate, thus permitting the gain to be increased by 3.8 dB before the false-alarm rate is objectionable. A minimum discernible signal (MDS) of −115 dBm can be achieved with the PriMUS-400 when receiving a pulsewidth equal to a standard (37-μs) storm cell.

Range and azimuth data are collected in polar (rho-theta) coordinate format, but displayed in x-y format.

Until recently, most airborne radar displays were scanned in the rho-theta format (Fig. 6a), which has the disadvantage of non-uniform resolution over the area of display. Near the origin of the display, the data is crowded, and at the edge of the display, it is spread out much as the spokes of a wheel. With the advent of digital data storage in solid-state random-access memories, many advantages of x-y scan became practical. Some of these advantages are:

- uniform brightness and resolution over the displayed area;
- efficient deflection and high-voltage system;
- compatibility with a tv raster to combine data from other sensors and systems; and
- compatibility with the requirements of a line-screen color CRT.

A preprogrammed read-only memory steers the received signals from each transmitted pulse to the appropriate location in a random-access memory corresponding to the antenna angle and target range. Scan conversion is achieved by reading the random-access memory in x-y format, as shown in Fig. 6b. The readout is performed at standard tv rates, thus providing a flicker-free display using a conventional tv crt.

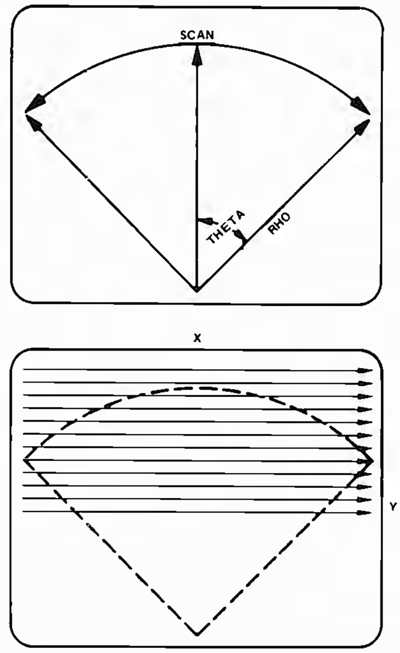


Fig. 6
Range and azimuth data is collected in polar coordinates (top), but displayed in tv-scan coordinates (bottom). Digital storage makes this display method practical and produces uniform brightness and resolution over the entire displayed area, something not possible with the polar-coordinate display.

Fig. 7
High-resolution dot pattern for range azimuth markers is difficult to produce on a 525-line tv raster. Special LSI circuit makes the dots appear as smooth lines.

The video display has high-resolution azimuth marks; it also accepts external inputs for pilot checklists and other data.

Very high video bandwidth is required to draw smooth arcs representing range marks and straight lines for azimuth marks on a 525-line tv raster. A custom large-scale-integrated circuit was developed with RCA's Solid State Technology Center. This IC provides 50-ns video pulses to generate a high-resolution dot pattern that appears as smooth lines on the display (Fig. 7). The color of these lines and marks is cyan in the weather mode and green in the map mode for good color contrast. Alphanumerics generated by a character generator identify the range marks, selected mode, and special alerts. An external video input connector allows the indicator to be time-shared for other functions such as checklist, navigation information, optimum flight profiles, and other tv-formatted data.

The antenna must have good stabilization with the high-resolution color display.

The antenna can be scanned through 120 degrees in azimuth and 60 degrees in elevation. The normal pattern is a horizontal line scan. A two-phase stepper motor drives the azimuth axis, based on command pulses from the indicator. The direction of scan is controlled by the phase relationship. A feedback signal determines when the antenna is passing the dead-ahead position and this signal is compared with the indicator command to verify synchronization. If an error exists, the radar data is blanked and the letters ANT are flashed on the screen.

To maintain a scan pattern that is fixed in space relative to the earth's surface, pitch and roll signals received from the aircraft attitude-reference system are applied to an elevation servo system. The use of two axes of freedom (typical in most general-aviation aircraft) means that the antenna elevation servo must continuously correct for the aircraft's roll and pitch. Brushless resolvers and a two-phase ac motor are used in the elevation axis servo for long life. A major improvement over previous stabilization designs has been achieved through the use of good servo design practices to achieve a high effective loop gain (K_v), which became more important when the high-resolution color display was introduced.

The waveguide slotted-array antenna used obtains 70% aperture efficiency with sidelobe levels 25 dB or more below the mainlobe. These two characteristics are extremely important to maximize the range performance of the radar and to minimize ground clutter when looking for weather.

Summary

The PriMUS-400 ColoRadar system described in this paper has introduced many new features that have led to its immediate popularity in the general-aviation marketplace. The most important feature was the introduction of a color indicator with 4 times the display resolution of previous digital storage systems. For a lightweight radar system, the 150 nautical miles of storm intensity calibration provides a capability not previously found in the most sophisticated large and expensive airline-type weather radars.

Ray Aires is Chief Engineer of Avionics Systems. Under his guidance, RCA has introduced the PriMUS-20 and -30 weather radars, which were the first to employ x-y scanned indicators providing alphanumeric information outside the radar presentation. Avionics Systems' PriMUS-21, -31, and -50 were developed specifically for helicopter applications. Most recently, he was responsible for RCA's introduction of the first weather radars with color indicators, including the PriMUS-90 for commercial air carriers and the PriMUS-300 and -400 for general aviation.

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George Lucchi has over 20 years of radar experience with RCA. His recent projects include a number of distance-measuring equipments and transponders, plus contributions to a number of weather radar systems—the AVQ-47, -21, and -30 systems plus the PriMUS series.

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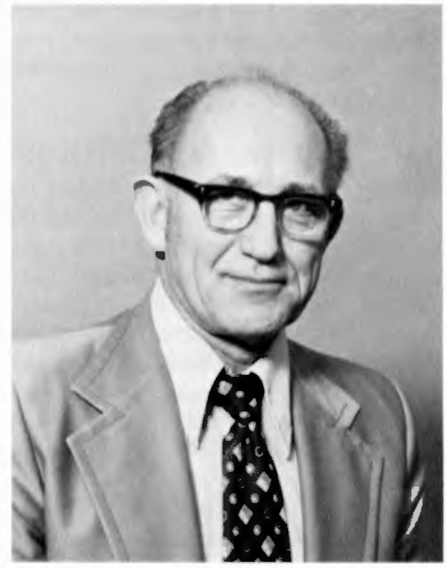

Advanced antenna design reduces electronic countermeasures threat

The expansion of electronic countermeasures has changed the ground rules for air-surveillance radar design. Low-sidelobe radar is a good example of electronic counter-countermeasures at work.

R.M. Scudder

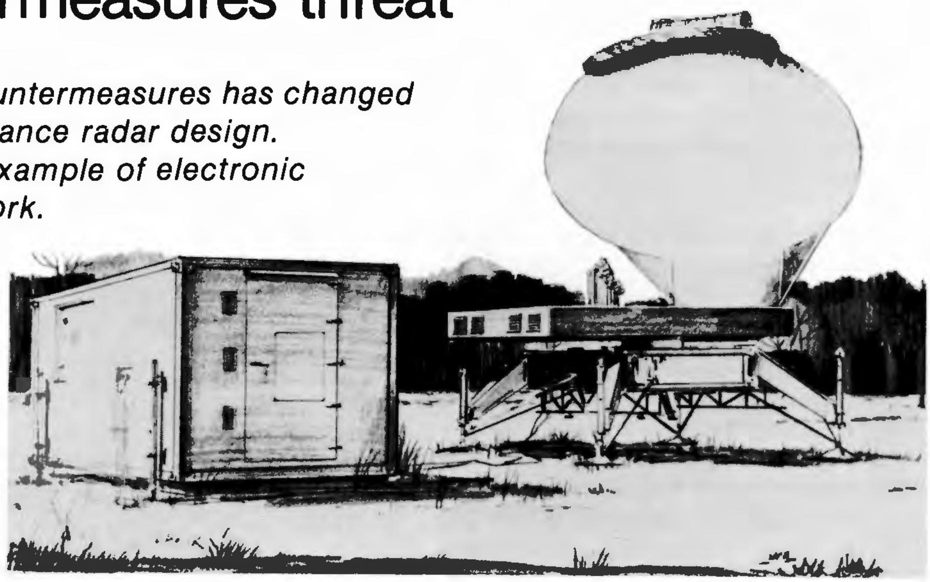

Fig. 1
Stepped-beam reflector antenna as it would be emplaced as an element of a tactical radar system. Typical rotation rate is 6 rev/m. Transportable radar shelter at left contains radar transmitter plus operator display and control functions.

The demands on radar systems are ever-changing, and nowhere is this more true than in those made on high-performance radar operations by the expanding environment of active countermeasures. The sophistication of advanced ECM (electronic countermeasures) equipment, and the recent addition of ARM (anti-radiation missiles) can, in combination, severely compromise the effectiveness of the standard surveillance radar systems built in the 1950s and 60s.

Countering the countermeasures involves two principal approaches:

1) *Signal diversity*—varying the frequency, power, polarization, or waveform of the radar signal so that the necessarily limited jamming capability of the ECM equipment receives more variety in received signals than it can counter.

2) *Sidelobe suppression*—maintaining the sidelobes that inevitably accompany the main radar beam at such low levels that the ECM equipment cannot generate effective blanking countersignals on these lobes.

Implementing these approaches takes a variety of mechanizations, any or all of which can be combined in advanced-design, sophisticated systems (e.g., multipurpose phased-array radars). Such systems, of course, are costly, usually large and therefore relatively immobile, and impose special power and signal-processing requirements. These requirements combine to preclude such an approch for tactical surveillance radars, which must be highly mobile and easy to set up and operate in forward areas.

But it *is* possible to apply ECCM (electronic counter-counter-measure) techniques to tactical systems, using straightforward modifications to standard radar design to achieve really effective operations in advanced ECM environments. This paper addresses such an approach and describes the preliminary development of a paraboloidal-reflector, stepped-beam antenna system that promises excellent radar performance in an environment of modern, advanced ECM.

Antenna design and the environment

The antenna configuration described here is compatible with the constraints associated with the operating environments for today's tactical radars. Attributes of the new antenna include:

very low azimuth peak sidelobes, and low average sidelobes;

polarization diversity necessary for all-weather operation;

electronically stepped beam in elevation, with mechanical rotation in azimuth, to provide full search capability with a single wideband signal-processing channel;

aperture size compatible with small-target detection and height estimation at extended ranges;

simple structure to assure minimum acquisition and life-cycle costs;

high reliability and maintainability, for operation in tactical environments;

ease of conversion into and out of the transport configuration; and

light weight for air transport.

Antenna description

A standard tactical-radar pedestal can rotate the antenna for azimuth scan, while the antenna rapidly steps its beam electronically up and down over 20 degrees of elevation scan.

Suitable for a radar using a single-channel, wideband signal processor, the new antenna achieves reduced ECM vulnerability primarily through reducing the magnitude and extent of its radiation sidelobes. Fig. 1 is an artist's concept of the antenna in operating condition. Major components include the reflector structure with edge-mounted shields (absorber panels), structural supports, the vertical array of dual-polarized feed-horns, and the associated waveguide interfaces with the transmitter and rf receiving equipment.

Other equipments located on the rotating structure include the unit containing the transmitter polarization switching and beam steering controls, the rf power distribution network, the circulator/transmit-receive limiter group, and the rf/if preamplifier group. All these items are located within the rf equipment housing structure, which also supports the feed and reflector structures in both the operating and transport configurations. A separate IFF (for identification friend or foe, a separate radar return coming from a transponder on friendly aircraft) antenna assembly is mounted at the top edge of the radar reflector.

Features of the antenna configuration include the following:

The reflector surface is 20 ft wide and 12 ft high, a section of a paraboloid with a 6.5-ft focal length, having its vertex at the bottom edge. The reflector-surface accuracy required for low azimuth sidelobe performance in operating environments is maintained by building the reflector as a lightweight monocoque structure. It is 10 in. deep, built in three sections, and joined by pin-aligned hook catches.

Absorber panels, at the top and bottom edges of the reflector, are designed to suppress wide-angle feedhorn spillover and/or edge diffraction around the periphery of the reflector surface.

The feedhorn cluster consists of seven corrugated horns, one protruding slightly above the paraboloidal axis, with the remainder below that axis. The feeds are positioned to provide secondary overlapping beams compatible with measurement of radar target-height data from the horizon to 20 degrees elevation. The crossover level between adjacent beams is at approximately −3 dB for each beam in the vertical cluster. Elevation beamwidths range from 1.7 degrees for the lower beams to 7.0 degrees for the highest-elevation beam. The beamwidth in the azimuth direction is less than 1.4 degrees for all beams. The feeds provide dual orthogonal-mode excitation to implement radar polarization diversity.

The microwave components, located in the rotating base structure, interface the antenna with its associated radar system.

The stepped-beam antenna system uses a combination of the orthogonal beam matrices, phase shifters, and power-distribution networks to provide both elevation beam steering and independent control of transmit and receive polarization modes.

Fig. 2 shows the system in block-diagram form. Stepped-beam steering in elevation is accomplished by commanded phase tapers that are identical for the orthogonal polarization paths. The polarization mode is selected by command of a mean phase difference between the two groups of eight phase shifters. Duplexing isolation between the transmit and receive paths is implemented by a 180-degree phase difference between the two groups of phase shifters, set immediately after the time of the transmit pulse to effectively "switch" the antenna from the transmitter channel to the receive path.

The power-distribution network provides amplitude weighting on various horns in the seven-horn group as a function of elevation beam steering position. Two horns are driven for the lowest beam, three for each of the next-higher elevation beams, and one for each of the three highest elevation beams.

Although the transmit and receive paths largely share common circuitry, they branch at a point where operation of the

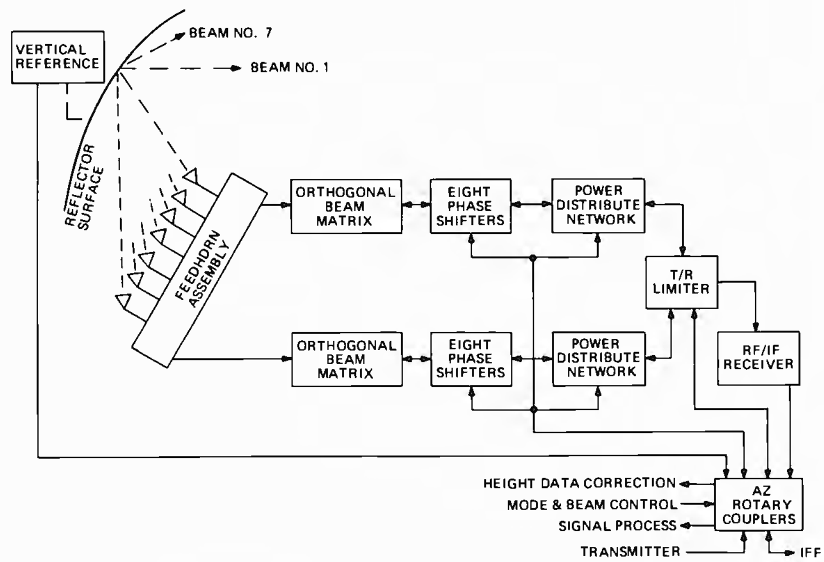

Fig. 2
Antenna subsystem block diagram indicates the general nature of the equipment housed in the rotating base assembly shown in Fig. 1. Components use rectangular waveguides, packaged to be compatible with field maintenance procedures.

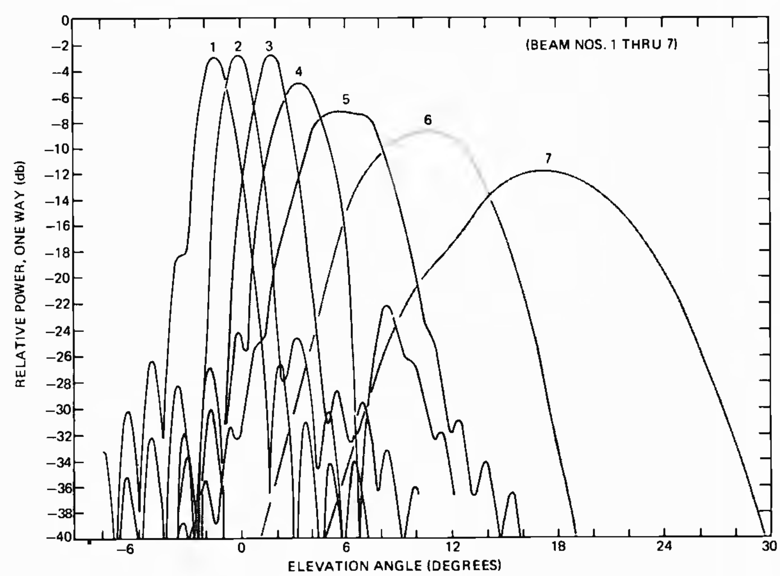

Fig. 3
Computed elevation patterns for the seven beams are shown in angular positions optimized for combined radar target detection and heightfinding functions. The beams become broader at higher elevation angle because they are created by feed assemblies displaced from the geometric focus of the paraboloid reflector.

elevation beam-steering phase shifters can permit those phasers to perform also a transmit-receive duplexing function. The antenna group includes low-noise rf and if amplification of signals for external single-channel wideband processing.

Complete receiver protection is provided by the transmit/receiver-limiter assembly. The vertical reference unit is used as the calibrated reference for measurement of target height.

For transport the antenna is disassembled and folded down. Two end sections of the reflector are unlatched from the center section and stowed flat on the base. The center section hinges down so that it, too, lies flat. The resulting transport configuration is a pallet-like assembly compatible with all modes of transportation, including C-130 cargo aircraft.

Antenna performance

Immunity of the antenna to ECM is a primary objective. The following discussion treats the measures taken to obtain a good ECCM design.

The antenna feed system was configured to provide peak azimuth sidelobes of the order of 40 dB down, while achieving the elevation beamshape required for precise target height estimation. The patterns of the antenna design were calculated using an RCA-developed computer program, DISH, a tool for observing and analyzing reflector-antenna pattern characteristics.

The elevation patterns have low sidelobes because the beams are formed by exciting adjacent feedhorns.

Elevation patterns obtained from the feed and reflector geometry were calculated and are shown in Fig. 3, which gives the elevation beam set (group) for vertical polarization. The patterns were calculated for a frequency of 3.35 GHz. The four lowest beams are formed by exciting sets of three adjacent feedhorns (the lowest beam is formed by exciting only two horns) in order to keep the elevation sidelobe levels below 24 dB and to obtain the beamwidths necessary for proper beam-crossover levels for target heightfinding functions. For example, to obtain the second-lowest beams, horns 1, 2, and 3 (Fig. 4) are excited simultaneously, with horn 2 receiving about 92 percent of the power and the remainder evenly split between horns 1 and

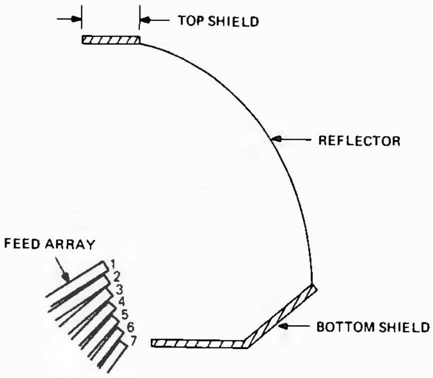

Fig. 4
Feed-reflector assembly includes several measures used to suppress wide-angle sidelobe responses in the elevation dimension. The microwave absorptive shielding reduces the radar's susceptibility to anti-radiation missiles and electronic intelligence devices.

3. Both the beam locations and crossover levels are dicatated by the required accuracy of height estimation. Elevation-pattern performance showed that, as expected, the maximum gain and minimum beamwidth correspond to a beam radiating along the axis of the paraboloid.

The azimuth patterns have a constant beamwidth and low sidelobes.

Whereas the elevation beamwidth increases as the beam is scanned in elevation from the axis of the paraboloid, the azimuth beamwidth is virtually independent of elevation beam position. This is the result of positioning the feed along the azimuth focal locus of the reflector.

In addition, the illumination of the reflector is tailored in azimuth to provide the very-low-azimuth sidelobes required for operation in an ECM environment. This constant beamwidth and low sidelobe performance is demonstrated in Fig. 5, which shows calculated azimuth patterns corresponding to beams 2, 4, and 7.

For successful operation of a radar antenna in an ECM environment, the antenna must radiate very little extraneous energy.

In other words, the antenna patterns have very low sidelobes. Low-azimuth sidelobes near the main beam were obtained by designing the feed for peak center illumination, with sharply tapered illumination toward the sides of the reflector. The edge illumination is typically −20 dB or less, resulting in peak azimuth sidelobe levels of −40 dB or lower in the absence of reflector errors or surface deformation.

Since the reflector will be fabricated as a self-supporting monocoque or honeycomb structure, manufacturing-produced surface errors will be random across the surface. The *average* sidelobe level caused by a 0.020-in. (rms) surface tolerance will

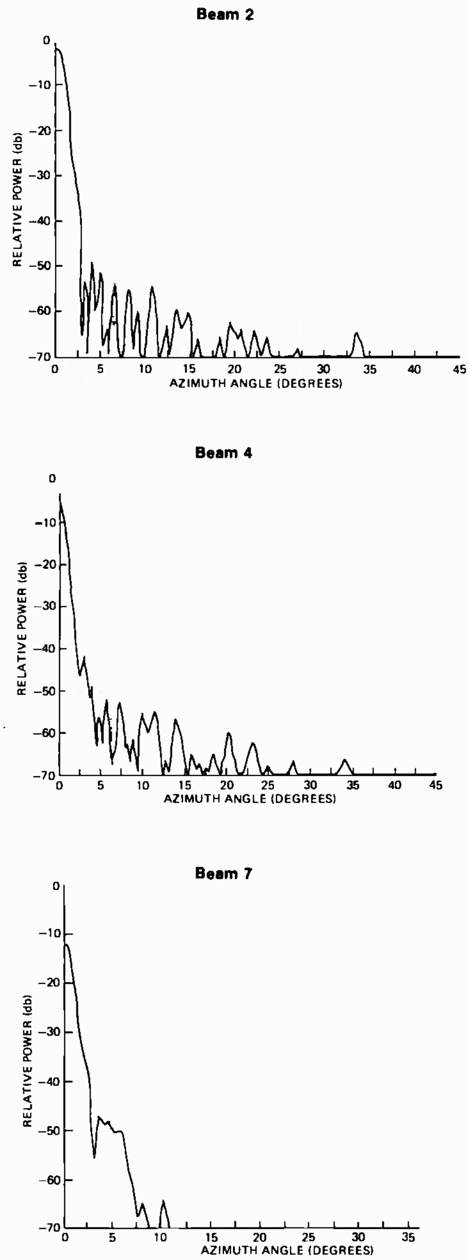

Fig. 5
Predicted azimuth patterns of elevation beam positions 2, 4, and 7 respectively. Achievement of low azimuth sidelobes is a primary objective of the antenna design. Computed patterns such as these, using the RCA simulation program DISH, guided the design to that end. Quantitatively, the objective is to provide azimuth sidelobe responses below -35 dB within 5° of the main beam, and below -50 dB outside of that azimuth angle region.

be lower than −70 dB. Wind-induced reflector deflection will lead to slightly increased sidelobe levels in the vicinity of the main beam, but for the 0.18-in. maximum deflection specified in the design, the impact on sidelobes is not significant.

Aperture blockage by the feed is often an important source of close-in sidelobes in most reflector antennas. Typically, the feed structure of a multiple-elevation-beam antenna is located directly in front of the reflector, creating an inherent blockage. As shown in Fig. 4, the feed system for this antenna is offset substantially, thereby minimizing the blockage. In the case of this antenna design, the maximum blockage area is 6 × 8 in., which results in a sidelobe level below −60 dB. The blockage contribution to close-in sidelobes is therefore negligible.

The primary contributor to wide-angle azimuth sidelobe energy is feed spillover past the edge of the reflector. In this design, spillover is controlled by a combination of directivity of the feed and reflector intercept intensity. The spillover sidelobe will be no greater than an acceptable −50 dB relative to beam peak.

Extraneous energy radiated into the conical region 45 degrees from the zenith is also caused by feed spillover. This would result in sidelobes of about −35 dB in the vicinity of the zenith. However, much of this spillover energy can be eliminated by placing an absorbing shield at the top of the reflector, as shown in Fig. 4. Suppression of spillover by this direct means has been experimentally demonstrated. Spillover energy below the bottom reflector is prevented in similar fashion, as shown in the sketch. A similar layer of absorbing material will be applied to the surface of the baseplate to make it nonreflective.

Since the reflector will have a solid, rather than a mesh, surface, no energy will penetrate the surface and produce backlobes.

Experimental results

A one-tenth scale model of the antenna verified that the desired sidelobe responses predicted by computed pattern simulations are attainable.

The model's reflector parabolic surface, with aperture dimensions of 2 ft width by

Fig. 6
One-tenth scale model verified low-sidelobe responses predicted by computer simulation. Operating frequency covers 31 GHz to 36 GHz. Test feed horns were designed to provide either horizontal or vertical linear polarization.

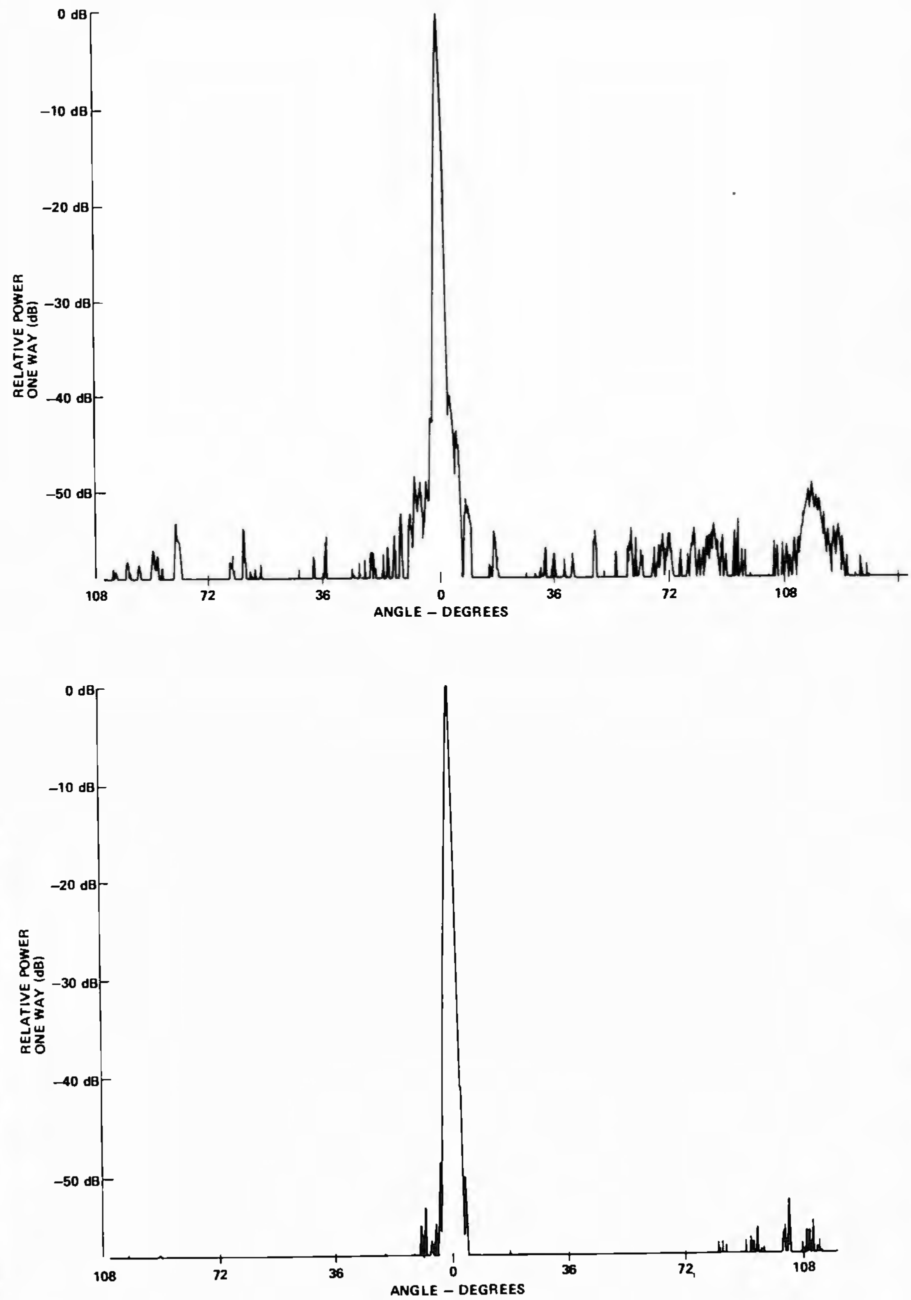

Fig. 7
Measured azimuth patterns of beam position number 4 at 33.5 GHz (top) and 36 GHz (scaled-up frequency taking model size into account) for the vertically polarized mode. These low sidelobes are typical of the key results of the development program, which verified that an antenna structure compatible with mobile, tactical environments can also be made to provide a high degree of immunity from ECM threats.

1.2 ft height, was machined from solid aluminum to a tolerance of better than 0.0015 in. rms. Fig. 6 shows the assembly of the scaled reflector, a five-horn segment of the feed group, and the absorptive shielding above and beneath the reflector, all mounted in test position.

An indoor anechoic test range was chosen as the pattern test site since it could measure antenna sidelobe responses reliably down to levels below −60 dB (this capability is difficult to obtain in most outdoor test ranges).

Fig. 7 shows vertically polarized azimuth patterns measured on the scale-model feed/reflector at two different operating frequencies, with peak near-in sidelobes below −40 dB diminishing rapidly to lower than −50 dB, in accordance with the design objectives. In general, wide-angle sidelobes are below −60 dB. These measured results correlate well with the computed pattern of beam No. 4 (shown in Fig. 5) in terms of maximum near-in sidelobe responses.

Fig. 8 shows how effective the absorptive shielding is in suppressing wide-angle elevation lobes in the zone of interest in relation to anti-radiation missiles. This pattern spans the angular region from directly overhead (at left) to vertically downward (at the right of the plot). The effectiveness of various widths of absorptive shielding at the top of the reflector is shown at the left, where upward radiation as a function of shield width is illustrated for widths equivalent to full-scale dimensions of 5 ft., 3 ft., and zero are overlaid. A nominal three-foot shield limits upward sidelobe radiation to less than −46 dB.

Implication/application of results

The overall result of this effort is an antenna design for tactical radar with: 1) wide instantaneous bandwidth (600 MHz at S-band); 2) low azimuthal sidelobes; 3) low sidelobes in a cone of 45° half-angle centered at the zenith (below −44 dB in a small region and below −50 dB elsewhere); 4) polarization diversity, including orthogonal, linear, and circular; 5) electronically steered beam over 20° in elevation compatible with one wide-bandwidth signal-processing channel.

This ECCM antenna demonstrates that, by applying design techniques specifically directed at sidelobe suppression, excellent sidelobe performance can be achieved with a reflector antenna. These techniques include: 1) much lower edge illumination than has been customary, at a modest sacrifice of aperture efficiency; 2) edge shielding to reduce the sidelobes caused by spillover at the edge of the reflector; 3) feed offset configurations that minimize blockage of the aperture by the feed structure; 4) shielding techniques that minimize high-angle radiation from the feedhorn structure.

This demonstrated capability shows the potential for the continued effective use of tactical radars of modest complexity and size—at modest cost—in an era of hostile environments for radar operations. And this potential, of course, implies even greater pressures on antenna designers in the future, to meet the inevitable demands of ever-growing sophistication and capability of ECM techniques.

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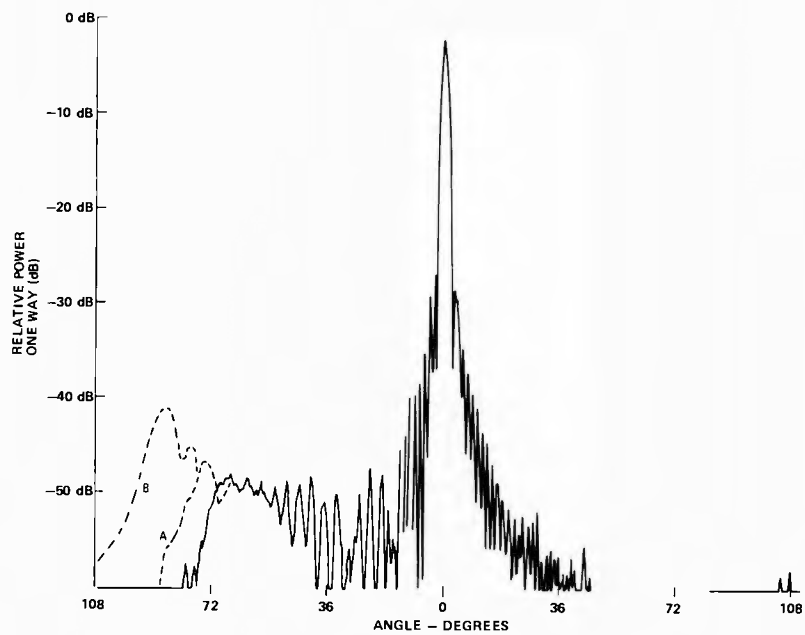

Fig. 8
Measured wide-angle elevation patterns of scale model. Strong spurious high-angle radiation increases the susceptibility of the radar to anti-radiation missiles. Most of this high-angle response is due to direct radiation propagating around the upper edge of the reflector from the feedhorn assembly. A moderate amount of shielding provides adequate suppression—dashed curves marked *A* and *B* show radiation pattern with small and no shield, respectively.

Bob Scudder has had approximately 30 years of professional experience at RCA in the design and development of antenna and microwave systems applicable to surface radars. This has included antennas associated with air-search and height-finding equipment, precision tracking radars, and phased-array antennas designed to support defense weapons systems.

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A short-range radar for measuring blast-furnace burden height

H.C. Johnson
R.W. Paglione
J.P. Hoffman

Radar's high reliability, ability to operate continuously, and lack of mechanical parts can find work in unusual locations.

To improve the control of iron-producing blast furnaces, key furnace variables must be measured more accurately and reliably. One of these variables is the height of the burden (iron-ore/coke/limestone mixture) in the furnace. Each furnace has an optimum burden height determined by operating and design considerations. Deviating from this optimum height lowers efficiency and, in an extreme case, can cause furnace damage.

Problems with electromechanical systems

Presently, two electromechanical methods are commonly used to measure burden height.

They use: 1) a bar known as a stockrod or 2) a steel cable and heavy weight assembly. Both methods measure burden height by monitoring the distance that the rod or weight travels before contacting the burden surface. These electromechanical methods seem ideally suited for an environment as severe as the interior of a blast furnace, but production experience shows otherwise. With either method, burden height measurement is inaccurate if the equipment is not operating freely or if the rod or weight contacts a fluidized region of the burden and penetrates too deeply. Even more important, both systems have a record of frequent breakdowns. Thus, the main reason for developing an alternative method of measuring burden height was to improve measurement reliability.

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System requirements

Reliability, maintainability, and accuracy were the major system requirements.

RCA and Bethlehem Steel worked together at producing a new measurement system. At the outset of the program, they established the following system requirements:

- high system reliability, to be gained by minimizing the use of mechanical components;
- easy equipment serviceability, to be gained in particular by eliminating the need for components that are installed inside the furnace;

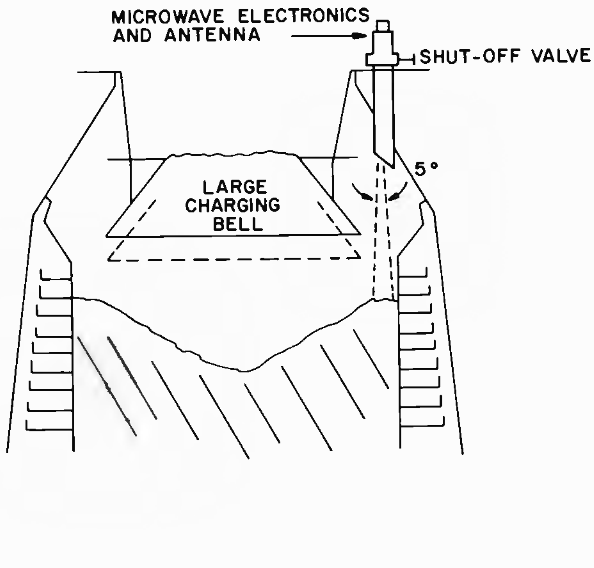

Fig. 1
Microwave measuring system, placed at the top of the blast furnace, avoids temperature extremes and problems with mechanical contacting systems. Blast-furnace burden (iron-ore/limestone/coke mixture) enters furnace through the top hopper, past charging bell and fills furnace as shown. Radar measures distance to burden surface within 6 inches.

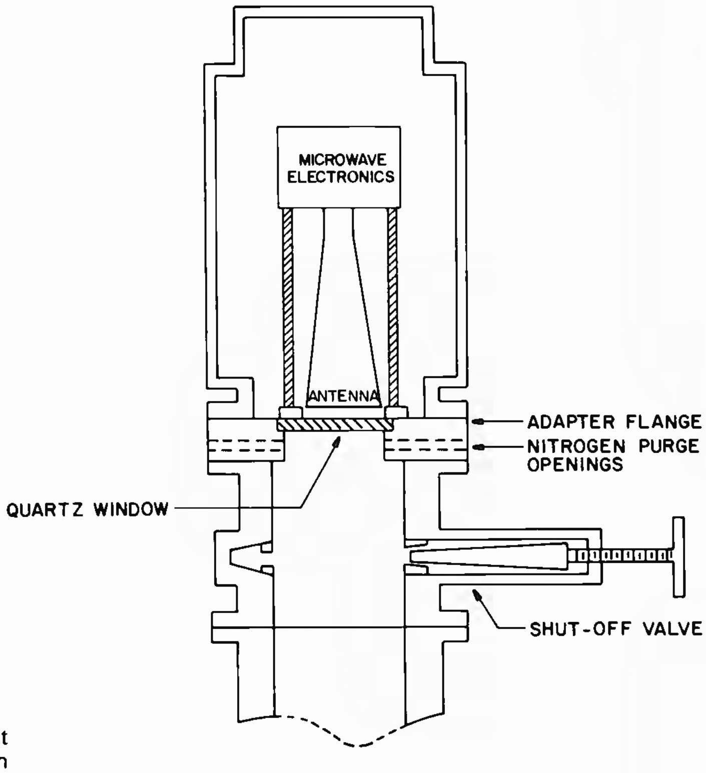

Fig. 2
Microwave instruments are external to the furnace and protected by the microwave-transparent quartz window and continuous nitrogen purge.

- measurement accuracy of ±6 inches;
- measurement range up to 35 feet from the furnace charging bell, as opposed to 15 feet or less for the conventional stockrods;
- fully automatic operation; and
- continuous operation (the mechanical stockrods must be raised above the charging bell while material is being dumped into the furnace).

These requirements led to a radar-based measuring system.

RCA and Bethlehem jointly developed a prototype measurement system; it was initially constructed and tested at RCA Laboratories in 1976 and then installed and evaluated on the "D" blast furnace at Bethlehem's Burns Harbor, Ind., plant. Initial startup problems were overcome and the equipment continues to be used for routine control of burden height. Based on the successful operation of the prototype, RCA developed two improved production systems, which were installed on the "C" blast furnace at Burns Harbor. They are currently being used in production to control furnace burden height. Design details of the production systems will now be described, in addition to results of the prototype evaluation program.

Mechanical equipment

The microwave instruments require a clean, dirt-free opening to the furnace interior and a protective enclosure for the microwave circuits.

The furnace had to be modified slightly for the microwave system. Fig. 1 is a simplified exposed view of the upper section of "C" blast furnace. Four stockrod pipes are located at 90° intervals around the conical section of the furnace exterior. One stockrod pipe houses a mechanical stockrod, the pipe located 180° from the mechanical rod is unused, and the remaining two pipes are used for the ranging radars.

While the furnace was down for a reline (a cleaning and resurfacing procedure done to the inside of the furnace approximately every five years), the following items, shown in Fig. 2, were added to the existing stockline indicator pipes:

- a furnace shut-off gate valve;
- an adapter flange with a quartz window;
- provisions for purging the window with nitrogen gas; and
- an enclosure to protect the microwave electronics and antenna.

The quartz window is transparent to microwaves and is required to pass microwave signals into the furnace interior. Nitrogen gas is introduced immediately below the window, through ports in the adapter flange, to prevent the buildup of carbon and iron dust deposits on the window.

Electronics

The electronic equipment consists of three basic subsystems;

1) *microwave electronics and antenna,* installed in a stainless steel enclosure on a rebuilt stockline indicator pipe;

2) *processing electronics,* also located on the furnace top and installed in a stainless steel enclosure; and

3) *display and computer interface electronics,* located in the furnace control room.

Fig. 3 shows the three electronic systems before installation.

The cw-fm (continuous-wave frequency-modulated system) determines burden range by measuring the instantaneous difference in frequency between the transmitted and received signals.

Fig. 4 illustrates the principle underlying the method of measuring burden height. As shown, a microwave oscillator is modulated in a manner that produces a swept transmission of frequencies. At some time, t_o, a frequency, f_1, is transmitted. This signal travels through the space in the furnace until it strikes the burden surface and is reflected back to the microwave electronics. This signal arrives at some time, t_1. However, now the transmitted signal has changed to a different frequency, f_2. The difference in frequency, f_b, between f_2 and f_1 is proportional to the range traversed by the signal and is given by:

$$f_b = 4R\,\Delta f\,f_m/c \qquad (1)$$

where

f_b = beat frequency or $|f_2 - f_1|$ (Hz)
R = range to the target (ft.)
Δf = swept frequency bandwidth (MHz)
f_m = modulation frequency (Hz)
c = 983.573 (ft.-MHz); speed of light

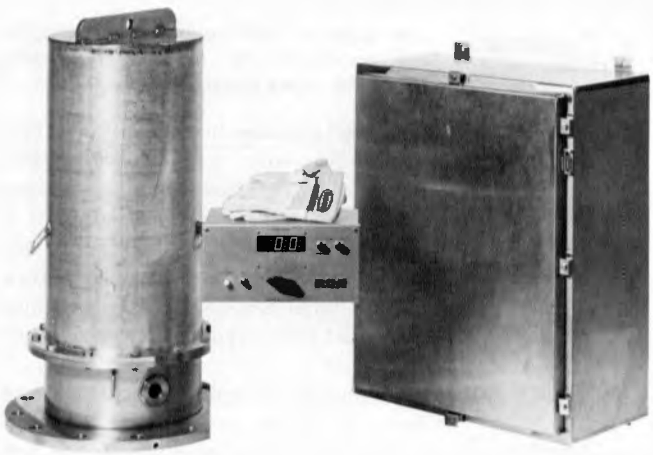

Fig. 3
System has three major components—microwave electronics/antenna enclosure (left) and signal-processing enclosure (right), which are installed on the furnace top, and display enclosure, which goes in furnace control room.

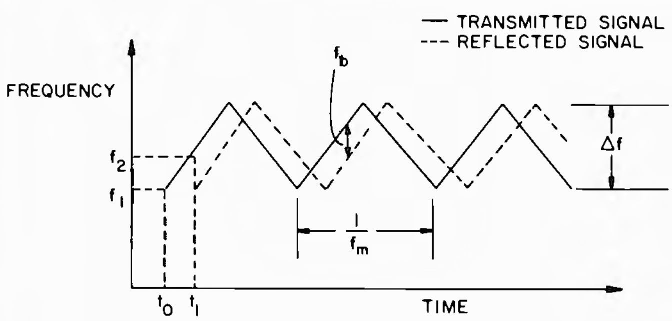

Fig. 4
Continuous-wave frequency-modulated system determines range by measuring the instantaneous difference in frequency between the transmitted and received signals. Because signal frequencies vary with time, frequency offset of reflected signal will depend on the time the reflected signal takes to return.

Fig. 5 is a block diagram of the microwave circuitry that generates and acquires the difference frequency signal. The modulated microwave signal is passed through a directional coupler and circulator and is transmitted to the burden surface through a 22-dB-gain waveguide horn antenna. A single antenna is used to both transmit and receive the signals. The mixer produces an output signal with a frequency, f_b, equal to the difference in frequency between the instantaneous transmitted and received signals.

Fig. 6 is a simplified block diagram of the entire radar system. All the electronics, including the microwave oscillator, employ high-reliability solid-state devices.

One difficulty often encountered in using high-accuracy, close-range radar systems is that any drift in the modulation parameters will produce an error in range.

To prevent such drift errors, calibration circuits, shown in Fig. 6, are incorporated into the production version. They are designed to maintain accurate range measurements regardless of modulation-parameter (f_m and Δf) drifts caused by component aging or temperature variations. These circuits operate as follows: a portion of the transmitted signal is directed through a separate coupler-mixer-circulator and sent down a coaxial delay line of fixed length that has been shorted at the far end. The signal is reflected at the shorted end of the cable and returns to the mixer, where it is combined with a portion of the transmitted signal. This produces a beat frequency determined by Δf and f_m. This "calibration" beat frequency is divided down digitally by the signal-processing circuits and used as a gate to count the target beat frequency. A change of the modulation parameters results in a corresponding change of both the calibration and the target beat frequencies. Since the change in the calibration beat frequency produces a corresponding change in the counter gate interval, the target frequency measured by the counter remains constant.

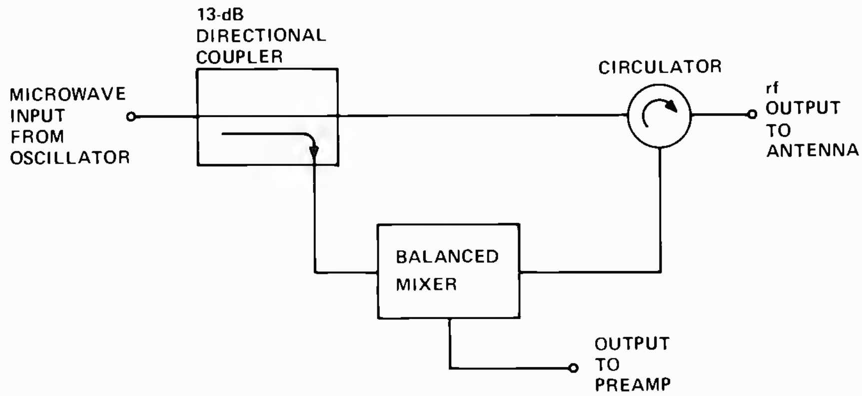

Fig. 5
Microwave circuitry sends and receives signals through same antenna, then produces frequency-difference output in mixer.

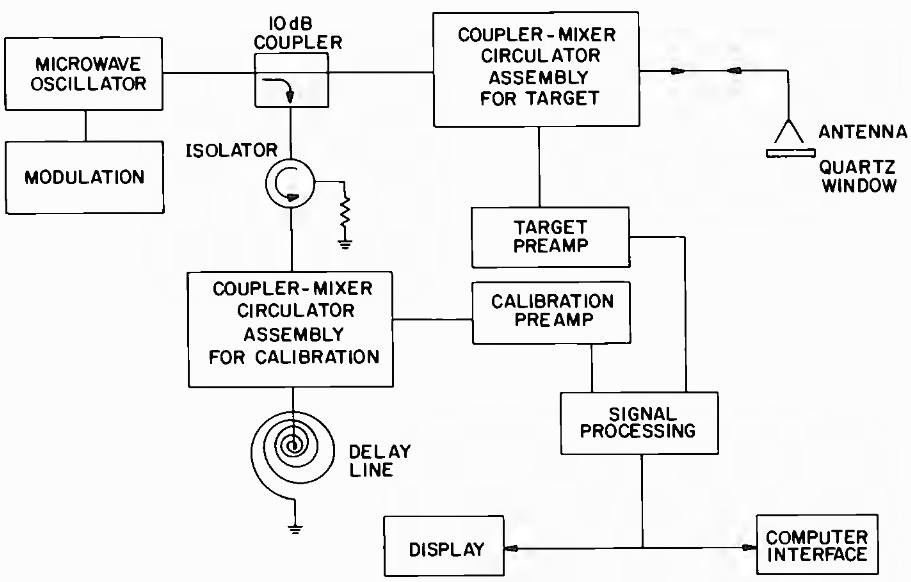

Fig. 6
Entire system incorporates microwave circuitry of Fig. 5, calibration circuitry to avoid problems with component drift, and separate signal-processing and display/interface electronics.

The calibration preamp includes a bandpass filter with 3-dB gain points at 94 and 109 kHz. The modulation parameters can therefore drift as much as 15% without affecting the measurement accuracy. The actual delay for the shorted coaxial line is 151.5 ns, which corresponds to a nominal frequency of 102 kHz.

The target preamp includes a bandpass filter with 3-dB gain points at 12.5 and 40 kHz. These frequencies correspond to a range between the large charging bell in its open position and a stockline of approximately 35 feet. The signal-processing circuits are shown schematically in Fig. 7. These circuits are contained in an enclosure that is also mounted on the "furnace top" next to the microwave components enclosure.

The target and calibration preamp outputs are connected to tuned-gain-response amplifiers in the electronics enclosure.

The target amplifier includes a 40-kHz low-pass filter with a 6-dB/octave gain response in the passband. This shaped response compensates for the fall-off in return-signal amplitude that occurs with increasing burden distance. The calibration amplifier is a 90-kHz high-pass filter with a flat gain response in the passband.

A portion of the amplified signal from each amplifier is used as a measure of return-signal amplitude. These signals are converted to a dc voltage and compared to preset threshold values by the signal-level detector circuits. The output of the calibration signal-level detector is used as an operational check for the system and the output of the target signal-level detector, which varies considerably during normal operation, is used as a squelch.

The target and calibration amplifiers connect to target and calibration phase-locked loops (PLL). The calibration PLL is a single loop with a long time constant to track the slowly varying calibration frequency. The target PLL has two series-wired loops with shorter time constants.

The output of the calibration PLL and the target PLL are connected to the divider-counter circuit. The target frequency is divided by three and counted over a gate time interval determined by the calibration frequency. The calibration frequency is divided by an adjustable constant ranging between 41160 and 49096. This produces a gating rate between 1.9 and 2.7 Hz, depending on the modulation parameters. The total number of target pulses counted in this gate interval is equal to 100 times the range in feet from the microwave receiver to the burden surface.

The three most significant digits are transmitted in BCD format to the control-room display.

Although these BCD digits represent the range in feet from the microwave receiver to the burden surface, the furnace operator generally is interested in knowing the distance in feet from the large bell in its closed position to the burden surface. This distance reading is developed in the display enclosure by digitally subtracting a user-specified fixed distance from the total range distance. This offset distance is determined by the furnace geometry and normally is between 15 and 25 feet.

The display enclosure also contains a stockline command circuit, which compares a user-selected burden level with the measured level. When the burden level falls below the user-selected level, the command circuit sends the furnace computer a signal requesting that more burden materials be added to the furnace. The furnace operator may select burden levels between 5 and 10 feet in steps of one foot.

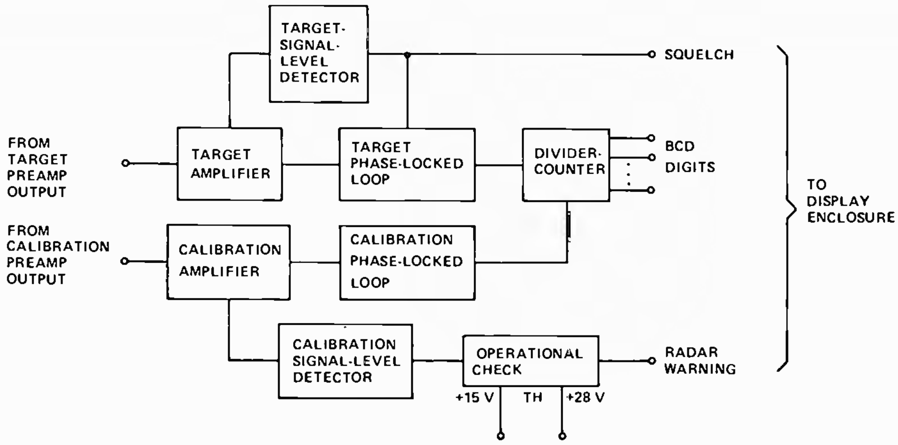

Fig. 7
Signal-processing circuits are also mounted at furnace top. Calibration works by automatically scaling the indicated target range by the ratio of the true to indicated delay line range. Target preamp is tuned to compensate for lower returned-signal amplitude at greater measuring distance.

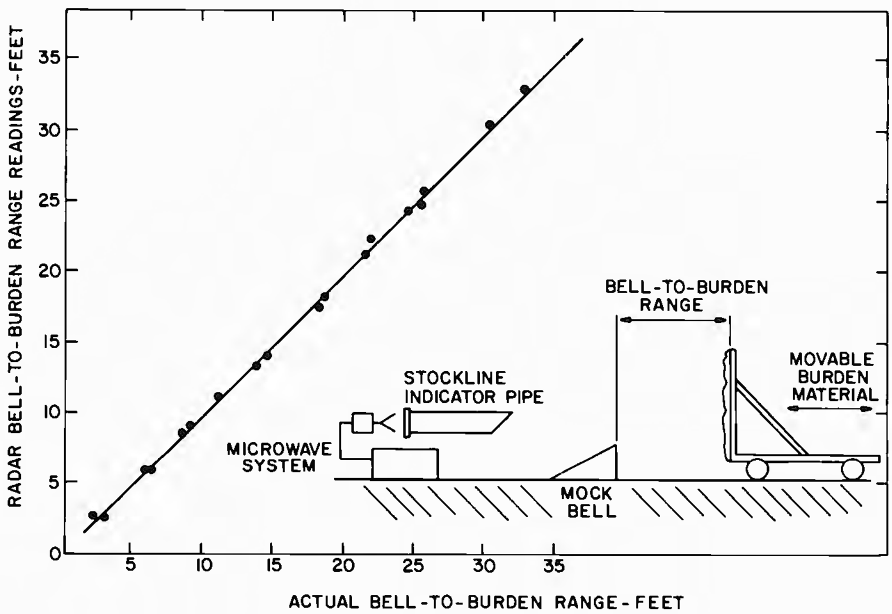

Fig. 8
Experimental setup showed that microwave system worked within the desired 6-in. accuracy over the 35-ft. range.

Evaluation of the prototype system

The six-inch accuracy goal was met, and the units have operated reliably so far.

Following construction, temperature and measurement-accuracy tests were conducted on the prototype system at RCA Laboratories before shipping the equipment to the Burns Harbor plant. Measurement accuracy was determined by constructing a horizontal target range to simulate the physical geometry inside the furnace. Fig. 8 shows this experimental setup together with test results. For these trials, a pipe of the same size and shape as the furnace stockline indicator guide-pipe was modified to accept the quartz window. Sheet metal, placed approximately 16 feet from the antenna, simulated the large charging bell. Samples of burden were attached to a movable 6-foot-square vertical surface. The trials conducted with this setup showed that the microwave distance measurements agreed with the actual distances to within the desired 6-in. accuracy over a range up to 35 feet from the bell. For the temperature trials, the range readout was monitored while equipment temperatures were varied from −20 to +140° F, which is the expected range for the externally mounted radar unit. The variations in range readings, at a range of 30 feet from the bell, were less than 3 inches over the entire temperature range.

Following the trials at RCA, the equipment was installed on the Burns Harbor "D" blast furnace. After initial equipment debugging, the equipment was calibrated and production evaluation was conducted. Although a rigorous determination of burden-height measurement accuracy was not possible, because there was no accurate independent reference in the furnace, a practical estimate of the accuracy was obtained by comparing the microwave measurements with mechanical stockline measurements averaged over many charging cycles and under various furnace operating conditions. Fig. 9 shows typical results obtained from the mechanical indicator and the microwave equipment during eight consecutive burden charges. The first three recordings show rapid burden movement, while the remaining five show slower movement. On the fifth recording, a small burden "slip" of approximately one foot in height occurred. Based on the data from the experimental trials at RCA and the analysis of operating data of the type shown in Fig. 9, we judge that the equipment indicates burden height within approximately 6 inches of actual burden height.

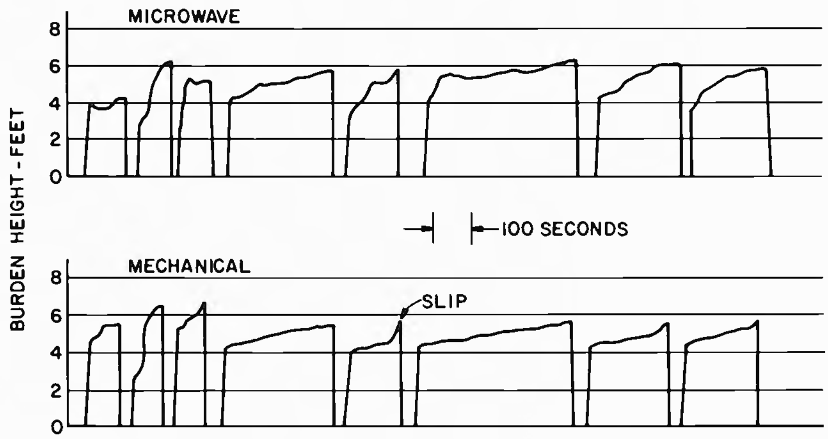

Fig. 9
Comparison of microwave and mechanical systems used in same furnace shows good agreement. Burden height is taken as the distance from the large charging bell to the burden surface. Burden "slipped" in fifth trial shown here.

Acknowledgments

Grateful acknowledgment is given to L.M. Zappulla, E. Mykietyn and J.E. Brown of RCA Laboratories and to G.R. Crossley, W.E. Swan and T. Koselke of Bethlehem Steel for their many constructive contributions to this effort.

Bob Paglione has ten years of experience in the microwave field. He is now working with rf and microwave equipment for heating biological materials. Besides designing numerous microwave components, he has also developed a computer-controlled variable mismatch used in designing solid-state microwave amplifiers.

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Henry Johnson has 19 years of experience with the Microwave Technology Center. His recent work has centered on commercial radar applications—besides the blast-furnace radar project described here, he has also worked on collision-avoidance radars and a microwave speed sensor for locomotives.

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John Hoffman has a background in electrical engineering and 17 years of experience with Bethlehem Steel's Research Department. His recent work has centered on the development of instrumentation for blast-furnace applications. Examples include the development of infrared imaging equipment to measure temperature distributions, tests involving the use of neutron gages to measure coke moisture, and participation in the development of the microwave equipment described here.

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Authors Paglione (left) and Johnson with the microwave electronics and antenna subsystem for the blast-furnace radar. Coil of coaxial cable at top is for calibration, rf/transmitter electronics are at center, and transmit/receive antenna is at bottom.

Microcomputers for radar systems

Radar designers are using microcomputers to distribute computer-processing load throughout their systems for lower cost, improved thruput, greater versatility, and easier system development.

B.D. Buch | S.L. Clapper | R.J. Smith

General-purpose digital computers have been used to control multifunction radars for the past ten years, but not without problems. In particular, the need for extensive software development and its control have been very costly. One alternative is to develop special-purpose hardware; however, this alternative is also costly with the additional drawback of inflexibility. Microprocessors offer a third alternative.

Special-purpose programmable microprocessors have already been used in radar for such functions as coordinate conversion. Antenna-array beam steering and tracking also have been prime candidates for microprocessor-based implementation. Removing such functions from the general-purpose computer and distributing them promises several benefits:

- *Lower cost*—a smaller general-purpose computer can be used. Removing well-defined computational functions permits more computer resource for control and decision processing. This also implies the use of higher-level command languages in the general-purpose computer for reduced software cost.
- *Higher traffic rates*—total processing capability is increased by adding more special-purpose processors.
- *Expandability*—the system can be upgraded to higher traffic rates by adding more special-purpose processors.
- *Software/firmware management*—the system partitioning forced by distributing the processors reduces the size of the large re-entrant program resident in the general-purpose processor. Each special-purpose processor is identified as a radar function, and design review techniques for firmware similar to those for hardware can be instituted.

Although a distributed processing approach solves some of the problems associated with controlling a radar by a general-purpose computer, new problem areas arise because a gap exists between the microprocessor as an LSI chip and its actual realization as hardware and firmware in a system. LSI microprocessors represent complex subsystems, but they require supporting hardware and software to become microprocessor-based systems.

In considering a microprocessor* for a particular application, several factors must be evaluated:

- *Speed*—Is the microprocessor fast enough for the application?
- *Word size*—Does the microprocessor have the required precision?
- *Architecture*—How is the microprocessor system best configured for the application?
- *Interface*—How is the processor interfaced with other system components (memories, control registers, busses, etc.)?
- *Packaging*—How can the microprocessor system functions be packaged to be consistent with existing packaging systems yet be flexible enough for future systems?
- *Programming*—Does sufficient support exist so that the microprocessor system programming can be performed?

*The terms microcomputer and microprocessor are often used interchangeably, yet there are important differences in their meanings. A microprocessor is the small central processing unit (CPU) that performs the logic operations in a microcomputer system. In the microprocessor or CPU, instructions are decoded, arithmetic and logic operations are performed, and timing signals are generated. However, much more hardware—such as memory, a clock, and interface circuits—may be necessary for full-scale "computing." This additional hardware, in conjunction with the microprocessor, is called a microcomputer.

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MSR's approach to distributed processing

Recent efforts at MSR have addressed the development of the operational elements (hardware and software) required for distributed processing in radars.[1] The first step in this development is the selection of a microprocessor family; the second step is partitioning the designs into functional modules that can be used with each other in different ways so that a given requirement can be met with a microcomputer matched to that need.

The questions of speed, word size and interface have been considered versus the application requirements, and the hardware approach developed is based on bit-slice functional modularity. We use a bit-slice bipolar microprocessor (Advanced Micro Devices, Type 2901) for speed, and other functional modules (RAM, PROM, bus interface, etc.) which can be interfaced and configured for word size in a variety of processing architectures as a function of the application.

Six functional modules have been identified and implemented.

The *microprocessor* module uses four AMD type 2901's in a 16-bit microprocessor module. The module is designed to be a 16-bit slice so that a 32-bit processor can also be configured. The module uses seven other LSTTL (Low power Schottky TTL) MSI/SSI devices and dissipates approximately 4.0 W of power.

The *microprogram PROM* module is a 512 word × 40 bit PROM (programmable read-only memory) to hold microprograms. It consists of 17 bipolar devices and dissipates approximately 4.3 W of power.

[1] Buch, B.D.; Clapper, S.L.; Smith, R.L.; "Bit-slice module set for microcomputing"—*private correspondence*.

The *macroprogram PROM* module is a 2k word × 16 bit PROM used to hold the macro-level program. It consists of 10 bipolar devices and dissipates approximately 5.1 watts of power.

The *RAM* module is a 1k word × 16 bit RAM (random-access memory). It uses 16 CMOS/SOS RAMs for optimum speed/power tradeoff and three bipolar devices (19 devices total). The typical power dissipation is estimated at 0.2 W.

The *bus interface* module contains tri-state registers and drivers and is used to "hold" the various system configurations together. It consists of 14 LSTTL devices and dissipates approximately 1.0W.

The goal is to incorporate high-density state-of-the-art packaging techniques with no loss of generality.

This goal was met by implementing the functional modules on 3.8 × 1.78-in. ceramic substrates with active devices enclosed in leadless hermetic packages.

The large packages in Fig. 1 are the leadless carriers holding the 2901 microprocessors. The smaller packages are the MSI/SSI devices. Each module is implemented as a large 72-pin (36 pins/side) dual-in-line package and is made to be mounted on standard 0.3-in. centers. This type of module can be used on either a printed-circuit board or wire-wrap board.

Software/firmware development

Since the hardware module set is subject to change as new devices are introduced, the main challenge is to produce firmware that does not become obsolete as the hardware changes. This has been accomplished through the development of "architecture independent" support software used in conjunction with a PDP 11/03-based microcomputer development system.

Richard Smith has 15 years experience in design and development of radar signal processing architectures. He was responsible for development of microprocessor-based radar applications for beam-steering control, tracking, coordinate conversion, and servo loops.

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Bruce Buch has contributed to design and development of special purpose microcomputer systems since 1975. He is presently engaged in developing signal and multiprocessor architectures for beam-steering control of phase array radars.

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Stephen Clapper has been involved in design and development of special purpose microcomputer systems since 1975. He has also contributed to various signal-processing designs since 1969.

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Authors (from left to right) **Stephen Clapper**, **Richard Smith**, and **Bruce Buch.**

Program development using the actual hardware is accomplished by using macro-ROM and micro-ROM simulator modules as shown in Fig. 2. These modules are loaded from the PDP 11/03 microcomputer but are functionally and mechanically identical to the micro-ROM and macro-ROM modules used in an actual application. The difference between the simulator modules and actual modules is speed. The simulator modules are slower since an instruction decode requires that control bits be obtained from the floppy disk.

Another approach to program development is to use a simulator. Simulators for 16- and 32-bit microcomputer systems have been developed to run on any PDP 11 minicomputer.

Microcomputer system

Although the hardware modules developed at MSR allow for architectural variations, many applications in radar systems can be satisfied using a standard processing architecture. The 16-bit microcomputer of Fig. 3 represents a general-purpose architecture that can be tailored to a specific application by using microcode and/or by adding special purpose processing hardware (e.g., multipliers). A 16-bit microcomputer with 2k words of macroprogram and 1k words of data RAM requires 12 modules total. The architecture can be extended to form a 32-bit microcomputer by adding more modules. A 32-bit microcomputer with the 2k words of macroprogram PROM and RAM may be added if required. The microcycle time of this 16/32 bit microcomputer is 250 ns with a typical register-to-register add time of 500 ns at the macro (assembly language) level. Provision has been made for microprogrammed two's complement multiply and divide. The 16-bit multiply requires 19 microcycles or 4.75 μs and the 16-bit divide requires 29 microcycles or 7.25 μs.

Although the microcomputer has been designed so that it can be tailored for a particular application using microcode, a general-purpose assembly-level instruction set has been implemented for branching, memory/memory moves, and memory/register moves. These instructions are modeled (not exact emulation) after the PDP-11 instruction set; actually, they form a subset of the PDP 11 instruction set and use the same assembler mnemonics so that a source program can be written on a PDP 11 and run on the microcomputer.

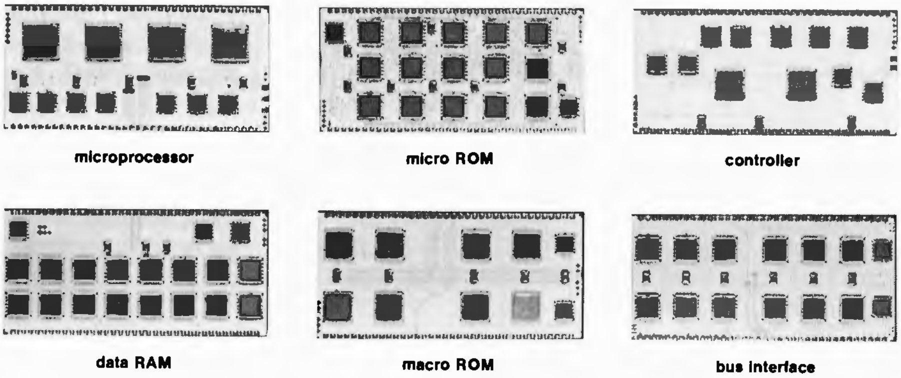


Fig. 1
Functional microcomputer modules. This approach permits use of advanced packaging technology to incorporate high density packaging without loss of generality.

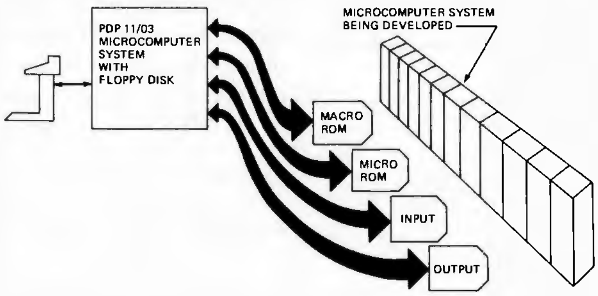


Fig. 2
Microcomputer development system. This system uses standard I/O ports to create a test bed for performing macro- and micro-level programming for the basic module architectures.

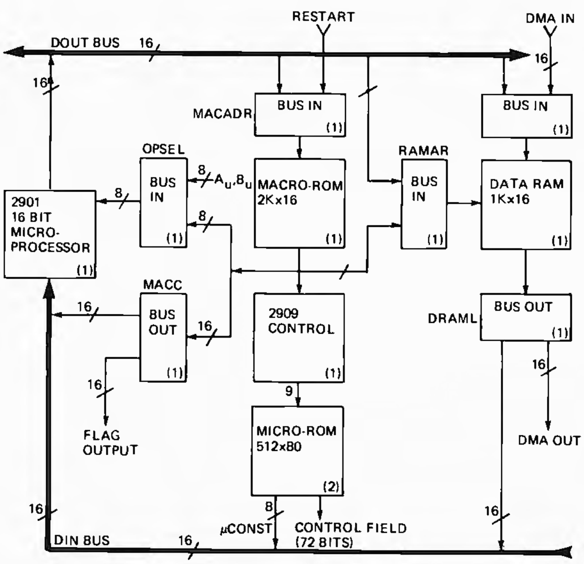


Fig. 3
Basic microcomputer architecture. This drawing shows the module types and quantities needed (in parenthesis) to implement a 16-bit microcomputer. Note that the modules labeled BUS IN and BUS OUT are actually one module type, the BUS INTERFACE module. The major functions in the 16-bit microcomputer are: 2901 16-bit microprocessor (CPU function); an operand select function (OPSEL) used to select 2901 register file addresses from either micro or macro program; a macroprogram address register (MACADR); a MACRO-ROM module for macroprograms; a 2909 control register (RAMAR) and DATA RAM module; two holding register/driver modules (DRAML) for RAM data (also DMA input/output); and a register/driver module for transferring 16-bit constants from the macroprogram ROM to the 2901 input (MACC).

Modular firmware concept

The basic microcomputer of Fig. 3 is the focal point for using hardware modules as a building block to construct "computer-like" hardware designs. A similar concept applies to the firmware.

Many radar algorithms are common to many radar systems. If these common algorithms can be identified and microprogrammed, elements of a radar-processing language can be evolved. The firmware concept entails development of many special-purpose microprograms found in radar systems, so that the system designer can select those microprograms useful to his application. Once PROMs are burned in, he then essentially has a special-purpose computer for his unique application.

Applications

Several radar functions have been identified for microcomputer implementation. As summarized in Table I, these fall into three categories: off-loading main computers by processing well-defined functions in special purpose microprocessor systems; replacing functions now performed in a minicomputer where the general-purpose nature of a minicomputer has more processing power (and cost) than required; and hardware reduction by using microprocessors to perform functions traditionally done with hardware. A few specific examples are described below.

Coordinate conversion can be performed in less than 3 ms using a microcomputer.

A basic computational task in a radar system where the antenna is located on a moving platform is to convert the variable platform coordinates to a fixed reference coordinate system. This task can be delegated to one of the system computers. Since the coordinate conversion must be updated at frequent intervals (i.e., 5 ms) and the computations involve generating sines and cosines, considerable CPU time is consumed. Furthermore, operation with large word size (i.e., > 20 bits) is required. If this task can be removed from the central computer and done with a bit-slice microprocessor, the central computer loading can be reduced significantly.

In the coordinate conversion process, a matrix based on the variable platform coordinates must be multiplied with a reference matrix. Fig. 4 shows the typical

Table I
Microprocessor application to various radar system functions.

Application	*Function*
Off-loading main computers	Coordinate conversion Track functions Radar return processing Command output processing
Minicomputer replacement	Displays Checkout and monitoring Servo computers Fire control computers
Hardware reduction	Beam steering controller Post processing (monopulse, interpolation, etc.) Input/output buffer to signal processor Data formatting (asynchronous data collection) Data bus controllers ("smart" busses)

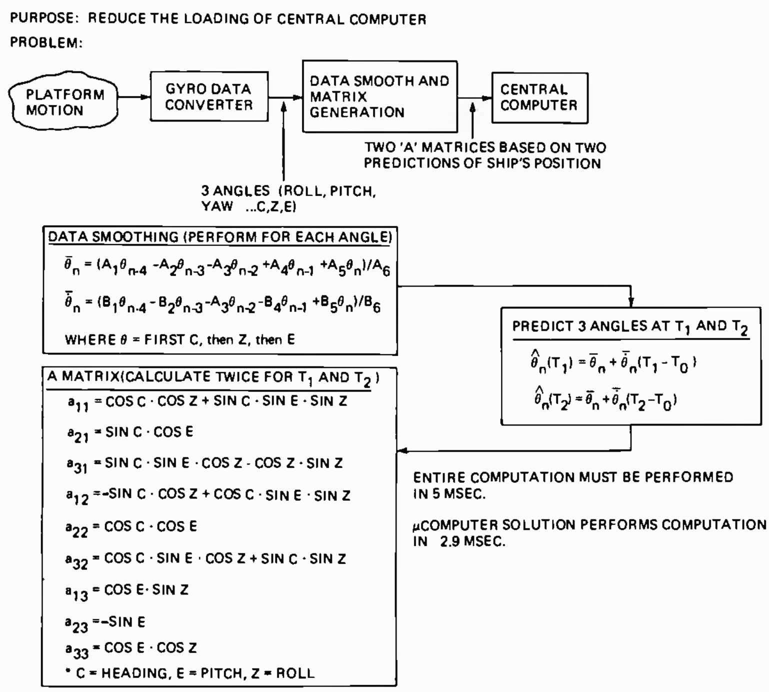


Fig. 4
Coordinate conversion problem. Variable motion of the antenna's platform must be converted to fixed reference coordinates and updated every 5 ms.

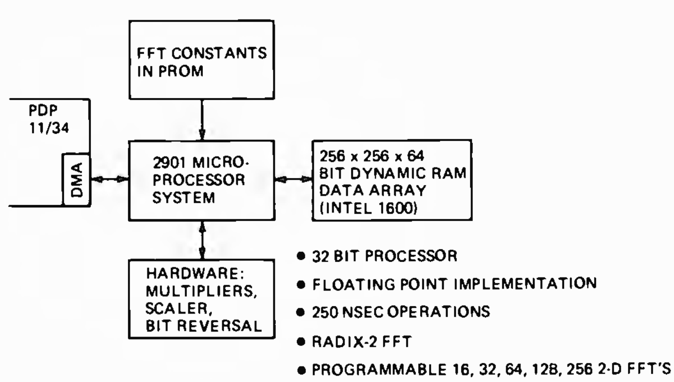


Fig. 5
Two-dimensional fast Fourier transform performed via microprocessor.

calculations required. Three position angles (roll, pitch, yaw) are digitized, then smoothed using a polynomial filter. The rate of change for each angle is also determined so that the platform position can be predicted at some future time (T_1 and T_2). The predicted position angles are used to calculate two 'A' matrices. These two matrices are then multiplied with the reference-coordinate matrix.

A bit-slice microprocessor system has been used for this type of coordinate conversion process in the AEGIS Air Defense System. This processor represents an early bit-slice design—a 24-bit implementation using standard AEGIS modules. The microprocessor is the AMD 2901 and has a 380-ns clock time. This allows computation of a 24-bit sine in 98 μs. This processor represents a significant off-loading of one of the AN/UYK-7 system computers.

Data Formatting Unit (DFU) is another bit-slice microprocessor implementation in AEGIS.

The Data Formatting Unit processes the interfacing data between the ship's data sensors and the command computers. The function of this processor is to gather asynchronous data (e.g., 1, 2, and 3 bits at a time) from the various ship sensors, place the data into standard formats (e.g., 16- or 24-bit words), and , upon command, transfer the formatted data to the central command and decision computer. This processor is the same basic AMD 2901 implementation as the AEGIS coordinate converter.

Microprocessors are being used to speed up the two-dimensional fast Fourier transform for antenna pattern measurements.

Testing and analysis of phased array antennas requires far-field pattern measurement. One technique for doing this is to take near-field measurements and transform these near-field samples to far-field patterns using a two dimensional (2-D) fast Fourier transform (FFT). In testing the phased array, a large amount of data is collected and the requirement exists for many 2-D FFT computations. This requires considerable computer processing, and results in a long delay between measured data and processed data used for analysis. One approach to reducing this time is the implementation of a bit-slice microprocessor system, microprogrammed to perform the FFT algorithm. This FFT processor is used in conjunction with a minicomputer (PDP 11) as shown in Fig. 5.

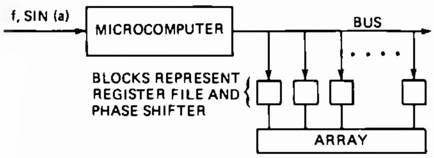
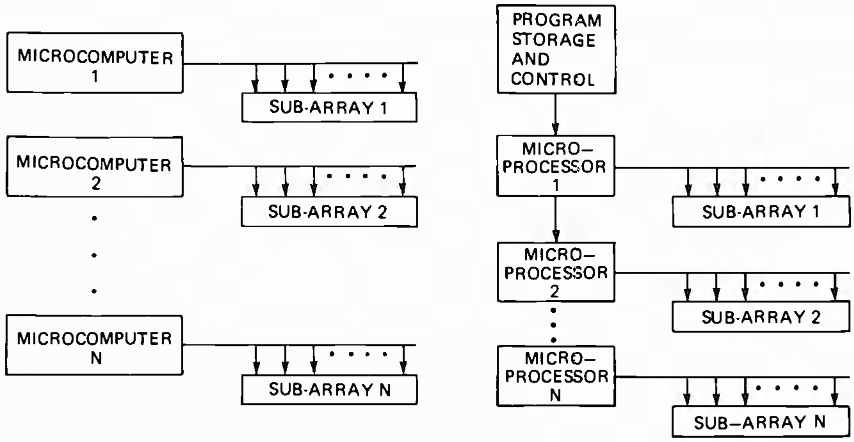


Fig. 6
Phased-array-antenna beam steering via microcomputer.



a. **Multicomputer** beam steering control. b. **Multiprocessor** beam steering control.

Fig. 7
New beam positions can be computed more rapidly if the array is partitioned for separate loading.

Since the processing is two dimensional, a large random access memory is required. Furthermore, special-purpose hardware such as TRW's 16×16-bit multiplier is employed to speed up the radix-2 FFT calculations. Communication between the FFT processor and PDP 11 computer is via a direct memory access (DMA) channel. This application is a good example of how the basic microcomputer of Fig. 3 can be tailored with special-purpose hardware and microprogramming to implement a very specific hardware function.

An approach for microprocessor steering of a phased array has been developed and proposed for future shipboard systems.

The technique used incorporates a "read 'A' - while write 'B' " type register file at each phase shifter. This enables the array to use the phase words for transmit and receive during radar dwell period N while the bit-slice microprocessor microcomputer is loading the phase words for dwell period $N+1$.

Since the loading of the phase-shifter storage elements is done sequentially, the microcomputer can interface to the phase shifter through a single bus for data, phase-shifter address, and control as shown in Fig. 6. The dwell time or time to compute new beam positions can be speeded up by partitioning the array into subarrays and using a microcomputer to load each subarray in Fig. 7a. This approach, however, is wasteful because of the redundancy of having many microcomputers executing the same routine. The redundancy occurs in program storage hardware and can be eliminated by using a multi-processor microcomputer. The multiple microprocessors execute a single instruction stream using constants which correspond to a particular subarray. This architecture is shown in Fig. 7b. This approach to beam-steering control, along with the hybrid packaging technology will result in a physically small beam-steering controller that can be located near the antenna. This will reduce the cabling required to interface the beam-steering controller to the array.

The beam-steering controller is yet another example of how the module types described earlier can be used to implement different computing architectures.

Another proposed microprocessor application is checkout and monitoring.

This approach is based on distributing microprocessor checkout-and-monitoring (CAM) systems based on functional and cabinet-level partitioning. Each microprocessor CAM (μCAM) is tied into hardware test- and data-monitoring points. The μCAMs sequence through test routines that query the individual hardware points and format the data for block transfers to the central processor. The central data processor manages the distributed μCAM system on a functional basis.

Faults are detected at the subsystem level through continuous monitoring by each μCAM. When a fault occurs, the μCAM senses this and notifies the central data processor via interrupt. The central data processor then queries the μCAM to determine the nature and seriousness of the fault. Any further diagnostics or fault isolation routines are then directed by the central data processor. Each μCAM will contain "canned" diagnostics for fault isolation at the least-replaceable-unit level of hardware and will report the failed hardware unit location back to the central data processor.

This approach to checkout and monitoring eliminates the large data base requirements of a central computer approach since the data required for fault detection and isolation (test-bit patterns) are distributed throughout the hardware.

Conclusions

The microprocessor in a radar system is a component to be sold as a part of a larger product, and can be used to implement those functions which are more or less common to all radars. The microprocessor as a device is not particularly significant in these applications; however, the microprocessor as a system function is. The impact of the microprocessor in radar systems is related to the degree to which it remains a flexible device that can be used for multiple functions.

The key issues, therefore, in applying microprocessors to radar systems, are not the device itself but the software and firmware required to make it into a radar subsystem component. The questions to be resolved are ones dealing with system architectures and firmware development. The modular approach to hardware and firmware described here is directed towards microprocessor use in that context.

Programmable processors and radar signal processing—an applications overview

M.G. Herold
M.C. Timken

Developers of programmable signal processors are continually attempting to outreach each other with greater throughput or programming ease, or both.

Marty Herold has been involved with the design of signal-processing systems since joining RCA in 1957. His experience includes analog computing, servos, frequency synthesis, receivers and digital circuit and system design. Since 1970 his primary assignments have involved systems design of real-time programmable signal processors for communications and radar applications. He is currently the systems engineer responsible for design and delivery of a programmable, real-time, digital communication receiver.

Maurice Timken joined MSR in 1957. He has extensive background in signal processing techniques and has designed and developed these subsystems for application to radar systems such as TRADEX, BMEWS, ASFIR, and AN/FPS-95. In his present assignment as a unit manager in the System Engineering Department, he is responsible for development of a programmable signal processor for communications application.

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Authors **Marty Herold** (left) and **Maurice Timken** with an SPS-81 Programmable Signal Processor in the background.

In radar, signal-processing functions are performed on received signals so that desired target returns are enhanced and noise, clutter, and other extraneous signals are de-emphasized.* In early radars, signal processing was an analog-circuit function; later came hardwired digital logic circuits; the more recent trend is toward programmable methods.

Today's radars place wide-bandwidth high-speed demands on the signal processors; these processors must also be adaptable to changing needs. Thus, speed and flexibility establish the architectural tradeoffs for selecting the best signal processor. Speed can be achieved in a variety of ways, principally by means of performing functions simultaneously or in parallel; flexibility is achieved by software.

At one extreme of the tradeoff is the hardwired approach—maximum speed, little flexibility; at the other extreme is the general-purpose computer—a lot of programming flexibility with high-level languages, but orders of magnitude below the speed required for radar processing. Programmable processors fall in a wide region between these two extremes, approaching one or the other limit, depending on the degree of parallelism in the architecture and hence the complexity in programming. No clear criteria can be set forth to identify an optimum level of flexibility (programmability) and speed (parallelism). The system design goals involved, however, are quite clear: maximum throughput, with optimum use of available resources, and without an overcomplicated program.

* Walt Weinstock describes the radar signal-processing function in some depth elsewhere in the issue.

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What's a programmable signal processor?

All programmable signal processors are "standalone" units controlled from a host minicomputer. The software package in the host minicomputer provides program assembly, control, and debugging capability. Programs for signal-processor operation can be stored on disk or tape and loaded under control of the host minicomputer. Therefore, all peripherals available to a computer (teletype, CRT terminal, printers, disk operating systems, magnetic tapes, etc.) can be integrated into a signal-processing module through the host minicomputer.

Programmable processors are usually delivered with a software library package providing such functions as array multiply, add, subtract, and combinations thereof, plus more complex functions such as complex multiply, FFT (fast Fourier transform), recursive filter, and power spectral density. The sophisticated user can add functions of his own to the library. The attractiveness of the array library software is that it provides a means of quickly applying a programmable processor to a computation problem, since the functions are Fortran-callable.

The major drawback to use of array library software for real-time signal-processing is the efficiency lost in overhead. That is, each library function called requires the computer to perform extra operations (use extra memory and time) needed to link these various "canned" programs at the processor level. For real-time signal-processing applications such as radar, the processor must be programmed in microcode to achieve the desired throughput. Programming at the microcode level, called microprogramming, requires that the user develop instructions practically at the logic design level.

What happens in the real world?

Consider a typical situation that might employ a programmable signal processor. The usual case is a multiplicity of baseband signal processing computations that would otherwise require many dedicated digital processors. For instance, a typical radar may require FFT, doppler filtering, range and monopulse angle estimation, interpolation, etc. If a programmable processor is fast enough to perform all of these functions, we have a prime application candidate. (The programmable processor is misused if dedicated to a single heavy-load function such as complex translation and filtering for preprocessing—the sample rates alone could take all the resources of the processor and you're not able to use its programmability.)

Two considerations are of prime importance when designing a programmable processor into a system:

- Partitioning of processing function for efficient "overlay" management.
- Efficient flow of input and output data.

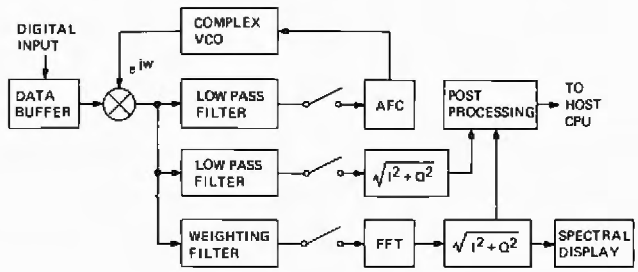

Fig. 1
Typical processing scenario. Hypothetical multiple-function radar processing involving time, frequency, and display processing.

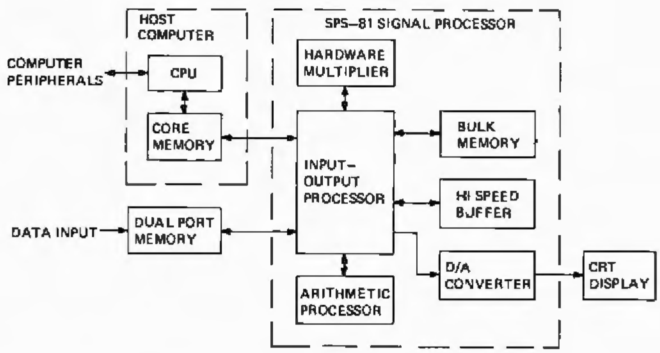

Fig. 2
Signal-processing system. A typical application architecture involving host computer control, display, and data/signal processing flow from input to computational output deposited in the host computer memory.

The functional partitioning of processing functions into overlays (smaller program segments) is necessary since programmable processors have relatively small program memories and thus cannot hold the total signal-processing repertoire. The program overlays are generally kept in large bulk memories, easily accessible to the processor. These program segments are then called and placed in program memory only when the functions they perform are needed in real time.

The dynamic swapping of program segments in program memory imposes the further requirement for sequential batch-mode processing of data queued up into blocks. This mode requires the completion of each processing program segment (on all data) before proceeding to the next signal segment. Such a characteristic leads to memory size tradeoffs to reduce the overhead associated with program swapping.

The input/output flow of data and accompanying control strategies must be coordinated. Some processors cannot reach out and obtain data. Instead, blocks of data and/or control must be moved into a processor memory before processing can begin. Output is the reverse process. In most cases, processors must be stopped for external program changes by the host CPU. If uninterrupted continuous processing is necessary in real-time control situations (e.g., operator inputs to add or subtract processing functions or change parameters), an indirect means of control is needed.

Because these processors operate independently of the host minicomputer, and because control is exercised indirectly via a control program in the mini's memory, an executive control program must be designed into the software system of the processor itself. These control programs can range from very rudimentary instructions to high-level control programs. The form of control advocated here is a control program residing in the signal processor which can fetch control statements from the host minicomputer's memory, interpret the requirement, and send to the proper control subroutine that part of the control program required to accomplish the intent of the control instruction.

A typical problem

Consider the typical processing segment shown in Fig. 1. The process shown involves an AFC loop for doppler extraction, with complex translation to baseband. The baseband signal envelope is detected for various post-processing uses while the input spectrum is analyzed in parallel for display and other automatic, spectrum-dependent post-processing functions.

Assume a typical programmable processor such as the SPS-81 (SPS, Inc.) which has a system architecture as shown in Fig. 2. This system provides a natural partitioning of functions. A dual-port memory is provided: one port buffers input data from an external processor; the second port is used by the processor to fetch data independently. The SPS-81 has a bulk memory to store program overlays, a high-speed buffer for scratch-pad and interim storage, a hardware (hard-wired) multiplier, and a DMA (direct memory access) interface to deposit results directly in host minicomputer's memory. Results can also be output via the D/A converter for display.

By functional partitioning, we match the process to be computed with the internal processor.

Filtering, AFC feedback, complex translation, FFT, and envelope detection are performed in the arithmetic section. All of these processes involve various combinations of multiplies and adds for which the arithmetic processor is designed. Post processing, which generally involves searching, thresholding and branching (i.e., single-thread processing) is performed by the input-output processor, which is, in fact, a highly efficient microprocessor. The hardware multiplier speeds computations and avoids the need to commit the arithmetic section (and its setup overhead) to randomly programmed, single multiplications.

Functional partitioning of the coding for the arithmetic processor depends very much on the small program memory of the arithmetic section. For example, a microcoded instruction for the arithmetic section has 96 bits per word, but only 16 instructions can be stored at once. The index section, which drives the arithmetic section, can store 64 program instructions; its instruction has 32 bits. Each of these instructions is very powerful, as evidenced by the number of bits in the instruction word, so that much can be accomplished in each instruction.

Experience in programming the SPS-81 indicates that our sample problem of Fig. 1 can be partitioned into three overlays: translation filtering with AFC, filtering with envelope detection, and FFT with weighting.

Next the partitioning of the process and the multiple channel capability of the input-output processor must be considered.

- The highest-priority channel can be used to output data to the D/A converter at a clocked rate. The clock rate will be very slow compared to the speed of the processor, and the high-priority channel is used to guarantee a steady output for flicker-free display.
- The next-highest-priority channel can be used to control and move data in and out of the arithmetic section.
- The next-lower-priority channel would contain the post-processing functions.
- The lowest-priority channel would contain data output to the host minicomputer and the executive program.

This prioritized partitioning provides for a natural flow of control from the highest-priority processing channel to the executive in the lowest. When a processing segment is complete on a block of data, the processing of the higher-priority channels stops, causing control to fall through to the next lower priority channel, etc.—finally reverting control back to the executive program. The executive then fetches the next control instruction from computer memory for appropriate action.

The architecture shown in Fig. 2 was chosen to facilitate optimum processing in a parallel pipeline fashion. The control program is resident in the host computer memory where it can be modified by the host minicomputer. Program overlays are stored in bulk memory from which high-speed overlaying of program memory of any internal processor can quickly be accomplished. Processing proceeds under control of the executive program that resides in the SPS-81.

The memory system is also partitioned and distributed to facilitate efficient processing flow. Data is fetched from the dual-port memory for input to the arithmetic section; interim results from the arithmetic section processing are then deposited in a high-speed buffer. Data volume at this point is much reduced, allowing use of the small high-speed memory to hold interim results. The buffer is high speed in that its cycle time is the same as the input-output processor clock.

The post-processing functions are then performed on these interim results. The results may be directly deposited in host memory or in bulk memory for later block transfer to the host minicomputer memory. The display data can be stored in any of the memories for continuous cycled output to the D/A converter.

Microcoding the arithmetic processor is akin to logic design.

Efficient coding of the arithmetic processor requires a somewhat formal programming organization so that the programmer can stay abreast of events at each step of the process. Optimum coding requires maximum use of the arithmetic section at each cycle.The primary difficulty lies in visualization of all the assets and multiplexer switched data paths when attempting to fold in pipelined or parallel processes. The efficient programming and subsequent debugging require careful charting of the processing flow through the arithmetic section.

For this purpose, a charting process has been developed that is akin to logic design. In this technique, the sequential arithmetic section cycles are charted out on a schematic format depicting the arithmetic elements, data paths, and memories. This provides immediate visibility of the state of the arithmetic section at the end of each cycle.

Once the program is mapped, programming requirements for addressing, function selection, scaling, etc., are charted into a table. This table is then analyzed to be sure that arithmetic section waiting time is minimized. The coding plan is juggled to best meet the waiting-time requirement. (At times, this juggling is unsuccessful and it may be necessary to modify the code.)

The input-output processor program is then coded to support the arithmetic-section requirements as coded. Input-output processor constraints may necessitate still another reshuffling of code. The microcoding of programmable processors, therefore, involves logic design with cut-and-fit programming of the various internal processors for efficient throughput. Processing is further enhanced via algorithm tradeoffs which select processing structures that best match the processor.

Speeding up the process

Faster devices are an obvious means of enhancing processing speed; however, the primary challenge is in the selection or design of efficient signal-processing architectures and appropriate programming techniques. The sequential processing and high-level languages found in the general-purpose machine have been replaced with highly parallel structures and machine coding. Although programming these highly parallel processors is more complex, the potential for increased throughput is great. The aim is to provide sufficient switching within the arithmetic hardware to allow optimum programming for a wide variety of signal-processing functions. Both architecture and programming design are tightly coupled with signal-processing techniques and these skills are required for optimum design.

Architecture enhancements: the ultimate goal is to use 100% of the resources 100% of the time.

The most widely used and accepted concept to improve processing speed is a multiple-processor architecture. This concept has been introduced to enhance throughput with a motive for efficient use of the arithmetic unit resources. By providing a separate processor to perform the tasks of input, output, and control, the arithmetic unit can be fully dedicated to arithmetic computation. The approach is to provide an arithmetic processor for computation only and support it with another processor for address computation, data movement, control, and other housekeeping chores.

The memory is in general the slowest device in any signal processor computer structure.

Regardless of the degree of throughput capability achieved with multiple processors and arithmetic unit resources, the cycle times of memories become the limiting factor. Much engineering effort has gone into the design of "smart" memory interfaces and memories to speed computer processing. This type of memory interface is programmed to allow fetching or storing of data arrays at given address increments from a specified starting address, thereby reducing the load on the controlling processor for address computations.

One technique used to overcome the memory speed problem is to distribute the memories (e.g., separating program from the data storage to provide program instruction fetches on a non-interfering basis with retrieving and depositing results in data memories). Distributed data memories and multiple bus structures are also utilized to increase processing speed by minimizing memory wait times. Other techniques applied to reduce memory access time include interleaving memory modules within a single memory on consecutive addresses, and using a small, fast, bipolar memory for scratchpad computation.

Software enhancements: the tradeoffs involve programming techniques as well as the language level employed.

A careful tradeoff must be made between the required performance and computational burden. Both programming and signal-processing ingenuity are essential skills to make this tradeoff. But the potential increase in throughput is high.

The primary effort in software development for computers has been toward higher-level languages. This development proceeds from machine code, to assembly language, to Fortran et. al. to even higher languages, such as those used for structured programming. Each level above machine coding invokes some overhead, and thereby sacrifices processing speed for programming generality. Even assembly code, when it is applied to a particular problem, is not necessarily the most efficient attainable for a particular problem.

The microprogrammable computer breaks this constraint by allowing the programmer to define new computational kernels matched to a particular problem, thus enhancing processing speed by more efficient exploitation of the computer architecture. Microprogramming therefore requires the partitioning of the process to be coded into an efficient set of kernels, followed by microcoding of the kernel.

The coding of programmable signal processors has similar tradeoffs in language level. All of the processor manufacturers provide a basic set of programs (commonly referred to as an array processing library) which can be called at the Fortran level. These libraries include a number of high-level processing functions so that a signal-processing function can be programmed. Use of these libraries, however, involves additional overhead and results in slower overall computational speed.

In general, the integration of the programmable signal processor into a system for real-time radar signal processing will not tolerate this loss in performance caused by extra overhead. It makes no sense to design a processor architecture for optimum efficiency and then throw away much of the performance with setup overhead. To a large extent, overhead will be proportional to processor complexity. Integrating a programmable processor into a real-time signal-processing system, then, imposes a requirement to microcode the application software rather than use the library building blocks.

In summary, speed enhancement via software has three main goals:

1) Selecting algorithms which best fit the architecture of the processor.

2) Partitioning processing functions to minimize overhead.

3) Microcoding the processor to obtain maximum use of the programmable processor's capability.

Conclusions

The programmable signal processor is one of the most important developments in signal-processing applications today. New processors providing greater processing speed and/or flexibility will continue to be developed. The primary effort is in more and more parallelism of one sort or another. Efforts to provide higher-level software will also continue, to ease programming complexity while extracting processing performance. Developers are continually attempting to outreach each other with greater throughput or programming ease, or both. Usually the ease of programming is based on the availability of a library of preprogrammed functions.

Although these libraries have their place, they extract a price in reduced efficiency because of their increased overhead. Each level of parallelism adds, in effect, a level of specialization which makes it much more difficult to develop a higher level language that takes advantage of the efficiencies of the parallel structure.

Application of this type of highly parallel structure to maximize throughput, then, demands that the programming be equally as efficient. The use of microcoding is therefore essential to overcome the inefficiencies of high-level languages. Hence the techniques employed are more akin to logic design. It is clear, then, that the practical implementation of a programmable processor into a system involves not only tradeoffs of system functions, algorithms, and processor structures, but also careful consideration of software design, encompassing the whole range of language levels and associated assemblers and programming aids.

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Comparison of typical programmable processor architectures

The three programmable signal processors discussed here are by no means the only commercially available processors, but were selected because they depict a range of differing architectures and typify the considerations described in this paper.

Some general comparisons

Table I compares the performance that can be achieved on typical signal-processing functions for these processors. Of additional interest, the MAP 300 and AP-120B are floating-point processors whereas the SPS-81 is 16-bit fixed point. Floating point provides greater dynamic range and relieves the programmer of scaling worries.

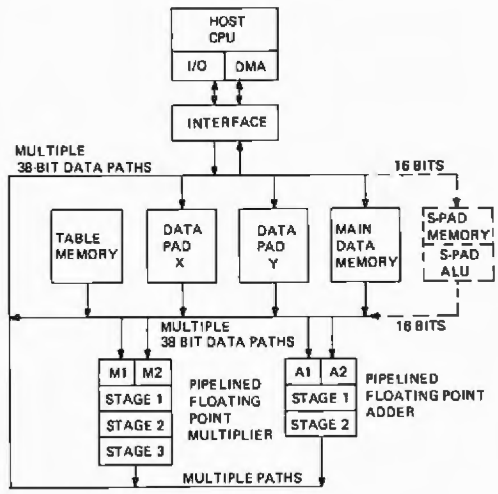
For data I/O the AP-120B and MAP 300 feature independent DMA processors. The DMA processors are set up with a word count, source, and destination address, and increment by either the processor or the host computer. They can then move blocks of data independent (and in the background) of on-going processing.

The SPS-81 has a primary difference in operation in this regard in that all the memories are in effect on the IOP processor bus. There is no need to move blocks of data in and out since it can reach out and fetch data as needed and deposit results in memories or devices requiring them when computed.

Table I
Performance comparison of three commercially available signal processors.

Function	Processing time, μs/point SPS-81	MAP 300	AP-120B
FFT (1024 pt. complex)	3.2	4.5	4.7
Recursive filter (2 pole/2 zero)	0.5	0.85	0.83
Complex mulitply	0.5	0.85	0.67

Array Transform Processor (AP-120B, Floating Point Systems, Inc.). A multiple processor architecture featuring pipeline arithmetic elements, a single interleaved memory, and independent I/O processing.

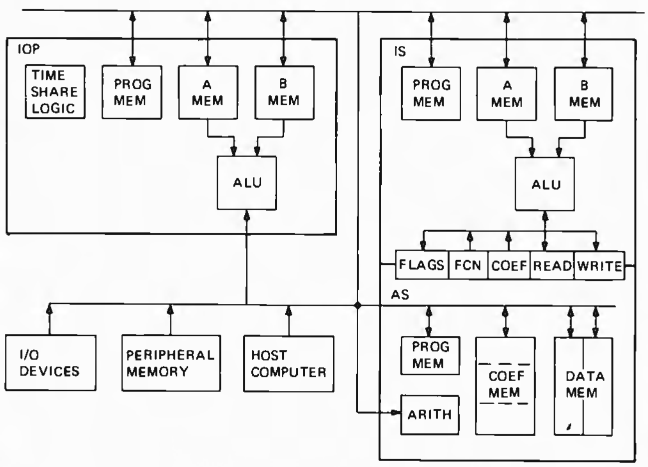


The AP-120B does not function at nearly the multiple-processor level of the other two processors; rather it provides a parallel architecture of varying computational and memory elements controlled from a single program memory. The primary arithmetic elements are a single multiplier and adder which can be pipelined to achieve speed.

Pipelining is a form of parallelism which, in the AP-120B case, is equivalent to three parallel multipliers and two parallel adders. That is, the multiplier of the AP-120B requires three cycles to compute a result; however, additional multiplies can be started before the result is obtained. The AP-120B multiply time is 0.5 μs, but pipelining increases the effective multiply time to 167 ns/computation. The AP-120B adder is also 2:1 pipelined, with a single multiply taking 333 ns and a pipeline rate of 167 ns/computation.

The architectural simplicity of the AP-120B arithmetic unit is deceptive in terms of programming difficulties. To obtain processing efficiency, the programmer must constantly visualize the time phasing of data in and out of memory and arithmetic elements. Also, the multiple processors of the AP-120B are not totally independent, since they operate from a single program memory.

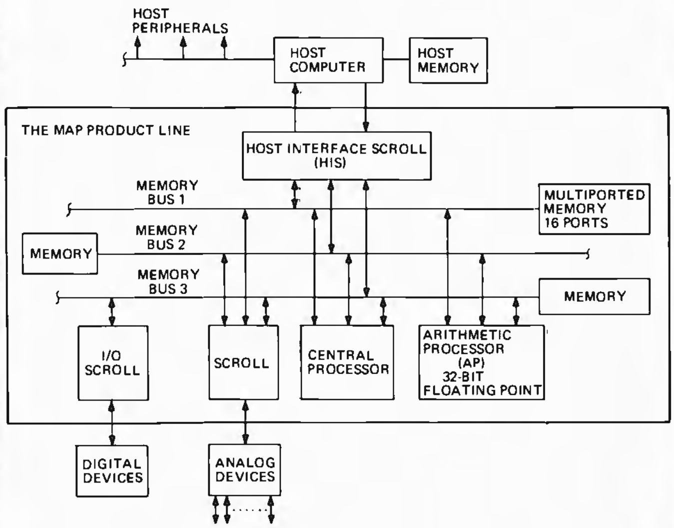
Programmable Digital Signal Processor (SPS-81, SPS, Inc.). This processor architecture features a highly parallel, number-crunching arithmetic processor (IS and AS), supported by a fast microcomputer-like I/O processor.



The three processors of the SPS-81 have independent program memories and they operate independently. The machine is synchronous in that the clocks for each processor are derived from a common source. The cycle time of the input-output processor and index section is 167 ns. The SPS-81 can do a full complex multiply (four real multiplies plus two adds) and two full complex adds (four real adds) in 0.5 μs. A hardware multiply in the input-output processor can also speed processing when use of the complex arithmetic processor is inappropriate.

In addition to being one of three processors, the SPS-81 input-output processor is itself a four-channel processor, thereby further extending processor parallelism. A memory register file, program counters, and control are replicated four times. Operation of the four channels is on a time-share basis. If a channel is waiting for a memory cycle to complete, the next-lower-priority channel can perform a computation in the arithmetic logic unit, service a device, or fetch data from an alternate memory.

Macro Arithmetic Processor (MAP-300, CSPI, Inc.). A multiple processor with a multiple-bus, multiple-memory architecture and separate, independently programmable I/O processors.



The MAP is also a federation of independently programmed parallel processors. The MAP is unusual in that is is a totally asynchronous processor. Operations are not clocked as in other processors; rather operations flow from one to the next as needed data or operands become available. Processing proceeds at device speed, theoretically obtaining maximum computational speed available from given devices. The MAP-300 performs two multiplies in 0.42 μs plus two adds in 0.21 μs (i.e., one in each arithmetic element), for an effective rate of 0.21 μs and 0.105 μs respectively.

The two arithmetic processors proceed similarly. As operands become available in the arithmetic-element input registers, computations proceed. If compuation results are required as inputs to the next computation, the next operation proceeds as soon as the previous result ripples into the operand register. Synchronism between processors is achieved on a programmed basis with flags and status bits.

Digital computer simulation of radar systems

J. Liston | G.M. Sparks

Simulation is a necessity for radar systems as complex as AEGIS. Without it, problems and optimizing would appear too late in the design process.

This paper provides an overview of the kinds of simulation models, together with their application to radar systems design and analysis. The simulations discussed in this paper are broadly categorized as real-time and non-real-time simulations. A real-time simulation includes real-time cycling constraints associated with operation in a realistic scenario. An example is a real-time operational simulation, which facilitates the routine evaluation and parameter "trimming" of an illustrative aircraft vectoring system without the necessity for flight support aircraft. A non-real-time simulation, on the other hand, is not constrained by the real computation time; however, such a simulation is a powerful tool for designing and evaluating algorithms and functional inter-relationships in a complex radar-centered system.

Within each of the foregoing categories, the elements of the system to be simulated are categorized as discrete or analog processes. Discrete processes are usually described by difference equations and can be directly programmed on a digital computer. These processes, such as those employed by digital signal processors, are usually simulated on a general-purpose digital computer by simply using the Fortran (or other high-level language) equivalent of the specific algorithm associated with the process in question. Analog processes are usually described by differential equations, so to program these equations it is necessary to convert them to a set of difference equations. The initial form of the process may be a set of differential equations or a transfer function, $G(s)$, which represents a set of differential equations. The approach to converting the analog process to a discrete process may be to solve the set of differential equations and to sample the solution at discrete intervals or to use transforms such as the bilinear transformation to develop the difference equations directly from the Laplace-transform transfer function, $G(s)$. Recursive algorithms can be used for either approach.

Discrete and analog process simulations can be realistically integrated to represent the operation of a complex radar system or perhaps certain critical elements of the system. This paper describes how the effects of noise, thresholds, nonlinearities, system errors, quantization, and various aspects of the system environment (propagation, multipath, etc.) are introduced and how each affects the overall system. It also gives specific examples on the simulation effort that RCA Missile and Surface Radar has used in the design and evaluation a number of radar systems.

Simulation approaches

Most processes encountered in the study and analysis of radar systems can be classified as either analog or discrete. Analog processes have a continuous time response to a given excitation function and, as such, are best described in terms of differential equations or Laplace transforms expressed as functions of the complex frequency variable; i.e., $G(s)$. Discrete processes, on the other hand, have process variables defined only at a particular set of time values, implying that the independent variable (time) is quantized. Such processes are typically described in terms of difference equations which can be directly programmed for solution on a digital computer.

One way of simulating analog processes on a digital computer is by solving the defining differential equation directly.

For some analog processes described by a set of N simultaneous linear constant-coefficient differential equations with M time-varying inputs, it is more efficient to solve the equations and store the results as an $N\times N$ and an $N\times M$ matrix in a data file, rather than use substitution techniques such as the bilinear transform. This data file is then available to the appropriate simulation program and can be executed by simple multiplications and additions at the system data rate. Substitution methods or numerical-integration techniques sometimes require integration time intervals much smaller than the computer system update time interval.

To illustrate this approach consider the scalar differential equation:

$$\dot{X}(t) = AX(t) + B\mu(t) \quad (1)$$

The solution to this equation is:

$$X(t) = e^{A(t-t_k)}X(t_k) + \int_{t_k}^{t} e^{A(t-\sigma)}\, B\mu(\sigma)d\sigma \quad (2)$$

where $X(t_k)$ is the initial condition and $\mu(t)$ is a time-varying input.

This is the solution to an analog process. For a discrete process, the equivalent solution is

$$X[(k+1)T] = e^{AT}X(kT) + [e^{AT}-1](B/A)\ \mu(kT) \quad (3)$$

This equation then solves for a sequence $X(kT)$ for $k = 1, 2,\ldots$ using an input sequence $\mu(kT)$ for $k = 1, 2,\ldots$. This solution can be used in a feedback system where $\mu\ (kT)$ is a function of previous values of X.

Eq. 3 is the solution to a single differential equation with one input. Consider now N differential equations with M inputs. The solution to these equations can be written in matrix form similar to Eq. 3.

The resulting matrix equation is written in the following general form:

$$X[k+1)T] = \alpha X(kT) \pm \beta\mu(kT) \quad (4)$$

where α and β are respectively $N\times N$ and $N \times M$ constant matrices.

The key to this solution is to determine the matrix $\underline{e^{AT}}$ in order to arrive at $\underline{\alpha}$ and $\underline{\beta}$. The matrix $\underline{e^{AT}}$ is computed by calculating the eigenvalues and eigenvectors of $\underline{A}$ and performing the appropriate transformations. This was a very convenient method, since the time-shared computer system available at RCA MSR had library routines which calculated eigenvalues, eigenvectors, and matrix inversions. A separate program used these library routines to calculate and store $\underline{\alpha}$ and $\underline{\beta}$ so that they were then available in a data file for use by a simulation program.

In substitution methods, the differential equation or its Laplace transform is represented as a discrete process that closely approximates the time response of the analog process.

Fryer and Schultz[1] describe various methods of simulating system transfer functions on a digital computer. These methods yield solutions that are expressed in terms of a recursive or difference-equation form, through the substitution $s = (2/T)(1-\Delta)/(1+\Delta)$ when T = time interval between data points and Δ = delay operator e^{-sT}.

$$G(s) \rightarrow G[f(\Delta)] = \frac{a_0 + a_1\Delta + a_2\Delta^2 + \ldots + a_m\Delta^m}{1 + b_1\Delta + b_2\Delta^2 + \ldots + b_m\Delta^m} \quad (7)$$

The corresponding difference equation or recursion formula is written by inspection as

$$y_n = a_0x_n + a_1x_{n-1} + \ldots + a_mx_{n-m} - b_1y_{n-1} - b_2y_{n-2} - \ldots - b_my_{n-m} \quad (8)$$

which can immediately be programmed on a digital computer. Fig. 1 gives a flowchart for such a program. Table I is a short table of bilinear transforms which give the values of the coefficients (a's and b's) in terms of the parameters of the transfer function $G(s)$ and time interval T. We note that the bilinear transform can be cascaded; that is, if $G(s)$ can be factored into the form

$$G(s) = G_1(s)G_2(s)$$

$G_1(s)$ and $G_2(s)$ can be programmed into two independent blocks of code and the output of the $G_1(s)$ simulation used to provide the input to the $G_2(s)$ simulation. The resulting output of the $G_2(s)$ block, under this condition, will simulate the output of $G(s)$.

The difference equation that is the result of the bilinear transform process is easily programmed; however, evaluating the constants a_0, a_1 ..., b_1, b_2 ... can involve a considerable amount of tedious algebraic manipulation, particularly in the case of high-order polynomials in s. However, this algebraic manipulation can be carried out using a digital computer, thus relieving the user of the burdensome algebraic manipulation and reducing the possibility of introducing errors in the process. The method assumes that the function $G(s)$ to be simulated is of the form of the ratio of two polynomials in s.

Simulation of discrete processes, such as digital filters, on a general-purpose digital computer is a straightforward procedure.

Fig. 2 shows illustrative digital filters and the corresponding difference equation that provides a discrete time series of output values, y_n, given a time series of input values, x_n. Such difference equations can be directly programmed on a general-purpose computer to exactly represent the discrete process of interest. The difference equations are derived from knowledge of the transfer functions appropriate to certain classes of digital filters[5]; e.g., direct form 1, direct form 2, parallel form, or in certain simple cases, by tracing the signal flow as implied by the examples in Fig. 2. Noise, signal-amplitude quantization effects, and logical operations can also be readily accommodated within the framework of a suitable high-level computer language such as Fortran.

Table I

Bilinear transforms (or Tustin transforms) convert Laplace transforms into discrete difference equations that are easily programmed on a digital computer.

Network	*G(s)*	y_n
Integrator	$1/s$	$(T/2)(x_n - x_{n-1}) - y_{n-1}$
Lag network	$1/[(s/b)+1]$	$[Tb/(2+Tb)]\,x_n + [Tb/(2+Tb)]\,x_{n-1} + [(2-Tb)/(2+Tb)]\,y_{n-1}$
Lead-lag network	$[(s/a)+1]/[(s/b)+1]$	$[b(2+Ta)]/[a(2+Tb)]\,x_n + [b(Ta-2)]/[a(Tb-2)]\,x_{n-1} + [(2-Tb)/(2+Tb)]\,y_{n-1}$

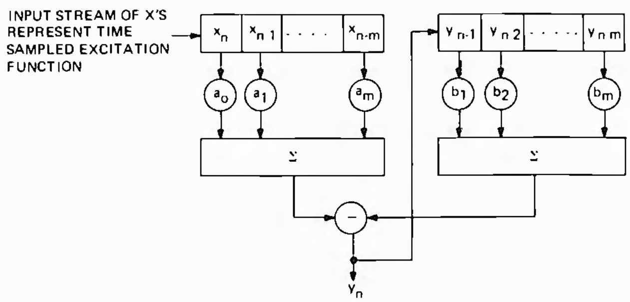


Fig. 1

Flowchart for program solving the difference equations of the type given in Table I.

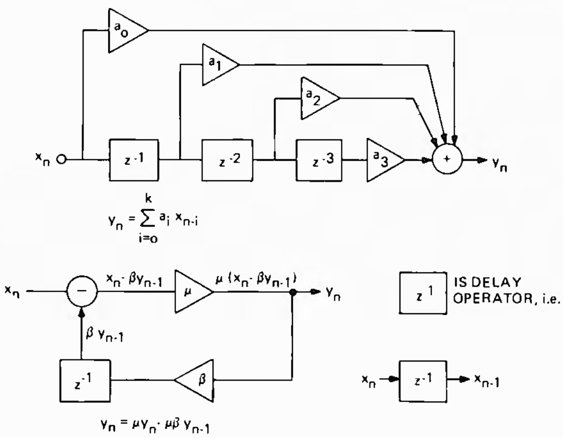


Fig. 2

Simulated digital filter is a result of using difference equations derived from knowledge of transfer functions or by tracing the signal flow.

In certain cases, the discrete process is defined in terms of an algorithm, which can be directly transcribed into simulation code. For example, a specific fast-fourier-transform algorithm used in a radar digital signal processor can be directly coded into a Fortran simulation of the processor.

Examples of small-scale analysis by simulation

Simulation can help analyze the central issue in many radar signal-processing systems—detection performance.

In order to illustrate a general methodology for such cases, let us use digital or Monte Carlo simulation to determine the target detection probability, given a specific signal-to-noise ratio and false alarm probability. The theoretical solution to this problem is well known,[6] thus we can compare simulation-derived and theoretical results to gain a feeling for what can be achieved in terms of accuracy.

Consider that the output from a linear detector, which provides the envelope of steady sinusoidal signal plus noise, is statistically governed by the modified Rayleigh distribution. This process is simulated by forming the vector sum of a steady signal and independent in-phase and quadrature-phase noise samples from a Gaussian distribution of zero mean and unity variance. A simple threshold detector can then be simulated by generating voltage samples in accordance with the above procedure and comparing the resulting amplitudes with a threshold given by

$$T = (-2 \log_e P_{fa})^{1/2} \qquad (9)$$

where P_{fa} is the false-alarm probability.

Some insight as to the accuracy of our signal-plus-noise simulation can be obtained by calculating detection probability versus signal-to-noise ratio (S/N) for various values of false-alarm probability and comparing the results with theoretical values computed with a highly accurate algorithm.[7] This has been done in Fig. 3 for 2000 Monte Carlo trials; correspondence with theoretical values is excellent.

Simulation is not limited to cases in which the radar signal is steady.

It is possible to simulate amplitude samples of the envelope of signal plus noise where the signal components are fluctuating. Such fluctuations arise due to changes in the relative phase relationships* among the various scattering centers which comprise the target. The fluctuations can be classified as either independent from sample to sample (rapidly fluctuating) or totally correlated within a given stream of samples (slowly fluctuating). Here, the stream of samples might simulate the sequence of target returns which occur as the radar beam scans past a target during a single rotation (or scan) of the antenna.

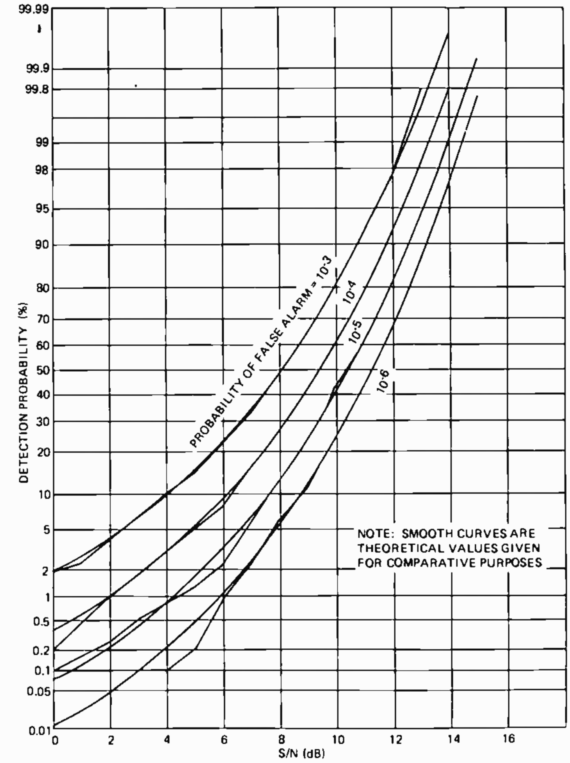


Fig. 3
Good comparison exists between theoretical (smooth curves) and simulated probability of detection.

Additional effects which influence the amplitude of the signal returns include the antenna pattern shape and reflections from the surface or other large objects in the vicinity of the radar. These are accounted for in many simulation analyses, but will not be discussed in detail here.

Radar system simuation is often called upon to provide a model of the dynamic effects of a moving target of interest.

The simulation generates a realistic time sequence of radar measurements (observables) in terms of range, azimuth, and elevation. These values are modeled to represent the "true" position of the target. The resulting time sequence of observables are then perturbed within the simulation to represent the effect of radar-induced "noise" on the process under analysis.

Simulation showed how adding a sidelobe blanker affected system performance.

A sidelobe blanker inhibits receiver response to signals which enter the radar via the antenna sidelobes. The gate into which the reference and blanker channels respectively feed passes the reference-channel signal-plus-noise only if the envelope of the signal-plus-noise of the reference channel exceeds that of the blanker channel by a specified blanker threshold, expressed in dB. If blanker threshold is exceeded, a single pulse "detection" or "hit" is declared if the envelope of signal-plus-noise exceeds the threshold established in a second gate. For linear envelope detection, this threshold value is given in accordance with Eq. 9.

N successive beacon response samples, characterized by a given reference-channel signal-to-noise ratio, are considered in the simulation. The detection probability is

*Due to changes in signal frequency (frequency diversity) or target rotation relative to the radar line of sight.

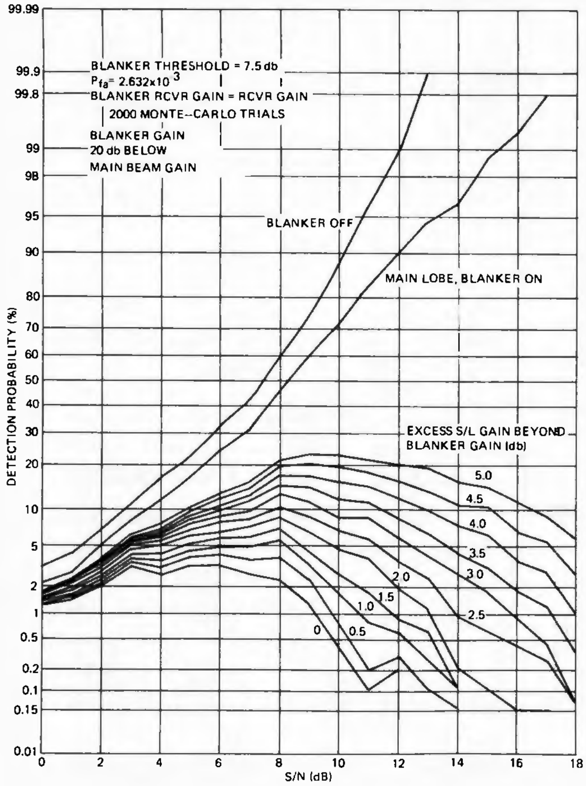


Fig. 4

Sidelobe-blanker simulation showed the loss in detection (two curves) performance that occurs when sidelobes are blanked out as an electronic counter-countermeasure. Set of 11 curves shows probability that sidelobe (S/L) signals will be falsely accepted as a mainlobe signal.

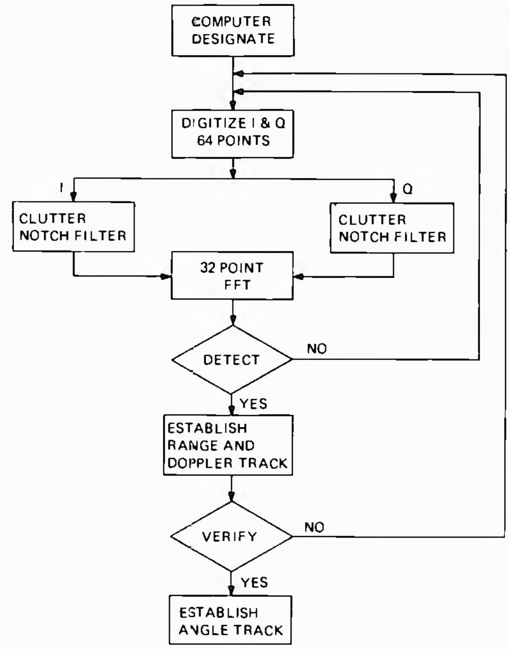


Fig. 5

Simulation of artillery-shell detection was useful in quantizing and scaling system during development, then debugging in field. *I* and *Q* are in-phase and quadrature signals.

then computed as ratio of the accumulated number of "hits" to the number of trials, N. For each trial, independent samples of in-phase and quadrature-phase Gaussian noise perturb the signal levels in the respective reference and blanker receiver channels. The effect of the reference-pattern beam shape loss or sidelobe attenuation on the reference-channel signal levels is accounted for in establishing respective signal-to-noise ratios in the reference and blanker receiver channels. Typical results obtained with such a simulation are shown in Fig. 4. These results show the loss in detection performance which is introduced by the blanker circuit; they also indicate the probability that a sidelobe signal will be falsely accepted as a mainlobe signal for various values of sidelobe gain greater than the blanker antenna gain.

Another program simulated a clutter filter and Fast Fourier Transform on an AN/MPS-36 radar modification.

This system problem was one of automatically detecting, acquiring, and tracking a high-speed artillery projectile with a pulse doppler radar in the presence of ground clutter. The goal was to complete the detection and acquisition process in less than one second.

The signal-to-clutter ratio (S/C) when attempting to acquire the target was approximately -30 dB. To acquire the target it was necessary, via signal processing, to improve this by 43 dB to an S/C of 13 dB.

The signal processor had available in-phase (I) and quadrature (Q) signals. Each of these signals was processed through a three-pole Cauer notch filter which gave a stop-band rejection of 51 dB. The I and Q were then processed with a 32-point Fast Fourier Transform (FFT). The output of the FFT was 32 signals equally distributed over a radar pulse repetition interval (PRI). The target doppler frequency and amplitude was determined by examining these 32 signals and performing a $\sin x/x$ interpolation between the largest returns. A threshold was then examined and, if it was exceeded, a target detection was declared. A three-pole bandpass filter then verified if this was indeed a target.

The entire detection process, shown in Fig. 5, with a clutter signal, target signal, and receive noise, was simulated on a digital computer. The program was set up to randomly select both a PRF and a doppler frequency within the middle 50% of the PRI. Using an $S/C = -30$ dB, 80 detections were made. The calculated doppler for each detection was within $\pm$ 10 Hz of the true doppler. This simulation program was also very useful in investigating such things as the effect of quantizing and scaling. It proved extremely useful in debugging operations in the field.

Examples of large-scale system simulations (non-real time)

The AN/MPS-36 instrumentation tracking radar was the subject of a detailed computer simulation.

A data rate approximately equal to the pulse repetition frequency was used and all radar functions, modes, and conditions were included. The basic modules of the program are:

Trajectory generator—target trajectory

Target effects—signal return from target

Power program and transmitter

Atmospheric effects—clutter and multipath

Automatic gain control

Track servos—azimuth, elevation, range and doppler (range rate)

Systematic errors

Random errors

Executive control—controls system by making *a priori* and real-time decisions

In simulating missile targets, the launch point, impact point, and trajectory can be programmed and either a passive echo target or a beacon-transponder target can be selected. The passive target consists of a cone-cylinder missile configuration with user-selected dimensions and a resulting radar cross section varying realistically with viewing aspects. For the beacon target an *N*-antenna-port system equally spaced about the missile, including resulting polarization and interferometer effects, is simulated. The simulation also includes range delay and doppler shift for echo or coherent-beacon targets.

The simulated electromagnetic environment includes error contributions caused by atmospheric refraction, ground clutter, and multipath. The multipath effects consider the diffraction, intermediate, and interference regions. The radar model includes the effects of the radar data processor so that the output data obtained from either the real radar or the simulated radar will have been identically processed.

All four of the radar tracking channels (azimuth, elevation, range, and range rate) were simulated using the same approach. First, detailed mathematical representations of the track circuitry were developed in the frequency domain. These expressions were then transformed into difference equations for digital simulation.

TPQSYM simulates the operation of the AN/TPQ-27 precision tracking radar, tracking filters, and all the guidance algorithms necessary to guide a "simulated" aircraft model on a radar-directed bombing-mission flight path.

Ballistic drag tables are stored within the program for a variety of bomb types along with a fourth-order Runge-Kutta integration routine to solve the ballistic equations of motion for the falling bomb. Major features of TPQSYM are as follows:

All four TPQ-27 guidance modes are incorporated;

F4 aircraft flight dynamics is based on high-degree polynomial representation of aircraft using manufacturer's data;

lateral and pitch control of aircraft is provided;

wind effect on the aircraft and bomb trajectory is accounted for;

earth's curvature between radar site and target is accounted for through a rotation matrix;

radar noise and bias effects can be specified;

input data (R, A, E) can be obatined from a recording of field-derived data (actual) or simulated on the basis of interval noise generators;

a wide variety of plots can be specified and made by the user; and

TPQSYM currently runs on MSR time-shared system in Fortran.

Fig. 6 shows a typical plot obtained from TPQSYM. This plot represents the altitude-control-channel response to an initial altitude error of 200 ft, given an F4B aircraft at a nominal 2000-ft. altitude and 500-knot airspeed.

A dynamic, single-target, weapon-system simulation measures AEGIS performance against contemporary threats in hostile, uncooperative environments.

This simulation, known as *S*ystem *P*erformance *E*valuator *C*omprising *T*arget, *R*adar, *M*issile (SPECTRM) models a target generator, the AN/SPY-1 phased-array radar, Mk91 slaved illuminator, SM-2 missile, and ship's motion along with the Mk19 gyro. Developed over the past seven years, SPECTRM is still undergoing changes which reflect field alterations, and additions which are included as new operating modes become viable.

To date, SPECTRM has had a variety of uses, including:

initial verification that slaving an illuminator to SPY-1 outputs was feasible against a wide spectrum of targets;

error budget analysis (error sensitivity and allocation); design and verification of a universal range-adaptive α, β-filter for weapons-system users;

measuring AEGIS performance against specification targets; developing 'special case' system logic, such as low-E-mode logic and coast-mode logic;

determining system performance against special threats;

assessing effect of face-to-face (array-to-array) handover errors on missile/target track, verifying that single-face testing was adequate;

assessing efficiency of various midcourse guidance laws for missile flight control;

comparing capabilities of several proposed rocket motors;

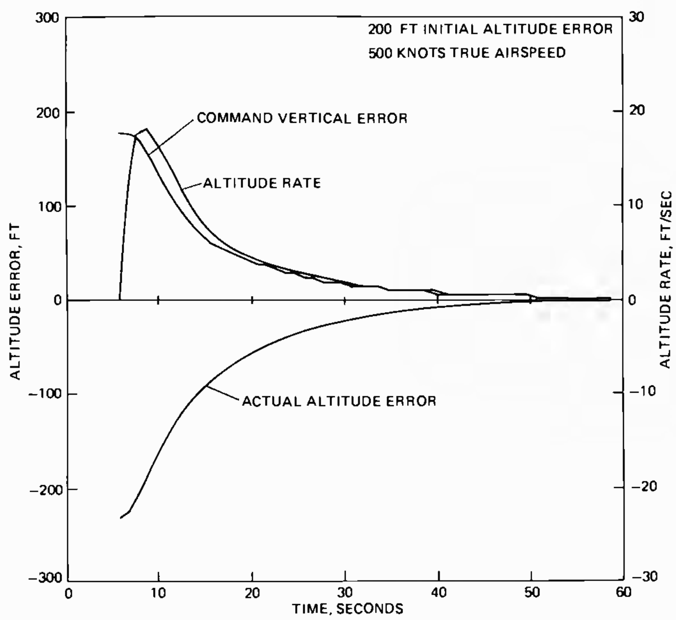


Fig. 6
Tracking-radar simulation is possible with TPQSYM program. Plot represents the radar's altitude-control response to an initial altitude error of 200 ft.

developing missile 'fly-out' curves; and

determining AEGIS performance in an ECM environment.

SPECTRM contains about 5000 Fortran statements, and requires approximately 300,000 bytes of memory. The program is extensively modularized and, through the use of control cards, only those equipments essential to the particular analysis need be exercised. In addition, the many system noise sources can be individually selected—or omitted entirely if a 'reference run' is desired. When the entire weapons system is under analysis, program running time is approximately three times faster than real time.

The MEDUSA simulation evaluates the performance of the AEGIS system against multi-target attacks.

MEDUSA (*M*ulti-target *E*ffectiveness *D*etermined *U*nder *S*imulation for *A*EGIS) is written in Fortran and currently requires approximately 160k words of DEC20 storage. It includes models of the SPY-1 radar, Mk 26 launcher, Mk 91 illuminator, SM-2 missile Combat Air Patrol (CAP) and software logic to control these equipments. Models to describe enemy scenarios are also provided.

The specific uses for MEDUSA are to provide:

a test bed to aid the design and evaluation of AEGIS tactical algorithms

an operation analysis tool to assess the tactical performance of AEGIS

assistance for AEGIS test analysis

MEDUSA has been successfully used as a test bed to evaluate candidate SM-2 scheduling algorithms and Threat Evaluation Weapon Selection (TEWS) algorithms. The modular structure of MEDUSA allows the simulation of an unlimited number of candidates for each AEGIS algorithm being evaluated. The algorithms for a particular run are specified by input parameters. MEDUSA is also capable of acting as a test bed to aid the design and evaluation of other Weapon Control System (WCS) and Command and Decision (C&D) algorithms. MEDUSA is not intended to be used to design AEGIS equipment. Models of the SPY-1 radar, Mk26 launcher, Mk91 illuminator, and the SM-2 missile are part of the MEDUSA test bed.

Trajectory-generator subprograms to model threat targets are also included in the test bed, as are default models for the algorithms being evaluated. The test-bed models are intended to have sufficient fidelity to provide valid results in the evaluation of tactical algorithms or system tactical performance. In general, this does not require that the models mimic in detail the equipment or phenomena they represent. Greatly simplified models are used wherever possible in the interest of simulation computer program development and running time costs.

As system design continues, more specific requirements for MEDUSA runs develop and with them come concomitant requirements for additional sophistication in some of the models. The modular structure of MEDUSA permits ready modification or replacement of the models (either those representing algorithms under test, or those making up the test bed) as the need arises. In the meantime, evaluations requiring only simple models are not delayed pending availability of the "ultimate" MEDUSA.

MEDUSA is now available for both pretest and post-test analysis for actual AEGIS tests at the Combat Systems Engineering Development site. Currently MEDUSA is being used to design scenarios before they are run on the AEGIS Interface System Simulator. This is an inexpensive way to uncover anomalies in the scenarios.

Real-time simulation of large systems

The develoment of radar command and control computer programs frequently occurs parallel with hardware development. The computer systems now contain functions which in the past were hardwired. Many of these functions, such as closure of angle servo loops, closure of range loops, target acquisition, target detection, and waveform selection, are implemented in computer programs, making the computer system an integral part of the radar system design.

To test the system, therefore, it is necessary to integrate the hardware and software. As the complexity of computer programs increases, a means of verifying the performance of the computer programs prior to hardware integration is needed to assure that schedule and cost objectives can be obtained.

Real-time simulation, therefore, has an important role to provide a real-time interface which can be used as a certification and maintenance tool to:

reduce costs over the total program, as the simulator

—does not require the use of a live hardware environment for operational computer program testing

—allows for parallel testing of hardware and computer program prior to and after integration.

minimize risk in development by

—providing a means for early detection of problems

—providing management with visibility of the program-development cycle and allow for action to be taken in problem areas

—assuring that problems in the computer programs and/or hardware do not paralyze independent testing of both

provide a means of verifying computer programs during acceptance testing and after implementation of approved computer program change requests.

TPQSIM verifies the AN/TPQ-27 operational program and conducts software acceptance tests in a controlled environment; i.e., without the need for physical radars and aircraft.

TPQSIM operates on the PDP-11/70 computer. It simulates, in real time, an IFF (identify friend or foe) radar, a precision tracking radar (PTR), a Tadil-C data link, and several aircraft. TPQSIM communicates with a program running on an AN/UYK-7 computer across a special-purpose hardware interface. The heading and attitude of each of the aircraft can be modified by Tadil-C messages. Messages concerning IFF and PTR detections, beam-steering commands, weapon-release signals, etc., are sent between the two computers in formats and rates identical to those used in the AN/TPQ-27 operational program.

TPQSIM is valuable because it:

exercises computer programs in real time without requiring live aircraft;

provides simulated I/O channel interface data for IFF, PTR, and communications functions,

generates dynamic aircraft positional data on line;

includes functional tracking radar hardware simulation for angle-error and range estimation;

includes functional IFF radar hardware simulation for antenna motion, azimuth estimation, and range estimation;

does not interfere with basic operational program timing;

does not require modification of basic operational computer programs;

synchronizes I/O using a real-time clock; and

allows for test operator control.

The AEGIS Interface Simulation System computer programs test the AEGIS tactical computer programs.

The interface simulators consist of an integrated, modular set of computer programs that can be tailored to simulate unavailable interfaces; e.g., comptuer programs and/or equipment and external stimuli; e.g., targets to the tactical computer programs. The interface simulators provide a test bed to support the verification, integration, test, and acceptance of the tactical computer programs during the various stages of their development. The interface simulators are used to support:

the tactical computer program system element builds and Phase II tests at the Computer Program Test Site (CPTS);

multi-element computer-program integration and test at the CPTS; and

Combat System integration and test at the Combat Systems Engineering Development Center (CSED).

The ISS computer programs operate in sets of two-bay and three-bay AN/UYK-7 computers and use a common user language (SCRIPT) and a common control system.

The ISS computer programs include several on-line programs which provide input to exercise the following segments of the AEGIS combat sysem:

AN/SPY-1A phased-aray radar—the basic AEGIS sensor;

C&D (Command and Decision), which drives displays and reacts to operator command;

ORTS (Operation Readiness Test System), which provides on-line monitoring;

GDC (Gyro Data Converter), which simulates ship's motion;

WCS/FCS (Weapons Control System/Fire Control System), which computes launch parameters and aiming angles for the missile launcher; and

SYSTEM, which exercises all system components as a complete system.

Glenn Sparks has been associated with MSR since 1954. During this period he has been engaged in key radar system engineering assignments emphasizing control-system analysis, computer simulation, command and control, and estimation theory. Most recently he was involved in system engineering of the HR-76 radar system.

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Jack Liston has held major systems responsibility for concept design, performance analysis, and design optimization on advanced phased-array radar system developments. Some of the areas of his principal contributions include system computer modeling for cost optimization and performance tradeoffs, advanced self-duplexing receiver concepts, and system performance verification through simulation. He is now systems engineer on the AN/TPQ-27 radar.

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Authors **Sparks** (left) and **Liston**.

Concluding remarks

We have presented a summary of the kinds of digital simulations which have been used at MSR during the past few years to design, troubleshoot, and validate a variety of radar systems. Specific examples have been drawn from the AN/MPS-36, AN/TPQ-27, and AEGIS programs. Such simulations have made a vital contribution towards the development of these systems.

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Enhancing antenna performance through multimode feeds and distribution networks

C.E. Profera

Parabolic antennas have high efficiency and gain when they are fed by electromagnetic energy that is radiating in more than one waveguide mode.

Probably the most widely used microwave antenna is the paraboloid reflector, illuminated by a source of electromagnetic energy called the feed, which is placed at the focal point of the reflector. The feed directs energy toward, and receives energy from, the reflector surface. The paraboloid reflector antenna radiates (or receives) energy in a prescribed pattern characterized by a single dominant narrow main beam or lobe and a plurality of lower-level minor lobes or sidelobes.

Reflector antennas that are required to exhibit optimum performance (generally implying maximum efficiency of antenna illumination by the feed and minimum sensitivity to external noise) are often illuminated by a Cassegrain[1] feed system as shown in Fig. 1. Such a feed system consists of a secondary hyperboloid subreflector and feed. In this configuration the feed directs and receives energy to and from the subreflector surface. The subreflector, in turn, directs and receives energy to and from the main paraboloid reflector surface.

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The feed, for either the conventional paraboloid reflector antenna or the Cassegrain antenna, is generally an electromagnetic waveguide horn connected to the associated system transmit/receive network by waveguide transmission line. The simplest horn feed that may be used is one which propagates and radiates the electromagnetic field characterizing the fundamental or dominant waveguide mode, denoted TE_{10} mode for general rectangular waveguide structures. Feeds of this type are always designed so that the only electromagnetic wave propagated and radiated characterizes the fundamental mode.

Horn antenna technology advancements in the 1960s included the discovery of a higher-order waveguide mode radiation property. When combined with fundamental mode radiation, this property produces feed radiation characterisitics leading to subsequent antenna performance enhancements.[2] The most notable improvements obtained relate to antenna efficiency. The primary advantages of this dual-mode radiation principle are reduced feed-pattern sidelobe levels and improved feed-pattern main-beam symmetry. These feed radiation properties produce lower spillover loss (i.e., feed radiation outside the boundaries of the collimating reflector system) and a symmetric reflector illumination characteristic, both of which increase antenna gain.

Additional specific higher-order waveguide modes produce the radiation-pattern characteristics necessary to perform monopulse radar tracking.[3,4] The ability to independently generate and control the multiple modes required for improved performance and monopulse tracking, within a single waveguide horn feed, has led to the development of the multimode monopulse feed. This feed configuration is the high-performance standard for tracking radar applications employing Cassegrain reflector antennas.

The low-sidelobe illumination properties provided by the multimode feeding technique are also applicable to antenna configurations employing horn feeds for phased-array antennas.[5] Multiple-mode, low-sidelobe distribution networks for both planar[6] and circular-array[7] antennas have been developed using this technique.

This paper presents the fundamentals of multimode feed techniques and describes both the reflector-antenna and phased-array applications where these techniques have been employed.

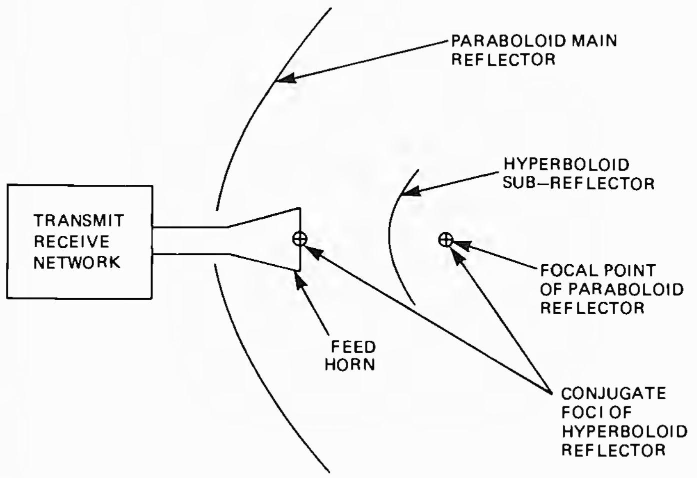


Fig. 1
Cassegrain reflector antenna system cross section illustrates the relationships among the feed horn, the confocal hyperboloid subreflector, and the paraboloid main reflector.

Multimode fundamentals

Monopulse tracking radar system requirements for reflector antennas with optimum high-gain and low-noise properties are most readily satisfied by the dual-reflector Cassegrain antenna with a multimode, monopulse feed.

This application of multimode technology is the one of most general interest at RCA MSR. Multimode fundamentals are

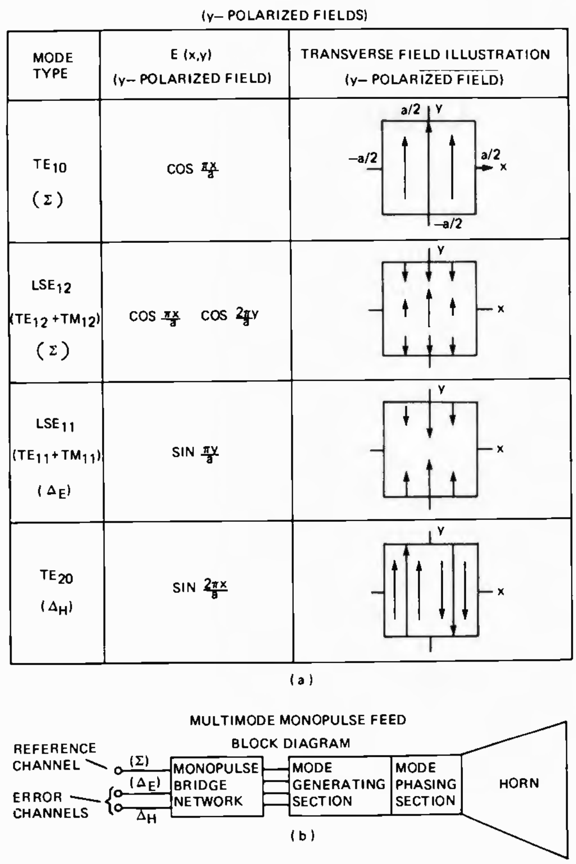


Fig. 2
Trigonometric functions and transverse electric fields are illustrated (a) to describe the feed aperture distributions produced by each of the modes of a high-performance multimode monopulse feed. The block diagram (b) shows the major functional sections of a typical multimode monopulse feed.

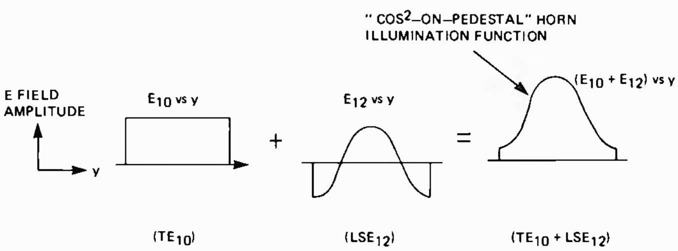


Fig. 3
E-plane feed aperture "tapering" shown here results when the TE_{10} and LSE_{12} modes are summed in a co-phased sense. The resulting "cos²-on-pedestal" distribution is produced by summing the uniform TE_{10} mode and cosine-tapered LSE_{12} mode E-plane distribution.

described here in terms of the monopulse application, but the techniques used are applicable, in a non-monopulse sense, to high-performance reflector antennas in other radar and non-radar applications.

The single-polarization waveguide mode set employed in a high-performance monopulse feed application contains the fundamental TE_{10}, and higher order TE_{12} + TM_{12} (called LSE_{12}), TE_{11} + TM_{11} (called LSE_{11}) and TE_{20} rectangular waveguide modes. The mathematical functions describing the transverse electric fields of these modes (in square waveguide) are tabulated in Fig. 2, along with their field configurations and a block diagram of a typical feed system that produces them.

The electric field composed of a sum of waveguide modes is "tapered" to control the beamwidth and sidelobe patterns of the feed.

The reference or sum channel of a conventional four-element monopulse comparator network connected to a multimode feed produces, at the feed aperture, an electric-field distribution composed of the sum of TE_{10} and LSE_{12} waveguide modes. Combining these modes produces a resultant electric-field distribution whose transverse amplitude (x-y plane), in a square feed aperture, is represented

Fig. 4
E- and H-plane sum and difference pattern functions of a well-designed multimode feed.

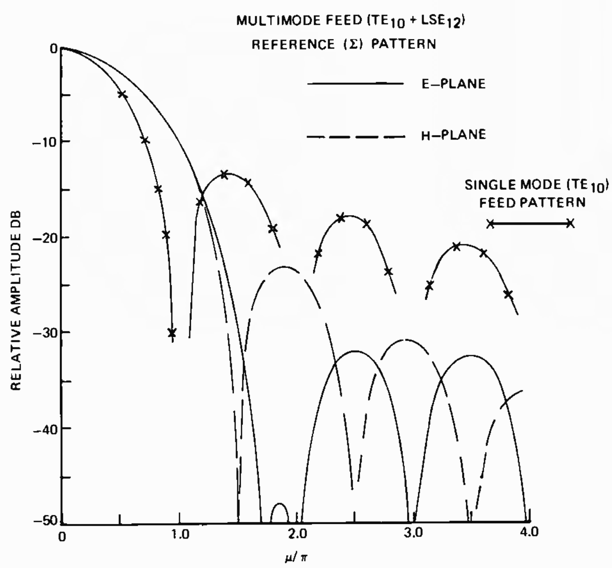


Fig. 4a
The sum patterns are compared with the fundamental mode (TE_{10}) pattern of a single horn to illustrate its lower beamwidth and higher sidelobe levels.

mathematically as

$$E_{REF}(x,y) = [1 + A_{21}\cos(2\pi y/a)]\cdot \cos(\pi x/a) \quad (1)$$
$$= 2A_{21}[T + \cos(2\pi y/a)]\cdot \cos(\pi x/a)$$

where $T = (1-A_{21})/A_{21}$

when the modes are co-phased. The distribution of E_{REF} is "cosine tapered" along the x-axis (H-plane) of the horn aperture and "cosine-squared-on-pedestal tapered" along the y-axis (E-plane), as illustrated in Fig. 3. The "cosine-squared-on-pedestal" amplitude tapering in the E-plane of the resultant distribution, which is the result of LSE_{12} mode incorporation, gives rise to the low-sidelobe and beamwidth equality (symmetry) property of dual-mode radiation. A_{21}, the ratio of LSE_{12} to TE_{10} mode amplitude, controls the E-plane beamwidth and sidelobe characteristics of the horn. For 10-dB beamwidth equality of E- and H-plane patterns, a typical design requirement for efficient illumination of a reflector antenna by a horn feed, A_{21} = 0.67.

The mathematical expression of the multimode-feed radiation-pattern function, for the reference-mode illumination characteristic of Eq. 1, is

$$g_{\Sigma}(u) = g_{10}(u) + A_{12}g_{12}(u) \quad (2)$$

where

$$g_{10} = \frac{\sin(u\sin\phi)}{u\sin\phi}\cdot\frac{\cos(u\cos\phi)}{(\pi/2)^2-(u\cos\phi)^2}$$

$$g_{12} = \frac{u\sin\phi\ \sin(u\sin\phi)}{\pi^2-(u\sin\phi)^2}\cdot\frac{\cos(u\cos\phi)}{(\pi/2)^2-(u\cos\phi)^2}$$

$u = (\pi a/\lambda)\sin\theta$
λ = wavelength
θ = angle measured from feed axis in the plane of pattern calculation
$\phi = \pi/2$ for E-plane, 0 for H-plane

Computed sum pattern functions of the multimode feed, with $A_{21} = 0.67$, are shown in Fig. 4a superimposed with the E-plane pattern function of the simpler single-mode feed. The E-plane beam broadening and sidelobe-level reduction afforded by the dual-mode technique are evident in this figure. Maximum E- and H-plane sidelobes (of the multimode feed patterns) are observed at levels of −30 dB and −23 dB respectively, relative to the pattern maximum. The 10-dB beamwidth equality and low sidelobe levels of the feed pattern produce nominally optimum illumination and spillover efficiencies for the Cassegrain reflector antenna, yielding an antenna gain that approaches the maximum available from a given aperture dimension. Reflector shaping techniques may be incorporated into the antenna design to obtain a further gain increase, but are beyond the scope of this paper. Well-designed multimode monopulse feeds are capable of providing Cassegrain reflector antenna reference efficiencies in the 55% to 65% range.

The monopulse radar tracking capability of the multimode feed derives from its ability to independently couple the monopulse comparator network difference ports to the TE_{20} and LSE_{11} waveguide modes in the multimode horn. The TE_{20} and LSE_{11} modes, whose transverse electric field configurations are also described mathematically and illustrated in Fig. 2, provide difference or monopulse error patterns along the principal x- (H-plane) and y-(E-plane) axes respectively. The H-plane difference-pattern function of the TE_{20} mode and E-plane difference-pattern functions of the LSE_{11} mode, which describe the feed error patterns, are:

$$g_{\Delta H}(u) = \sin u/(\pi^2 - u^2) \quad (3a)$$
$$g_{\Delta E}(u) = u\cos u/[(\pi/2)^2 - u^2] \quad (3b)$$

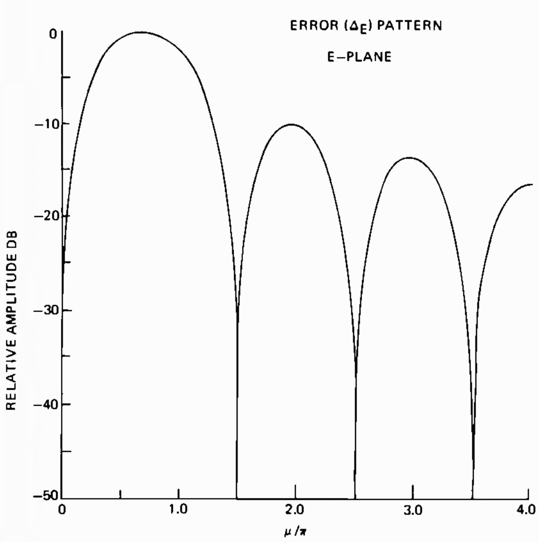


Fig. 4b
E-plane difference (monopulse error) pattern function for a multimode feed provides the radar tracking function in a single plane.

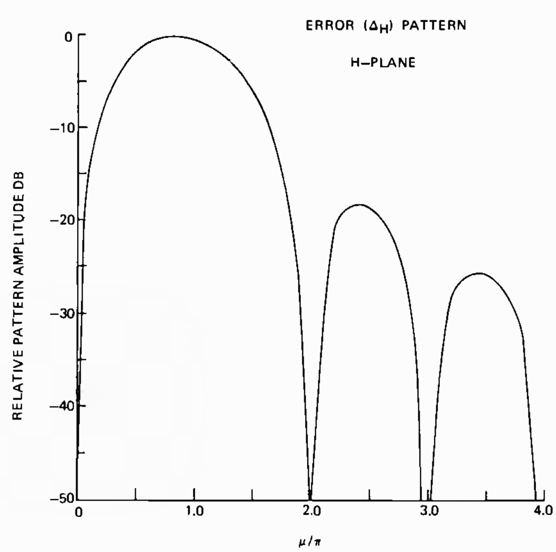


Fig. 4c
H-plane difference (monopulse error) pattern function provides the radar tracking function in a second, orthogonal plane.

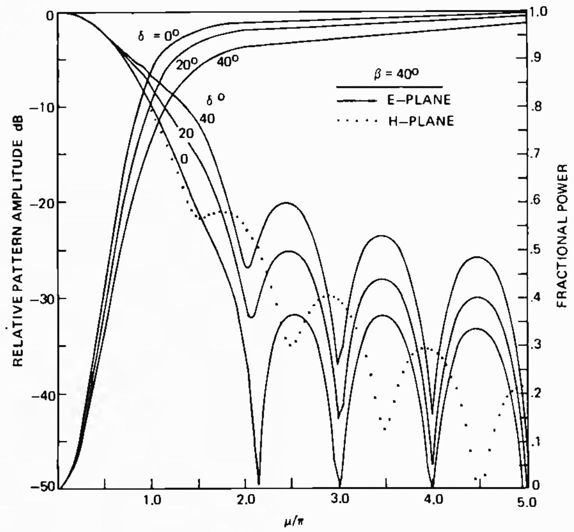


Fig. 5
Computed patterns illustrate the effects of mode phase error (δ) and horn flare angle phase error (β) on the E-plane sum patterns of the multimode feed. Note the increasing beamwidth and sidelobe levels accompanying these phase errors.

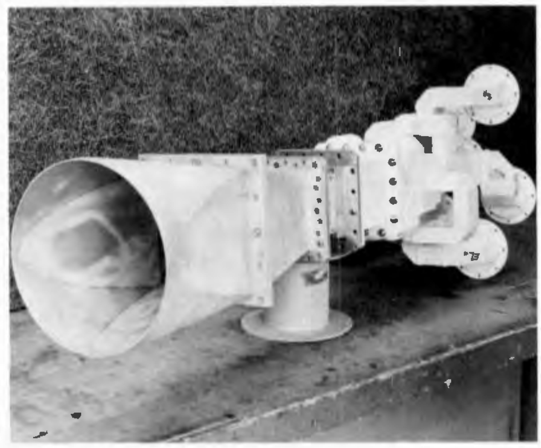


Fig. 6
RCA MSR's first high-performance multimode monopulse feed was developed for the Apollo Ships Instrumentation Radar (ASIR). This feed operated over a nominal 5.4 to 5.9 GHz frequency band.

Computed *E*- and *H*-plane difference-pattern functions of the multimode feed are illustrated in Figs. 4b and 4c, and together with the reference patterns complete the monopulse pattern set.

Antenna efficiencies associated with the difference patterns, which directly affect radar tracking sensitivity, are better for the multimode feed than for conventional four- and five-horn monopulse feeds.

This improvement is the result of a reduced difference-mode spillover loss characteristic afforded by the rotationally symmetric, low-sidelobe reference illuminations, permitting an increased angle intercept of feed radiation by the Cassegrain subreflector.

The previous multimode analysis assumed a "co-phase" condition between the TE_{10} and LSE_{12} reference modes. Since these modes do not constitute a degenerate pair (i.e., propogate with the same phase velocity), this condition will exist at only a single frequency. The relative phase shift between these modes, which is introduced by the waveguide feed structure, is a function of frequency and is the major parameter that determines the useful bandwidth of the multimode feed. Increased bandwidth is obtained with minimum relative phase difference of the TE_{10} and LSE_{12} modes, introduced by the section of feed between the mode generator and horn aperture. Feed designs requiring a 2π-radian phase shift between TE_{10} and LSE_{12} modes have been developed, and provide up to 10% useful bandwidth capability. Increased bandwidth capabilities in excess of 10% have been realized with feeds requiring a phase shift of only π radians between reference modes.

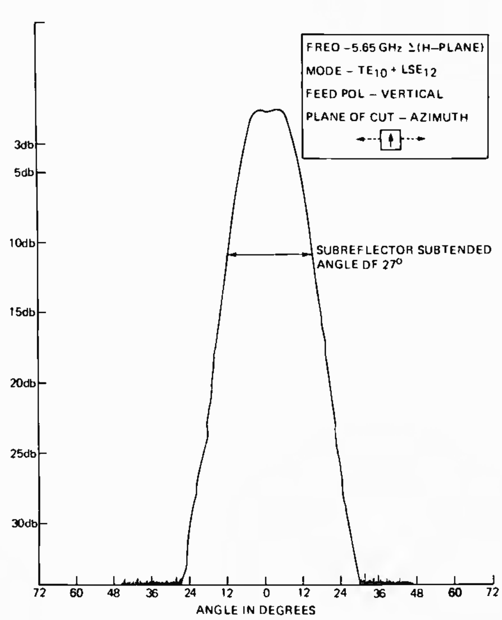
A second parameter influencing the performance capability of the multimode feed is the flare angle of the waveguide horn.

This flare angle imparts a nominal quadratic phase distribution to the transverse modal aperture illumination function, and degrades the low-sidelobe characteristics of the feed. The effect of phase difference between the TE_{10} and LSE_{12} modes at the horn aperture and the quadratic phase distribution produced by the horn flare angle are illustrated in the computed *E*- and *H*-plane reference-pattern data of Fig. 5. This data illustrates the *E*- and *H*-plane pattern functions of a square-aperture horn with dual-mode sum illumination, where a relative-mode phase difference and quadratic phase distribution are assumed.[8] The fractional power distribution of the complex pattern is superimposed on this data so that the fractional power content of any angular portion of the feed pattern can be determined or the feed spillover losses can be estimated. Data shown in Fig. 5 assumes a relative phase difference between modes of 0°, 20°, and 40°, coupled with a maximum quadratic phase error of 40°, introduced by the horn flare angle. The variation of *E*- and *H*-plane pattern beamwidths and degradation of *E*-plane sidelobe levels attributable to these effects are evident in the figure. A rule of thumb for high-performance multimode feed designs restricts the maximum-mode phase error to ±10° over the operational bandwidth, with a maximum quadratic phase error due to horn flaring of less than 50°.

Multimode feed developments at MSR

The first of the high-performance multimode monopulse feeds for Cassegrain antennas developed at MSR was the ASIR (Apollo Ships Instrumentation Radar) feed.

This feed, shown in Fig. 6, was designed for operation over the 5.4- to 5.9-GHz radar



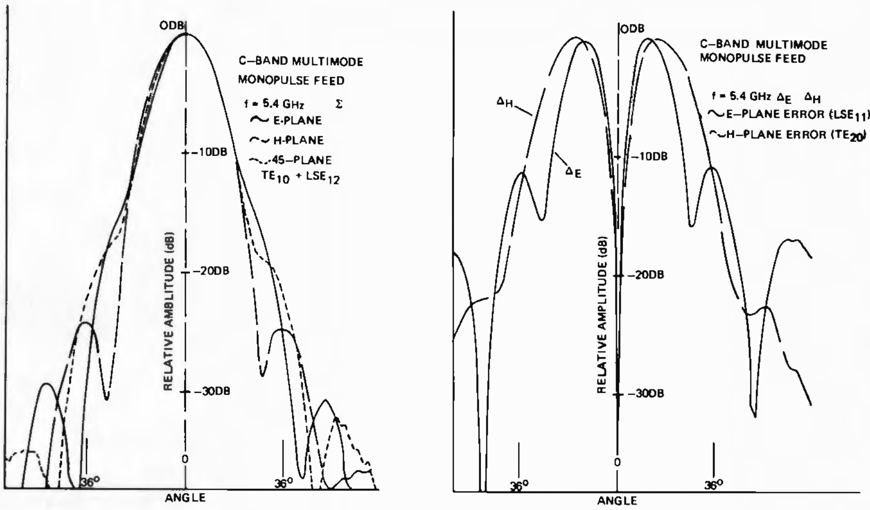


Fig. 7
Measured sum and difference patterns of the ASIR multimode monopulse feed.

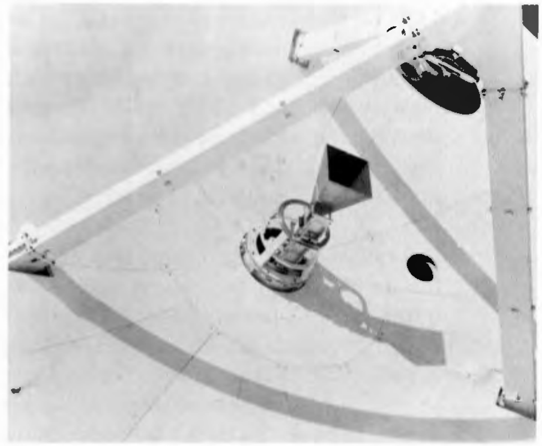


Fig. 8
Near-field multimode monopulse feed installed in a 29-foot diameter Cassegrain antenna. Operating frequency range was nominally 5.4 to 5.9 GHz.

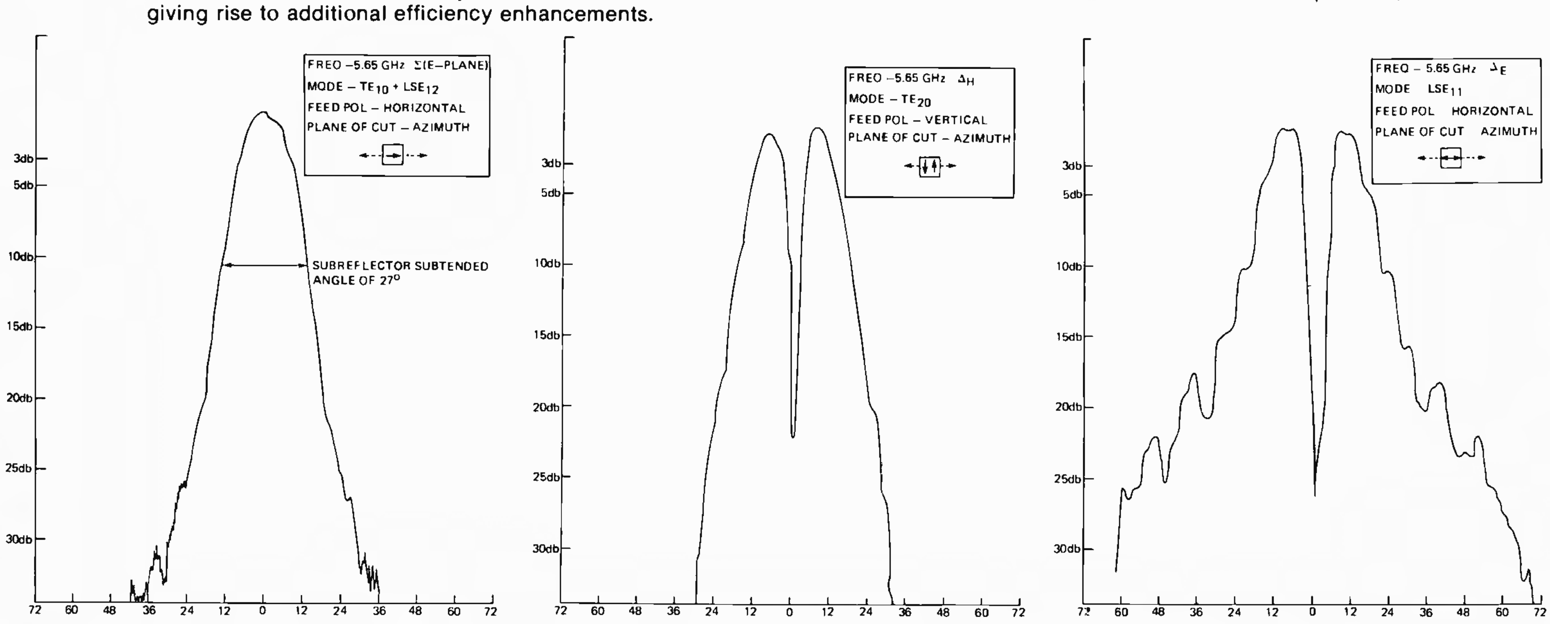
band, and was subsequently used in 16- and 12-ft-diameter Cassegrain reflector antenna systems. The feed employed a circular-aperture horn to obtain additional pattern improvements. Measured sum and difference patterns obtained from the feed, shown in Fig. 7 demonstrate the low-sidelobe reference-pattern available with multimode techniques. The antenna efficiency, determined by analysis of feed radiation pattern data and later verified by gain measurements on the antenna configuration, was nominally 60 to 65%.

A subsequent feed development at RCA MSR combined the advantages of multimode excitation and near-field horn radiation properties to achieve a further improvement of Cassegrain antenna efficiency.[9] The near-field multimode, monopulse feed employed the mode-generating network of the multimode feed in an electrically large pyramidal horn, and produced reference patterns that were essentially free of sidelobes. Spillover efficiencies obtained from this feed were thereby increased relative to the previous multimode feed. Although only useful in large Cassegrain reflector antenna configurations,[10] this marriage of techniques produced antenna efficiencies greater than 70%. Fig. 8 is a photograph of the near-field, multimode monopulse feed in a 29-ft.-diameter FPQ-6 Cassegrain reflector configuration. Measured monopulse feed pattern data is shown in Fig. 9, illustrating the improved low-sidelobe reference-pattern characteristics obtained.

Recent multimode, monopulse feed developments at MSR have addressed increased bandwidth capabilities and reducing the cross-polarization crosstalk problems inherent in all monopulse feeds.

A K_u-band multimode monopulse feed for a small Cassegrain antenna has been developed that permits operation over a

Fig. 9
Measured sum and difference patterns of the near-field feed. Note the virtual absence of sidelobes in the sum feed patterns, giving rise to additional efficiency enhancements.



14.7- to 15.6-GHz frequency band.[11] This feed uses a mode-generation technique requiring a π-radian relative phase shift between TE_{10} and LSE_{12} modes, thereby deriving the wide bandwidth capabilities. Fig. 10 is a photograph of this feed in a 26-in.-diameter Cassegrain geometry.

The mode-generating technique developed for the described feed above was incorporated in a K_a-band (34.5 - 35.5 GHz) feed design because of its attractive low-depolarization characteristic. This feed was combined with other selective mode-tuning devices to produce a multimode monopulse feed system with significantly reduced difference-channel, cross-plane depolarization. Using this design has reduced difference-channel depolarization by greater than 10 dB.

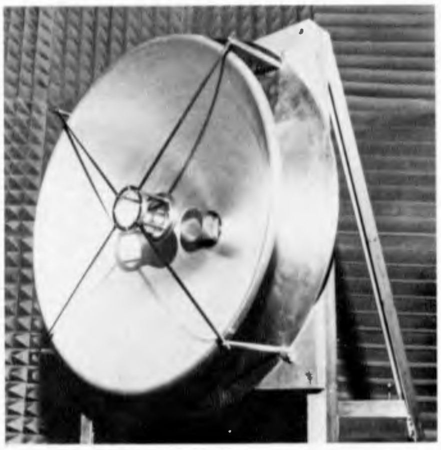


Fig. 10
A new wideband multimode monopulse feed for a small Cassegrain antenna. The new mode-generating technique has doubled bandwidth capabilities.

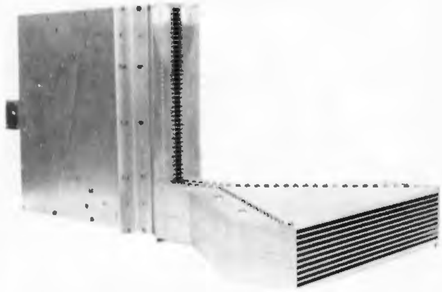


Fig. 11
Dual-mode sectoral horn power divider for a single-plane-scanned, low-sidelobe phased array. The low-loss "optical divider" properties of this horn make it attractive for millimeter-wave array applications.

Several unique array-feed concepts have been demonstrated and developed at MSR using the low-sidelobe properties of the dual-mode illumination characteristic.

A millimeter-wave planar-array configuration, developed by MSR under contract to NASA, employed a dual-mode *E*-plane sectoral horn as a constrained power divider.[5,6] This power divider, which is shown feeding a portion of the array in Fig. 11, was incorporated with a 50-element linear array of *H*-plane sectoral horn elements. The result was a low-loss, low-sidelobe planar phased array with wide-angle, single-plane electronic scan capabilities. Power division was accomplished by terminating the continuous aperture of the dual-mode, *E*-plane sectoral horn with a linear *E*-plane array of waveguide elements. These elements fed, in turn, phase shifters and the *H*-plane sectoral horn radiating elements of the array.

An experimental model of the complete array is shown under test conditions in Fig. 12. The phased-array model was designed to operate over a 15.2- to 16.8-GHz frequency band with a ±60° *E*-plane scan capability. Principal-plane pattern data obtained from this antenna for a 0° and 40° scanned beam is shown in Fig. 13. The dual-mode technique produced broadside *E*-plane array patterns at 16.0 GHz with maximum sidelobes below −28 dB. *H*-plane patterns of the array at this frequency were characterized by a maximum sidelobe of −39 dB. Pattern characteristics were nominally equivalent over the full design bandwith.

Sidelobe deterioration with scan angle is an intrinsic property of planar arrays; hence, the 40° *E*-plane scan patterns exhibited a somewhat increased maximum sidelobe level. Although not specifically developed for a radar application, the addition of a monopulse tracking capability to this array was demonstrated by generating a difference mode within the *E*-plane sectoral horn power divider and measuring the resulting array difference patterns.

A second array application of dual-mode power division techniques was realized at MSR by using a dual-mode radial waveguide power divider as a feed for a circular array antenna.[7] An X-band (7.9-8.5 GHz) model of a dual-mode, radial-waveguide, 16-way power divider is shown in Fig. 14, and an experimental model of a 64-element circular array antenna employing the power divider is shown in Fig. 15. Radiation patterns of this array demonstrated maximum sidelobes of −23 dB.[12] A monopulse tracking capability is also available for radar application of the circular array by using an orthogonal radial waveguide mode of the already available dual-mode set.

Conclusions

The low-sidelobe properties of dual or multimode illumination functions characterizing several waveguide types have been applied by MSR to a variety of antenna applications. The most widely used application of multimode technology has been for the design of high-performance monopulse feed systems for Cassegrain antennas. The combination of multimode and near-field radiation properties of horn feeds has resulted in further feed performance improvements. Wideband applications of multimode techniques have been demonstrated by minimizing the differential reference-mode

Chuck Profera joined RCA MSR as a member of the Antenna/Microwave group in 1959. With the exception of a two-year period, during which he attended Drexel University as a Sarnoff Fellow, he remained a member of that activity until June 1977, when he assumed his present position as MSR's coordinator of Independent Research and Development.

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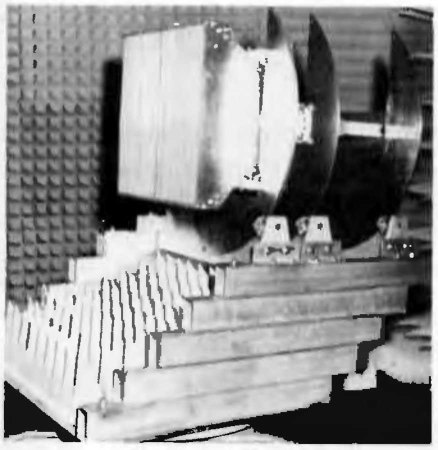

Fig. 12
Low-sidelobe phased array with dual-mode horn power divider undergoing testing in an MSR anechoic chamber.

phase shift introduced by the feed system. These newer mode-generation techniques have led to monopulse feed designs with significantly reduced difference-channel, cross-plane depolarization.

The application of dual-mode, low-sidelobe illumination techniques has also been extended to use with planar and circular arrays. Most noteworthy performance has been obtained from a planar-array antenna using multimode sectoral-horn power-divider techniques. This array provided wideband, low-sidelobe antenna-pattern characteristics with a single-plane ±60° electronic scan capability.

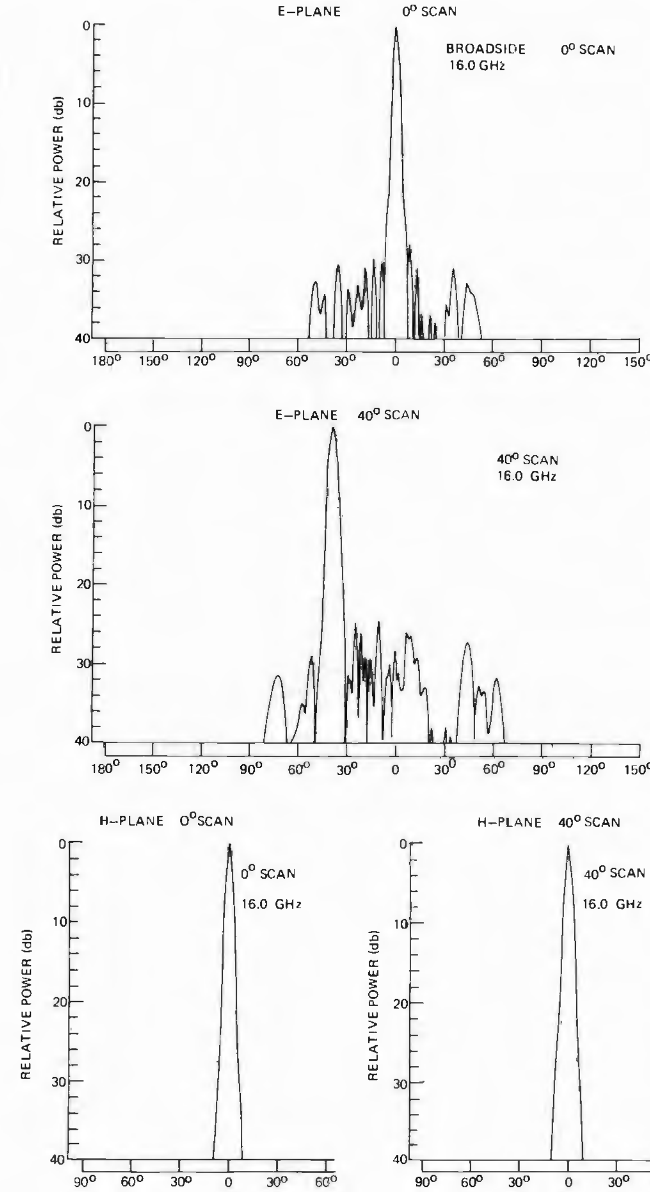

Fig. 13
E-(scan plane) and H-plane patterns of the low-sidelobe phased array with dual-mode sectoral horn power divider.

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Fig. 14
Low-loss dual-mode radial waveguide power divider for feeding a circular cylindrical array antenna.

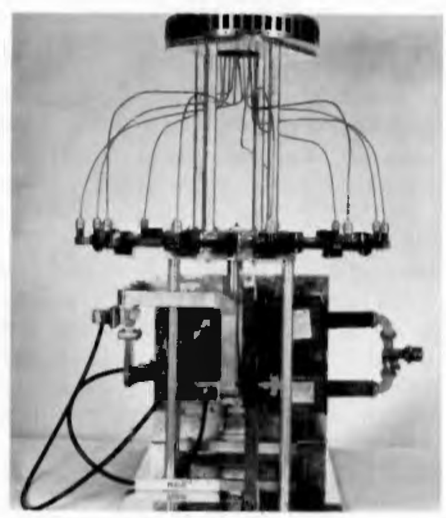

Fig. 15
X-band model of a circular array antenna with the radial waveguide dual-mode power divider. This configuration is capable of producing a beam that can be scanned 360° in a single plane.

on the job/off the job

Electronic speed control for model railroad realism

W.S. Pike

Electronic speed control of miniature locomotives enables this hobbyist to simulate realistic operation of his trains.

The N-gauge Susquehanna Southern Railway exists principally for the purpose of hauling coal from the mines in the mountains above the headwaters of the Susquehanna River to the port city of Susquehanna. Although coal traffic is the line's major source of revenue, passenger service has recently been expanded to cope with the increasing number of tourists attracted to this picturesque region.

Why electronic speed control?

In the initial stages of the railroad's existence, locomotive speed was controlled by using a conventional variable series resistance controller. This type of controller, as most model railroaders know, is not very satisfactory, leading to "jack-rabbit" starts, unrealistically abrupt stops, and difficulties in slow-speed running. One of the solutions to the problem is to use unidirectional pulses of variable duty cycle rather than dc for traction power. However, this tends to make the tiny permanent-magnet motors in the engine run hot, so that many variable-duty-cycle controllers also incorporate provision for either automatic or manual switchover to dc running. Our throttle is of the latter variety.

It is also desirable to incorporate an "inertia" circuit to simulate the "coasting" of real trains. This may be done with a diode and capacitor, which delays the fall of track voltage when the throttle is closed. Often a "brake" control is added, comprising one or more resistors which can be switched across the "inertia" capacitor to increase its rate of discharge. We have found it prudent also to include a "panic" button which short circuits the inertia capacitor so that a quick stop can be achieved in the event of imminent catastrophic collision.

Throttle operation

Fig. 1 depicts the Susquehanna Southern Railway control panel on which the throttle circuit is mounted. The throttle controls are at the edges of the panel. Also on the panel is the mimic diagram of the trackage. The duplicate throttle system permits each block of the layout to be powered from either throttle to permit simultaneous operation of two trains.

The large knob labeled SEL and BRAKE controls the various operating modes of the throttle. In the extreme counter-clockwise position, labeled "pulse," pulses of approximately 12 V amplitude at a 100-Hz repetition rate are applied to the tracks. As the THROTTLE knob at the top is advanced clockwise, the duty cycle of the pulses changes smoothly from 5% on and 95% off to 95% on and 5% off. The average dc value of this waveform thus changes from about 0.6 V to about 11.4 V. This range of control will permit extremely smooth starting of most N-gauge locomotives. They may also be made to inch along the track (if the track and wheels are clean) at one or two scale miles per hour or run up to any desired fraction of full speed.

No inertia is provided in the pulse mode of operation as it is advantageous (though less challenging to the operator) for

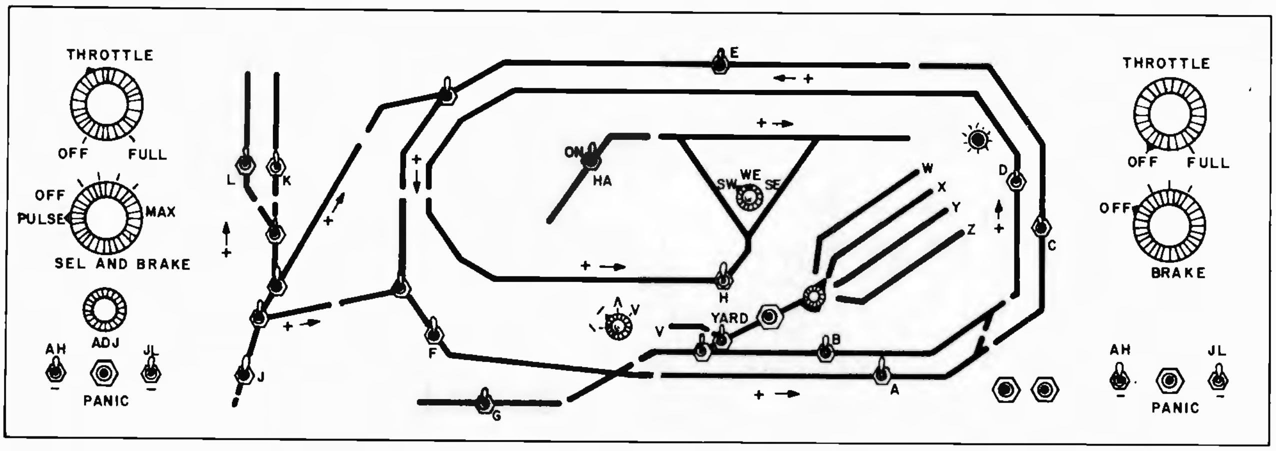

Fig. 1
Control panel of Susquehanna Southern Railway. Dual throttle control system permits simultaneous powering of two trains. Route selection and power switching of trains is accomplished by toggle and modified rotary switches.

some critical switching moves to have one throttle mode without inertia.

Moving the SEL and BRAKE knob to the next position changes over to dc operation with inertia. Thus a train may be started on pulse power and then changed over at any time to dc running. In the dc position, most of the Susquehanna Southern Railway's motive power will permit a locomotive to coast about three-fourths of a scale mile when unloaded and somewhat less when hauling a train. Braking action is available in five steps by advancing the SEL and BRAKE knob further clockwise. The PANIC button may be seen at the bottom of the panel between a pair of reversing switches.

Win Pike joined RCA Laboratories in 1946. The recipient of five RCA Laboratories Achievement Awards, he has worked on a variety of projects including reading machines for the blind, standard and special-purpose television cameras and receivers, equipment for automatic driving, and solid-state sensors. In addition to building model railroads for a hobby, he also works on pipe and electronic organs.

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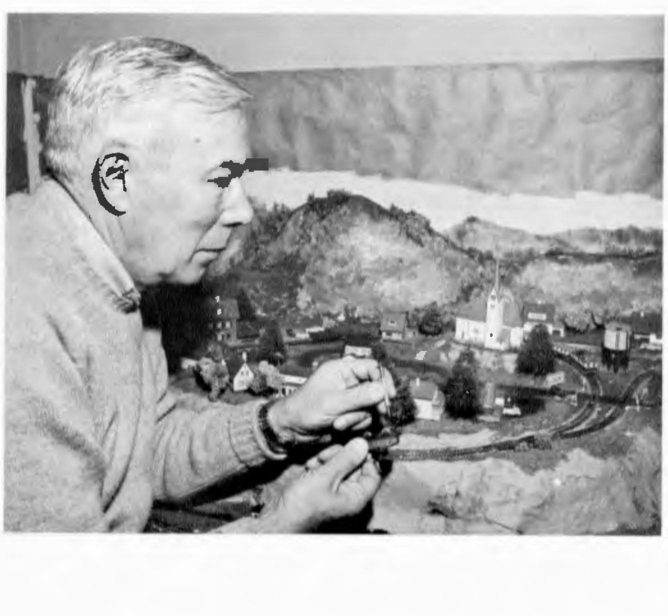
Throttle circuit theory

Although there are many fine published circuits for accomplishing all this, the engineering department of the Susquehanna Southern Railway decided to design its own throttle circuit. A block diagram of the result is shown in Fig. 2. A COS/MOS CD4047 integrated circuit wired as an astable multivibrator clocks the entire system at about 100 Hz. This is followed by a second CD4047 connected as a one-shot multivibrator. The THROTTLE knob adjusts the pulse width of the one shot within the limits previously described. In the "pulse" position of the mode selector



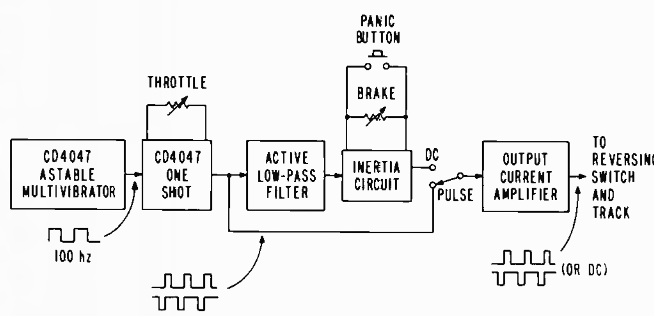


Fig. 2
An advantage of the author's throttle circuit design is that the same throttle potentiometer can be used for either dc or pulse operation without requiring complicated switching.

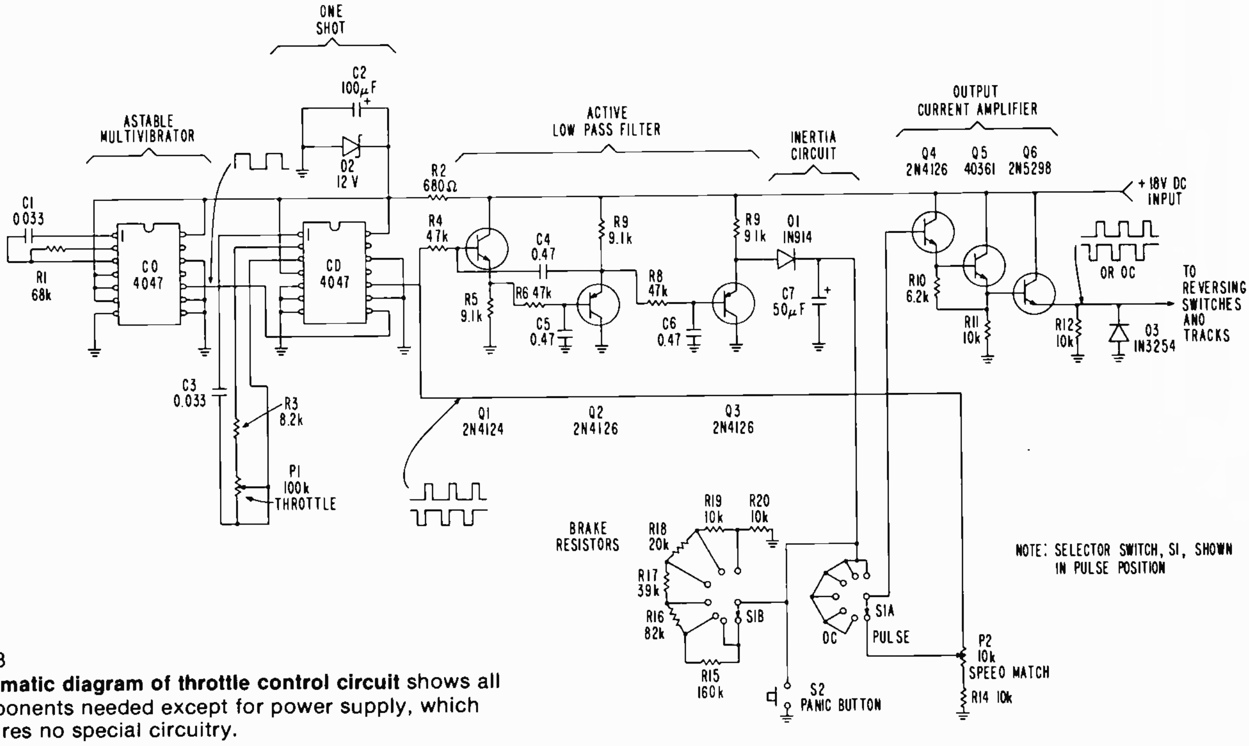


Fig. 3
Schematic diagram of throttle control circuit shows all components needed except for power supply, which requires no special circuitry.

control, the output of the one shot is applied without further processing via a Darlington current amplifier to the track. In the dc mode, an active low-pass filter with a turnover frequency of about 10 Hz (and a rate of cutoff of 18 dB/octave) and the diode/capacitor inertia circuit with its brake resistor are interposed between the one-shot and the current amplifier. The low-pass filter extracts the average dc value of the 100-Hz pulses and presents it to the output amplifier, thus permitting the same throttle potentiometer to be used for both dc and pulse operation without any switching complications. A reverse-biased diode is shunted across the output, mainly to protect the throttle circuitry from damage if a train happens inadvertently to enter a block already energized from the second throttle circuit and set for the opposite direction of travel (opposite polarity).

Throttle circuit design

The complete throttle control circuit is shown in Fig. 3. The CD4047 astable and monostable multivibrators require little comment. Potentiometer P1 is the throttle potentiometer controlling the pulse width of the monostable. Transistors Q1, Q2, and Q3 comprise the active low-pass filter, basically the well-known Sallen and Key configuration with one added RC section. Diode D1 and capacitor C7 comprise the "inertia" circuit, R15 through R20 are the braking resistors, and Q4, Q5, and Q6 comprise the Darlington-connected output current amplifier. Transistor Q6 is mounted on a heat sink. Diode D3 serves as the protective device.

Potentiometer P2 (visible in Fig. 1 just above the PANIC button and labeled ADJ), provides a means of adjusting the match between locomotive speed when running on pulse power and running on dc. It allows a limited adjustment of the pulse amplitude applied to the output amplifier. In practice, I have found that different locomotives sometimes require slightly different settings of this control to ensure a smooth mode transition from pulse to dc and vice versa.

If any reader chooses to duplicate this circuit, I should perhaps caution that depending on the tolerances of the timing components in the multivibrators, R3 and C3 may require tailoring to ensure that the one-shot varies smoothly from minimum to maximum duty cycle without entering a frequency-halving region at full throttle or ceasing operation at minimum throttle. Another possible modification would be to include "inertia" on opening the throttle. This may be done by adding resistance in series with D1.

I have not shown the details of the 18-V raw dc source which energizes the throttle circuit, as no special circuitry is required. Our supply comprises a transformer, bridge rectifier, and 5500-microfarad filter capacitor. Note, however, that the COS/MOS multivibrators are isolated from this supply by a resistor, R2, Zener diode, D2, and capacitor, C2.

The author will be glad to answer inquiries from anyone interested in duplicating this circuit, which has been in successful operation on the Susquehanna Southern Railway for over two years.

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Final manuscript received December 29, 1977.

Building control circuitry, collecting trains, and designing the track layout for an N-gauge system are just part of the fun for a model railroader. These views of the author's "Village of Gap" in the Susquehanna Valley show the realism in detail put into building the structures and scenery.

Ed. Note: Although the subject of this article is electronic speed control, model railroad buffs most certainly will want additional details on Win Pike's railroad system. The following gives some construction and operating particulars about his Lilliputian transportation network. *FJS*

The Susquehanna Southern Railroad, an N gauge (9 mm between running rails) model railroad is constructed entirely on a standard 36-inch wide, flush door. A sheet of Homasote is glued to the top surface of the door, and the raised portions of the railroad have been constructed by the "cookie cutter" method, raising and supporting the Homasote where necessary with glued-in wooden supports.

Scenery is made up of plaster on wire screen, again supported where necessary with wooden framing. Although this method of construction is not as flexible as open benchwork, it is simple to make and, particularly with N gauge, results in quite a lot of readily portable railroad in a small space.

The structures visible in the photographs are a mixture of commercial plastic model kits and scratch-built buildings. The backdrop (as yet unfinished) is in the process of being painted by the author's son, Eric Pike.

The trackage contains 16 separate blocks and 15 electrically operated track switches, including two double slip switches (to save space). All but two of these switches are commercial units using conventional, double-coil mechanisms. The remaining two, which are more satisfactory, are driven by "hook lever" type, single-coil mechanisms "liberated" from a defunct pipe organ. Because of their size, these mechanisms are concealed under the scenery.

Most of the wiring is simple; a double-throw, double-pole, center-off switch associated with each block permits powering it from either of the two power supplies. However, in a few areas, notably the upper level wye (visible in the center of the control panel) route selection and power switching have been combined into a single rotary switch which has been modified to include a coaxial pushbutton. One selects the desired route by rotating the switch, then pushing the button to align the track switches to the selected route. A similar system is used in the yard area of the railroad.

An extension running down the side wall of the room in which the railroad is housed is planned for a later date. This will connect on to the existing trackage and will probably require a second control panel.

Rolling stock comprises a mixture of European and American models and includes 2 diesel locototives, 2 steam locomotives, and 2 electric locomotives. In operation, most trains are kept fairly short because of the relatively sharp curves and the 4% gradient to the upper level.

The 1978 David Sarnoff Awards for Outstanding Technical Achievement

RCA's highest technical honors have been announced for 1978. Each award consists of a gold medal and bronze replica, a framed citation, and a cash prize.

Albert Feller

Advanced Technology Laboratory, Camden, N.J.

For outstanding achievement in the use of computer-aided design techniques for large scale integrated circuits.

Feller

At a 1977 IEEE workshop on the use of computer-aided design approaches, it was indicated that RCA's system for LSI design is the most advanced in the industry. Al Feller is the prime contributor to this advanced position. His work in the development of computer-aided standard-cell LSI array design and technology resulted in the development of advanced signal-processing equipment for RCA communication and radar systems. These same design approaches have also allowed cost-effective development of semiconductor products. He made specific contributions to: APAR, the automatic placement and routing program for CMOS standard-cell arrays; the SUMC-DV computer for NASA, in CMOS and CMOS/SOS form; an automotive on-board processor; the multiport two-dimensional placement and routing program; the ATMAC microprocessor; and radiation-hardened CMOS/SOS standard-cell LSI arrays.

Adam

Aires

Clark

Davis

Gorski

Katagi

Sasaki

Kenneth C. Adam | Ramon H. Aires Charles A. Clark, Jr. | William J. Davis John C. Gorski | Kazuo Katagi | Akira Sasaki

Avionics Systems, Van Nuys, Calif.

For outstanding technical achievement in the development of airborne color weather radar indicators.

RCA's PriMUS-90 and -400 ColoRadar units were industry's first airborne weather radars to use color indicators. The new designs also provide four times the resolution of previous digital-memory-refreshed indicators, and allowed the use of a standard color crt by converting the radar scan from polar coordinates to x-y (tv-style) scan. The design team worked very quickly; RCA was thus able to announce color radar availability significantly ahead of the competition and even go to production ahead of schedule. Customer acceptance for the color-indicator radars has been above expectation, so much so that production schedules had to be accelerated twice during the first nine months after announcement.

David W. Luz|James A. McDonald|John C. Peer

Consumer Electronics Division, Indianapolis, Ind.

For outstanding team achievement in the development of scan and power supply systems for color television.

All of the color-tv sets now being manufactured by Consumer Electronics enjoy the benefits of this team's design effort: better power efficiency; substantially lower cost; and improved scan and high-voltage performance. These benefits come from combining the functions of horizontal deflection and power supply regulation. A weighted average of power consumption for the "XtendedLife" models is 92 W; the immediately preceding line had a weighted power average of about 135 W. The improved efficiency and reduced power consumption are expected to contribute substantially to the reliability and life-cycle savings of the "XtendedLife" sets. Improved performance results from the excellent scan stability, which is independent of line and load variations. RCA's "XtendedLife" XL-100 and ColorTrak receivers, which use the new design, have been successful in terms of sales and reliability.

Luz

McDonald

Peer

Fernand F. Martin|Samuel Waldstein|Jason H. Woodward

Automated Systems, Burlington, Mass.

For excellence of team effort in the product development of a hand held laser rangefinder.

The AN/GVS-5 laser rangefinder is as much as ten times improved over previous rangefinder designs in terms of weight, power consumption, and cost, while meeting or exceeding the operational characteristics of its predecessors. For example, the previous 25-lb. units cost $30,000 apiece to produce, but the 5-lb. AN/GVS-5 is producible for under $4,000. Army users can now determine the range to targets instantly, and can make up to seven hundred 10,000-meter range measurements with one charge of the self-contained 8-oz. battery. The success of the rangefinder design (present orders total $30 million) is based in large part on the rangefinder's design-to-unit-cost program, which combined the efforts of the design and production teams to produce the best tradeoff among size, weight, power consumption, availability of parts and materials, and cost.

Martin

Waldstein

Woodward

Murray A. Polinsky|Otto H. Schade, Jr.

Solid State Division, Somerville, N.J.

For outstanding technical achievement in the development of high performance BiMOS integrated circuits.

BiMOS integrated circuits, which combine bipolar and MOS transistors on the same chip, are a unique development of the Solid State Division. The circuits have the outstanding performance characteristics of each type of transistor, and so have been very popular, with millions per year sold. The applications for BiMOS so far have included operational amplifiers, comparators, smoke detectors, and television digital tuning circuits. Murray Polinsky's process engineering work greatly simplified the method of fabricating the MOS and bipolar devices on the same chip, and Otto Schade had the prime responsibility for the circuit design.

Polinsky

Schade

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Dates and Deadlines

Upcoming meetings

Ed. Note: Meetings are listed chronologically. Listed after the meeting title (in bold type) are the sponsor(s), the location, and the person to contact for more information.

MAY 1-3, 1978—**Microwave Power Tube Conf.** (IEEE) Naval Postgraduate School, Monterey, CA **Prog Info:** Dr. George Caryotakis, Varian Assoc., 611 Hansen Way, Palo Alto, CA 94308

MAY 6-11, 1978—**American Ceramic Soc. 80th Annual Mtg. & Expo.** (ACS) Cobo Hall, Detroit, MI **Prog Info:** Frank P. Reid, Exec. Director, The American Ceramic Society, Inc., 65 Ceramic Drive, Columbus, OH 43214

MAY 10-12, 1978—**Conf. on Software Engrg.** (IEEE, NBS) Hyatt Regency Hotel, Atlanta, GA **Prog Info:** Harry Hayman, Conf. on Software Engrg., PO Box 639, Silver Spring, MD 20901

MAY 15-19, 1978—**Intl. IEEE/AP Symp. & USNC/URSI Mtg.,** (IEEE, AP, USNC/URSI) Adult Education Ctr., Univ. of MD, College Park, MD **Prog Info:** G. Hyde, Room 2146, Comsat Labs., Box 115, Clarksburg, MD 20734

MAY 16-18, 1978—**NAECON (National Aerospace & Electronics Conf.)** (IEEE) Dayton Convention Ctr., Dayton, OH **Prog Info:** NAECON, 140 E. Mounument Ave., Dayton, OH 45402

MAY 17-19, 1978—**Circuits & Systems Intl. Symp.** (IEEE) Roosevelt Hotel, New York, NY **Prog Info:** H.E. Meadows, Dept of Elec. Engineering & Computer Science, Columbia Univ., New York, NY 10027

MAY 18, 1978—**Trends & Applications: Distributed Processing** (IEEE, NBS) Natl. Bureau of Standards Conv. Ctr., Gaithersburg, MD **Prog Info:** Ms. Helen Wood, NBS, Bldg. 225 B 212, Washington, DC 20234

MAY 23-25, 1978—**Electro/78** (IEEE) Boston-Sheraton, Hynes Auditorium, Boston, MA **Prog Infor:** W.C. Weber, Jr., IEEE Electro, 31 Channing St., Newton MA 02158

MAY 29-JUN 1, 1978—**Intl. Quantum Electric Conf. (10th)** (IEEE) Atlanta, GA **Prog Info:** Joseph Giordmaine, Bell Labs, 600 Mountain Ave., Murray Hill, NJ 07974

JUN 4-7, 1978—**Intl. Conf. on Communications** (IEEE, et al) Sheraton Hotel, Toronto, Ont. **Prog Info:** F.J. Heath, Power System Operation Dept., Ontario Hydro Electric Power System, 700 Univ. Ave., Toronto, Ont.

JUN 5-8, 1978—**Natl. Computer Conf.** (AFIPS, IEEE, ACM) Anaheim Conv. Ctr., Disneyland Hotel Comp., Anaheim, CA **Prog Info:** Stephen Miller, SRI Intl., ISE Division, Menlo Park, CA 94025

JUN 5-8, 1978—**13th Photovoltaic Spec. Conf.** (IEEE) Shoreham Americana Hotel, Washington, DC **Prog Info:** John Goldsmith, M/S 169/422, JPL, 4800 Oak Grove Dr., Pasadena, CA 91103

JUN 12-13, 1978—**Microcomputer Based Instrumentation** (IEEE) Natl. Bureau of Standards Conf. Facil., Gaithersburg, MD **Prog Info:** Bradford Smith, A-130 Technology, Natl. Bureau of Standards, Washington, DC 20234

JUN 13-15. 1978—**Power Electronics Specialist Conf.** (IEEE) Syracuse, NY **Prog Info:** F.B. Goldin, Mail Drop 30, General Electric, Genessee Street, Auburn, NY 13021

JUN 19-21, 1978—**Design Automation** (IEEE) Caesar's Palace, Las Vegas, NV **Prog Info:** S.A. Szygenda, Univ. of Texas at Austin, Dept. of Elect. Engr., Austin, TX 78712

JUN 20-22, 1978—**Pulsed Power Modulator Conf.** (IEEE) Statler Hilton, Buffalo, NY **Prog Info:** Sol Schneider, U.S. Army, ERADCOM, Code DREL-TL-BG, Fort Monmouth, NJ 07703

JUN 21-23, 1978—**Machine Processing of Remotely Sensed Data** (IEEE) West Lafayette, IN **Prog Info:** D. Morrison, Purdue Univ. LARS, 1220 Potter Drive, West Lafayette, IN 47906

JUN 26-28, 1978—**Device Research Conf.** (IEEE) Univ. of Calif., Santa Barbara, CA **Prog Info:** Dr. James McGroddy, IBM, T.J. Watson Research Ctr., Yorktown Heights, NY 10598

JUN 26-29, 1978—**Conf. on Precision Electromagnetic Measure** (IEEE, NBS, URSI/USNC) Conf. Ctr., Ottawa, Ont. **Prog Info:** Dr. Andrew F. Dunn, Natl. Research Council, Montreal Road, Ottawa, Ont.

JUN 27-29, 1978—**Intl. Microwave Symp.** (IEEE, et al) Chateau Laurier, Ottawa, Ont. **Prog Info:** A.L. VanKoughnett, Communications Research Ctr., POB 11490, Station H, Ottawa, Ont. K2H 8S2

JUL 18-21, 1978—**Nuclear & Space Radiation Effects** (IEEE) Univ. of New Mexico, Albuquerque, NM **Prog Info:** B.L. Gregory, Sandia Labs., Dept. 2140, Albuquerque, NM 87115

AUG 20-25, 1978—**Intersociety Energy Conversion Engr. Conf.** (IEEE) Town & Country Hotel, San Diego, CA **Prog Info:** George P. Townsend, Hamilton Standard Div., United Technologies Corp., Windsor Locks, CT 06096

AUG 22-25, 1978—**Intl. Conf. on Parallel Processing** (IEEE) Shanty Creek Lodge, Bellaire, MI **Prog Info:** Prof. T.Y. Feng, Dept. of Elect. & Comp. Engr., Wayne State University, Detroit, MI 48202

SEP 5-8, 1978—**COMPCON FALL** (IEEE) Washington, DC **Prog Info:** COMPCON FALL, P.O. Box 639, Silver Spring, MD 20901

SEP 6-8, 1978—**Intl. Optical Computing Conf.** (IEEE) Imperial College, London, Eng. **Prog Info:** S. Horvitz, Box 274, Waterford, CT 06385

Calls for papers

Ed. Note: Calls are listed chronologically by meeting date. Listed after the meeting (in bold type) are the sponsor(s), the location, and deadline information for submittals.

JUN 13-15, 1978—**Automated Testing for Electronics Mfg.** (ATE) Boston Park Plaza Hotel, Boston, MA **Deadline Info: ab. 200-500 wds. and short biog. to:** Sheila Goggin, ATE Seminar/Exhibit Coordinator, Circuits Mfg. Magazine, 1050 Commonwealth Ave., Boston, MA 02215

OCT 9-11, 1978—**Semiconductor Laser Conf. (6th)** (IEEE) Hyatt Regency Hotel, San Francisco, CA **Deadline Info: 6/15/78 to** T.L. Paoli, Bell Laboratories, 600 Mountain Ave., Murray Hill, NJ 07974

OCT 11-12, 1978—**3rd Specialist Conf. on Tech. of Electroluminescent Diodes** (IEEE) Hyatt Regency Hotel, San Francisco, CA **Deadline Info: 6/15/78 to** R.N. Bhargava, Phillips Lab., Briarcliff Manor, NY 10510

NOV 7-9, 1978—**PLANS '78 (Position Location & Navigation Symp.)** (IEEE) San Diego, CA **Deadline Info: 5/15/78 to** Nelson Harnois, Cubic, PO Box 80787, San Diego, CA 92138

DEC 4-6, 1978—**Natl. Telecommunications Conf.** (IEEE) Hyatt Hotel, Birmingham, AL **Deadline Info: 5/78 to** H.T. Uthlaut, Jr., South Central Bell, PO Box 771, Birmingham, AL 35201

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Recent RCA technical papers and presentations

To obtain copies of papers, check your library or contact the author or his divisional Technical Publications Administrator (listed on back cover) for a reprint. For additional assistance in locating RCA technical literature, contact RCA Technical Communications, Bldg. 204-2, Cherry Hill, N.J., extension PY-4256.

Automated Systems

D.R. Bartlett
The YAH-64 ATE support program—Autotestcon '77, Hyannis, MA (11/2-4/77)

H.L. Fischer|R.E. Hanson
New techniques for automated engine diagnostics—an update—Autotestcon '77, Hyannis, MA (11/3/77)

E.B. Galton
Welcoming address and introduction—Autotestcon '77 Hyannis, MA (11/2/77)

J.I. Herzlinger
The use of commercial equipment in military mobile systems—Mobile Electronics Systems Packaging Symp., Boxborough, MA (11/2/77)

Advanced Technology Laboratories

E. Hutto
Emile Berliner, Eldridge Johnson and the Victor Talking Machine Company—*J. Audio Engineering Soc.*, Centennial Issue, Vol. 25, No. 10/11 (Oct/Nov 77) pp. 666-73

R. Kenville|G.J. Ammon|C.W. Reno
Optical video disc for high rate digital data recording—Electro-Optics/Laser Conf. and Expo., Anaheim, CA (10/25/77)

W. Thomas
Industry views of government specifications and standards—Defense Specifications Management Course, Army Logistics Management Center, Ft. Lee, VA (12/8/77)

Globcom

M.E. Logiadis
International field tests of digital facsimile equipment—CCITT, Study Group XIV, Geneva (11/14-18/77)

Government Communications Systems

M. Nguyen|R. Pickholtz
Bounds for the queue in loop system—1977 Intl. Mtg. Data Transmission, Liege, Belgium (11/14/77)

S. Yankelewitz
High density tape recording—Drexel University, Philadelphia, PA (12/5/77)

Laboratories

C.R. Carlson
Thresholds for perceived image sharpness—*Proc.*, SPSA Conf., Rochester, NY (10/24/77) pp. 76-80

R. Dawson|J. Preisig
J. Carnes|J. Pridgen
A CMOS buried-N-channel CCD compatible process for analog signal processing applications—*RCA Review*, Vol. 28, No. 3 (9/77) pp. 406-435

C.A. Deckert
Etching of CVD Si_3N_4 in acidic fluoride media—Electrochemical Soc. Mtg., Phila., PA (5/8-13/77)

R.E. Enstrom|D.A. Doane
A finite element solution for stress and deflection of a centrally loaded silicon wafer—The Electrochemical Soc., Seattle, WA (5/21-26/77)

K.G. Hernqvist
Continuous laser oscillation at 2703 angstroms in copper ion—*IEEE J. Quantum Electronics*, Vol. QE-13, No. 11 (11/17) p. 929

K.G. Hernqvist
Long-life hollow cathode laser—*IEEE J. of Quantum Electronics*, Vol. QE-14, No. 2 (2/78) pp. 129-132

M.L. Hitchman
Analysis of equilibrium potentials of hydrogen tungsten bronzes—*J. of Electroanalytical Chemistry*, Vol. 85 (1977) pp. 135-44

P.J. Zanzucchi|D.E. Carlson
Optical properties of discharge-produced a-Si—Electrochem. Soc. Meeting, Atlanta, GA (10/9-14/77)

P.J. Zanzucchi|M.T. Duffy|R.C. Alig
Optical reflectance method for determining the surface quality of sapphire (Al_2O_3)—*J. Electrochemical Soc.*, Vol. 125, No. 2 (1978) p. 299

P.J. Zanzucchi|C.R. Wronski|D.E. Carlson
Optical and photoconductive properties of discharge-produced amorphous silicon—*J. Appl. Phys.*, Vol. 40, No. 12 (1977) p. 5227

Missile and Surface Radar

R. J. Bannister|H. B. Boardman
M. D. Brazet
ORTS—A shipboard automatic test system *Proc.*, Autotestcon '77, Hyannis, MA (11/2-4/77)

J.A. Bauer
Leadless carrier applications for avionics packaging—Digital Avionics System Conf., Los Angeles, CA (11/2-4/77)

J.A. Bauer
The use of chip carriers for high packaging density, high reliability, high performance products—Workshop on the Impact of LSI on Contact Systems (11/77)

M.W. Buckley, Jr.
Project management—Education for Business and Industry, Ltd., London, England (11/1-2/77)

M.W. Buckley, Jr.
Project management—Seminar, Drexel Univ., Phila., Pa. (11/9-11/77 and 12/7-9/77)

R. DiFelice|J. Drenik
Mechanical design and integration of phased arrays naval sea systems command—*Proc.*, Mechanical Engineering in Radar Symp., Washington, DC (11/8-10/77) pp.230-35

B. Fell
Basic radar concepts: an introduction to radar for optical engineers—*Proc.* BMDATC (12/77)

W.A. Harmening
Static mass balancing with a torsion spring and four-bar linkage—*Proc.*, Mechanical Engineering in Radar Symp., Washington, DC (11/8-10/77), pp. 169-72

J.W. Hurley
Industrial logistics management—Phila. Chapter of the Soc. of Logistics Engineers (10-wk symp.) Philadelphia, PA (Oct-Dec 77)

P.R. Kalata
On system identification with and without certainty—*J. of Cybernetics*, Vol. 8, Issue 1 (Jan-Mar 1978) pp. 31-50

R.J. Kosich
AEGIS ship combat system distributed computer system design—WINCON '78, Sheraton-Universal Hotel, CA (2/15/78)

E.J. Nossen|E.R. Starner
One-way doppler extractor—*RCA Review*, Vol. 38, No. 4 (12/77)

R.P. Perry|L.W. Martinson
Radar matched filtering—Chapter in *Radar Technology*, Artech (10/77) pp. 163-69

S.A. Steele
Characteristics of managing real time solftware development for military systems—AIAA Computers in Aerospace Conf., Los Angeles, CA (11/1/77)

L. Weinberg
Scheduling multifunction radar systems—*Proc.*, IEEE Electronics and Aerospace Systems Conv. (12/77)

Patents

Astro-Electronics

L. Muhlfelder|J.E. Keigler|B. Stewart
Momentum biased active three-axis satellite attitude control system—4071211

R.J. Treadwell
Brushless phase locked servo drive—4072884

Automated Systems

R.F. Croce|G.T. Burton
Holographic high resolution contact printer—4043653 (assigned to U.S. government)

C.S. Warren
Data packets distribution loop—4071706

Avionics Systems

J.E. Miller
Multi-target tracker—4072943

J.R. Hall
Circuit for inhibition of autogenetic false alarms in a collision avoidance system—4076010

Broadcast Systems

L.J. Bazin
Signal comparator circuit—4069432

R.A. Dischert|R.N. Hurst|A.C. Luther, Jr.
Signal processor using charge-coupled devices—4074307

E.P. Herrmann
Four-quadrant multiplier—4071777

R.N. Hurst
Arrangements for testing color television systems—4069500

B.M. Pradal
Network for temperature compensation of an at cut quartz crystal oscillator—4072912

D.M. Schneider|L.J. Bazin
Constant pulse width sync regenerator—4064541

H.G. Seer, Jr.
Apparatus for automatic color balancing of color television signals—4064529

Consumer Electronics

D.J. Carlson
Remote control transmitter with an audible battery life indicator—4067000

M.N. Norman
Automatic beam current limiter—4067048

Commercial Communications Systems Div. Staff

L.P. Orchard
Food product extrusion apparatus and method—4068008

Government Communications Systems

W.A. Borgese
Apparatus for measuring a dimension of an object—4063820 (assigned to U.S. government)

M. Lysobey
Wide range frequency modulation of narrow loop bandwidth phase-locked oscillators—4074209 (assigned to U.S. Government)

L.P. Nahay
20Hz ringdown solid state two-wire/four-wire converter—4037065 (assigned to U.S. government)

Laboratories

C.H. Anderson
Flat panel display with beam injection cleanup—4069439

F. Aschwanden
SECAM identification circuit—4072983

D.E. Carlson
Semiconductor device having a body of amorphous silicon—4064521

J.M. Cartwright, Jr.
Current mirror amplifiers with programmable current gains—4064506

A.G. Dingwall
Method of making a semiconductor device—4069577

A.G. Dingwall|B.D. Rosenthal
Direct-coupled cascade amplifier with automatically adjusted quiescent output signal level—4068182

A.G. Dingwall|B.D. Rosenthal
Voltage controlled oscillator having equally controlled current source and current sink—4072910

A.H. Firester|J.P. Walentine
Defect plotting system—4069484

R.A. Geshner|L.J. Sciambi
Photomask dryer—4068390

W.G. Gibson
Delay line network for processing a composite electrical signal—4074308

A.C. Ipri
Silicon resistive device for integrated circuits—4072974

H.C. Johnson
Monotonically ranging fm-cw radar signal processor—4072947

G. Kaganowicz|J.W. Robinson
Video disc with a dielectric layer formed from styrene and nitrogen—4072985

P.J. Kannam
Transistor having improved junction breakdown protection integrated therein—4071852

H. Kressel|R.V. D'Aiello|P.H. Robinson
Polycrystalline or amorphous semiconductor photovoltaic device having improved collection efficiency—4070206 (RCA has title (waiver), NASA has license)

W.G. McGuffin
Adaptive delta modulation system—4071825

J.I. Pankove
Apparatus and method for maskless ion implantation—4074139

J.I. Pankove|D.E. Carlson
Electroluminescent semiconductor device having a body of amorphous silicon—4069492

H.L. Pinch|B. Abeles|J.I. Gittleman
Method of making high resistance cermet film—4071426

J.H. Reisner|W.H. Morewood|G.H. Riddle
Electron beam disc recorder—4074313

W. Rosnowski|R. Denning
Method of fabricating a semiconductor device—4066485

J.M. Shaw|K.H. Zaininger
Method of manufacturing apertured aluminum oxide substrates—4069094 (assigned to U.S. government)

Mobile Communications

R.M. Kongelka
Releasable mounting system—4071217

Missile and Surface Radar

P.T. Patterson
System and method for authenticating an electronically transmitted document—4064389 (assigned to U.S. government)

Picture Tube Division

A.M. Morrell
Corrugated shadow mask assembly for a cathode ray tube—4072876

RCA Ltd., Canada

J.M. Keelty
Wide acquisition range MSK demodulator input circuit—4072905

A. Waksberg
Automatic optical bias control for light modulators—4071751

A. Waksberg
Retro-reflection communication system—4064434

Solid State Division

A.A. Ahmed
Current mirror amplifier—4068184

B. Crowle
Voltage regulators of a type using a common-base transistor amplifier in the collector-to-base feedback of the regulator transistor—4074181

N.F. Gubitose|L. Gawelko|R.J. Satriano
Method for cracking brittle material—4068788

R.C. Heuner|S.J. Niemiec
M.B. Goldman|G.I. Morton
Protection circuitry for insulated-gate field-effect transistor (IGFET) circuits—4066918

R.H. Isham, 2nd
Sawtooth voltage generator for constant amplitude sawtooth waveform from varying frequency control signal—4071776

J.R. Jasinski|J.B. Pickard|C.E. Doner
Double tuned input circuit for television transmitter amplifier—4070627

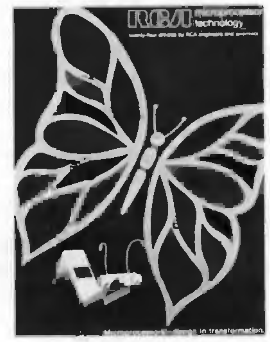
N. Kucharewski
Amplifier circuit—4069431

A.J. Leidich
Amplifier circuit—4064463

T.J. Robe
Input stage for fast-slewing amplifier—4074205

Microprocessor technology, electro-optics, and automotive electronics anthologies available

Three new comprehensive reprints that uniquely display RCA's current skills in microprocessors, electro-optics, and automotive electronics are now available. These reprints consist of selected papers from four of the most popular recent issues of the *RCA Engineer*. Only papers of current value are included.



Microprocessor technology offers 118 pages of general microprocessor information, discusses RCA's general-purpose microprocessor—the COSMAC CDP 1802—as well as advanced RCA designs, and describes more than a dozen specific applications. This reprint contains 24 articles, presenting the work of more than 40 RCA engineers.

Electro-optics covers electro-optics work at RCA and has specific sections on light sources, light transmission devices and media, light detectors, electro-optics systems, electro-optics for inspection and detection, and television. This reprint contains 28 articles presenting the work of more than 40 RCA engineers; it also contains several editorial features introducing the major topics.

Automotive electronics presents the technical contributions of more than 30 RCA engineers to research, design, and application of automotive devices, equipment, and systems.

In addition to these three reprints, a limited supply of past reprints is available. All reprints have color covers. A complete list follows:

Reprint	Price	Date
Microprocessor technology (118 pages)	$2.00	1977
Electro-optics (145 pages)	$2.50	1977
Automotive electronics (112 pages)	$2.00	1977
COS/MOS technology (76 pages)	$1.00	1973
Solid state technology (135 pages)	$1.50	1971
Consumer electronics (60 pages)	$1.00	1970
Integrated circuits (88 pages)	$1.00	1967

How to Order . . .

Although single-copy orders will be accepted, minimum orders of five are preferred. Send your name, location, and account number (if a personal order—send check or money order, payable to RCA Technical Communication Programs) to:

Reprints
RCA Technical Communication Programs
Bldg. 204-2
Cherry Hill, N.J. 08101
Phone: PY-4256

Engineering News and Highlights

More Fellows, more PEs

Apparently, one way to elicit reader response is to publish a list of people, and miss some of them. Last issue we published two—a list of RCA engineers who had attained the grade of Fellow of the IEEE and a list of Licensed Professional Engineers at RCA.

Thanks to all of you who wrote in to complete our lists, particularly to Dr. George Brown who called our attention to seven IEEE Fellows left off our original list. We will continue to update our lists as we receive new information. Here are the updates we have thus far:

IEEE Fellows

Name	Awarded
Goldsmith, Alfred N.	1915
VanDyck, Arthur F.	1925
Shackelford, Ben E.	1938
Guy, Raymond F.	1939
Crosby, Murray G.	1943
Seeley, Stuart	1943
Burnap, Robert S.	1947
Ingles, Harry C.	1948
Bingley, F. James	1950
Law, Russell R.	1953
Firestone, William L.	1965
Hittinger, William C.	1967
Cohen, Robert M.	1967
Dodds, Wellesley J.	1972
Pritchard, Dalton H.	1976
Clark, John F.	1976

Licensed professional engineers

Alascom

Henderson, W.	AK-CE4488
Strid, G.	AK-EE4502
Swanson, D.	AK-CE4507

Astro-Electronics

D'Amanda, A.W.	NJ-18747
Schnapf, A.	NJ-9310

Avionics Systems

Aires, R.H.	CA-CS2196

Broadcast Systems

Schacht, W.F.	NJ-12594

Consumer Electronics Division

Chaney, H.E.	IN-15932
Olson, L.A.	IN-12407

Government Communications Systems

Bradshaw, J.L.	NJ-24610

Laboratories

Gange, R.A.	NJ-21860

Missile and Surface Radar

Groman, E.M.	PA-17495E NJ-11557
Ringo, K.A.	OH-E-019719

Picture Tube Division

Ehrlich, M.A.	OH-E040294
Fanale, J.M.	PA-007009E
Ferguson, J.E.	OH-E29169
Follis, G.R.	IN-06773
LeMay, B.B.	OH-E034462
Parker, W.A.	PA-29874-E IN-12907
Pearlman, S.	PA-022917E
Schneider, R.K.	OH-28908
Swander, T.E.	OH-19669
Thall, E.S.	Canadian 5131200 CHEM-MET

Service Company

Williams, J.A., Jr.	VI-325E NH-2464

Solid State Division

Cole, E.W.	M.I.E.R.E.
Davenport, F.A.	M.I.E.R.E.
Free, J.J.	PA-012070E
Gershey, J.T.	PA-23048-E
Medway, N.W.	M.I.E.E.
Stevens, R.	M.I.E.R.E.

Promotions

Astro-Electronics

L. Jones from Senior Engineer to Manager, (Spec) Engineering.

R. Horner from Senior Engineer to Manager, (Spec) Engineering.

Consumer Electronics

Ronald L. Hess from Head, Deflection and Power Supply Systems Research, RCA Laboratories, to Manager, TV Systems Development, New Products Laboratory.

Arthur Kaiman from Member Technical Staff, RCA Laboratories, to Manager, Manufacturing Systems, New Products Laboratory.

Robert M. Rast from Head, TV Systems Technology Research, to Manager, New Products Development, New Products Laboratory.

Recent books by RCA authors

Dynamic Business Strategy
the art of planning for success

Theodore A. Smith
Published by McGraw-Hill
[$12.95]

Author Ted Smith was an Executive Vice President of RCA for 13 years, holding various positions as a general manager of groups of operating units, and serving as Director of Corporate Planning. Subsequently, as a consultant for The Conference Board, he was Associate Director for study of management trends. In this project, leaders in management sciences prepared reports which were published under the title: *Challenge to Leadership: Management in a Changing World.*

The jacket of *Dynamic Business Strategy* offers the following introduction:

"The myth that business strategy must be intuitive costs American industry millions of dollars each year. Reflect on the numerous divestitures, liquidations, and writeoffs that have been taken by otherwise well-managed companies. Strategy is the formula for success . . . and it need not be intuitive."

"Here is a realistic guide that describes step-by-step methods for developing a winning business strategy, for avoiding future pitfalls, and for amplifying current profit potential."

Awards

Eight receive Technical Excellence Awards at Moorestown

William Beckett—for creativity, judgment, and team leadership in design, production and integration of AN/SPY-1A Interface Simulator.

Glenn Everhart—for outstanding development effort on critical computer program modules for the AN/TPQ-27 operation.

George Friedman—for creative and resourceful design effort leading to the development of a Requirements Traceability Program for a complex mass of requirements and functional threads on a classified software development program.

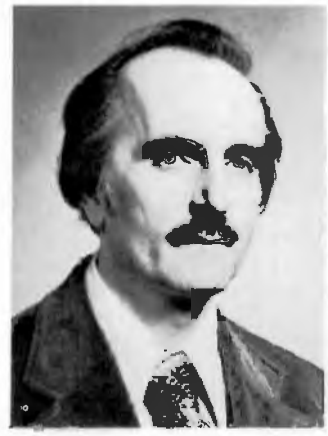
Paul Horton —for personal proficiency and perseverance in developing systems and procedures to assure total operating safety of the AEGIS Combat System during installation, checkout, and system testing at the CSED site.

John Mehling—for special contributions in development of hardware test support software for AN/TPQ-27 equipment subsystems.

Herbert Olson—for technical leadership in the formulation of circuitry and logic for improved integration of the AEGIS Guided Missile Launching System with overall system operation.

David Phillips—for outstanding performance in the definition of AEGIS Command and Decision software performance requirements for advanced AN/SPY-1A ECCM capability.

William Smith—for technical competence and personal initiative demonstrated in the design and implementation of the real-time portion of the AN/SPY-1A Interface Simulator.



Beckett

Everhart

Friedman

Horton

Mehling

Olson

Phillips

Smith

Stiller and Wine are Labs Fellows

Wine

Stiller

Dr. William M. Webster, Vice President, RCA Laboratories, recently appointed **Thomas M. Stiller** and **Charles M. Wine** Fellows of the Technical Staff, in recognition of their outstanding contributions. The designation of Fellow, which was established by RCA Laboratories in 1959, is comparable to the same title used by universities and virtually all technical societies, and is given in recognition of a record of sustained technical contribution in the past and of anticipated continued technical contribution in the future.

Presently the Fellows of the Technical Staff at RCA Laboratories are:

Charles H. Anderson
Kern K.N. Chang
Roger L. Crane
Andrew G.F. Dingwall
Robert E. Flory
James J. Gibson
Joseph J. Hanak
Karl G. Hernqvist
Ralph W. Klopfenstein
Simon Larach
Jacques I. Pankove
Dalton H. Pritchard
Allen H. Simon
Henry S. Sommers, Jr.
Thomas M. Stiller
Chih Chun Wang
Paul K. Weimer
Richard Williams
Charles M. Wine
J. Guy Woodward

Joseph Corso wins annual technical excellence award

All the 1977 technical excellence award winners from Missile and Surface Radar gathered for this photo. **Joe Corso,** the annual award winner is holding his award—flanked by **Max Lehrer** (left), Div. VP and General Manager, MSR, and **Joe Volpe,** Chief Engineer.

Joseph T. Corso, Principal Member, Engineering Staff, at Missile and Surface Radar in Moorestown was recently selected as the winner of the 1977 Annual Technical Excellence Award.

Joseph C. Volpe, Chief Engineer, MSR Engineering Department, in announcing the award said:

"The choice of an annual award winner is never an easy one, and in 1977 CETEC [Chief Engineer's Technical Excellence Committee] selected a record 29 engineers for quarterly Technical Excellence awards. Joe Corso's selection as a winner of the 1977 Annual award, then reflects a level of achievement that is truly extraordinary.

"Although Joe has been with MSR only since 1970, we've had the benefit of his missile guidance expertise for a considerably longer time—from the early 60's when he served as a consultant on missile-related developments leading ultimately to the AEGIS Program. His work has been uniformly superior, as exemplified by... his accomplishments on AEGIS during 1977.

Hap Easter receives two honors

Dr. William L. Firestone (left), Div. VP and General Manager, Avionics Systems, hands **Hap Easter** one of his two awards in a ceremony in Dr. Firestone's office.

Finis C. ("Hap") Easter of RCA Avionics Systems in Van Nuys, California, recently received two honors for his professional and technical activities. He was elected to the College of Fellows of the Institute for the Advancement of Engineering, "in recognition of his outstanding contribution to the advancement of the engineering profession."

His second honor came from the San Fernando Valley Engineers' Council, a group of 22 engineering societies of the various disciplines. "Hap" was one of eight receiving an Engineering Merit Award "for outstanding professional qualities and meritorious achievement within the field of engineering."

Hap, an engineer with RCA for 27 years, has five issued patents, three additional patents pending and several active disclosures. This year he is chairman of the San Fernando Section of IEEE with a membership of some 1700.

Staff Announcements

RCA Records

Paul Potashner, Group Vice President, appointed **Robert D. Summer** President, RCA Records Division.

Consumer Electronics

J.B. Thomas, Manager, Manufacturing Engineering, appointed **Douglas J. McGinnis** Manager, Process Engineering.

President and Chief Executive Officer

Edgar H. Griffiths, President and Chief Executive Officer, announced the following appointments:

Eugene J. Beyer, Jr. is Senior Vice President and General Counsel. In this capacity, he is responsible for the RCA law organization and the Secretary's office.

Steven S. Barone continues as Vice President, Licensing, and reports to the President and Chief Executive Officer.

John V. Regan continues as Vice President, Patent Operations, and reports to **William C. Hittinger,** Executive Vice President, Research and Engineering.

Patent Operations

Harold Christoffersen, Director, Patents, Solid State and Electronic Systems, has appointed **Robert A. Hays,** Resident Patent Counsel, Cherry Hill; and **Birgit E. Morris,** Sr. Managing Patent Attorney.

Edward J. Norton, Director, Patent Planning and Administration, has appointed **Sharon K. Stepno** Manager, Patent Office Washington.

Eugene M. Whitacre, Director, Patents, Consumer Products and Broadcast Equipment, has appointed **Paul J. Rasmussen,** Sr. Managing Patent Attorney; and **Joseph S. Tripoli,** Managing Patent Attorney.

Commercial Communications Systems Division

Adron M. Miller, Manager, RCA Photophone Systems, has appointed **Gordon E. Cordell** as Manager, Product Management, for RCA's line of professional motion picture film records and projectors.

Automated Systems

Fernand F. Martin has been appointed Manager, Radiation Systems Engineering.

Advanced Technology Laboratories

James A. Colligan has been appointed Manager, Marketing for Advanced Technology Laboratories.

RCA Globcom

Eugene F. Murphy, President, RCA Global Communications, Inc., has announced the election of **Dr. Thomas Mathai** to the newly created position of Vice President, Data Services.

RCA Laboratories

Thomas O. Stanley, Staff Vice President Research Programs, has announced that the organization formerly known as Management Information Systems will be restructured as follows: **Marvin Blecker** is appointed Head, Systems Analysis Research; **Emilie M. Lengel** continues as Manager, Automation and Computing Services; and **Warren C. Sayre** is appointed Manager, Administrative Systems.

Solid State Division

Carl R. Turner, Division Vice President Integrated Circuits, and **Gerald B. Herzog,** Staff Vice President, Technology Centers, announced that **Joseph H. Scott,** Director, Integrated Circuit Technology will assume additional responsibilities. He will provide all technical and strategic direction in Silicon and Sapphire Technology within the Solid State Division, RCA Laboratories and Technology Centers. While continuing in his present position under the Staff Vice President, Technology Centers, for this assignment he will report to **Carl R. Turner,** Division Vice President, Integrated Circuits, Solid State Division.

Picture Tube Division

Charles W. Thierfelder, Division Vice President Product Safety, Quality and Reliability, has announced the organization of Product Safety, Quality and Reliability as follows: **Sherman L. Babcock,** Administrator, Technical Quality Programs; **David C. Ballard,** Manager, Product Safety; **Wellesley J. Dodds,** Director, Quality and Reliability Assurance Operations Analysis; **J. Edward Fagan,** Administrator, Quality Assurance Coordination; **Frank J. Hinnekamp,** Manager, Life Test, Reliability and Warranty; and **J. Paul Sasso,** Administrator, Customer Quality Acceptance.

Barr on IEEE committee

Ken Barr, Component Engineer, at the Consumer Electronics Division in Indianapolis was recently appointed to a three-year term as RCA's representative to serve on the Administrative Committee of the Broadcast, Cable TV and Consumer Electronics Group of the IEEE. Currently, Ken is also the treasurer of the Central Indiana IEEE.

Obituaries

Edward Bliss, an electrical engineer with RCA Global Communications, died April 1, 1978.

Mr. Bliss designed the transmitter for the historic Relay Communications Satellite and for the first Lunar Excursion Module used during the moon landing in 1969. For his accomplishments, he received the RCA Engineering Award in 1970. During his tenure with RCA, he also pioneered the application of computer-aided design techniques to the development of solid-state microwave devices and authored several technical papers on that subject. He was a recognized authority on the design of travelling wave tubes and contributed a chapter on the subject to the *RCA Electron Tube Design* book.

He joined the RCA American Communications Division in 1974 to work on the RCA Satcom Satellite Program. He was part of the launch team that supported two successful launches and conducted the on-order performance checkout.

Nils E. Lindenblad, one of RCA's most prolific inventors, died on February 18. He retired from RCA Laboratories in 1960.

A pioneer in transoceanic radio communications in the 1920's and 1930's, he joined the RCA Corporation in 1920 at the company's transmitting station at Rocky Point, L.I. He transferred to RCA Laboratories in Princeton in 1950.

Mr. Lindenblad was credited with more than 300 patents. He was widely known for his development of the rhombic and slot antennas, the travelling wave tube, and the basic elements of thermoelectric cooling systems. He helped to develop the first wideband television antenna placed on top of New York's Empire State Building in 1938.

A Fellow of the IEEE and the RCA Laboratories, Mr. Lindenblad was awarded the 1958 David Sarnoff Outstanding Achievement Award "for his invention and pioneering development of many important electronic devices and for his research on thermoelectric cooling apparatus."

Finite Element Symposium Program Held

An RCA Finite Element Symposium was held on March 13 and 14 at RCA Laboratories in Princeton. About 60 engineers and managers assembled to listen to formal presentations, discuss mutual problems, and, for those with no direct experience, to gain an understanding of this powerful new tool.

Ron Enstrom, RCA Laboratories, was chairman of the program which included speakers from Astro Electronics, Missile and Surface Radar, Solid State Division, Picture Tube Division, and RCA Laboratories as well as a guest speaker from Massachusetts Institute of Technology.

Phillips receives Goldsmith award

John Phillips, Editor of the *RCA Engineer* recently received the 1977 Alfred N. Goldsmith Award of the IEEE Group on Professional Communication.

Established by the Professional Communication Group in 1974, the Alfred N. Goldsmith Award is given in recognition of service within the Group's organization to improve the quality of engineering communication.

Lauffer promoted to Associate Editor, *RCA Engineer*

Bill Lauffer, who has worked as Assistant Editor of the *RCA Engineer* since May 1976, was recently promoted to Associate Editor.

Bill has made important contributions to the quality of the *RCA Engineer* and has contributed to, or initiated, several innovative features.

Willis is new Ed Rep at Consumer Electronics

Don Willis has been appointed Editorial Representative for Consumer Electronics in Indianapolis. Don is a senior engineer and has worked at CE for 15 years on signal circuiting, video tape recorders, and deflection circuits. He has written several articles and holds 17 patents.

As Editorial Representative, Don will assist CE authors with papers for the *RCA Engineer,* and will keep the editors informed of new developments as well as professional activities, awards, publications, and promotions in their areas.

Authors and inventors honored at Moorestown

Fifty-one individuals were honored on February 23 at Missile and Surface Radar's Authors' Reception held in Moorestown, N.J. This reception, hosted by **Joe Volpe,** Chief Engineer, was the eleventh in a series to honor people who have presented or published papers or received patents.

In congratulating the MSR authors and inventors, Mr. Volpe called attention to the efforts involved in professional authorship.

Editorial Representatives

Contact your Editorial Representative, at the extensions listed here, to schedule technical papers and announce your professional activities.

Commercial Communications Systems Division

Broadcast Systems

BILL SEPICH* Camden, N.J. Ext. PC-2156
KRISHNA PRABA Gibbsboro, N.J. Ext. PC-3605
ANDREW BILLIE Meadow Lands, Pa. Ext. 6231

Mobile Communications Systems

FRED BARTON* Meadow Lands, Pa. Ext. 6428

Avionics Systems

STEWART METCHETTE* Van Nuys, Cal. Ext. 3806
JOHN McDONOUGH Van Nuys, Cal. Ext. 3353

Electronic Industrial Engineering

JOHN OVNICK* N. Hollywood, Cal. Ext. 241

Government Systems Division

Astro-Electronics

ED GOLDBERG* Hightstown, N.J. Ext. 2544

Automated Systems

KEN PALM* Burlington, Mass. Ext. 3797
AL SKAVICUS Burlington, Mass. Ext. 2582
LARRY SMITH Burlington, Mass. Ext. 2010

Government Communications Systems

DAN TANNENBAUM* Camden, N.J. Ext. PC-5410
HARRY KETCHAM Camden, N.J. Ext. PC-3913

Government Engineering

MERLE PIETZ* Camden, N.J. Ext. PC-4155

Missile and Surface Radar

DON HIGGS* Moorestown, N.J. Ext. PM-2836
JACK FRIEDMAN Moorestown, N.J. Ext. PM-2112

Solid State Division

JOHN SCHOEN* Somerville, N.J. Ext. 6467

Power Devices

HAROLD RONAN Mountaintop, Pa. Ext. 827
SY SILVERSTEIN Somerville, N.J. Ext. 6168

Integrated Circuits

FRED FOERSTER Somerville, N.J. Ext. 7452
JOHN YOUNG Findlay, Ohio Ext. 307

Electro-Optics and Devices

RALPH ENGSTROM Lancaster, Pa. Ext. 2503

Consumer Electronics

CLYDE HOYT* Indianapolis, Ind. Ext. VH-2462
FRANCIS HOLT Indianapolis, Ind. Ext. VH-4393
PAUL CROOKSHANKS Indianapolis, Ind. Ext. VH-2849
DON WILLIS Indianapolis, Ind. Ext. VH-2829

SelectaVision Project

ROBERT MOORE Indianapolis, Ind. Ext. VR-3313

RCA Service Company

JOE STEOGER* Cherry Hill, N.J. Ext. PY-5547
RAY MacWILLIAMS Cherry Hill, N.J. Ext. PY-5986
DICK DOMBROSKY Cherry Hill, N.J. Ext. PY-4414

Distributor and Special Products Division

CHARLES REARICK* Deptford, N.J. Ext. PT-513

Picture Tube Division

ED MADENFORD* Lancaster, Pa. Ext. 3657
NICK MEENA Circleville, Ohio Ext. 228
JACK NUBANI Scranton, Pa. Ext. 499
J.R. REECE Marion, Ind. Ext. 566

Alascom

PETE WEST* Anchorage, Alaska Ext. 7657

Americom

MURRAY ROSENTHAL* Kingsbridge Campus, N.J. Ext. 4363

Globcom

WALT LEIS* New York, N.Y. Ext. 5029

RCA Records

JOSEPH WELLS* Indianapolis, Ind. Ext. VT-5507

NBC

BILL HOWARD* New York, N.Y. Ext. 4385

Patent Operations

JOSEPH TRIPOLI Princeton, N.J. Ext. 2491

Research and Engineering

Corporate Engineering

HANS JENNY* Cherry Hill, N.J. Ext. PY-4251

Laboratories

MAUCIE MILLER Princeton, N.J. Ext. 2321
LESLIE ADAMS Somerville, N.J. Ext. 7357

*Technical Publications Administrator, responsible for review and approval of papers and presentations.

RCA Engineer

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"by and for the RCA Engineer"

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CLIFFORD WINNER, JR.

Robert I Lieber
in the New Jersey, Death Index, 1901-2017

Name:	Robert I Lieber
Age:	81
Birth Date:	6 May 1926
Birth Place:	Philadelphia, Pennsylvania, USA
Death Date:	6 Jan 2008
Death Place:	New Jersey, USA

Source Citation
Surname Range: *A-Z*; Title: *New Jersey Death Index, 2001-2017*

Source Information
Ancestry.com. *New Jersey, Death Index, 1901-2017* [database on-line]. Lehi, UT, USA: Ancestry.com Operations, Inc., 2016.

Original data: Death Indexes. New Jersey State Archives, Trenton, New Jersey.

Description
This collection consists of images of an index to deaths occurring in New Jersey between 1901 and 2017. Learn more...

Robert Lieber

in the Web: Burlington County, New Jersey, Death Index, 1814-2010

Go to website

Add alternate information

Report issue

Name:	Robert Lieber
Death Date:	6 Jan 2008
Death Location:	Medford, Burlington, New Jersey, United States
URL:	http://www.co.burlington.nj.us...

This record is not from Ancestry and will open in a new window. You may need to search for the record when the web page opens. For more information on web records, click here.

You will need to log-in or register to save this record to your tree.

Save & create tree Cancel

Source Information

Ancestry.com. *Web: Burlington County, New Jersey, Death Index, 1814-2010* [database on-line]. Provo, UT, USA: Ancestry.com Operations, Inc., 2011.

Original data: *Surrogate Record Search*. Burlington County. http://www.co.burlington.nj.us/Pages/SR/SurrogateSearch.aspx.

Description

All data in this third-party database was obtained from the source's website. Ancestry.com does not support or make corrections or changes to the original database. To learn more about these records, please refer to the source's website. Learn more...

Suggested Records

U.S., Social Security Death Index, 1935-2014
Robert Lieber

New Jersey, Death Index, 1901-2017
Robert I Lieber

U.S., Obituary Collection, 1930-Current
Robert Lieber

1930 United States Federal Census
Robert Leiber

Global, Find A Grave Index for Burials at Sea and other Select Burial Locations, 1300s-Current
Robert Lieber

U.S., Department of Veterans Affairs BIRLS Death File, 1850-2010
Robert Lieber

1940 United States Federal Census

Robert Lieber

U.S. WWII Draft Cards Young Men, 1940-1947
Robert Lieber

Pennsylvania, Veteran Compensation Application Files, WWII, 1950-1966
Robert Lieber

Write a comment.

Make a Connection

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