microwave JOURNAL

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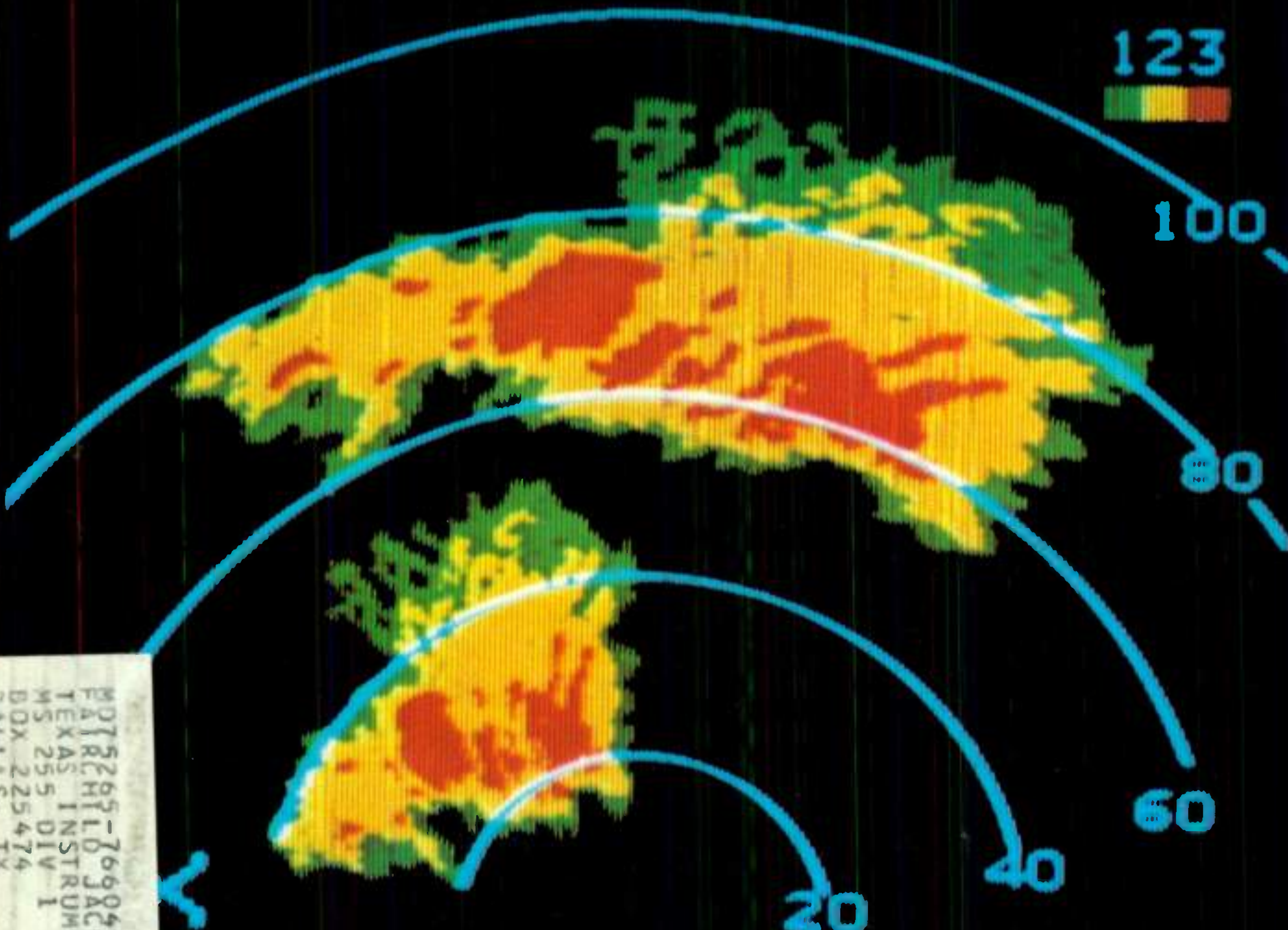


RADAR

History of Radar
Color Weather Radar
Solid State Transmitter
and
URSI/APS Report

IDEAL PULSED SIGNALS

For Testing Radars

No Carrier Leakage And Fast, Clean Pulses

New Signal Generators 0.8 - 21 GHz Better Than All Solid-State

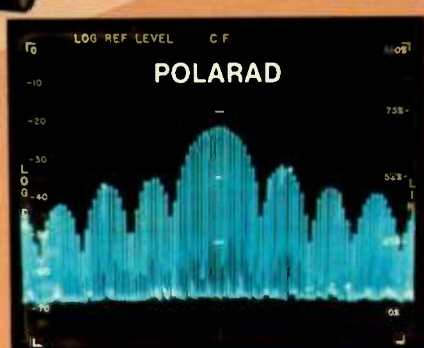
Reliable "E" Series Signal Generators consist of all solid-state modules and a low-noise klystron cavity-tuned oscillator...they conform to MIL-T-28800B.

Modern radar and ECM receivers require pulsed test signals with negligible output between pulses. 80 dB on-off ratio is needed for accurate measurement of MDS and dynamic range. Polarad Signal Generators have no carrier leakage...on-off ratio is infinite.

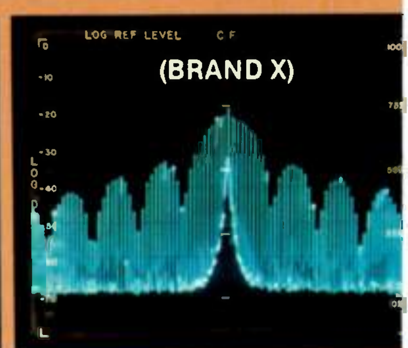
Other advantages of the new "E" Series are:

- Pulse widths from 0.2 to 2,000 μs; rates 10-10,000 pps.
- Low phase noise sidebands for receiver sensitivity tests
- Stable, spectrally pure signals
- Accurately calibrated CW, FM, square wave and pulsed outputs. Digital frequency readout
- Low Cost

Full specifications on request.



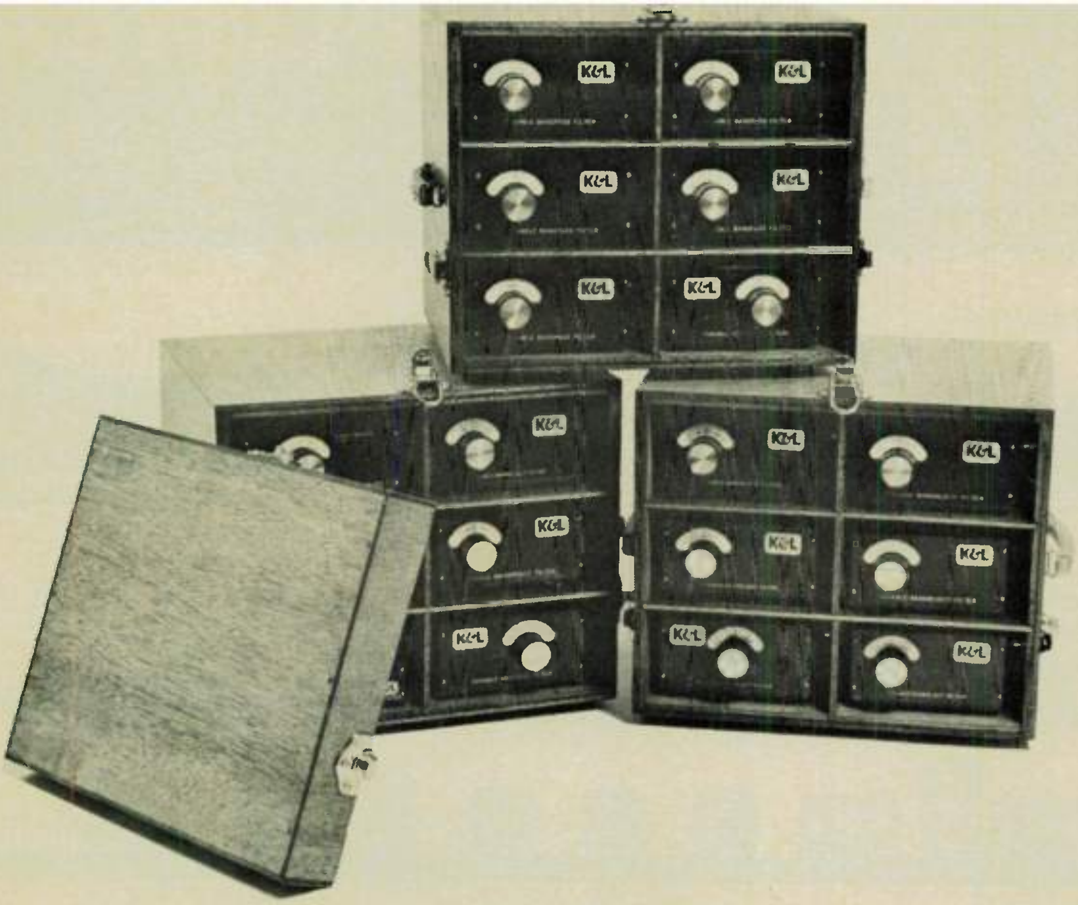
Pulsed output spectrum of Polarad "E" Series Generator.
Note: no carrier leakage.



Carrier leakage is clearly seen.

polarad polarad polarad

Polarad Electronics, Inc. 5 Delaware Dr. Lake Success N.Y. 11042 Tel 516-328-1100 TWX 510-223-0414



When you have a K&L kit, you'll never have to wait for the right filter.

PROBLEM:

Remember the times you've needed a filter at the last minute to complete a breadboard or test? You probably lost valuable time waiting for the filter.

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Tuning ranges covering 24 MHz to 18 GHz in octave and half octave bands.
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*3dB Passband typically 5% of the tuned frequency.
Power handling 50 watts.

*We'll manufacture special bandwidths for your specific needs. Call or write for our filter kit data sheet.
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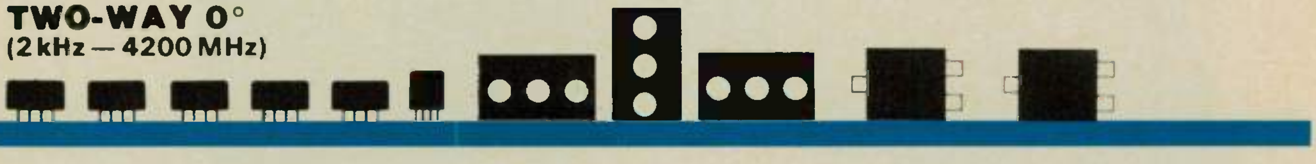
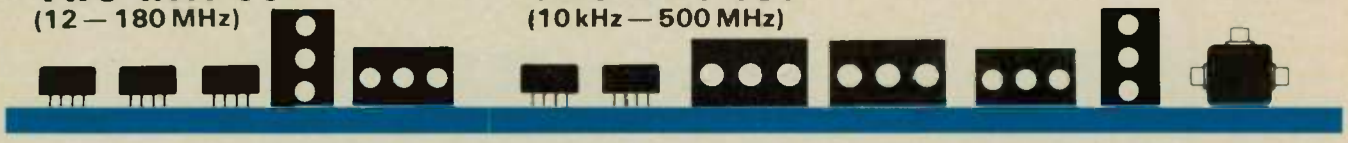
BASIC CASE STYLES

TWO-WAY 0°
(2 kHz — 4200 MHz)

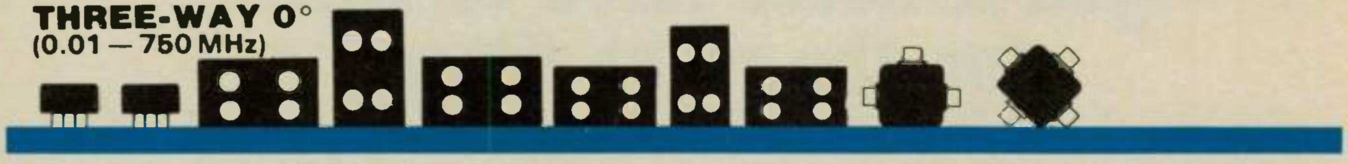


TWO-WAY 90°
(12 — 180 MHz)

TWO-WAY 180°
(10 kHz — 500 MHz)

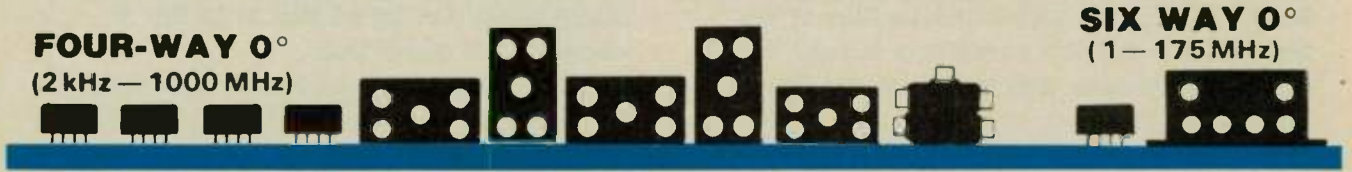


THREE-WAY 0°
(0.01 — 750 MHz)



FOUR-WAY 0°
(2 kHz — 1000 MHz)

SIX WAY 0°
(1 — 175 MHz)



EIGHT-WAY 0°
(0.5 — 700 MHz)

SIXTEEN-WAY 0°
(0.5 — 125 MHz)

TWENTY-FOUR-WAY 0°
(0.2 — 100 MHz)

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Over 80 models covering 2 kHz to 4.2 GHz

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For complete specifications and performance curves, refer to 1979-80 MicroWaves Product Data Directory pages 161-369, or 1979 EEM pages 2770-2970.

SELECT THE MODEL YOU NEED

2-WAY 0°

Model	Freq. range (MHz)	Min. isol.-dB (Mid-band)	Max. insert. loss-dB (Mid-band)	See notes below	Price (Qty.)
PSC-2-1	0.1-400	20	0.75		$9.95 (6-49)
PSC-2-1W	1-650	20	0.9		$14.95 (6-49)
PSC-2-2	0.002-60	20	0.6		$19.95 (6-49)
PSC-2-1-75	0.25-300	20	0.75	1	$11.95 (6-49)
PSC-2375	55-85	25	0.5	1	$19.95 (6-24)
PSC-2-4	10-1000	20	1.2		$19.95 (6-49)
MSC-2-1	0.1-450	20	0.75		$16.95 (5-24)
MSC-2-1W	2-650	25	0.8		$17.95 (5-24)
ZSC-2-1	0.1-400	20	0.75	3	$27.95 (4-24)
ZSC-2-1-75	0.25-300	20	0.75	1,3	$29.95 (4-24)
ZSC-2-1W	1-650	20	0.8	3	$32.95 (4-24)
ZSC-2-2	0.002-60	20	0.6	3	$37.95 (4-24)
ZSC-2375	55-85	25	0.5	3	$37.95 (4-24)
ZMSC-2-1	0.1-400	20	0.75	4	$37.95 (4-24)
ZMSC-2-1W	1-650	20	0.8	4	$42.95 (4-24)
ZMSC-2-2	0.002-60	20	0.6	4	$47.95 (4-24)
ZFSC-2-1	5-500	20	0.6	5	$31.95 (4-24)
ZFSC-2-1W	1-750	20	0.8	5	$35.95 (4-24)
ZFSC-2-2	10-1000	20	1.0	5	$39.95 (4-24)
ZFSC-2-4	0.2-1000	20	1.0	5	$44.95 (4-24)
ZFSC-2-5	10-1500	20	1.0	5	$49.95 (4-24)
ZFSC-2-6	0.002-60	20	0.6	5	$36.95 (4-24)
ZFSC-2-6-75	0.004-60	20	0.8	5	$38.95 (4-24)
ZAPD-1	500-1000	19	0.6	6	$39.95 (1-9)
ZAPD-2	1000-2000	19	0.6	6	$39.95 (1-9)
ZAPD-4	2000-4000	19	0.8	6	$39.95 (1-9)

2-WAY 90°

Model	Freq. range (MHz)	Min. isol.-dB (Mid-band)	Max. insert. loss-dB (Mid-band)	See notes below	Price (Qty.)
PSCQ-2-13	12-14	25	0.7†	2	$12.95 (5-49)
PSCQ-2-14	12-16	25	0.6†	2	$16.95 (5-49)
PSCQ-2-40	23-40	18	0.7†	2	$16.95 (5-49)
PSCQ-2-50	25-50	20	0.7†	2	$19.95 (5-49)
PSCQ-2-90	55-90	20	0.7†	2	$19.95 (5-49)
PSCQ-2-180	120-180	15	0.7†	2	$19.95 (5-49)
ZSCQ-2-50	25-50	20	0.7†	2,3	$39.95 (4-24)
ZSCQ-2-90	55-90	20	0.7†	2,3	$39.95 (4-24)
ZSCQ-2-180	120-180	15	0.7†	2,3	$39.95 (4-24)
ZMSCQ-2-50	25-50	20	0.7†	2,4	$49.95 (4-24)
ZMSCQ-2-90	55-90	20	0.7†	2,4	$49.95 (4-24)
ZMSCQ-2-180	120-180	15	0.7†	2,4	$49.95 (4-24)

2-WAY 180°

Model	Freq. range (MHz)	Min. isol.-dB (Mid-band)	Max. insert. loss-dB (Mid-band)	See notes below	Price (Qty.)
PSCJ-2-1	1-200	25	0.8		$19.95 (5-49)
PSCJ-2-2	0.01-20	25	0.5		$29.95 (5-49)
ZSCJ-2-1	1-200	25	0.8	3	$37.95 (4-24)
ZSCJ-2-2	0.01-20	25	0.5	3	$47.95 (4-24)
ZMSCJ-2-1	1-200	25	0.8	4	$47.95 (4-24)
ZMSCJ-2-2	0.01-20	25	0.5	4	$57.95 (4-24)
ZFSCJ-2-1	1-500	25	1.5	5	$49.95 (4-24)
ZFSCJ-2-3	5-300	25	1.5	5	$39.95 (4-24)

3-WAY 0°

Model	Freq. range (MHz)	Min. isol.-dB (Mid-band)	Max. insert. loss-dB (Mid-band)	See notes below	Price (Qty.)
PSC-3-1	1-200	25	0.7		$19.95 (5-49)
PSC-3-1W	5-500	15	1.4		$29.95 (5-49)
PSC-3-1-75	1-200	25	0.7	1	$20.95 (5-49)
PSC-3-2	0.01-30	25	0.45		$29.95 (5-49)
PSC-3-13	1-200	35	0.6		$24.95 (5-49)
ZSC-3-1	1-200	25	0.7	3	$37.95 (4-24)
ZSC-3-1-75	1-200	25	0.7	1,3	$38.95 (4-24)
ZSC-3-2	0.01-30	25	0.45	3	$47.95 (4-24)
ZSC-3-2-75	0.02-20	25	0.6	1,3	$48.95 (4-24)
ZMSC-3-1	1-200	25	0.7	4	$47.95 (4-24)
ZMSC-3-2	0.01-30	25	0.45	4	$57.95 (4-24)
ZFSC-3-1	1-500	20	0.9	5	$39.95 (4-24)
ZFSC-3-1W	2-750	20	1.0	5	$41.95 (4-24)
ZFSC-3-13	1-200	35	0.6	5	$39.95 (4-24)

4-WAY 0°

Model	Freq. range (MHz)	Min. isol.-dB (Mid-band)	Max. insert. loss-dB (Mid-band)	See notes below	Price (Qty.)
PSC-4-1	0.1-200	20	0.75		$28.95 (6-49)
PSC-4-1-75	1-200	20	0.9	1	$24.95 (6-49)
PSC-4-3	0.25-250	20	0.75		$23.95 (6-49)
PSC-4A-4	10-1000	15	1.1		$49.95 (6-49)
PSC-4-6	0.01-40	25	0.5		$29.95 (6-49)
ZSC-4-1	0.1-200	20	0.75	3	$46.95 (4-24)
ZSC-4-1-75	1-200	20	0.8	1,3	$46.95 (4-24)
ZSC-4-2	0.002-20	25	0.5	3	$69.95 (4-24)
ZSC-4-3	0.25-250	20	0.75	3	$43.95 (4-24)
ZMSC-4-1	0.1-200	20	0.75	4	$56.95 (4-24)
ZMSC-4-2	0.002-20	25	0.5	4	$79.95 (4-24)
ZMSC-4-3	0.25-250	20	0.75	4	$53.95 (4-24)
ZFSC-4-1	1-1000	18	1.5	8	$89.95 (1-4)
ZFSC-4-1W	10-500	20	1.5	8	$74.95 (1-4)
ZFSC-4375	50-90	30	1.2	1,8	$89.95 (1-4)

6-WAY 0°

Model	Freq. range (MHz)	Min. isol.-dB (Mid-band)	Max. insert. loss-dB (Mid-band)	See notes below	Price (Qty.)
PSC-6-1	1-175	18	1.0		$68.95 (1-5)
ZFSC-6-1	1-175	20	1.2	9	$89.95 (1-4)

8-WAY 0°

Model	Freq. range (MHz)	Min. isol.-dB (Mid-band)	Max. insert. loss-dB (Mid-band)	See notes below	Price (Qty.)
PSC-8-1	0.5-175	20	1.1		$68.95 (1-5)
PSC-8-1-75	0.5-175	20	0.8	1	$69.95 (1-5)
PSC-8A-4	5-500	18	1.8		$89.95 (1-5)
PSC-8-6	0.01-10	23	1.1		$79.95 (1-5)
ZFSC-8-1	0.5-175	20	1.1	10	$89.95 (1-4)
ZFSC-8-1-75	0.5-175	20	1.0	1,10	$90.95 (1-4)
ZFSC-8375	50-90	25	1.3	1,10	$119.95 (1-4)
ZFSC-8-4	0.5-700	20	1.5	10	$129.95 (1-4)
ZFSC-8-6	0.01-10	23	1.1	10	$109.95 (1-4)

16-WAY 0°

Model	Freq. range (MHz)	Min. isol.-dB (Mid-band)	Max. insert. loss-dB (Mid-band)	See notes below	Price (Qty.)
ZFSC-16-1	0.5-125	18	1.6	11	$174.95 (1-4)

24-WAY 0°

Model	Freq. range (MHz)	Min. isol.-dB (Mid-band)	Max. insert. loss-dB (Mid-band)	See notes below	Price (Qty.)
ZFSC-24-1	0.2-100	20	2.0	12	$264.95 (1-4)

1 75 ohms impedance
†2 Average of coupled outputs less 3 dB
3 BNC connectors standard, TNC available
4 SMA connectors only
5 BNC connectors standard, TNC available, SMA & Type N available at $5 additional cost
6 BNC, TNC, SMA & Type N at $5 additional cost. Please specify connectors
7 TNC, SMA & Type N at $5 additional cost. Please specify connectors
8 SMA connectors standard, BNC on request.
9 BNC connectors standard, TNC available, SMA available at $15 additional cost
10 BNC connectors standard, TNC available at $10 additional cost, SMA at $25 additional cost.
11 BNC connectors standard, TNC available at $20 additional cost, SMA available at $45 additional cost.
12 BNC connectors standard, TNC available at $35 additional cost, SMA available at $65 additional cost.

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* Euro-Global Edition Only

ON THE COVER: The airborne weather radar color display improves a pilot's ability to recognize and avoid potentially dangerous storms. See the Technical Feature beginning on p.42.

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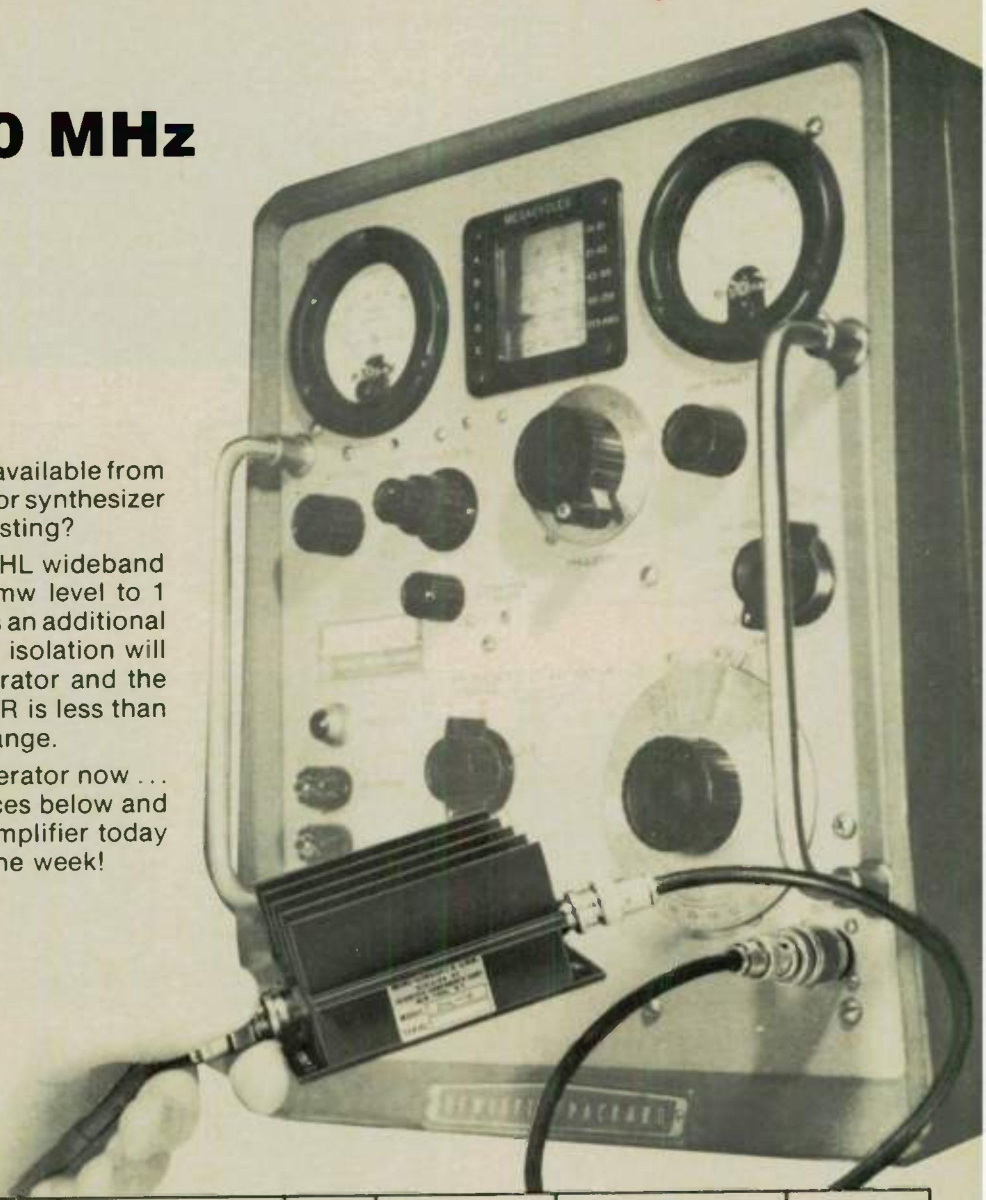

Need more than the 10 mw available from your signal/sweep generator or synthesizer for system and subsystem testing?

Just add a Mini-Circuits' ZHL wideband amplifier and boost the 10 mw level to 1 watt or +30 dBm. Also, there's an additional benefit ... as much as 40 dB isolation will be added between the generator and the system under test. And VSWR is less than 2:1 over the full frequency range.

Upgrade your present generator now ... check the specs and low prices below and order your ZHL wideband amplifier today ... and we will ship within one week!

MODEL NO.	FREQ. MHz	GAIN dB	GAIN FLATNESS dB	MAX. POWER OUTPUT dBm 1-dB COMPRESSION	NOISE FIGURE db	INTERCEPT POINT 3rd ORDER dBm	DC POWER		PRICE	
							VOLTAGE	CURRENT	$ EA.	QTY.
ZHL-32A	0.05-130	25 Min.	±1.0 Max.	+29 Min.	10 Typ.	+38 Typ.	+24V	0.6A	199.00	(1-9)
ZHL-3A	0.4-150	24 Min.	±1.0 Max.	+29.5 Min.	11 Typ.	+38 Typ.	+24V	0.6A	199.00	(1-9)
ZHL-1A	2-500	16 Min.	±1.0 Max.	+28 Min.	11 Typ.	+38 Typ.	+24V	0.6A	199.00	(1-9)
ZHL-2	10-1000	16 Min.	±1.0 Max.	+29 Min.	18 Typ.	+38 Typ.	+24V	0.6A	349.00	(1-9)
ZHL-2-8	10-1000	27 Min.	±1.0 Max.	+29 Min.	10 Typ.	+38 Typ.	+24V	0.65A	449.00	(1-9)
ZHL-2-12	10-1200	24 Min.	±1.0 Max.	+29 Min.*	10 Typ.	+38 Typ.	+24V	0.75A	524.00	(1-9)

Total safe input power +20 dBm, operating temperature 0° C to +60° C, storage temperature −55° C to +100° C, 50 ohm impedance, input and output VSWR 2:1 max.
* +28.5 dBm from 1000–1200 MHz
For detailed specs and curves, refer to 1979/80 MicroWaves Product Data Directory, p. 364-365 or EEM p. 2970-2971.

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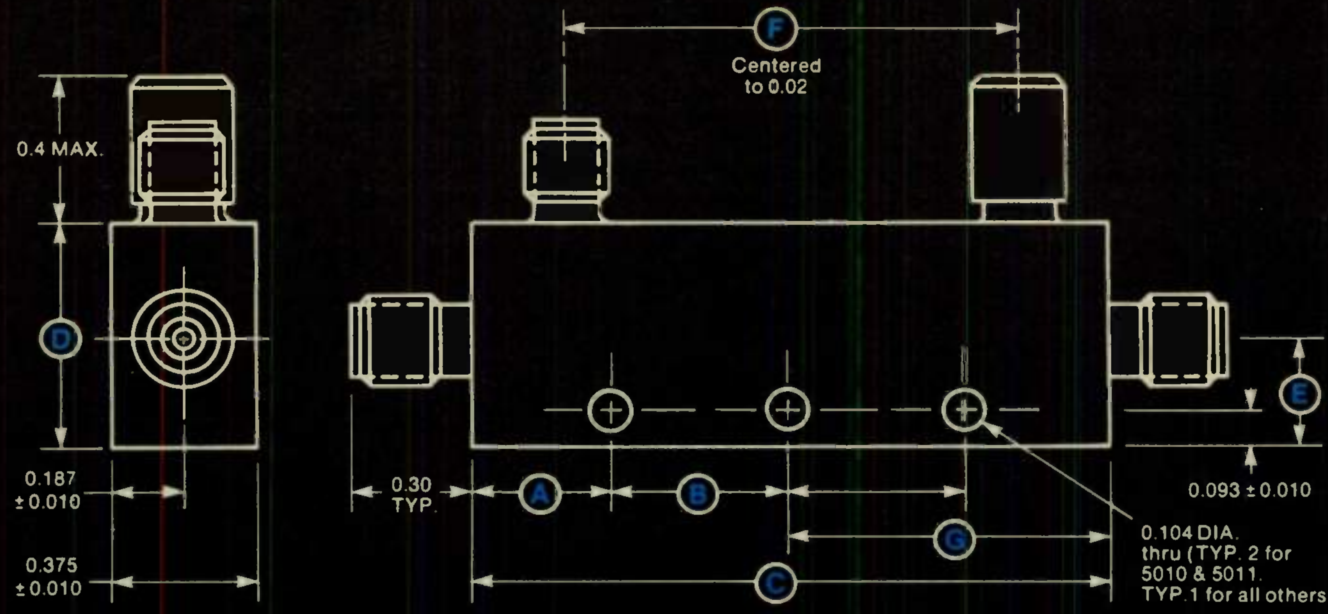

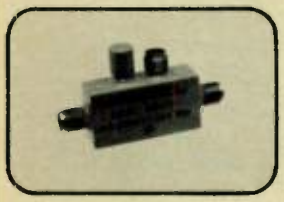

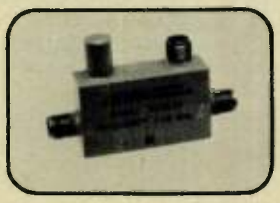

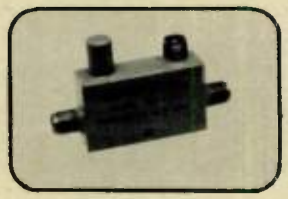

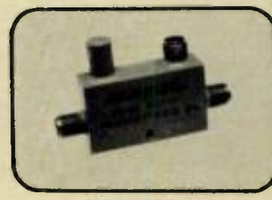

5014-6	5014-10	5014-20
ALL ARE 7-12.4		
6 ± 1.00	10 ± 1.25	20 ± 1.25
ALL ARE ± 0.50		
15	BOTH ARE 17	
ALL ARE 1.30		
ALL ARE 0.40		
N/A		
N/A		
ALL ARE 1.15		
BOTH ARE 0.60		0.65
ALL ARE 0.30		
ALL ARE 0.36		
ALL ARE 0.57		

5015-6	5015-10	5015-20
ALL ARE 7-18		
6 ± 1.00	10 ± 1.25	20 ± 1.25
± 0.60	BOTH ARE ± 0.75	
BOTH ARE 12		15
ALL ARE 1.40		
ALL ARE 0.50		
N/A		
N/A		
ALL ARE 1.25		
BOTH ARE 0.75		0.80
ALL ARE 0.30		
ALL ARE 0.77		
ALL ARE 0.63		

5016-6	5016-10	5016-20
ALL ARE 8-16		
6 ± 1.00	10 ± 1.50	20 ± 1.25
± 0.60	BOTH ARE ± 0.75	
BOTH ARE 12		15
ALL ARE 1.40		
ALL ARE 0.50		
N/A		
N/A		
ALL ARE 1.25		
BOTH ARE 0.75		0.80
ALL ARE 0.30		
ALL ARE 0.77		
ALL ARE 0.63		

5017-6	5017-10	5017-20
ALL ARE 12.4-18		
6 ± 1.00	10 ± 1.00	20 ± 1.00
ALL ARE ± 0.50		
ALL ARE 15		
ALL ARE 1.40		
ALL ARE 0.40		
N/A		
N/A		
ALL ARE 1.25		
BOTH ARE 0.75		0.80
ALL ARE 0.30		
ALL ARE 0.77		
ALL ARE 0.63		

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Coming Events

13TH ANNUAL CONNECTOR SYMPOSIUM OCT. 8-9, 1980 Sponsor: Electronic Connector Study Group, Inc. Place: Benjamin Franklin Hotel, Philadelphia, PA. Fee: Registration — $35; Proceedings — $25. Topics: Materials, Finishes and Platings I & II; Cabling Techniques I & II; Design and Application — Plexible Wire Termination etc. Contact: Jim Pletcher, Ex. Dir., ECSG, Inc., P.O. Box 167, Fort Washington, PA 19034. Tel: (215) 279-7084.

MILITARY MICROWAVES '80 CONFERENCE AND EXHIBITION OCT. 22-24, 1980 Sponsor: Microwave Exhibitions and Publishers Ltd. Place: Cunard Int'l. Hotel, London. Topics: Military applications of microwave engineering. Contact: R. C. Marriott, Managing Director, MEPL, Kent TN13 1JG. Tel: (0732) 59533, 59534. Telex: 95604 YNLTD G.

GOVERNMENT MICROCIRCUIT APPLICATIONS CONFERENCE NOV. 19-21, 1980 Sponsors: DoD, Army, Navy, AF, ASA, NBS, etc. Place: Shamrock Hilton, Houston, TX. Themes: Signal Processing, Directions of Gov't. Electronics for the '80s, Terrestrial Applications of Aerospace Technology plus VHSIC program session. Contact: Palisades Institute for Research Services, Inc., 201 Varick St., New York, NY 10014.

1980 IEEE INT'L. ELECTRON DEVICES MEETING DEC. 8-10, 1980 Call for papers. Sponsor: IEEE Electron Devices Society. Place: Washington Hilton Hotel, Washington, DC. Topics: Solid State Devices, Device Technology, Integrated Electronics, Electron Tubes, etc. Contact: Melissa M. Widerkehr, Conf. Mgr., Courtesy Associates, Inc., 1629 K St., N.W., St. 700, Washington, DC 20006.

1981 IEEE/MTT-S INT'L. MICROWAVE SYMPOSIUM JUNE 15-17, 1981 Sponsor: IEEE MTT-S (held jointly with IEEE AP-S — June 17-19, 1981. Place: Bonaventure Hotel, L.A., CA. Theme: "Around the World with Microwaves." Paper topics include: CAD and measurement techniques, microwave and mm-wave solid state devices and ICs, etc. Submit 35-word abstract and 500-1000 word summary by Jan. 15, 1981 to: Dr. Don Parker, TPC 1981 MTT-S Symposium, Hughes Aircraft Co., Bldg. 268, M.S. A54, Canoga Park, CA 91304.

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An Applications Panel, chaired by S. G. Pitroda, Managing Director, WESCOM Switching, Inc., Downers Grove, Illinois, will explore "The Role of Semiconductor Development In Shaping the Future of Telecommunications."

Components Symposia

CUSTOM LSI/VLSI DESIGN FOR THE SYSTEMS ENGINEER
Doug Fairbairn
Publisher
LAMBDA – The magazine of VLSI design

SOLID STATE SOURCES FOR COMMUNICATIONS
Carl Sirles – Manager of RF Component Development
Rockwell International

TUBES FOR COMMUNICATIONS SYSTEMS
Chet Lob
Technical Director
Varian Associates

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A sixth session on fiber optics components is being organized.

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- "Programs and Field Trials of Fiber Optics Technology."

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HEWLETT PACKARD

RADAR HISTORY

In this paper, Dave Barton selects a number of major innovations in techniques and microwave components as milestones in the evolution of modern radars. His key component list includes the magnetron, the klystron, the phased array and solid-state devices. The technique milestones include coherent signal processing, monopulse tracking, pulse compression and digital processing and control. The liberally illustrated article discusses the significance of each of these in the development of radar and also identifies the systems which demonstrated their usefulness.

Sum Up

URSI/AP-S MEETING

Since the 1980 URSI/AP-S Meeting, held during the first week in June in Quebec, Canada, consisted of more than 500 technical papers, the report in this issue can only touch highlights of that program. Bob Mailloux notes the expanding success of Foster Sessions at the Quebec meeting and an apparent growing preference for that kind of presentation in place of formal lectures. The Plenary Session of the URSI Conference was devoted to a discussion of the important contributions to radio science that have been made by Canadian researchers and the Canadian scientific satellite program was singled out for discussion. There were 21 sessions concerned with antenna theory or technology. These were divided almost equally between reflector and phased array topics. The report touches on many of the papers and provides sufficient information so that interested readers might identify individual papers which would be of interest to them.

COLOR WEATHER RADAR

Weather radar with color indicators for both commercial air carriers and general aircraft users is described. The article begins with a discussion of the relationship between rain density and turbulence and describes the manner in which various rainfall rates are depicted by the color display. The microwave front end of the system is described in detail as is the signal processing section which feeds the display. The equipment also provides a ground mapping mode which makes effective use of the color feature.

MILLIMETER-WAVE RADAR TRANSMITTERS

The article provides a complete discussion of moderate to high-power millimeter-wave power sources for radar applications. Much of the discussion centers on sources for use about 70 GHz. Pulse IMPATT's and their characteristics are covered. The advantages and problems of millimeter-wave magnetrons are discussed. A new entry, the extended interaction oscillator is described in detail and TWT's and gyrotrons are also covered. A proper selection of a modulator for a millimeter-wave radar is emphasized and examples of the available designs with their characteristics are discussed.

L-BAND SOLID STATE TRANSMITTER

The applicability of a balanced transistor design to a pulsed L-band radar transmitter is discussed. Peak pulse powers up to 400 W are available from a single balanced device. The high input and output impedances of the balanced design offer additional significant advantages over single ended devices. Balanced transistor performance, construction and circuit designs are covered in detail.

Howard Ellowitz

Workshops & Courses

SPREAD SPECTRUM COMMUNICATIONS

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Lecturer: Dr. David Nicholson
Dates & Sites: August 11-13, 1980 Los Angeles, CA; September 22-24, 1980 Palo Alto, CA; October 20-22, 1980 Woburn, MA
Fee: $595 per seminar
Contact: Hellman Associates, 299 S. California Ave., Palo Alto, CA 94306 Tel: (415) 328-4091

SHORT COURSE ON ELECTROMAGNETIC COMPATIBILITY ENGINEERING

Sponsor: Center for Professional Advancement (CPA)
Date: September 22-24, 1980
Site: Sheraton Motor Inn, Rt. 16, East Brunswick, NJ
Fee: $545
Contact: R. Razzano, Dept. NR, CPA P.O. Box H, East Brunswick, NJ 08816

MICROWAVES FOR MANAGERS

Sponsor: Enrichment Cassettes
Dates & Sites: October 6-7, 1980 Inn at the Park, Anaheim, CA, October 27-28, 1980 Holiday Inn, Waltham, MA
Fee: $425 per person
Seminar Leader: Mr. Allan W. Scott, Senior Scientist/ Mgr. of Adv. Devel., Varian Associates, Microwave Tube Div.
Topics: Survey of microwave systems and devices, financial aspects and future trends.
Contact: Enrichment Cassettes, Box 11534, Palo Alto, CA 94306 Tel: (415) 493-4000 x 2508

RADAR TECHNOLOGY COURSE

Sponsors: Boston IEEE AESS/IEE
Date: October 20-21, 1980
Site: Cunard Int'l. Hotel, London
Lecturer: Dr. Eli Brookner, Consulting Scientist, Raytheon Co. £122 – IEEE/IEE members, £135 – nonmembers
Topics: Fundamentals of radar, trends in signal processing, components, tracking etc.
Contact: B. V. Atkinson, Int'l Electrical Engineers, Savoy Place, London WC2R OBL, England Tel: 01-240 1871

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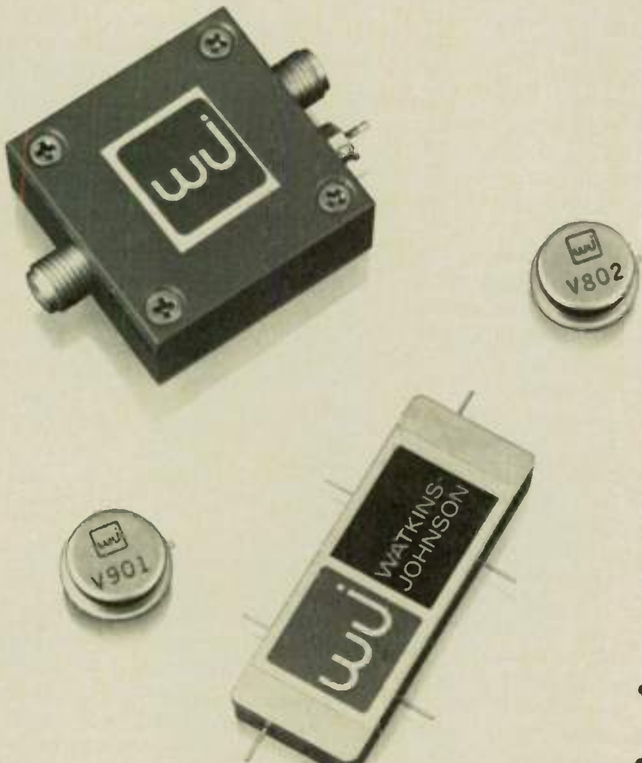

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Circle 14 on Reader Service Card

Malcolm R. Currie *is a native of Spokane, Washington and received his early schooling there. Following service in the Navy, he attended the University of California, Berkeley, receiving his A.B. in Physics in 1947, and an M.S. in Electrical Engineering in 1951 and his Ph.D. in 1954.*

His technical career includes university teaching, research in various fields of electronics and physics, and the development of communications, radar, electro-optical, laser and propulsion systems for space and airborne applications. A number of publications and patents resulted.

Dr. Currie's industrial management experience includes various positions to Corporate Vice President and Manager of a large engineering division at Hughes Aircraft Company (1955-1969); Vice President - Research and Development at Beckmann Instruments (1969-1973); Director of Defense Research and Engineering - Department of Defense; and Chairman of the Intelligence Research and Development Council (1973-1977). He is presently Corporate Vice President and Group Executive of the Missile Systems Group at Hughes Aircraft Company.

The Rising Importance of Radar in Tactical Missiles

MALCOLM R. CURRIE
Hughes Aircraft Co., Missile Systems Group
Canoga Park, CA

Typically, a majority of the cost in engineering as well as in production of a tactical missile is expended in guidance. Furthermore, guidance considerations almost always limit missile performance and are frequently the primary source of risk in design. Thus guidance projects deservedly receive a majority of our R and D attention and resources.

There are a variety of forces that are currently changing our approach to and the design of radar missile seekers. Explosive advances in the component technology comprise one set of factors. Of significant importance are the development of high-power solid-state devices and techniques for combining many of these devices to obtain powers once reserved only for tubes. Thus quick-starting and simpler power supplies might be realized in exchange for lower efficiency. X-band pulsed silicon IMPATT diodes are capable of 40 watts peak and GaAs double drift IMPATT's produce 30 to 40 watts peak. Circuits have been developed to combine many of these devices and over 300 watts peak have been realized. The increased efficiency of GaAs IMPATT's opens the opportunity for 500 watt to a kilowatt peak power transmitters in tactical missiles.

At 94 GHz, peak powers of 5 to 10 watts have been obtained from silicon IMPATT diodes. Power combining techniques developed at X-band are now being applied at millimeter wave frequencies. Missile seeker applications at millimeter wave frequencies exist with potentials for extremely large volume production if these powers can be provided reliably and consistently.

Recent advances in power FET's are also very encouraging. Power levels of 5 to 10 watts and amplifier gains of 3 to 4 dB have been reported at X-band. At K_u-band, 1 and 2 watts has been obtained. Circuits to combine several FET's are being developed. Because of bandwidth and stability considerations, FET's are potential candidates for driver stages in high power missile transmitters.

Improvements in missile signal-to-noise ratios can be realized in the very near future with low noise FET amplifiers. For example, X-band FET amplifiers with 2 dB noise figures or less are available. Use of these devices in microwave integrated circuit (MIC) receiver front ends will allow very high performance in a small volume and low weight. The latter two factors are of prime importance in small missile applications. Low noise FET amplifiers and MIC techniques also open up the possibility for active arrays in certain missile applications.

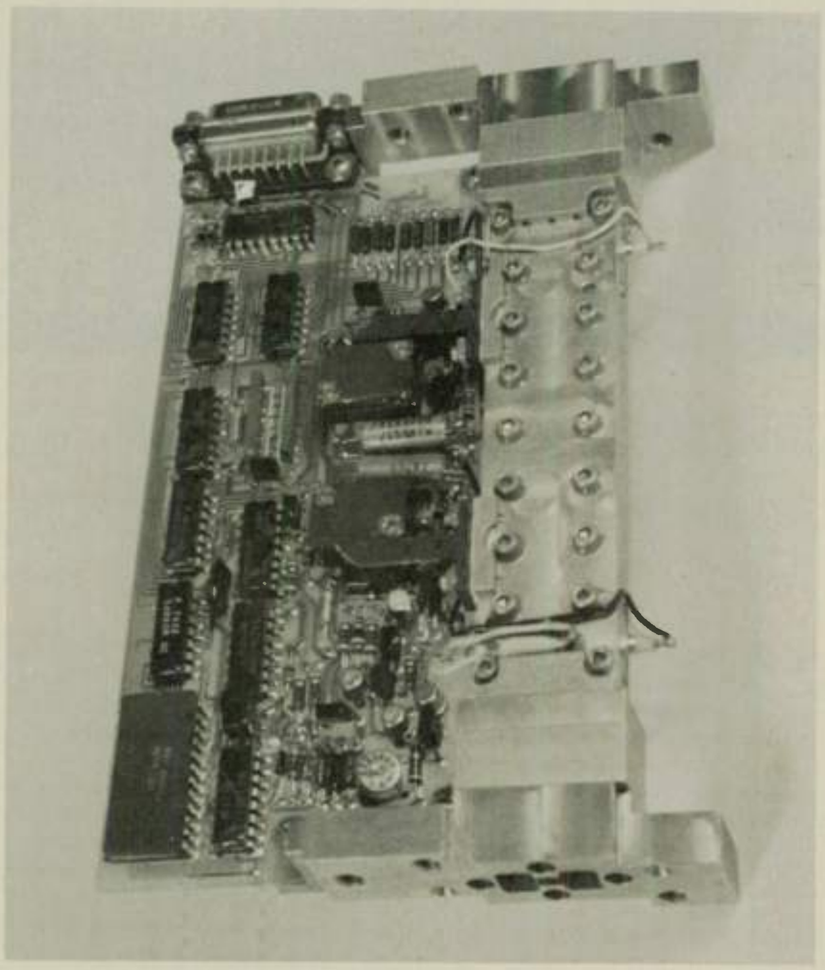
Improved in GaAs beam-lead mixer diodes and Gunn diodes will lead to improved low noise receivers at millimeter wave frequencies. These devices used in conjunction with MIC techniques at the higher frequencies will provide capabilities not previously available for the small missiles and projectiles.

By themselves, these technological advances would naturally lead to improvements in our weapon systems. But the process has been accelerated by the simultaneous emergence of a variety of systems pressures. As an example, strike weapon systems must be effective while enhancing survivability in the presence of significantly more lethal defenses. Typical "requirements" that result include more stand-off, self-acquisition of the target by the missile, and higher lethality—all impose more demands on the guidance subsystem. In the air superiority mission area, the emergence of the stand-off jammer (SOJ) threat and longer range weapons such as the AA-9 are driving systems to longer range and higher speed. Again, a better guidance subsystem is required to meet the threat. The numerical disadvantage we face in force structure drives us to strive for increased firepower and range, the answer to which also rests heavily on guidance subsystem capability. On our side of the fence, we see the gradual emergence of improved missile propulsion systems with specific impulses (thrust per pound) potentially increasing by a factor of 3 to 5. Thus our vehicles are capable of accommodating longer guidance ranges. Similar performance improvements are

(continued on page 70)

Phase Shifters

super-octave RF bandwidth
highly accurate phase control



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VSWR:	1.35:1 max. (1.2:1 typ.) over 80% of band 1.5:1 worst case
Ambient Temperature Range:	-28 to +65° C
Switching Time:	9 microsec. max.

*Includes phase shift error, insertion phase match unit-to-unit and insertion phase tracking over the entire temperature and frequency range and for all states.

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For the radar specialist . . .

INTRODUCTION TO SYNTHETIC ARRAY AND IMAGING RADARS

S.A. Hovanessian, Ph.D., Hughes Aircraft Co., Radar Systems Group, 156 pages, 1980, #3-50353, $41.75

Certain to become the standard sourcebook on this innovative area of modern radar design and application, this book is distinguished by crisp presentation, generous illustrations (74 figures, 15 tables), and the use of the simplest derivations in obtaining needed mathematical relationships.

Sections detailing the latest information on real-time digital signal processing methods, as well as "real world" design examples are of special interest.

RADAR DETECTION

J.V. DiFranco and W.L. Rubin, Sperry Rand Corp. Sperry Gyroscope Division, 654 pages, 1980, #3-50334, $50.75

A reissue of the important 1968 work, this volume is both a text for a graduate course on radar detection theory and a reference for the practicing radar engineer.

The book presents a comprehensive tutorial exposition of radar detection using the methods of mathematical statistics. Problems and exercises follow each chapter and important practical results are provided on large full-page graphs.

AUTOMATIC DETECTION AND RADAR DATA PROCESSING

D.C. Schleher. Ph.D., Director of Planning, Eaton Corp., AIL Division, 550 pages (approx.), 1980, #3-50375, $57.25

An up-to-date collection of 49 key papers, this definitive text should be of interest to both the radar specialist who wants a readily accessible compilation of the most recent results, and the radar generalist who wants an overview of the subject with keys into significant details.

Dr. Schleher has added extensive introductory and interpretive material, as well as detailed outlines of both detection and estimation theory.

INTRODUCTION TO MONOPULSE

Donald R. Rhodes, North Carolina State University, Department of EE, 199 pages, 1980, #3-50371, $32.50

A reissue to the 1959 classic radar sourcebook, this volume is both an excellent introduction for the student and a quick "refresher course" for the practicing engineer.

The book defines a unified theory of monopulse in the form of *three postulates* and identifies the underlying relationships among all the various forms, from which the apparent differences can then be resolved.

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SEPTEMBER	Bhartia and Bahl, MICROSTRIP ANTENNAS (Microwave Library)
OCTOBER	Johnston, MILLIMETER WAVE RADAR (Radar Library reprint volume)
NOVEMBER	DiLorenzo et al. PRINCIPLES OF GaAs FET TECHNOLOGY (Microwave Library)

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NUMBER 10 AUGUST 198

E&C MICROWAVE BULLETIN

MICROWAVE ABSORBERS—ANECHOIC CHAMBERS—EMI/RFI SHIELDING—MICROWAVE DIELECTRICS

EMERSON & CUMING DEWEY AND ALMY CHEMICAL DIVISION W.R. GRACE & CO.

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Low Frequency Slotted Line: dielectric and magnetic properties from 200 MHz to 850 MHz.

Dielectrometer for dielectric constant, magnetic permeability and loss tangents, 1 to 8.6 GHz.

Cavities for measuring block materials, 1 to 2 GHz.

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Bridges and Q-Meter for dielectric constant and loss tangent of disc samples, 1 kHz to 50 MHz.

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Waveguide Slotted Lines up to 2′ x 12′ for measuring reflection loss. 100 to 500 MHz at Gardena; 300 to 500 MHz at Westerlo; 500 MHz to 1.8 GHz at Kuriyama.

Reflectivity Arches for near-field quality control of absorber, 1 to 16 GHz.

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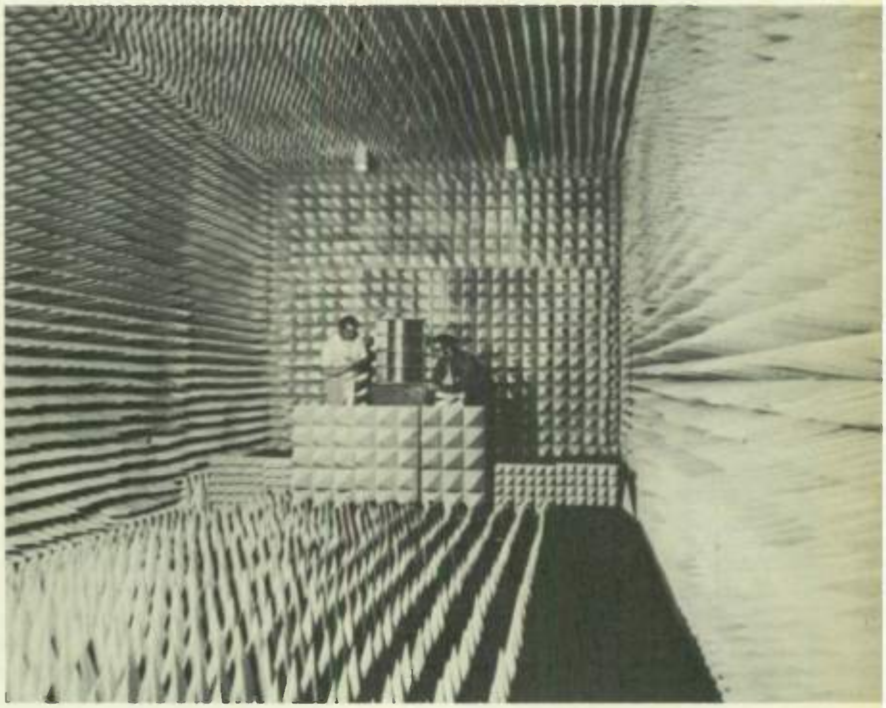

ECCOSORB SPY open-cell foam pyramidal absorber is used extensively in an advanced-design microwave anechoic chamber built by Hughes Aircraft Company in Fullerton, California.

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The list price of the new ECCOSHIELD FAS Economy Shielded Door is approximately 50 percent of that of the original, patented ECCOSHIELD MAS Shielded Door. A new Technical Bulletin gives specifications, technical data, and installation data.

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ANECHOIC CHAMBER FLOORING WITH UNIQUE PROPERTIES

When a shielded anechoic chamber is built, it is necessary to shield the floor as well as the ceiling and walls. In most chambers, the metal floor is then covered with absorber to improve the anechoic performance, while at the same time retaining the integrity of the shielding.

In the recent design of a shielded anechoic chamber, the customer wanted the floor to have reflectivity properties which simulate earth. This would make it possible to mount test objects in the chamber and to measure electromagnetic emissions and susceptibility as though the measurements were being done outdoors on genuine earth. Thus we coined the term "Eccoearth" as the nomenclature for a floor design which simulates true earth.

The accuracy of the simulation is based on a site attenuation measurement method pioneered by the Radio Interference Branch of the Directorate of Radio Technology of the British Government. It is often referred to as the "St. Albans" technique for the site where it was first used.

Similar methods have been described in Publications of the International Special Committee on Radio Interference. The method was adapted by E&C to make the special, Proprietary product, "Eccoearth." If you're interested in having your shielded anechoic chamber simulate an earth floor, send for more information.

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LOSSY FLEXIBLE FOAM SHEET IS VERSATILE ABSORBER

ECCOSORB LS is a series of low-density, high-loss flexible foam sheet materials used to absorb electromagnetic energy in applications other than free-space. It can be used to line the interior of a cavity to lower its Q, or wrapped around a radiating element to eliminate surface currents, or trimmed to tapered pieces and used inside waveguides as dissipative material.

Each sheet of ECCOSORB LS is uniform in characteristics from point to point throughout the sheet. Standard sizes are 24" x 24" (61 cm x 61 cm). Thickness 1/8" (0.3 cm), 3/8" (0.9 cm), and 3/4" (1.8 cm). Density is approximately 5 lb/cu ft (0.08 g/cc). Types are offered in a wide range of dielectric properties (insertion loss and dielectric loss factor), which can be combined to produce graded absorber for custom applications. The composite sheet can be surface-coated for outdoor use.

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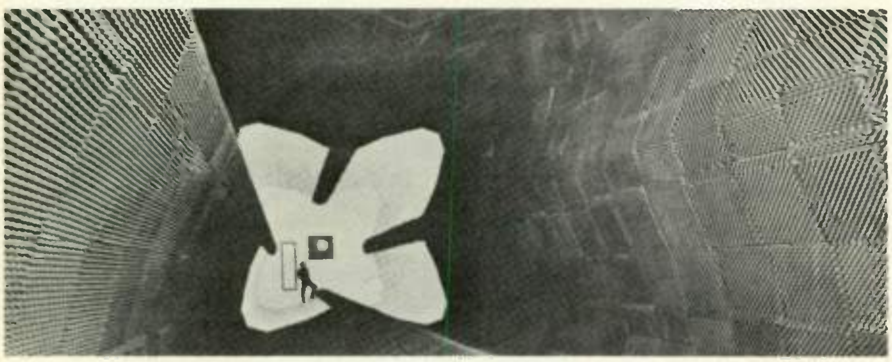
PREMIUM QUALITY ABSORBER FOR HIGHEST FREQUENCIES



ECCOSORB CV is a series of premium-quality electrically tapered broadband absorbing materials intended primarily for use in anechoic chambers where superior performance is required at the highest frequencies. Power reflectivity of 0.01 percent (-40 dB) and less is assured at frequencies above 9 GHz up to frequencies in excess of 100 GHz.

ECCOSORB CV is made from lightweight artificial-dielectric loaded flexible foam. The front surface is rippled for optimum impedance match at the higher microwave frequencies. Sheet size is 24" x 24" (61 cm x 61 cm). Sheets may be cut readily to any required outline and can be contoured to surfaces of moderate curvature by appropriate procedures.

The photo is a chamber using ECCOSORB CV, built in the 1960's to aid development of aircraft radomes.

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Historical Perspective on Radar

DAVID K. BARTON
Raytheon Company
Missile Systems Division
Bedford, MA

Fig. 1 The last of Sir Watson-Watt's experimental radar towers, at Bawdsey on the North Sea coast of England.

INTRODUCTION

The evolutionary development of radar has been punctuated by several major innovations in techniques and components: the microwave magnetron, the high-power klystron, coherent signal processing, monopulse tracking, pulse compression, the electronically steered arrays, digital processing and control, and solid-state microwave devices. By comparing the appearance and performance of typical radar systems developed before and after each of these innovations, we can see how they have affected the art of radar, and what we may expect of future developments along these lines.

Early radar equipment was adapted from the radio communications field, using HF, VHF and UHF tubes and antenna techniques. Thus, the early British radar chain, operating at 25 MHz, was marked by the use of antennas hardly distinguishable from shortwave radio stations (**Figure 1**). Radars available in the US at the beginning of World War II included the SCR-270, at 105 MHz (**Figure 2**) and the SCR-268 at 205 MHz (**Figure 3**). The SCR-270 will be remembered as the set that gave advance warning of the approach of Japanese aircraft toward Pearl Harbor, only to have the message terminated in an inoperative command and control channel.

As an example of a phased array radar, the SCR-268 provided a preview of some techniques used in modern equipment. The array was thinned by removing top and bottom rows of dipoles from the main portion of the an-

Fig. 2 SCR-270 air surveillance radar.

Fig. 3 SCR-268 anti-aircraft tracking radar.

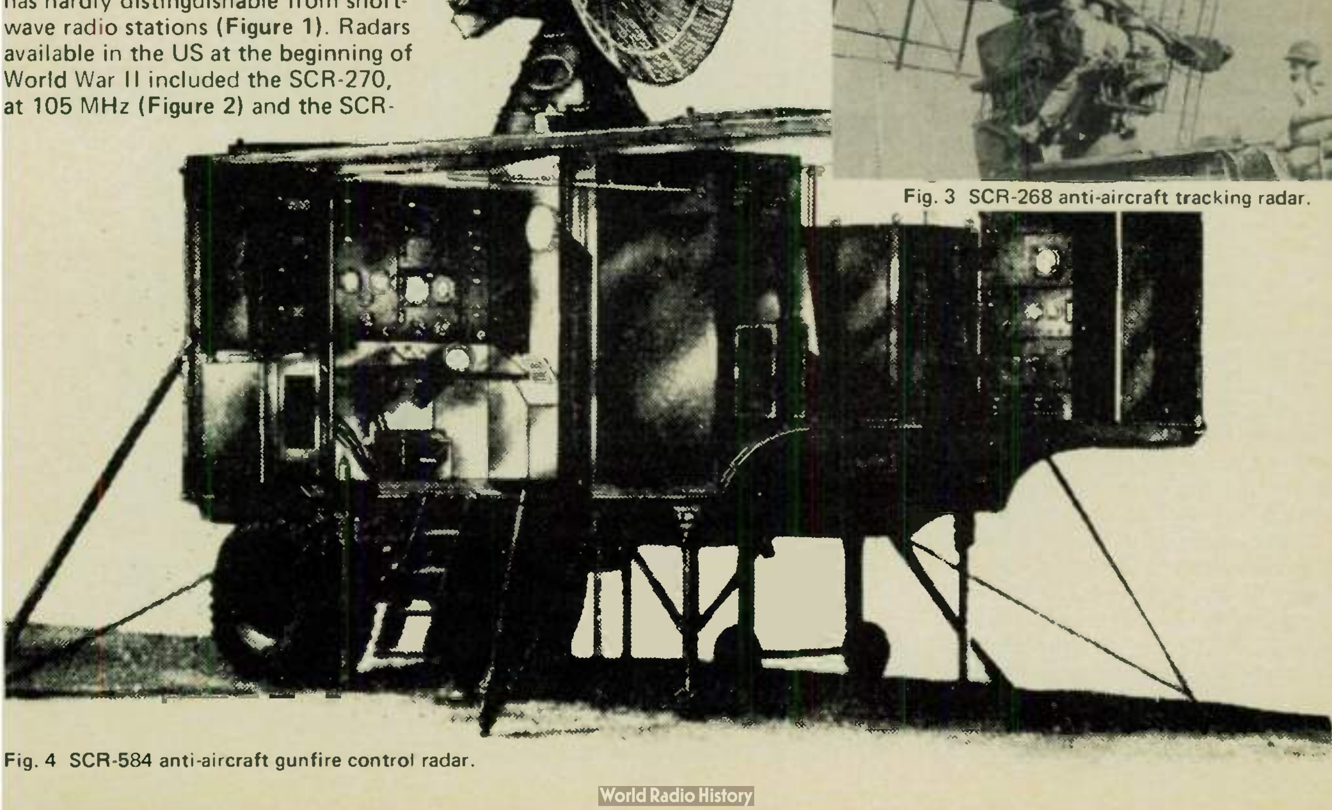


Fig. 4 SCR-584 anti-aircraft gunfire control radar.

tenna, where the evaluation resolution was not of prime concern. Only the right-hand section of the array (**Figure 3**) had the full height needed for elevation measurement. The array itself, and subsequent processing, was highly redundant, so that individual dipoles and feeders could be damaged or destroyed with minimal loss in performance. Once amplified by the receiver, the signals followed duplicate paths to separate displays, where the detection and tracking processes were performed by operators, each with two eyes, two hands, and with back-up crew members available in case of incapacitation of any member. What was lacking was the electronic beam switching for multiple-target tracking and search, which has since become available from digitally controlled arrays.

Another problem and modern solution illustrated by the SCR-268 is that of limited resolution and accuracy. With beamwidths of 15°, the best beam-splitting techniques yielded accuracy of ½°, or about 10 mr, which was insufficient for control of AA gunfire. To overcome this basic limitation of VHF radar, a dual-frequency tracking technique was used, the high-frequency element being an optical tracker. For nighttime use, an illuminating searchlight was slaved to the radar tracker, and the combination of optical angles with radar range provided an adequate input to the gun director.

MICROWAVE DEVELOPMENTS

Microwave radar was made practical by development of the magnetron and of methods for its mass production. Low-power klystrons for receiving local oscillators had already been developed, as had parabolic dish and cylindrical parabola antennas for generating pencil or fan beams. Thus, only a year was required to make the transition from the laboratory magnetron (mid-1940, in England) to the first 10-cm experimental tracker at MIT. Another year produced a field test model of the XT-1, and by mid-1943 production delivery of the SCR-584 had begun. This radar (**Figure 4**) had a beamwidth of only 4° (70 mr) and could provide about 1.5 mr rms accuracy for direct input to the gun director. Optical tracking thus became an optional input.

In the search radar field, the early parabolic cylinder with a line feed (**Figure 5**) was supplemented in the US by the doubly-curved reflector, developing shaped fan beams either through modified curvature of upper or lower edge, or through use of extended feeds (**Figure 6**). Other antenna types included microwave lenses and various fast-scanning feeds: organ-pipe feeds, Foster scanners, and the Eagle scanner (**Figure 7**). Originally developed for airborne use, the Eagle appeared in 1944 as an essential element of the precision approach radar for ground controlled landing of aircraft. It remains in that role today, in successful competition with more capable and expensive electronically steered arrays.

In Europe, the microwave dish antenna was widely adopted but did not completely replace the parabolic cylinder for search radar use. One of the most advanced of today's radars (**Figure 8**) seems to have been inspired by

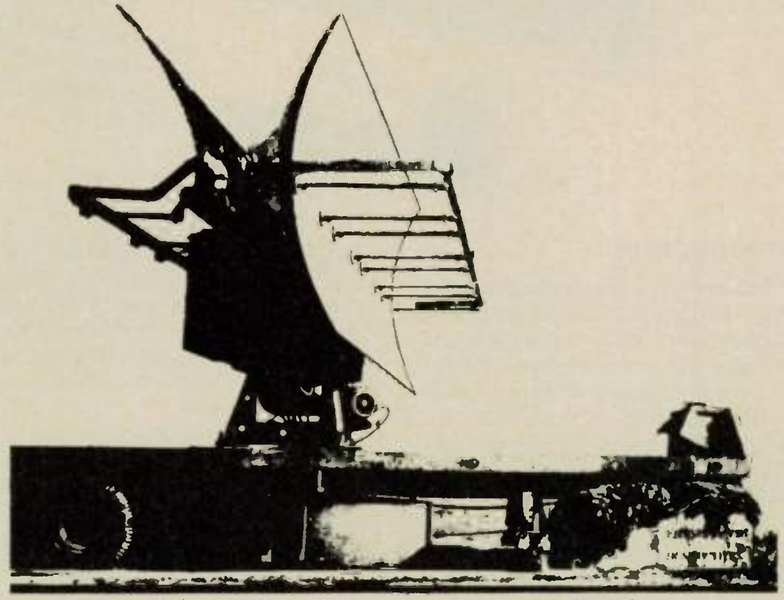


Fig. 5 AN/CPS-1, the first microwave early warning (MEW) radar.

Fig. 6 AN/FPS-20, modernized version of the AN/FPS-3 long-range air surveillance radar (photo courtesy Bendix Corp.).

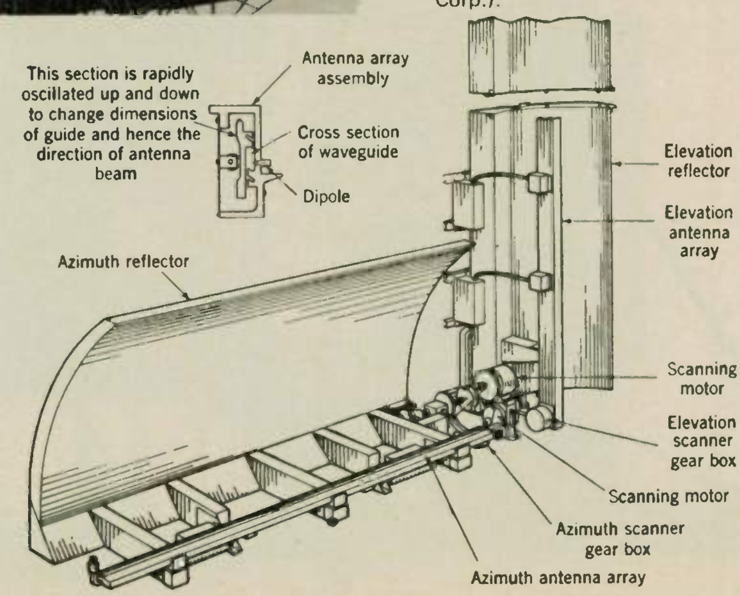
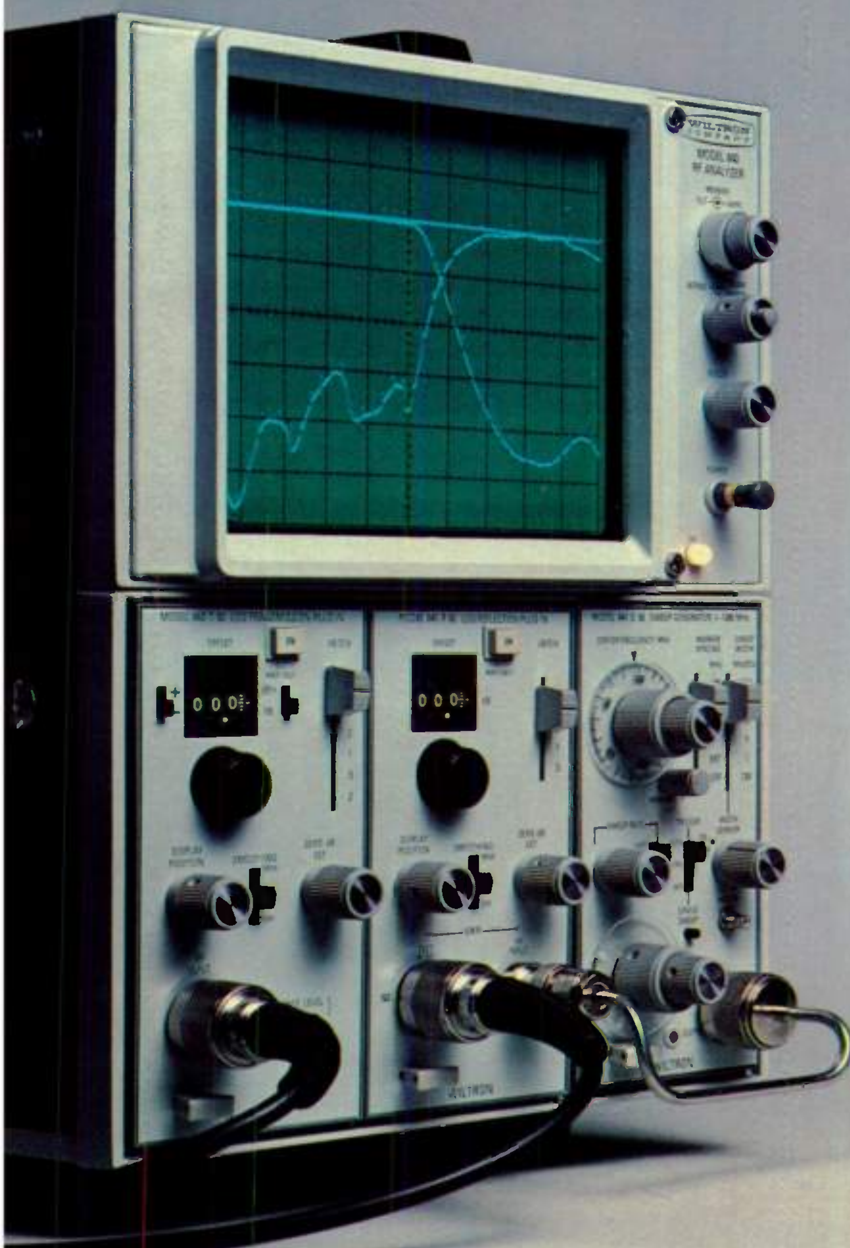


Fig. 7 The Eagle scanner, as used in the AN/MPN-1 precision approach radar.

(continued on page 24)

Measure transmission and reflection with stark simplicity, 1-1500 MHz.

It's a Wiltron.



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It gives you the most versatile marker system available, stable, crystal accurate, on a dual-trace display with a ±90 dB calibrated offset.

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Five plug-ins are offered: a swept signal source, log reflection unit, log transmission unit, linear amplifier unit and log transmission/reflection unit for use with external detector and SWR Autotester.

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For complete details ask for a copy of Technical Review #7. For an early demonstration, call Walt Baxter, Wiltron, 825 East Middlefield Road, Mountain View, CA 94043. Phone (415) 969-6500.

WILTRON

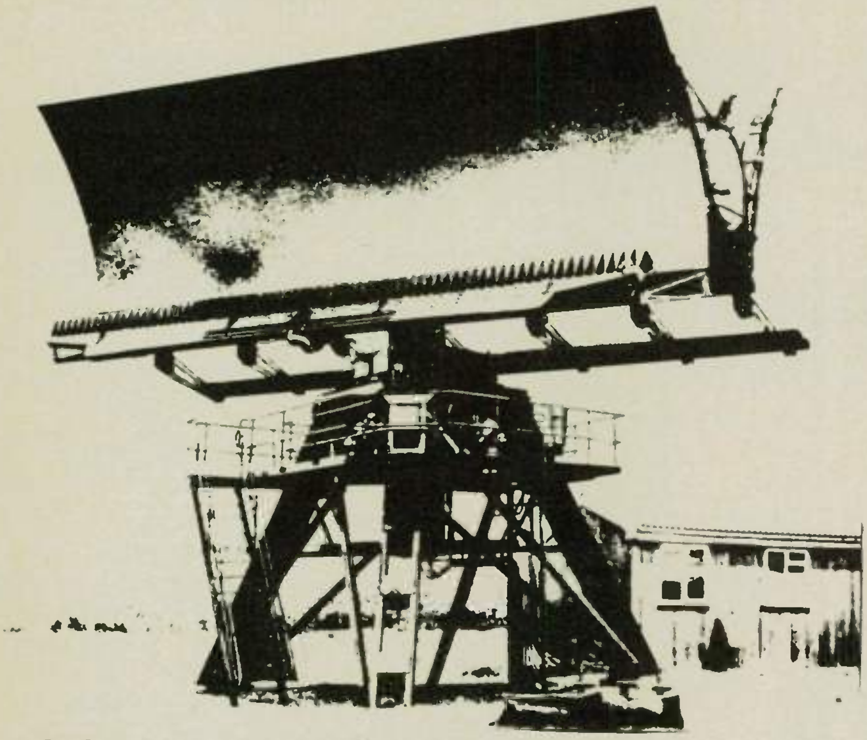


Fig. 8 Modern air defense radar, S631, using back-to-back L- and S-band systems to overcome jamming (photo courtesy Marconi Radar Systems).

Fig. 9 Monopulse radar for guided missile range instrumentation, the AN/FPS-16 (photo courtesy RCA).

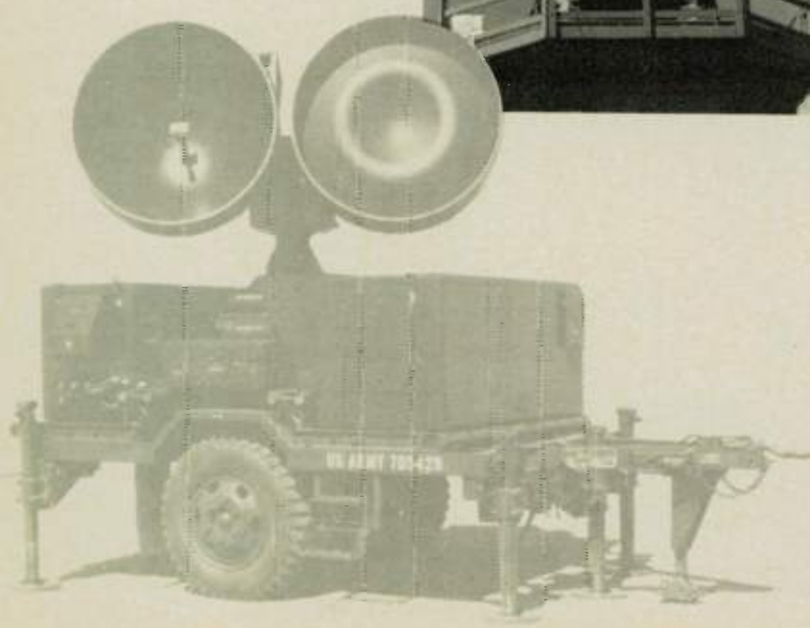


Fig. 10 AN/MPQ-39 tracker-illuminator for the Hawk missile system (photo courtesy Raytheon Company).

the CPS-1, in using back-to-back cylindrical reflectors. When very low sidelobes and broadband operation are required, this design can have significant advantages over the doubly-curved reflector fed by a single horn or vertically extended line feed.

An important postwar development in microwave antennas was the monopulse antenna (**Figure 9**). The monopulse tracking technique, using microwave networks to form two difference beams and an on-axis sum beam, provided an order of magnitude decrease in target-induced errors. This was combined with advances in mechanical pedestal design and in data output devices to attain 0.1 mr accuracy for guided missile range instrumentation, and comparable performance for tactical applications.

COHERENT SIGNAL TECHNIQUES

Another important thrust in postwar radar technology was the development of coherent transmitters and associated receiving and signal processing systems. While coherent MTI had been developed for magnetron systems, using locked coherent oscillators to remove the random transmitter phase on each pulse, the availability of high-power klystrons and crossed-field amplifiers provided new capabilities. Pulsed MTI, pulsed Doppler, and CW systems developed during the 1950s used higher power levels and achieved greater stability, to see small moving targets in clutter. One unique radar developed during this era and still very much in use today is the Hawk CW illuminator (**Figure 10**), a high-power, dual antenna capable of acquiring and tracking small targets at high or low altitude in any type of clutter.

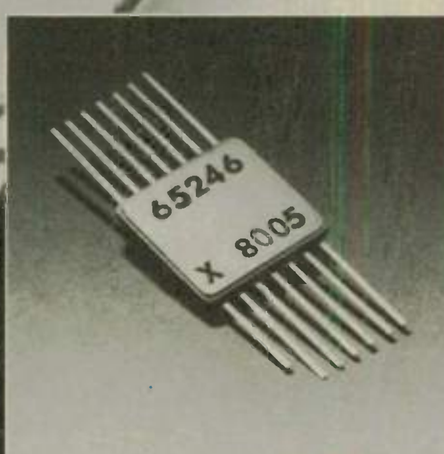
For more conventional, pulsed radars, pulse compression techniques made it possible to transmit wide pulses with high energy at reasonable peak power levels, while retaining the range resolution of short-pulse radars. When pulse compression was combined with pulse-to-pulse coherence in Doppler systems, high resolution in both range and Doppler was obtained. The components involved in these techniques consisted of highly stable oscillators and amplifiers, both at RF and IF, along with dispersive filters using lumped-constant components, metallic acoustic delay lines, and surface acoustic wave lines.

PHASED-ARRAY SYSTEMS

During the 1950s, elevation frequency-scanned arrays using mechanical rotation in azimuth were intro-

(continued on page 27)

For some people thick film drivers give a fighting chance.



When ultrafast switching is critical, consider the unique advantages of Alpha's thick film switch drivers. Designed for high speed, they switch microwave UHF and IF pin diode switches and attenuators on command of TTL logic signals. Compact. Rugged. Reliable. All with MIL-SPEC quality, quick delivery, and low cost through Alpha's advanced thick film technology. Solid state-of the-art performance . . . the Alpha advantage. For more information, call or write Alpha Industries, Inc. Optimax Division, P.O. Box 105, Advance Lane, Colmar, PA 18915 (215) 822-1311 TWX 510-661-7370.

Model Number	Output Signal Logic 0	Output Signal Logic 1	Switching Speed (Maximum)	Supply Voltages	Supply Current (Maximum) Logic 0	Supply Current (Maximum) Logic 1	Features
DS-02	−30mA, −10V	+10mA, +4V	10 nsec	+5V	5.5mA	35mA	Low cost Non-Inverting for SPST Switches
DS-011*				−12V	−38mA	−2mA	
DS-07	+10mA, +4V	−30mA, −10V	7 nsec	+5V	18mA	2mA	Low Cost Inverting for SPST Switches
DS-011*				−12V	−2mA	−38mA	

*DS-011 has the added advantage of working in both the inverting and non-inverting mode.

Alpha

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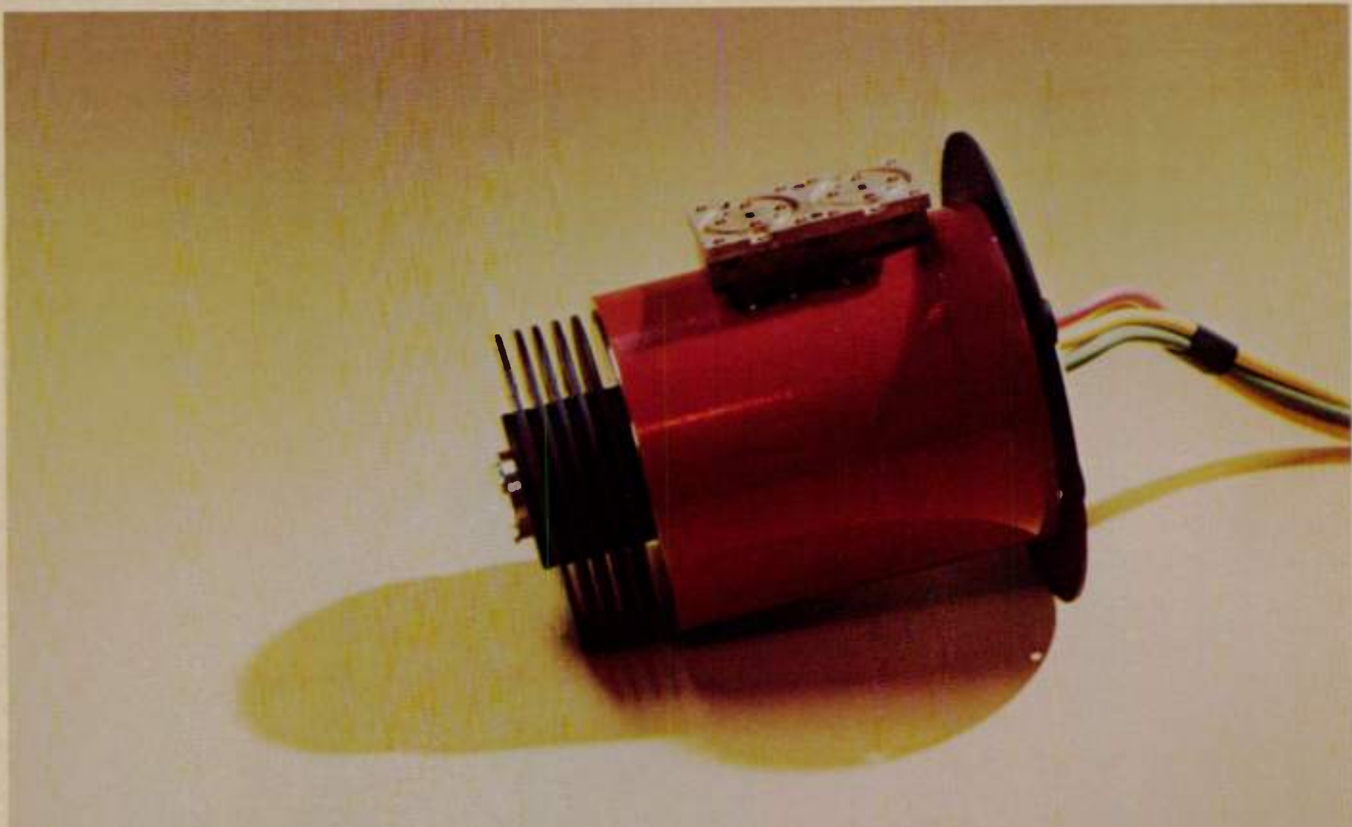

Enhance target detection. Varian Canada introduces the first 95 GHz EIA.

Varian Canada, a leader in millimeter wave technology, has developed the world's first Extended Interaction Amplifier for new millimeter radars.

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The new EIA is designed to be mechanically tuned over 1 GHz minimum with an instantaneous bandwidth of 200 MHz and has demonstrated 2.3 kW peak RF output at 33 dB gain. Light weight is achieved by using samarium cobalt and volume is less than 90 cubic inches.

Varian Canada's millimeter developments continue to advance to meet new generation radar systems requiring pulsed or CW amplifiers in the 35, 95, 140 and 220 GHz windows.

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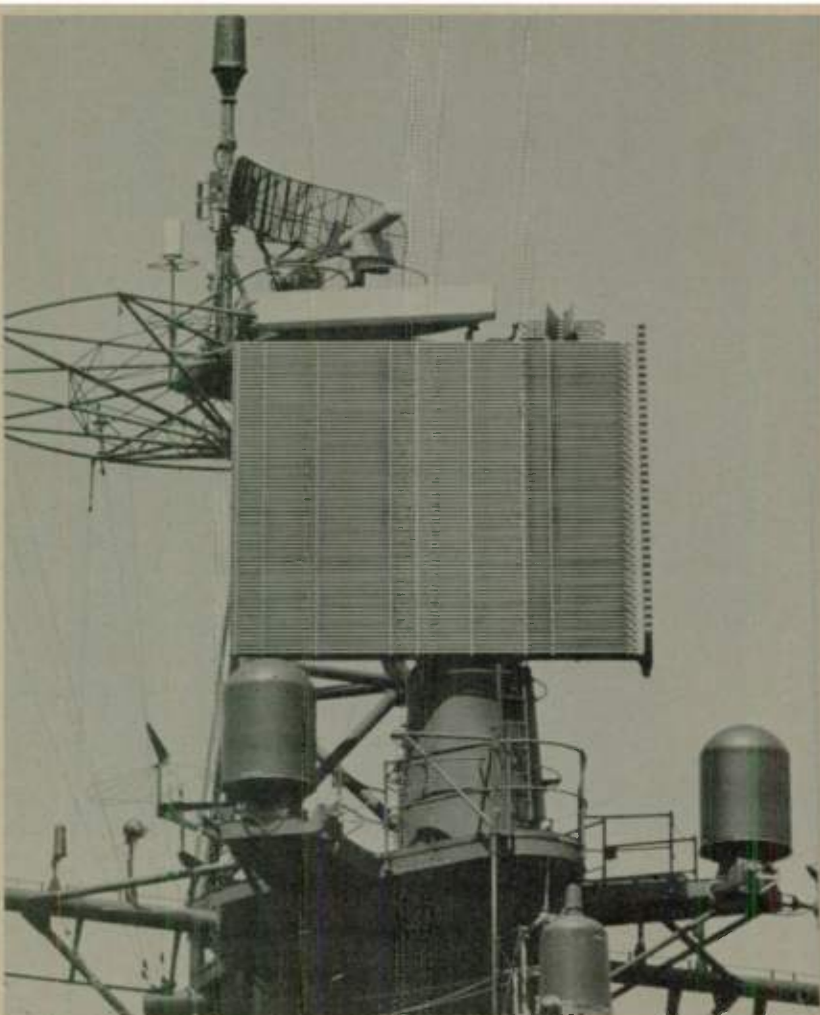


Fig. 11 AN/SPS-48 frequency-scanned 3D radar (photo courtesy ITT Gilfillan).

duced, and a number of those systems achieved production status. One of the most successful is the US Navy's AN/SPS-48, shown in **Figure 11**, which combines frequency scanning with stacked-beam reception to ease the time-budget problem of the pencil-beam 3D scanner. By operating several simultaneous beams, more hits per target are made available for MTI and target signal integration.

Many designs for electronically phase-steered radars were generated during the 1960-1980 period, but until recently none of these had achieved production status. A landmark in one-of-a-kind radar designs was the AN/FPS-85 space tracker (**Figure 12**), which typifies the large active array of the past decades. While two of these systems were built, this was only because the first was destroyed by fire before it became operational.

Fig. 12 AN/FPS-85 Spacetrack radar, as completed in 1968 (photo courtesy Bendix Corp.).

An approach which appears most promising for lower-cost production radars is the optically-fed array (**Figure 13**), in which a single transmitter-receiver of conventional design can be used. The refined technology of multimode monopulse feed clusters, originally developed for mechanically tracking reflector antennas, can be applied directly to this type of phased array. The phase shifting elements then direct the sum-and-difference beam cluster to the desired scan angle, and switch from one to another position in microseconds to provide interlaced search and multiple-target tracking. Similar types of array are appearing in airborne applications.

Fig. 13 Multifunction phased array radar for the Patriot missile system (photo courtesy Raytheon Company).

Another even lower-cost approach is the limited-scan array-reflector antenna (**Figure 14**), in which a small lens array (again fed by a conventional monopulse horn cluster) is used to control illumination of a large reflector. In this way, the one-degree pencil beam can be formed and controlled by a few hundred phase-shift elements instead of the ten thousand which would have been required in a full array. The economy of this design is obtained at the cost of a limited scan sector, 15 x 20 degrees in the AN/TPN-19 as compared to the 120° cone available in most arrays.

Finally, it should be noted that the successful exploitation of electronically scanned radar systems requires flexible waveform selection, signal processing and control techniques, made possible by today's digital technology. While the optically fed systems can be used with conventional transmitters, receivers and processors, the demands of fast changes in operating mode will usually force a greater investment in these subsystems than would be warranted if mechanical scanning were used.

TABLE I

DIGITAL PROCESSING AND CONTROL
Automatic detection
Range-Doppler matrix processing
Constant false-alarm rate systems
Digital pulse compression
Digital waveform generation
Digital beam forming
Tracking, scheduling and control

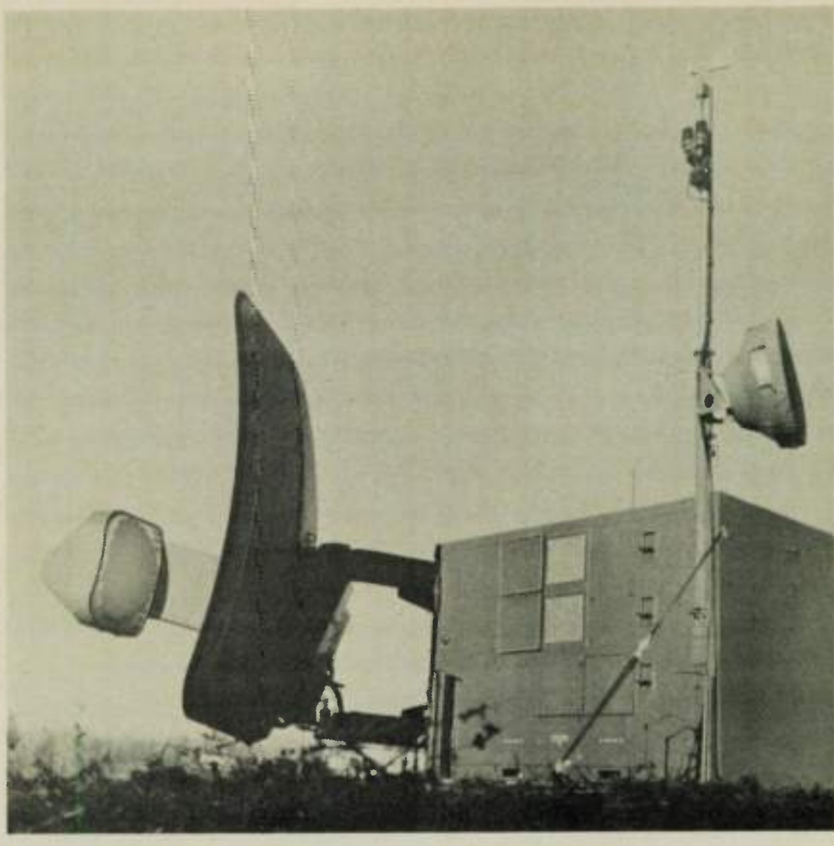


Fig. 14 AN/TPN-25 precision approach radar of the AN/TPN-19 landing system (photo courtesy Raytheon Company).

DIGITAL PROCESSING AND CONTROL

Most of the processes now performed by digital apparatus (**Table I**) were originated in older radar systems using analog circuits, with some success. The improved performance of digital circuits has been so dramatic, however, that radars using automatic detection, range-Doppler matrix processing, and modern constant-false-alarm-rate processes are almost entire-

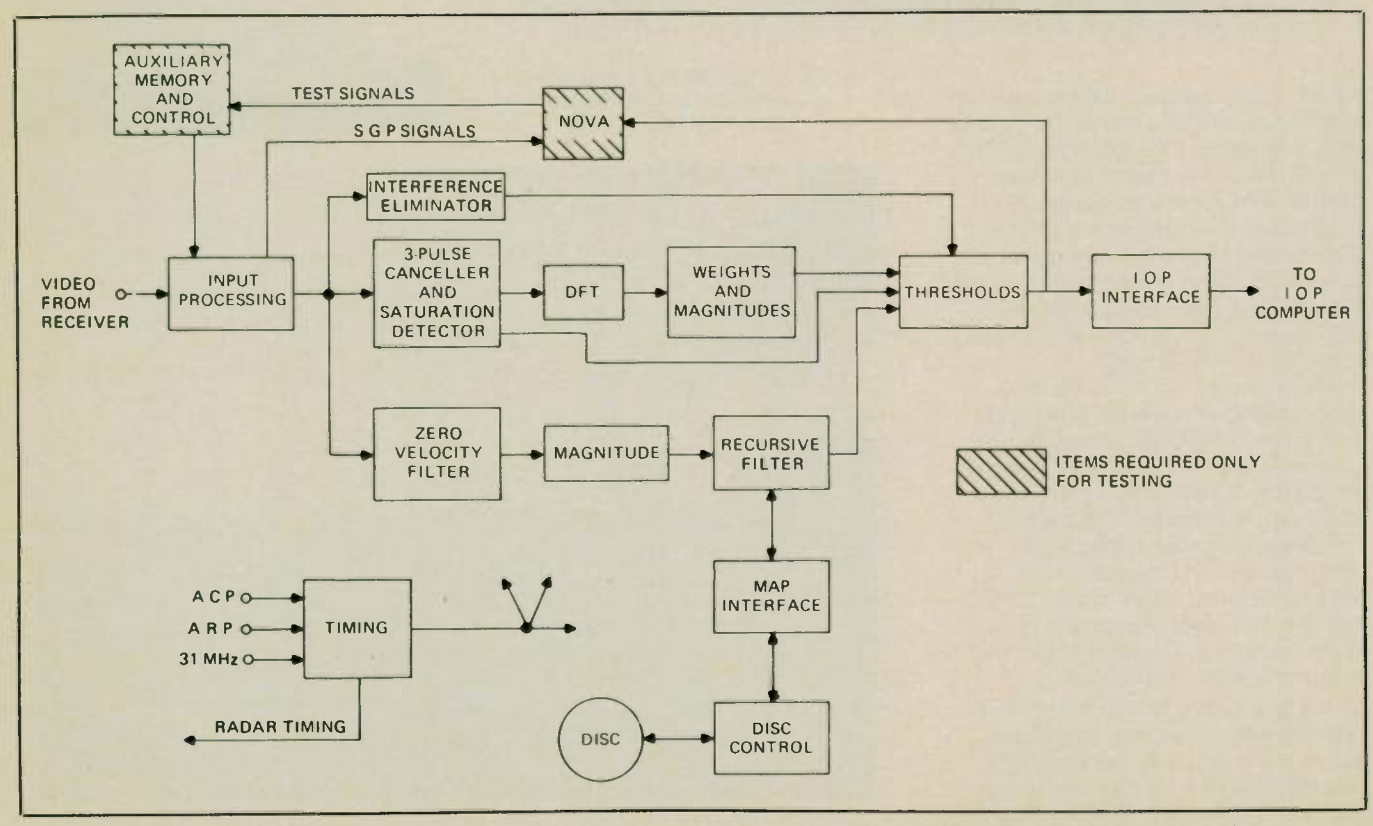


Fig. 15 Block diagram of the moving-target detector for airport surveillance radar (courtesy MIT Lincoln Laboratories).

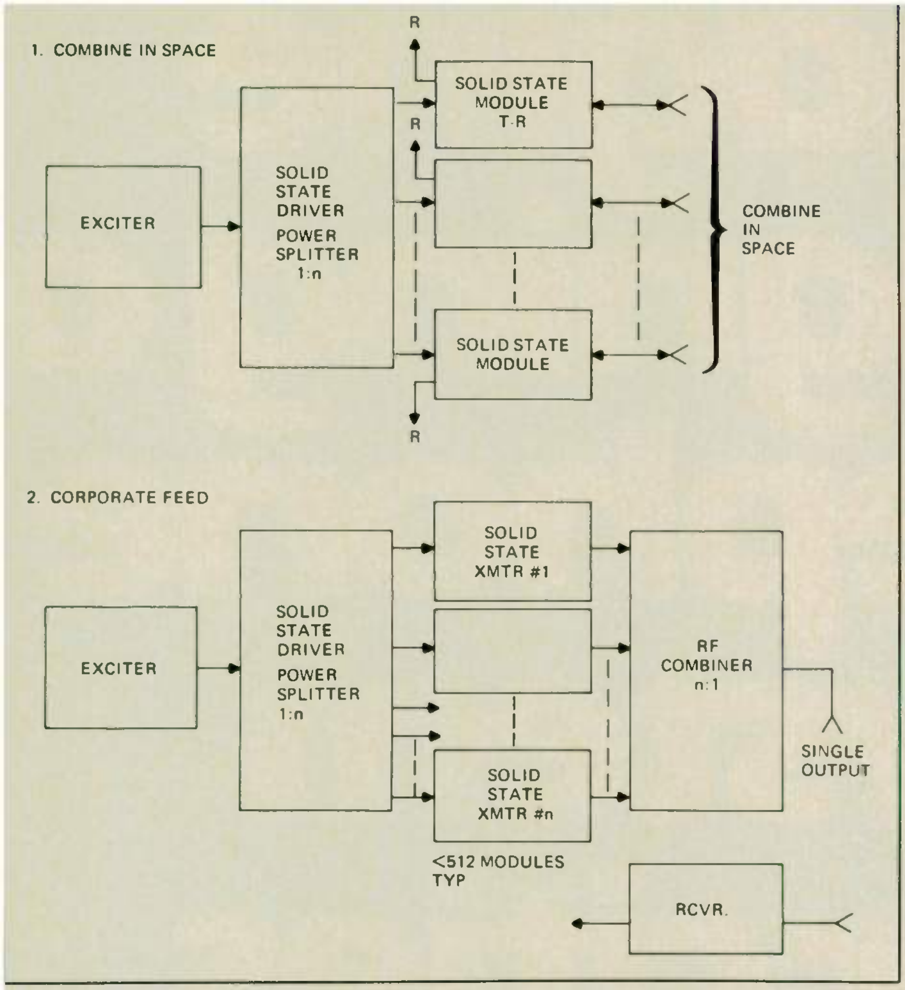


Fig. 16 Solid state transmitter configurations (courtesy D. J. Hoft).

ly digital in implementation. An example is the moving-target detector system (**Figure 15**), in which a key element is a high-resolution clutter map containing minute-by-minute averages of clutter background in each of half a million range-azimuth cells. This clutter map, as much as the discrete Fourier transform filter bank and digital MTI canceller, provides a level of performance unmatched by conventional MTI systems.

Digital pulse compression and waveform generation are less widely used, largely because the technology of surface-acoustic-wave lines has been able to compete on the basis of cost, size and performance. In beam forming, steering and control of array systems, digital technology is essential.

SOLID-STATE MICROWAVE DEVICES

Solid-state microwave components have been used in radar from the beginning, in the form of RF mixer diodes. During the 1960s and 1970s, low noise RF amplifiers for receiving became available in solid state form, replacing the unwieldy traveling-wave tubes, masers and paramps developed during the late 1950s. More recently, low-power solid-state RF sources have become common as local oscillators and as drivers for coherent transmitter systems. The trend now is toward combining these sources to produce useful transmitter power levels, eliminating thermionic devices entirely from the radar. Two methods of combining are shown in **Figure 16**: the combine-in-space array of modules, and the corporate combiner with a single output port.

The area of significant success in solid-state transmitters has been at the lower radar frequencies (UHF), in large active arrays such as PAVE PAWS. In these applications, the use of very long transmitted pulses is permitted by the large minimum range of desired targets. In tactical radar for air surveillance, solid-state transmitter technology has been less helpful, basically because of the need to operate these devices at high duty ratios. This constrains the choice of waveforms, and complicates the time budget problems in scanning arrays. Use of multiple-transmitter arrays (**Figure 17**) limits the radar sys-

ducing the availability of multiple-pulse Doppler processing over most of the surveillance coverage.

MILLIMETER-WAVE SYSTEMS

The trend in World War II radar was toward increasing frequency: 15 MHz in the British radar chain, 100 and 200 MHz in early US radars, 3 to 10 GHz in later fire control radars. By the end of the war, 15 and 35 GHz equipment was in the experimental stage, and both these bands were used to a limited extent in postwar systems. Then, for almost three decades, the movement to higher frequencies was halted. Largely because of atmospheric limitations, but also from lack of high-power sources and low-noise receivers, the frequencies above 10 GHz found relatively little use. Recently, thermionic tubes with power outputs of tens of kilowatts at millimeter wavelengths have begun to appear. Even these powers would not be particularly useful except for a new emphasis on short-range tactical weapons, both surface and airborne.

One result of this emphasis has been the reappearance of anti-aircraft guns as a significant weapon, especially against low-altitude aircraft. In this role, the fire-control tracker must provide milliradian accuracy on targets less than one degree above the horizon or above local surface features. This requires narrow beams, while mobility and survivability require small antennas. Use of millimeter-wave radar is an obvious answer, subject to propagation limitations in weather. One ingenious solution, used in a European AA system (**Figure 18**), is the dual-frequency tracker. Acquisition range is set by the lower-frequency system (in this case at X-band), and the higher-frequency (K_a-band) system need have only the open-fire range needed for the guns.

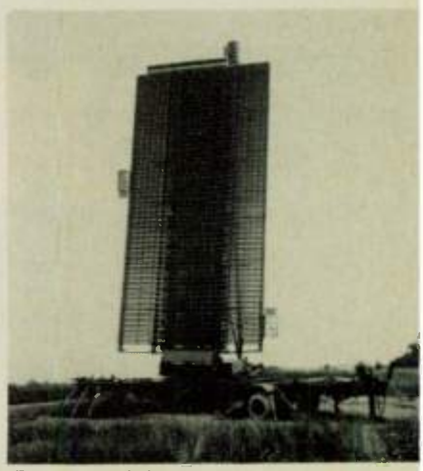


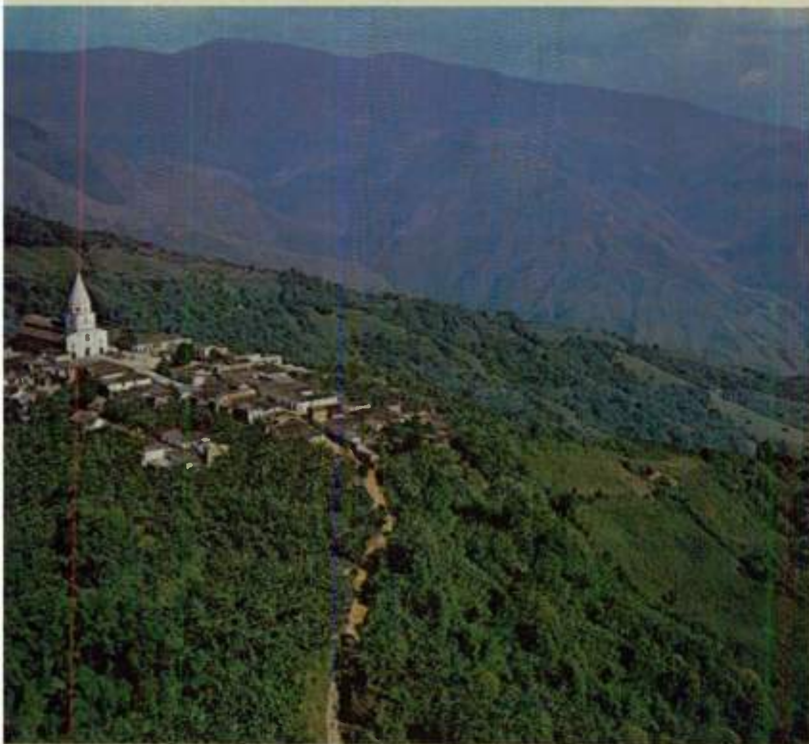
Fig. 17 AN/TPS-59 solid-state L-band 3D radar (photo courtesy General Electric).

(continued on page 38)

Imagine designing a telephone system for cities that don't exist yet.

populations of one million for the first time.

Anybody planning a telephone network for a country has to consider growth in years to come.



As a country expands, ITT's new System 12 can expand with it.

And must ask whether this or that telephone exchange will be able to keep up with it.

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This means, among other things, that as cities grow and traffic expands, you can add to the network easily to keep up—without ever running out of the controlling computer capacity.

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Even to needs that don't exist yet.

ITT

ITT NETWORK 2000

Around the Circuit

PERSONNEL

Solid State Technology, Inc. appointed **Tom Clark** as Sales Manager. . .Texscan Corp. announced the appointments of **John Shaw** as Western Regional Sales Manager and **Katherine Larson** as Advertising Manager. . . **Dr. Charles Buntschuh** joined Narda Microwave Corp. as Chief Scientist, a newly created position, to oversee R & D programs. . .California Microwave, Inc. named **John A. Macaulay** as Director of Marketing for the Defense Products Div. . .E-Systems, ECI Div. appointed **James A. Wittkower** as V.P. - Employee Relations. . . Among the ranks of the recently promoted include **David B. White** to the post of V.P. of Daico Industries and **Stephen C. Lang** to the position of Sales Manager of Valtec Corp.'s Communication Fiberoptics Group. . .Other corporate changes include the naming of **Joseph F. Lee** as V.P. and General Manager of Applied Technology, an Itek Corp. Division and the advancement of three directors to the following posts: **James R. Brennan**, V.P. of Marketing; **Roger W. Anderson**, V.P. of Domestic Programs; and **Charles A. Simon**, V.P. of Employee Relations. . .Alpha Industries, Inc. also promoted two of its division managers to vice president posts – **Constantine Kamnitsis**, to V.P., Optimax Thin Film Products and **David M. Milligan**, to V.P. Solid State Components Div.

CONTRACTS

Cardion Electronics, unit of **General Signal Corp.**, received a contract award from the Royal Danish Naval Materiel Command to furnish ground-based radar systems for Danish coastal defense purposes. . .The UK Royal Air Force awarded a $4M, multi-year contract to **Norlin Communications** for digitally tuned VHF/UHF synthesized receivers and associated equipment. . .**E-Systems, Inc.** was granted a $4M contract by the US Air Force Logistics Command for the development and production of transportable satellite communication stations (AN/TSC-102 systems) for use by rapid deployment forces. . .ERADCOM granted a $16.5M contract to **Fairchild Systems Corp.** for 70 AN/TLQ-17A (V) CM sets and a $1.9M contract to **ESL, Inc.** for 4 AN/TSQ-114 Special Purpose Detection Sets. . .**Applied Technology**, Div. of **Itek Corp.**, received a $9.6M contract from USAF for radar warning and power management systems and aerospace ground support equipment. . .**McDonnell Douglas Aircraft Co.** announced the purchase of **American Electronic Laboratories, Inc.** antennas valued at $108K. . .**American Microwave Corp.** received a $20K contract from **Sperry Microwave Systems** for two prototype automatic direction-finding radar receivers. . .**Scientific-Atlanta, Inc.** announced an agreement to supply digital satellite earth stations valued at $7.5-$15M to American Satellite Corp. through 1982. SA also received an order from **Entertainment and Sports Programming Network** (ESPN), for a new 11-meter uplink earth station to be located at ESPN's Bristol, CT headquarters.

NEW MARKET ENTRIES

International Microwave Devices (IMD) of Somerville, NJ has entered into agreements with **IMA Microwave Products AB of Stockholm**, Sweden, a majority stockholder in IMD. The US company, founded by Messrs. Ronald Lessnick, Timothy Boles, Chuck Jackson and John Locke, will introduce microwave power transistors and amplifiers in the first quarter of 1981. Product lines will incorporate both Si bipolar and GaAs FET technologies. IMD will occupy a 16,000-sq. ft. facility at 51 Chubb Way, Somerville, NJ. . .**Magnum Microwave Corporation** has been formed by four former Watkins-Johnson Co. managers to manufacture a line of RF components for the satellite and telecommunications industry. Future products will include frequency sources, amplifiers and integrated front ends. Company President is: Harry E. McGrath, Jr.; Vice President of Manufacturing is Harry R. Soza; Engineering Director is Joseph T. Lee; and Marketing Director is David N. Fealkoff. Magnum's Chairman is Nolan Bushnell, founder and former Chairman of ATARI and presently Chairman of Pizza Time Theater, Inc.

INDUSTRY NEWS

M/A-COM, **Inc.** has reached an agreement in principle with **Valtec Corp.** to become a M/A-COM Company. M/A-COM will issue one share of its common stock in exchange for each share of Valtec common stock, including shares to be issued in conjunction with certain stock options for a total of about 4.6M shares of M/A-COM common stock. . .**Harris Microwave Semiconductor, Inc.** has been formed by **Harris Corp.** to produce ICs and other GaAs devices. Dr. Richard W. Soshea will head the San Francisco firm. Also, Harris announced that **Farinon Electric**, a unit of the **Harris Transmission Systems Div.**, plans to invest about $9M over the next five years for a 50,000-sq. ft. manufacturing facility in San Antonio, TX. . .**Scientific-Atlanta, Inc.** and **Systems Communications Cable, Inc.** (SCC) reached an agreement in principle for the acquisition of SCC by Scientific-Atlanta. . .**Westinghouse Electric Corp.** and **Satellite Business Systems** (SBS) announced an agreement for SBS to provide satellite-transmitted communications service between Pittsburgh, Baltimore, Dallas and Los Angeles starting in 1982.

FINANCIAL NEWS

Harris Corporation expects to report year-end sales of $1.3B, net income of $80M. or $2.60-$2.65 per share for the period ended June 30, 1980. This compares with 1979 results of sales of $1.075B, net income of $68.8M or $2.32 per share. . .On July 11, 1980 the Board of Directors of **Raymond Industries Inc.** declared a quarterly dividend of 13¢ per share, payable to shareholders of record July 3, 1980. . .**Racal Electronics Ltd** announced that Group net profit before taxation for the year ended March 31, 1980 came to £63.6M on revenues of £263K. This compares with 1979 results of £61.6M net profit, on revenues of £226.6M. . .**Narda Microwave Corp.**'s stockholders approved an amendment to the firm's Certificate of Incorporation on June 30, 1980 to increase authorized shares of common stock from 1M shares to 5M shares.

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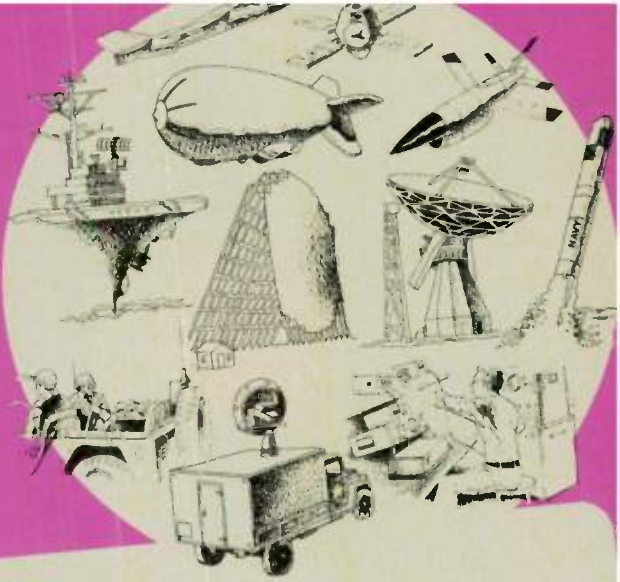

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- Class A linear or Class C
- 1500 to 2300 MHz
- "Space-Qualified" transmitters

Satellite Ground Stations

- GaAs FET power amplifiers, up to 8.4 GHz
- 1 and 5 MHz distribution amplifiers, up to 26 outputs
- FM carrier baseband video distribution amplifiers
- IF amplifiers, 70, 700 and 1100 MHz

Terrestrial Microwave Amplifiers

- Microwave LOS, 100 watts
- High power troposcatter, L-band, 1000 watts
- Microwave and UHF radio relay, 1000 watts

Broadcast

- UHF/VHF color TV transmitters, up to 1.5 KW peak synch
- Airborne TV visual/sound power amplifiers
- FCC type-accepted driver amplifiers
- UHF TV internal 3-tone amplifiers

Avionics

- FAA and MIL TACAN transmitter systems— power amplifiers, modulators, synthesizers, power supplies
- L-band digital transmitters (JTIDS)
- Data link transmitters
- Up/down converters
- Airborne pulse amplifiers

Missile Systems

- Command/destruct transmitters
- Guided weapon data link amplifiers
- Military drone transmitters

Radar Amplifiers

- L-band transmitters
- S-band pulse drivers for 3-D radar
- Shipboard drivers for AN/SPS-48 radars

Electronic Warfare

- Communication jammers
- Class A linear power amplifiers
- Linear AB wideband jammers
- Jamming simulators

Military Communications Amplifiers

- Long-pulse data links
- Communication command links
- UHF transceiver amplifiers/modulators
- MIL RF power boosters (ECCM)

Laboratory Instrumentation/Test

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HOLLOW SHAFT RF ROTARY JOINTS

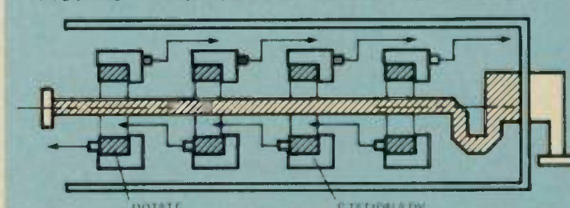
Some Kevlin RF Rotary Joints Have Holes in Them

Hollow shaft rotary joint technology was developed by Kevlin Manufacturing to meet the needs of system designers for compact, reliable, multi-channel R.F. rotary joints.

Hollow shaft rotary joints are designed with large thru holes allowing passage of other mechanical and electrical devices such as semi-rigid coax., encoder shafts, slip rings, etc. This unique technology allows the stacking of individual channels giving the designer many options for multi channel designs. Each channel is modularly constructed and isolated allowing easy maintenance and service. They can be designed to cover octave bandwidths and for most bandwidths are totally non-contacting. Rotary joint life of 25,000 hours without service or replacement is now attainable.

Consummated designs operate from DC-18 GHz in discreet bandwidths with the size of the hole proportional to the frequency. These designs are performance proven in ground base, shipboard, and space environment systems. Small wonder when it comes to hollow shaft rotary joint technology Kevlin leads the way.

MULTICHANNEL MECHANICAL SCHEMATIC INCORPORATING HOLLOW SHAFT RF ROTARY JOINTS



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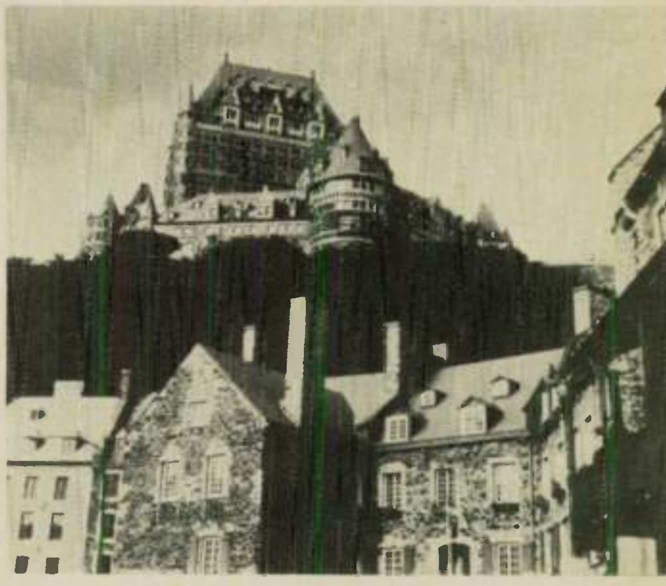
N. American Radio Science Meeting and IEEE/AP-S International Symposium



ROBERT J. MAILLOUX
Rome Air Development Center/EEA
Hanscom AFB, MA

THE SYMPOSIUM

Including more than sixty half-day technical sessions and more than five hundred papers, the combined North American Radio Science Meeting and IEEE Antenna and Propagation Society International Symposium was held from 2 to 6 June at the Université Laval in Quebec, Canada. The North American Radio Science Meeting was sponsored by the United States and Canadian Committees of the International Union of Radio Science (URSI) and offered presentations from URSI commissions A through J. The program also included a plenary session on Radio Science in Canada.

Host for the combined meeting was the Université Laval, a beautiful university with large, well equipped meeting rooms all in such proximity that attendees could divide their time efficiently between several technical sessions. Chairman of the meeting Steering Committee, Professor Jules A. Cummins of the Université Laval, along with his Steering Committee, Local Arrangement, Publications and Technical Program Committees devoted great care in planning and much energy in executing this large meeting, and an excellent, smoothly run program resulted from their efforts. In addition to the technical program there were a number of tours to nearby attractions and an elegant banquet in the Château Frontenac just upstairs from the banquet for Prince Philip. A second, silent host for the meeting was the lovely old city Quebec, the oldest city in Canada and the only walled city in North America. Overlooking the Saint Lawrence River and containing a magnificent collection of historical sites, fortifications and buildings, Quebec presided over the nights and weekends.

THE PROGRAM/ THE PRESENTATION

Amid all this beauty it took some dedication to concentrate on the technical program, but most did and so shall I for the remainder of this report. URSI Commissions A through J are chartered to cover most topics in electromagnetics, including metrology, systems, noise, propagation, waves in plasma and radio astronomy. The Antenna and Propagation Society's interests overlap most of these areas, and the distinction between the two programs lies in URSI's primary concern with research and basic knowledge, and the AP-S accent on engineering. The size and scope of the meeting, with up to nine technical sessions running concurrently, makes it impossible for one person to attempt an unbiased review, giving proportional coverage to all topics. I have not tried such even treatment, but have emphasized the antenna topics and the special sessions.

In addition to the plenary session on Radio Science in Canada, the URSI program included special sessions on Optical Communication, Inverse Scattering, Electromagnetic Earth Induction from Overhead Conductors and Ionosonde Techniques. These are described in more detail in the next section.

The meeting was also testimony to the expanding success of Poster Sessions. Born of the frustrations accompanying such large meetings with many concurrent technical sessions, the Poster Session can include up to twice as many authors and so can substantially alleviate the problem of parallel sessions with the same subject matter. I've found it somewhat surprising when talking with a number of Poster Session attendees and authors that there is a growing number of both who prefer Poster Sessions to the usual lecture sessions. Authors did note that the poster paper gets somewhat less exposure than a lecture presentation, but the degree of audience participation is much higher and more satisfying. In Quebec the audience participation was extremely high with presenters answering questions, debating, exchanging references with attendees and, for the most part, enjoying it. Audiences seem to have learned to appreciate the Poster Sessions as well, and have stopped behaving as if they were in an art gallery; they aren't standing back away from the authors in hushed silence as if from veneration or fear. They aren't embarassed to ask an author what his work proves or to walk by a poster if it doesn't interest them. Highly theoretical and very practical studies are equally at home in Poster Sessions and I spoke with authors of both types who sincerely enjoyed the experience. In fact, for the first time I heard one enthusiastic engineer say we should have only Poster Sessions, no lectures.

SPECIAL SESSIONS

A number of topics were accorded added visibility through the use of special sessions. The URSI conference opened with the Plenary Session entitled Radio Science in Canada which was dedicated to the memory of John H. Chapman, a scientist with the Canadian government. This session outlined some of the important contributions to Radio Science that have been made by Canadian researchers in satellite studies of the ionosphere, ionospheric propagation, very long baseline interferometry and electromagnetic techniques for prospecting. The Canadian scientific satellite program, now over 20 years old, was summarized in a paper by C. A. Franklin of Communications Research Center, Department of Communications in Ottawa. Beginning with the development of the topside sounder Alouette-I in 1959, the Canadian government created an advanced capability for producing satellite technology within Canada. The successful Alouette program was followed by the more complex ISIS satellites. Present Canadian plans call for more participation in the scientific satellite programs of other countries. The most important civilian space programs in Canada today are the ANIK and HERMES communications satellites, which are leading Canada to commercial direct television broadcasting to homes using 12 and 14 GHz frequencies.

The Alouette program also led to a number of scientific discoveries in ionospheric propagation. These were the subject of a paper by R. E. Barrington who described past experiments and new initiatives in non-linear effects, wave-particle interactions and other planned experiments using the NASA Spacelab. J. L. Yen from the University of Toronto detailed Canadian advances in very long baseline interferometry and outlined a number of technological developments required by scientists working in VLBI. These included high density magnetic tape recording, precision maser oscillators, image reconstruction from undersampled data and the use of satellites for synchronization of distant oscillators. In the concluding paper of the session G. F. West, of the University of Toronto, described ongoing Canadian studies aimed at developing improved ground and airborne prospecting systems for the discovery of base metal ores.

A series of special sessions on optical communications were organized by Professor Y. L. Yip. These included three sessions on Fiber and Guided Wave Optics and a session on Devices and Systems. The sessions were a blend of invited survey papers and current state-of-the-art research on many topics including single and multimode fibers, coupled modes, inhomogeneous waveguides, optical fiber systems, detectors and sources.

Professor Wolfgang Boerner of the University of Illinois at Chicago Circle organized a series of special sessions on inverse scattering. This topic has begun to receive increasing interest from a number of different quarters that were well represented in the scheduled sessions. In addition to analytical studies of generalized inverse scattering problems and issues of non-uniqueness. There were a wide variety of applications addressed including the characterization of electron density profiles, biomedical applications, the obvious and important characterization of radar targets and an entire session devoted to geophysical sounding. Inverse scattering studies, once considered a fairly exotic mathematical frontier, seem now to be leading to some profitable new areas for research and technological invention.

A special session on electromagnetic earth induction from overhead conductors was organized by Dr. J. R. Wait of the US Department of Commerce and chaired by Prof. W. R. Goddard of the University of Manitoba. This session dealt with the currents induced on transmission lines and vertical magnetic dipoles by lightning discharges, local electromagnetic sources and buried cables. In addition to these coupling problems there were two papers by staff members of the University of Manitoba on image theory approximations for the fields of horizontal wires over conducting earth. The session also included measurements and theoretical studies of the effect of solar storms on long high voltage power lines and reference to their generation of harmonics at transformers within the transmission system. The last paper in the session dealt with induced voltages on gas pipeline networks caused by 60 Hz inductive coupling.

The M. Lindeman Phillips Memorial Session on Ionosonde Techniques was chaired by Dr. K. Toman of the Electromagnetic Sciences Division, Rome Air Development Center, Hanscom AFB. Topics discussed in this session included processing and display of digital ionosonde data and the first results from the NOAA HF Radar.

ANTENNAS

Twenty-one sessions, slightly over one third of the total number in the meeting, concerned antenna theory or technology. Judging by attendance at these sessions that fraction is probably a good estimate of the relative number of attendees whose main interest is antennas. This was a huge antenna meeting with parallel simultaneous antenna sessions throughout much of the symposium. The Poster Sessions helped a great deal because the papers were on display for such a long period that one could always find time to get to see those that were especially interesting. Still it was difficult to see much more than one third of the antenna papers.

Antenna papers were divided almost equally between reflector or lens papers and phased array papers. There is remarkable vitality currently in the technical community that deals with large reflectors and lenses. At least three stimuli account for this interest; needs for multiple beam satellite antennas, extremely efficient ground-based satellite communication antennas, and very low sidelobe ground-based radar and communication system antennas. These three tasks all seem to require large high gain antenna structures and so there is obvious interest in extending reflector and lens technology to address the needs. Satellite antennas have become extremely sophisticated in recent years, with advanced pattern contour synthesis and severe polarization purity requirements. The session on Satellite Antennas contained five papers dealing with pattern optimization for contiguous or contoured beams with multiple beam on scanning beam antennas. Most of these systems use a combination of low sidelobes and polarization diversity to isolate nearby beams, although the paper by C. E. Chen, C. E. Franklin and W. F. Croswell described a K_u-Band system which also used frequency dispersion. Offset fed apertures for all of these systems. Feed system technology has also achieved an advanced degree of sophistication. In the session on horn antennas there are several papers on horn design that emphasize aspects of corrugated horns for equalized E- and H-plane patterns, low sidelobes and low cross polarization levels. In addition there are two papers on the use of dual depth corrugations for dual band corrugated feed designs. A new polarizer designed for antennas operating in the 12 and 14 GHz bands was presented by Crone, Adatia, Watson and Dang, of the RF Technology Center, ERA Technology Ltd, England. The polarizer has low-loss, high-polarization purity and can operate over a single broadband or two widely separate bands.

Reflector Antennas

The sessions on reflector antennas highlighted the degree of pattern control available with modern reflector systems. In the area of increasing aperture efficiency, Caulfield, Rush and Williams presented design results and a physical optics analysis of a highly tapered dual reflector system with aperture efficiency of approximately 92%. Adatia and Keen presented data on a dual offset reflector antenna designed for a planned European communication satellite and achieved cross polarized peak values of −42 dB with respect to the main beam. Dual offset reflectors have found increasing use because of this achievable low cross polarization, but to date the lowest sidelobes are obtainable with single reflector offset systems. An example of this characteristic is the paper presented by H. K. Miersch, AIL Division of Eaton Corporation, who addressed the ground-based radar case and demonstrated near sidelobe levels below −40 dB and far sidelobes well below −50 over about 20% bandwidth. The antenna had a shaped beam pattern in elevation.

Phased Arrays

Phased arrays and elements were well represented at this symposium, ... sions on wire antennas, two on microstrip techniques, one on synthesis, two on adaptive arrays and one on array antennas. Among the highlights, and there were too many to mention, are a number of studies dealing with very accurate pattern control, whether using adaptive circuitry or low sidelobe techniques. In the adaptive area there is an increasing concern for obtaining broader band nulling, and papers by Mayhan, Simmons and Cummings of Lincoln Laboratory, by Bowers and Perry of E-Systems, and by Takao, Ito and Kompyama of Kyoto University addressed the problem of determining bounds on multi-tapped delay line circuitry for wideband interference cancellation. The sidelobe and nulling properties of overlapped subarray scanning arrays were described by R. Fante of the Deputy for Electronic Technology, Rome Air Development Center with particular attention to the situation of nulls within the main beam region. The second session on adaptive arrays had several papers that addressed the purely electromagnetic aspects of adaptive nulling systems. The paper by Kitsin and Griffiths of the University of Colorado dealt with a problem often encountered from a sidelobe reduction point of view, namely the search for methods to reduce grating lobe effects in a non-overlapped subarrayed antenna. The authors show that subject to the added constraint of adaptive null steering convergence, a solution for an array of 192 elements divided into six subarrays can be obtained with good grating lobe suppression and main lobe response and with convergence slightly faster than the uniform subarray case. The authors compare several other subarray choices and demonstrate the relative sensitivity of convergence and main lobe degradation to subarray selection. The optimization of array nulling properties as a function of element position was the subject of a paper by Lin of Harris Corporation. Lin chose as optimization parameter the ratio of signal-to-noise plus inter-

(continued on page 38)

(from page 37) SYMPOSIUM

ference, and obtained bounds for the values of this ratio. This criterion was then used as a means of inferring element positions and patterns that approached the optimum.

The phased array session also included several papers that addressed the issue of very precise pattern control. The paper by Herper, Hessel, Mandenino and Tomasic considered element patterns of dipoles in cylindrical arrays mounted around a conducting cylinder. The principle observed result was that the element pattern ripple, a well known characteristic of circular array radiation, disappears when the element spacing is approximately a half-wavelength. This condition is most important for the synthesis of low sidelobe arrays since circular array synthesis must include the fine structure of each element pattern. The ripples tend also to be frequency dependent and so this conclusion appears also to be necessary for broadband performance with controlled sidelobes. The paper by R. M. Rudish and P. J. McVeigh of AIL Division, Eaton Corporation also dealt with an area of great interest as regards accurate pattern control in order to produce highly accurate phase steering in a low cost design array.

The authors developed an array of four series fed subarrays with eleven elements per subarray. Since each phase shifter within a subarray has the same phase setting only a single driver wire is used for all four subarrays. The phase is precisely controlled by comparing the measured phase against a precision standard. Phase shift errors on the order of one degree were measured.

FUTURE AP-S/URSI SYMPOSIA

Combined AP-S/URSI symposia are scheduled through 1984. Future meetings and locations include the Bonaventure Hotel, Los Angeles 15-19 June 1981, the University of New Mexico, Albuquerque, New Mexico, 24-28 May 1982, the University of Houston, 23-26 May 1983 and Northeastern University, Boston, 18-22 June 1984.

(from page 29) PERSPECTIVE

Thus, the cycle of history repeats the experience of the SCR-268, whose excessive beamwidth and tracking error were refined by passing the target to a shorter-range, high-resolution angle tracker (optics, in that case). In the US, the recent insistence on solving all problems at a single frequency has prevented exploitation of this old and proven approach.

Fig. 18 Flakpanzer AA tank for the Dutch Army, showing X-K_a-band tracker in front (photo courtesy Hollandse Signaalapparaten).

CONCLUSION

Most of the basic techniques used in modern radar were conceived for use in World War II or soon thereafter, but suffered then from inadequate components and lack of full understanding of theoretical and environmental limitations. Thus, the German engineers who attempted to add MTI to the Wurzburg radar, as a counter to Allied chaff, would envy the modern designer who can select from a variety of off-the-shelf stable oscillators and digital storage elements. Today's components make radar design seem easier, and have led to greatly increased demands on modern radar. Unfortunately, these demands tend to outstrip the new capabilities, leading to more complex and expensive radar designs, packed with the newest technology and difficult to get into production and field use.

Modern components and techniques make it possible to produce simple, economical equipment meeting most radar requirements. In Europe and elsewhere, many varieties of such radars are in production in increasing quantities. In US commercial radar areas such as sea navigation and aircraft weather avoidance, production of economical equipment is also going forward. The government radar field has not yet fully exploited this potential. The challenge facing the developers of radar today is to find the right compromise between new technology and high performance, on the one hand, and simplicity and economy, on the other. Perhaps a broader perspective into past accomplishments and trends can aid in finding this balance.

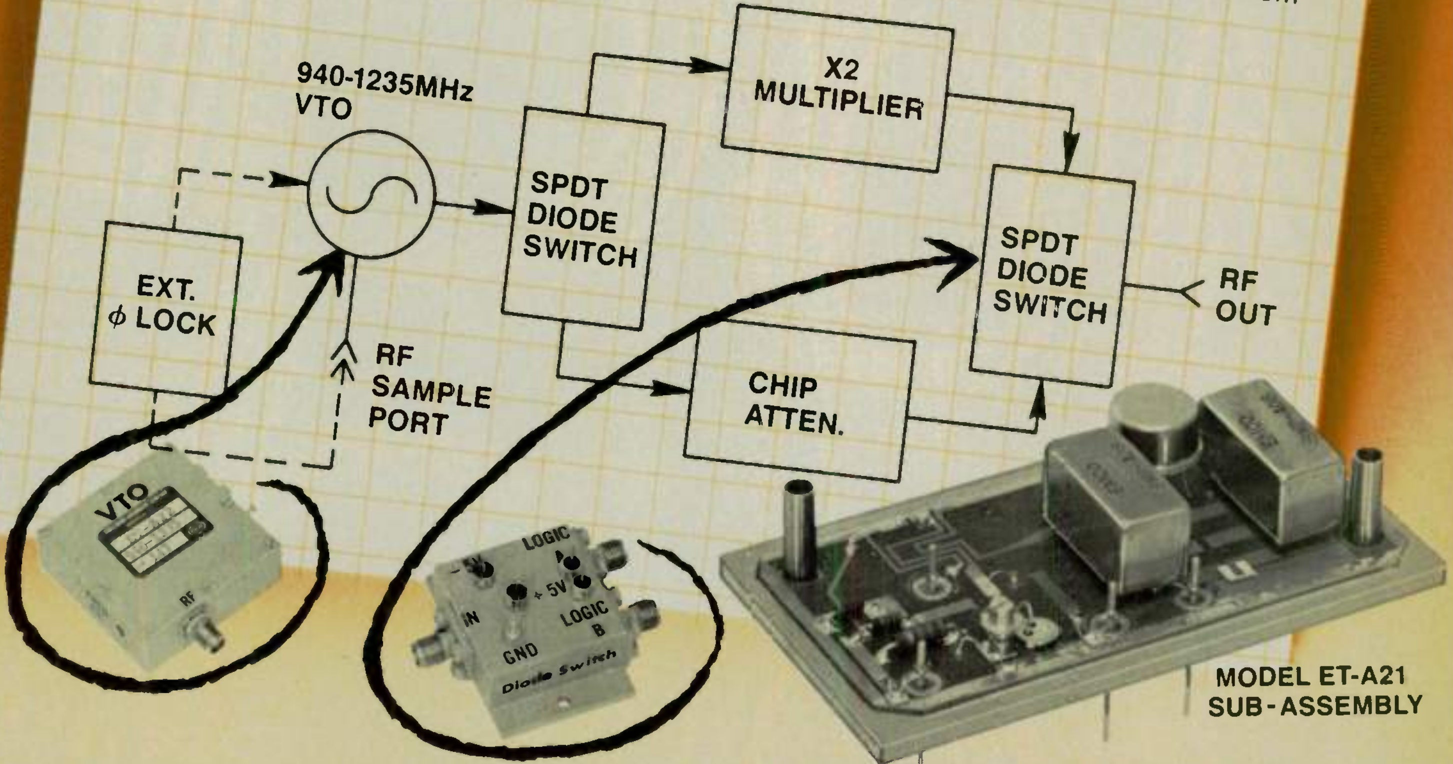
System Components FROM ENGELMANN

Sub-assembly uses low-cost MIC techniques

Integration of a voltage controlled oscillator, SPDT diode switch, a frequency doubler, and a chip attenuator provides a cost effective (under $200) microstrip subassembly. This Engelmann plug-in pin package Model ET-A21, is used as a phase locked and synthesized marker generator in an oscilloscope calibrator with signals in the 1 and 2GHz region. The microstrip resonator oscillator can be voltage tuned over the range of 940-1235MHz and has a sample RF output port which is used to generate synthesized tuning voltage for phase locking. The phase locked output of the oscillator is switched through an Engelmann toroidal frequency doubler or chip attenuator.

The oscillator is provided with tunable capacitors to minimize final RF alignment and test time. The frequency doubler provides a 2GHz output with unwanted signal rejection of 20db minimum. The special plug-in package is designed for PC board mounting and eliminates the expense of connectors and housing construction normally used.

Engelmann can supply a cost effective VCO, discreet components, or a complete MIC package to your specifications, from RF to microwave.



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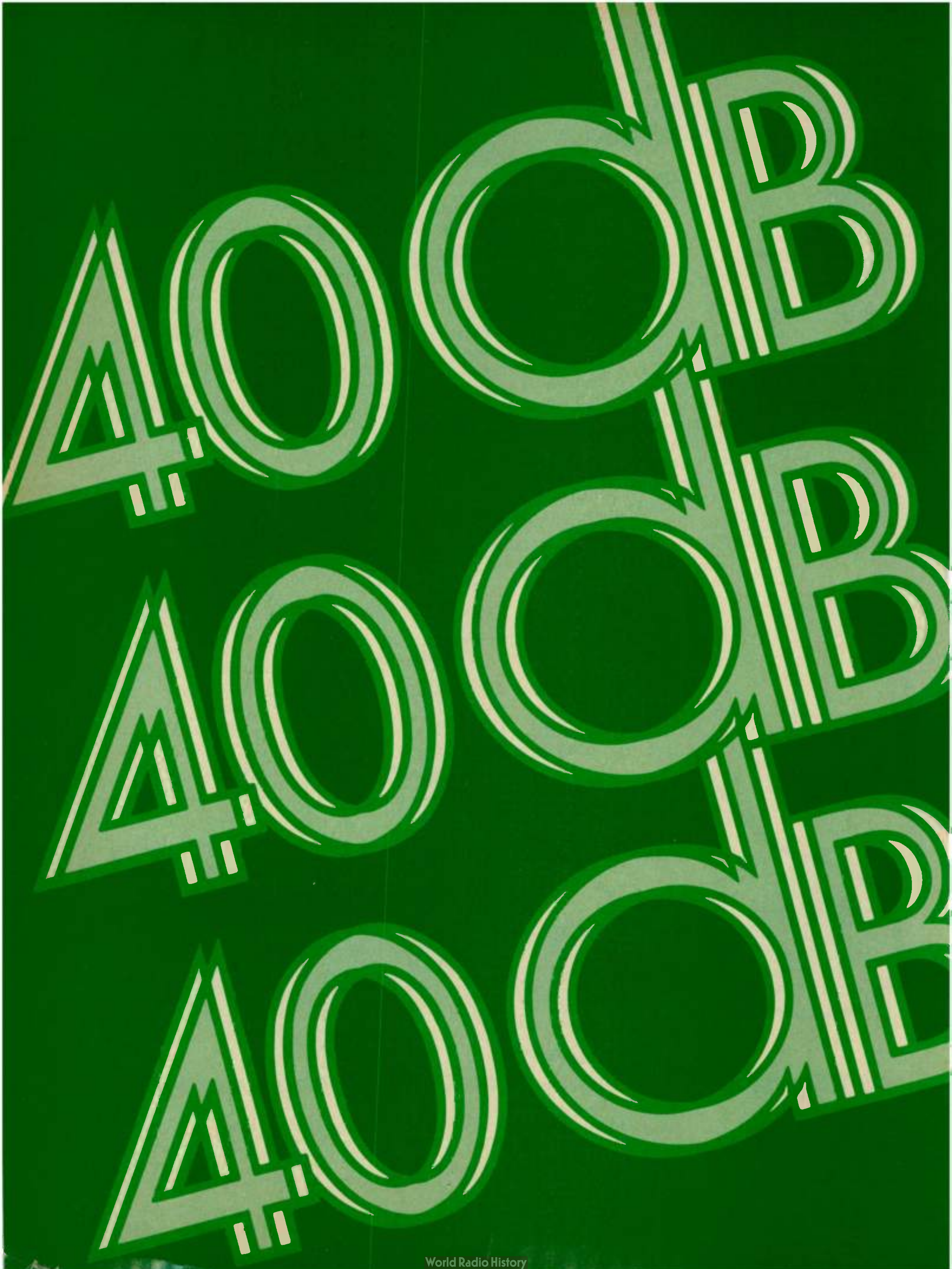
40 dB
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40 dB

Color Radar: Blend of New Technology and Good Design

R. H. AIRES and G. A. LUCCHI
RCA Avionics Systems
Van Nuys, CA

In 1977 RCA introduced weather radar systems with color indicators for both commercial air carriers and general-aircraft users. In 1980 there were 70 commercial airlines using the RCA color radar. 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. Before describing this advance, some background on weather radar technology 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.

Equation 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.

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.

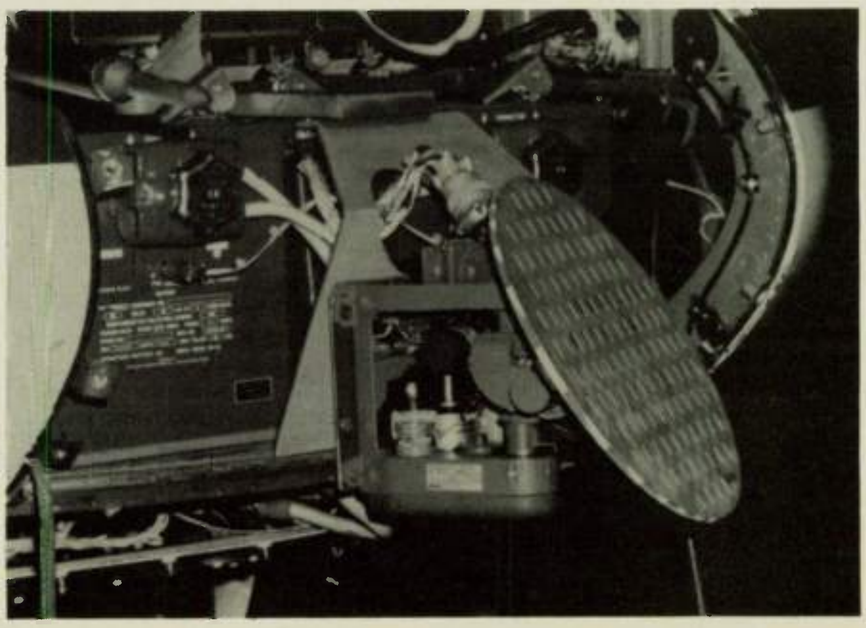
The radar backscatter coefficient Z for spherical raindrops has been empirically established. The coefficient is a function of the sixth power of the raindrop diameter and the number of raindrops in a specific volume. It is denoted by:

$$Z = \sum_{i=1}^{N} D_i^6$$

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; $Z = 55r^{1.6}$ is sometimes used for convective storms.

Reprinted from *RCA Engineer*, Feb./March, 1978, Vol. 23, No. 5, pp. 54-60.



Primus-400 12" antenna installed under radome of Bell 212.

TABLE I

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.

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.

This backscatter coefficient is shown in Equation 2.

$$\sigma = (\pi^5/\lambda^4)\, ZK^2 (\pi/8) R^2 \theta^2 cT \qquad (2)$$

By substituting σ from Equation 2 into Equation 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 Equation 3. This format makes the equation suitable for relatively simple graphing and so assists trade-off analyses in design.

$$P_r = 10\log P_t + 20\log\theta + 10\log T + 10\log Z - 20\log\lambda - 20\log R + 2G - L - 168.25 \text{ (dB)} \qquad (3)$$

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, Equation 3 must be modified by substituting the non-beam-filling volume equation $(\pi/8)d^2 cT$ for the beam-filling volume equation $(\pi/8)R^2\theta^2 cT$ into Equation 2, where d is the storm cell diameter. The same procedure used to establish Equation 3 yields Equation 4 for non-beam-filling storms.

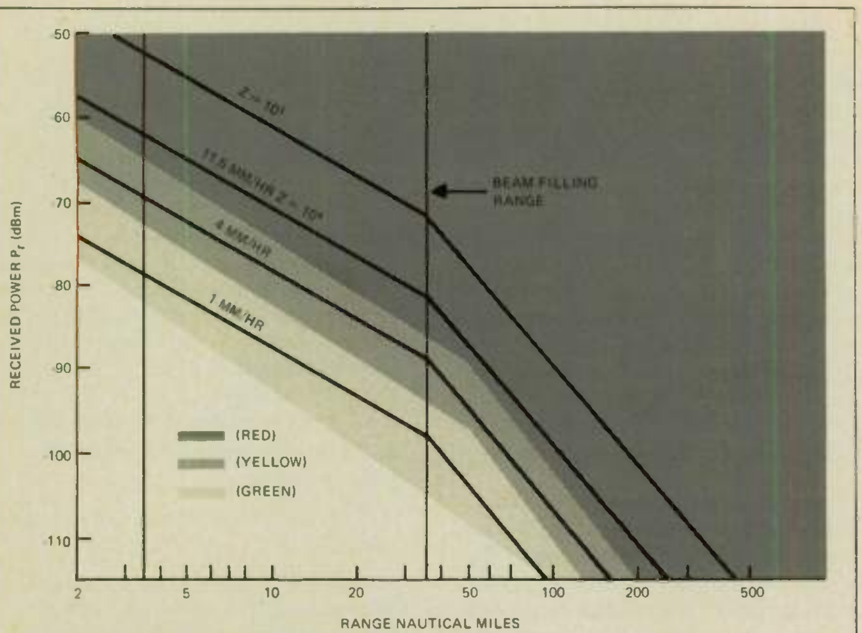


Fig. 1 Weather detection characteristics of the PriMUS-400 ColoRadar. The four solid lines show the returned power from storms with different rainfall rates. The 11.5 mm/hr. storm is potentially dangerous. System identifies levels of storm intensity by different colors on the display. The vertical "beam-filling" 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.

$$P_r = 10\log P_t + 20\log d + 10\log T + 10\log Z - 20\log\lambda - 40\log R + 2G - L - 133.08 \text{ (dB)} \qquad (4)$$

All terms in Equation 4 have the same units as in Equation 3 except d, which is in nautical miles.

Equations 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 **Figure 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.

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 is detected and displayed as the second 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 much 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

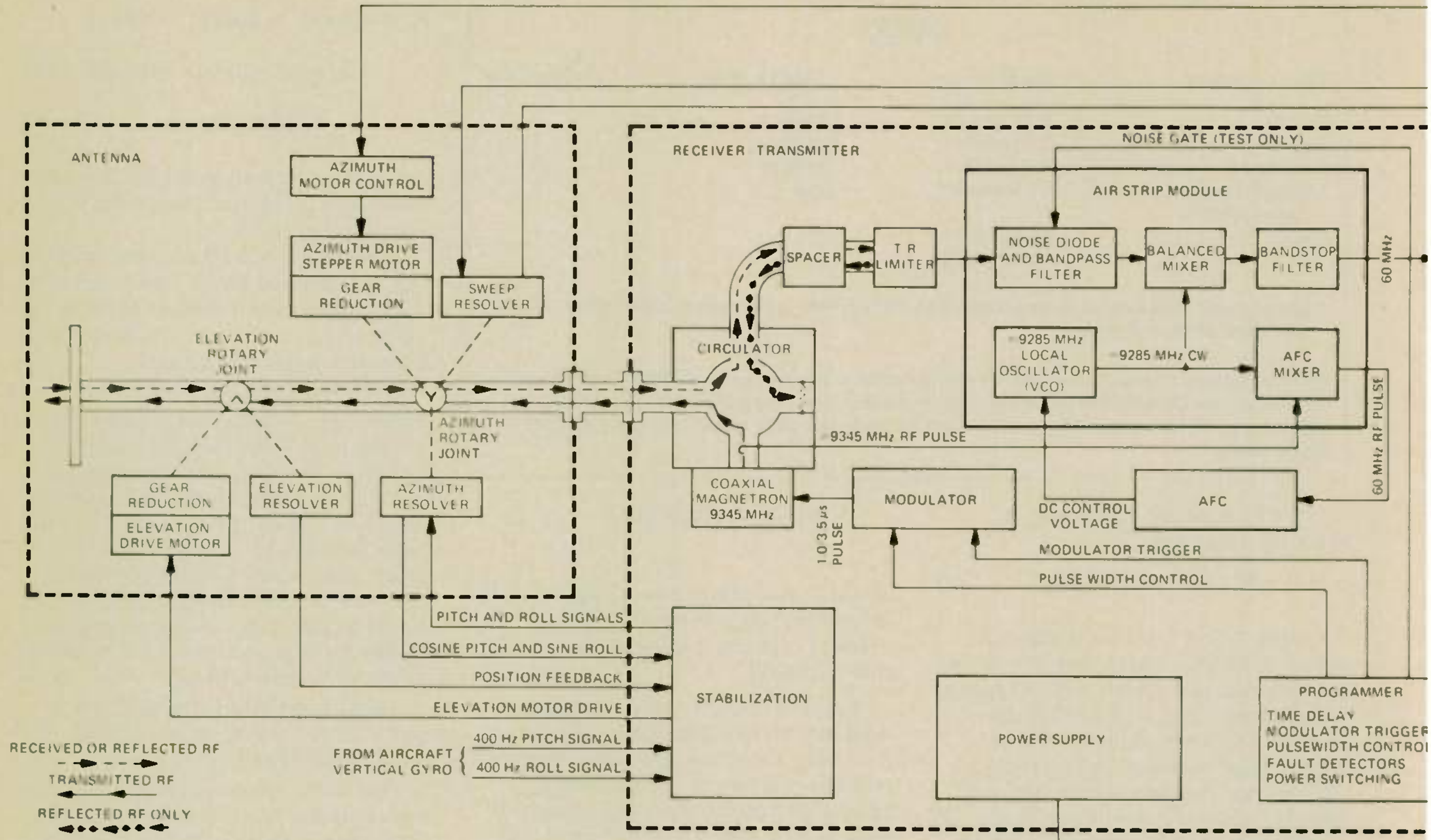


Fig. 2 PriMUS-400 system. Radar pulse (variable width for looking at ground or weather) goes through circulator to stabilized antenna, then returns through antenna and circulator. After signal processing and amplification, the returned signal is digitized to one of four storm-intensity levels, scan-converted from polar to x-y coordinates, and displayed on the color CRT.

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 time better than previously available digital storage type indicators. The effective display storage memory has been increased by four times. 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.

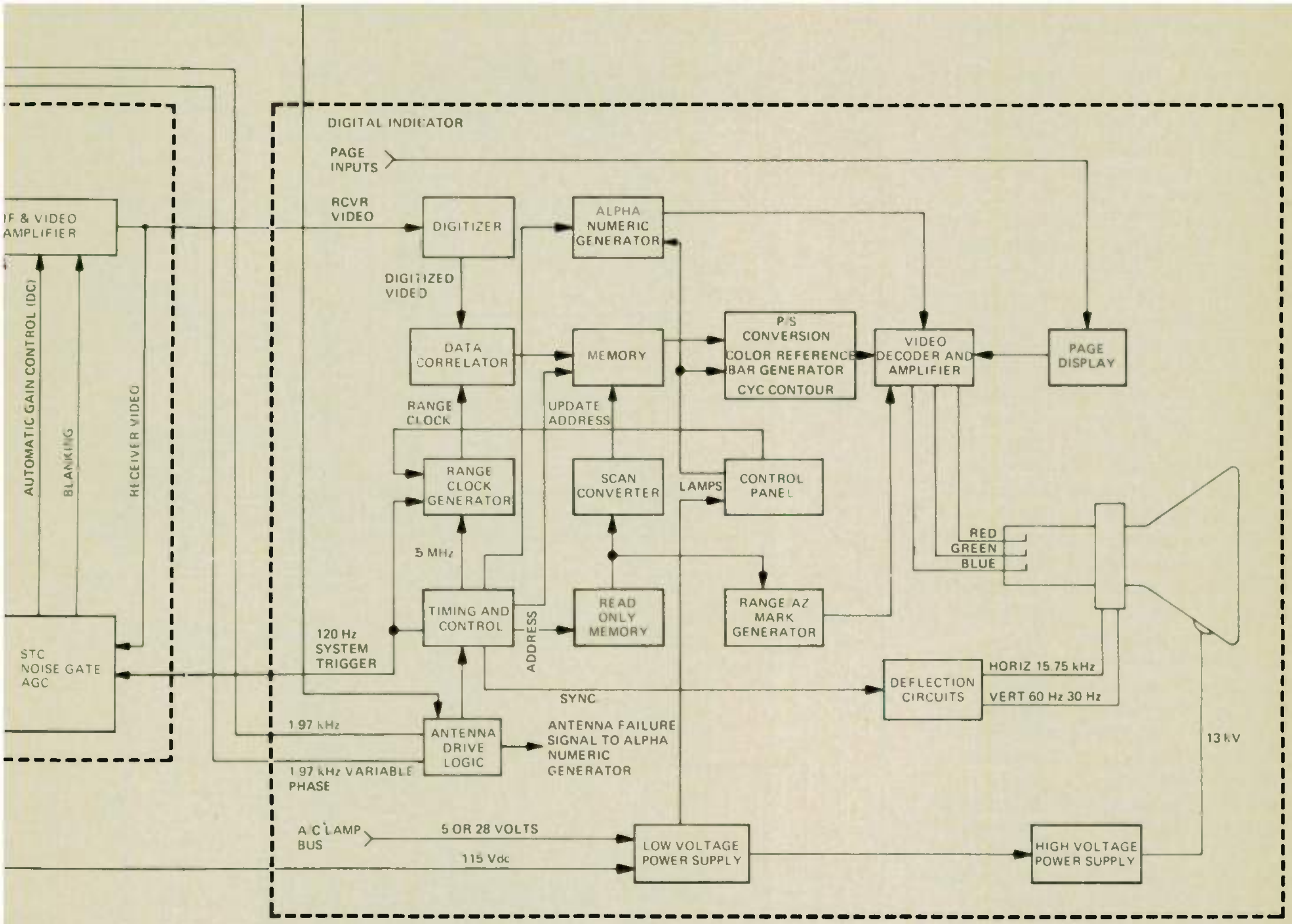
Figure 2 is a block diagram of the radar system. A magnetron generates microwave pulse energy at 9345 MHz and the circulator then directs it to the antenna, where it is radiated to illuminate the target. Reflected energy from the target is intercepted by the antenna and directed by the circulator to the microwave mixer. The mixer converts the microwave frequency to a first IF of 60 MHz. After amplification at 60 MHz, a second conversion to 10.7 MHz occurs within the IF 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 IF bandwidth of approximately 350 kHz. From Equations 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 trade-off 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 x 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 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 IF 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 IF 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 (**Figure 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 **Figure 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. **Figure 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.

Figure 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, 7dB/octave is achieved by varying the IF gain, as shown in **Figure 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 approximately 150 miles (18 minutes away at a jet speed of 500 knots).

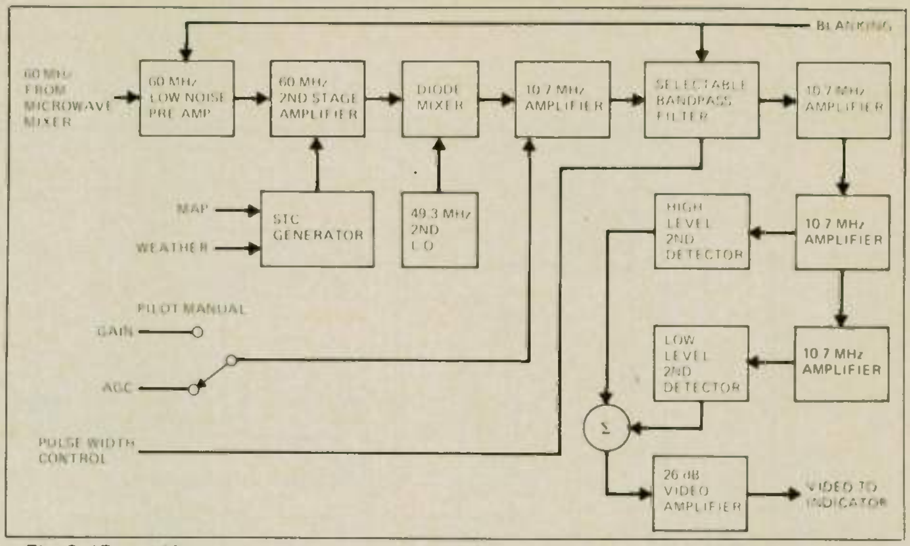


Fig. 3 IF amplifier optimizes system sensitivity by generating a second IF center frequency of 10.7 MHz. Sensitivity time control (STC) adjusts gain with range; manual gain control allows pilot to vary color-level settings and see which part of storms are most intense.

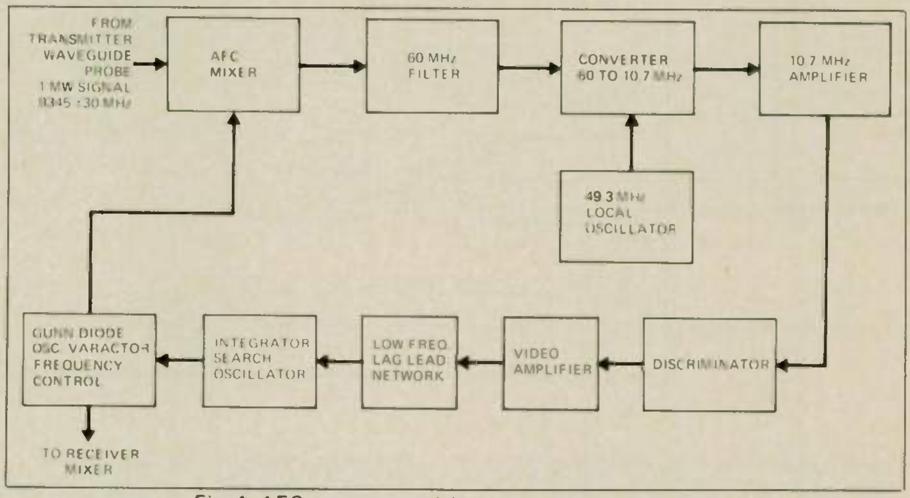


Fig. 4 AFC system essentially guarantees "lock-on."

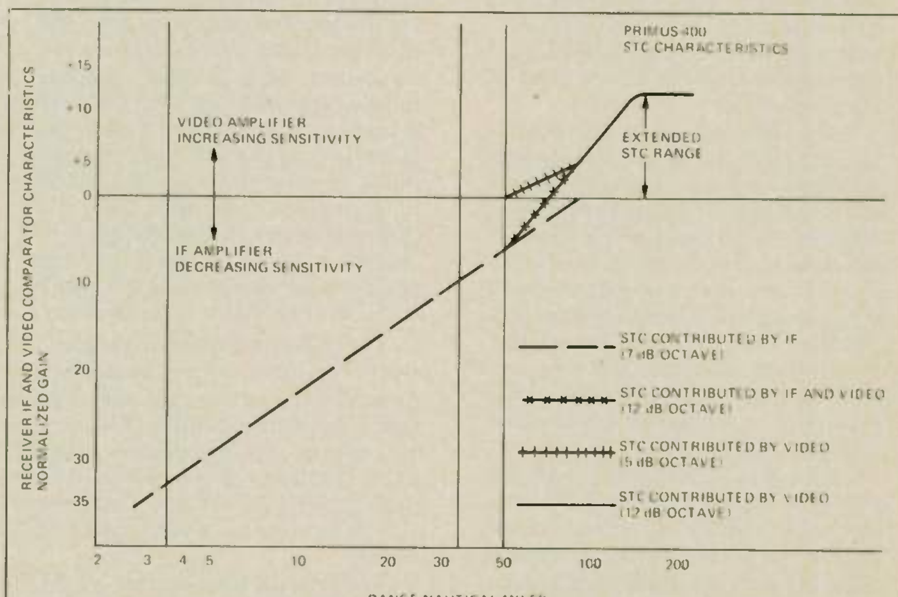


Fig. 5 Perceived-power/range slope can be varied at the IF amplifier or video amplifier. Beyond 50 nautical miles range, additional sensitivity comes from varying the reference voltages of the comparators.

(continued on page 48)

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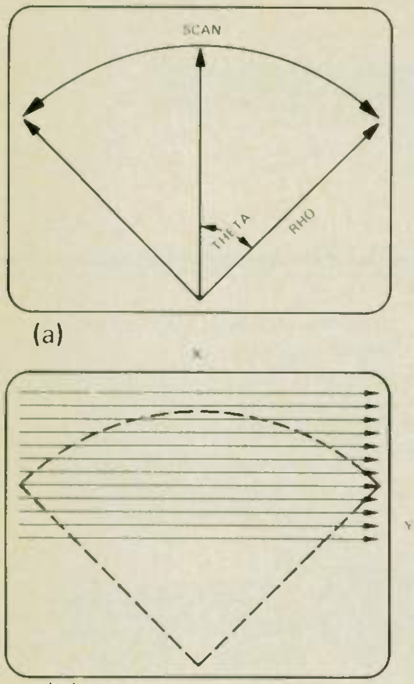

Fig. 6 Range and azimuth data is collected in polar coordinates (a), but displayed in TV-scan coordinates (b). Digital storage makes this display method practical and produces uniform brightness and resolution over the entire displayed area, something not possible with the polar-coordinate display.

A 4-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 pulse-width 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 (**Figure 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 **Figure 6b**. The readout is performed at standard TV rates, thus providing a flicker-free display using a conventional TV CRT.

The video display has high-resolution azimuth marks; it also accepts external inputs for pilot checklists and other data.

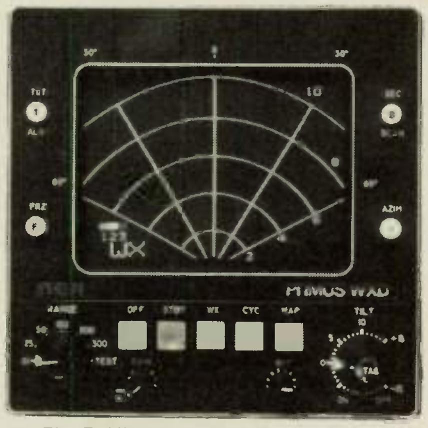

Fig. 7 High-resolution dot pattern.

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 (**Figure 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.

This 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 four 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.

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.

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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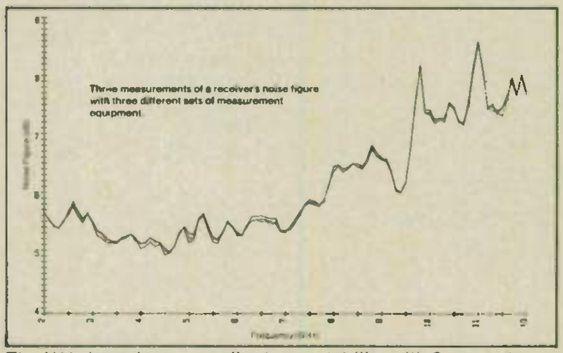

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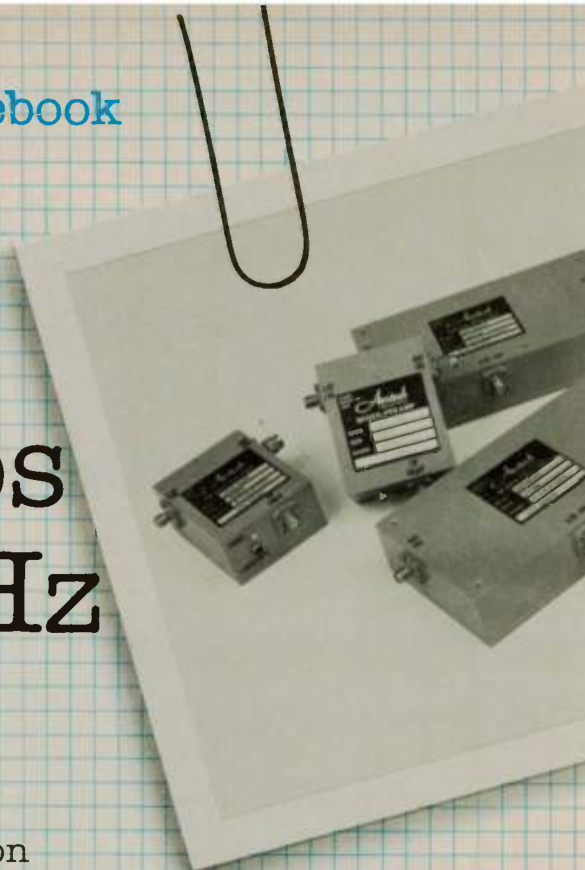

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RF–IF Gain	18 dB	18 dB
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N.F. (S.S.B.)	12 dB	12 dB
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It is now economically possible to use a solid-state power source for short pulse L-band radar. 400 W of short pulse power is easily achieved from a single balanced transistor, such as the CTC 1214P400. The use of push-pull circuit techniques permits full advantage to be taken of the high power levels available from L-band balanced transistors.

A balanced transistor consists of two transistor chips mounted in one package. Each of the chips operates 180° out of phase with the other, with the midpoint being at RF ground. If good balance is maintained there will always be a zero RF potential midpoint, a virtual ground. Since each side of the balanced transistor is operating 180° out of phase with the other, the input and output load impedances are combined in series. Figure 1 shows that the "input to input" and "load to load" impedances of the balanced transistors are four times higher than those of an equivalent single ended transistor. When a larger single ended transistor is made, additional chips are combined in parallel, creating the much lower impedance for matching.

The higher impedances of a balanced transistor offer significant advantages:

- Lower loss in the impedance matching networks means better gain and higher efficiency.
- Less critical circuit means fewer problems in manufacturing.
- Wider bandwidths.
- Power output is 6 dB more than for a single ended transistor with similar impedances.

There are two other good reasons for operating push-pull:

- A virtual ground exists inside the transistor package decreasing effective common lead inductance and improving stability and efficiency.
- Push-pull operation suppresses even order harmonics making the output filtering problem easier. Efficiency is also improved since power is not wasted in even harmonics.

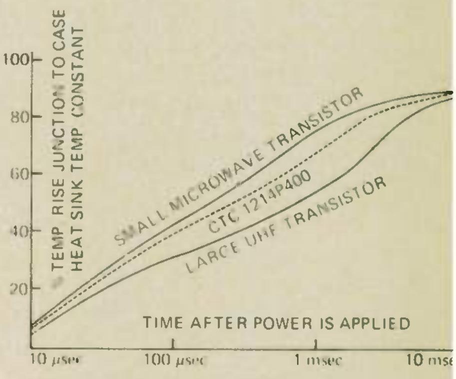

Fig. 2 Thermal response of a transistor when a CW signal is applied at time = 0.

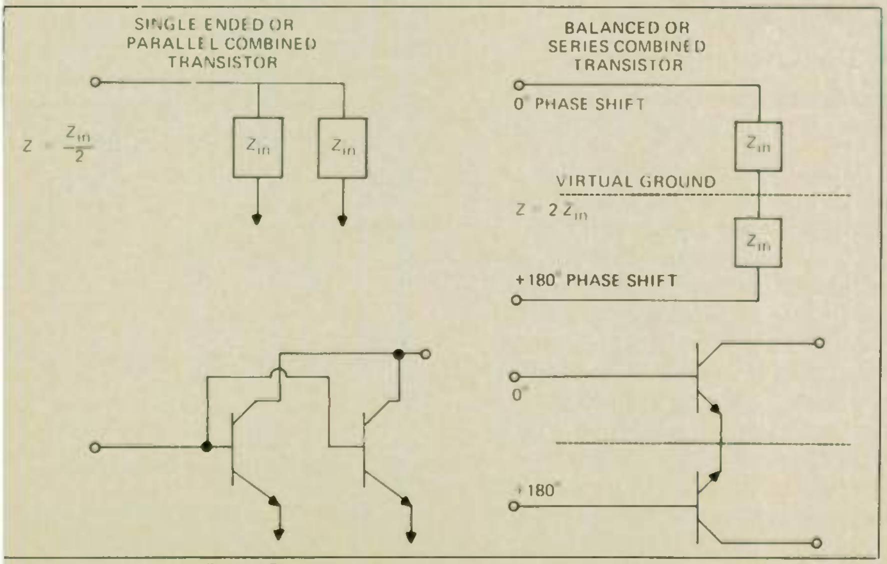

Fig. 1 Parallel and series impedance combination.

Since pulse modes of L-band radars generally involve low duty cycles, the thermal problems associated with achieving very high power outputs are greatly alleviated and the extremely low impedance level becomes the limiting factor. The push-pull mode at higher impedance levels makes significantly higher power levels possible.

PULSE OPERATION

In a radar application, one of the most important parameters is the average power delivered to the target. Some systems require long pulses (1-2 msec) with high duty cycles (10-20%) and others require short pulses (5-50 μsec)

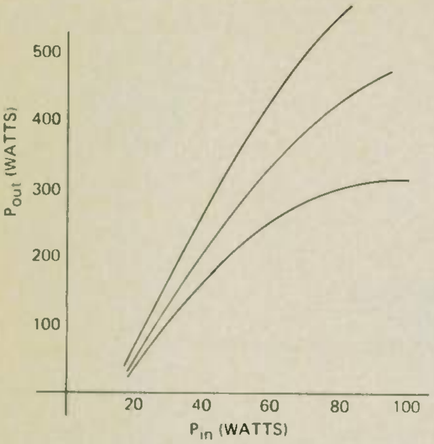

Fig. 3 Saturation characteristics for the CTC 1213P400 at 1.3 GHz.

and low duty cycles (5-10%). The system that requires a short pulse has a real advantage when an all solid-state power source is required. Today's best short pulse transistors can deliver 40 watts of average power (400 W peak) while the long pulse transistor can deliver 20 watts at best (100 W peak). The long pulse part could provide more average power but more than 20% duty cycle is not useful in the radar system.

The short pulse transistor is designed specifically for that application while long pulse transistors are designed for CW operation. In the special design, high peak power can be achieved because of the reasonably long chip thermal time constant. **Figure 2** shows that the junction temperature rises to only 7% of the CW value during a 10 μsec pulse while junction temperature reaches 80% of the CW value for a 2 msec pulse. Does this mean that it is possible to obtain more than 10x as much power for the short pulse device without exceeding rated junction temperature?

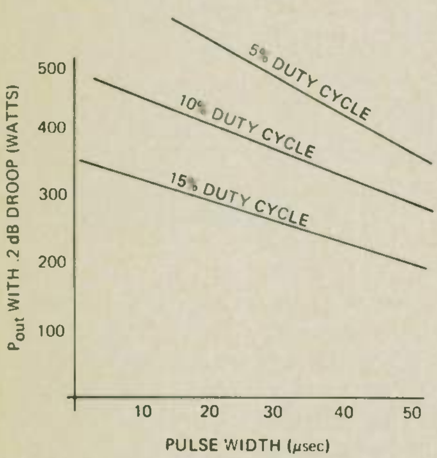

Fig. 4(a) CTC 1214 power output with various pulse widths at 1300 MHz.

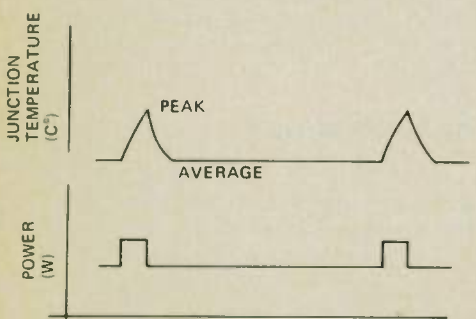

Fig. 4(b) Junction temperature.

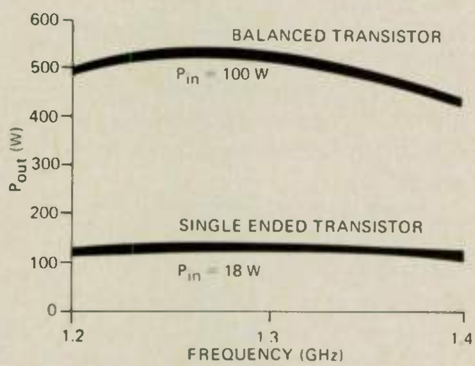

Fig. 5 Comparison of balanced and single ended transistor performance.

The maximum power output capability of a pulse transistor is controlled by several parameters:

- The saturation characteristics of the transistor chip.
- The thermal response time of the transistor chip.
- The power distribution or the development of hot spots over the transistor chip.
- The pulse duty cycle.
- Transistor efficiency.
- Average power dissipation of the transistor and its heat sink.

It is easy to determine the saturation characteristics of the transistor chip by using a low duty cycle and short pulse. These characteristics for the 1214P400 are shown in **Figure 3** for 50, 40 and 30 volts. The absolute maximum power output is limited by the device's maximum voltage rating and junction temperature limitations. The temperature reached by the junction is related to pulse width and the thermal response time of the transistor. An additional limitation is the

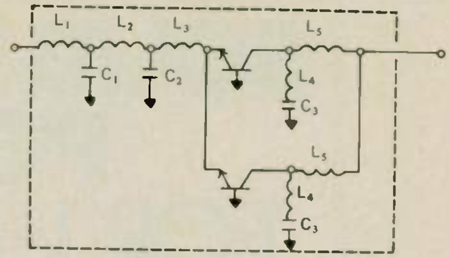

Fig. 6 Typical single ended device internal model.

power distribution over the chip surface or the development of hot spots. The closer a transistor is operated to its voltage breakdown limit the sooner hot spots will develop.

A good indication of the presence of hot spots is the amount of pulse droop. A junction reasonably free of hot spots will have a pulse droop of less than .2 dB with a 30°C flange. In general, this will provide a pulse droop of better than .5 dB over the entire temperature range. A pulse droop of more than .5 dB usually indicates hot spots, power imbalance between the two chips or excessive power dissipation. See **Figure 4(a)**.

Pulse duty cycle, transistor efficiency, thermal resistance, and power output determine average junction power dissipation. This average power dissipation may be used to calculate the average junction temperature. The instantaneous temperature rises during the pulse as shown in **Figure 4(b)**.

BALANCED TRANSISTOR PERFORMANCE

The 1214P400 is a new short pulse balanced transistor that is capable of providing more than 400 watts of output power across the L-band radar band. **Figure 5**

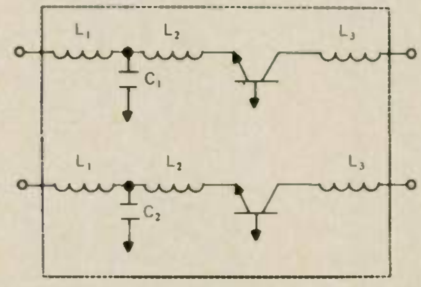

Fig. 7 Balanced device internal model.

compares the performance of the balanced design to that available from single ended devices.

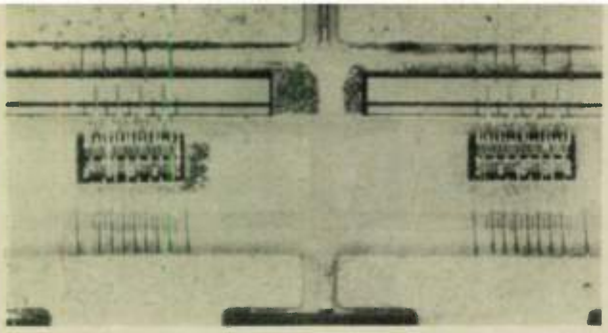

Fig. 8 Interior view of balanced transistor.

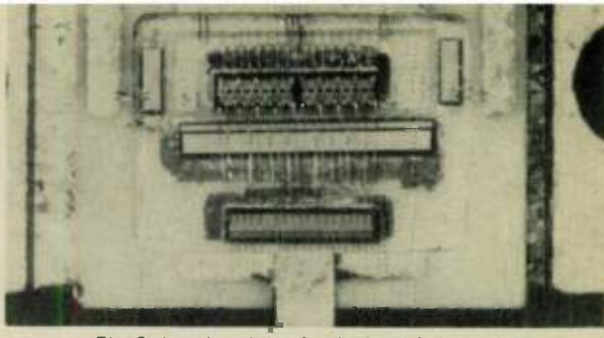

Fig. 9 Interior view of a single ended transistor.

TRANSISTOR CONSTRUCTION COMPARISON

Photographic and schematic comparisons of balanced and single ended L-band devices are shown in Figures 6-9. Each inductor in the schematics of Figures 6 and 7 is a group of wire bonds in the devices. The capacitors shown are MOS types. The difference in complexity between the devices is striking. This difference translates into lower cost for balanced devices and, due to fewer internal sections, to improved reliability as well. The dc blocking capacitors in the single ended device (C_3) are particularly troublesome due to potential failure from dc voltage *and* high RF currents. In addition, the series resonance of L_4 and C_3 in a single ended device, typically just below the low end of the band (about 1.1 GHz), causes serious oscillation problems when fast rise/fall times are employed. This usually shows up as a "noisy" spurious signal at 1.1 GHz only 20-30 dB down or as a distortion "glitch" on the detected pulse turn-off side.

BALANCED TRANSISTOR CIRCUIT DESIGN

The microstrip circuit design used for the balanced device is a simple low pass ladder-type network which is straightforward to design and construct (Figure 10). Since the input and output (load conjugate) impedances of the device are quite similar (and both are inductive), the matching circuit is basically the same for both input and output.

First, a simple ladder network is designed to match the impedance of *one* side of the device referenced to ground (which equals half of the side to side impedance) to a 25 Ω generator (load). Figure 11 illustrates a simple "pi" type match from the device impedance to 25 Ω. Next, the single ended match is transformed to a balanced configuration as shown in Figure 12. Note that C1 has been split for each side of the device into two separate components. Half of C1 (C1/2) for each side is connected to ground. The other half of C1 is connected to the opposite (180° phase) side and becomes C1/4 since the voltage potential between the two sides is *twice* that for one side referenced to ground. As shown in Figure 10, the two C1/2 components are actually physically realized by plated area capacitors. C1 must be split for a symmetrical matching current return to both sides of each port to optimize power transfer and minimize the inductance of the external matching circuit ground return to the device. C2 (and any other shunt capacitors from the single ended design model) becomes C2/2, again because of the double voltage potential between the two sides.

The 180° phase shift required between points A and B in Figure 12 is provided by ℓ_2 which is a λ/2, 25 Ω line. The 25 Ω impedance from A (via ℓ_2) is combined with the 25 Ω from B′ to provide a net impedance at B′ of 25/2 = 12.5 Ω. The 12.5 Ω at B′ is transformed to 50 Ω by ℓ_3 which is a λ/4, 25 Ω line

Fig. 10 400 W L-band radar microstrip circuit.

As shown in Figure 10, care must be taken with the dc feed design for best rise time performance, particularly on the input (emitter) side. The feeds should be connected to the lowest possible RF impedance point (at the device leads) and have only enough inductance to avoid matching circuit detuning. Note that the emitter dc return chokes are connected directly to the device mounting screws for closest possible dc return and therefore fastest rise time. The rise time at the intrinsic transistor is very fast (less than 10 nsec).

The transient dc energy available during the pulse "on time" has a significant effect upon both

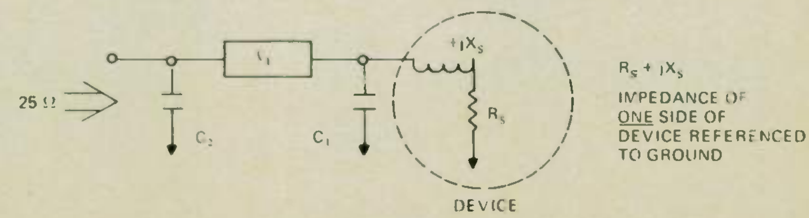

Fig. 11 Single ended design model.

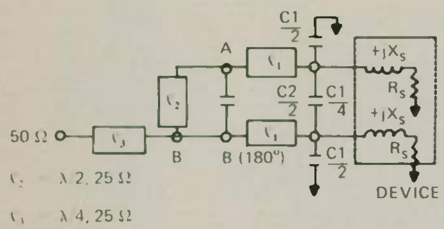

Fig. 12 Balanced circuit configuration.

the pulse droop and the pulse rise time. The dc feed design is shown in **Figure 13**. In order to maintain a constant supply voltage at the transistor during the entire pulse, the majority of the collector current must come from C. For a balanced circuit design, the capacitor is usually divided into two halves (C/2). The R_s and L_s associated with the lines going to the power supply will cause considerable droop if C is not large enough. For a short pulse it is possible to calculate the value of C required by assuming all the

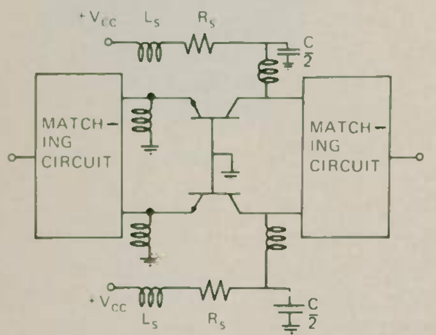

Fig. 13 Balanced circuit dc feed network design.

energy required for the pulse must come from the capacitor.

$$C = \frac{I_p \Delta t}{\Delta V}$$

I_p = Total peak current during pulse
Δt = Pulse width
ΔV = Allowable drop in collector voltage

For the 1214P400 I_p will be approximately 25 amps. If Δt is 10 μsec and ΔV = 1 volt:

$$C = \frac{25 \text{ amps } 10 \times 10^{-6} \text{ sec}}{1 \text{ volt}}$$

$$= 250\ \mu f$$

If only 0.1 volt drop in V_{CC} is required:

$$C = \frac{25 \text{ amps } 10 \times 10^{-6} \text{ sec}}{0.1 \text{ volt}}$$

$$= 2500\ \mu f$$

CONCLUSION

Short (less than 50 μsec) pulse operation tends to heat only the surface of the device die while longer pulses heat the entire die. Therefore, much greater power levels can be achieved for short pulse operation for a given maximum junction temperature. In addition, because of their higher impedances and lower matching circuit losses, balanced devices have been able to deliver at least twice the power of single ended devices at the same gain and collector efficiency levels. The net result is balanced device power output capability about four times that of single ended long pulse devices and the potential for even greater power levels.

It has been shown that through the use of chip level push-pull circuitry, a very favorable dollar per watt L-band figure of merit may be obtained for short pulse radar systems as compared to tube transmitters.

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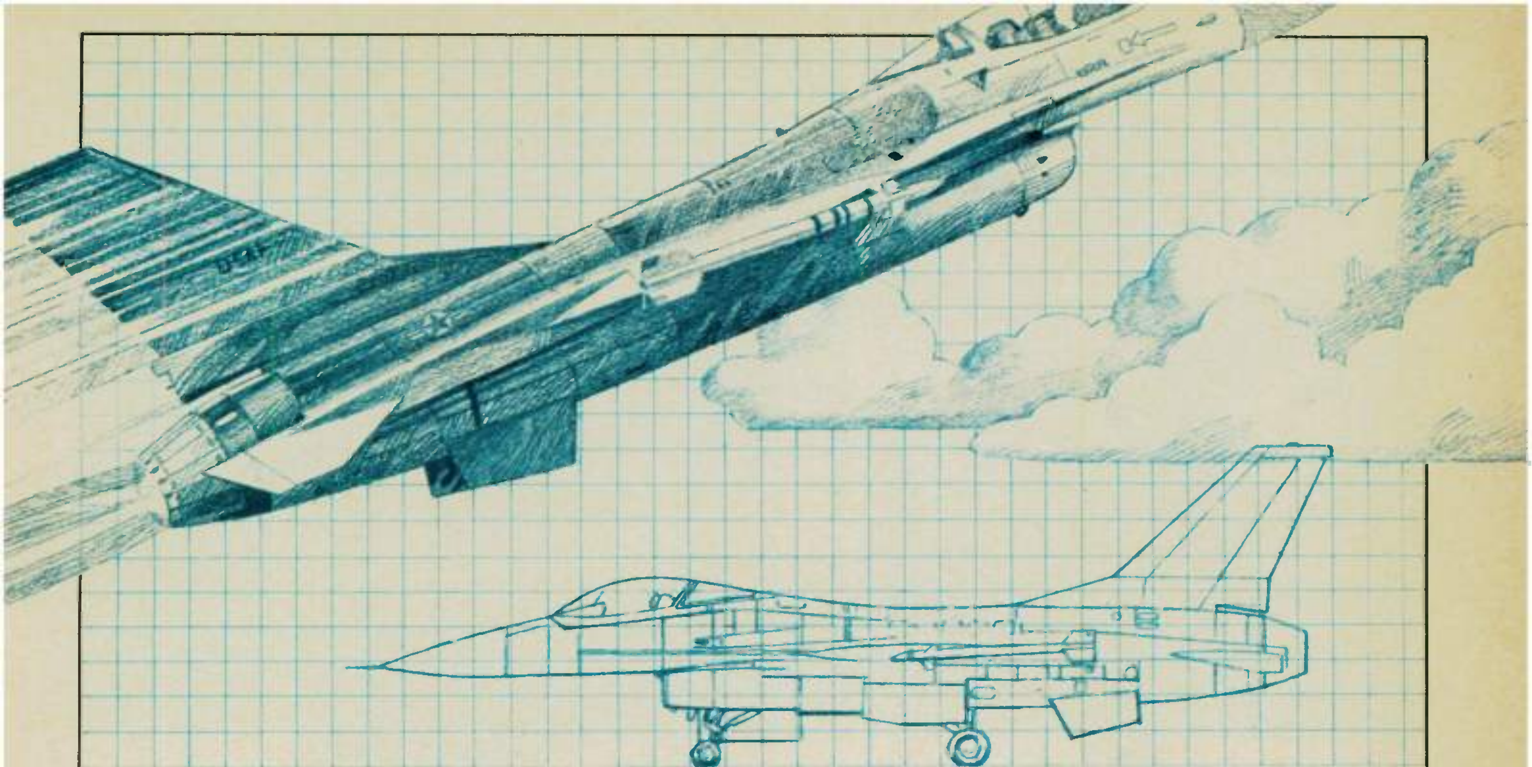

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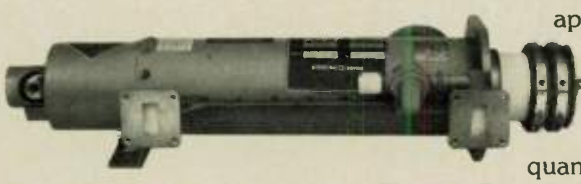

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SP6T Basic Unit	CS-38S16
SP6T w/indicators	CS-38S16C
SP7T Basic Unit	CS-18S17*
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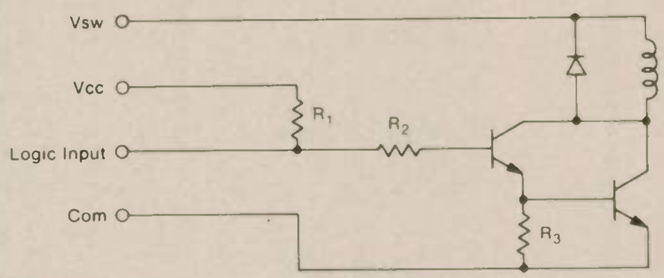

R_1 = 6.2K ohms
R_2 = 2.7 - 6.3K ohms

Switch requires one of the above drivers per position (except Failsafe). VSW, Vcc, and Com terminals are common to all positions.

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High Power Millimeter-Wave Radar Transmitters

GEORGE W. EWELL, DAVID S. LADD, and J. CLARK BUTTERWORTH
Engineering Experiment Station
Georgia Institute of Technology
Atlanta, GA

The selection of a radar transmitter for a millimeter-wave radar system (35 GHz and above) is governed by many of the same factors which influence the selection of any other radar transmitter. Such factors may include peak and average power, pulsewidth, PRF, stability, bandwidth, and tunability, to name only a few. The small physical size of the RF structure, transmission line losses and breakdown, and the limited variety of devices available at millimeter wavelengths, however, makes implementation of a millimeter-wave radar transmitter a somewhat specialized effort.

This article discusses the selection and implementation of a millimeter-wave radar transmitter with emphasis on available devices, modulator techniques, and interaction of the modulator with the RF generation device.

RF SOURCES

RF sources[1,2] for millimeter-wave radar transmitters may be either solid-state or thermionic devices. The solid-state devices are primarily the IMPATT and the Gunn devices. Thermionic sources include magnetrons, TWT's, klystrons, extended interaction oscillators (EIO's), BWO's, and gyrotrons. **Figure 1** shows several moderate to high-power sources, including EIO's, magnetrons, and an IMPATT diode oscillator.

Most of the high-power, pulsed solid-state sources at millimeter wavelengths are IMPATT diodes and they may be used as amplifiers or oscillators. A cross sectional view of a millimeter-wave IMPATT diode package is shown in **Figure 2**. This package may be mounted in the waveguide in two different manners as shown in **Figure 3**, providing tuning of the mount in both the waveguide and the coaxial sections so that the device may be well matched. **Figure 4** shows output power, frequency, and efficiency for a 94 GHz IMPATT oscillator as a function of diode or bias current. Because both current changes and thermal heating during the pulse may affect the frequency of oscillation of the pulse, the pulse shape is sometimes controlled as shown in **Figure 5** to provide a degree of control of the transmitted pulse spectrum. Even with such compensation, the output of IMPATT devices sometimes tends to be broadband with considerable phase noise; these tendencies can be reduced by injection locking the diode. Typically injection locking with about 13 dB gain considerably improves the output spectral shape.[4] **Figure 6** gives power output versus frequency for both CW and pulsed IMPATT oscillators,

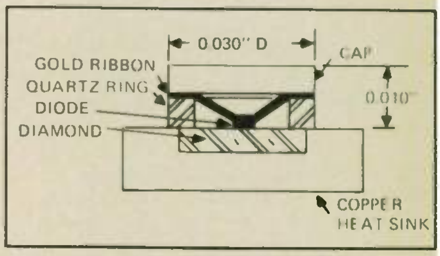

Fig. 2 Cross section view of a millimeter-wave IMPATT diode package.[3]

Fig. 1 Photograph of several commonly used high power millimeter-wave transmitter sources. In the middle is a 5 watt Gunn oscillator, surrounded by (from left to right) an EIO with a samarium-cobalt magnet, and EIO with an Alnico magnet, a 500 watt 70 GHz magnetron, a 8 kW 95 GHz magnetron, and a 1 kW 96 GHz magnetron.

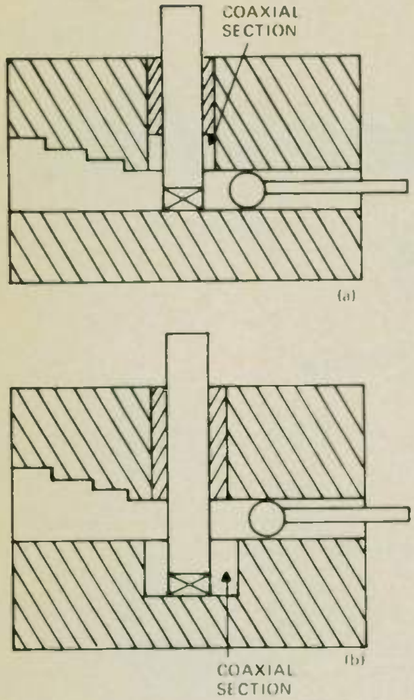

Fig. 3 Two methods of mounting an IMPATT diode in a waveguide structure, with provision for matching included.[3]

and the outputs of several amplifiers may be combined to increase the total output power.[6] It may not be unreasonable to expect to see hundreds of watts produced by pulsed, combined IMPATT diodes in the next few years.

At the present time, 5 to 10 watts are available from pulsed IMPATT's at 95 GHz,[4] laboratory development models have demonstrated 3 watts at 140 GHz,[7] and devices at 225 GHz are under development.[3] Both IMPATT and Gunn oscillators are suitable as CW sources and may be quite useful where a few milliwatts of output power are desirable for use as an FM-CW or a biphase coded transmitter.

Magnetrons may be used as sources for higher power, pulsed transmitters. At millimeter-wave frequencies, most magnetrons are the "rising sun" type, although experimental inverted coaxial devices have been fabricated. Simplified cross sectional views of such configurations are given as Figure 7. In a magnetron, electrons are emitted from the cathode and under influence of crossed electric and magnetic fields pass to the anode. During this period, energy is coupled to the RF field, which is subsequently transferred to the output. One of the major problems with the operation of magnetrons, particularly when operated at short pulse lengths, is that more than one mode of RF oscillation is possible and obtaining correct oscillation in the desired mode may be difficult. One of the major factors influencing this mode selection is the rate of rise of voltage (rrv) applied to the tube. This, coupled with specifications on pulse shape and ripple, are often the dominant factors in the tube/modulator interface.[1] Typical peak powers available are 125 kW at 35 GHz, 10 kW at 70 GHz, 1 to 6 kW at 95 GHz, to 1 kW at 140 GHz. Typical duty cycles are 0.0002 to 0.0005, and efficiencies are on the order of ten percent.

One of the problems with millimeter-wave magnetrons is the small cathode sizes which must be used; this results in high cathode current densities which may result in short tube life. The ex-

(EIO) was developed to circumvent this problem. Figure 8 shows a cross sectional view of an EIO; the cathode is separated from the RF interaction region, to permit a substantial increase in cathode area. Table I summa-

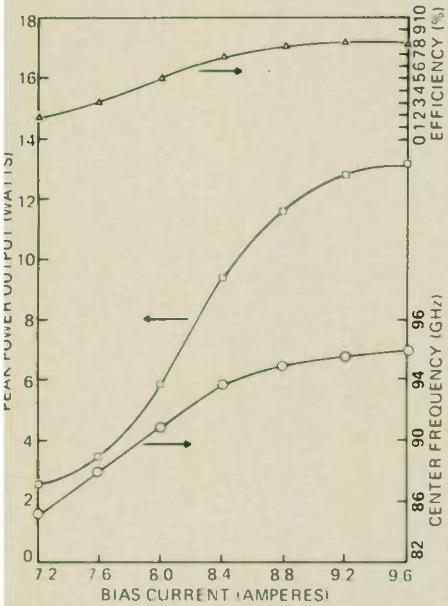

Fig. 4 Output power, frequency, and efficiency for a 94 GHz IMPATT oscillator as a function of current.[4]

pulsed millimeter-wave EIO's. Connections to an EIO are typically as shown in Figure 9. There are anode, cathode, and filament voltages which must be provided for proper operation of the tube. The anode may be operated with either a negative dc or pulsed voltage, the cathode voltage is pulsed negative with respect to the anode and ground, and the filament is operated at cathode potential. Variation in anode or beam voltage can provide a degree of electronic tuning, but larger amounts or tuning require mechanical adjustments of the extended interaction oscillator.

When comparing EIO operation with that of a pulsed millimeter-wave magnetron, a number of significant differences are soon apparent. The most obvious difference is the ease of operating an EIO; arcing and moding problems often associated with magnetrons are not evident. While one prototype tube has exhibited too low voltage, low power modes as beam voltage was varied and presented no problems, and final versions of this tube only evidenced a single mode. Another striking difference is that the EIO (being a space-charge limited diode for which $I = KV^{3/2}$) behaves like an almost resistive load-significantly different from the biased diode char-

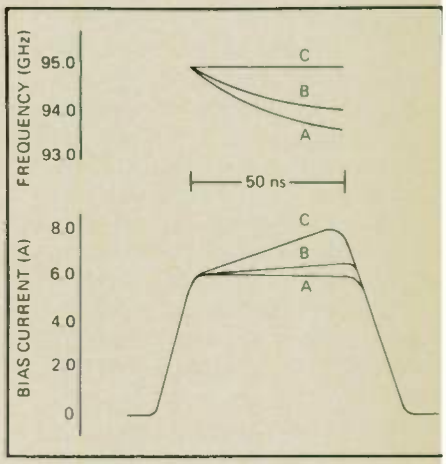

Fig. 5 IMPATT device frequency as a function of pulse shape showing compensation for frequency change during pulse by control of diode current.[5]

TABLE I

CHARACTERISTICS OF SOME PULSED MILLIMETER EIO's

Tube Type	Mech. Tuning Range (GHz)	Power Output (Peak, Watts)	Beam Voltage WRT Cathode	Anode Voltage WRT Cathode	Electronic Tuning Range MHz
VKF 2443	92.7-96.0	950-1770	21 kV	12 kV	300-360
VKT 2419	139.7-140.3	270	20 kV	7.6 kV	370
VKY 2429	225.5	70	21.3 kV	8.2 kV	400

acteristics of magnetrons. An EIO, however produces no RF output until the beam voltage reaches approximately 70% of its final value. Finally, unlike a magnetron, the EIO operating frequency is a quite sensitive function of electrode voltages, requiring extremely flat pulses to avoid excessive frequency shifting. The EIO has proven to be a rather easy device to pulse; nevertheless, satisfactory operation (particularly for short pulses) requires careful selection and design of the modulator. The extreme voltage sensitivity and large amounts of stray capacitance of the EIO often necessitate special modulator techniques. Plans are underway for development of gridded EIO's and extended interaction amplifiers, but none are available at this time.

The development of millimeter-wave TWT's has been rather limited until recently, but Hughes has operated an experimental 1 kW peak, 250 watt average power tube at 95 GHz,[10,11] and a 60 GHz, 5 watt tube for communications purposes has been developed.[12]

Backward wave oscillators (BWO's) are another source of CW power in the millimeter-wave region; they have been operated at frequencies as high as 1300 GHz. However, more representatives results are 10 milliwatts over the 325 to 390 GHz band, or 5 watts at 280 GHz.[13]

In recent years, a new class of microwave and millimeter-wave oscillators and amplifiers has been developed. These devices, called gyrotrons or electron cyclotron masers, show promise of providing peak millimeter wave power outputs considerably higher than that obtainable using previous techniques.[14–20]

Gyrotron devices typically utilize a relativistic electron beam and convert constant electron energies to microwave energies in an intense electro-magnetic field. Initial results typically involved operation at megavolt levels, and super-conducting magnets were necessary to obtain the extremely high magnetic fields required. Devices having much more modest voltage and magnetic field requirements can be built, although they operate at somewhat lower power levels.

Figure 10 is a presentation of the achievable and predicted gyrotron power levels over a range of frequencies, and Table II presents additional details on a num-

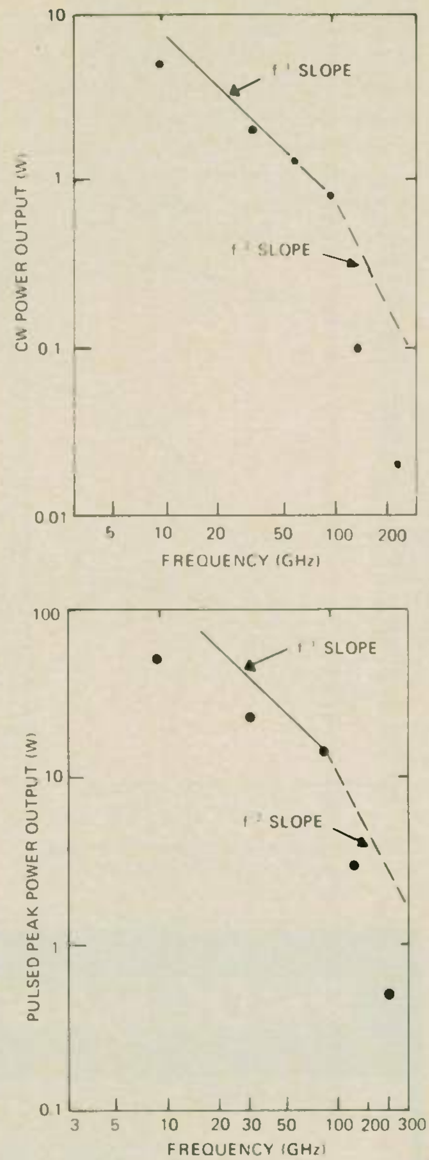

Fig. 6 Power output as a function of frequency for IMPATT oscillators.[3]

ber of Soviet devices. Although relativistic devices are capable of substantially higher peak powers, their large size and weight make them unsuitable for many radar applications. Thus, the data pre-

TABLE II

REPORTED CYROTRON OPERATING CONDITIONS AND OUTPUT PARAMETERS
(Adapted from Reference 16)

Model No.	Mode of Oscillation	Wavelength mm	CW or Pulsed	Harmonic Number	B-field kG	Beam Volts kV	Beam Amps.	Output Power kW	Measured Eff. %	Theoretical Eff. %
1	TE_{021}	2.78	CW	1	40.5	27	1.4	12	31	36
2	TE_{031}	1.91	CW	2	28.9	18	1.4	2.4	9.5	15
	TE_{231}	1.95	Pulsed	2	28.5	26	1.8	7	15	20
3	TE_{231}	0.92	CW	2	60.6	27	0.9	1.5	6.2	5

(continued on page 63)

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1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125
126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150
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301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325

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sented in Figure 10 and Table II appear to be representative of present and projected gyrotron capability.

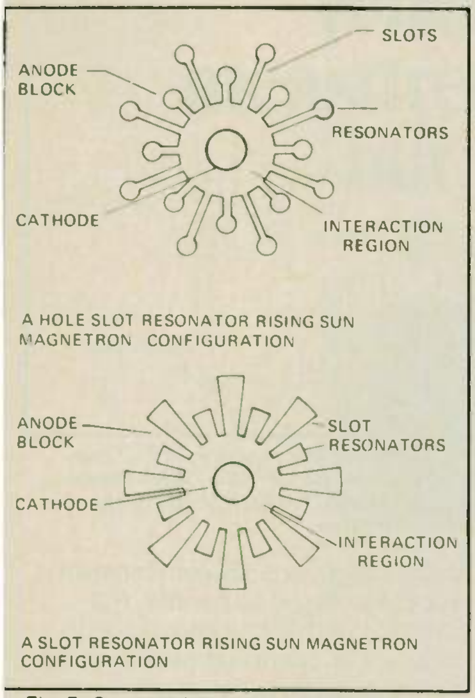


Fig. 7 Cross sectional view of two possible configurations of rising sun magnetron interaction regions. The slot resonant structure is most commonly used at millimeter wavelengths.

Up to this point, discussions have centered about the utilization of gyrotrons as oscillators; however, it is possible to configure gyrotrons as amplifiers by providing appropriate input and output couplings to initially bunch the electron beams and to extract energy from the resulting beam. To date, most activities have concentrated about the implementation of a gyro-klystron as an amplifier in the lower portion of the millimeter-wave spectrum, and 200 kW has been achieved at 28 GHz.

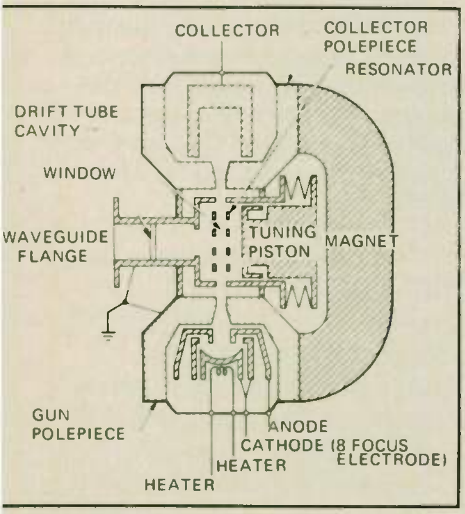


Fig. 8 Cross section view of a millimeter-wave extended interaction oscillator (EIO). Note the removal of the cathode from the RF interaction region, permitting increased cathode area.[8] (Courtesy Varian Associates of Canada).

MODULATORS

The device used to provide proper voltages and currents to the transmitter RF source is usually called the modulator or pulser. Modulators[1,21,22] can be built over a wide range of powers, pulsewidths and efficiencies, and a number of techniques may be used in such devices. IMPATT diodes operate at relatively low voltages and currents, and conventional solid-state circuit design techniques may be used in such cases; SCR discharge circuits are often employed for pulsing IMPATT diodes. Since the pulser for IMPATT diodes is often supplied with the diode, they will not be discussed further. Modulators for magnetrons and EIO's may require relatively high voltages and currents, necessitating special design techniques. These higher power modulators may be either of the line-type or hard tube variety, and each has its own advantages and disadvantages. The line-type modulator utilizes discharge of an energy storage network (called a PFN or pulse forming network) to generate the output pulse. Special forms of the line-type modulator include the Blumlein, "Pedestal," and SCR-magnetic modulators. Such modulators are small and lightweight, but lack flexibility in controlling of pulse shape. Hard tube modulators use a grid controlled vacuum tube to control formation of the output pulse; they tend to be larger and more complex than line-type modulators but provide more control of the output pulse.

LINE-TYPE MODULATORS

Conventional line-type modulators[1] use a pulse-forming network (similar to an artificial transmission line), a switch (such as a hydrogen thyratron, a SCR,

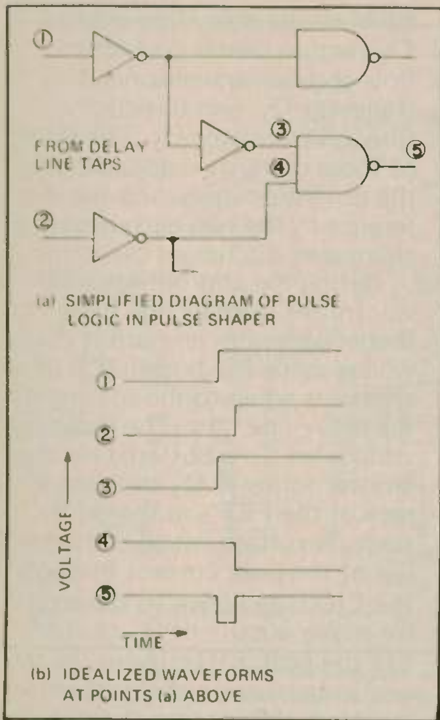
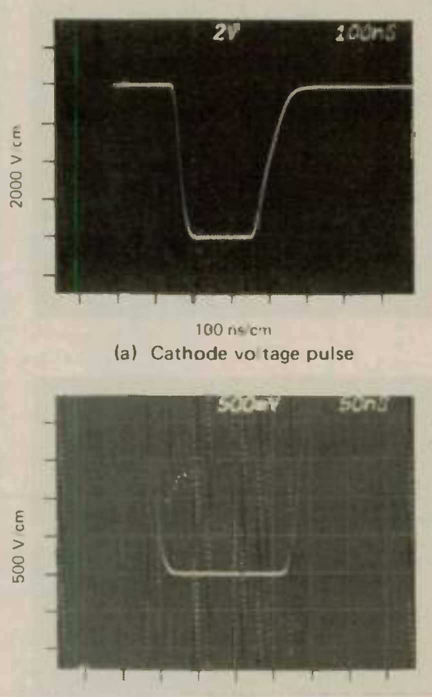


Fig. 15 Simplified circuit diagram and waveforms for one section of pulse shaping logic

monitored to terminate the pulse; when the signal reached this preselected tap, the "stop" pulse was generated, discharging the capacitor C_1 and terminating the driver pulse. Selection of the tap to be multiplexed permitted ready adjustment of the output pulsewidth.

A relatively low value resistor for the plate load for the Y690 triode switch tube was chosen to time. Unfortunately, this resulted

properly discharge the stray capacitance associated with the EIO to achieve the desired rapid fall



(a) Cathode voltage pulse

(b) Expanded cathode voltage pulse

Fig. 16 Modulator output waveforms at cathode of EIO.

in a reduction in modulator efficiency, but for this application pulse fidelity and pulse shape control were more important than efficiency. Capacitive coupling to the cathode was utilized, and a bifilar-wound choke provided heater current for the EIO from a filament supply floating at the −10 kV bias level.

Using this design approach, it was possible to generate a voltage waveform to pulse an EIO with a high degree of flatness; **Figure 16(a)** shows the voltage waveform on the cathode of an EIO operating at 140 GHz. The extreme flatness achieved is shown in **Figure 16(b)**, an expanded view of the same waveform, illustrating that a voltage flatness of less than 50 volts was achievable by this method.

Another example of a hard-tube modulator is a so-called blocking oscillator modulator. A series of these were built to moderate 70 GHz magnetrons operating at the 500-1000 W level. A simplified schematic diagram of such a modulator is shown in **Figure 17**.

Operation of the circuit of **Figure 17** was initiated by a positive input trigger which turned on V_1, and through transformer T_1, turned on V_2. Feedback through T_1 kept V_2 saturated, generating an output pulse, until either T_1 saturated or C_1 discharged sufficiently to increase the plate voltage of V_1. Once the plate voltage of V_2 began to increase, feedback through T_1 rapidly turned the tube off, terminating the output pulse. If C_1 is made variable and used to control output pulse width, simple control of the output pulse is achieved. A continuously variable pulse width of 20 to 45 ns has

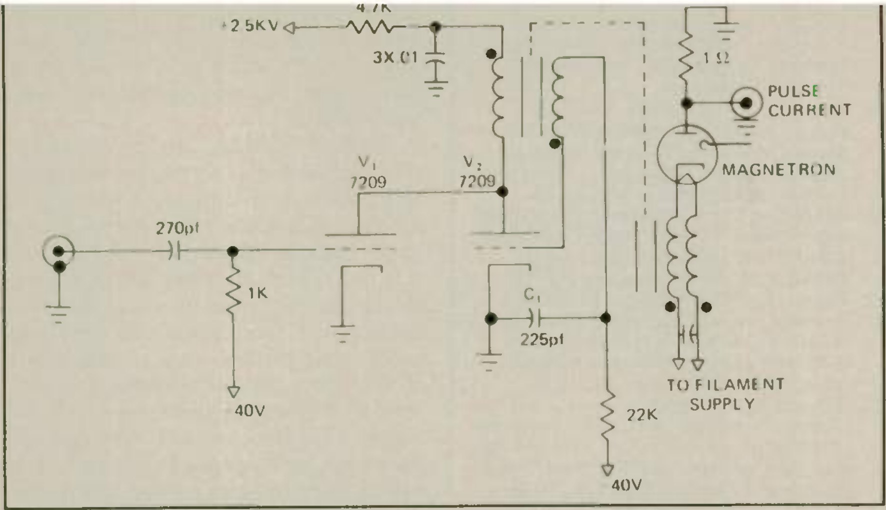


Fig. 17 Schematic diagram of a parallel-triggered blocking oscillator used to pulse a millimeter magnetron.

been demonstrated, as was a switched capacitor generating 15, 30, and 45 ns output pulses.

FUTURE TRENDS

Probably the most active area of development in millimeter wave radar transmitters is in the IMPATT device area. As discussed earlier, the improvement in material and development of combining techniques may allow several hundred watts to be obtained from IMPATT arrays at 95 GHz within the next few years.

Another area for development is in the gyrotron area. Here efforts are centering about development of coherent amplifiers, primarily of the gyro-klystron type.

Due to technical problems, development of millimeter wave magnetrons does not appear to be an active area at this time; no major new developments are anticipated in the immediate future.

While millimeter wave TWT transmitters have not been an area for intense high visibility development, significant powers have been achieved at frequencies as high as 95 GHz; status of future development programs in this area are not clear at this time.

Current research efforts centered about the EIO include grid controlled devices and the development of an extended interaction amplifier (EIA). Current efforts also include the feasibility of injection or phase locking an EIO and frequency modulating the device for use in pulse compression systems. Coupled with these efforts are development of techniques for the precise control of the voltages and currents to achieve the phase and amplitude stabilities required for such applications.

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(continued on page 70)

(from page 69) TRANSMITTERS

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(from page 16) TACTICAL MISSILES

expected of midcourse guidance subsystems such as low cost inertial measurement units and grid systems such as the Global Positioning Satellite System (GPS).

Tactical missiles are produced in very high volume; hence, the increased application of microwave and millimeter-wave subsystems represents a very large business potential. To convert this into real business, I see several challenges that must be met. We must develop the fabrication processes and productize critical new components so that they are produceable and reliable. For example, the future of high-power solid-state devices in missile applications will depend primarily on having the processes refined to provide devices with repeatable characteristics and high yield for low cost. To compete with electro-optical sensors and offer all-weather capability, radar seekers with better resolution and signature recognition need to be developed. This opens the door to application of millimeter-wave and synthetic array radars, and suggests the application of image and signal processing to enhance target recognition and acquisition. Thus the opportunity and need for breakthroughs in increased application of radar guidance to tactical missiles are here.

Microwave Products

Components

HYBRID RF AMPLIFIER COVERS 5-500 MHz BAND

Model QBH-104 is a hybrid RF amplifier which covers the 5-500 MHz frequency range. Amplifier offers 12.0 ± 0.5 dB gain, gain flatness of ± .5 dB max., and a noise figure of less than 5 dB from 5-500 MHz, less than 4.5 dB from 15-300 MHz. SWR in/out is 1.5, max., 1.2, typ. Reverse isolation is greater than 23 dB at 5-500 MHz. Housing is TO-8 with gold-plated Kovar header and nickel cap. Weight: 2.3 g. **Q-bit Corporation, Palm Bay, FL. (305) 727-1838.** **Circle 134.**

MINIATURE TRIMMING CERAMIC CAPACITOR

DV2 is a series of microminiature ceramic trimming capacitors which are available from 2.5-7 pf to 10-60 pf in six ranges. Their operating temperature range is −25° to +85°C; working voltage is 100 Vdc. Size: 6 mm diameter and 4.8 mm mounted height, with completely enclosed package design to resist dust and flux penetration. Price: 31¢ each in 1,000 qty. Del: stock to 4 wks. **JFD Electronic Components Corp., Oceanside, NY. (516) 536-7200.** **Circle 121.**

SERIES OF DIRECTIONAL COUPLERS

Models 860 and 861 are 5-lead, TO-5 directional couplers offering 10 dB and 20 dB nominal coupling, respectively. Both units are 50 ohms and rated at 1 W, within the 5-500 MHz frequency range. Couplers are constructed with nickel Kovar caps and gold-plated headers and leads, all of which are welded and hermetically sealed. Leads are heavy-duty, to allow either plug-in assembly or PC board mounting. **Summit Engineering, Bozeman, MT. (406) 587-4511.** **Circle 136.**

50 OHM SMA TERMINATION

PCX-SM-1A is a 50 ohm termination designed for high reliability applications. Unit has power rating of 1.0 W at 70°C and 1.0 kW, peak. Average power rating doubles when termination is mounted with semiconductor type heat sink. Model operates over from dc to 18 GHz and has a SWR of 1.15 max. at 18 GHz. Available with male and female connector versions and stainless steel nut is passivated per QQ-P-35. Price: $6.90 each in 50 piece qty. Del: stock to 8 wks ARO. **KDI Pyrofilm Corp., Whippany, NJ. Al Arfin, (201) 887-8100.** **Circle 124.**

A line of tubular bandpass filters, Models BPF, operate over the 60 MHz-4.0 GHz range. These fixed tuned filters are constructed with 3-8 sections with 3 dB bandwidths of 2-60% of center frequency; they use direct coupled sections and have a maximally flat (Butterworth) response. Outside the passband, no spurious responses exist from dc to 15 GHz (BPF 250 models); dc to 10 GHz (BPF 500 models); dc to 8 GHz (BPF 750 models) and dc to 4 GHz (for BPF 1250 models). Price: start at $90, in unit qty. Del: 4 wks., in small qty. **RLC Electronics, Inc., Mt. Kisco, NY. (914) 241-1334.** **Circle 135.**

94 GHz VCO COVERS 600 MHz BAND

Model B936WS-VCO is a 94 GHz varactor-controlled oscillator which delivers 30 mW CW over a 600 MHz band. Unit has a tuning speed of 600 MHz/µsec and settling time of 0.5 µsec. Frequency stability is 1 MHz/°C and tuning voltage is +20 V nominal. Tuning sensitivity is 30 MHz/V and tuning characteristics are monotonic. Price: $16,125. Del: 180 days. **Alpha Industries, Inc., TRG Division, Woburn, MA. (617) 935-5150.** **Circle 117.**

HIGH POWER TRANSMIT/ BYPASS SWITCH

A solid-state, 600 W CW, 2000 W peak, transmit/bypass switch covers the 225-400 MHz frequency range. Part Number 100C1545 has 50 dB minimum isolation transmit, 30 dB minimum isolation bypass mode, .15 dB maximum insertion loss and 1.25 maximum SWR. +5 and −200 Vdc power is required. Maximum switching speed is 50 µsec. TNC connectors are standard and an internal driver compatible with TTL logic is included. Size: 7" x 5.25" x 2.5", outside case dimensions. **Daico Industries, Inc., Compton, CA. Jim Adamson, (213) 631-1143.** **Circle 119.**

WR-137 SATELLITE COMMUNICATION SWITCHES

A line of WR-137 dual waveguide switches for satellite communication span the 5.925-6.425 GHz band. Units combine waveguide and coaxial assemblies. Waveguide switch performance characteristics include: 1.05 maximum SWR; insertion loss of 0.025 dB max., 90 dB isolation min., with a power handling capacity of 10 kW CW max.; and 1.25 maximum SWR; 0.3 dB max. insertion loss and 60 dB min. isolation for the coaxial portion. Modular construction is featured. **Logus Manufacturing Corp., Deer Park, NY. (516) 242-5970.** **Circle 122.**

SERIES

IB10 is a series of miniature bandpass filters with center frequencies in the 160 MH: to 3.0 GHz band. Bandwidths can be specified at 3-70% of the center frequency and devices can be manufactured with 2-8 resonant sections. Models can meet full range of military environmental requirements, including temperatures from −62°C to +125°C. Small size of components allow connection of input and output terminals to other circuitry via glass feed-through pins; SMA, SMB or SMC connectors can be provided. Volumes down to .04 cu. in. Price: $250-$475, for 1-2 pieces. Del: 6-8 wks. **K & L Microwave, Inc., Salisbury, MD. Charles Schaub, (301) 749-2424.** **Circle 125.**

LOW LOSS PIN DIODE ATTENUATOR COVERS 1.4 - 2.6 GHz

An absorptive PIN diode attenuator, Model AGC-1426, operates over the 1.4 to 2.6 GHz frequency range. The unit features 0.5 dB max. insertion loss; attenuation range of 25 dB; and a SWR of 2.0:1 maximum over the band. Attenuation flatness is ± 1 dB maximum at 10 dB attenuation setting, operating bias current range of 0-10 mA, RF connectors are SMA female and bias connector is SMC. Size: 1.5" x 1.1" x 0.5". Avail: 60 days. Price: $345, for 1-9 qty. **American Microwave Corp., Damascus, MD (301) 253-6782.** **Circle 113.**

SERIES OF ROTARY ATTENUATORS

RA-80 is a series of rotary attenuators which cover the dc to 12.4 GHz frequency band (Models RA-80, RA-81) and dc to 8 GHz frequency range (Models RA-808 and RA-818). The former provide 0-10 dB in 1 dB steps and 0-60 dB in 10 dB steps, respectively with accuracies of ± 0.4 dB, 0-10 dB and ± 3% from 0-60 dB. RA808 and RA-818 offer the same performance from dc to 8 GHz. Attenuators feature 2 W power handling capability; insertion loss is 0.4 dB to 8 GHz and 0.6 dB to 12.4 GHz. All units constructed of ceramic substrate resistive elements. Price: from $250-$450 each, depending upon model. Del: 8-10 wks. **Texscan Corp., Indianapolis, IN. Raleigh B. Stelle, III, (317) 357-8781.**
Circle 131.

GRIDDED MINI TWT AMPLIFIER

A gridded mini traveling wave tube amplifier, Model VZV-6996F6, covers the 8.0-18.0 GHz frequency band and is suited for ECM, data link and radar applications. Amplifier operates from 0 to 100% duty cycle, with pulse widths from 0.5 μs to CW. Minimum power output is 20 W at 40 dB gain. Total pulse acquisition time is 75 ns, typical and prime operating power is 115 Vac (40 Hz). Size: 2.75" H x 7.5" W x 12.88" L. Weight: 12 lbs. Meets MIL-E-5400, Class II requirements. **Varian Associates, Microwave Components and Subsystems Div., Santa Clara, CA. (408) 496-6273.**
Circle 114.

ULTRA BROADBAND TERMINATION OFFERS 5 W TO 18 GHz

Model TO-18N is a type N termination which covers dc to 18 GHz with a 5 W rating at 95°C. Unit has SWR (worst case) of 1.25 from 8-18 GHz and lower below 8 GHz. Unit adheres to environmental requirements of MIL-E-16400, Class 1 and MIL-E-5400, Class 3. **Micronetics, Inc., Norwood, MA. Gary Simonyan, (201) 767-1320.**
Circle 133.

SERIES OF DIGITAL RADIO SOURCES

A series of high stability, narrowband, phase locked sources for digital radio applications cover L-band through K_u-band and are available in a range of output power configurations of from 10-200 mW. Units minimize microphonics and conform to MIL-STD-202 specifications. Size: 3" x 4" x 2 7/8". **West Division, Frequency Sources, Inc., Santa Clara, CA. (408) 727-8500.**
Circle 120.

POWER AMPLIFIERS FOR 1.3-2.4 GHz BAND

A series of solid-state microwave power amplifiers cover the 1.3-2.4 GHz region with output power of up to 20 W CW. Amplifiers require a 20 or 24 Vdc power source and achieve overall efficiencies are better than 20%. For Model A 2123-150, typical specifications include a 2.1-2.3 GHz frequency range; power output of 15 W min. at power input of 350 mW; input/output SWR of 2.0 max. (50 Ω). Phase characteristics for 20 MHz BW include: time delay slope of 0.1 ns/MHz max.; parabolic time delay of 0.025 ns/MHz 2 max. and ripple of 0.25 ns max. Spurious output is -100 dBc and harmonic rejection is -20 dBc (2nd order) and -30 dBc (3rd order). Size: 5.5" x 2.75" x 1.25". Weight: 1 lb. 3 oz. **Microwave Power Devices, Inc., Hauppauge, NY. Philip A. Kennedy, (516) 231-1400.**
Circle 130.

PROGRAMMABLE ATTENUATOR SERIES

The 50P is a series of programmable attenuators with bandwidths of 10-200 MHz or 10-650 MHz. Designs covering bands from 200 kHz to 1.5 GHz are available. These all solid-state components are TTL compatible and require 5 V supply at 80 ma. Impedance is 50 Ω; attenuation ranges are 0-14 dB in 1 dB steps or 0-70 dB in 10 dB steps; SWR is 1.3 to 1.4, max.; insertion loss is 1.3 dB to 3 dB, nominal and switching speed is 50 μs. Attenuation accuracy ranges from ± .4 dB (any setting) to ± 5 dB (any setting). Price: from $175, 1-9 qty. **JFW Industries, Inc., Beech Grove, IN. (317) 783-9875.**
Circle 126.

END LAUNCH DOUBLE-RIDGE WAVEGUIDE-TO-COAXIAL ADAPTERS

A series of end launch adapters in WRD-750D24 double-ridge waveguide for use in EW/ECM systems are available with choice of coaxial connectors. Models R40-3E, R40-NE and R40-7E operate from 7-18 GHz with SMA, Type N and 7 mm connectors, respectively; Model R40-TE covers 7-16 GHz with TNC connector. All units have SWR of 1.25, typ., 1.35, max. and are constructed of aluminum with stainless steel coaxial connectors. Size: 2.38" long, max., excluding connector. **Microwave Research Corporation, North Andover, MA. (617) 685-2776.**
Circle 127.

MICROMINIATURE RF RIGHT-ANGLE CABLE PLUG

A right-angle cable plug, Part No. 59-428-3702, in the NanoheX connector line is designed for use on .056" diameter cables. Component offers standard Nanohex features such as crimp-on attachment to the cable, 50-ohm impedance, with screw-on engagements and telescoping design. Size: .490" overall from mating end to rear of body. **RF Components Div., Sealectro Corporation, Mamaroneck, NY. (914) 698-5600.**
Circle 129.

ANALOG PIN DIODE ATTENUATOR

Model AG-1293 is a precision digitally controlled analog PIN diode attenuator which covers the 7.9-8.4 GHz band. The unit has an attenuation range of 0-75 dB in steps of 1 dB. Attenuation accuracy is ± 0.25 dB from 0-20 dB; ± 0.50 dB, from 20 to 75 dB and attenuation repeatability is ± 0.25 dB maximum. Other performance characteristics include: insertion loss of 3 dB maximum; SWR (in/out) of 1.6 at 0-40 dB and 2.0 at 40-75 dB; RF power handling of +10 dBm and switching speed of 4 μs maximum. Operating temperature range is 0° to +50°C and dc voltage of ± 15 at 50 mA is required. **Triangle Microwave, Inc., East Hanover, NJ. Martin Rabinowitz, (201) 884-1423.**

Circle 116.

500 W VARIABLE ATTENUATOR

A continuously variable attenuator, Model 4417-20X, operates over the 2.0-4.0 GHz band and can dissipate up to 500 W average power, 10 kW peak, over its 0-20 dB attenuation range. Insertion loss of the unit is .1 dB and SWR is 1.5. Unit is controlled by 1" micrometer. Size: 12" x 7" x 2". Price: $2000, small qty. Del: 6 wks. ARO. **Arra, Inc., Bay Shore, NY. Mike Geraci, (516) 231-8400.**

Circle 118.

FULL OCTAVE TUNABLE OSCILLATORS

Two full octave tunable oscillators, CC-12 and CC-24, feature ultra-fine mechanical tuning over the 1-4 GHz frequency range. Resolution to within 10 kHz is achieved with these transistor oscillators and they provide a minimum of 50 fundamental mW of CW power over the band. Units are supplied with AFC varactor tuning intended for external phase lock or voltage tuning or synthesizer applications. Maximum spurious content is specified at 80 dBc and FM noise is 72 dBc at 1 kHz and 100 dBc at 10 kHz. Full-band tuning requires 50 turns. Price: $550, for both models. Del: from stock. **Engelmann Microwave Company, Montville, NJ. Carl Schraufnagl, (201) 334-5700.**

Circle 115.

MINIATURE AMPLIFIER CHAIN FOR 30-400 MHz BAND

PHA4000 series of miniature amplifiers cover the 30-400 MHz range. The hybrid modules may be series connected to amplify a +13 dBm signal to 24 W CW/FM over the 30-88 MHz, 116-174 MHz and 225-400 MHz bands, and to 64 W PEP over the 116-174 MHz and 225-400 MHz frequencies. Units operate over the −54°C to + 100°C temperature range. Weight: 105 g, for 2-module chain. Module size: 1" x 2 1/8" x 1/2". Price: 1 to 5 PHA4000-1 (nickel-plated Al package), $1,800, each; PH4000-2 (nickel-plated Cu package), $1,200, each. Del: 4 wks. ARO. **Power Hybrids Inc., Torrance, CA. (213) 370-6160.**

Circle 128.

ADAPTORS

A line of improved SMA between-series adaptors are available covering SMA to Type N, TNC and BNC connectors. Typical performance characteristics of the SMA to N adaptor, P/N 705718-101, include: SWR of 1.05 + .005F (GHz) dc to 18.0 (GHz), insertion loss is .04 x F (GHz). Price: $8.09 each in 1,000 qty. Del: from stock. **Cablewave Systems, Inc., North Haven, CT. Steven Raucci, Jr., (203) 239-3311.**

Circle 123.

1.5-10.0 GHz BAND

Model PD-1510 is a power divider which covers the 1.5-10 GHz frequency range. Unit offers a 0.4 dB typical insertion loss at 2-8 GHz, with 0.6 dB typical at 1.5 to 10 GHz; SWR is 1.7 at 1.5-10 GHz typ., 1.2 at 2-8 GHz. Isolation is 15 dB typical over the full band, 25 dB typical at 2-8 GHz. Also available with amplitude and phase match specifications. **Western Microwave, Inc., Sunnyvale, CA. (408) 734-1631.**

Circle 132.

 Circle 45 on Reader Service Card

Antennas

MM-WAVE CIRCULARLY POLARIZED ANTENNA

A circularly polarized millimeter-wave antenna is offered which operates at 23.0 GHz (± 5%) with omnidirectional coverage on the horizon and approximately 35° half-power beamwidth in elevation. Unit features SWR of 2.0, max. and a gain of 0 dBi, min. Size: 2" H. x 3" D. The input connector mates with SMA Jack. Sanders Associates, Inc., Manchester, NH. (603) 669-4615. Circle 142.

PETALIZED LIGHT WEIGHT EARTH STATION ANTENNAS

A line of segmented fiberglass earth station antennas with reflectors from 4 ft. to 5 m feature strength with light weight. The 10 ft. model is segmented into 8 interchangeable petals weighing less than 15 lbs. each. Reflectors are rated for winds up to 125 mph and they are MIL-STD-810-B certified. Antennas offer rear polarization adjustment, unpressurized feed and U/L approved fire retardant fiberglass. Prodelin Antennas, Hightstown, NJ. (603) 448-2800.

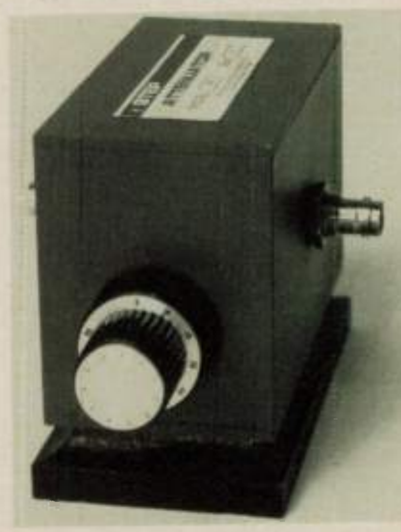
Circle 143.

Instrumentation

MULTI-PURPOSE CONTROLLER FOR IEEE-BUS

Model MPC-1000 is a multi-purpose controller for IEEE-488 Bus applications originally designed to operate the MSR-903 Surveillance Receiver. Instrument is a complete computer with 32K RAM and 340K in a dual floppy disk arrangement; programing is BASIC. Particular attention has been paid to RFI shielding and radiated interference has been reduced below −90 dBm/cm^2. Size: standard 19" rack cabinets. Price: $8,500, includes computer, dual disks, CRT and printer. Micro-Tel Corporation, Baltimore, MD. D. I. Horan, (301) 823-6227. Circle 137.

BENCH ATTENUATOR SERIES



Series 3050, 3051 and 3052 are bench attenuators which operate from dc to 2 GHz and are offered in six standard attenuation ranges/steps: (0-1 dB/0.1 dB steps; 0-10 dB/1.0 dB steps; 0-100 dB/10 dB steps; 0-110 dB/1.0 dB steps; 0-11 dB/0.1 dB steps, and 0-140 dB/10 dB steps). All models are rated at 1 W average, 100 W, peak; SWR is 1.20-1.35 max., depending on model; frequency sensitivity is 0.1-0.2 dB up to 2 GHz. RF leakage is greater than 85 dB below input signal. Connector options include female BNC and Type N. Prices: start at $295 (US). Avail: stock to 60 days ARO. Weinschel Engineering, Gaithersburg, MD. (301) 948-3434. Circle 138.

1 MHz - 1 GHz RANGE

Model 4191A, an RF impedance analyzer, measures 14 impedance parameters over the 1 MHz to 1 GHz frequency range with a basic accuracy of 0.5 to 2%. Model contains an internal frequency synthesizer, automatic calibration, automatic error correction and test fixtures which can make impedance measurements possible over a range of 1 mΩ to 100 mΩ. Unit features an internal bipolar dc bias source (0 to ± 40 V with 10 mV resolution), linear and log sweep capability of frequency and bias, plus self-test and deviation measurement capability on all 14 parameters. Measurement resolution is 0.1 fF for capacitance and 1 µs for conductance. Price: $14,260, US. Del: from Jan., 1980. **Hewlett-Packard Co., Palo Alto, CA. (415) 856-1501.** **Circle 145.**

Materials

FLEXIBLE FOAM PYRAMIDAL ABSORBER

ECCOSORB® HPY is a series of partially hollow pyramidal microwave absorbers, for use in anechoic chambers. Material is lightweight polyurethane foam and pyramids are mounted on a solid flexible base of material. Typical infrared reflectance varies from 0.1% at 1 µm to 6% at 40 µm for any surface color (color is normally black but pastel shades can be special ordered). All materials conform to ASTM-D 1692-74 (self-extinguishing) and are incombustible under L.A. Building Code (1963) Div. 4, Sec. 91.040 (i) by ASTM Method E136-59T (modified). **Emerson & Cuming, Canton, MA. Jeanne B. O'Brien, (617) 828-3300.**

Circle 139.

EMI/RFI ENVIRONMENTAL SEALS

The O-Ring Spira Combo gasket series (ORSS) provide a positive EMI/RFI bond (15 lbs. per linear in. force) and environmental seal. Two versions are available (Standard Series and Moderate Force Series); both resemble an "O" ring, fit in an "O" ring groove and can be purchased in straight lengths or as a finished "O" ring seal. Diameter sizes range from .060-.140 inches. To compress gaskets .25 of their diameter, the force requires is .30 lbs/linear inch for Standard Series (SS) and .10 lbs/linear inch for Moderate Force Series (MS). SS gasket and MS versions are composed of an outer conductive coating of Cu filled silicon elastomer; intermediate conductive spiral is tin plated BeCu; and resilient inner core is 60 Durometer Neoprene. **Spira Manufacturing Corp., Burbank, CA. George M. Kunkel, (213) 843-5880.**

Circle 162.

(continued on page 76)

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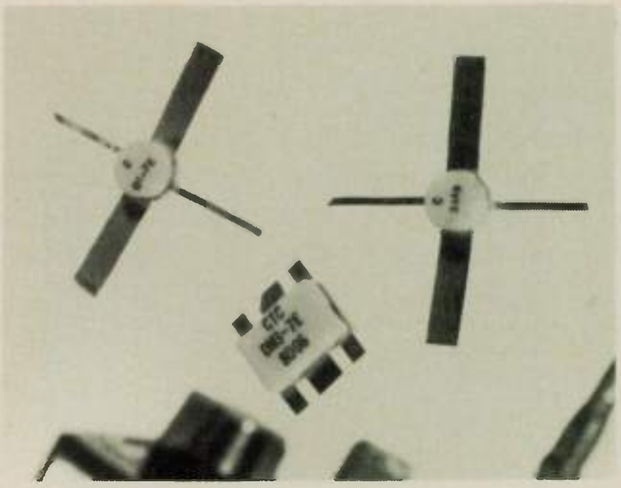
COMPOSITE ELASTOMETER EMI/RFI SHIELD VULCANIZED STRIP GASKETING

Combo® Seal is vulcanized strip gasketing combining silicone rubber with knitted metal mesh to provide an effective EMI/RFI shield. Gaskets can be extruded in a variety of forms and shapes which adapt to original designs and permit retrofitting into the existing product configurations. Material offers shielding effectiveness of up to 90 dB, 10.0 kHz - 1.0 GHz, at 20 psi. Silicone rubber components of the product meets ZZ-R-765, Class 11a, Grade 50 specifications. Combo Seal is gray, has 1.13 ± 0.03 specific gravity, brittle point of 100° F and offers a peel strength of 3 lbs. (min) per linear inch. **Metex Corporation, Edison, NJ. John Severinsen, (201) 287-0800.**

Circle 151.

Devices

7.5 V TRANSISTORS FOR 800 MHz BAND



A family of transistors designed to operate from a 7.5 V supply cover the hand-held radio 806-866 MHz band. Specifications include BV_{ces} = 36 V min., BV_{ebo} = 4 V min. for all types and: for the CD3499 - min. power output of 0.3 W at min. power input of 0.1 W and I_c is .25 A. For the D1-7E, min. power output is 1.0 W at min. power input of 0.3 W and I_c is .04 A. For Model DM3-7E, power output is 3 W, min. at 1.0 W min. input and I_c is 1 A. **Communications Transistor Corporation, Varian Associates Subsidiary, San Carlos, CA.** (415) 592-9390. **Circle 140.**

POWER TRANSISTOR SERIES

NE4200 is a series of three microwave power transistors specified at 4.2 GHz. Model NE4201 provides power output of 1.5 W and 8 dB gain; Model NE4203 has power output of 3.0 W and 5 dB gain and NEM4205 has power output of 5.0 W and 4 dB gain. Price: start at $68.00 (1-9 qty.). **California Eastern Laboratories, Inc., Santa Clara, CA. (408) 988-3500.**
Circle 141.

1.5 W PULSED TWT's SPAN 8-18 GHz RANGE

Two high gain, grid-controlled pulsed TWTs, Models 8722H and 8754H operate in the 8-18 GHz frequency band and have power outputs of 1.5 kW. Units use PPM focusing and conduction cooling, and their peak power output is > 1.0 kW at up to 8% duty. Nominal large signal gain is 45 dB, and models come in either grounded collector or depressed collector configurations. Model 8722 has a TNC output connector, while Model 8754H employs a waveguide output connector. Price: $13,000. Del: 7 months ARO. **Electron Dynamics Div., Hughes Aircraft Company, Torrance, CA. (213) 534-2121.** **Circle 144.**

New Literature

RF AND MICROWAVE MODULES BROCHURE

A 6-page brochure features a full line of RF and modular amplifiers in TO-12, TO-8, 4 PIN dual-in-line and TO-3 packages. Two-color leaflet includes product photographs, and complete specifications for gain, noise figure, SWR and power output of amplifier series with 0.5 MHz to 2000 MHz frequency range. **Optimax, Div. of Alpha Industries, Inc., Colmar, PA. (215) 822-1311.** Circle 101.

CONDUCTIVE COATING BULLETIN

Bulletin ESG-10 provides detailed specifications, as well as surface resistivity data and shielding effectiveness tables and charts for Xecote® conductive coating and Xeprime® primers. This 6-page brochure also displays product photographs and provides ordering instructions. **Metex Corporation, Electronic Products Division, Edison, NJ. John Severinsen, (201) 287-0800.** Circle 102.

BROCHURE SUMMARIZES ELECTRON DEVICE PRODUCTS

A two-color brochure lists over 60 types of Electron Device Group products cross referenced for specific applications in communications, electronic warfare, instrumentation, medical and scientific and radar systems. Business reply cards for requesting additional information are included. **Varian Associates, Electron Device Group, Palo Alto, CA. (415) 493-4000.** Circle 103.

APPLICATION NOTE ON PRECISION TIME INTERVAL GENERATION AND MEASUREMENT

A note on precision time interval generation and measurement, No. 191-6 describes techniques to measure the length, dielectric constant and propagation delay matching of transmission lines. The five-page pamphlet covers theory, analysis of measurement errors and describes a lab set-up which is sensitive to length changes as short as 1 millimeter. **Hewlett-Packard Co., Palo Alto, CA. (415) 857-1501.** Circle 152.

HEAT SINK GUNN DEVICES

A 4-page product bulletin describes the GC5700 and GC5800 series of high power negative and positive bias plated heat sink Gunn devices. Literature includes description, performance specifications, applications, package styles and maximum ratings for these products. **Frequency Sources, Inc., GHZ Division, S. Chelmsford, MA. Robert C. Antonucci, (617) 256-8101.** Circle 105.

DATA SHEET ON FUSED FEEDTHROUGH ADAPTORS

Technical Bulletin #32 describes fused feedthrough adaptors. The two-page piece contains electrical, mechanical and environmental characteristics as well as mounting information for adaptors incorporating 1/8 A (optional 3/8 A) fuses for protecting equipment from excessive input signals. **Cablewave Systems, Inc., North Haven, CT. Steven Raucci, Jr., (203) 239-3311.** Circle 106.

MATCHED SCHOTTKY DIODE DETECTOR BROCHURE

A 4-page bulletin provides information on a family of matched pair Schottky diode detectors. Performance data and specifications for octave and multioctave band, types are provided in the two-color brochure. **Omni Spectra, Inc., Microwave Component Division, Merrimack, NH. John C. Callahan, (603) 424-4111.** Circle 111.

REFLECTOMETER CALCULATOR/ SHORT-FORM CATALOG

A reflectometer calculator, which doubles as a temperature conversion chart and short-form catalog of RF terminations is offered. The selector provides information for more than 42 of the most often used terminations and the calculator features an expanded SWR scale. **KDI Pyrofilm Corporation, Whippany, NJ. A. Arfin, (201) 887-8100.** Circle 108.

BROCHURE ON SIX-PORT REFLECTOMETER

Brochure describes a six-port reflectometer designed for the 2-18 GHz frequency band. This 8-page note explains the uses and accuracies of the instrument, as well as some theory of operation. Also gives alternatives for building blocks and measurement system block diagrams. **Norsal Industries, Inc., Central Islip, NY. Norman Spector, (516) 234-1200.** Circle 109.

CW POWER AMPLIFIER SYSTEM

Brochure describes "4-In-One," 1000 W RF, CW power amplifier system which covers 40 to 1000 MHz in four bands. Options available for the system, a compatible driver and two other amplifier systems are described. **MCL/ Inc., La Grange, IL. Robert Morgan, (312) 354-4350.** Circle 110.

WAVEGUIDE SWITCH BROCHURE

An illustrated brochure describes a waveguide switch line. The 6-page pamphlet provides complete electrical and mechanical specifications. **Waveline, Inc., W. Caldwell, NJ 07006. (201) 226-9100.** Circle 112.

PIN DIODE DESIGNERS GUIDE

A 164-page guide offers the RF circuit designer a comprehensive reference on PIN diodes. Document includes handling techniques for chip devices, descriptions of pertinent diode measurements, discussions of device physics, performance trade-offs and functional details for the design of 17 different switches, limiters and attenuators. Also covers driver considerations, package parasitics and PIN diode quality and reliability. **Microwave Associates, Inc., Burlington, MA. (617) 272-3000.** Circle 104.

SELECTION GUIDE FOR RF SIGNAL GENERATORS AND SOURCES

An 8-page guide to selection of RF signal generators and sources includes specification comparisons for 9 different generators and an application selection chart. A single-sideband phase noise comparison chart for 5 generators, a glossary of terms and capsule descriptions of each of the generators within the 10 kHz-2600 MHz frequency band are also provided. **Hewlett-Packard Co., Palo Alto, CA. (415) 587-1501.** Circle 107.

CAPABILITIES BROCHURE

A four-color, 16-page brochure describes the electronic defense, electro-optic, and intrusion detection capabilities of the Western Div., Sylvania Systems Group. Separate sections cover strategic reconnaissance, scientific intelligence analysis, security, electronic warfare and optical tracking and ranging systems designed and manufactured by the Western Division. **GTE Sylvania Systems Group — Western Div., Mountain View, CA. Frank A. Arneson, (415) 966-2452.** Circle 148.

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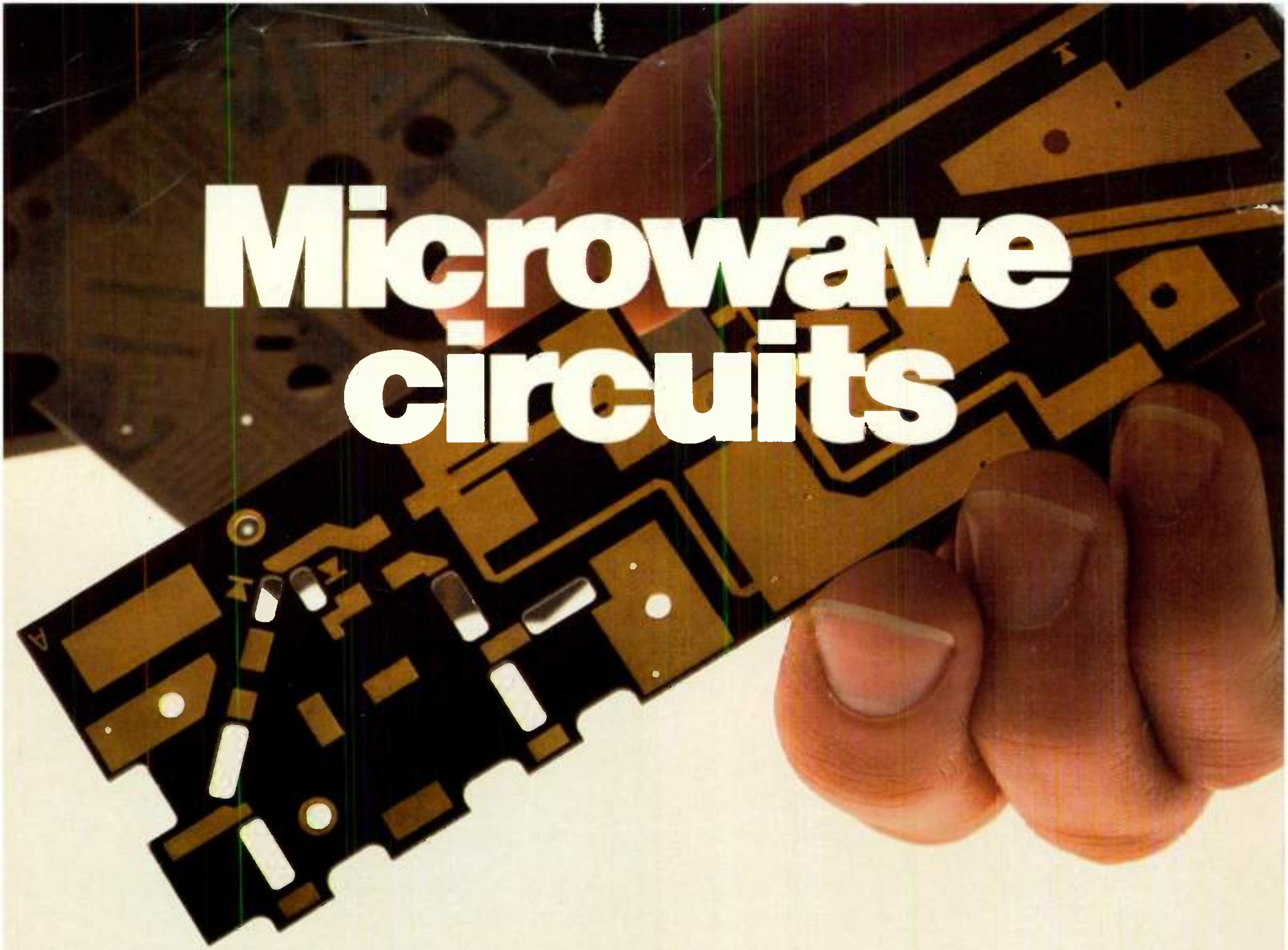
Microwave circuits



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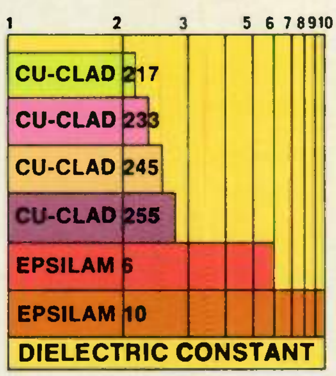

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