microwave
JOURNAL

INTERNATIONAL EDITION □ VOL. 23, NO. 9 □ SEPTEMBER 1980

TRONIC WARFARE

eband Receivers

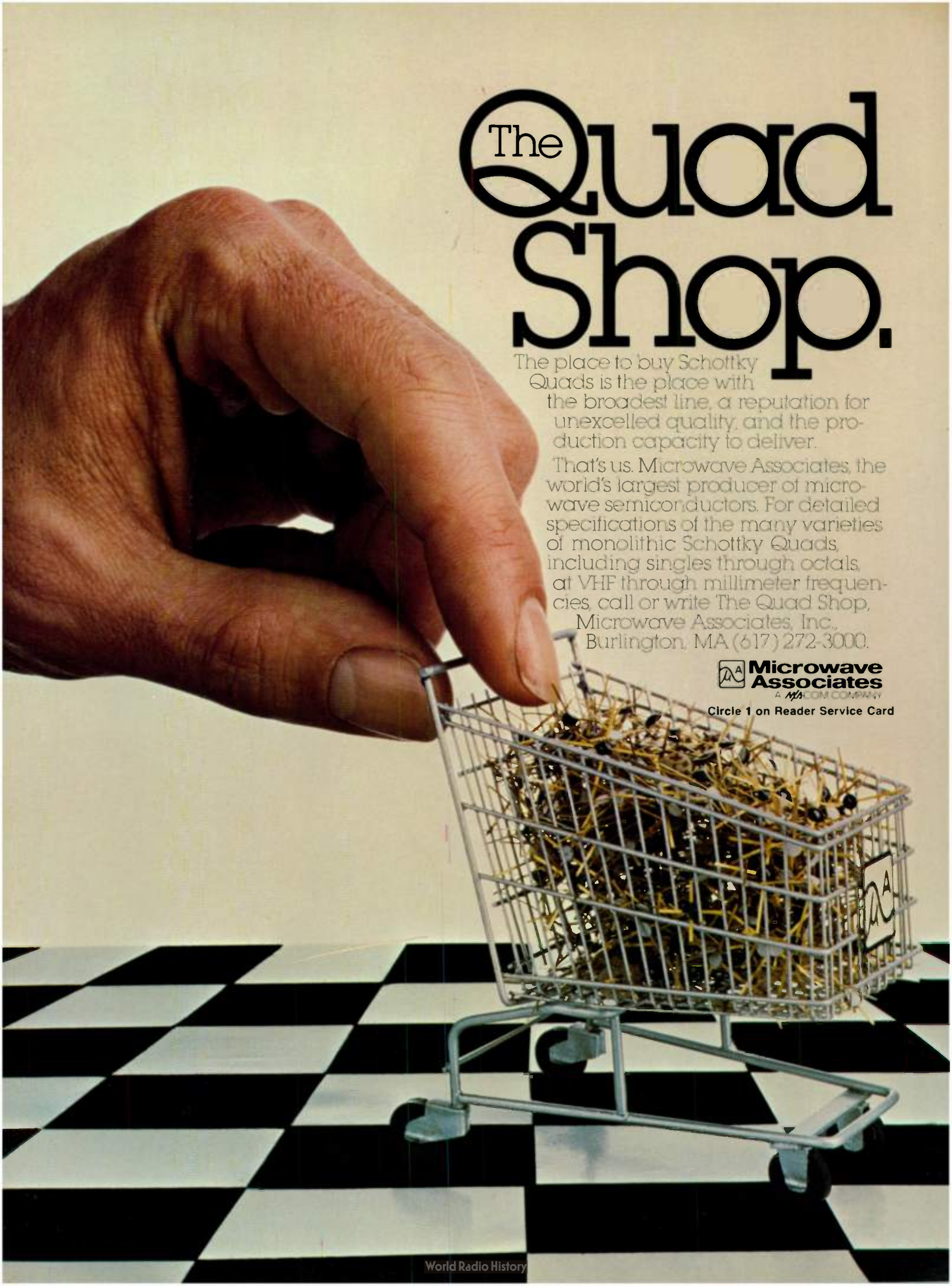
able Transmitters

ical RF Spectrum Analyzer

Wave ECM

mps vs. TWTA's

horizon house



MITEQ

FREQUENCY SOURCES AGILE PHASE LOCK

- **Automatic locking to input reference frequency**
- **Low phase noise**
- **Fast acquisition time (1 ms) (PLA-FA Series)**
- **Alarm options**

The Miteq series of frequency-agile phase lock sources automatically lock to and track the input reference signal. These units exhibit low phase noise through use of a high Q microwave oscillator. Acquisition times to 1 ms are available with the PLA-FA Series.

PLA-AA SERIES (100 ms Acquisition)

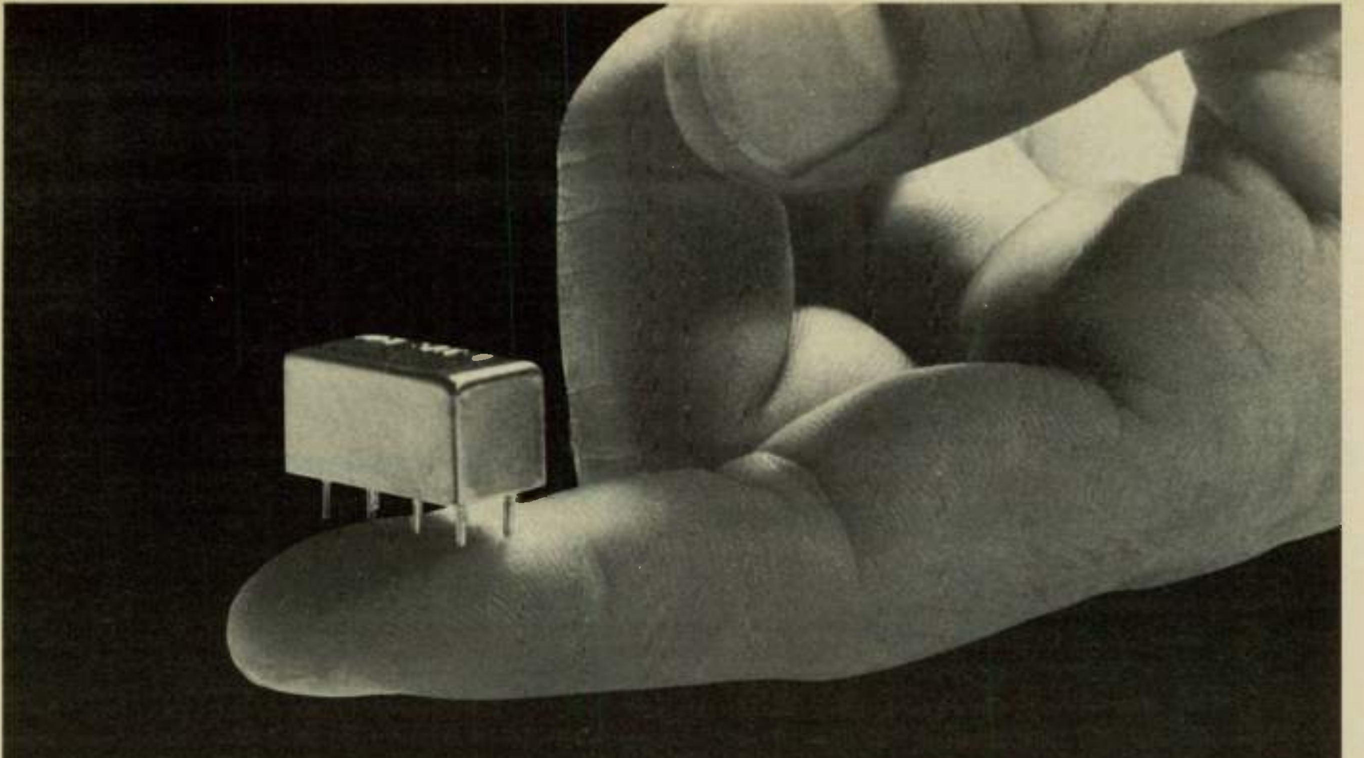
MODEL NUMBER	OUTPUT FREQUENCY (GHz)	POWER OUTPUT (MIN.) (dBm)	REFERENCE FREQUENCY RANGE (MHz)	MULTIPLICATION FACTOR
PLA-AA-3742	3.7-4.2	+13	123.3-140.0	X 30
PLA-AA-4449	4.4-4.9	+13	91.6-102.1	X 48
PLA-AA-4853	4.8-5.32	+13	100.0-110.8	X 48
PLA-AA-6570	6.55-7.05	+10	109.1-117.5	X 60
PLA-AA-7075	7.0-7.55	+10	116.6-125.8	X 60
PLA-AA-7277	7.2-7.7	+10	120.0-128.3	X 60

PLA-FA SERIES, FAST SWITCHING (1 ms Acquisition)

MODEL NUMBER	OUTPUT FREQUENCY (GHz)	POWER OUTPUT (MIN.) (dBm)	REFERENCE FREQUENCY RANGE (MHz)	MULTIPLICATION FACTOR
PLA-FA-3742	3.7-4.2	+13	102.7-116.7	X 36
PLA-FA-4449	4.4-4.9	+13	91.6-102.1	X 48
PLA-FA-4853	4.8-5.32	+13	100.0-110.8	X 48
PLA-FA-6570	6.55-7.05	+10	109.1-117.5	X 60
PLA-FA-7075	7.0-7.55	+10	97.2-104.9	X 72
PLA-FA-7277	7.2-7.7	+10	100.0-106.9	X 72

MITEQ INC., HAUPPAUGE, NY 11787, (516) 543-8873, TWX 510-226-3781

CIRCLE 4 ON READER SERVICE CARD



There's a new way to increase your system's dynamic range!

Very high level MIXERS featuring +20dBm RF input -70dB IM spec ... $54.95 (1-9 qty)

Model No	Freq (MHz)	Conv loss (dB max.)	Signal 1 dB compr level (dBm min.)	Connections	Size (in.) (W x L x H)	Price (1-9)
SAY-1	0.1-500	7.5	+20	8 pins	0.4×0.8×0.4	$54.95
SAY-2	0.1-1000	9.5	+20	8 pins	0.4×0.8×0.4	$59.95
SAY-11	10-2400	10.0	+18.5	8 pins	0.4×0.8×0.4	$64.95
ZFY-1	0.1-500	7.5	+20	*BNC, TNC, SMA, N	1.25×1.25×0.75	$74.95
ZFY-2	0.1-1000	9.5	+20	*BNC, TNC, SMA, N	1.25×1.25×0.75	$79.95
ZFY-11	10-2400	10.0	+18.5	*BNC, TNC, SMA, N	1.25×1.25×0.75	$84.95

Impedance 50 ohms, Isolation 20 dB min.
*BNC standard, TNC on request, Type N and SMA $5.00 additional
Third order intercept point +35 dBm typical

- wide bandwidth ... models cover 100 KHz to 2.4 GHz
- 1 dB compression point at +20 dBm RF input
- only +23 dBm LO power required
- low conversion loss ... 6 dB
- -70 dB, 2-tone, 3rd order IM with each tone at 0 dBm (LO at +23 dBm)
- compact size, 0.128 cu. inches
- high isolation ... 45 dB
- PC and four connector versions available
- immediate delivery
- surprisingly low priced ... from $54.95

World's largest manufacturer of Double Balanced Mixers

Mini-Circuits
MINI-CIRCUITS LABORATORY
A Division of Scientific Components Corp.

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CIRCLE 5 ON READER SERVICE CARD

POWER DIVIDERS

Broadband, 0.5 — 4.2 GHz • Only 0.2 dB insertion loss
Isolation over 30 dB midband, 25 dB at bandedges • Octave bandwidths
Two way • up to 10 W (matched output)

- High performance microstrip construction
- Housed in rugged RFI-shielded aluminum case
- Available with BNC, TNC, SMA and Type N connectors
- Meets MIL-202E standards
- Also useful as power combiners at signal levels up to +10 dBm

$39.95 (1-9)

Now you can specify and purchase state-of-the-art power dividers at ⅓ to ½ the price of competitive units, with immediate off-the-shelf delivery. . . from Mini-Circuits, of course.

This breakthrough in price/performance is a natural extension of our extensive experience in high volume manufacturing, exacting quality control and thorough testing. This expertise assures you highly reliable power dividers with guaranteed repeatability of performance at lowest cost.

So, if you are among the thousands of companies now using Mini-Circuits signal-processing units in your systems designs, add power dividers to the list of price/performance industry standards available from Mini-Circuits.

Model	Frequency Range, GHz	Insertion Loss, dB		Isolation, dB		Amplitude Unbalance, dB	VSWR (All Ports) Typ	Power Rating-W		Price	Qty.
		Typ	Max	Typ	Min			Divider	Combiner		
ZAPD-1	0.5-1.0	0.2	0.4	25	19	±0.1	1.20	10 W	10 mW	$39.95	1-9
ZAPD-2	1.0-2.0	0.2	0.4	25	19	±0.1	1.20	10 W	10 mW	$39.95	1-9
ZAPD-4	2.0-4.2	0.2	0.5	25	19	±0.2	1.20	10 W	10 mW	$39.95	1-9

Dimensions 2" × 2" × 0.75" **Connectors Available:** BNC, TNC, available at no additional charge
$5.00 additional for SMA and Type N

World's largest manufacturer of Double-Balanced Mixers

Mini-Circuits

A Division of Scientific Components Corp.

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JOURNAL

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DEPARTMENTS

* Euro-Global Edition Only

ON THE COVER: The environment of ESM receivers is suggested by Litton's (Amecom Division) artist Mark Dangle. For featured Special Report, see p. 24. Also on the cover is the first reported integrated optical circuit fabricated by Westinghouse, a microwave spectrum analyzer utilizing Ti-doped $LiNbO_3$ optical waveguide technology which opens new signal processing vistas. See page 37.

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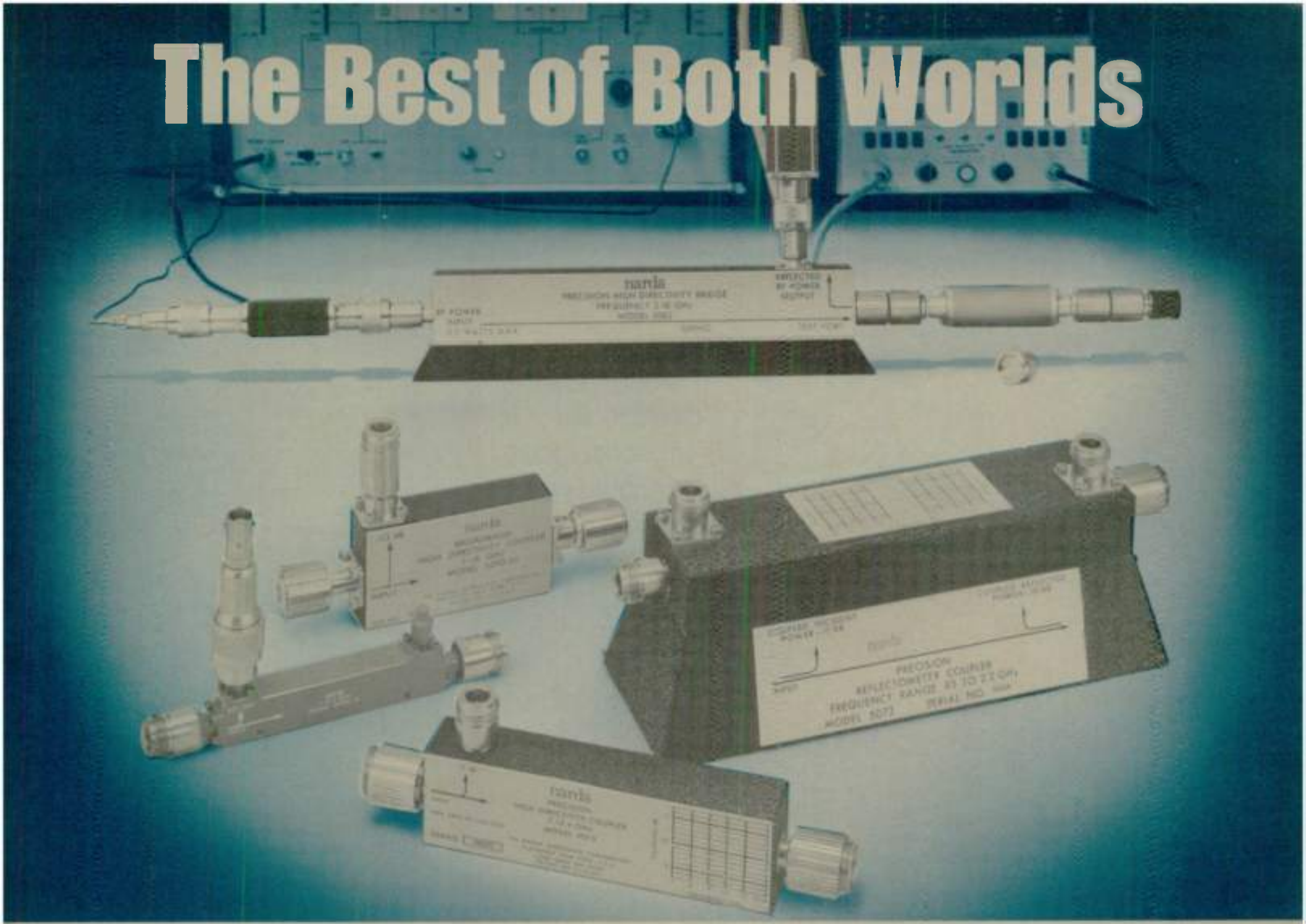
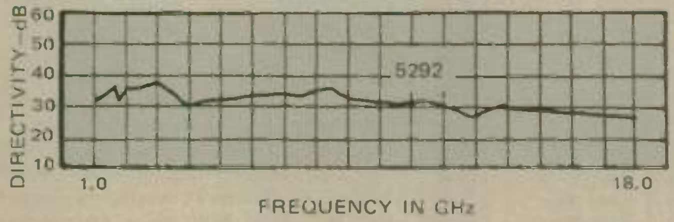
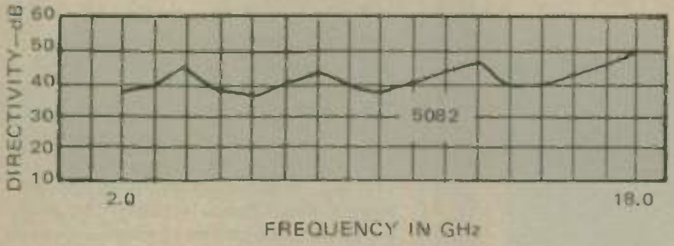
World Radio History

The Best of Both Worlds



High Directivity Precision Bridge or High Directivity Precision Couplers - your choice only from NARDA





Measuring your wideband components for attenuation and return loss simultaneously from *1 to 18 GHz*, the Narda high directivity couplers continue to offer unexcelled performance. Many of these precision devices have been used to do octave and multi-octave measurements over the last 20 years by almost every company in the industry.

Now to complement our coupler line the high directivity SWR Bridge is available. It improves the accuracy of all your broadband and narrowband VSWR measurements. With the *35 dB* minimum directivity over *2 to 18 GHz*, several couplers can be replaced in swept systems. The new bridge provides you with increased accuracy for swept return loss measurements for your bench work.

wherever microwaves go... **narda**

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CIRCLE 7 ON READER SERVICE CARD

Coming Events

1980 ANTENNA MEASUREMENT TECHNIQUES MEETING
OCT. 14-15, 1980

Sponsor: Antenna Measurement Techniques Assn. Place: Holiday Inn, Torrance, CA. Topics: aspects of antenna measurements, including automated testing, compact antenna ranges, near-field testing, etc. Contact: Joseph H. Pape, Steering Comm. Chrmn., Scientific-Atlanta, Inc., 3845 Pleasantdale Rd., Atlanta, GA. 30340. Tel: (404) 449-2354.

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 TN 13 1 JG. Tel: (0732) 59533, 59534. Telex: 94504 YNLTD G.

AUTOMATIC RF TECHNIQUES GROUP MEETING
NOV. 6-7, 1980

Sponsor: ARFTG Place: Marriott Hotel North, Dallas, TX. Topics: Hardware and software developments in computer-aided RF design and testing, plus automated test equipment. Contact: for tech. program and manufacturers demonstration, L.F. Saulsbery, Conf. Chrmn., National Bureau of Standards Div. 724.01, Boulder, CO. 80303. Tel: (303) 497-3970.

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. Manager, Courtesy Associates, Inc., 1629 K St., N.W., Suite 700, Washington, DC 20006.

1981 IEEE/MTT-S INT'L. MICROWAVE SYMPOSIUM
JUNE 15-17, 1981

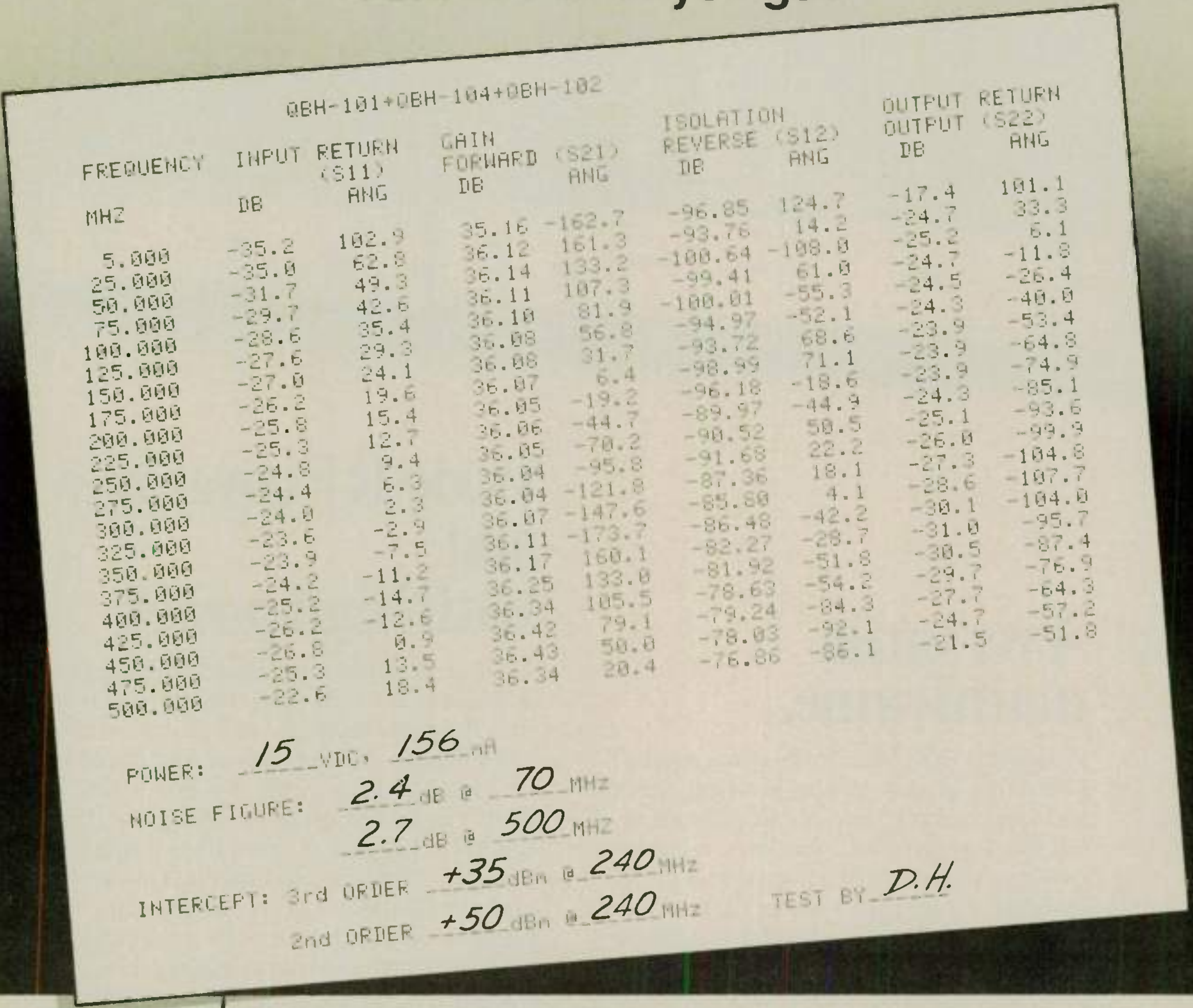
Call for papers. Sponsor: IEEE MTT-S (held jointly with IEEE AP-S June 17-19, 1981). Place: Bonaventure Hotel, L.A., CA. Theme: "Around the World with Microwaves." Paper topics include: CAD and measurement techniques, microwave and mm-wave solid state devices and ICs, etc. Submit 35-word abstract and 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.

When you need the low noise of the QBH-101...

and the high intercept of the QBH-102...

...interface with the new QBH-104.

And see what you get.



QBH-101+QBH-104+QBH-102

FREQUENCY	INPUT RETURN (S11)		GAIN FORWARD (S21)		ISOLATION REVERSE (S12)		OUTPUT RETURN OUTPUT (S22)	
MHZ	DB	ANG	DB	ANG	DB	ANG	DB	ANG
5.000	-35.2	102.9	35.16	-162.7	-96.85	124.7	-17.4	101.1
25.000	-35.0	62.8	36.12	161.3	-93.76	14.2	-24.7	33.3
50.000	-31.7	49.3	36.14	133.2	-100.64	-108.0	-25.2	6.1
75.000	-29.7	42.6	36.11	107.3	-99.41	61.0	-24.7	-11.8
100.000	-28.6	35.4	36.10	81.9	-100.01	-55.3	-24.5	-26.4
125.000	-27.6	29.3	36.08	56.8	-94.97	-52.1	-24.3	-40.0
150.000	-27.0	24.1	36.08	31.7	-93.72	68.6	-23.9	-53.4
175.000	-26.2	19.6	36.07	6.4	-98.99	71.1	-23.9	-64.8
200.000	-25.8	15.4	36.05	-19.2	-96.18	-18.6	-23.9	-74.9
225.000	-25.3	12.7	36.06	-44.7	-89.97	-44.9	-24.3	-85.1
250.000	-24.8	9.4	36.05	-70.2	-90.52	50.5	-25.1	-93.6
275.000	-24.4	6.3	36.04	-95.8	-91.68	22.2	-26.0	-99.9
300.000	-24.0	2.3	36.04	-121.8	-87.36	18.1	-27.3	-104.8
325.000	-23.6	-2.9	36.07	-147.6	-85.80	4.1	-28.6	-107.7
350.000	-23.9	-7.5	36.11	-173.7	-86.48	-42.2	-30.1	-104.0
375.000	-24.2	-11.2	36.17	160.1	-82.27	-28.7	-31.0	-95.7
400.000	-25.2	-14.7	36.25	133.0	-81.92	-51.8	-30.5	-87.4
425.000	-26.2	-12.6	36.34	105.5	-78.63	-54.2	-29.7	-76.9
450.000	-26.8	0.9	36.42	79.1	-79.24	-84.3	-27.7	-64.3
475.000	-25.3	13.5	36.43	50.0	-78.03	-92.1	-24.7	-57.2
500.000	-22.6	18.4	36.34	20.4	-76.86	-86.1	-21.5	-51.8

POWER: 15 VDC, 156 mA

NOISE FIGURE: 2.4 dB @ 70 MHz
2.7 dB @ 500 MHz

INTERCEPT: 3rd ORDER +35 dBm @ 240 MHz
2nd ORDER +50 dBm @ 240 MHz

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CIRCLE 9 ON READER SERVICE CARD

HP: EXPERIENCE IN MICROWAVE TECHNOLOGY

The HP 8620 Sweeps the Spectrum–10 MHz to 22 GHz.

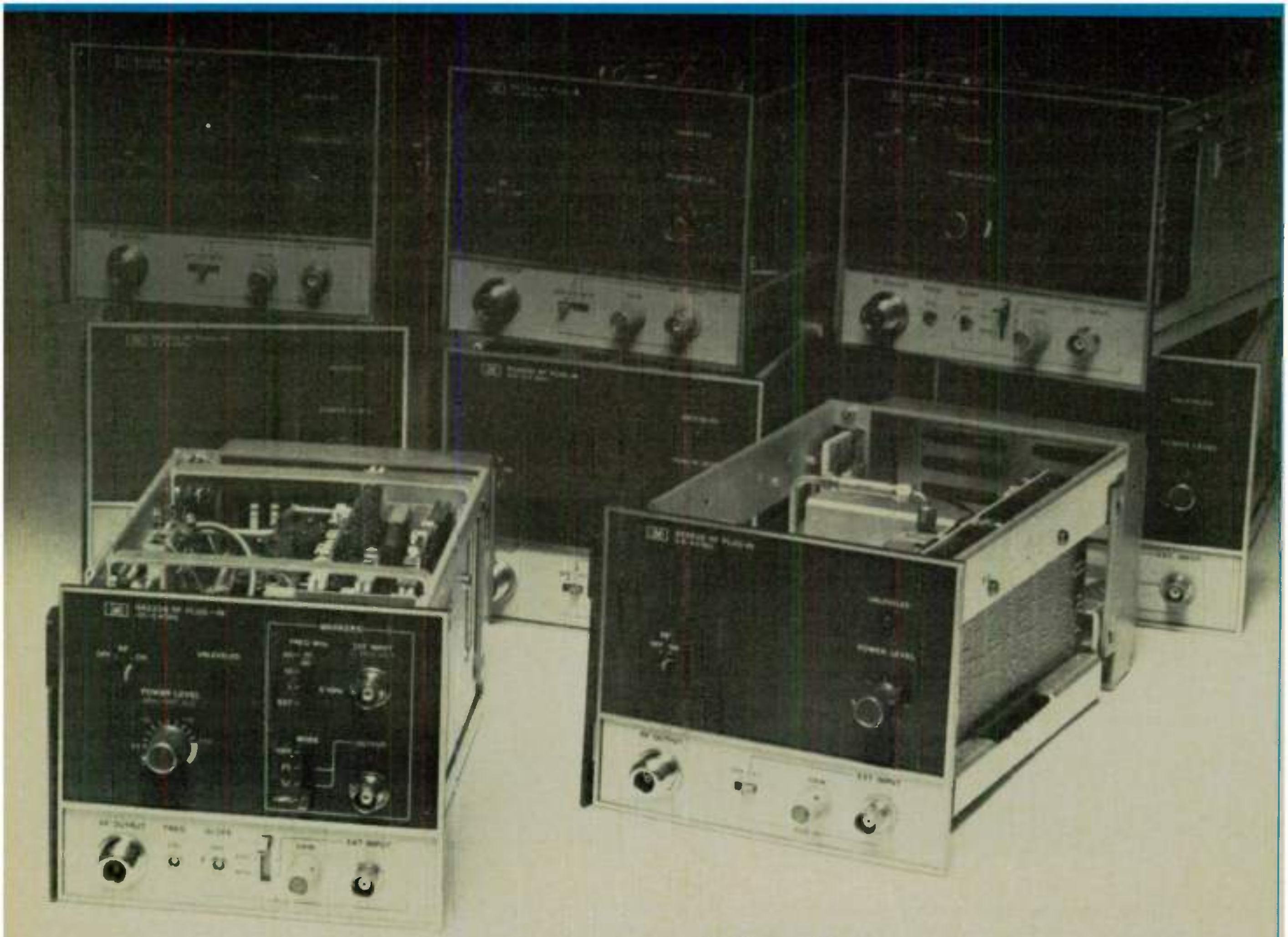
A versatile mainframe.

With the 8620C Mainframe, you get the sweep modes and markers you need for both wide and narrow band measurements: a full band sweep with 3 markers, a marker sweep at the touch of a button and a △F sweep that can be as wide as 100% of band. Plus precise frequency setability with the convenient CW vernier and △F "expand" controls; you can set a 1 MHz △F sweep even at 18 GHz. 8620C Mainframe, $2850.

Wide RF coverage–and with high power.

Choose from ultra wideband RF plug-ins–10 MHz to 2.4 GHz with the HP 86222, 2 to 18.6 GHz (optional to 22 GHz) with the HP 86290B–or from octave and double-octave plug-ins, several of which offer 40 mW or more output power. These RF units also provide the excellent frequency accuracy, linearity, and spectral purity that make them ideal sources for general purpose bench and field test applications. They're especially useful in swept frequency test systems such as the HP 8410 and 8755 Network Analysis Systems.

45006B



Popular plug-ins include:

Model No.	Freq. Range	Output Power	Price
86222A/B	10 MHz-2.4 GHz	20 mW	$4550/5450
86235A	1.7-4.3 GHz	40 mW	$3700
86240A	2.0-8.4 GHz	40 mW	$4550
86240C	3.6-8.6 GHz	40 mW	$5450
86245A	5.9-12.4 GHz	50 mW	$5100
86260A	12.4-18 GHz	10 mW	$4350
86290A	2-18 GHz	5 mW	$14,250
86290B	2-18.6 GHz	10 mW	$16,250
86290B opt. H08	2-22 GHz	2 mW	$19,250

HP-IB programmability option adds value.

DESIGNED FOR
HP-IB
SYSTEMS

HP-IB: Not just IEEE-488, but the hardware, documentation and support that delivers the shortest path to a measurement system.

When you add the HP-IB option ($950) to the 8620C Mainframe, you can program up to 10,000 frequency points per band on up to 4 bands with a variety of sweep modes. With the precision 86222 or 86290 RF units installed in the 8620C, excellent repeatability is achieved thanks to the exceptional frequency accuracy and linearity of these plug-ins.

A real advantage of HP-IB is you get not only the bus architecture you need, but the documentation support that can help you get your system up and running in weeks, instead of months.

A prime example is the scores of HP-IB automatic microwave network analyzer systems now in use. Major elements of these systems are the 8620C/86290B Sweeper, HP 8410 Network Analyzer, and HP 9825A Desktop Computer. Systems like this are fully described in HP Application Notes 221 and 187 Series. You can get copies of these plus information on the 8620C from your local HP sales office, or write Hewlett-Packard, 1507 Page Mill Rd., Palo Alto, CA 94304.

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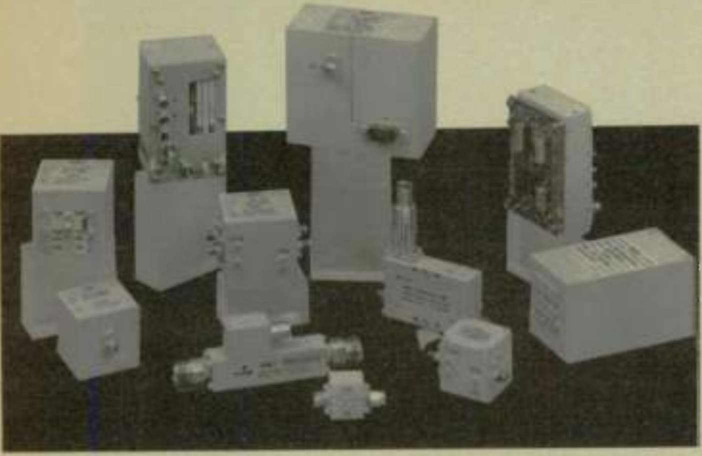

Systron-Donner's setting the standards for:

- Yig-tuned devices
- Voltage-tuned oscillators
- Mechanical and voltage-tuned oscillators

Yig-tuned oscillators are available in transistor and Gunn-diode types.

Specifications are given for typical standard models. In most cases, standard units with higher (100 mW) or lower (10 mW) power are also available.

MODEL:	Frequency Range (GHz)	Power Output, Min. (mW)	Power Variation vs. Frequency	Spurious Signals: Harmonic Min.	Spurious Signals: Non-Harmonic Min.	Residual FM, 1 Hz—30 kHz	Frequency Stability: Vs. Temperature	Frequency Stability: Vs. Power Supply	Frequency Stability: Vs. Load Variation	Frequency Stability: Hysteresis
SDYX-3038	0.5—1.0	20	5 dB p-p	12 dBc	60 dBc	10 kHz p-p	0.03%/°C	1 MHz/V	500 kHz	2 MHz
SDYX-3034	1.0—2.0	20	5 dB p-p	15 dBc	60 dBc	10 kHz p-p	0.03%/°C	1 MHz/V	500 kHz	2 MHz
SDYX-3034-114	0.5—2	20	6 dB p-p	12 dBc	60 dBc	10 kHz p-p	0.03%/°C	1 MHz/V	1 MHz	4 MHz
SDYX-3036	2.0—4.0	20	5 db p-p	15 dBc	60 dBc	10 kHz p-p	0.03%/°C	1 MHz/V	500 kHz	4 MHz
SDYX-3036-125	1.0—4.0	20	7 dB p-p	15 dBc	60 dBc	10 kHz p-p	0.03%/°C	1 MHz/V	500 kHz	6 MHz
SDYX-3039-107	2.0—6.0	10	7 dB p-p	15 dBc	60 dBc	10 kHz p-p	0.03%/°C	1 MHz/V	6 MHz	7 MHz
SDYX-3000	8.0—12.4	25	6 dB p-p	30 dBc	60 dBc	10 kHz p-p	0.01%/°C	10 MHz/V	10 MHz	10 MHz
SDYX-3001	12.4—18.0	25	6 dB p-p	30 dBc	60 dBc	10 kHz p-p	0.01%/°C	10 MHz/V	10 MHz	15 MHz
SDYX-3001-111	8.0—18.0	10	8 dB p-p	30 dBc	60 dBc	10 kHz p-p	0.01%/°C	10 MHz/V	10 MHz	25 MHz
SDYX-3003	18.0—26.5	10	6 dB p-p	20 dBc	60 dBc	10 kHz p-p	0.01%/°C	10 MHz/V	10 MHz	35 MHz
SDYX-3004	26.5—40.0	5	8 dB p-p	20 dBc	60 dBc	10 kHz p-p	0.01%/°C	20 MHz/V	20 MHz	100 MHz

YIG DRIVERS

Any Systron-Donner YIG device may be ordered with a matched YIG driver to provide accurate voltage/frequency conversion and to facilitate installation of the YIG device in a system. Two types of drivers are available: a standard version and a high-stability version. Both types operate with input power of ±15 V (±20 or ±12 V available with some frequencies on special order), control voltage of 0 to 10 V, and minimum input impedance of 10kΩ. Units meeting either commercial or military environmental requirements may be provided. Options available with 12-bit digital tuning.

VOLTAGE-TUNED OSCILLATORS

MODEL:	Frequency Range (MHz):	Power, Min. (mW): Leveled	Power, Min. (mW): Power vs. Frequency	Power, Min. (mW): Unleveled	Power, Min. (mW): Power vs. Frequency	Spurious Signals: Harmonic Min.	Spurious Signals: Non-Harmonic Min.	Residual FM: in 1 Hz-30 kHz Band	Amplitude Control: Full Output	Amplitude Control: Down 40 dB
SDVX-2011	470-1030	20	<4 dB	30	<4 dB	20 dBc	60 dBc	2 kHz p-p	−5 V @ 30 mA	0 V @ 0 mA
SDVX-2012	940-2060	20	<4 dB	30	<4 dB	20 dBc	60 dBc	4 kHz p-p	−0.6 V @ 0 mA	+5 V @ 30 mA
SDVX-2013	1240-2060	20	<4 dB	25	<4 dB	20 dBc	60 dBc	4 kHz p-p	−0.6 V @ 0 mA	+5 V @ 30 mA
SDVX-2108	0.1-32	20	±0.3 dB[2]	25	<4 dB	20 dBc[1]	50 dBc	4 kHz p-p	−5 V @ 15 mA	0 V @ 0 mA
SDVX-2110	8-112	20	±0.1 dB[2]	30	<4 dB	30 dBc[1]	60 dBc	2.5 kHz p-p	−5 V @ 15 mA	0 V @ 0 mA
SDVX-2111	25-305	20	±0.2 dB[2]	30	<4 dB	30 dBc[1]	60 dBc	1.5 kHz p-p	−15 V @ 15 mA	0 V @ 0 mA
SDVX-2112	90-510	20	±0.2 dB[2]	30	<4 dB	30 dBc[1]	60 dBc	1.5 kHz p-p	−5 V @ 15 mA	0 V @ 0 mA
SDVX-2000	235-515			50	<4 dB	20 dBc	60 dBc	1 kHz p-p		
SDVX-2001	470-1030			50	<4 dB	20 dBc	60 dBc	2 kHz p-p		
SDVX-2002	940-2060			50	<4 dB	20 dBc	60 dBc	4 kHz p-p		
SDVX-2003	1340-2460			50	<4 dB	20 dBc	60 dBc	4 kHz p-p		

1) @ 20 mW leveled   2) internal Detector

MECHANICAL AND VOLTAGE-TUNED OSCILLATORS

MODEL:	Mechanical Tuning Frequency Range (GHz):	Voltage Tuning Bandwidth (MHz)	Power Output (mW)	Power vs. Frequency (dB)	Spurious Signals: 2nd Harmonic	Spurious Signals: Non-Harmonic	Voltage Tuning Range (volts)	DC Power (VDC) See Note 1
SDYX-2015-105	5.925-6.425	120	50	1	30 dBc	70 dBc	2-25	+15 @ 500 mA
SDVX-2016-110	7.25-7.75	120	50	1	30 dBc	70 dBc	2-25	+15 @ 500 mA
SDVX-2016-114	7.9-8.4	120	50	1	30 dBc	70 dBc	2-25	+15 @ 500 mA
SDVX-2016-107	8.5-9.1	120	50	1	30 dBc	70 dBc	2-25	+15 @ 500 mA
SDVX-2016-108	9.0-9.6	120	50	1	30 dBc	70 dBc	2-25	+15 @ 500 mA
SDVX-2017-106	10.7-11.2	100	30	1	20 dBc	70 dBc	2-30	+15 @ 600 mA
SDVX-2017-107	11.2-11.7	100	30	1	20 dBc	70 dBc	2-30	+15 @ 600 mA
SDVX-2017-112	12.7-13.2	100	30	1	20 dBc	70 dBc	2-30	+15 @ 600 mA
SDVX-2017-120	14.0-14.5	100	30	1	20 dBc	70 dBc	2-30	+15 @ 600 mA

Note 1: Current is steady state. Surge current will be 70% higher.

Components: Update 1980

YIG-TUNED FILTERS

Systron-Donner SDYF-4000 Series reciprocal bandpass filters are available in one, two, three, four, and dual-two stage versions in single bands and multi-octave versions from 0.5 to 40 GHz. These filters are ideal for use in receiver systems, frequency synthesizers, or test sets for preselection, signal sorting, or any other application in which a tunable filters must pass a desired signal or band of signals with minima attenuation and reject undesired out-of-band signals.

SDYF-4000 Series filters may be ordered individually, with a YIG driver, as part of a tracking filter/oscillator/driver assembly meeting specific system applications.

		MODEL:	Frequency Range (GHz)	Bandwidth (MHz, Min.)	Insertion Loss (dB, Max.)	O.R.I. (dB, Min.)	O.R.S. (dB, Min.)	PB Ripple & Spurious (dB, Max.)	Linearity (MHz, Nom.)	Hysteresis (MHz, Nom.)
BANDPASS	Two-Stage	SDYF-4021	0.5—1	12	6.0	40	25	2.5	±2	4
		SDYF-4022	1—2	20	3.0	40	25	2.5	±2	4
		SDYF-4023	2—4	20	3.0	50	25	2.5	±3	6
		SDYF-4024	4—8	25	3.0	50	25	2.5	±5	8
		SDYF-4025	8—12.4	30	3.0	50	25	2.5	±8	15
		SDYF-4026	12.4—18	30	3.0	40	30	2.5	±10	15
		SDYF-4027	18—26.5	35	4.0	40	30	2.5	±15	20
	Three-Stage	SDYF-4028	0.5—1	12	6.0	70	35	2.0	±2	4
		SDYF-4029	1—2	18	5.0	70	40	2.0	±2	4
		SDYF-4030	2—4	20	4.0	70	40	2.0	±3	6
		SDYF-4031	4—8	25	4.0	70	40	2.0	±8	8
		SDYF-4032	8—12.4	25	4.0	70	40	2.0	±10	15
		SDYF-4033	12.4—18	30	4.0	70	40	2.5	±10	15
		SDYF-4034	18—26.5	35	5.0	70	40	2.5	±15	20
	Four-Stage	SDYF-4035	0.5—1	10	8.0	70	40	2.8	±2	4
		SDYF-4036	1—2	15	6.0	70	50	2.8	±2	4
		SDYF-4037	2—4	15	5.0	70	50	2.8	±3	6
		SDYF-4038	4—8	20	5.0	70	50	2.8	±8	8
		SDYF-4039	8—12.4	20	5.0	70	50	2.8	±10	15
		SDYF-4040	12.4—18	25	5.0	70	50	2.8	±10	15
		SDYF-4041	18—26.5	30	5.5	70	50	2.8	±15	20
	Dual Two-Stage (Per Channel)	SDYF-4042	0.5—1	12	6.0	40	25	2.0	±2	4
		SDYF-4043	1—2	20	3.0	40	25	2.8	±2	4
		SDYF-4044	2—4	20	3.0	50	25	2.5	±3	6
		SDYF-4045	4—8	25	3.0	50	25	2.5	±5	8
		SDYF-4046	8—12.4	25	3.0	50	25	2.5	±8	15
		SDYF-4047	12.4—18	25	3.0	40	25	2.5	±10	15
		SDYF-4048	18—26.5	30	4.0	40	25	2.5	±15	20
	Multi-Octave	SDYF-4000	1.8—18	20	5.0	70	60	1.5	±10	15
		SDYF-4000-102	1.8—26.5	15	8.5	70	60	1.5	±20	20
		SDYF-4000-113	2—18	30	3.0	40	40	1.5	±10	15
		SDYF-4000-114	2—12	30	3.0	40	40	1.5	±10	15
WIDE-BAND		SDYF-4235	8—18	250	7.5	70	50	2.8	±15	20

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Publisher's Note: This month's Sum Up is provided by one of our Associate Editors, H. Warren Cooper. He is currently Manager, Electromagnetic Technology at the Westinghouse Defense and Electronic Systems Center in Baltimore, MD. Mr. Cooper was responsible for assembling the contributed articles on electronic warfare topics which are featured in this issue.

Electronic countermeasures challenges microwave engineers because of the broad frequency bands and wide range of power levels required in reacting to the design output of the radar and communications engineer. This month's issue addresses both passive and active technology, as well as systems simulation.

Sum Up

SS AMPLIFIERS vs. TWT's

A panel session at the 1980 International Conference on Communications in Seattle examined the progress which solid state microwave amplifiers have made in replacing traveling-wave tubes. In the first of a two-part Special Report in this issue, an introduction by Ferdo Ivanek, the panel organizer, and summaries of presentations by three of the panel members appear. The principal application examined by the panel was terrestrial microwave communications systems since that sector has, by far, the largest number of installed TWT's.

WIDEBAND ESM SYSTEMS

C. B. Hofmann and A. R. Baron describe the current art in wideband ESM receiving systems — crystal video, instantaneous frequency measurement IFM, channelized receivers using RF filters, as well as acousto-optic Bragg cells and microscan. Each of these systems has problems and advantages, and their excellent summary shows that no one system is a panacea.

MM-WAVE ECM

Another of this issue's special reports addresses the EW challenge in the millimeter spectrum. Fred Dyer has surveyed the field and concluded that the millimeter wave applications which we have been anticipating for many years are finally here. He reports on receiver technology up to 100 GHz — the electronic support measures capability in millimeter waves is rapidly equaling that of microwaves.

ECM TRANSMITTERS

The active side of electronic warfare is addressed in the paper "The Challenge of Designing Reliable ECM Transmitters," by F. A. Wolf, H. E. Conway, and P. S. Spiecker. They treat a problem that has been a serious detractor from the reliability of active countermeasures systems — the high voltage power supplies for the traveling-wave tube amplifier chain. An interesting insight for the microwave device engineer is provided in showing that some of the ancillary voltage problems of power microwave devices are just as difficult as breakdown in high power microwave transmission circuits. Liquid dielectric improves maintainability and a unique bladder configuration compensates for changing liquid volume to increase the system reliability markedly.

INTEGRATED A-O BRAGG CELL

The world's first reported experimental demonstration of an integrated acousto-optical Bragg cell is described by Mergerian and Malarkey. This demonstration is significant in realizing cost advantages of integrated circuits. Key to the success of the device are very high quality diamond machined lenses and optical waveguides formed by diffusing titanium into the lithium niobate substrate. The device is featured on our cover this month.

In summary, electronic warfare systems are alive and well, and are taking advantage of the latest technology in electromagnetics, opto-acoustics, and microwave semiconductors.

HW Cooper

Workshops & Courses

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.
Fee: £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

CALCULATOR AND COMPUTER-AIDED MICROWAVE CIRCUIT DESIGN

Sponsors & Dates: COMPACT Engineering and Control Data Corp. — Pre-registration required.
October 20-21, 1980/London
October 27-28, 1980/Munich
Contact: Doug Ashby, Control Data, London, Tel: 411-240-3400. Hans Gall, Munich, Tel: 089-470-1041

PRINCIPLES OF MODERN RADAR SHORT COURSE

Sponsor: Georgia Institute of Technology
Date: November 3-7, 1980
Site: GIT, Engineering Experiment Station
Subjects: Radar systems analysis, synthesis and evaluation; plus demonstration sessions.
Contact: Dept. of Continuing Education, GIT, Atlanta, GA 30332. Tel: (404) 894-2400.

MICROWAVE ENGINEERING VIDEOTAPE COURSE (ECE 584)

Sponsor: University of Mass., School of Engineering, Office of Extended Engineering Ed.
Fee: $360 per 3-credit course (2-semester course) — Five-student minimum
Content: Generation, transmission and detection of electromagnetic radiation from 1-300 GHz.
Contact: Harvey R. Stone, Senior Coord., Office of Extended Eng. Ed., U. of Mass., 133 Eng. East Bldg., Amherst, MA 01003. Tel: (413) 545-0063.

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Millimeter Waves– The EW Challenge

FREDERICK B. DYER
Engineering Experiment Station
Georgia Institute of Technology
Atlanta, GA

A strong revival of interest in the application of millimeter waves to systems is currently taking place in the radar community.[1,2] Significant increases in the publication of millimeter applications are appearing in the literature of a number of countries as more and more design teams direct attention to the practical application of the frequency region beyond 18 GHz. When such attention is focused on an area of technology, successful systems are likely to be the result. In fact, there is some reason to believe that several such systems are eminent.[3] The EW community needs a wider recognition of the challenge posed by the use of the millimeter wave region and begin even more serious efforts to meet the threat represented by the unique nature of new millimeter systems.

Technological "surprise" often occurs, not because of true technical innovation, but due to the lead time required to make the transition from threat definition to fielded equipment.[4] Unfortunately many times the gap results from a lack of technology transfer from the laboratory researcher to the system designer because much of the new technology exists as one-of-a-kind items and involves a significant degree of very specialized knowledge. Millimeter technology has been in such a state for many years as portions of the overall technology were being developed. Fortunately, the current push in radar and communications systems development will also have an appreciable fall out effect for the EW community in the form of components for receivers and sources for ECM use. However, the EW designer will still have to take the lead in development of such critical subsystems as antennas, wideband receivers, and transmitters.

The primary near term millimeter threat that seems to be emerging is the result of increasing requirements for high-performance missile seekers, battlefield sensors, and precision weapons delivery systems. The combination of requirements for small size, high accuracy and high reliability in adverse environmental conditions is probably the key motivation for the use of millimeter radar over either microwave systems or E-O systems. For example, at the ranges which might ordinarily be expected to be useful for battlefield engagements, a millimeter-wave based system would appear to be better for penetration of smoke, fog, dust, etc. than either an optical or an infrared-based system. While microwave-based systems are even better in an adverse environment, constraints on weight, size and accuracy can still tend to suggest the choice of a millimeter wave system.

In the continuing battle of wits between the EW designer and the radar designer (i.e., ECM vs. ECCM), the same characteristics which make a millimeter-wave based system interesting to the radar designer, make the job hard for the EW designer. The inherently narrow mainbeam and low sidelobes of a good millimeter antenna make intercept and jamming difficult. In addition, the relatively high atmospheric losses at the higher millimeter frequencies virtually preclude the use of stand-off surveillance and/or jamming techniques. Currently proven ECCM techniques such as pulse compression, spread spectrum, and other frequency diversity, techniques to make millimeter wave systems even more resistant to countermeasures. Coherent systems are also under development. Many ECM techniques which have been traditionally useful at microwave frequencies, such as chaff, radar camouflage, etc., become less effective due to changing physical effects as scaling is attempted. Even the traditional advantage of one-way versus two-way propagation needs to be looked at carefully in light of high mainbeam/sidelobe ratios and receiver bandwidth/sensitivity trade-offs.

Fortunately, there is evidence that designers are beginning to address some of these problem areas. While at present, it appears ment of very wideband receivers, it can be surmised that other developments are underway. Excellent examples of new receiver technology work include the 26 to 42 GHz receiver reported by Eaton Corporation's AIL Division,[5] the ERADCOM development of an 18 to 66 GHz receiver[6] and the NOSC developed 88 to 100 GHz receiver front-end.[7]

Examples of other activities, including very wideband, low-noise millimeter wave amplifiers, new solid state sources, and fabrication techniques can be found in such sources as References 1 and 8. These component and subsystem developments are illustrative of the wider range of activities currently underway; however, there still appears to be significant deficiencies yet to be adequately addressed in the development of a complete EW system. For example, suitable EW antenna systems are needed which can provide a successful combination of characteristics to satisfy the various requirements of a millimeter wave EW suite.

On one hand, very broad frequency and solid angle coverage are required, but on the other hand, the antenna must have high directivity so as to provide high-accuracy bearing data for threat location and high gain to overcome the mainlobe/sidelobe ratio problem. This can be particularly challenging on an airborne platform, where site choice, dynamics, weight, and drag are also major factors.

While many other specific subsystem needs can be identified, perhaps the most important aspect of the challenge here is the need to recognize that the use of the millimeter region is going to require a fresh look at the overall EW system, since simply adding fixes to current systems is probably not going to do much good.

For example, it doesn't help much to provide a Radar Warning Receiver (RWR) which tells the aircrew a missile is on the way; if its too late to react or if there's nothing to use to counter it with. This, unfortunately, is a possibil-

tempted in the manner of a few years ago. Therefore, the challenge to the EW community is to become informed about the advances in the millimeter wave area, to take a hard look at the countermeasures which will be required to meet the threat, and to help provide those countermeasures.

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Frederick B. Dyer, who holds B.S. and M.S. degrees in Physics, has devoted his efforts toward research in radar and related systems for more than twenty years. While at Georgia Tech, he has served as project director on a number of projects concerned with the design, construction, and evaluation of experimental radar and electronic warfare systems, including special signal processing and analysis techniques. In addition, he has worked extensively in the development of radar performance prediction models. He is recognized internationally in a number of fields of endeavor; including millimeter reflectivity measurements, detection of targets in a clutter background, and radar cross section reduction/enhancement. Mr. Dyer currently serves as Chief Scientist of the Systems Engineering Laboratory of the Engineering Experiment Station at Georgia Institute of Technology.

Amplifiers

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Ultra Low Noise Amplifiers

Model Number	Frequency (MHz)	Min. Gain (dB)	Flatness (dB)	Noise Figure (dB) typ.	Noise Figure (dB) max.	Pwr. Out @ 1 dB Compression Pt. (dBm)	Case/ Connectors*
W50ETD	0.01-50	50	± .5	1.3	1.5	0	C/SMA
W50ETC	0.01-50	20	± .5	4.0	4.5	+ 23	C/SMA
W250G	5-250	43	± .5	1.3	1.5	+ 25	B/SMA
W500E	5-500	30	± .5	1.3	1.4	0	C/SMA
L60E	50-70	60	± .5	1.0	1.2	+ 10	C/SMA
L450E	400-500	27	± .5	1.2	1.4	+ 5	C/SMA
W1GE	5-1000	20	± .5	1.6	1.8	0	C/SMA
W2GHH2	1-2 GHz	30	± .5	2.3	2.5	+ 5	AB/SMA

Special Purpose Amplifiers

Model Number	Frequency (GHz)	Gain (dB)	Noise Figure (dB)	Pwr. Out @ 1 dB Compression Pt. (dBm)	Case/ Connectors
L13GE	1.25-1.35	25	2.2	+ 5	C/SMA
W89DGA	0.47-0.89	25	2.0	+ 5	C/SMA
L215GA	2.15-2.165	11	3.2	–3	C/N
L215GC	2.15-2.165	29	2.9	+ 7	C/N
W2GH	0.5-2.0	25	3.0	+ 10	B/SMA
P150P	0.08-150 MHz	60	1.5	+ 30	H/BNC
W15GB1	0.05-1.5	20	1.8	–3	C/SMA
W23GA	0.1-2.3	8	9.0	+ 20	C/SMA

Wide Dynamic Range Amplifiers

Model Number	Frequency (GHz)	Min. Gain (dB)	Pwr. Out @ 1 dB Compression Pt. (dBm) typ.	Pwr. Out @ 1 dB Compression Pt. (dBm) min.	Noise Figure (dB)	Case/ Connectors	Typical Intercept Pt. (dBm)
P60F	30-90 MHz	30	+ 32	+ 31	5.5	H/BNC	+ 43
P150H2	0.1-150 MHz	27	+ 31.5	+ 30	6.5	H/BNC	+ 44
P400C	10-400 MHz	20	+ 31	+ 30	7.0	H/BNC	+ 42
P500N	2-500 MHz	17	+ 31	+ 30	8.0	H/BNC	+ 42
P10GL	0.5-1.0	30	+ 31	+ 30	5.0	H/SMA	+ 42
P1000E	0.05-1.0 GHz	20	+ 23	+ 21	5.0	A/SMA	+ 32
P24GB	1.4-2.4	16	+ 20	+ 19	8.0	A/SMA	+ 32
P700S	0.6-0.8	40	+ 36	+ 34	3.5	FS/BNC	+ 47

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A	3.375	1.875	0.465
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AB	3.00	1.875	0.465
B	2.625	1.875	0.465
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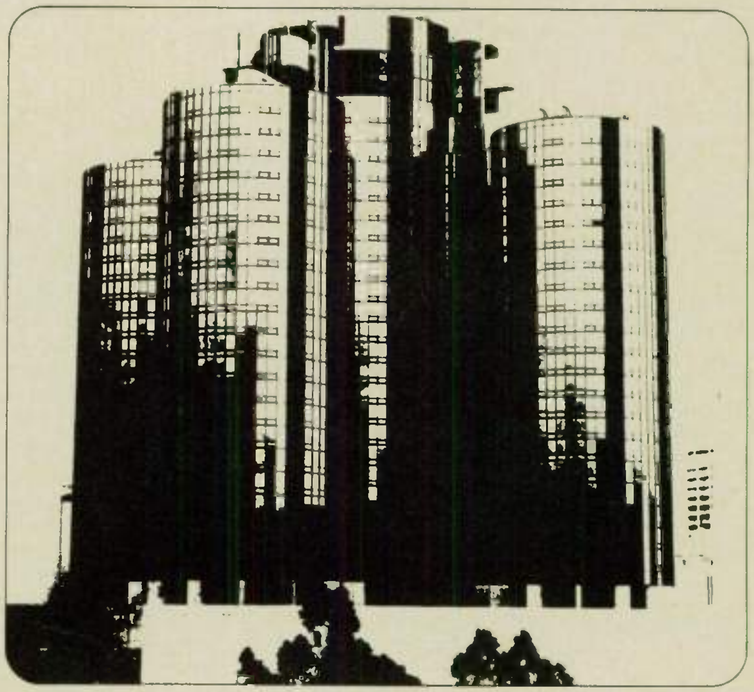

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Around the Circuit

PERSONNEL

Mike Salkeld joins Microwave Control Co., a Div. of Micon, Inc., as General Manager. . .**Col. William R. Crawford** assumed the role of Deputy Commander of the US Army Electronics Research and Development Command (ERADCOM) in Adelphi, MD. And at ERADCOM's Ft. Monmouth base, **Vincent J. Kublin** was named Acting Director of the Combat Surveillance and Target Acquisition Laboratory. . .Power Hybrids, Inc. announced the appointment of **Wayne E. Schaub** as Executive V.P., **Jim Curtis** as V.P., Engineering, **Williams H. Glaven**, V.P., Operations and **Fred McAdara**, V.P., Sales and Marketing. . .At Pacific Measurements, Inc., **David K. Bradley** was named as Eastern Regional Sales Manager and **Phil Szuszitzky** as Technical Writer. . .**Leo F. Trearchis** was promoted to V.P. of Programs/Operations at Adams-Russell's Anzac Div. . .Singer Co. announced the appointment of **Terry W. Heil** as President of its subsidiary, HRB-Singer Inc. . .At Hewlett-Packard Co, two of its group V.P.'s, **William E. Terry** and **Paul C. Ely** have been elected directors and prompted to the post of Executive Vice President. . .Bunker Ramo Corp. appointed **Herman R. Staudt** as President of its Electronic Systems Div. in Westlake, CA. . .**Harlan Howe, Jr.** was named V.P., Advanced Technology at Microwave Associates, Inc.

CONTRACTS

Scientific-Atlanta, Inc. received a $1.5M contract for 22 satellite earth stations for Mexico's national television network. . .**Eaton Corp.'s AIL Div.** was granted a $17.5M contract by the US Navy to provide additional AN/ALQ-99 tactical jamming systems for EA-6B aircraft. . .**Thomson-CSF** awarded a $17M contract to **Ford Aerospace & Communications Corp.** for design, development and manufacture of engineering and flight models of X-band transponders to be flown on the French domestic satellite Telecom-I. . .**American Electronic Laboratories, Inc.** received a $438K contract from US Army's CORADCOM for installation of communications and navigational equipment in T-42 aircraft. . .**TerraCom Div.** of **Loral Corp.** received a $1.1M contract for its portable microwave radio links from Ireland's Department of Post and Telegraph. . .A USAF contract valued at $9.6M was awarded to **Applied Technology**, an **Itek Corp. Div.**, for ALR-46 and ALR-69 radar warning and power management systems and aerospace support equipment. . .**Microdyne Corp.** was awarded a contract with **Video Vista** to supply **Ramada Inns, Inc.** with 5 earth stations for an entertainment service.

INDUSTRY NEWS

Electronic Space Systems Corp. (ESSCO), the metal space frame radome manufacturer, has entered into an agreement with **Morrison Molded Fiber Glass Co.** (MMFG) under which ESSCO markets and engineers and MMFG manufactures fiberglass radomes. . .**Microwave Control Co.**, div. of **Micon, Inc.**, has completed renovations which doubled its 13,200 sq. ft. plant. . .**LNR Communications, Inc.** launched a $5M, 3-year expansion project. LNR has purchased 13 acres of property next to its existing facility in Hauppauge, NY for new plant construction in 1980.

NEW MARKET ENTRY

ITM Systems, Inc. was formed in May, 1980 to serve the satellite communications and ground terminal markets. Founders Walter I. Berg and Darrell T. Mounts indicate that products will include high power RF switching and combining systems. TDMA and RMS power monitoring, site installation of transmitter chains, etc. Office location is: 568 Weddell Dr., Sunnyvale, CA 94086; Tel: (408) 745-6247.

FINANCIAL NEWS

Microwave Power Devices, Inc. third quarter results for the period ended April 30, 1980 include net sales of $1.6M and net earnings of $139.8K, or 11¢ per share. This compares with 1979 third quarter net sales of $1.0M and net earnings of $70.6K, or 5¢ per share. . . **AEL Industries, Inc.** reported a net loss for the first quarter ended May 30, 1980 at $2.8M or $1.47 per share on sales of $12.7M. This compares with 1979 results for the same period of net income of $474K of 25¢ per share on sales of $13.8M. . .**Adams-Russell** announced 1980 third quarter earnings per share of 39¢, net income of $714K on sales of $9.2M for the period ended June 29, 1980. This compares with 1979 results of 31¢ per share, net income of $545K on sales of $7.4M. . .**M/A-COM, Inc.** reported preliminary figures for the third quarter ended June 28, 1980 of net income of $3.8M, sales of $42.8M and earnings per share of 38¢. This compares with 1979 quarterly results of net income of $2.2M, sales of $32.3M and earnings per share of 26¢. . .**Electromagnetic Sciences, Inc.** announced net earnings of $106K or 12¢ per share on sales of $2.58M for the six months ended June 30, 1980. This contrasts with 1979 half-year net earnings of $49K or 6¢ per share on sales of $1.77M. . . For the six months ended May 31, 1980, **Premier Microwave Corporation** reported sales of $2.15M and earnings per share of $1.07. This compares with 1979 half-year sales of $2.12M or $1.05 per share. . .**Scientific-Atlanta, Inc.** reported year end sales of $192M, net earnings (unaudited) of $12.7M or $1.31 per share, for the year closing June 30, 1980. During 1979, sales were $129.8M, net earnings were $7.6M, 89¢ per share. . .**Alpha Industries, Inc.** had first quarter sales of $6.3M, net income of $518K or 24¢ per share for the period ended June 30, 1980. During the same 1979 quarter, sales were $5.1M, net income was $408K, 21¢ a share. . .**Narda Microwave Corporation** announced a 3-for-2 common stock split with respect to shareholders of record on August 15, 1980 and declared a quarterly cash dividend of 5¢ per share on the split shares. . .**Anderson Group, Inc.** reported year-end results for the period ended February 29, 1980 of net sales of $21.3M, net income of $893K, or $1.35 per share. This compares with 1979 annual net sales of $19.3M, net income of $810K, or $1.21 per share. . .**Cubic Corp.**'s Board of Directors announced a regular 30¢ per share semi-annual cash dividend to be paid September 15, 1980 to shareholders of record on August 15, 1980. This brings total dividends paid to shareholders in 1980 to 60¢ a share.

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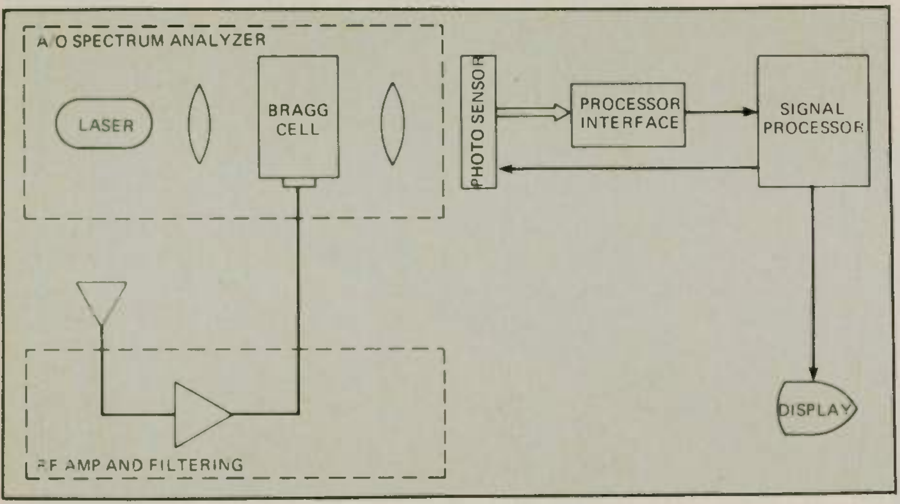

Fig. 3 A/O receiver block diagram.

propagated. It was also found that when the angle of incidence was properly adjusted, the first order diffraction line became intense, while the other orders were significantly decreased. This angle is known as the Bragg angle.

This phenomenon is the basis of the current development efforts in acousto-optical (A/O) receivers, an alternative type of channelized receiver. It offers the broadband frequency coverage and high frequency accuracy of an IFM receiver together with the ability to measure frequencies of multiple simultaneous signals.

Figure 2 is a simplified diagram of the A/O Bragg cell concept. An RF signal is fed to a transducer which is bonded to a piezoelectric material (typically lithium niobate or quartz crystal). The transducer converts the RF electromagnetic signal to a sound wave which propagates down the length of the crystal. A monochromatic (laser) light beam is focused on the crystal at the Bragg angle. Light passing through the crystal is deflected due to the variation in the crystal index of refraction caused by the sound wave. The angular deflection and intensity of the light beam is proportional to the frequency and power of the RF signal respectively. If more than one RF frequency is present simultaneously, the light beam will be deflected into distinct, separated beams, each representing one of the RF input frequencies.

Figure 3 is a conceptual block diagram of a total A/O receiver. It consists of an optical power source, optic train, Bragg cell, photosensing circuitry, RF front end, signal processor and display.

The optic train consists of two lenses. The first spreads the laser optical power over the crystal aperture. The second focuses the diffracted beam. The photosensor at the focal point of the diffracted beam may be an array of individual PIN photodiodes spaced very closely together, or a monolithic charge coupled device (CCD) array. **Table 1** gives typical A/O receiver performance characteristics achievable today.

TABLE 1

TYPICAL A/O RECEIVER PERFORMANCE CHARACTERISTICS

RF Bandwidth	**1 GHz**
Dynamic Range	**30 dB**
Sensitivity (S/N = 1)	**−90 dBm**
Frequency Resolution	**1 MHz**
Frequency Accuracy	**± 1.5 MHz**
TOA/PW Resolution	**1 μsec**

Disadvantages of the A/O receiver are its relatively small dynamic range, the complexity of the processor interface hardware required to preserve accurate pulse time-of-arrival and the bulky packaging associated with the laser source and optical train.

Hybrid and monolithic integrated optic techniques are potential solutions to the latter problem. The approach is to package a solid state laser device, Bragg cell, lenses and photosensor all on a single substrate as shown in **Figure 4**.

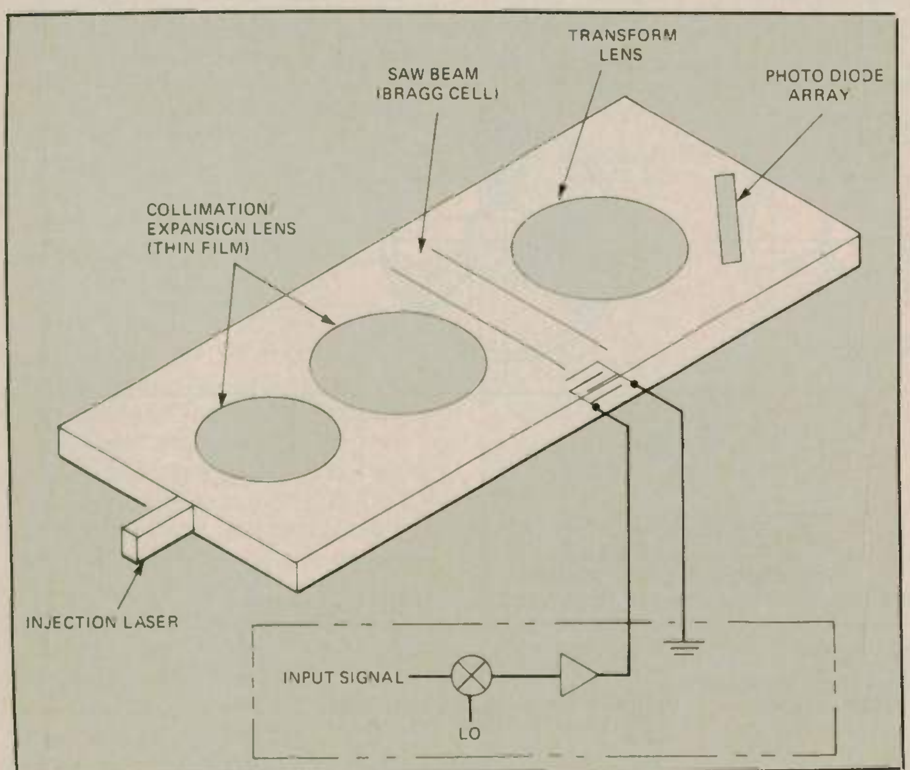

Fig. 4 Integrated acousto-optic spectrum analyzer.

If elements of a phased array are connected to a multiple transducer on a common Bragg Cell, the light will be deflected in two dimensions. These two dimensions represent direction-of-arrival (DOA) and frequency as shown in **Figure 5**.

(continued on page 30)

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Electrical Characteristics (25°C)

Test	Condition	Minimum	Maximum	Unit
Total Capacitance (C_t)	$V_r = 0$ Vdc	–	1.0	pF
Total Resistance (R_t)	$I_f = 5.0$ mA dc	–	15.0	ohms
Forward Voltage Drop (V_f)	$I_f = 5.0$ mA dc	–	400	mV dc
Forward Voltage Unbalance (ΔV_f)	$I_f = 5.0$ mA dc	–	20	mV dc

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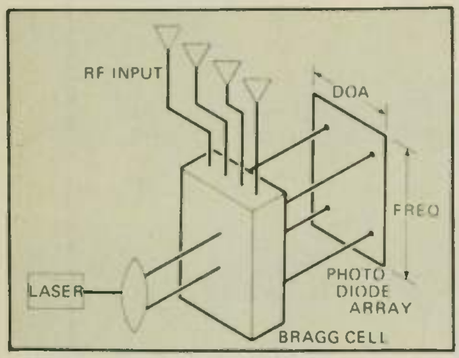


Fig. 5 Two-dimensional A/O receiver.

COMPRESSIVE (MICROSCAN) RECEIVER

The compressive or microscan receiver is basically an extremely fast tuning superheterodyne receiver. Ideally, the local oscillator (LO) scans the RF bandwidth being covered in a time less than the narrowest pulse to be intercepted. The output for an RF input pulse mixing with such an oscillator, is a "chirped" or frequency modulated pulse.

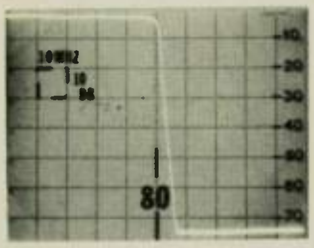
The output of the mixer is applied to a pulse compression filter with a slope opposite to the tuning characteristic of the LO. The filter output is a compressed pulse whose position in time relative to the start of the LO sweep is a function of the frequency of the RF input pulse.

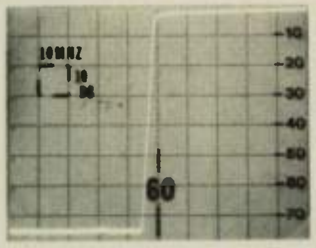
The block diagram of the compressive receiver is shown in Figure 6. The incoming signal is mixed with a linear up-chirp of duration T and bandwidth B. The compressive receiver provides the near unity intercept probability usually associated with a broadband or wide open receiver yet maintains the ability to separate signals closely spaced in frequency as in a narrowband superheterodyne receiver.

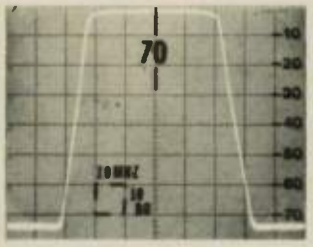
In the compressive receiver, the IF output of the mixer is scanning in frequency at the same rate as the scanning local oscillator. The frequency dependent delay of the compressive filter is such that the beginning of the IF pulse is delayed by the pulse width and the rest of the pulse is delayed proportionately less. The result is that all energy tends to exit the filter at the same instant. In actual practice, due to the band limiting nature of the filter, the output pulse is not a perfect impulse and in fact has some finite duration. The shape of the output pulse is the Fourier transform of the IF bandpass and the duration is approximately 1/IF bandwidth. With increasing IF bandwidth, the duration of the output pulse is reduced and frequency resolution of the receiver improves.

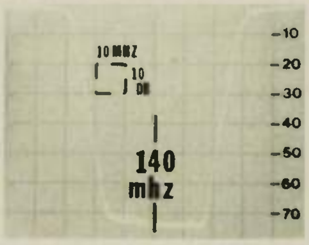
Practical limitations in compressive receivers are associated with the scan speed and linearity of the local oscillator and the delay linearity of the compressive filter. The product of the differential delay of the compressive filter, ΔT, and the IF bandwidth, W, is used as a figure of merit for the compressive receiver (the time bandwidth product).

The output of each LO scan is a representation of the spectral energy distribution at the input of the receiver. A CW signal will develop an output pulse each receiver scan as will a pulsed signal whose pulse width is equal to or greater than the scan time. For a pulsed signal whose pulse width









output will still occur but it will be lower in amplitude and spread in frequency (this represents the spectrum of the input pulse).

The signal time-of-arrival is quantized into time intervals equal to the scan time. If the scan time is 1 μsec, then the time-of-arrival (TOA) of an arriving pulse cannot be measured to an accuracy better than 1 μsec.

pressive receiver is high. Since the direction of frequency change for the image pulse is the reverse of the real pulse, the compressive filter, matched to the scan direction, will spread the image pulse to twice its original duration and reduce its amplitude.

In a compressive receiver, the noise bandwidth is determined by the integration time (ΔT) of the compressive filter, rather than the proximately 1/ΔT. It therefore offers the high probability of intercept afforded by a large bandwidth without sacrificing sensitivity or suffering from ambiguities when handling time coincident pulses.

The shape of the IF passband is critical to proper frequency resolution. A rectangular IF passband shape will cause high sidelobes in the compressive filter

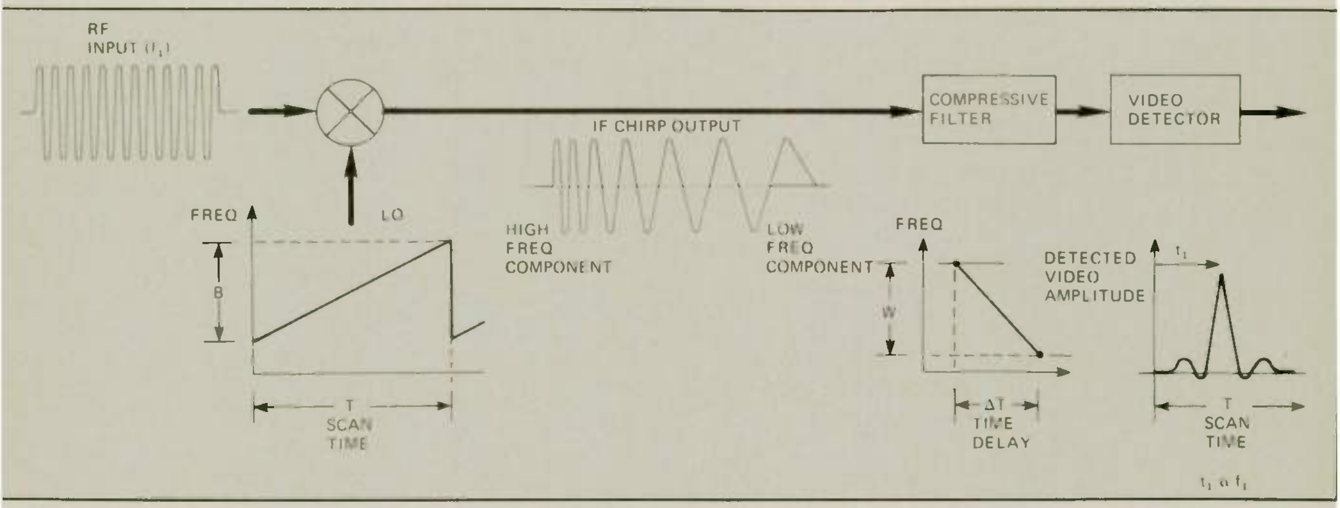
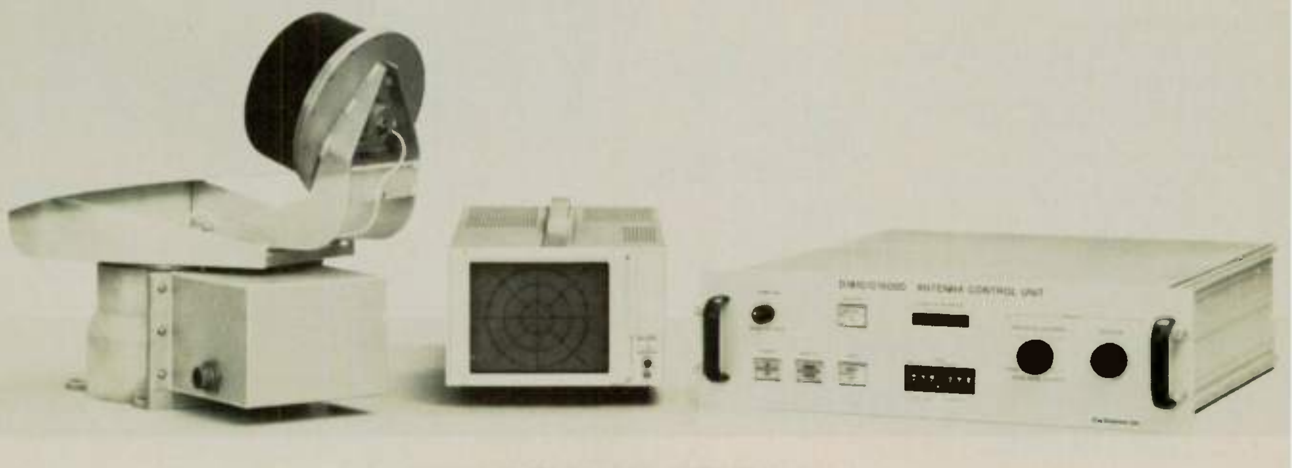


Fig. 6 Compressive receiver concept.



output and a Gaussian shaped passband is desired. In practice, a truncated Gaussian shape is realized and the first side lobes are typically down 20 dB or more. Scan linearity and compressive filter matching also contribute to the ultimate side lobe levels achieved. For signals separated by 20 or more resolution bandwidths, dynamic ranges of 60 dB are attainable.

Due to the wide bandwidth and very short band tuning time, the compressive receiver normally requires a preprocessor that can handle very high data rates. Finally, time-of-arrival (TOA) can be measured to an accuracy no better than the scan time.

IFM RECEIVER

Digital IFM receivers are capable of excellent frequency accuracy, can have wide instantaneous bandwidths and are able to operate at pulse rates well in excess of 2 million pulses per second. The IFM receiver is based on the use of a delay line discriminator, Figure 7. An incoming RF signal is divided into two paths — one having a delay of known length relative to the other path. The signal passing down the delay line will experience a phase shift with respect to the undelayed signal which will be related to its frequency. A phase correlator which consists of three 90° hybrids, one 180° hybrid and a pair of square law detectors, forms two video signals; one proportional to the sine of the phase shift and the other to the cosine of the phase shift.

The output of the delay line discriminator phase correlator repeats itself each time the input frequency changes by an amount equal to the reciprocal of the electrical length of the delay line. Ideally then, the length of the delay line would be shorter than the wavelength corresponding to the operating bandwidth. As the length of the line is diminished, the amount of phase shift associated with a given frequency resolution is also reduced. For example, to cover a 2 GHz frequency band with an accuracy of 10 MHz using one delay line, requires a phase accuracy of less than 1.8

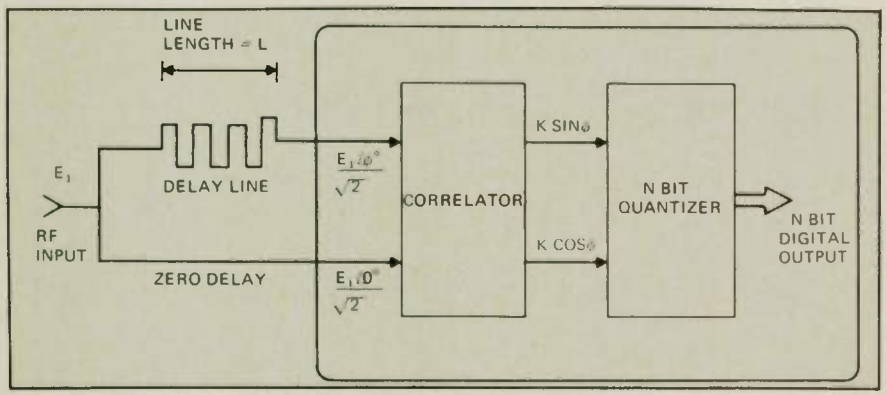
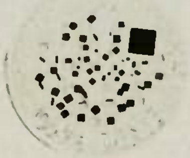
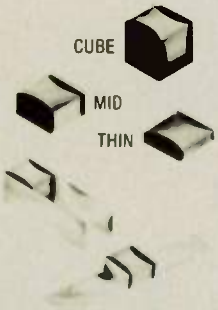
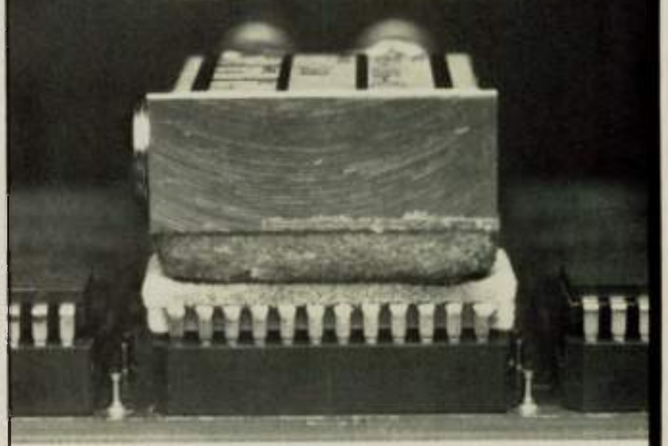


Fig. 7 IFM delay line discriminator concept.







correlator. A delay line discriminator with such a requirement for phase accuracy, if realizable, would be quite expensive. Inordinately high signal-to-noise ratios would be required to measure these small phase changes. To cope with this problem, multiple discriminators are used as shown in **Figure 8**. The longest delay line (40 MHz) is chosen based on the desired frequency resolution. The output of this discriminator is connected to a five-bit quantizer so that the 40 MHz frequency region is divided into 32 cells having a width of 1.25 MHz. Ambiguous outputs, however, will occur every 40 MHz.

If it is desired that the basic IFM operate from 2-4 GHz, the other delay line discriminators shown are required. The shortest one is chosen to be one wavelength long at 2.560 GHz to provide guard bands for signals falling on the skirts of a 2-4 GHz roofing filter. The other discrimi-

guities. The 160 MHz line resolves ambiguities due to the 40 MHz line and the 640 MHz line resolves ambiguities due to 160 MHz line and so forth.

The choice of the ratio between delay lines is important since this determines the amount of allowable channel phase mistrack and phase noise.

operation in high density environments is the potential for inaccurate measurements due to signals occurring simultaneously. As a result, a circuit which detects the presence of two or more simultaneously occurring signals is often included. Frequency measurement of pulses tagged as occurring simultaneously with othe signals may then be regarded as

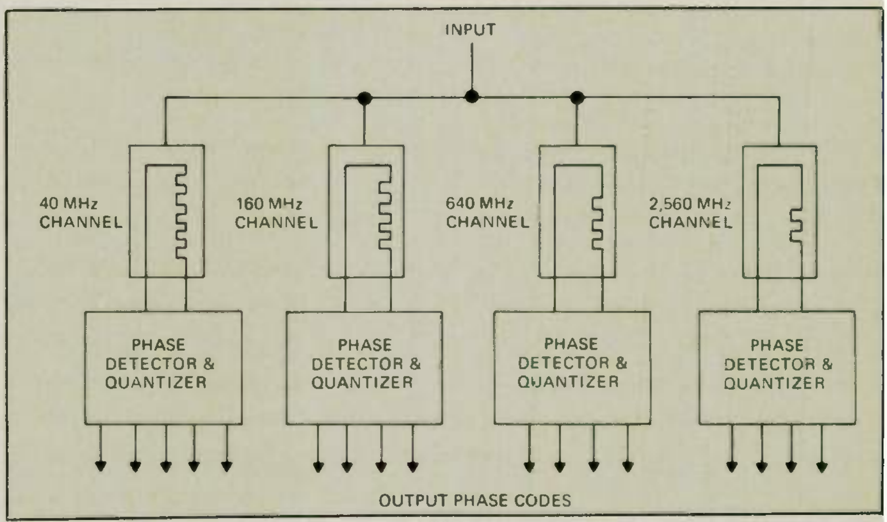


Fig. 8 2-4 GHz digital IFM.

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erroneous. Experimental results have shown that if signal levels differ by more than 3 dB, the largest signal will be measured with no loss of frequency accuracy. It has also been determined that the presence of simultaneous signals can be readily detected when the two signal levels differ by less than 10 dB and are separated in frequency anywhere from 50 to 2,000 MHz.

TABLE 2

MULTIOCTAVE IFM RECEIVER PERFORMANCE SPECIFICATIONS

Instantaneous Frequency Coverage (with Parallel Frequency Converters)	**2 to 18 GHz**
Frequency Resolution	**1.25 MHz**
Frequency Accuracy	**1.7 MHz rms**
Dynamic Range	**60 dB**
Baseband IFM Bandwidth	**4 GHz**
Minimum Pulse Width	**100 ns**
Sensitivity (SNR = 14 dB)	**–60 dBm**

A multioctave IFM receiver can be designed using either direct signal frequency measurement IFM units or by employing down conversion to a baseband IFM as shown in **Figure 9**. Here the input signal is down converted and then multiplexed to the basic 2-6 GHz IFM band. Parallel RF channel activity detectors, plus a short delay line and switch inserted in each RF channel provide a dynamic multiplexer which is switched from RF channel to RF channel on a pulse-by-pulse basis. **Figure 10** shows a 2-18 GHz IFM Receiver developed at Amecom which is similar in configuration to that illustrated in **Figure 9**. In this unit, additional circuits have been included to provide TOA, CW, pulse-on-CW, pulse width, amplitude, chirp and phase modulation-on-pulse measurement capabilities. **Table 2** shows some of the key performance specifications of this unit.

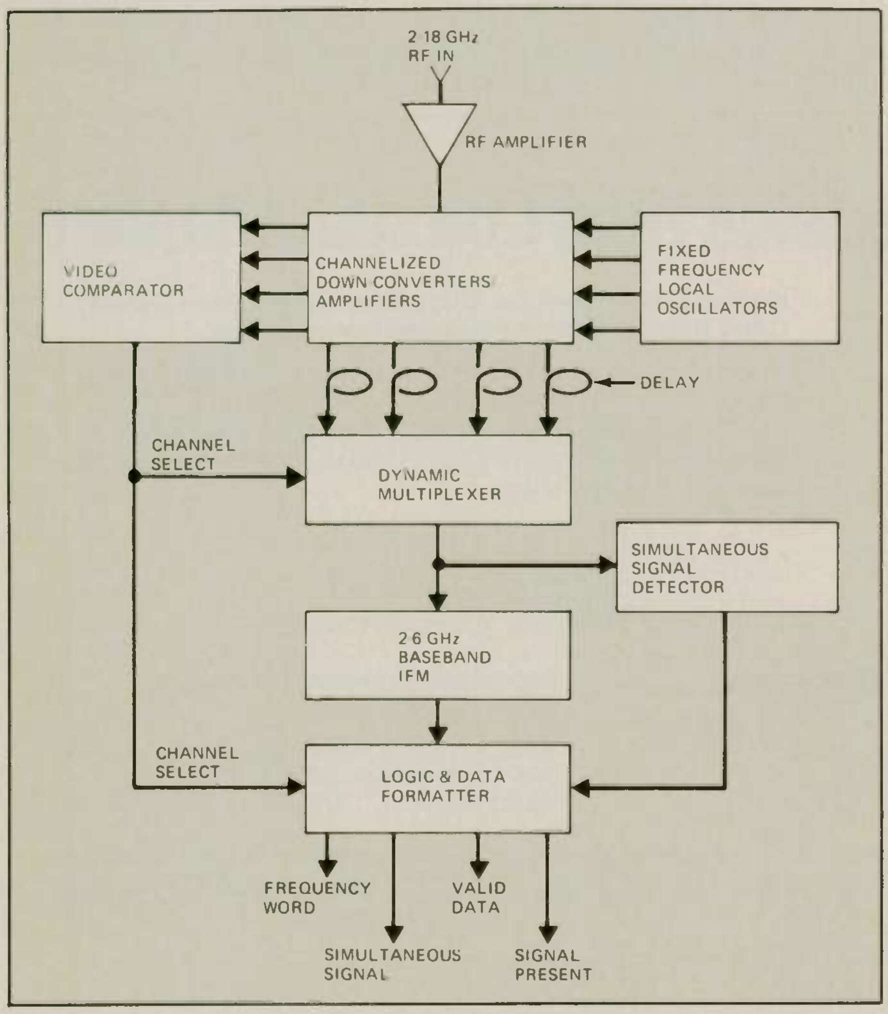

Fig. 9 Multioctave IFM receiver.

CW signals can be accommodated by using dc coupled circuitry in the log-video amplifiers in the activity detectors and IFM quantizers. Pulses larger than the CW signal by some predetermined level, can also be detected and measured. A YIG device configured as a notch filter can also be set by the IFM to the CW frequency in a matter of milliseconds to remove the CW. Any signal obscured by the CW signal can then be measured.

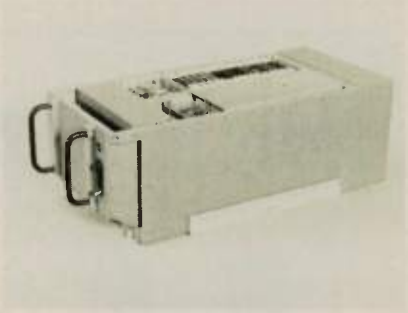

Fig. 10 Multioctave 2-18 GHz IFM receiver.

The intrinsic large instantaneous bandwidth and high resolution of its frequency measurement makes the IFM an ideal acquisition receiver operating in conjunction with one or more superheterodyne analysis receivers. The IFM receiver intercepts signals of interest and an analysis receiver is tuned to the measured frequency. This optimizes analysis receiver scan routines and prevents the analysis receiver from stopping on signals of no interest.

Editor's Note: Part II of this article will discuss channelized receivers, the interrelation of the receiving and processing subsystems and summarize the relative virtues of the various receivers.

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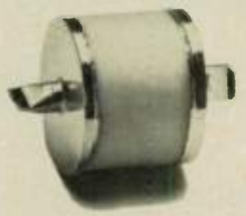
MAG19	35·0	11·0	11·0	0·5	0·001
MAG23	1·50	2·25	3·0	0·25	0·001

2.



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Integrated Optical RF Spectrum Analyzer

D. MERGERIAN and E. C. MALARKEY
Westinghouse Electric Corporation,
Defense and Electronics Systems Center
Baltimore, MD

An integrated optical RF spectrum analyzer (IO RF SA) was put into operation early this year at the Westinghouse Advanced Technology Laboratories. This device, which embodies significant improvements in several key component technologies, was the first working model of a complex IO circuit, and its successful demonstration concluded an intense competition among R&D establishments in the US and abroad. It is a major advance toward the development of flight-worthy, high-speed analog signal processing hardware based upon acousto-optic (AO) interaction in Bragg cells.

The device, which has been developed under partial support from the Naval Research Laboratory (NRL), operates over a 400 MHz bandwidth with a frequency resolution of 4 MHz. The optical imaging performance of the SA is nearly perfect, with virtually diffraction-limited spot sizes being produced by a system of two aspherically-corrected geodesic lenses which are machined into the surface of the IO substrate by single point diamond turning. A new photodiode array, designed and fabricated at Westinghouse especially for this and other AO systems, allows read-out of the entire 400 MHz spectrum every 2 microseconds. A dynamic range in excess of 20 dB has been demonstrated for long input pulses, with 30 to 35 dB expected in the near future. The device has readily detected and analyzed pulses of 0.3 μsec duration, the shortest duration pulse produced by the available test circuit. Simultaneous double pulses of 0.3 microsecond duration and 30 MHz frequency separation have been detected with no interpulse interaction.

ACOUSTO-OPTIC SPECTRUM ANALYZER

The heart of an AO receiver is the Bragg cell, the operation of which is depicted in Figure 1. The RF signals to be analyzed are converted to the operational bandwidth of the Bragg cell, and then fed to the transducer which generates a broad fan-shaped beam of acoustic waves at the same frequencies. The acoustic waves propagate through the AO medium wherein their alternating rarefactions and condensations cause variations in the optical index of refraction, thus forming, in effect, moving diffraction gratings having grating periods determined by the acoustic frequencies present at any instant. The gratings interact with a collimated light beam, which is usually but not necessarily a laser beam, causing some of the light to be diffracted or deflected. The angle

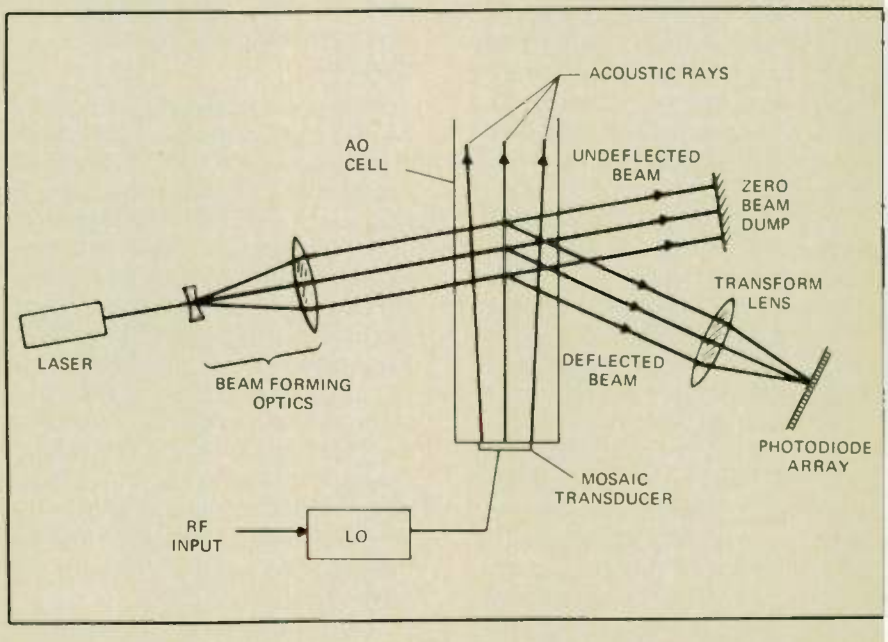

Fig. 1 Acousto-optic interaction in Bragg Cell receiver exhibits unique deflection angle for each frequency thus yielding multiple parallel channel operation with high probability of intercept.

of deflection and the fraction of light deflected are determined, respectively, by the period set by the acoustic or RF frequency and the depth of the ruling set by the acoustic intensity proportional to the incident RF power.

Two conditions must be met for Bragg diffraction — the first requires that the acoustic beam be wide enough to allow the development of interference effects in the diffracted beam, and it is usually expressed as:

$$Q = \frac{2\pi\lambda_o L}{n\Lambda^2} >> 10 \qquad (1)$$

where λ_o is the optical wavelength in air, n is the refractive index of the AO medium, L is the width of the acoustic beam, and Λ is the acoustic wavelength in the medium. The second condition specifies that the optical and acoustic beams intersect at an angle, θ_B, given by:

$$\theta_B = \sin^{-1} \lambda_o/2n\,\Lambda = \ldots \qquad (2)$$

$$\sin^{-1} \lambda_o f/2nv_s$$

where f is the acoustic frequency and v_s is the acoustic velocity. Matching of these conditions guarantees that constructive interference will occur only in either the first positive or the first negative diffraction order so that there will be only one deflected beam for any input signal frequency.

Since the diffraction process does not affect the collimation of the optical beam, the deflected signals are collimated beams having spatial directions and intensities which are measures, respectively, of the RF frequency and power. After traversing the AO interaction region, the light is focused by the transform lens onto a photodiode array in the output plane of the Bragg cell. Each element in the array corresponds to a known frequency interval, and, since most photodetectors have square law response, the output signal from any element is linearly proportional to the RF power at that frequency. The Bragg cell thus produces an instantaneous snapshot of the frequency and power content of the RF signal, updated continually with new incoming signals.

The Bragg cell is, in effect, a multiple channel receiver with the number of channels being equal to the number of detector elements. Since all channels are fully operational at all times, the probability of intercept is virtually 100% and the ability to handle multiple simultaneous signals is excellent. The inherent dynamic range of the AO cell itself is high, limited on the low end by background scattered light and on the high end by the onset of nonlinear interactions. Results reported to date for bulk AO devices have been limited to a much narrower range by photodetector performance. The RF spectral information presented to the focal plane of the Bragg receiver is completely refreshed in each acoustic transit time (see Table 1), but commercially available photodetector arrays require times that are longer than the transit time by three to five orders of magnitude for full readout. Post-processing bandwidth requirements can be made quite moderate because data can be extracted from the detector array on multiple parallel channels, with only one or a few detectors feeding each channel.

Receiver bandwidths in excess of 500 MHz with resolutions of 1 MHz and up to 25 to 30 dB of useful dynamic range can be achieved in commercially-available Bragg cells of moderate size, weight, and cost. Acoustic transit times are 2 μsec or less in these devices, but typical total detector readout times yield Bragg cell response times of more than a millisecond. A new detector array developed for the Westinghouse IO SA extends the attainable dynamic range to beyond 40 dB while at the same time decreasing the readout time for the entire array to 2 μsec.

Two characteristic features of AO receivers require special mention. The first of these is a deflection efficiency limitation which arises as a consequence of the fact that the AO device operates upon all signals in parallel so that interactions can occur between the signals. The other, is an interplay between time and frequency resolution which, though it is inherent to all spectrum analyzers, takes a different form in acousto-optics.

- *Diffraction Efficiency Limitation* — Maintenance of linear response in the presence of strong signals and avoidance of spurious responses which can be generated when two or more signals are present requires that a limit be placed on the maximum allowable deflection by any signal. The limit is a function of the total dynamic range, the fractional bandwidth of the receiver, and the number of strong signals which may have to be handled simultaneously. A typical limit lies between 1% and 5% of the light intensity. Achievement of a very broad dynamic range in the face of even a 5% deflection limit requires a rather powerful laser and very low system and detector background noise levels. Even so, it is likely that dynamic ranges of at least 50 to 60 dB will ultimately be achieved for input signal pulse durations of 0.1 μsec.
- *Time and Frequency Resolution* — In AO systems which have been demonstrated to date, the detector integration and access times set lower limits of the order of milliseconds to the accuracy to which time of arrival (TOA) of a signal can be specified. As detector arrays are improved, the TOA uncertainty will be reduced to the submicrosecond level. It is now 2 μsec in the Westinghouse IO SA. In order to achieve a given frequency resolution capability, δf, in a total frequency bandwidth, Δf, it is necessary to set a minimum width of the optical aperture such that $N = \Delta f/\delta f$ spots can be resolved within the total range of deflection angles. The resolution requirement governs the minimum

the aperture which is given by:

$\tau_a = N/\Delta f$

Thus, for example, for the previously cited AO device capability of 500 MHz bandwidth and 1 MHz resolution, $N = 500 \times 10^6/10^6 = 500$ and $\tau_a = 1\ \mu sec$. No pulse duration shorter than τ_a can be resolved, and no temporal information with resolution finer than τ_a can be extracted. Furthermore, any pulse which does not fill the optical aperture degrades the resolution capability of the system by causing the output focal spot to be enlarged and the sidelobe structure in the focal plane to be distorted, either of which can cause reports of spurious signal identifications.

ADVANTAGES OF INTEGRATED OPTICS

To this point no distinction has been made between bulk and integrated optics. Bulk optics utilizes optical components of classical three-dimensional design, and virtually all prior optical signal processing has used bulk systems. In its simplest form, integrated optics (IO) employs light beams which are constrained by total internal reflection to propagate in a thin waveguide formed by the growth of a transparent layer which has an index of refraction higher than that of the medium on either side of the layer. IO sources use laser beams coupled into the waveguide and detectors integrated directly into the wave-

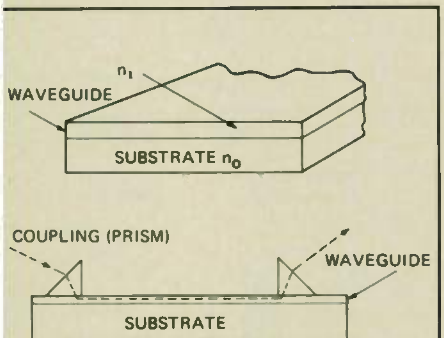

Fig. 2 Planar optical waveguide traps light beam in layer with higher index of refraction (n_1). Use of frustrated total internal reflection in high index prisms allows light to be coupled into the waveguide.

cally coupled to the waveguide. **Figure 2** illustrates the concept of an optically waveguiding layer into which light is coupled by means of frustrated total internal reflection in a prism of higher refractive index than that of the waveguide.

The spectrum analyzer shown sketched in **Figure 1** is a bulk AO cell in which all of the components are of conventional design. Each component has to be individually mounted and the entire system has to be aligned and locked in place on a platform of sufficient rigidity to maintain the alignment. Most bulk AO receivers employ gas lasers which add to system weight and volume, but progress is being made toward adapting the optical system design to the use of injection lasers. The AO cell uses bulk acoustic waves which travel through the crystal, and the process is thus truly three dimensional.

A completely integrated IO SA would have the entire device on a single wafer. To date, no material has yet been discovered in which all of the functions can be performed efficiently, however, and it is necessary, therefore, to use a hybrid assembly in which the laser and detector arrays are separate items. The IO substrate itself contains the waveguide, the beam forming optics, the acoustic wave transducers, and the transform lens. The acoustic waves are surface waves which penetrate only a few micrometers into the AO substrate, a depth which is comparable to the thickness of the waveguide, so that the AO interaction becomes essentially a two-dimensional process.

These contrasting descriptions of bulk and IO Bragg cells illustrate two of the major advantages which integrated optics exhibits — greatly reduced RF drive requirements and greatly improved system stability.

- *Drive Power Requirements* — The ultimate strength of a deflected signal must be limited to 5% or less of the total optical intensity, but in bulk systems even this modest strength may require excessive drive choice of an AO material at frequencies above a few hundred megahertz, but its bulk AO Bragg diffraction efficiency at 1 GHz using the best available transducer design approach appears to be no better than 2% of the light deflected per watt of RF input. Thus, peak signals of 1 W are required to reach the top of the dynamic range and a 50 dB dynamic range would cover inputs from -20 dB to +30 dBm which requires an input amplifier with good linearity and spurious signal suppression.

  In IO both the acoustic and the optical beams are constrained to propagate within a depth of only one to a few micrometers, so there is no diffraction loss from either wave in the depth dimension and the AO interaction is very much stronger, greatly increasing efficiency and greatly reducing RF drive power. Test samples employing the same transducer design and the same waveguide thickness as are used for the IO SA have exhibited deflection efficiencies at the He-Ne laser wavelength (632.8 nm) of as high as 6% for RF generator power outputs of 40 to 80 mW, corresponding to efficiencies of the order of 100% per watt of available drive power. These results were obtained with impedance mismatch to the source causing two-way insertion losses in excess of 20 dB throughout the operating bandwidths of the transducers
- *Stability* — Bragg cells are complex optical systems which must be maintained in precise alignment under adverse environmental conditions. Proper design of the optical system for a bulk AO receiver can minimize the effects of vibration, g-force loadings, and temperature and pressure excursions, but even a massive optical bench cannot eliminate them entirely. It becomes necessary, therefore, to provide means for frequent system recalibration, a requirement

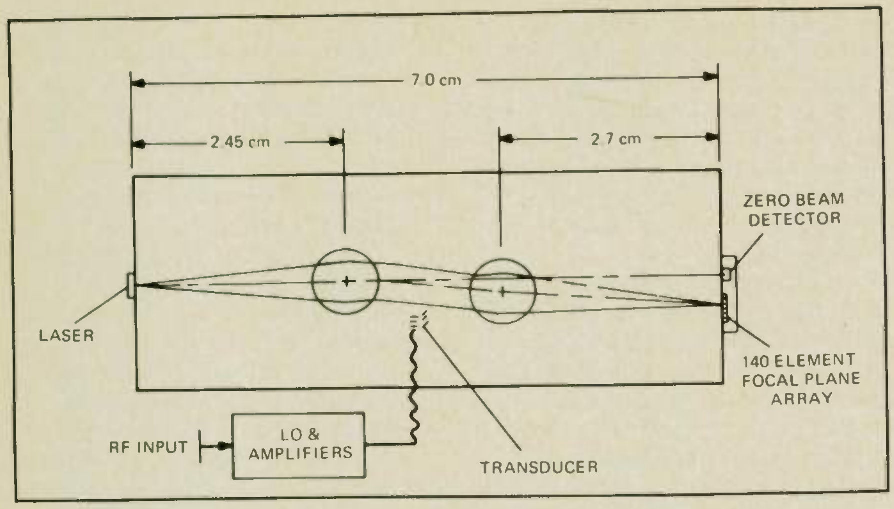

Fig. 3 IO RF spectrum analyzer uses precisely positioned aspherically-corrected lenses and newly developed high-speed photodiode array to provide wide dynamic range with 2 μs response.

which increases system complexity and cost and which reduces receiver operating time.

The IO system is inherently small in size and weight, and, even though it is a hybrid assembly, its geometric features are well-suited to highly rigid, environment-resistant mounting procedures. The optical system of the IO SA is so designed that the three separate principal components are mounted against and have their optically active regions within a few micrometers of a material on a miniature optical bench made of Cer-Vit,* a partially crystallized glass which exhibits a near-zero coefficient of thermal expansion in addition to great mechanical strength and stability; this approach virtually ensures maintenance of alignment under even the most severe environmental conditions.

Other advantages of the IO format are simplicity of transducer design and fabrication and better match of injection laser characteristics than for bulk systems. SAW transducer technology on $LiNbO_3$ requires only simple interdigitated metal fingers to form a transducer, providing superior performance and greater yields over transducer deposition techniques required for bulk optics. The recently developed double heterojunction GaAlAs injection lasers provide output beam parameters well-suited for direct butt-coupling into the edge of an IO guide but much less satisfactory for use with three-dimensional lens systems; the power levels available from the most-recently-developed diodes, moreover, allow far greater IO power densities to be achieved than are possible in bulk AO systems using injection or gas lasers.

IO is a wholly new technology requiring many further component developments before it is exploited in optical processing systems. Recent efforts have resulted in major technological advances in lenses and lens fabrication techniques, transducer technology, and waveguide development, but much remains to be done. Other problems to be solved include optical scattering in waveguides, efficient and simple coupling techniques, and minimization of optical losses in IO systems.

THE IO RF SA

Layout of the integrated optical RF spectrum analyzer is shown in **Figure 3**. The basic IO substrate which contains the waveguide, the lenses, and the SAW transducer arrays is a slab of X-cut $LiNbO_3$ approximately 7 x 2.5 x 0.3 cm^3. The waveguide is formed by indiffusion of Ti at 1000°C. The laser beam is coupled into the waveguide at the center of the precisely square, chip-free input edge, and it spreads by diffraction to a width of 2 mm ($1/e^2$ points) before being collimated by the input lens. The collimated beam interacts with the SAW which bears the RF signals to be analyzed and part of it is diffracted. The transform lens, offset so that the deflected beam at the center frequency of 600 MHz will be centered on the lens, focuses the light onto the output edge, which also is precisely square and chip-free. The detector array is butt coupled to this edge at an angle of 45° so that any light reflected by the surface of the array will not return to the waveguide. The device is designed to utilize a butt-coupled GaAlAs double heterojunction laser, but all tests to date have been performed using an end-fire-coupled He-Ne laser beam. The photodiode array actually consists of 140 elements, but only 100 are used with GaAlAs and 75 with He-Ne; as the figure shows, there is also a large dump diode for intercepting and monitoring the undeflected beam.

The important parameters of the IO SA are summarized in **Table I**. The bandwidth and resolution were chosen for a typical application and the center frequency to cover the bandwidth in one octave. The 2 μsec detector integration time is a compromise between speed and output data rates. A two-element, tilted transducer array in which each element is positioned at the Bragg angle for its center frequency was chosen after preliminary tests

TABLE 1

IO RF SA PARAMETERS

• Center frequency	600 MHz
• Frequency bandwidth	400 MHz
• Frequency resolution	4 MHz
• Detector Integration time	2 μsec
• Detector pitch	12 μm
• Acoustic transit time	0.6 μm
• SAW Transducer Array	2-element, tilted
• Diffraction efficiency	50 to 100%/watt

(continued on page 42)

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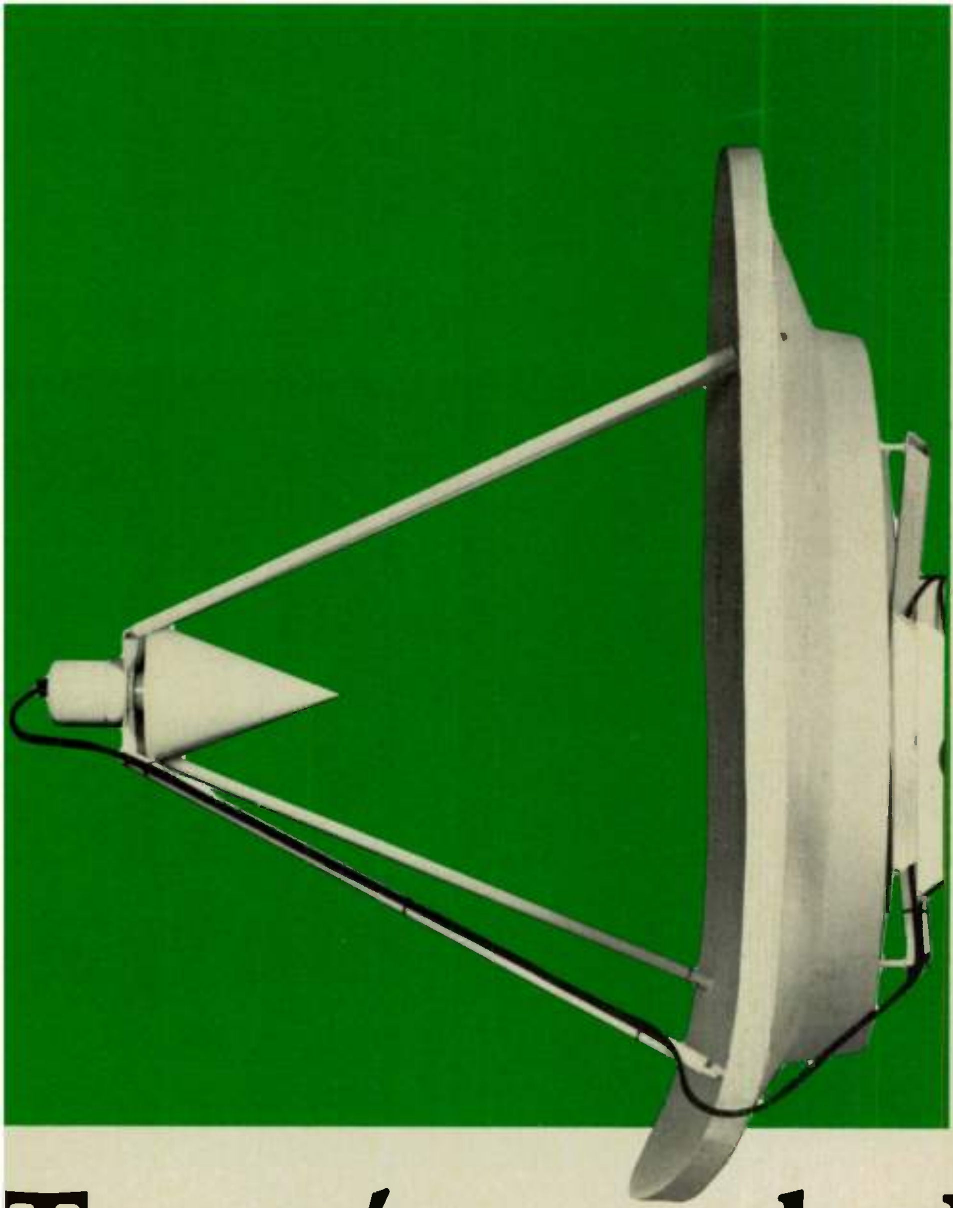

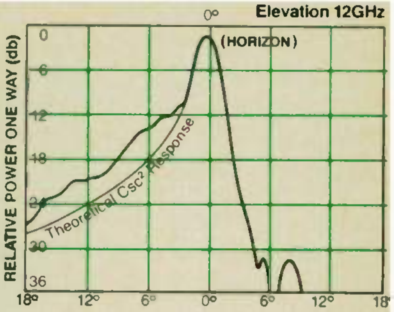

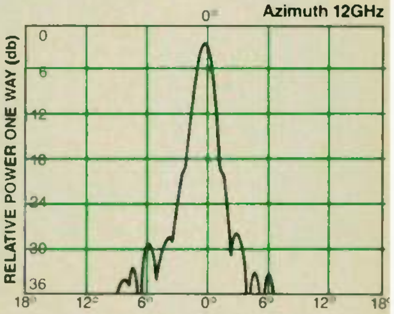

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showed a 400 MHz bandwidth with less than 3 dB variation with such an array. The diffraction efficiency is that measured for the same test transducers.

The acoustic transit time was determined when the optical aperture was specified. The optical system was designed to produce 100 focal plane spots overlapping at the $1/e^2$ intensity points with a safety margin of 1.5 allowed for lens aberrations. This results in a collimated $1/e^2$ beam width of 2 mm. The input lens focal length was chosen to be 2.45 cm to expand a 6 μm GaAlAs laser spot to 2 mm by diffraction. The output focal length was selected to allow 100 pixels of 12 μm width to be filled by the 400 MHz range of Bragg angles in $LiNbO_3$.

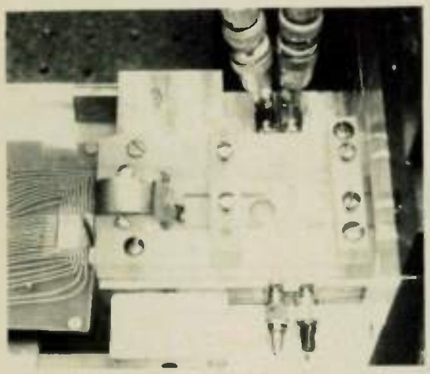

Fig. 4 Completed IO RF SA mounted face down on optically polished Cer-Vit fixture with photodiode array butt coupled at a 45° angle to output edge. Laser beam is end-fire coupled to opposite edge.

IO SA fabrication begins with polishing of the input and output edges to be square to better than 0.1 μm and to be as chip-free as practically achievable. Next, the lenses are machined into the substrate, each positioned a focal length from its edge to an accuracy of ± 0.5 μm. A film of Ti is deposited over the top face of the crystal and indiffused at 1000°C, in an atmosphere that is controlled to prevent loss of Li_2O, to form a single mode waveguide. Following this, the transducer arrays are deposited using standard SAW transducer deposition techniques, the end faces are then AR-coated with SiO_2, and transducer bonding is completed. The completed substrate assembly is mounted face down on the polished Cer-Vit mounting surface, leads to the RF input ports are affixed, and the detector array is aligned to the output edge and locked into position. Eventually positioning of the commercially-procured diode laser will follow the detector mounting step, but this has not yet been effected. A photograph of an IO RF SA completed through the photodiode array mounting is shown in **Figure 4**.

Several of the components of the IO SA represent important improvements in the state-of-the-art of their fabrication or performance. The crystal edge polishing, performed at the Westinghouse R&D Center, has resulted in edge squareness to considerably better than a quarter fringe (0.07 μm) and, in some cases, in edges on which no nicks can be seen over the central 1.3 cm under 1000 power magnification. More than 1 mW of He-Ne laser radiation has been coupled without causing damage in a spot of less than 10 μm full-width, and such power densities are far higher than any previously reported for $LiNbO_3$/Ti guides. Far more significant, however, are the lens and detector array developments.

- *Lens Development* — At the time the spectrum analyzer program was initiated, adequate imagery in optical waveguides generally was considered to be the least tractable of all problems facing integrated optics, and achievement of nearly diffraction-limited performance appeared to be almost impossible. We decided to explore aspheric geodesics.

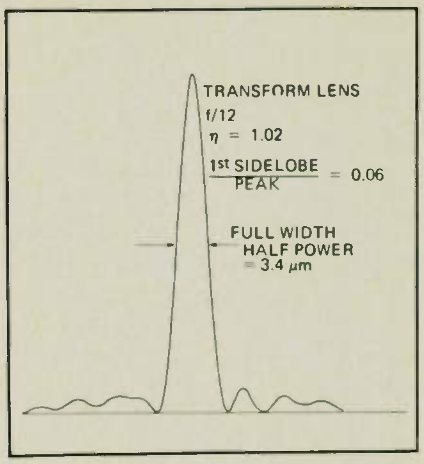

Fig. 5 Focal plane scan of IO SA transform lens operating at f/12 shows a spot size only 1.02 times the diffraction-limited width.

A geodesic lens is actually a depression in or protrusion from the waveguide-bearing surface which focuses by causing light rays to travel different distances along geodesics of the surface. A spherical geodesic suffers from spherical aberration similar to, but opposite in sense, to that of a conventional spherical lens. Our approach was to design the necessary correction for aberration into the geodesic profile and then investigate methods of producing this surface. Error analyses conducted as part of the lens design effort showed that surface contour controls to better than 1 μm were necessary. Profiles with the required accuracies are now routinely produced, by single point diamond turning at the Moore Special Tool Co. The focal plane pattern produced by a test version of the transform lens of the IO SA at f/12,

TABLE 2

FEATURES OF WESTINGHOUSE 5050 PHOTODIODE ARRAY

• **Detector Type:**	**Self-scanned silicon photodiode array**
• **Number of elements:**	**140**
• **Element spacing:**	**12 μm with no dead space between elements**
• **Access Time:**	**2 μsec to all elements**
• **Output Data Rate:**	**5 MHz (14 output channels; 10 pixels per channel)**
• **Dynamic Range:**	**42 dB demonstrated; 50 dB expected**
• **Crosstalk**	**−16 dB nearest neighbors demonstrated**
• **Holdover Crosstalk:**	**−40 dB demonstrated after two integration periods**

(continued on page 44)

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Tel: (213)822-0800 Telex 65-2448 TWX 910-343-6469 which is approximately equal to the f-number at which the same lens is utilized in the spectrum analyzer, is compared to the diffraction limit for this lens in **Figure 5**. The central spot width is seen to be only 1.02 times the diffraction limit.

- *Photodiode Array Development* – The salient features of the detector array developed under separate contract support from NRL are listed in **Table 2**. The element spacing of 12 μm with no lost area is an improvement over available arrays which have pitches of 15 to 25 μm. The access time of 2 μsec to all elements represents an enormous advance over other arrays. The dynamic range also represents a major advance in the state-of-the-art. The array is shown in **Figure 6**.

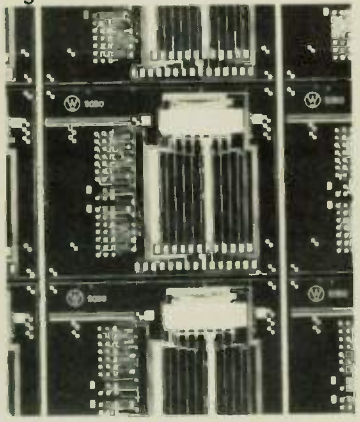

Fig. 6 Photodiode Array with 140 active elements on 12 μm centers achieves large dynamic range through area extension in the other direction.

PERFORMANCE OBSERVED AND EXPECTED

Operation over the full 400 MHz bandwidth with He-Ne input radiation has been repetitively demonstrated and is shown in **Figure 7** which compares the measured and expected deflection angles against frequency. The experimental points were taken by measuring the separation between the deflected and undeflected spots on the output edge through a microscope equipped with a calibrated reticule.

Dynamic range has been measured by two different methods. In the first and more direct approach, a sweeping RF input signal of 40 to 80 mW is applied to the two transducers in parallel through a calibrated attenuator which can be varied in 1 dB steps. The signal from a representative photodiode is taken through a sample and hold circuit and displayed on an oscilloscope. Attenuation is inserted into the line until the signal can no longer be distinguished from the noise. Dynamic range evaluated in this manner has been seen to vary between 18 and 22 dB. The second approach compares the maximum signal observed from an arbitrarily chosen pixel to the minimum detectable signal estimated for the array. Representative values are 30 to 60 mV for the peak signal and 70 to 80 μV for the noise level, and these correspond to 26 to 29 dB. In both cases, 8 μsec integration times have been employed.

The peak observable signal in these tests has been limited by the optical power coupled into the waveguide. In order to prevent optical damage to the guide, the He-Ne laser power focussed onto the edge of the guide has been kept below 0.5 mW. It is expected that the use of GaAlAs laser radiation will allow 5 mW to be presented to the waveguide edge without fear of damage and that this will increase the dynamic range by at least 10 dB. A further increase of at least 5 dB in dynamic range should be observed with new diode arrays which have been redesigned to reduce leakage currents. Thus, at least 35 dB of useful dynamic range should be achievable.

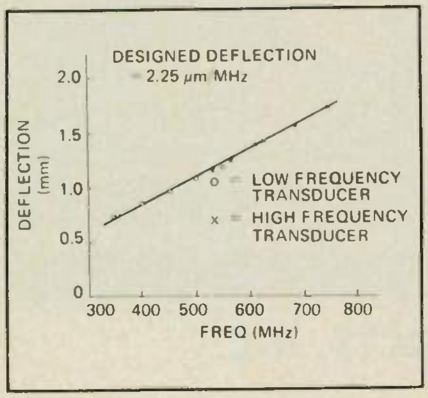

Fig. 7 Exact agreement between predicted and observed beam deflection vs. frequency over the entire 400 MHz bandwidth of IO RF SA shows that frequency of RF signal can be identified unequivocally.

SA performance under pulsed operation has shown even greater promise. Pulses of 0.3 to 0.4 μsec duration are readily detectable when photodiode outputs are only slightly greater than those required to identify CW or long pulse signals. Outputs of at least several hundred millivolts have been observed when the RF power has been increased well beyond the 1% to 5% diffraction efficiency limit, thus indicating that the transducers can take far higher power loadings and that the 1 to 1.5 V onset of detector saturation is approachable in the IO format. As a result of these tests, we anticipate that 40 dB of dynamic range with 2 μsec integration times will eventually be observed with the existing IO RF SA.

One of the key features of Bragg cell receivers is their ability to handle several pulses simultaneously. A two-channel pulse circuit using VCO's to control the two RF frequencies has been employed in preliminary tests of the two-simultaneous-signal handling capability of the IO SA. No change from the single pulse detection threshold and no interaction between the pulses has been observed when the two 0.3 μsec signals have been brought to within 30 MHz of each other.

The experiments were not carried beyond this point because of instrumental problems, but no pulse intermodulation problem is expected at frequency separations down to the resolution limit of the device.

CONCLUSION

An IO RF SA has been demonstrated to have a dynamic range comparable to that of bulk AO SA devices, and test results have shown promise of a very much larger dynamic range. It is expected that the performance of this device will soon have been improved to 30 to 35 dB of dynamic range with complete RF spectral updating every two microseconds; no problem is anticipated, moreover, with handling multiple pulsed signals of submicrosecond duration.

(continued on page 48)

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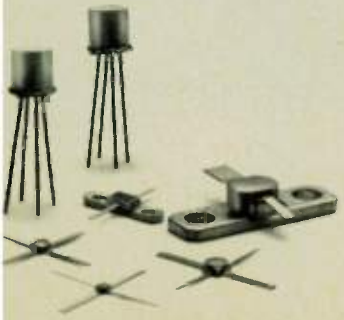

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VHF			
AT-0017A	1.2dB	25dB	60MHz
AT-0017	1.5dB	25dB	60MHz
UHF			
AT-0045	1.5dB	13dB	500MHz
AT-0025A	2.0dB	12dB	500MHz
AT-0025	2.5dB	11dB	500MHz
BIPOLAR SMALL SIGNAL LOW NOISE TRANSISTORS UP TO 4 GHz (70 mil pkg)			
AT-4680	2.8dB	8.8dB	4.0GHz
AT-4690	3.0dB	9.5dB	4.0GHz
AT-4641	3.5dB	7.5dB	4.0GHz
AT-4642	4.0dB	7dB	4.0GHz
AT-2645A	3.0dB	11dB	2.0GHz
AT-2645	3.5dB	11dB	2.0GHz
BIPOLAR SMALL SIGNAL LOW NOISE TRANSISTORS UP TO 4 GHz (100 mil pkg)			
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AT-4890	3.0dB	9.5dB	4.0GHz
AT-4841	3.5dB	7.5dB	4.0GHz
AT-4842	4.0dB	7dB	4.0GHz
AT-1845A	2.2dB	14dB	1.0GHz
AT-1845	2.5dB	14dB	1.0GHz
AT-1825	3.0dB	13dB	1.0GHz
GaAs FETS UP TO 12GHz			
AT-8110 Chip AT-8111	1.3dB	12dB	4GHz
AT-8060	2.8dB	8dB	12GHz
Chip AT-8061	2.5dB	9dB	12GHz

POWER-BIPOLAR UP TO 4 GHz

PART NO.	TYP. P_o (−1dB)	TYP. G @ P (−1dB)	TYP. P_o (SAT)	TEST FREQ.
AT-7510	27.5dB	9.5dB	29dBm	4GHz
PART NO.	**P_o (−1dB)**	**TYP $\|S_{21}\|^2$**	**G max**	**TEST FREQ.**
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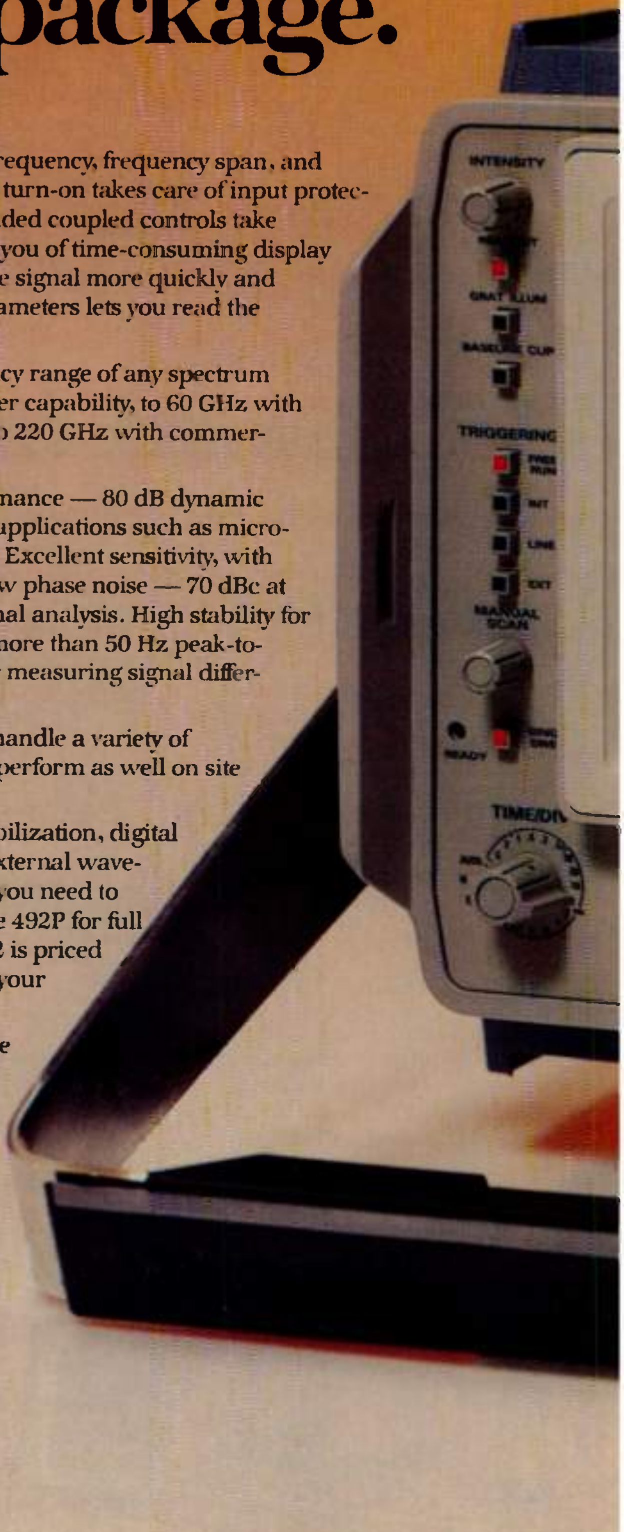

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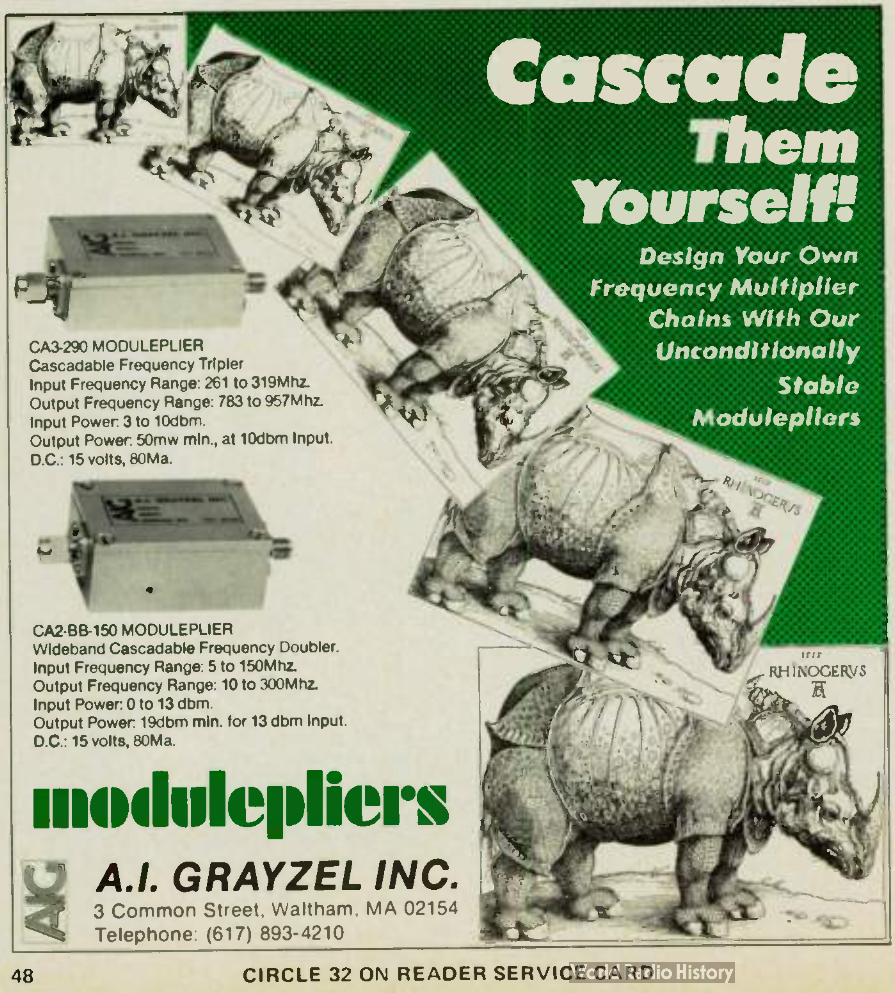
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CIRCLE 32 ON READER SERVICE CARD

(from page 44) ANALYZER

Dick Mergerian received his B.S. and M.S. degrees from Columbia University and his Ph.D. in physics in 1962 from the Illinois Institute of Technology. He joined Westinghouse as a Fellow Physicist the same year and later served as an Advisory Physicist before assuming his present position as Manager of the Applied Sciences Group at the Advanced Technology Laboratories. He has been engaged in and has directed research efforts in electron spin resonance, spin echo matched filters for radar applications, high energy laser, magnetic memories and optical signal processing. He has served as Program Manager on a number of Westinghouse programs including the Cylindrical Laser Optical Test Program which involved the development of unstable resonators for lasers having toroidal output beams, and most recently the Integrated Optics Program under which the integrated optical RF spectrum analyzer was developed.

Ed C. Malarkey received the A.B. degree, maxima cum laude, from LaSalle College, Philadelphia, Pa. in 1958 and the Ph.D. in Physical Chemistry from MIT in 1963. He joined what is now the Westinghouse Defense and Electronics Systems Center in 1963 and is now a Fellow Physicist in the Applied Sciences Group at its Advanced Technology Laboratories. At Westinghouse, he has been involved in a variety of research and development programs in several different areas of Applied Physics, but with heaviest emphasis on optics, lasers, and integrated optics. He has served as Technical Director on several programs including the Cylindrical Laser Optical Test Program, funded by the Air Force Weapons Laboratory, under which optical systems for extraction of energy from cylindrical chemical lasers were devised and tested on the Westinghouse electron-beam-pumped, high energy cylindrical CO_2 laser. Since 1977, he has been working in integrated optics, and has been the Technical Director of the IO SA Program since its inception in 1978.

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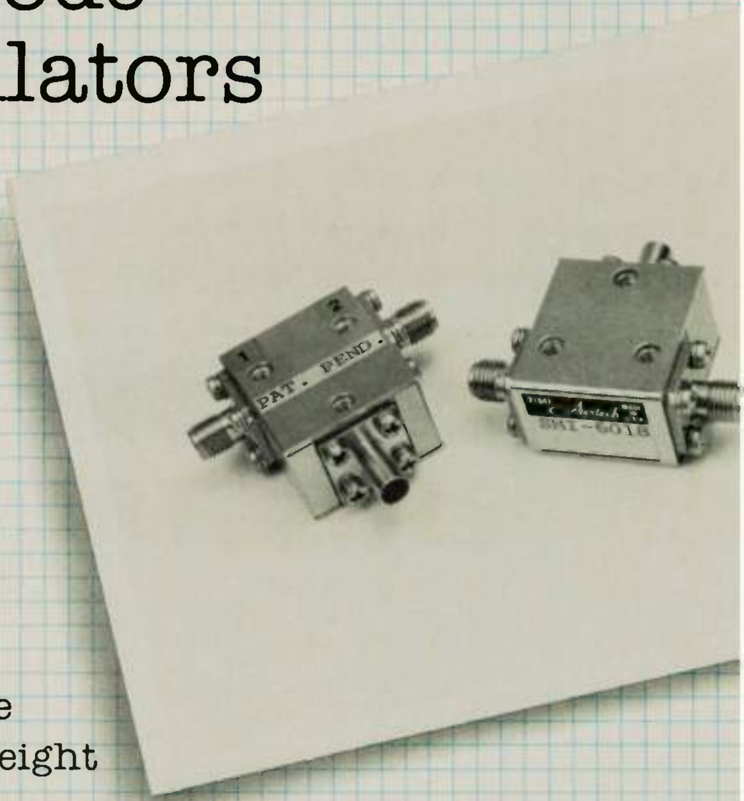

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6.5-18.0	SMI 6518	SMC 6518	15	.7	1.50:1	−40 to +60
7.0-18.0	SMI 7018	SMC 7018	16	.7	1.45:1	−40 to +60
8.0-18.0	SMI 8018	SMC 8018	17	.7	1.35:1	−40 to +60
8.0-20.0	SMI 8020	SMC 8020	16	.8	1.45:1	−40 to +60

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Circle 34 on Reader Service Card

The Challenge of Designing Reliable ECM Transmitters

F. H. WOLF, H. E. CONWAY, P. S. SPIECKER
Westinghouse Electric Corporation,
Defense and Electronic Systems Center,
Baltimore, MD

INTRODUCTION

State-of-the-art electronic countermeasures (ECM) transmitters present numerous technical challenges to the transmitter designer, and he must ever be aware of reliability as he seeks solutions to these technical problems. Regardless of the performance levels achieved, ECM is of no value if it fails during the mission or requires continuous maintenance to keep it in a state of operational readiness. Transmitter design requires a disciplined approach to realize the high degree of reliability necessary for ECM systems.

Two new transmitters were recently designed for the AN/ALQ-131 (V) countermeasure system at Westinghouse Aerospace Division, Baltimore, Maryland, with the emphasis on reliability and maintainability. The design engineers undertook the task by carefully studying which factors frequently cause failure in transmitters, and then devising solutions that would prevent these weaknesses from occurring in the new AN/ALQ-131 equipment.

The design involved two of the high voltage power supplies which contain most of the complex circuitry of the transmitters. The design approach was to use standardized circuits that were common with other programs, or that could be used in future power supply designs. The power supplies were required to fit within the available volume and function in the environment specified for the prime AN/ALQ-131 system. The two supplies have been qualified and are in the production start up cycle.

The AN/ALQ-131(V) is an advanced, tactical ECM system designed for external, pod mounting on high performance aircraft. The system provides electronic deception jamming to defeat hostile radar interception. The pod housing provides for a high degree of adaptability to mission needs by allowing interchange of functional modules, each designed to cover segments of the typical microwave ECM frequency region. Each functional mod-

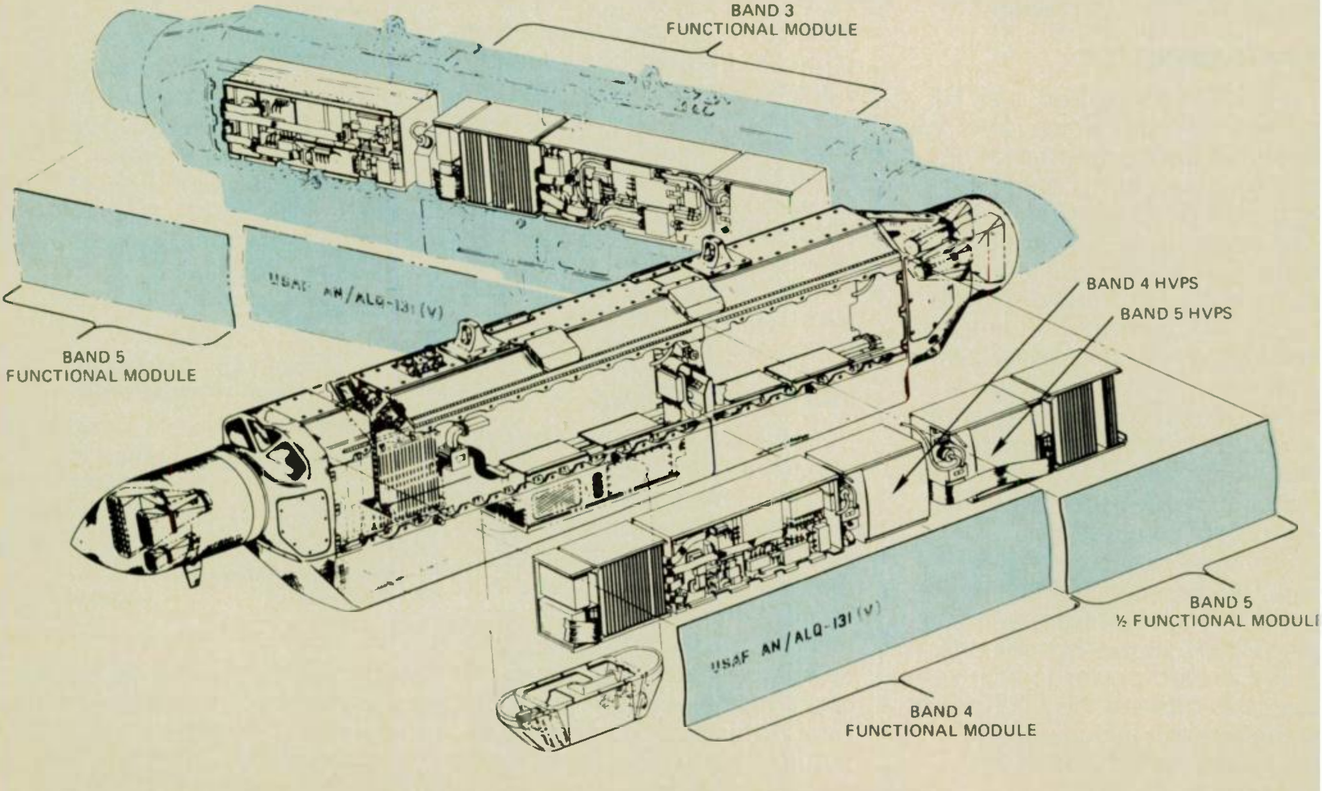


Fig. 1 AN/ALQ-131(V) electronic countermeasure system.

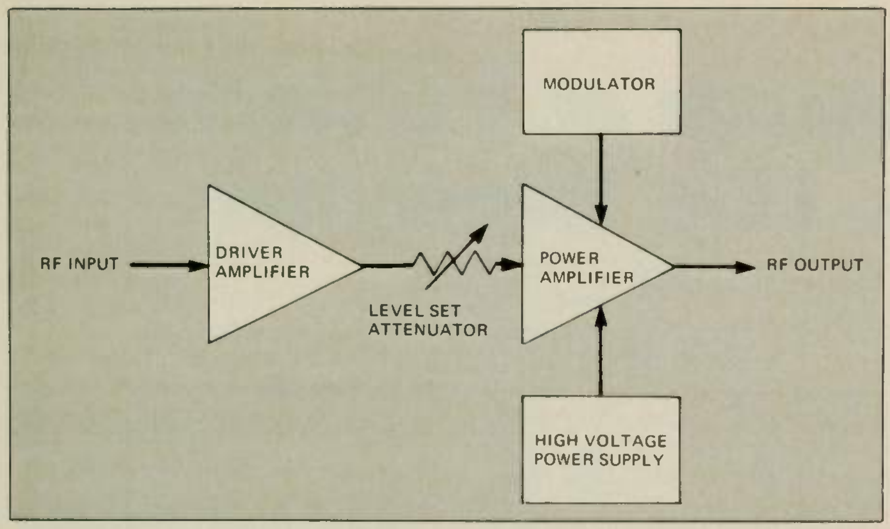


Fig. 2 Electronic countermeasure transmitter.

ule mounts to the basic pod frame structure which provides support and cooling (Figure 1). A multiplexed control system allows interchangeability of modules. The transmitter for each frequency region is contained with a functional module along with the associated amplitude and frequency deception components for that frequency. The overall design of the system stresses high reliability and ease of maintenance. The new transmitter designs were required to conform to that philosophy.

ECM TRANSMITTER

An ECM transmitter is an RF amplifying chain which raises low level microwave repeater or noise jamming signals to a specified output power level (Figure 2). The operating bandwidth is usually an octave or greater. Because of the broadband requirements and the need for compact and lightweight microwave power amplifiers, helix type traveling-wave tubes (TWT's) are most often used for the high power final amplifier stage. TWT's can be designed to meet either pulsed or CW output requirements. The driver stage may be either a TWT amplifier or a solid state amplifier. The high voltage power supply (HVPS) converts three-phase prime aircraft power to high voltage dc to operate the TWT power amplifier, and includes a grid modulator in the case of the pulsed output TWT.

PROBLEMS ENCOUNTERED

Other than TWT failures, the problems most often encountered in the transmitter can be grouped into three categories.

- Failure of the power conditioning circuits (rectifier/inverter) during high voltage faults.
- Failure of the high voltage insulation system.
- Thermal management.

The environment in which the ECM system must operate complicates the design. Usually there is limited availability of cooling and prime power; and if the jammer is packaged in an externally mounted pod such as the AN/ALQ-131, there are high levels of vibration and wide excursions in temperature. There are also stringent restrictions on volume and weight. Many factors which can lead to transmitter failure combine in the ECM application.

THE DESIGN PROCESS

Reliable ECM transmitter design is the marriage of good electrical and mechanical design where strict attention has been paid to details. Equally important in achieving the potential reliability of a good design is the manufacturing process. Special techniques and a high degree of cleanliness plus control of the total manufacturing process is required when assembling high voltage hardware.

The transmitter design process starts with the specification and selection of the TWT power amplifier. It is essential that the transmitter engineer be an active participant in the initial system design studies which establish the system performance parameters.

Once the TWT specification is established, the design of the high voltage power supply can begin. To be assured that the design will have the potential of achieving the specified reliability, many factors must be considered including:

- Choice of power conditioning circuits
- Speed and location of protective circuits
- High voltage design constraints
- Thermal management
- Insulation systems
- Component part derating policy
- Manufacturing process

All of these factors must be considered individually and in concert when formulating the design concept.

The HVPS for a typical ECM transmitter provides the following ranges of voltages to the various elements of the TWT. The exact voltages and range of adjustment required tube to tube is a function of a particular TWT design and varies with operating frequency, output power, TWT manufacturer, and type of beam control (intercepting grid, shadow grid, or modulating anode) as shown in Table I:

TABLE I

VOLTAGE RANGES OF ECM TRANSMITTER

Cathode to ground:	-5 to -10 kV$_{dc}$
Cathode to Collector:	50% to 60% of Cathode to Ground
Filament:	6.3 V$_{rms}$
Grid to Cathode:	-200 to $+300$ V$_{dc}$
Modulating Anode to Cathode:	-1000 to $+20$ V$_{dc}$

The regulated power supply for the airborne application must operate from three phase, 115 V$_{rms}$, 400 Hz aircraft power conforming to MIL-STD-704B.

Electrical Design

At some time a TWT will arc, so the high voltage power supply must be able to repeatedly survive a short circuit on its output. Problem solution begins with the selection of the power conditioning mechanization. In the airborne case, volume and weight constraints preclude a brute force approach whereby all of the components making up the high voltage driving circuits (power train) are large and can sustain the high fault currents of an arc. Most transmitters of the airborne class are mechanized using an inverter of some form operating between 10 and 20 kHz which permits the use of smaller magnetic and filter components (**Figure 3**). However, the inverter must be protected from short circuit damage.

The inverter operates from the filtered output of a full wave bridge rectifier and drives step-up transformers. The rectified output from this dc-to-dc converter drives the TWT cathode and collector from a "stacked" series of the transformer windings and rectifiers. Regulation is accomplished by the comparison of a cathode voltage sample to a ref-

signal is generated to vary the dc-to-dc input power.

Because of the necessity of operating the RF circuit in a TWT at ground potential, it is necessary to operate the cathode of the tube at a negative potential with respect to ground. Therefore, all voltages which are referenced to the cathode potential (filament, bias, and grid or anode) must be isolated from ground. This is accomplished by means of isolation transformers insulated to withstand the high negative cathode potential. Much care must be exercised in designing the magnetics with attention directed towards the insulation and thermal design in these very small packages.

Numerous types of inverters have been devised with many variations. Some of these are unsuitable for use in a transmitter high voltage power supply. Voltage driven inverters as a class should be avoided in transmitter work because their switching transistors are much too vulnerable to overstress during TWT arcs. The two inverter types which offer the greatest immunity to overstress are the flyback and current driven inverters.

wave system where energy is accumulated and stored in the core of a transformer during the period the inverter switches are closed and then is transferred to the load when the switches open. Since load current is not drawn when the inverter switching transistors are conducting, they are isolated from fault conditions in the load.

- *Current Driven Inverter* — An inverter system where drive to the switching bridges of the inverter is limited by means of inductors, thereby also limiting the current switched by the bridges.

Regardless of the inherent immunity of a particular inverter power train to excessive fault currents, additional inverter protective circuits are required. While all transmitters incorporate TWT body current overload protection this type of protection by itself may not be entirely adequate to protect the power train. High body current (or ground current) is an indication of a defocused TWT beam and, if allowed to persist, could cause damage to the helix or other parts of the tube.

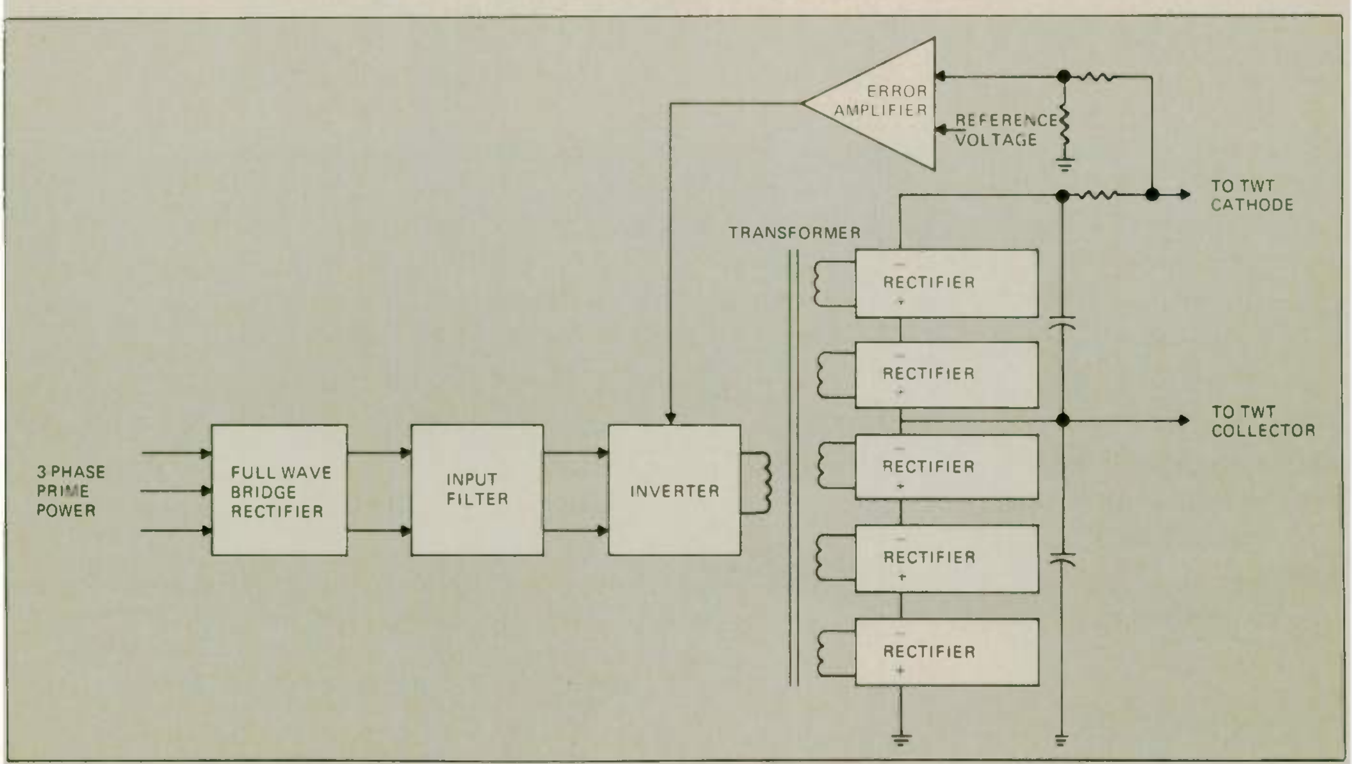


Fig. 3 Inverter type high voltage power supply.

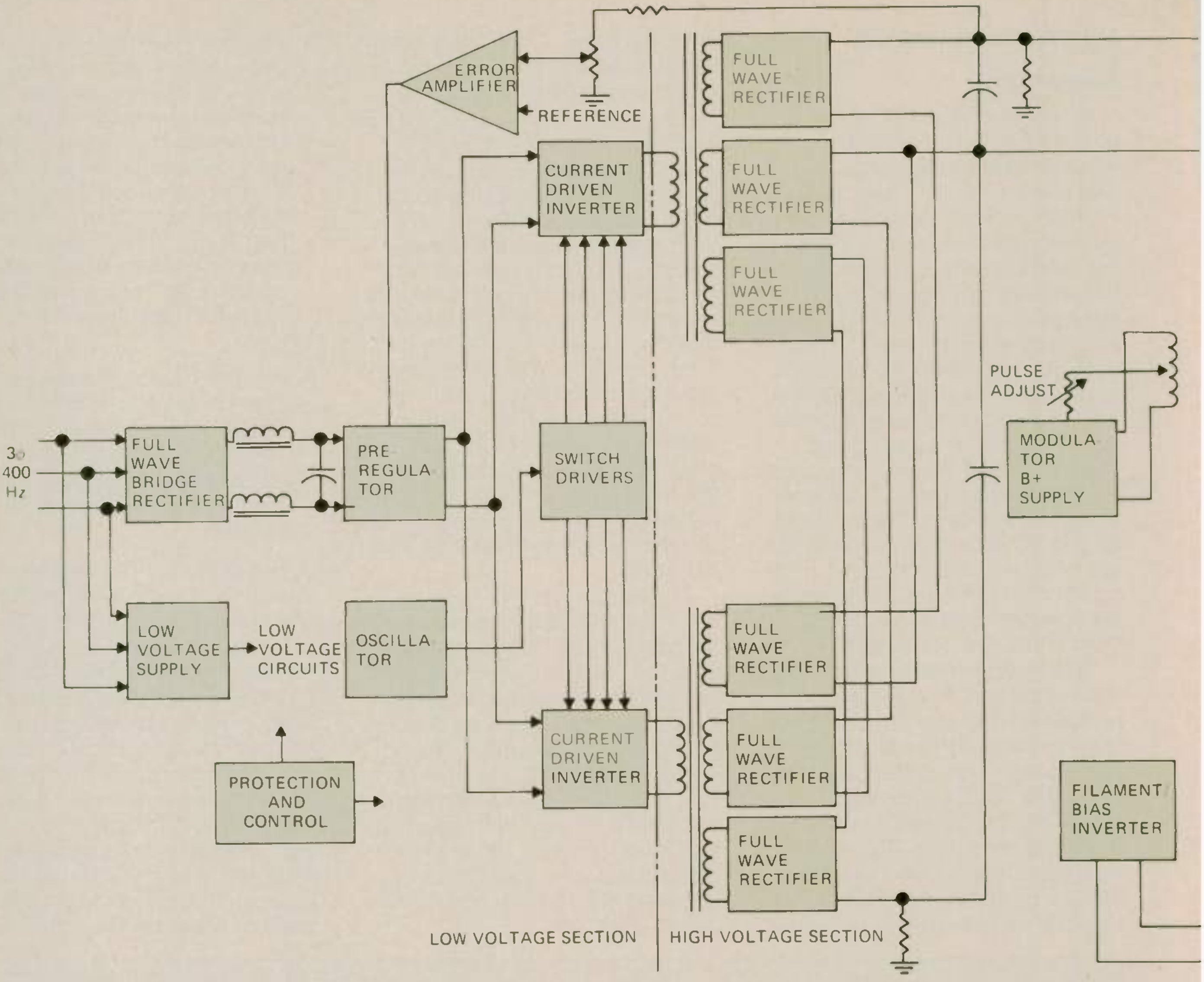
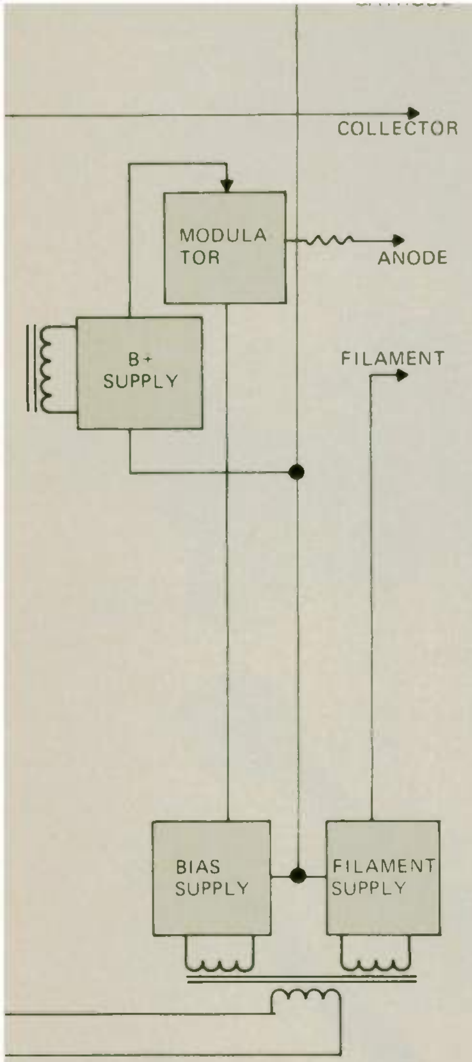


Fig. 4 High voltage power supply functional diagram.



tion circuit offers the greatest protection to the power train. This circuit senses the input current to the inverter transformer primary; and when the input current exceeds a threshold, drive is removed from the inverter switching transistors within one or two microseconds.

For the AN/ALQ-131 transmitters, both the flyback and the current driver inverter configurations were chosen. For the lower average power, pulse-type transmitter the flyback scheme was used. This type of inverter, while having the greatest inherent protection of the power transistors, does not make efficient use of its magnetics. For the much higher power CW transmitter the current driven approach was necessary to be able to package within the allowable volume. The inherent protection provided by the current drive coupled with the fast input overcurrent protection has proved during repeated testing to be excellent against output short circuits. This combination matches the flyback inverter in reliability.

Other protective features must be incorporated into the transmitter to insure the reliability of both the TWT and the HVPS. Although the major event to be protected against is TWT arcing, be anticipated such as:

- Improper grid voltages
- Power line transients
- Loss of cooling

Further protection for the TWT is provided by a resistor in the cathode circuit which limits the magnitude of the fault current when the tube arcs.

The amount of energy stored in the ripple filter at the output of the HVPS must also be limited to that which can be safely dissipated within the TWT during an arc. If this is not possible, a "crowbar" must be incorporated which will divert and dissipate the stored energy and any follow through energy. The crowbar circuit provides a safe, high current ground path to divert energy away from the TWT during an arc. This was not needed for the AN/ALQ-131 designs.

To prevent filament damage by the initial turn on surge, current limiting is designed into the filament supply. To assure long filament and cathode life, the filament supply should also be regulated and well protected against transients.

Non-intercepting types of TWT control grids (shadow grids) can be destroyed if a positive voltage is applied to the grid of a tube which has a heated

(continued on page 59)

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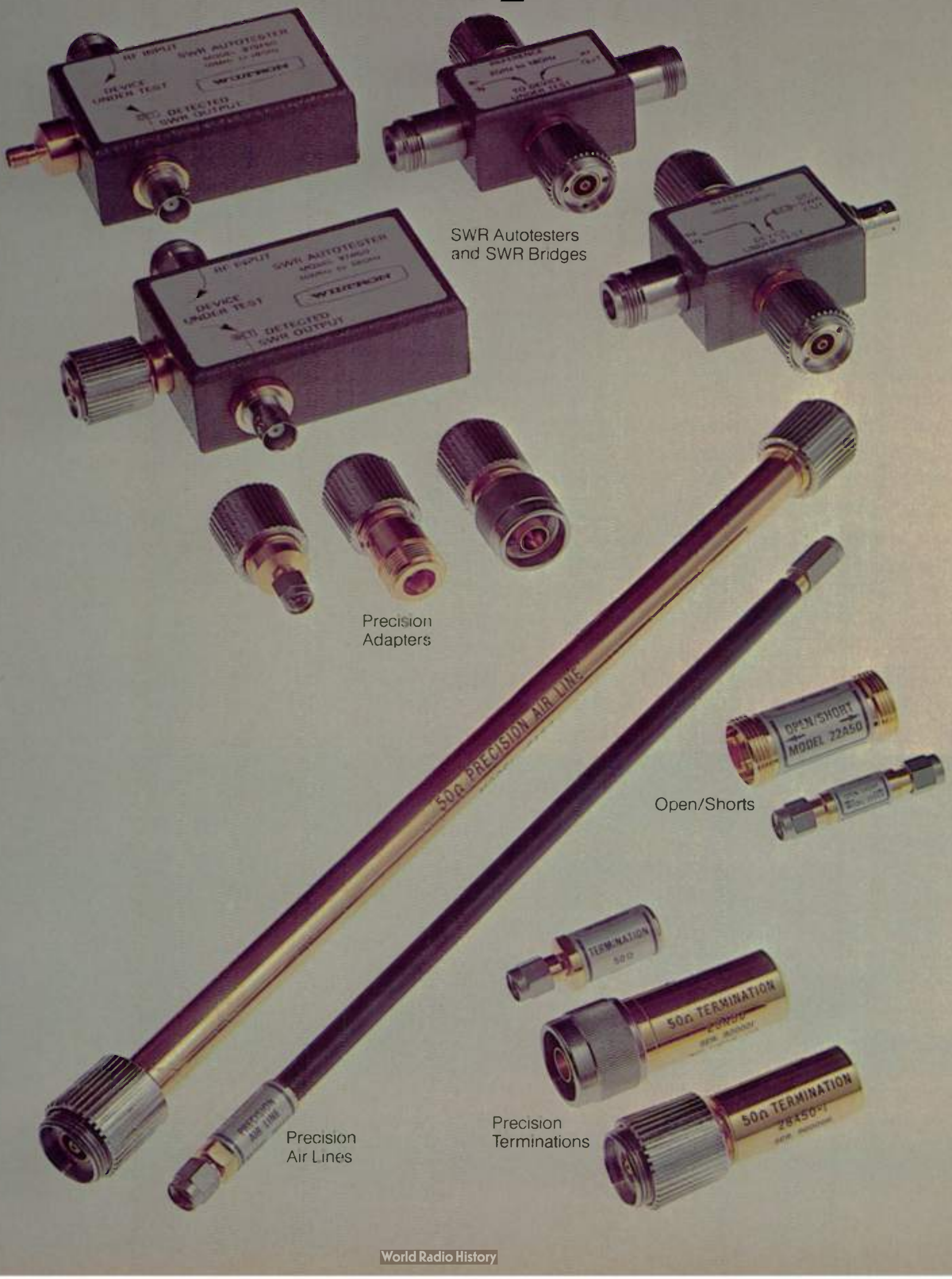

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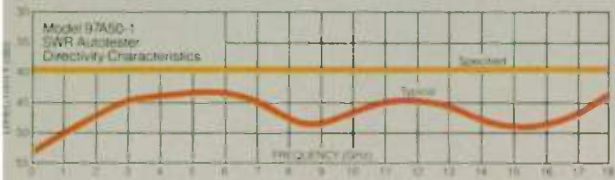

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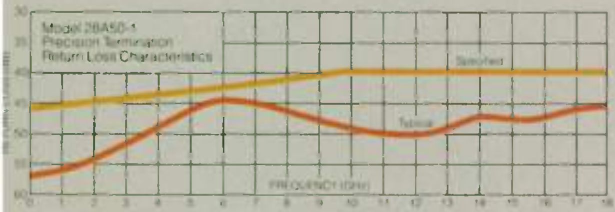

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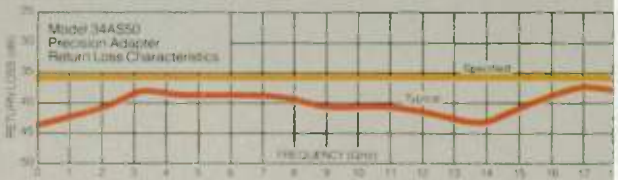

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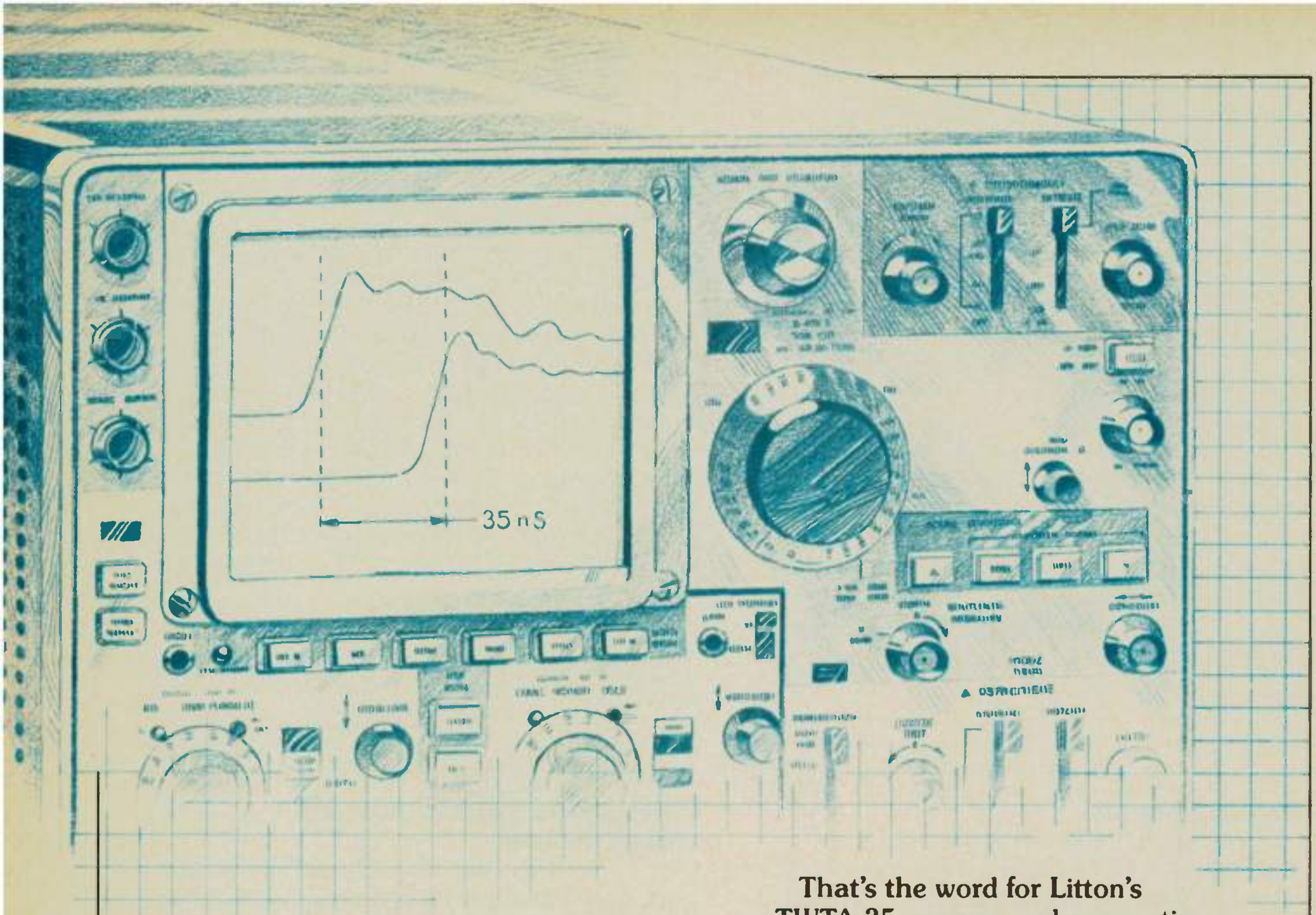

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cathode but has not had high voltage applied. This is prevented by interlocking the grid modulator with the HVPS such that cutoff bias is maintained on the grid at all times that the filaments are energized and high voltage is not applied. In addition, the protection and control circuits provide a turn-on and turn-off sequence of voltages applied to the TWT which prevents tube damage during both normal operation and fault conditions.

In addition to the protection provided for the TWT, the grid modulator and the HVPS must also be protected from damage which might be sustained during a TWT arc. The basic inverter mechanization and input current overload protection previously discussed provided this function for the HVPS. The grid modulators for pulse type ECM transmitters which operate in a repeater mode have stringent specifications for allowable delay and rise time. To achieve this requirements, advanced FET technology are used. The modulator must survive a TWT arc, but the protective circuitry must not add excessive delay or rise time. Spark gaps, zener diodes, and current limiting at strategic circuit locations have been used to provide the required protection.

A loss of cooling for either the TWT or the HVPS is sensed by thermal switches mounted on the TWT collector housing and in the HVPS. These are interlocked through the HVPS to shut it down in the event of overtemperature.

The ALQ-131 HVPS functional diagram shown in **Figure 4** illustrates the integrations of the individual HVPS elements into a complete HVPS. This supply powers a CW type TWT which has anode type of beam control.

Mechanical Design

The mechanical design of the high voltage power supply must incorporate features to allow a unit that can be manufactured and is reliable and maintainable. Specifically for the AN/ALQ-131, the new design was constrained by existing package di-

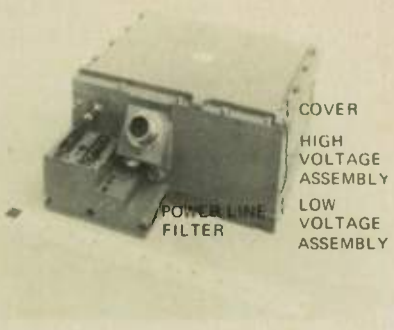

Fig. 5 AN/ALQ-131 high voltage power supply.

mensions. **Figure 5** is a photograph of the HVPS as it has been configured to meet the AN/ALQ-131 requirements.

To design a unit for manufacture, the low voltage and high voltage components were separated into two subassemblies. The higher heat dissipation in the low voltage section dictated that it be mounted directly on the system baseplate heat sink. The high voltage section was then mounted above the low voltage section. This division allowed the subassemblies to be manufactured and tested separately, each with the special attentions required for that unit.

Within the low voltage section the use of Westinghouse built power hybrid packages saved half of the volume which would have been required for discrete components. The hybrid packages dissipate the major portion of the heat generated in the low voltage sub-assembly. By mounting directly to the bottom cover, thermal interfaces and thus the semiconductor junction temperatures are minimized. Wiring interconnection is between larger packages than with a discrete design and mechanical assembly is simplified by reduced wiring. The low profile of the hybrid packages minimizes the volume of the low voltage section making additional volume available for the high voltage section. The mounting base of the high voltage section is contoured to fit closely around the low voltage section components (**Figure 6**). The increased volume in the high voltage section allows better component spacing to reduce high voltage stress and thus increase relia-

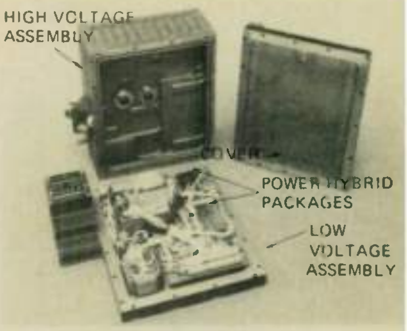

Fig. 6 AN/ALQ-131 high voltage power supply subassemblies.

bility. Several of the power hybrid packages are common to other programs.

At this point in the design, it was necessary to evaluate the dielectric system and cooling for the high voltage section. Dielectric foam and other types of encapsulation were eliminated immediately because of higher operating temperatures, possible component adhesion problems, and maintainability. Repair of an encapsulated unit is complicated by the need to remove and rebond the dielectric medium for each retest. Encapsulation of high voltage power supplies is adequate in low power units; i.e. with flux densities of about 1 watt per square inch or less. While gaseous dielectrics are adequate for higher watt densities/ and limited volume, closer component mounting dictated the use of a liquid dielectric. Because of the high operating temperatures, a fluorinated liquid was selected. A liquid dielectric saturates and penetrates inductive components conducting heat from the source. All components are completely immersed in a void free coolant and ebullient cooling eliminates hot spots. Voids and hot spots can cause reliability problems with encapsulating. Ebullient cooling uses the latent heat of vaporization to conduct heat away from a source.

Controlling the geometry of the high voltage surfaces allowed spacing which fully utilized the dielectric capability of the fluid, attaining flux densities about 10 to 15 watts per square inch. Sharp angles and points were avoided and corners were rounded at locations of high voltage potential difference. Maintenance of the liquid filled supply is greatly simplified – remove the liquid, repair and replace the liquid. The accessibility of the components in the high voltage compartment can be seen in the high voltage assembly in (**Figure 7**).

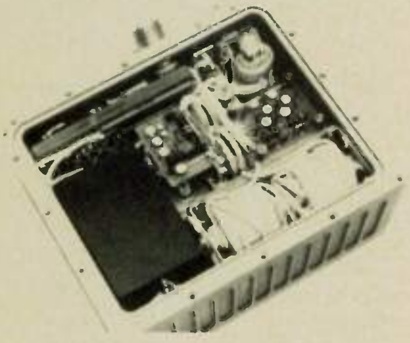

Fig. 7 High voltage assembly.

A novel system is employed to handle liquid expansion. Within the high voltage section a bladder compensates for the changing liquid volume. The air from the other side of the bladder is ducted to the low voltage section. The low voltage section is sealed, and the air displaced by the bladder is combined with the air already in the section, raising the pressure (**Figure 8**). The low voltage section air storage feature maintains a pressure on the bladder liquid combination regardless of altitude. With this system, liquid expansion or contraction is compensated for within the power supply, eliminating the need for an external compensator. The liquid dielectric is contained within the high voltage section, so that no components are uncovered at any altitude or position of the power supply during flight.

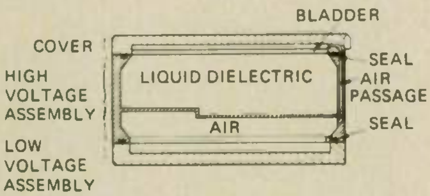

Fig. 8 Liquid dielectric pressure compensation system.

The high voltage housing is one piece with a sealed top cover. The low voltage housing forms the unit base and seals against the high voltage housing. Only two housing seals are used for the entire assembly minimizing possible leakage. Both the liquid and air filled sections have overpressure relief valves. Electrical connections are made through hermetic seals and a high voltage hermetic connector.

Manufacturing Process

To realize the full reliability potential of the hardware, the manufacturing process has been carefully planned and controlled. This is especially necessary in high voltage hardware where careless fabrication or assembly can easily cause excessive corona or high voltage break-down within the unit.

Assembly of all high voltage components is done in a controlled environment. Before assembly into the high voltage unit all material is cleaned with agents compatible with the high voltage environment, and material handling is controlled to prevent contamination prior to assembly. Assembly personnel are trained in high voltage assembly and soldering techniques. Care is taken to prevent entry of any foreign material into the assembly and to prevent burrs or any other sharp edges or points. Spacing between components and subassemblies is critical. Extra care is taken during the assembly process to assure that component positioning is maintained within tolerance.

Corona testing provides an excellent means of evaluating the quality of assembly. Excessive corona (partial discharge) is indicative of improper assembly of well designed high voltage equipment. If the corona were not detected and corrected, the life of the hardware would be shortened. Corona induced failures can occur within a few hours to several hundred hours of operation.

The manufacturing cycle for the hybrid circuit packages includes steps to ensure long failure-free life. After assembly and before sealing they are electrically tested. At this point, any assembly errors or defective components can be detected and corrected. After hermetic sealing, the packages are subjected to a 24-hour stabilization bake at 125° C without power applied. The units are then centrifuged to test the integrity of the internal bonds followed by a 168-hour burn-in under power at 110°C. The unit is then given a parameter check at three different temperatures: -55°C, +25°C and +110°C. The hybrids which complete this cycle of processing can be installed in the HVPS with a high degree of confidence. Further confidence in the completed HVPS is gained by subjecting the entire unit to a burn-in test of 48 hours duration at a temperature of 80°C. The unit is then operated in a combined temperature-altitude environment in which the temperature extremes are -55°C and +100°C at the maximum system altitude with the input voltage varied between 106 and 123 V_{rms}.

Prototype Evaluation

The final phase of the design process is the testing and evaluation of production prototypes. In this phase the performance is verified and any design iterations found necessary can be incorporated without seriously impacting the production schedule. For the AN/ALQ-131(V) transmitters, prototypes were built and evaluated in a series of engineering tests, production acceptance tests and environmental qualification tests.

ACCOMPLISHMENTS

It is possible to build reliable transmitters. Solutions to the classic transmitter failures have been developed and incorporated into the new high voltage power supplies designed for the AN/ALQ-131. Prototypes have been fabricated and subjected to a complete set of electrical evaluations and qualification tests. By carefully considering reliability and produceability from initial concept through a testing of a prototype, a production program can be entered with confidence.

The question of "can we afford reliability?" has been addressed. It is true that the initial acquisition costs of transmitters designed using the techniques described here may be more than those for units designed without the emphasis on reliability. Life-

(continued on page 62)

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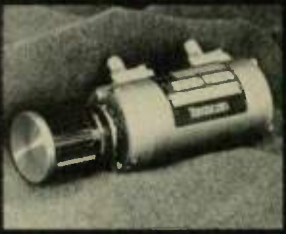

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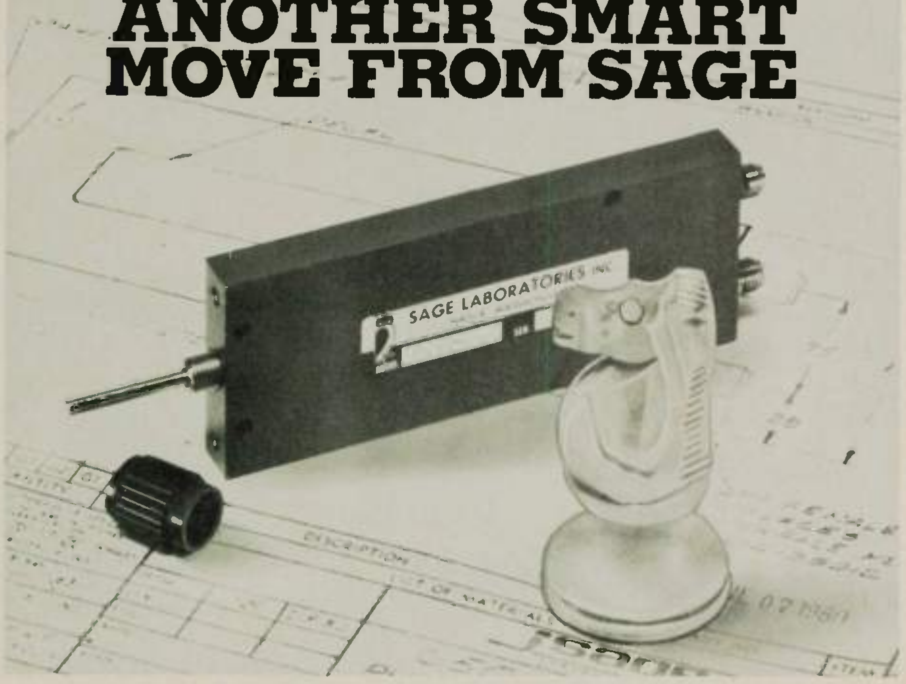

cycle cost studies, however, prove that reliability in the field can more than offset the greater acquisition cost for the equipment over its total life span.

The high voltage power supplies developed for this program were each packaged in a volume of 350 cubic inches. One provides input power to a CW type of TWT, while the other furnishes input power to a pulse TWT. These units contain cathode, collector, and filament power supplies, a grid modulator, and all of the protection and control circuits required by the transmitter. The supplies have demonstrated their ability to function over a range of heat sink temperatures from -55°C to +100°C and to the maximum system altitude. Successful operation during military standard tests for temperature altitude, vibration, shock, humidity and explosion also was demonstrated.

Significant accomplishments of the design include:

- high power density of drive circuits through the use of power hybrid packages;
- reduced high voltage stress by increased spacing due to low voltage circuit integration (reducing size) and use of liquid dielectric; and
- improved maintainability by use of removable liquid dielectric and a modular design.

Portions of the designs can be applied to future programs through the use of standardized circuit partitioning. This approach produces transmitter equipment with high reliability and good produceability, increasing the unit mean time between failure and thus the electronic countermeasure operational readiness.

Harry Conway is a Fellow Engineer at the Westinghouse Defense and Electronics Systems Center.

Paul S. Spiecker is a Senior Engineer and is Program Manager for the Westinghouse High Voltage Power Supply Program.

Frederick H. Wolf is the Supervisory Engineer in charge of a transmitter design group at the Westinghouse Defense and Electronic Systems Center.

STANDARD DESIGNS

FERRITE ISOLATORS AND CIRCULATORS

POPULAR OCTAVE BANDS — STANDARD DESIGNS

These units are internally terminated circulators (isolators) with SMA female connectors and are available from stock*

Frequency (GHz)	Model No.	Isolation (dB min.)	Insertion Loss (dB max.)	VSWR (max.)	Size Height	Size Width	Size Thickness
1.0 - 2.0	T-1S63T-18	18	0.5	1.30:1	2.75	2.75	0.88
2.0 - 4.0	T-2S63T-6	17	0.5	1.35:1	1.63	1.63	0.75
2.6 - 5.2	T-2S63T-44	17	0.5	1.35:1	1.25	1.25	0.70
4.0 - 8.0	T-4S63T-10	17	0.4	1.35:1	1.06	1.00	0.76
4.5 - 9.0	T-4S63T-13	17	0.5	1.35:1	1.13	0.95	0.76
5.2 - 10.4	T-5S63T	17	0.5	1.35:1	1.06	1.00	0.76
8.0 - 16.0	T-8S63T-18	17	0.5	1.35:1	0.75	0.63	0.40
10.0 - 20.0	T-10S63T-5	17	0.7	1.35:1	0.68	0.51	0.56

S-T-R-E-T-C-H OCTAVE BANDS — STANDARD DESIGNS

Both circulators and isolators are available with either SMA-male or female connectors. Model Nos. shown are isolator versions with SMA-female connectors.

Frequency (GHz)	Model No.	Isolation (dB min.)	Insertion Loss (dB max.)	VSWR (max.)	Size Height	Size Width	Size Thickness
1.7 - 4.2	T-1S83T-2	16	0.7	1.50:1	1.70	1.63	0.76
2.0 - 4.5	T-2S73T-4	16	0.6	1.40:1	1.70	1.56	1.10
3.7 - 8.2	T-3S73T-2	16	0.7	1.40:1	1.06	1.00	0.76
4.4 - 10.0	T-4S73T-2	16	0.7	1.40:1	1.13	0.95	0.76
5.9 - 13.0	T-5S73T-1	17	0.6	1.35:1	0.81	0.63	0.80
7.6 - 18.0	T-7S83T-20	16	0.8	1.50:1	0.76	0.63	0.62

POPULAR NARROW BAND — STANDARD DESIGNS

Frequency (GHz)	Model No.	Isolation (dB min.)	Insertion Loss (dB max.)	VSWR (max.)	Size Height	Size Width	Size Thickness
.95 - 1.225	T-0S23T-2	20	0.5	1.25:1	1.20	1.20	0.75
1.2 - 1.6	T-1S23T-7	17	0.5	1.35:1	1.25	1.25	0.70
1.9 - 2.3	T-1S13T-2	20	0.4	1.30:1	1.25	1.25	0.75
2.2 - 2.3	T-2S03T-2	20	0.4	1.35:1	1.00	1.00	0.62
3.7 - 4.2	T-3S13T-9A	25	0.25	1.10:1	0.75	0.75	0.50
4.4 - 6.5	T-4S33T-1	17	0.5	1.35:1	0.75	0.75	0.50
5.9 - 6.4	T-5S03T-3A	26	0.3	1.10:1	0.75	0.75	0.69
7.0 - 11.0	T-7S43T-6	28	0.4	1.10:1	0.85	0.75	0.60
8.0 - 12.4	T-8S43T-1A	17	0.4	1.35:1	0.78	0.63	0.70
12.4 - 18.0	T-12S43T-8	18	0.5	1.30:1	0.68	0.51	0.56
18.0 - 26.5	T-18S33T-7	16	1.0	1.50:1	0.68	0.51	0.53

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Solid-State Amplifiers as TWT Substitutes

FERDO IVANEK
Harris Corporation
Farinon Electric Operation
San Carlos, CA

Progress in replacing TWT's with solid-state microwave amplifiers appears to be slower than generally desired. Attention concentrates on terrestrial microwave communications, because this application leads in quantity of installed TWT's. The most often heard order-of-magnitude estimate is 10^5 units. The total is likely to be stabilizing in spite of the continued use of TWT's in some new equipment; there are many instances in which old equipment using TWT's is being replaced with new all solid-state equipment.

Around 1970, some European microwave equipment manufacturers started to exploit silicon bipolar power transistors and varactors in a microwave power amplification scheme. This scheme used frequency division at the input and frequency multiplication at the output of a multistage transistor amplifier operating in most cases in the 1.5 to 2.0 GHz frequency range. This approach found a number of applications in the various communication frequency bands between approximately 4 and 12 GHz. The obtainable output power and efficiency necessarily decline with increasing output frequency, but this limitation was partially compensated in systems applications by the increasing availability of receiver front ends with lower noise figures.

US and Japanese manufacturers of microwave communication equipment showed little interest in this "indirect" power amplification scheme as substitute for TWT amplifiers, and instead started to pursue the "direct," fundamental-frequency amplification approach as soon as promising solid-state devices became available for power amplification. By the mid 70s Gunn and IMPATT diodes found several systems applications of this kind. These stimulated the panel session "Solid-State Amplifiers as TWT Substitutes in Microwave Systems for Frequencies above 5.9 GHz," held at the 1974 National Telecommunications Conference in San Diego, California, which has been covered by a Special Report in the *Microwave Journal* ("Solid-State Amplifiers vs TWTA's," February 1975, pp. 14-20, and March 1975, pp. 22-28, 60).

In the late 70s, the GaAs FET became the most promising solid-state microwave device for power amplifier applications competing with TWT's. This stimulated a follow up in the form of a sequel panel session, which has been held at the 1980 International Conference on Communications in Seattle, Washington, under the title "Solid-State Amplifiers as TWT Substitutes — Half a Decade Later." The panelists participating were:

P. G. Debois, Bell Telephone
Manufacturing Co.
Antwerp, Belgium

J. W. Gewartowski, Bell Telephone Laboratories, Inc.
Allentown, Pennsylvania, USA

I. Haga, Nippon Electric Co., Ltd
Yokohama, Japan

C. C. Hsieh, Harris Corp.,
Farinon Electric Operation
San Carlos, California, USA

R. L. Metivier, Thomson-CSF,
Electron Tube Division,
Paris, France

K. Morita, Nippon Telegraph and
Telephone Public Corp.
Yokosuka, Kanagawa, Japan

F. Ivanek of the Harris Corporation, Farinon Electric Operation, organized the panel and served as moderator.

In our two-part Special Report (the second part to be published in October), each panelist presents selected portions of his opening statement[+] and summarizes his views expressed in the panel discussion or formed as a result of it.

Part I provides the presentations by R. L. Metivier, P. G. Debois, and J. Gewartowski.

- R. L. Metivier provided the frame of reference by presenting the capabilities and prospects of modern TWT amplifiers for terrestrial microwave communications.
- P. G. Debois concentrated on the single-stage, high-gain capability of a phase-locked microwave transistor oscillator and described corresponding applications in the place of a TWT amplifier.
- J. Gewartowski summarized the extensive experience accumulated with IMPATT power

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Editor's Note: Part I of the Special Report describing the Panel Session held at the 1980 International Conference on Communications, Seattle, Washington.

[+] ICC '80 Conference Record, Vol. 1, pp. 17.0.1-17.6.1.

amplifiers in two different categories of systems applications and presented information on the introduction of GaAs FET power amplifiers in the 4 GHz band.

The three presentations by I. Haga, C. C. Hsieh, and K. Morita will be included in Part II.

Additional short presentations from the floor were solicited in order to broaden the discussion basis. Four such presentations were made and will be summarized at the end of the second part of this Special Report, together with notes on the discussion.

The opening statements by the panelists and the short presentations from the floor were most informative and stimulated a highly productive discussion. We welcome the opportunity to highlight this session for the benefit of the interested readers who were unable to participate.

MODERN HIGH-EFFICIENCY MICROWAVE LINK TWT AMPLIFIERS

ROBERT L. METIVIER
Thomson-CSF, Electron Tube Division
Paris, France

The imminent demise of traveling-wave tube amplifiers (TWTA's) for microwave links, in favor of solid-state types, has long been forecast and sometimes even announced. But to paraphrase Mark Twain, the reports of the death of the microwave-link TWTA are greatly exaggerated! In fact, the general trend to digital modulation techniques may well make tube-type amplifiers even more popular, because of the higher power levels required. Similarly, the soaring cost of electrical energy can only favor the modern TWTA, with its overall efficiency of 30% or better – more than twice as good as the most efficient solid-state types now commercially available.

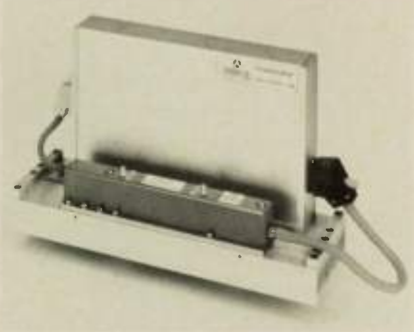


Fig. 2 A compact, high-efficiency Thomson-CSF microwave link TWTA mounted on an optional radiator.

PROFILE OF A MODERN TWT

First of all, it is important to emphasize the progress made in TWT amplifiers over the past decade, as illustrated graphically in **Figure 1**. We are no longer talking about the old "glass bottle" TWT, replaceable in its focusing assembly. Instead, the tubes now being fitted in new high-capacity links (1800 or 2700 telephone channels or equivalent) are of rugged metal-ceramic construction and feature reliable multiyear operation. Outgrowth of a major 11/12 GHz, satellite-TWT development program, the "TH 3600 series" tubes from our company have integral ppm beam focusing and impregnated cathodes with expected operating lives of 200,000 hours or more. They also have two-stage depressed collectors, the second stage operated at half the first-stage potential, for higher efficiency.

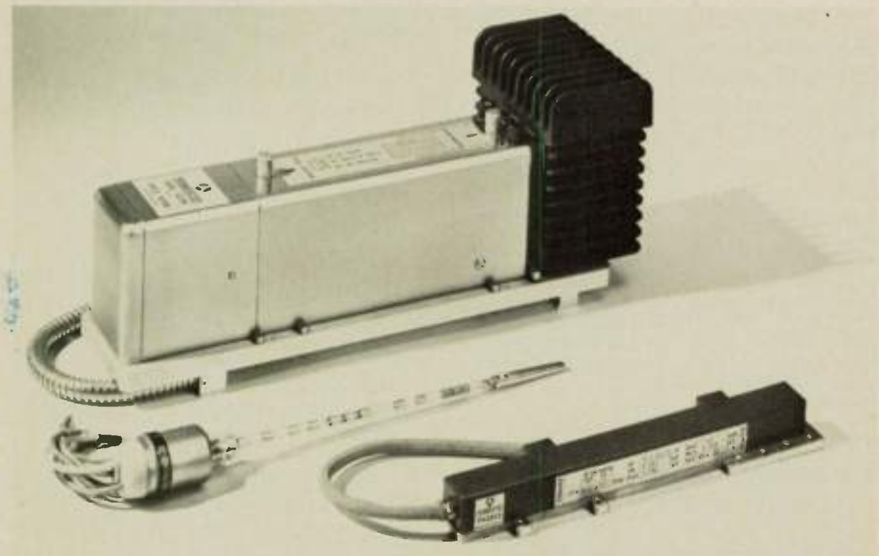


Fig. 1 A modern microwave-link TWT (bottom) alongside an older-model glass-metal tube with its bulky beam-focusing assembly.

Characteristics measured on regular production models include 36% efficiency at saturation, typical noise figures ranging from 24 dB at 6 GHz to 27 dB at 11 GHz and an AM/PM conversion coefficient at tube saturation under 4°/dB.

Large-scale life testing of similar satellite TWT's has seen 58 tubes accumulate more than 2 million hours of failure-free operation as of June 1980, with the first tubes placed in testing having already operated *continuously* for over 5 years.

Concern has sometimes been expressed regarding the reactivation of TWT's after a long period of storage. But this is no problem at all for these modern impregnated-cathode types. We have successfully restarted tubes that had been in storage for *7 years*. Another example is the back-up tube in the CTS satellite, which was recently reactivated after 4 years of cold standby in the orbiting satellite. After three minutes warm-up, the high voltages were applied and the TWT operated perfectly.

THE AMPLIFIERS

The power supplies for these TWT amplifiers have also been "revolutionized." Now incorporating no tubes, these high-frequency chopping types feature high efficiency and long-term reliability. Our model operates from a non-regulated dc line (21 to 56 V) or can be fitted with an ac/dc converter to operate from any 120 or 230 V, 50 or 60 Hz supply. The computer-determined MTBF, based on component failure probabilities, is in excess of 100,000 hours (over 11 years), and current operating

MTBF of 180,000 hours.*

One of the really important features of these modern TWTA's is their standardization. The tubes of a given model all have the same operating voltages (except for a slight and simple anode-voltage adjustment, using just one control knob) and RF drive-power levels (for example, 1 mW for tube saturation). This makes the power supply and TWT completely interchangeable for each TWTA model — a real simplification for the link-operating companies.

Figure 2 shows one of these new-generation TWTA's mounted on an optional heat sink/radiator. For those users so desiring, all of these amplifiers can also be ordered in integrated units for mounting in standard 19-inch racks.

LINEARITY

Proponents of solid-state amplifiers often point to their linearity as one concrete advantage over TWT-equipped types. We all know that the traveling-wave tube is an inherently non-linear device, but with sufficient backoff, the TWT's RF-transfer characteristic becomes extremely linear, while the overall efficiency is still 10%. And with an appropriate negative-feedback system at intermediate frequency, it is certain that linear TWT operation could be obtained close to tube saturation. For example, French UHF-TV transmitter high-power amplifiers with positive modulation operate with only 0.5 dB backoff for the white-level video signal.

CONCLUSION

Despite all the claims made for solid-state amplifiers, the modern high-efficiency TWTA continues to sell well. Increasing numbers of new 1800-channel and 2700-channel links, both in the USA and elsewhere, are now being equipped with these amplifiers, and the switch to digital modulation is not expected to have a

Highly cost competitive, reliable and featuring excellent everyday performance in the field, TWTA's are alive and well — and no push-over for anyone!

TWTA SUBSTITUTES USING A TRANSISTOR PLL VCO

P. G. DEBOIS
Bell Telephone Manufacturing Co.
Antwerp, Belgium

Increasing the reliability of radio relay systems has been greatly enhanced by the use of solid-state amplifiers. Either direct RF amplification or the division-amplification-multiplication (DAM) scheme are in use. Most European manufacturers use the DAM scheme because power amplification is accomplished with silicon bipolar power transistors available in the 2 GHz range, and frequency multiplication with conventional varactor doublers and/or triplers.

Among the different methods of frequency division the phase-lock loop (PLL) approach offers several advantages which also apply to RF amplification. A schematic block diagram of TWTA substitutes using PLL VCO's is shown in **Figure 1** together with a tabulation of some applications DC-to-RF conversion efficiencies are of the order of 10%. The typ-

trated in **Figure 2**. The inherent feedback scheme advantages of the PLL VCO are listed in **Table 1**. Broadband feedback loops are needed for communication signal transmission.[1]

Such high-gain power amplifiers have an AM/PM conversion of less than 1°/dB (typically 0.6°/dB) for an input variation of ±1 dB, even with output power amplifiers having 5 to 15°/dB. VCO thermal drift does not influence the intermodulation, the modulation response, or any other characteristic.

System performances have been demonstrated since 1973,[2,3] in production and field tests, e.g. for 1800 FDM channels with CCIR loading and emphasis:

- fixed thermal noise contribution: maximum 8 pWOp, typical 2 pWOp;
- intermodulation noise contribution: maximum 10 pWOp, typical 6 pWOp;
- modulation response: ±0.5 dB maximum up to 10 MHz typical ±0.3 dB; and
- differential phase and gain: 2° and 1%, respectively, for a test frequency of 4.43 MHz across a band of ±12 MHz.

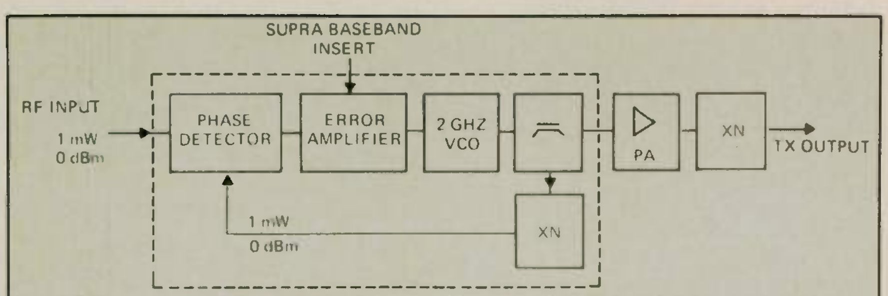
TABLE 1

FEATURES AND ADVANTAGES OF POWER AMPLIFIERS USING PLL VCO's

FEATURES	ADVANTAGES
• LARGE GAIN: 25 TO 30 dB FOR ONE MICROWAVE DEVICE	• EFFICIENCY RELIABILITY
• "ACTIVE FILTER" LOCKING	• NO S.S.B. FILTER NECESSARY
• NEARLY IDEAL LIMITER WITH LOW AM/PM CONVERSION	• NO AMPLITUDE EQUALISATION NECESSARY NO GROUP DELAY EQUALISATION NECESSARY AM/PM OF SUBSEQUENT POWER AMPLIFIERS NEGLIGIBLE
• GROUP DELAY NEGLIGIBLE (LESS THAN 1 NSEC)	• NO GROUP DELAY EQUALISATION NECESSARY
• FEEDBACK	• LOW INTERMODULATION NOISE CONTRIBUTION
• "SINGLE KNOB" VCO-FREQUENCY TUNING	• AMPLIFIER TUNES OVER FULL CCIR BAND
• LOW TRANSISTOR BIAS VOLTAGE	• SAFETY

---

* We hear reports of million-hour microwave transistor MTBF's, but the experience of the manufacturers and users of solid-state microwave-link amplifiers is another story, and a much less satisfactory one!



RADIO FREQUENCY GHZ	MULTIPLICATION FACTOR N	VCO POWER mW	P A OUTPUT W	TX OUTPUT W	TRANSMISSION CAPACITY TF CHANNELS
6.4-7.1	4	400	7	2	1260
7.1-7.7	4	400	6	1.5	1260
3.6-4.2	2	400	10	5	1800
5.9-6.4	4	400	15	5	1800

Fig. 1 Schematic and examples of TWTA substitutes using a transistor PLL VCO.

The application of PLL VCO's in RF amplifiers for radio links also results in a systematic amplitude equalization per hop. Group delay characteristics are added as in other systems, but the IF-to-IF amplitude response of a radio relay section will be the IF-to-IF amplitude response of the last hop.

The availability of reliable new GaAs active microwave devices has strong influence on the RF amplifier market including the amplifier type discussed above, specifically:

- use of Gunn and IMPATT devices shifts to frequencies above 18 GHz;
- straight broadband amplification up to 15 GHz is readily available; and
- direct RF amplification with a FET PLL VCO offers advantages in reliability and gain.

When installing new radio routes with low-level interference conditions, the use of low-noise FET amplifiers at the receiver front end drastically reduces the required transmitter output power. For the transmission of 1800 channels a 5 dB noise figure for a receiver and a transmitter output power of 2.5 W is equivalent to an 11 dB noise figure and a 10 W TWT RF output power.

In building up new radio relay networks, where no constraints exist concerning interference problems, the use of lower transmitter output with simultaneous reduction of noise figure is therefore stimulating the use of FET's.

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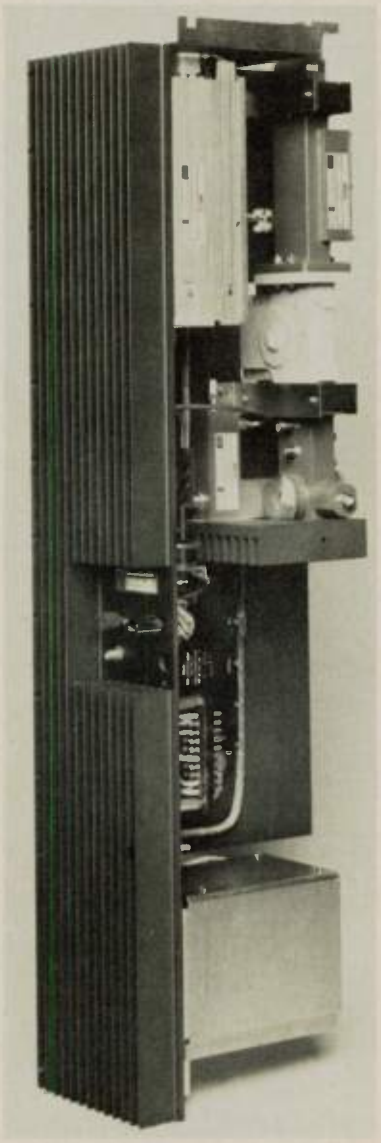

Fig. 2 Hardware-implementation of TWTA substitute using a transistor PLL VCO.

SOLID-STATE MICROWAVE POWER AMPLIFIERS USED IN THE BELL SYSTEM

J. W. GEWARTOWSKI
Bell Telephone Laboratories, Inc.
Allentown, PA

Solid-state microwave power amplifiers have been used in the Bell System since 1972. The first amplifier was a 1 W, 6 GHz IMPATT amplifier, which used a single Si IMPATT diode.[1] In February, 1975 a 3 W 11 GHz IMPATT amplifier went into service. This amplifier uses three GaAs IMPATT diodes.[2] These IMPATT amplifiers were designed to allow field replacement of the IMPATT diodes.

A continuing study has been maintained of the reliability of the 11 GHz amplifier. The replacement diode is shipped from the factory together with a one-page questionnaire and a mailing envelope. The completed questionnaire provides information on the circumstances associated with the failure. This is important since diode failures can occur from improper installation procedures in addition to intrinsic failure mechanisms. The failures due to improper installation procedures were not included in the reliability analysis. As of June 1, 910 amplifiers have accumulated over 57 million device hours of operation, with 31 in-service IMPATT diode failures. This corresponds to 1.8 million hours between failures.

Although IMPATT amplifiers have provided reliable service, they do have disadvantages. Since the IMPATT diodes must be used in circulator-coupled reflection amplifier stages, they are narrowband and have appreciable variation of output power with temperature. Thus, when a new transistor, the GaAs FET, became available in the mid-70s with

(continued on page 72)

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3.95 - 5.85	187	UG149A/U	G213D2	G214D2	G209D2
5.9 - 6.5	159	CPR159F	F213G	F214G	F209G
5.85 - 8.2	137	UG344/U	C213D2	C214D2	C209D2
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watts of output power, attention shifted to using it instead of the IMPATT for new system applications. The GaAs FET is superior to the bipolar transistor in gain, power output, noise performance, and linearity at frequencies of 6 GHz and higher. The first Bell System application was at 4 GHz where GaAs FET's and bipolar transistors had comparable performance. GaAs FET's were chosen for this application because of their superior linearity for potential digital transmission applications.

Two 4 GHz GaAs FET amplifiers are being manufactured for use in the TD-2 and TD-3D radio-relay systems.[3,4] One delivers 2 W, and the other 5 W. These amplifiers are replacing the vacuum triode amplifiers, which have been in use since 1950. Besides improved reliability, the GaAs FET amplifiers offer the additional advantage of being operable directly from the –24 V battery plant.

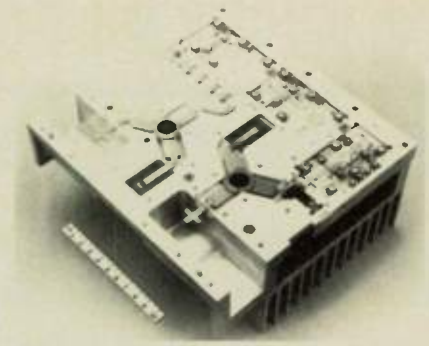

Fig. 1 A 5 W, 4 GHz GaAs FET amplifier, with 25 dB gain.

Figure 1 shows an open view of the 5 W amplifier, with the input waveguide at the lower right. It has four stages of amplification with GaAs FET's of gatewidths 1, 3, 6, and 16 mm, respectively, from input to output. Typical dc current input is 2.4 A.

The 2 W amplifier is similar in construction, with the fourth stage omitted. In this case, the dc current required is typ. 1.0 A.

Two 2 W amplifiers have been in service in the Bell System since August, 1979. As of June 1, 2100 amplifiers have accumulated an estimated 19.7 million GaAs FET device hours of operation, with 16 GaAs FET failures. This corresponds to 1.2 million hours between failures. This number is expected to improve by an order of magnitude as time goes on because the GaAs FET design has been improved for greater reliability since the initiation of manufacture. The first 1500 amplifiers were manufactured with GaAs FET's having a failure rate of approximately 1000 FIT's (failures in 10^9 hours).[5] Subsequent amplifiers used GaAs FET's with failure rates less than 100 FIT's.[6]

Six prototype 2 W amplifiers have operated in an aging rack at Bell Laboratories for over 14 months. Some 187,000 GaAs FET operating hours have accumulated without failure. More significantly, the amplifiers have not evidenced any gain degradation over this period.

As of June 1, 5 W amplifiers had not yet been installed in the system. Failure data for the 5 W amplifiers are expected to be better than those given for the 2 W amplifiers, since all the GaAs FET's will be of the improved-reliability design.

Thus, field experience has verified that the GaAs FET amplifier can provide reliable service as the power amplifier in radio-relay systems. It is expected to be the preferred component for many of the new and retrofit system applications.

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Designers Tip

Installation and RF Matching of

Power Terminations for Microstrip and Stripline Applications

PHILIP LEVINE, Product Manager, RF Components
KDI Pyrofilm Corporation
Whippany, NJ

Flange-Mounted Conduction Cooled Terminations are presently available for power levels up to 800 watts for use in microstrip or stripline circuits. Typical applications are terminating unused ports of hybrids or circulators. Two major considerations are of importance in the application of these terminations:

- Proper installation in order to assure that the specified power rating of the termination is obtained.
- Proper RF matching in order to minimize the RF reflection from the load.

The termination is usually mounted to the ground plane of the stripline or microstrip by screws which go into through tapped holes in the ground plane as shown in **Figures 1, 2, or 3.** The ground plane surface should be flat and a thin layer of thermal grease applied between the termination and the ground plane for maximum thermal transfer.

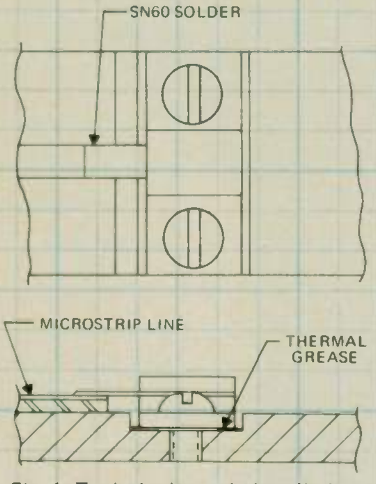

Fig. 1 Typical microstrip installation.

Since the case temperature of the load must be maintained at some maximum temperature (typically 100°C), the ground plane of the circuit adjacent to the termination must be cooled.

The temperature of the load depends upon the ambient temperature plus the temperature rise of the load plus the temperature rise of the heat sink above ambient. The following calculation illustrates the determination of the maximum heat sink thermal resistance for a typical application.

Ambient temperature	**=25°C**
Load temperature rise at 150 watts input power and 0.4°C/watt thermal resistance.	**=60°C**
Limit of heat sink temperature rise	**=15°C**
	100°C Total
Maximum heat sink thermal resistance	$= \frac{15°C}{150W}$
	=.1°C/watt

This may be realized by using cooling fins with forced air cooling, or with liquid cooling on the surface of the ground plane.

In order to obtain optimum RF performance, i.e., minimum SWR, the load must be mounted to minimize the reactive discontinuity between the termination and the microstrip or stripline circuit. In both cases the termination contact tab must be lined up to the center line of the circuit center line as shown in **Figures 1, 2, and 3.** Depending on the ground plane spacing, it may be necessary either to undercut or add material to the ground plane to obtain the correct spacing.

The other factors affecting SWR are any reactive step discontinuities between the stripline or microstrip ground plane spacing and the ground plane to center conductor spacing of the termination and any reactance of the termination resistive film. Both of these reactances are essentially capacitive and it is usually possible to compensate for such discontinuities by the introduction of equal inductive reactances. Matching may be accomplished either by moving the load back from the end of the stripline or by adding a matching capacitance 1/4 wavelength back on the transmission line.

These techniques also allow terminations to be applied in narrow bands well above their design frequencies. For example, a typical 20 W. termination designed for use up to 2.0 GHz has a capacitance of 1.4 pf. At 4 GHz, its capacitive reactance is 28.42 ohms and its SWR in a 50 ohm system would be 1.8. The addition of a compensating reactance of one of the types described will match the termination at 4 GHz and yield SWR's below 1.2 over a 10% band.

It is also possible for the termination manufacturer to shape the resistive film area to obtain a better SWR at a specified frequency but this will usually reduce the power handling capacity of the termination.

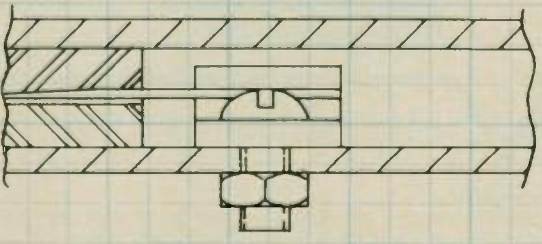

Fig. 2 Typical dielectric stripline installation.

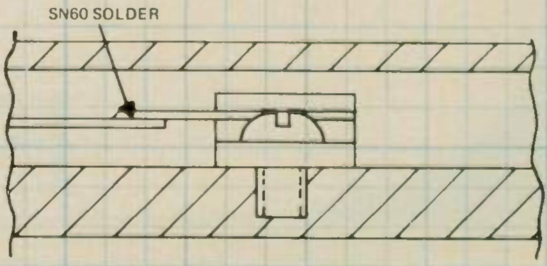

Fig. 3 Typical air stripline installation.

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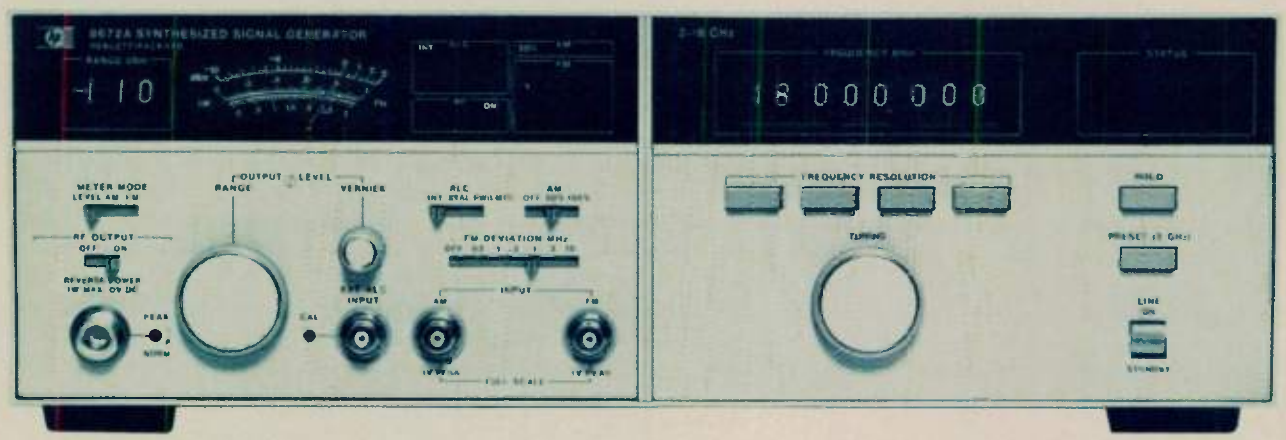

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In radar and EW applications you can use the frequency range and the high performance pulsing of the associated Model 11720A (2-18 GHz <10 ns rise/fall times, >80 dB on-off ratio).

Now combine the 8672A's full HP-IB programmability with its fast settling time (<15 ms to be within 1 kHz) and you have an ideal instrument for automatic test systems.

And all of these features add up to make the 8672A a highly versatile general purpose bench generator. Prices: 8672A, $30,500*; Option 008, add $2,800*; 11720A, $2,500.*

For local oscillator applications, consider the HP 8671A Synthesizer featuring a 2-6 GHz programmable frequency range, FM, and +8 dBm output level (unlevelled). $17,600.*

To find out more about these ideal microwave signal sources, contact your nearby HP sales office or write Hewlett-Packard Co., 1507 Page Mill Road, Palo Alto, CA 94304.

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Microwave Products

Instrumentation

DOWN CONVERTER PERMITS RF DISTORTION TESTS WITH LINK ANALYZER

Model 3730B down converter is a transparent RF-to-IF interface and makes it possible to analyze RF distortion using a microwave link analyzer at the lower IF. Plug-ins cover the 1.7 to 14.5 GHz range; the 4, 6 and 8 GHz bands are covered with one plug-in. A tracking AFC and recovered sweep facility permits tracking of swept RF signals; sweep compression of the IF signal permits measurements with conventional MLA's over bandwidths of up to 250 MHz. Other features include: upper/lower sideband operation; an RF input isolator option and dual 70/140 MHz IF output. U.S. prices: 3730B mainframe - $3785; plug-in options from $4610 (3736B) to $9425 (3739B). Del: 10 wks. **Hewlett-Packard Co., Palo Alto, CA. (415) 857-1501. Circle 117.**

SWEEPER PLUG-IN YIG-TUNED OSCILLATORS

The 503 series of YIG-tuned oscillator plug-in units for the Systron-Donner Sweep Generator Mainframe are offered in a variety of power levels and bandwidths. Frequency bands span .5-6 GHz in one-half octave, full and two-octave steps. Power output options range from 10-1000 mW on some bands. Frequency stability vs. temperature is better than ± .01% per C; frequency pulling with load SWR up to 3 is less than ± .002%; frequency change vs. full range power change is less than ± .005% and harmonic content in the output is less than -20 dB; other spurious products are less than -70 dB. Series feature plug-in circuit boards, oscillator and front panel controls. Price: 503-25, (2-4 GHz, 25 mW) $2,000; 503-50, (2-4 GHz, 50 mW) $2,500. Avail: 4 wks. **Electronics Surveillance Components, Inc., Palo Alto, CA. (415) 494-7803. Circle 116.**

IEEE 488-1978 BUS TESTER

The GPIB-400 bus tester is compatible with any IEEE standard 488-1978 instrumentation system. It permits checkout of all system elements, monitors bus management and data lines and verifies data transfers and commands. It demonstrates IEEE 488 operation, can simulate an instrument and performs Controller, Talker and Listener functions. Unit features LED's for monitoring all IEEE 488 bus lines, switches for controlling these lines, automatic source handshake mode, and automatic acceptor handshake mode. Price: $995. Avail: 30-60 days. **National Instruments, Austin, TX. William C. Nowlin, Jr., (512) 454-3526.** **Circle 118.**

Devices

1 kW 95 GHz AMPLIFIER

VKF-2400T is an extended interaction amplifier (EIA) which delivers 1 kW minimum peak power output (with a 30 dB minimum gain at 95 GHz. Operating life is warranted for 1000 hrs. The amplifier has a 200 MHz (3 dB) instantaneous bandwidth, and a mechanical tuning range of 1 GHz. Nominal pulse length is 10 μs, with a pulse voltage of 13 kV. Beam voltage is 21 kV and peak beam current is 650 mA. Vol: 90 cu. in. Weight: < 15 lbs. Choice of forced-air or water cooling. **Varian Associates, Electron Device Group, Varian Canada, Inc., Georgetown, Ontario, Canada. (416) 457-4130.** **Circle 120.**

LOW NOISE TRANSISTOR

Transistor type NE683 offers typical NF of 3.5 dB and G_{NF} of 7 dB at 1 GHz. It features low collector-to-emitter (V_{CE}) voltage of 1-5 V, and low collector current (I_C) of 0.1-1.0 mA. Device is designed for low power consumption, battery-operated systems and comes in Micro-X package. Price: $4.05, for 100 qty. Del: Immediate. **California Eastern Laboratories, Inc., Santa Clara, CA. Jerry A. Arden, (408) 988-3500.** **Circle 119.**

Materials

BROADBAND, HIGH PERFORMANCE FOAM ABSORBER

ECCOSORB® AN/PXP is a line of weatherproof and fuelproof UHF microwave absorbers composed of lightweight flexible oam. Absorbers have extra performance of −20 dB or better over a broad band of frequencies (bandwidth 6:1 or better). No outer fabric or coating is needed for environmental protection, because construction uses a closed-cell foam. Although not recommended for high vacuum environments, absorber has urvived prolonged exposure to positive air pressures up to 200 psi (14 kg/sq. cm.). Service temperature is 200°F (93°C). Size: 2' x 2' (0.61m x 0.61m). **Emerson & Cuming, Canton, MA. Jeanne B. O'Brien, (617) 828-3300.** **Circle 115.**

(continued on page 78)

Components

DIRECTIONAL COUPLERS SPAN 10-1000 MHz

Models DC-1000-10 and DC-1000-20 are directional couplers with 11.5 dB and 19 dB coupling, respectively which operate from 10 to 1000 MHz. Coupler flatness is ± 0.25 dB for the former and ± 0.5 dB for the latter. Units have SWR of 1.5 maximum in a 50 Ω system and directivity is 20 dB, minimum over the band. Typical insertion loss is 1.0 dB (DC-1000-10) and 0.5 dB (DC-1000-20). Input power is 5 W CW maximum. Size: 1.344" x 1.344" x .750" for package and couplers are offered with SMA, BNC, TNC or type N connectors. Price: $85-90 each. Avail: from stock. **American Microwave Corp., Damascus, MD. Raymond Sicotte, (301) 253-6782.**
Circle 122.

LOW COST 3.7-4.2 GHz GaAs FET LNA

The low noise amplifier, Model AWC-4215, covers the full 3.7-4.2 GHz frequency range, provides 120°K maximum noise temperature (1.5 dB noise figure) and 50 dB typical gain (with ± 0.5 dB full-band gain flatness). Unit also offers +5 dBm minimum output power (1 dB gain compression), +15 dBm intercept point for third-order intermodulation products and maximum input and output SWR in a 50-ohm system is 1.3 and 1.5, respectively. Input power is +15 to +18 Vdc, 150 mA, typical. Price: $795, for single quantity. **Avantek, Inc., Santa Clara, CA. Jim Lindauer, (408) 249-0700. Circle 123.**

COAXIAL BANDPASS FILTER

A three-section coaxial bandpass filter, #200975, is mechanically tunable with single knob control and direct frequency output. Tuning range is 780 to 970 MHz; insertion loss is 1.5 dB maximum at $f_0 \pm 1$ MHz; and SWR is 1.30 at $f_0 \pm .5$ MHz. The 3 dB bw is $f_0 \pm 2.5$ MHz; 18 dB bw is $f_0 \pm 5$ MHz; and 42 dB bw is $f_0 \pm 16.0$ MHz. Power rating is 50 W CW and temperature range is -46°C to +71°C. Connectors are SMA female. Price: in small qty., $16 each. Del: 8-10 wks. ARO. **Coleman Microwave Co., Edinburg, VA. (703) 984-8848.**
Circle 125.

MIC STEP ATTENUATORS

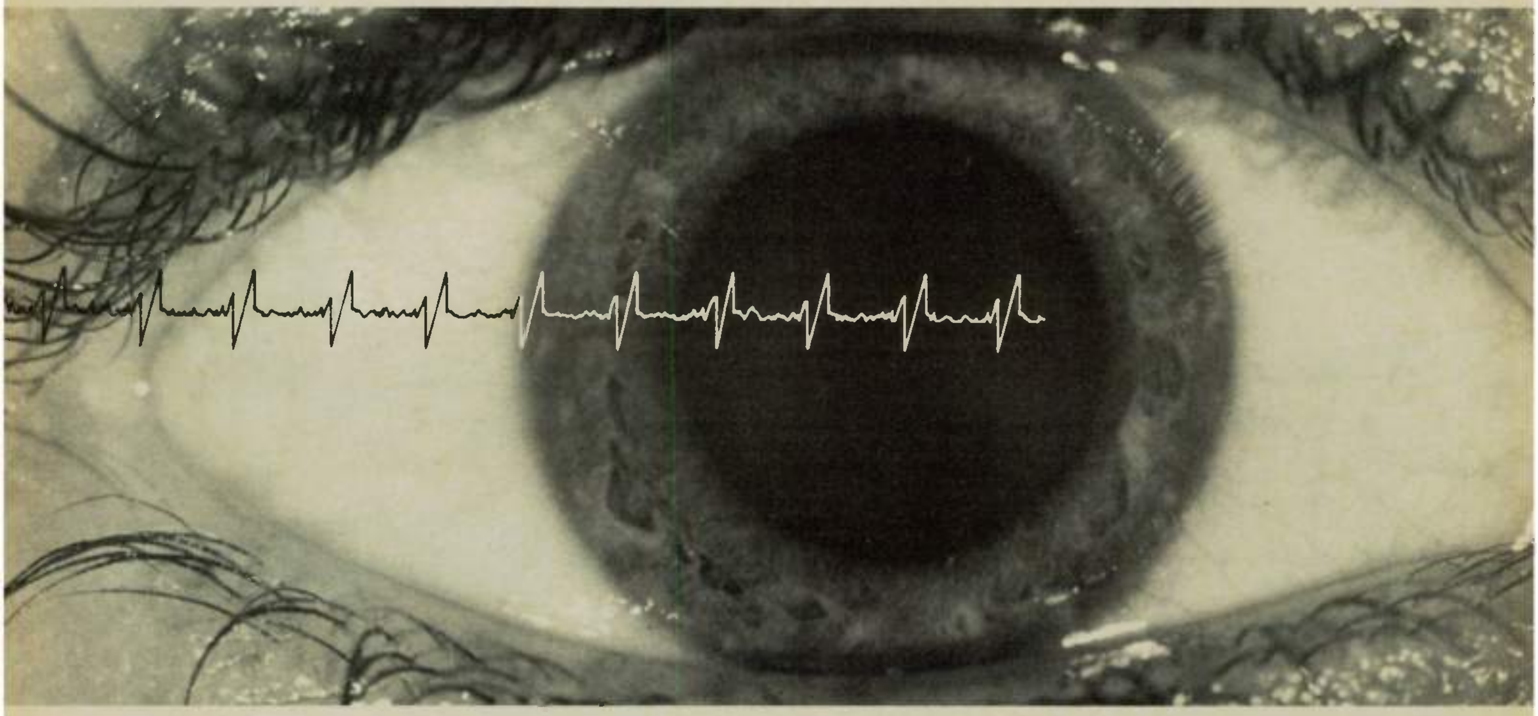
A series of high reliability, 7-bit thin film MIC attenuators span the 30-500 MHz frequency range. Units feature 0.5 dB steps through 63.5 dB as well as 5 μs switching speeds, 50 impedance, 1.35 max. SWR, 6 dB max. insertion loss and +13 dBm max. RF power. They have all-metal, 38-pin hermetic DIP package configuration. Model DAO295 operates from +5 Vdc at 50 mA and contains an internal TTL compatible driver; Model DAO285 uses any dc supply from +5 to +15 Vdc at 25 mA and its internal driver is CMOS compatible. **Daico Industries, Inc., Compton, CA. Jim Adamson, (213) 631-1143. Circle 126.**

RECEIVER WITH GAS PLASMA DISPLAY

The SR-2100 receiver covers a range of 20-500 MHz. Standard modules extend coverage into the UHF and SHF bands. The receiver features a gas plasma display in place of a CRT and signal strength meter. Tuned frequency, signal strength in dBm and logarithmic IF PAN spectrum are displayed simultaneously by the gas plasma device. Sweep width is variable to 4 MHz and a built-in marker generator is included. A wide range of IF bandwidths (from 10 kHz to 10 MHz) and detector modes are available. Receiver is equipped for remote tuning in BCD format. Frequency resolution in the 20-500 MHz range is 1 kHz; AM, FM or CW signals may be handled. Size: 5.25" H x 19" W x 21" D. Weight: 65 lbs. **Norlin Communications Div., Gaithersburg, MD. Bruce Duerson, (301) 948-5210.**
Circle 142.

VOLTAGE-TUNED FILTER ASSEMBLY

Model 2155-01 is a voltage-tuned filter assembly which covers 20 MHz to 510 MHz in six bands. Only one RF input and one output connector are used through the incorporation of TTL-compatible band selection and recombination. Each varactor-tuned filter has a 1.8 to 1 tuning range and requires a tuning voltage of 0-10 V; linearization to within ± 4% of a best straight line fit is provided. 6 dB bandwidth is 5% of the center frequency and 50 dB rejection is obtained at 40% bandwidth. Integral amplifiers provide 10 dB gain, 11 dB noise figure and 4 dB total variation over the entire band. Switching/tuning time is < 1 ms; input voltages are ± 15 V and +65 V. Size: 5"x10"x2.5". **Zeta Laboratories, Inc., Santa Clara, CA. (408) 727-6001. Circle 140.**



Giga-Trim® capacitor series incorporates a zero temperature coefficient and a Q factor of > 3000 to > 5000. Components feature sapphire dielectric and a one-piece self-locking constant torque mechanism (US Patent No. 3,468,160) which provides zero TC, high Q and low dynamic tuning noise. Sub-miniature trimmer series can be ordered in PC, threaded stud, cavity and stripline mounting styles. Available in four capacitance ranges of 0.3-1.2 pf to 0.8-8.0 pf and units have a rated voltage of 5000 Vdc. Price: $2.65 to $4.25 each in 5000 qty. Del: 12 wks. **Johanson Manufacturing Co., Boonton, NJ. Eric Fagerlund, (201) 334-2676.** Circle 129.

DOWNCONVERTER SPANS 10.95-11.70 GHz

DN4780 is a downconverter designed to translate the 10.95-11.70 GHz frequency range to the 4.20-3.45 GHz band. Local oscillator is at 15.15 GHz and is phase-locked to an externally supplied 5 MHz reference. Performance characteristics include: 15 dB nominal gain, with ± .5 dB flatness over full band and gain control range; 5 dB min. gain control; 1.25:1 input-output SWR; 12 dB maximum noise figure and dynamic range is +13 dBm output. **Miteq Inc., Hauppauge, NY. (516) 543-8873.** Circle 141.

ADAPTORS

A line of fused feed through adaptors protect equipment front ends from large input signals. Components are 50 ohms, with SWR of 1.75:1, maximum (dc to 2 GHz range) including fuse. Standard fuse supplied is 1/8 A with a blow time of 0.01 s (3/8 A with 0.1 s blow time also offered). Contacts made of heat-treated BeCu, gold plated – all other metal components are Ni-plated. Interface dimensions are per MIL-C-39012 and units are available in SMA Jack to SMA Jack (705483-001), "N" Jack to SMA Jack (705486-001) and BNC Jack to SMC Jack (701938-002) configurations. **Cablewave Systems, Inc., North Haven, CT. Steven Raucci, Jr., (203) 239-3311.** Circle 130.

SMALL O.D., HIGH PERFORMANCE COAXIAL CABLE ASSEMBLIES

A series of high performance, flexible .120" O.D. Gore-Tex® cable assemblies is designed to replace .085" semi-rigid and solve problems of performance, packaging, vibration and installation. The basic coax employs a very low dielectric constant material. Typical specifications include: impedance of 50 ± 1 Ω; time delay of 1.2 nsec/ft (85% speed of light); capacitance of 26 pf/ft, maximum; SWR of 1.35 through 18 GHz and dielectric withstanding voltage of 500 V, rms. Operating temperature range for the cable is −55 to 200°C and is −55 to 150°C for assemblies. Minimum bend radius is ½ inch. Weight: 7.5 gms/ft of cable, plus 4.5 gms per SMA connector pair. **W. L. Gore & Associates, Inc., Electronic Assembly Div., Newark, DE. (302) 368-3700.** Circle 128.

TRANSMITTER

Model 0937-1B is a tunable S band (2500-2600 MHz) transmitter with 3000 W peak power and .01 duty cycle. PRF is 10-30 kHz (adjustable) and pulse width is 0.1-0.5 ms (adjustable). Housed in a single unit, the transmitter provides all operating controls on the front panel. Price: $9,800 in 1-9 qty. **Microwave Control Company, Bricktown, NJ. (201) 458-3000.** Circle 134.

MIXER WITH 5 dB CONVERSION LOSS SPANS 3.7-4.2 GHz

Model MLK-125 is an addition to a toroidal line of mixers designed for TVRO applications. It has a conversion loss of 5 dB at an IF of 70 MHz. RF and LO frequency range is 3.7-4.2 GHz and full frequency range is dc to 500 MHz, with LO input power specified at +7 dBm nominal. Component is supplied with SMA female connectors. Size: .25" x 1.25" x .625" for package. Price: $125 per unit. Avail: 30 days ARO. **Engelmann Microwave Co., Montville, NJ. Carl Schraufnagl, (201) 334-5700.** Circle 127.

WIDEBAND MIXER SERIES SPANS 1-1000 MHz

A miniaturized high and low level double balanced TO-8 mixer line covers the 1-1000 MHz frequency range. Mixers also available in DIP package (relay header) from 10-1000 MHz. Model M43T (low level) operates at +7 dBm LO; Model M46T (high level) operates at +13 dBm LO, featuring high intermod performance. Line of mixers offer typical conversion loss of 6.5 dB, typical isolation of 45 dB from 1-100 MHz; 35 dB from 100-500 MHz; 30 dB from 500-1000 MHz. **Magnum Microwave Corporation, Sunnyvale, CA. David Fealkoff, (408) 738-0600.** Circle 145.

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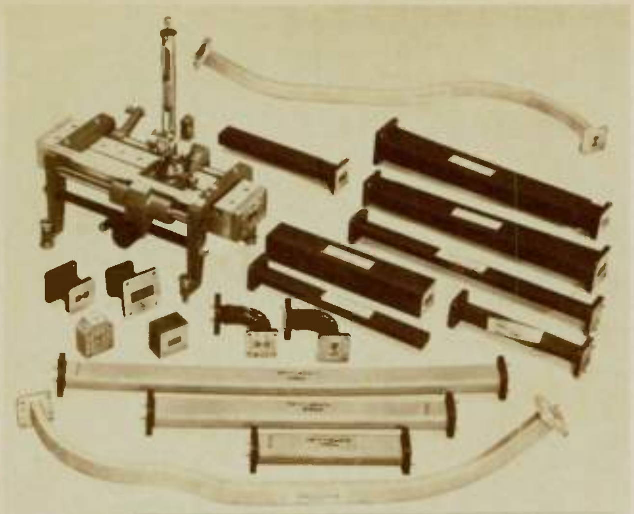

TUNABLE BANDPASS FILTER COVERS 225-440 MHz

UHF military communications band tunable bandpass filter covers the 225-440 MHz frequency range. Unit is continuously tunable to any frequency in that band with typical 3 dB bandwidths of 0.004 times the tuned frequency. Filter is rated at 50 W for both transmit and receive applications, and includes power monitor for peaking maximum output power in the transmit mode. Conforms to military environmental specifications. Avail: 120 days for start up. **K & L Microwave Inc., Salisbury, MD. (301) 749-2424.** **Circle 131.**

GaAs FET AMPLIFIERS

Series AG-6012-XX are GaAs FET amplifiers which operate in the 6-12.5 GHz frequency range. They offer internal voltage regulator, balanced cascade stages and thin film hybrid construction. Model AG-6012-04, has minimum gain of 25 dB, with a noise figure of 7.0 dB maximum. SWR is 2:1, with a +10 dBm min. power out at 1 dB compression point. For this model, third order intercept point is +22 dBm typical; maximum current is 220 mA at +15 V. Other models are available in 6 dB gain increments. **Western Microwave, Inc., Sunnyvale, CA. (408) 734-1631.** **Circle 139.**

YIG MULTIPLIER WITH 1-18 GHz OUTPUT

Model YOM1028X is a multioctave, YIG multiplier which can be used as a 1-18 GHz continuous or fixed tuned output. With input frequency of 200-400 MHz at 0.6 W provided, harmonic outputs can be selected from 1-18 MHz. All spurious responses and adjacent harmonics are 60 dB down; fundamental feedthrough is 35 dB minimum (typical 45-50 dB). RF power outputs are: from 12-18 GHz: -25 dBm minimum; from 8-12 GHz: -20 dBm, from 4-8 GHz: -15 dBm, from 2-8 GHz: -10 dBm and from 1-2 GHz: -5 dBm minimum. Size: 1.7" cube. **Omniyig, Inc., Santa Clara, CA. (408) 988-0843.** **Circle 135.**

SMC PRECISION ADAPTOR

A GR-900 to SMC adaptor provides SWR of 1.02 + .005F (GHz) from dc to 8.5 GHz. Model 50-074-6401-89 interfaces with GR-900 connector series and SMC connector. Size: 1 31/32" long overall. Wrench flats for holding unit while torquing up the two mating ends are provided. **Sealectro Corp., RF Components Div., Mamaroneck, NY. (914) 698-5600.** **Circle 136.**

HIGH POWER COAXIAL DIVIDER

Model FP2756-1 is a high power S-band coaxial divider which operates at an input power of 13 kW peak, 780 W average. It offers input of SWR < 1.15:1 and an output SWR < 1.2:1. Insertion loss for the unit is 0.12 dBm maximum, phase unbalance is 3° maximum, amplitude unbalance is 0.2 dB maximum and isolation between outputs is 20 dB minimum. Unit will operate into a 3.5:1 mismatch of any phase without damage. Input and outputs are 7/8" coaxial, and load ports are type N. **Sage Laboratories, Inc., Natick, MA 01760. Ken Paradiso, (617) 653-0844.** **Circle 137.**

SUBMINIATURE ATTENUATOR

Model FP-89 is a subminiature microwave attenuator for the dc to 18 GHz frequency range. It has a 2 W power handling capability with peak power handling capacity of 100 W, 3 μs pulse. Model is available in 1, 2, 3, 6, and 10 and 20 dB values. Accuracy is ± 0.5 dB for values below 20 dB and ± 1 dB at 20 dB. Impedance is 50 ohms, maximum SWR is 1.25, max. from dc to 6 GHz, and 1.5 max. from 13.3-18 GHz. Attenuator operates from -55°C to + 125°C; connectors are SMA, male female per MIL-C-39012. Weight: 0.302 oz (815 gm). Price: $40 each. Del: Stock to 4 wks. **Texscan Corporation, Indianapolis, IN. Raleigh B. Stelle, III, (317) 357-8781.** **Circle 144.**

A series of SMA cubed right-angle connectors for 0-18 GHz applications feature low SWR and high reliability. Constructed of teflon insulators and a one-piece, pre-bent center contact, these connectors have maximum SWR of $1.05 + 0.008 \times f$GHz; maximum insertion loss of 0.03 dB x $\sqrt{f}$ GHz; and a center contact captivation of 6.0 lb minimum axial force. They are offered in receptacle, cable and adapter type configurations. Price: $4.85 each in 1000 qty. Del: 12 wks. **Solitron/Microwave Connector Div., Port Salerno, FL. (305) 287-5000.** Circle 138.

HIGH STABILITY OVEN CRYSTAL OSCILLATORS

PMTP5 is a series of oven crystal oscillators with a stability of better than $\pm 5 \times 10^{-11}$ per day and better than $\pm 1 \times 10^{-9}$ per month. Frequency range is 4 to 6 MHz; relative stability at room temperature after a 24-hour turn off measured after 1 hr. is $\pm 5 \times 10^{-9}$. Power consumption is 1.5 W. Complies with MIL-STD 202E method 2136 Table 213 1 test A (shocks) and MIL-STD 202E method 201-A regarding vibrations. The miniature metal case (2.36" x 2.64" x 1.57") is designed for PC board mounting. Price: Starts at $660 each per 100 pieces. **Thomson-CSF Components Corp., Special Products Div., Clifton, NJ. (201) 779-1004.** Circle 143.

REMOTE MINI COAXIAL SWITCHES

Type RSM2 broadband SPDT coaxial switches provide RF and microwave signal switching from a common input to either of two outputs. Switches have insertion loss < 0.5 dB and SWR < 1.5 from dc to 18 GHz; isolation is > 60 dB. Drive power is 28 Vdc, a 115 Vac option is available. Input and output connectors are SMA, control power connection is via solder terminals. Optional features include indicator circuits, solid state driver circuits and failsafe or latching type actuators. Del: 4 wks. **Micronetics, Inc., Norwood, NJ. Gary Simonyan, (212) 249-0798.** Circle 133.

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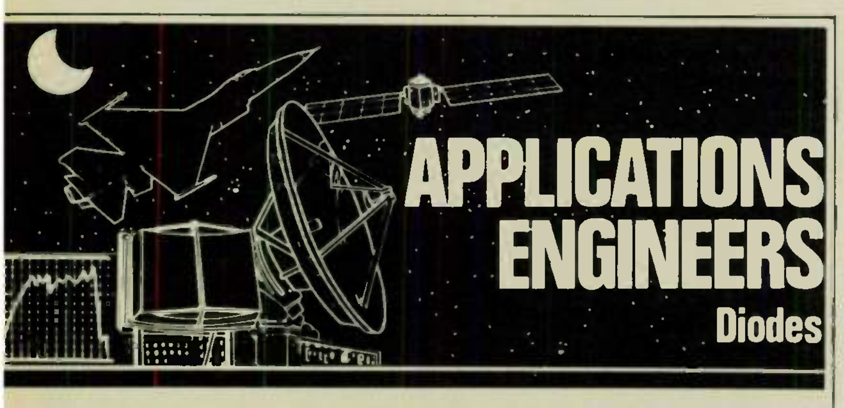

Alpha Industries, the leading supplier of microwave diodes, has openings for experienced Applications Engineers to provide application support for the PIN-Limiter product lines. You will be the primary technical customer interface and will closely interact with both customers and the Product Line Manager. Duties will involve recommendations of particular diodes based on customer application, design of special test fixtures, and special diode tests. BSEE with a minimum of 3 years' experience is desired; ability to work with people under minimal supervision. 5-10% travel involved.

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Learn how you can use personal programmable calculators to solve complex circuit design problems without resorting to large computer systems. Following the step-by-step instructions provided in this important new volume, any engineer can slash design time, save money, and dramatically increase efficiency with the TI-59, HP-67/97 or HP-41C calculators.

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297 pages. 8 1/2" x 11". Hardcover. June 1980.

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Fiber Optics

FIBER OPTIC DATA CABLE

Fiber optic Model RS232 Data Cable provides a link consisting of a 25 pin "D" connector with integral fiber optic transmitter and receiver circuits in a special shell attached to each end of a two fiber cable through strain reliefs. The unit can carry duplex asynchronous data at rates to 100K baud over spans up to 500 meters. Power is supplied to the active components either through the "D" connector itself or externally through a three-wire cable. Cable and ends may be ordered separately or as a preterminated cable assembly. Cable termination requires no epoxy or glass polishing. Price: $195 per end plus cable and factory termination charge, if desired. **OPTELECOM, Inc., Gaithersburg, MD. (301) 948-4232.** **Circle 121.**

ERRATUM

In the May, 1980 issue of the *Microwave Journal*, Equation 6 on p. 98 has an incorrect value in the penultimate row. The correct form is:

$$[3.705308 \times 10^{0} - 3.608271 \times 10^{-3} K + \ldots$$

$$4.988216 \times 10^{1} / (K + 3.696888 \times 10^{0})^{1.0471590}]\, xy^{3} -$$

New Literature

DATA SHEET FOR CONDUCTOR GLASS PASTE

A data sheet, #3680, describes a screen printable glass paste developed to be fired as an overglaze on thick film conductors in hybrid circuits. Sheet includes a general discussion of use of this material as a means to substitute silver alloys for gold conductors, its typical properties and methods appropriate to its printing and firing. **Electro-Science Laboratories, Inc., Pennsauken, NJ. (609) 663-7777. Circle 101.**

SILVER-PLATED Cu CONDUCTIVE ELASTOMER BULLETIN

Bulletin ESG 802 details application information and technical specifications and provides performance curves for Xecon SPC silver-plated Cu conductive elastomer. This 6-page brochure illustrates the different forms in which the material is available and provides ordering instructions. **Metex Corp., Electronic Products Div., Edison, NJ. (201) 287-0800. Circle 102.**

BROADBAND POWER AMPLIFIER GUIDE

A 12 page booklet describes a line of broadband power amplifiers which cover the 10-1000 MHz frequency bands. This two-color guide discusses the manner in which amplifiers are rated and defines their characteristics. It also outlines the applications for which the particular line are best suited and describes a line of accessories. Complete product specification information is included. **Amplifier Research, Souderton, PA. (215) 723-8181. Circle 103.**

DIVISION RELIABILITY TESTING CAPABILITY BROCHURE

The booklet, "A Total Capability in High Reliability Testing," describes the high reliability test programs available for its products from this manufacturer of RF and microwave power transistors. This 12-page, four-color guide details procedures followed by its quality assurance and reliability/environmental test departments and includes a reliability flow chart. **Thomson-CSF Corp., Solid State Microwave Div., Montgomeryville, PA. (215) 362-8500. Circle 104.**

DATA SHEET ON ISOLATORS AND CIRCULATORS

A 2 page data sheet describes a series of small coaxial isolators and circulators with up to 100% bandwidth for 6-20 GHz applications. This two color sheet includes photographs, descriptions, block diagrams™ and specifications for the Surface Mode™ series of broadband coaxial isolators and circulators. **Aertech Industries, Sunnyvale, CA. (408) 732-0880. Circle 106.**

COMPONENTS

A short form catalog gives electrical and mechanical specifications plus photos and block diagrams for a line of stripline microwave components. Sections on hybrid and directional couplers, in phase power dividers, mixers and modulators, PIN diode attenuators, phase and frequency discriminators and EW systems elements are provided. Product codes (cross-referenced), other publications available from the company and its sales offices are also listed. **Anaren Microwave, Inc., Syracuse, NY. (315) 476-7901. Circle 105**

LINE

A set of 6 data sheets are offered which describe a line of GaAs diodes. These two-color sheets include a description, general characteristics, absolute ratings and outline drawings as well as photographs of the CW and pulsed IMPATT diodes for 6-15 GHz applications, Gunn diodes for 5-18 GHz and 18-95 GHz and tuning varactors for use between VHF and 60 GHz. **Varian Associates, Electron Device Group, Solid State Microwave Div., Santa Clara, CA. (408) 496-6273. Circle 113.**

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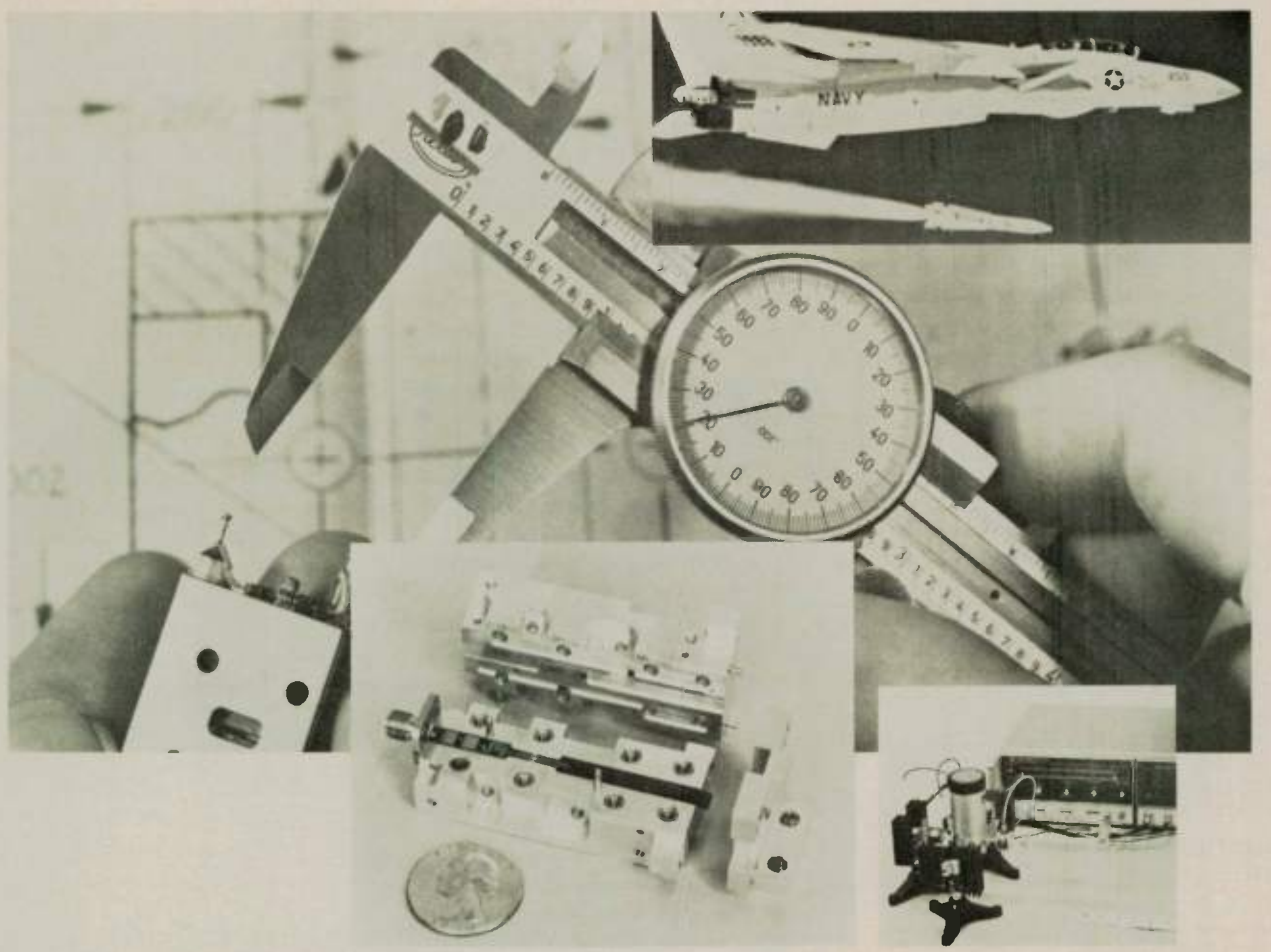
NAVY

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NEW LITERATURE

LISTING OF SMA QPL CONNECTOR

A two page listing of MIL C 89012 SMA QPL connectors is offered. This two color data sheet includes cross references the Sealectro and MIC part numbers for clamp type, field serviceable; types requiring special assembly tools; and crimp, captive contact types. **Sealectro Corp., RF Components Div., Mamaroneck, NY. (914) 698-5600.** Circle 108.

BULLETIN ON BANDPASS FILTERS

An illustrated technical bulletin (No. 776) describes bandpass filters packaged within miniature semi-rigid Micro Coax Cables. Bulletin provides complete technical data for these one-piece bandpass filter assemblies which can be used in the 1000-18000 MHz frequency band. **MicroDelay Div., Uniform Tubes, Inc., Collegeville, PA. (215) 539-0700.** Circle 109.

SCHOTTKY BARRIER BEAM LEAD BULLETIN

Bulletin 4219A describes a series of Schottky barrier beam lead diodes which are matched and connected in a classic "T" configuration. Complete specifications for Series L, M, and H of Model 4E200 are included. **Microwave Associates Inc., Burlington, MA. (617) 272-3000.** Circle 110.

RADAR SIMULATORS BROCHURES

Two brochures describe radar simulators (REES 200 and REES-100). Typical applications are illustrated; these include pilot and EW personnel training, radar system design verification and test, radar and TWR maintenance, and flight line testing. A description and chart of performance characteristics for the models are given. **Republic Electronic Industries Corp., Melville, NY. John Michaels, (516) 249-1414.** Circle 111.

RF POWER GENERATOR BROCHURE

A 4-page brochure describes a line of standard RF power generators with power to 100 W for the frequency range of 10-2500 MHz. Typical applications, electrical and mechanical specifications plus performance curves and photographs for the series are included. **MCL/Inc., LaGrange, IL. (312) 354-4350.** Circle 112.

APPLICATION NOTE/DATA SHEET ON SINEWAVE OSCILLATORS

A 14 page technical guide on tunable sine wave oscillators gives operating equations, application limits, calibration techniques and full mechanical/electrical specifications for the series. Pamphlet gives resistive, capacitive and voltage tuning methods for linear and BCD weighted frequency selection, as well as fast start techniques for precision control of oscillation commencement. Literature also describes characteristics, application techniques and specifications of the amplitude control module and features a table of standard 1% resistor standard decade values. **Frequency Devices Inc., Haverhill, MA. (617) 374-0761.** Circle 159.

EARTH STATION EQUIPMENT BROCHURE

An expanded edition of a product line brochure includes information about satellite earth station equipment. This 24-page guide offers specifications, photos and diagrams for earth station products in the C, X and K_u band frequency bands. Sections on receivers, up and down converters, modulators and demodulators, modems, IF filters and equalizers, translators, oscillators, amplifiers, subsystems and test sets are included. **LNR Communications, Inc., Hauppauge, NY. Jeannie Piotrowski, (516) 273-7111.** Circle 107.

DATA SHEET ON CERAMIC SUBSTRATES

A data sheet describes polished ceramic substrates for hybrid, microwave and thin film applications. Literature also outlines basic substrate parameters and provides options for specialized requirements. Data also includes a list of typical properties of 99.5% alumina from which these polished substrates are fabricated. **Valley Design Corporation, Littleton, MA. (617) 486-8933.** Circle 155.

DATA SHEET ON COAXIAL POWER DIVIDERS

A series of coaxial power dividers is described in a two page bulletin. Series applications, line drawings, performance curves, and specifications are included. Sheet also lists distributors and sales offices for the product. **Omni Spectra, Inc., Microwave Component Division, Merrimack, NH. John C. Callahan, (603) 424-4111.** Circle 156.

CHIP CAPACITORS BROCHURE

A six page, illustrated, brochure on chip capacitors includes general characteristics, information on chip geometries and electrode configurations, capacitor arrays, custom designs and dielectric material selection plus CSA chip capacitor selection chart. Specifications are high-lighted as well as block diagrams. Ordering code is also explained. **Compex Corporation, Cherry Hill, NJ. (609) 667-6795.** Circle 157.

SHORT FORM CATALOG ON POWER SEMICONDUCTORS

A 16 page short form catalog describes a power semiconductor product line. This two color literature gives details (specifications, schematic diagrams, and configurations) on rectifiers, rectifier assemblies and transistors. **Solid State Devices, Inc., La Mirada, CA. (213) 921-9660.** Circle 158.

COMPONENT AND DEVICE CATALOGUE

This microwave device and component catalogue has parallel French and English text. Areas covered include microwave diodes, bipolar transistors, field effect transistors, microwave functions, optical components, delay lines, ferrite components and packages. An index is provided and addresses to contract for further information. **Thomson-CSF, Division Composants, Microonde, 101 Boulevard Murat, 75781 Paris, Cedex 16, France. 1 743 9640.** Circle 160.

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MC 1100	10 - 1500	15.5 dB	±0.50 dB	+28V, 10mA
MC 1040	10 - 4000	25.5 dB	±0.50 dB	+28V, 15mA
MC 5112	1000 - 12400	25.0 dB	±0.50 dB	+28V, 15mA
MC 5118	1000 - 18000	25.0 dB	±0.50 dB	+28V, 15mA
MC 50018	5 - 18000	25.5 dB	±0.75 dB	+28V, 15mA
STANDARD BAND COAXIAL				
MC 5012	1000 - 2000	30.0 dB	±0.50 dB	+28V, 15mA
MC 5024	2000 - 4000	30.0 dB	±0.50 dB	+28V, 15mA
MC 5048	4000 - 8000	30.0 dB	±0.50 dB	+28V, 15mA
MC 5812	8000 - 12400	30.0 dB	±0.50 dB	+28V, 15mA
MC 51218	12400 - 18000	28.0 dB	±0.50 dB	+28V, 15mA
WAVE GUIDE BAND				
MC 5046W	3950 - 5850	15.5 dB	±0.50 dB	+28V, 15mA
MC 5068W	5850 - 8200	15.5 dB	±0.50 dB	+28V, 15mA
MC 5812W	8200 - 12400	15.5 dB	±0.50 dB	+28V, 15mA
MC 51218W	12400 - 18000	15.0 dB	±0.50 dB	+28V, 15mA
MC 51826W	18000 - 26500	25.0 dB	±2.00 dB	+28V, 20mA
MC 52640W	26500 - 40000	23.0 dB	±3.00 dB	+28V, 20mA
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1-250 MHz		5.5	7.0
0.5-500 MHz		6.5	8.5
Isolation (dB)		**Typ.**	**Max.**
0.5-5 MHz	LO-RF	50	45
	LO-IF	45	35
5-250 MHz	LO-RF	45	30
	LO-IF	40	25
250-500 MHz	LO-RF	35	25
	LO-IF	30	20

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