microwave JOURNAL

INTERNATIONAL EDITION ☐ VOL. 23, NO. 11 ☐ NOVEMBER 1980

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- AND -

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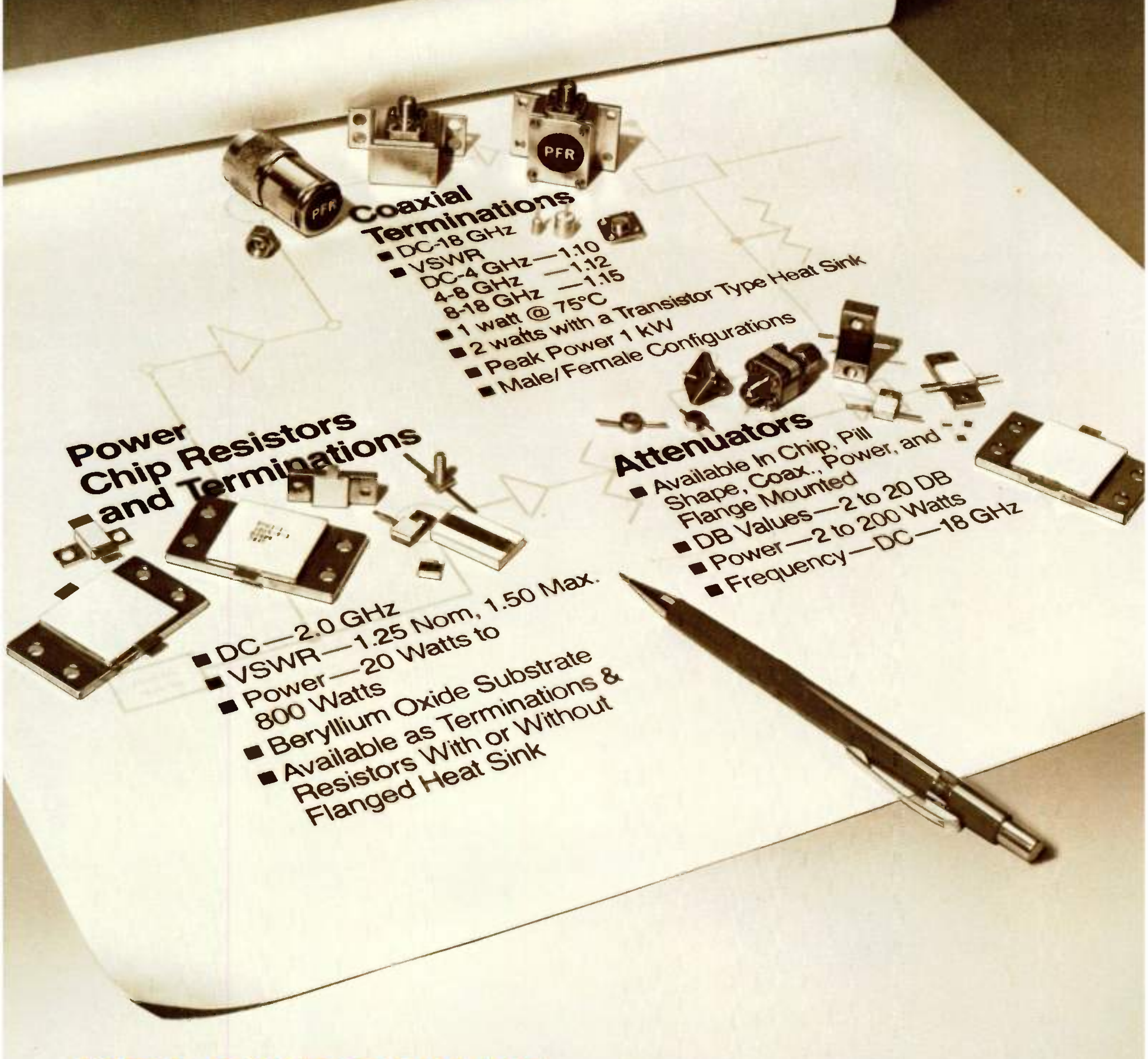

Coaxial Terminations

- DC-18 GHz
- VSWR
  DC-4 GHz —1.10
  4-8 GHz —1.12
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- 2 watts with a Transistor Type Heat Sink
- Peak Power 1 kW
- Male/Female Configurations

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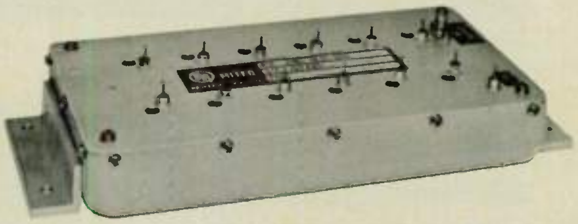
Specifications	±30 PPM Stability (-25 to +75°C) Model XT-01	±1.0 PPM Stability (-25 to +55°C) Oven Control Model XTO-01	±0.1 PPM Stability (-25 to +50°C) Oven Control Model XTO-02
Frequency Range	5.0 to 195 MHz	5.0 to 195 MHz	20-125 MHz
Power Output (minimum)	+7 dBm	+7 dBm	+7 dBm
DC Power - Oscillator	+15V/50 mA	+15V/50 mA	+15V/50 mA
- Oven (25°C)	N/A	+15V/300 mA Stabilized	+15V/300 mA Stabilized
Oven Stability Time (maximum)	N/A	20 min. (25°C)	20 min. (25°C)
Connectors - RF	SMA Female	SMA Female	SMA Female
- DC	Solder Filter Terminal	Solder Filter Terminal	Solder Filter Terminal



MULTIPLE CRYSTAL OSCILLATOR MODELS

Number of Oscillators	Models XM-6, XM-12 Plug In Cards XM-6. . 2-6 XM-12. . 6-12	Models XMO-6, XMO-12 Plug In Cards Oven Control XMO-6. . 2-6 XMO-12. . 6-12	Model XMI-12 12
Frequency Range	30-150 MHz (15% BW)	30-150 MHz (15% BW)	90-125 MHz
Power Output (minimum)	+7 dBm	+7 dBm	+7 dBm
Frequency Stability	± 30 PPM (-25 to +75°C)	± 1 PPM (0 to +55°C)	± 10 PPM (-5 to +55°C)
DC Power - Oscillator	XM-6. . +15V at 360 mA XM-12. . +15V at 660 mA	XMO-6. . +15V at 360 mA XMO-12. . +15V at 660 mA	+15V at 175 mA
- Oven (25°C)	N/A	XMO-6. . +28V/.3A Stabilized XMO-12. . +28V/.5A Stabilized	N/A
Connectors - RF	SMA Female	SMA Female	SMA Female
- DC	Solder Filter Terminal	Solder Filter Terminal	Solder Filter Terminal

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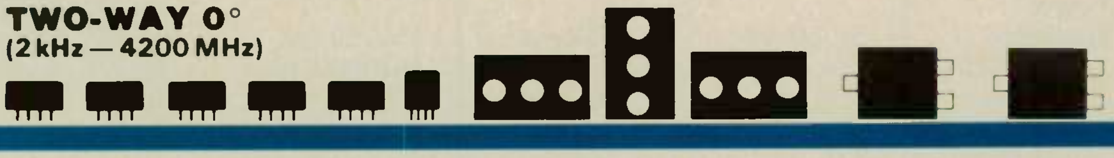
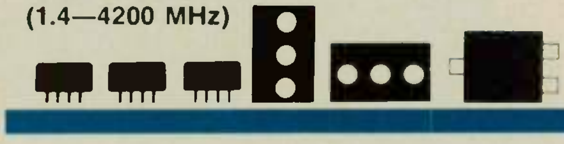
BASIC CASE STYLES

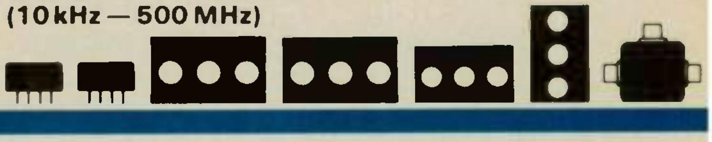
TWO-WAY 0°
(2 kHz — 4200 MHz)



TWO-WAY 90°
(1.4—4200 MHz)



TWO-WAY 180°
(10 kHz — 500 MHz)

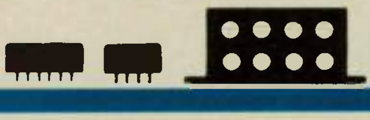


THREE-WAY 0°
(0.01 — 750 MHz)

FOUR-WAY 0°
(2 kHz — 1000 MHz)

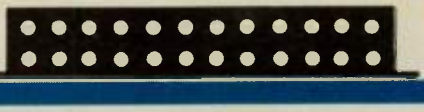
SIX WAY 0°
(1 — 175 MHz)

EIGHT-WAY 0°
(0.5 — 700 MHz)



SIXTEEN-WAY 0°
(0.5 — 125 MHz)

TWENTY-FOUR-WAY 0°
(0.2 — 100 MHz)



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1980-81 MicroWaves Product Data Directory 1980-81 EEM 1980-81 Gold Book, Vol. 2

2-WAY 0°

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

2-WAY 90°

Model	Freq. range (MHz)	Min. isol-dB (Mid-band)	Max. insert. loss-dB (Mid-band)	See notes below	Price (Qty.)
PSCQ2-1.5	1.4-1.7	25	0.7†	2	**$12.95** (5-49)
PSCQ2-3.4	3.0-3.8	25	0.7†	2	**$16.95** (5-49)
PSCQ2-6.4	5.8-7.0	25	0.7†	2	**$12.95** (5-49)
PSCQ2-7.5	7.0-8.0	25	0.7†	2	**$12.95** (5-49)
PSCQ2-10.5	9.0-11.0	20	0.7†	2	**$12.95** (5-49)
PSCQ2-13	12-14	25	0.7†	2	**$12.95** (5-49)
PSCQ2-14	12-16	25	0.7†	2	**$16.95** (5-49)
PSCQ2-21.4	20-23	25	0.7†	2	**$12.95** (5-49)
PSCQ2-50	25-50	20	0.7†	2	**$19.95** (5-49)
PSCQ2-90	55-90	20	0.7†	2	**$19.95** (5-49)
PSCQ2-180	120-180	15	0.7†	2	**$19.95** (5-49)
ZSCQ2-50	25-50	20	0.7†	2,3	**$39.95** (4-24)
ZSCQ2-90	55-90	20	0.7†	2,3	**$39.95** (4-24)
ZSCQ2-180	120-180	15	0.7†	2,3	**$39.95** (4-24)
ZMSCQ2-50	25-50	20	0.7†	2,4	**$49.95** (4-24)
ZMSCQ2-90	55-90	20	0.7†	2,4	**$49.95** (4-24)
ZMSCQ2-180	120-180	15	0.7†	2,4	**$49.95** (4-24)
ZAPDQ-1	500-1000	20	0.9	2,13	**$59.95** (1-9)
ZAPDQ-2	1000-2000	18	0.9	2,13	**$59.95** (1-9)
ZAPDQ-4	2000-4200	20	0.9	2,13	**$59.95** (1-9)

2-WAY 180°

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

1. 75 ohms impedance
†2. Average of coupled outputs less 3 dB
3. BNC connectors standard. TNC available
4. SMA connectors only
5. BNC connectors standard. TNC available
SMA & Type N available at $5 additional cost
6. BNC and TNC connectors. (SMA and Type N at $5 additional cost.) (BNC not available on ZAPD-4)
Please specify connectors
7. TNC, SMA & Type N at $5 additional cost
Please specify connectors

3-WAY 0°

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

4-WAY 0°

Model	Freq. range (MHz)	Min. isol-dB (Mid-band)	Max. insert. loss-dB (Mid-band)	See notes below	Price (Qty.)
PSC-4-1	0.1-200	20	0.75		**$28.95** (6-49)
PSC-4-1-75	1-200	20	0.9	1	**$24.95** (6-49)
PSC-4-3	0.25-250	20	0.75		**$23.95** (6-49)
PSC-4A-4	10-1000	15	1.1		**$49.95** (6-49)
PSC-4-6	0.01-40	25	0.5		**$29.95** (6-49)
ZSC-4-1	0.1-200	20	0.75	3	**$46.95** (4-24)
ZSC-4-1-75	1-200	20	0.8	1,3	**$46.95** (4-24)
ZSC-4.2	0.002-20	25	0.5	3	**$69.95** (4-24)
ZSC-4-3	0.25-250	20	0.75	3	**$43.95** (4-24)
ZMSC-4-1	0.1-200	20	0.75	4	**$56.95** (4-24)
ZMSC-4-2	0.002-20	25	0.5	4	**$79.95** (4-24)
ZMSC-4-3	0.25-250	20	0.75	4	**$53.95** (4-24)
ZFSC-4-1	1-1000	18	1.5	8	**$89.95** (1-4)
ZFSC-4-1W	10-500	20	1.5	8	**$74.95** (1-4)
ZFSC-4375	50-90	30	1.2	1,8	**$89.95** (1-4)

6-WAY 0°

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

8-WAY 0°

Model	Freq. range (MHz)	Min. isol-dB (Mid-band)	Max. insert. loss-dB (Mid-band)	See notes below	Price (Qty.)
PSC-8-1	0.5-175	20	1.1		**$68.95** (1-5)
PSC-8-1-75	0.5-175	20	0.6	1	**$69.95** (1-5)
PSC-8A-4	5-500	18	1.8		**$89.95** (1-5)
PSC-8-6	0.01-10	23	1.1		**$79.95** (1-5)
ZFSC-8-1	0.5-175	20	1.1	10	**$89.95** (1-4)
ZFSC-8-1-75	0.5-175	20	1.0	1,10	**$90.95** (1-4)
ZFSC-8375	50-90	25	1.3	1,10	**$119.95** (1-4)
ZFSC-8-4	0.5-700	20	1.5	10	**$129.95** (1-4)
ZFSC-8-6	0.01-10	23	1.1	10	**$109.95** (1-4)

16-WAY 0°

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

24-WAY 0°

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

8. SMA connectors standard. BNC on request
9. BNC connectors standard. TNC available. SMA available at $15 additional cost
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JOURNAL

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VOLUME 23, NUMBER 11
USPS 396-250
NOVEMBER 1980

GUEST EDITORIAL

BUSINESS/SPECIAL REPORTS

TECHNICAL/APPLICATIONS SECTION

DEPARTMENTS

* Euro-Global Edition Only

ON THE COVER: The full programmable scalar analyzer from Pacific Measurements, Inc. joins the growing list of sophisticated microwave instruments whose capabilities provide a small measure of relief from the problems raised by the critical shortage of engineers and trained technicians. See Cover Story on p. 75. Cover art courtesy of Pacific Measurements, Inc. and illustration by Cliff Spohn.

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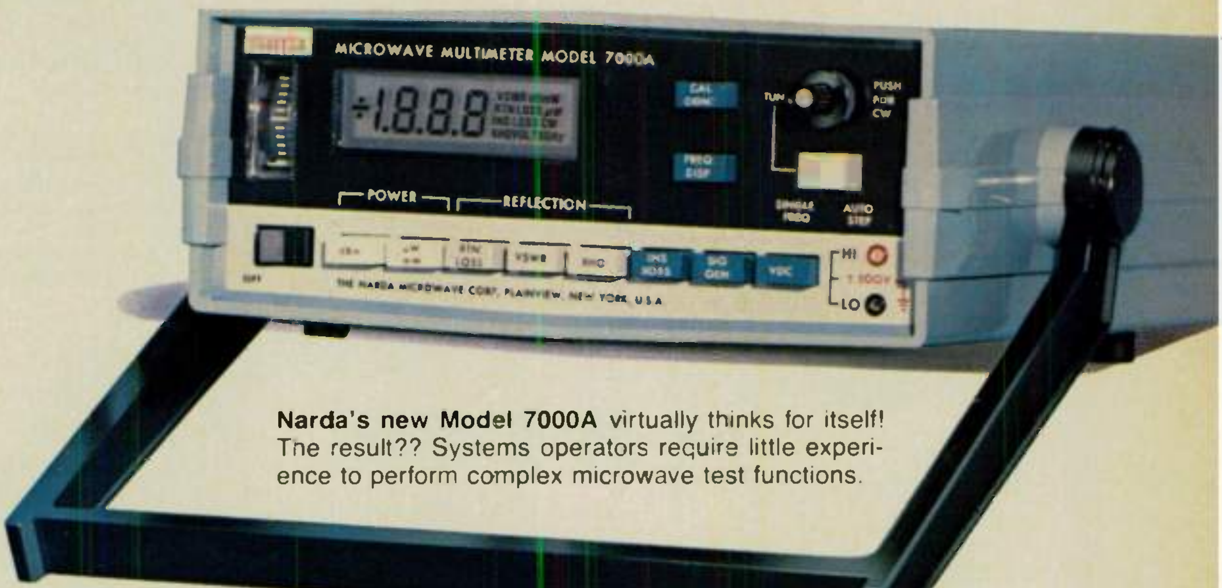

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CIRCLE 6 ON READER SERVICE CARD

Coming Events

2ND AFCEA CONFERENCE AND EXPOSITION JAN. 7-9, 1981 Sponsor: Armed Forces Communications and Electronics Association. Place: Disneyland Hotel, Anaheim, CA. Program Panels: The Role of Satellites for C^{3}I, Information Systems for the 1980s, Command, Intelligence and Communications – Integrating Evolving Automation. Contact: Judith H. Shreve, Editor, Signal Magazine, 5205 Leesburg Pike, Suite 300, Falls Church, VA 22041.

5TH INTERNATIONAL CONFERENCE ON DIGITAL SATELLITE COMMUNICATIONS MARCH 23-26, 1981 Sponsors: INTELSAT, Telespazio S.p.A., IIC, AEI, IEEE, Region 8. Place: Congress Building – International Fair, Genoa, Italy. Topics: Systems engineering, technology and operations and services of digital communications via satellite. Contact: Manager, Administrative Office, ICDSC-5, Telespazio, S.p.A., Corso d'Italia, 43, 00198 Rome, ITALY.

CONFERENCE ON LASERS & ELECTRO-OPTICS JUNE 10-12, 1981 Call for papers. Sponsors: Quantum Electronics and Applications Society, IEEE, Optical Society of America. Place: Washington Hilton, Washington, DC. Topics: Electro-optic devices and components, lasers, optical-fiber communications, sensors, holographic, military, medical and industrial applications, etc. Submit a 35-word abstract and 200 to 500-word summary (2 copies) by Jan. 12, 1981 (US) and Jan. 1, 1981 (Europe and Japan) to: CLEO, c/o Optical Society of America, 1816 Jefferson Place, N.W., Washington, D.C. 10036. Exhibition Information: Carole Benoit, CLEO, 28301 S. Ridgethorne Court, Rancho Palos Verdes, CA. 90274. Tel: (213) 541-9256.

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 on June 17-19, 1981). Place: Bonaventure Hotel, Los Angeles, CA. Theme: "Around the World with Microwaves," including such topics as CAD and measurement techniques, microwave, and mm-wave solid-state devices and IC's, etc. Submit 35-word abstract and 500 to 1000-word summary by Jan. 15, 1981 to: Dr. Don Parker, TPC 1981 MTT-S Symposium, Hughes Aircraft Co., Bldg. 268, M.S. A54, Canoga Park, CA 91304.

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Total Range		6.5	8.5
Isolation, dB		**Typ**	**Min.**
Lower Band Edge to One Decade Higher	LO-RF	50	35
	LO-IF	45	30
Mid Range	LO-RF	45	30
	LO-IF	40	25
Upper Band Edge to One Octave Lower	LO-RF	35	25
	LO-IF	30	20

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Impedance, All Ports 50 ohms
Electronic Attenuation Min (20mA) 3dB

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CIRCLE 8 ON READER SERVICE CARD

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magine resolving frequencies as close as
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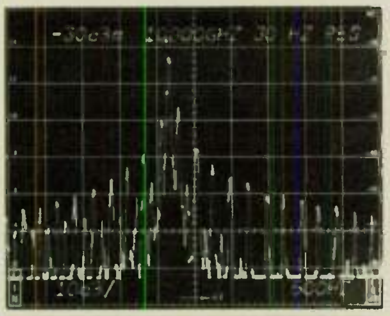

ike this sample of 240 Hz sidebands at
0 GHz.

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controls . . . plus a built-in tracking pre-
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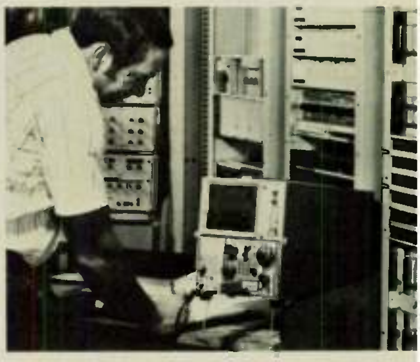

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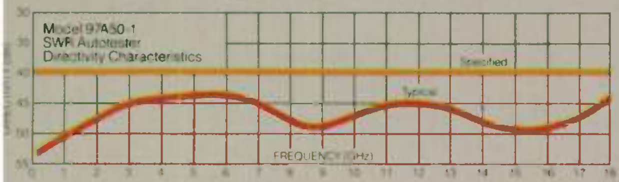
Wiltron is also a precision components house. No one else is better prepared to show you how to make microwave measurements simply and accurately and then provide you with all the precision components and the measurement system you need. No one offers a comparable group of SWR Autotesters, precision air lines, terminations, adapters, SWR Bridges, open/shorts and RF detectors.



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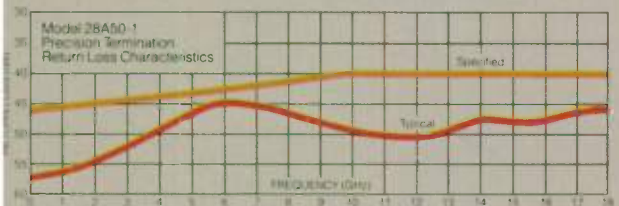
Latest in Wiltron's family of SWR Autotesters is the Series 97. Here in one small package, we integrate a broadband microwave bridge, a precision termination, a detector and your choice of test port connectors. Performance is exceptional with directivity of 40 dB and a frequency range of 10 MHz to 18 GHz. Several other models with N or WSMA test ports offer comparable performance. The Wiltron family of SWR Bridges is equally accurate over most of its 10 MHz to 18 GHz range.

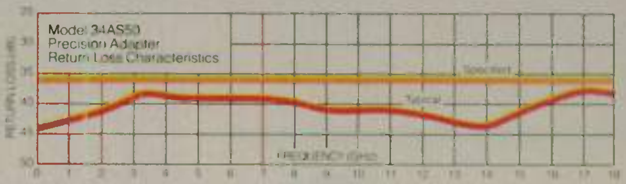


Terminations and Open/Shorts

Wiltron Terminations provide an accurate reference for SWR measurements as well as a termination for test instruments and devices under test from DC to 26.5 GHz. They are available in GPC-7, N and WSMA connectors and feature aged termination resistors for long-term stability. Maximum SWR varies from 1.002 at low frequencies to 1.135 at 26.5 GHz. Wiltron 22 Series Open/Shorts for the DC to 18 GHz range are offered with a choice of connectors.

Precision Air Lines

When you want better accuracy in measuring return losses from 0dB to 55dB, you'll need a Wiltron Air Line. These 50-ohm Air Lines provide both a standard impedance and a time delay for use in Wiltron Ripple Averaging and Magnified Reflection Measurement Techniques. Series 18 covers the 2 to 18 GHz range. The 18A50 offers a GPC-7 connector and features an SWR of 1.002. The 18N50 has an N male or female connector and an SWR of 1.006. Series 19 operates from 2 to 26.5 GHz with an SWR of 1.006 to 18 GHz and 1.01 to 26.5 GHz.



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Wiltron 50-ohm Series 34 Adapters virtually eliminate errors caused by mismatch. The adapters are available in GPC-7/N, GPC-7/WSMA, N/N and WSMA/WSMA. Range is DC to 26.5 GHz. Typical SWR ratios are 1.02 to 18 GHz and 1.1 to 26.5 GHz.

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UHF ACOUSTIC OSCILLATORS

Part I of this Special Report discusses high fundamental frequency oscillators eliminate the need for multipliers and associated filters which introduce size, weight, power and cost penalties. The paper deals with surface acoustic wave oscillators for 100 to 1500 MHz applications which use delay line or resonator techniques. It also considers high overtone bulk acoustic resonators for 1 to 10 GHz applications. Both of these types are compared with multiplier designs and their benefits and specific applications are described. The design principals for each of the acoustic resonator types are covered. Suitable materials for the designs are listed together with their characteristics. In Part II their short-term stability and the effect of temperature on their operation are discussed and aging data is provided. Finally, areas requiring further research for improving overall performance are identified.

Sum Up

A LOW SIDELOBE 4/6 GHz ANTENNA

Mutual interference and coordination problems in the 4/6 GHz satellite communications bands become more severe as the number of earth stations as well as the number of satellites increases. A significant reduction in sidelobe characteristics of earth station, 6 GHz transmitting antennas would contribute to an easing of those problems. The paper describes an earth station antenna design whose sidelobe gain performance is far better than the currently legislated requirements. Major contributors to sidelobe levels are discussed and illustrated and the design approach for the low sidelobe model is presented. Experimental results for a full scale 7.6 meter offset antenna are shown. While an aperture efficiency penalty is taken by the design, its peak sidelobe envelope is 10-15 dB lower than present FCC/INTELSAT requirements.

NBS NEAR-FIELD ANTENNA MEASUREMENTS

Recent near-field scanning work at NBS is discussed and comparisons with far-field measurements are shown. Specifically, the planar scan of a large microstrip array for satellite-borne synthetic aperture radars is described. In this instance, there was an important requirement for far-field phase control and, in addition, the array was so large that a single scan would not suffice to measure the entire near-field pattern. Secondly, probe-corrected measurements made on a cylinder are compared to measurements derived from planar scanning. Finally, a hybrid technique employing both planar and cylindrical scanning which allows sidelobes to be measured at large angles off boresight is described.

CLAD LAMINATES FOR MICROWAVE ANTENNAS

The virtues of two types of PTFE-based laminates for microwave antenna applications are discussed. The article considers the need for low anisotropy and describes test methods for that property. It considers the effects of temperature on dielectric constant and physical expansion. The fabrication characteristics of the laminates and recommended processing routines are also covered.

GaAs FET LOAD PULL CHARACTERIZATION

Load pull characterization of GaAs FET's under large signal conditions can be used to predict performance and facilitate circuit design. The procedure requires multiple measurements of device performance under variable load conditions and is a fairly tedious and time-consuming process. The paper describes a load pull characterization method employing a substitution technique which considerably simplifies the mechanical routine involved in the measurements. The system and its application are discussed as are the correction factors which must be considered in same test set ups.

Howard Ellowitz

Workshops & Courses

26TH SPUTTER/PLASMA ETCH SCHOOL AND CONFERENCE

Sponsor: Materials Research Corporation (MRC)
Site: La Posada Resort Hotel, Scottsdale, AZ
Date: December 9-11, 1980
Lecturer: Dr. Eric May, IBM San Jose Research Labs.
Theme: Plasma surface physics, automated systems for sputtering and plasma etching of high resolution ICs.
Contact: Rosemary McPhillips, MRC
Orangeburg, NY 10962
Tel: (914) 358-2002

NEAR-FIELD ANTENNA TESTING SHORT COURSE

Sponsors: Technical University (TU) of Denmark, Electromagnetics Institute (EI) plus NBS (US) and ESA (Europe)
Site: TU, Lyngby, Denmark
Date: January 26-30, 1981
Subject: Near field antenna testing.
Contact: Dr. J. Appel-Hansen, EI
Bldg. 348, TU,
DK-2800, Lyngby Denmark

RELIABILITY ENGINEERING SHORT COURSES

Sponsor: UCLA Extension
Site: U of California, LA
Dates: February 9-13, 1981;
March 16-20, 1981
Lecturer: Dr. Dimitri Kececioglu, P.E.
U. of Arizona, Aerospace & Mechanical Engrg. Dept.
Fee: $750
Courses: Reliability Engrg., Testing and Maintainability; Engrg. Reliability, Probabilistic Design
Contact: Cont. Ed. in Engrg. and Math., UCLA Ext.
Box 24901, LA, CA 90024
Tel: (213) 825-1047

SHORT COURSES IN ELECTRIC DESIGN & MANUFACTURING

Sponsor: The Center for Professional Advancement (CPA)
Dates: January 19 - April 2, 1981
Site: Sheraton Motor Inn, Rt. 18, East Brunswick, NJ
Topics: Digital communications, electro-optical systems, etc.
Fees: $560-710 (courses vary)
Contact: Rosanne Razzano, Dept. NR, CPA, P.O. Box H, East Brunswick, NJ 08816
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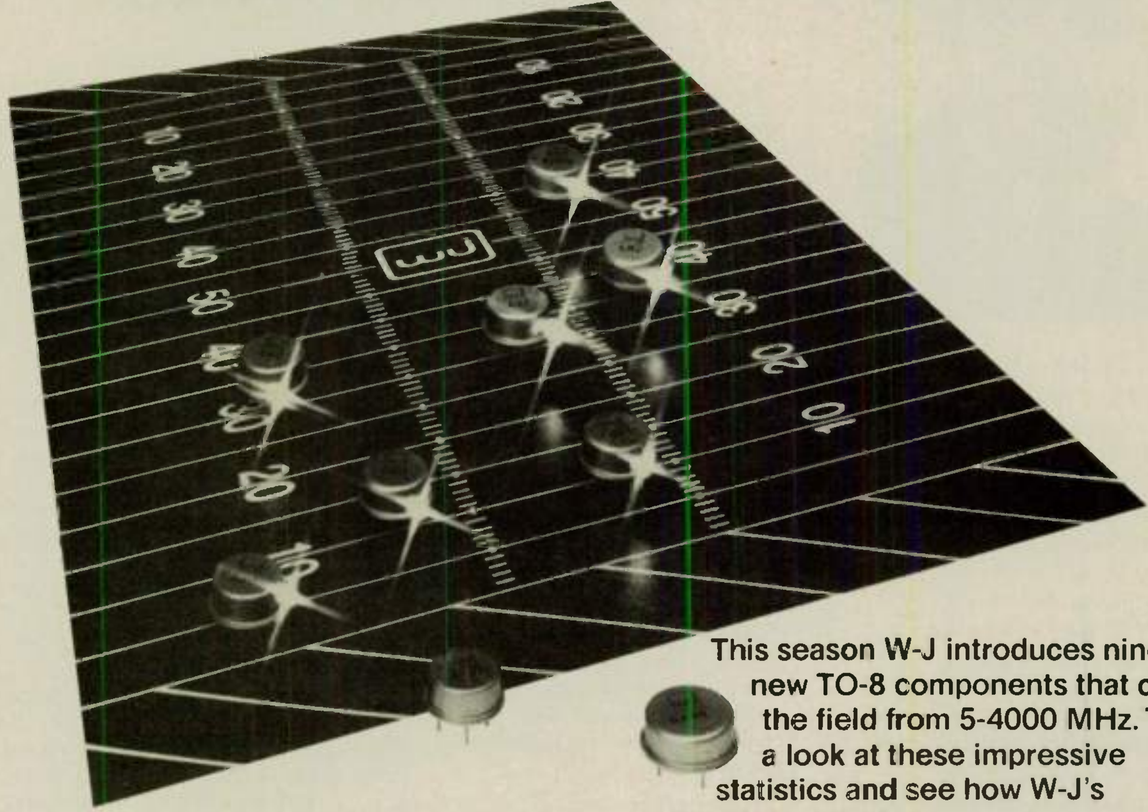

This season W-J introduces nine new TO-8 components that cover the field from 5-4000 MHz. Take a look at these impressive statistics and see how W-J's Rookies of the Year can give your team its best season yet!

Name	Frequency Range	Outstanding Characteristics
WJ-A83	10-500 MHz	30-dB gain, 3 dB NF runs from +5 VDC. An outstanding performer.
WJ-A83-1	10-250 MHz	35-dB gain, 2.5 dB NF runs from +5 VDC. The big gainer on the field.
WJ-A87	10-400 MHz	+17 dBm P_{OUT}, but draws only 31 mA at +15 VDC. Runs with power, but never loses its cool.
WJ-RA89	5-500 MHz	24-dB gain, +20 dBm P_{OUT}. Larger new TO-8B package. The big playmaker with plenty of muscle.
WJ-A19-1	10-1000 MHz	11-dB gain, 7-dB NF, +20 dBm P_{OUT}. Unstoppable in the 1000-MHz dash.
WJ-A43	100-3200 MHz	11-dB gain, 7-dB NF, +7 dBm P_{OUT}. First round draft choice for high frequency applications.
WJ-LA7	50-500 MHz	Limiter amplifier. 12-dB gain, +15 dBm maximum output. Plays both offense and defense.
WJ-G30	100-2000 MHz	Voltage controlled attenuator. >40-dB attenuation range, 2 µsec switching speed. Fastest player on the field.
WJ-L40	500-4000 MHz	Signal Limiter. 3.5-dB insertion loss, limits at 0 dBm. Captain of the specialty team.

To obtain the latest statistics on our complete lineup of TO-8 amplifiers, contact the Watkins-Johnson Field Sales Office in your area or phone Amplifier Applications Engineering in Palo Alto, California at (415) 493-4141, ext. 2637.

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Causes and Solutions to the Shortage

Microwave Engineers

GEORGE I. HADDAD
Department of Electrical & Computer Engineering
The University of Michigan
Ann Arbor, MI

George I. Haddad *(S'57, M'61, SM'66, F'72) was born in Aindara, Lebanon, on April 7, 1935. He received the B.S.E., M.S.E., and Ph.D. degrees in electrical engineering in 1956, 1958, and 1963, respectively, from The University of Michigan, Ann Arbor.*

From 1957 to 1958 he was associated with the Engineering Research Institute of U. of Mich., where he did research on electromagnetic accelerators. In 1958 he joined the Electron Physics Laboratory, where he has been engaged in research on masers, parametric amplifiers, detectors, electron-beam devices, and presently on microwave solid-state devices. He acted as Director of the Lab from 1968-75. From 1960-69 he served successively as Instructor, Assistant Professor, and Associate Professor in the Electrical Engineering Department. He is presently a Professor and Chairman of the Department of Electrical and Computer Engineering.

Dr. Haddad received the 1970 Curtis W. McGraw Research Award of the American Society for Engineering Education for outstanding achievements by an engineering teacher. He is a member of Eta Kappa Nu, Sigma Xi, Phi Kappa Phi, Tau Beta Pi, the American Physical Society, and the American Society for Engineering Education.

I am assuming in my remarks here that there is definitely a shortage of microwave engineers at the present time. This is based on discussions I have frequently with recruiters, on telephone calls I receive daily from friends and personnel managers in industry, and on my own experiences in recruiting faculty and training students in this field. This shortage of well-trained microwave people is becoming a serious national problem and unless some remedies are instituted immediately to attract students into this field, the national defense, our technological leadership, and our industrial production will suffer immensely. My brief remarks here will address some of the reasons for the shortage of engineers in general and microwave engineers in particular and will propose some remedies for alleviating the problem.

During the late sixties and early seventies the reputation of the engineering profession suffered immensely from layoffs in the aerospace industries, the Vietnam War, environmental concerns and others. Engineering was unjustifiably blamed for many of the problems facing society during those years. This, of course, led to decreased interest by students in engineering and enrollments in engineering programs plummeted. During those years the support for engineering education diminished from all directions including research funding from the federal government, state funding for faculty and facilities, and direct funding from industry which was never substantial anyway. Several excellent research groups, particularly in the microwave area, which were closely tied to the educational programs and contributed significantly toward the training of students were disbanded either due to lack of funding or due to the classified research that they were carrying out. Well, all that is behind us now but that period had a major impact on our present capabilities to train engineering students in general and microwave engineers in particular. When the pendulum of engineering enrollments started swinging in the other direction in the mid-seventies colleges and universities were not prepared for this and with the major increase that has taken place over the last five years in engineering enrollments we find our resources to be inadequate to accommodate such an increase in terms of the number of faculty and available space, facilities, and equipment.

Even though enrollments in electrical engineering departments have increased significantly over the last five years, few new faculty members have been added and few students go into the microwave area. As compared to the sixties, there is now a great deal of competition from other areas such as digital electronics, integrated circuits, computers and others. Had it not been for microwave solid-state devices and more recently high-speed GaAs integrated circuits, I doubt very much that any universities would now have any programs related to microwaves. Fortunately, however, because these advances are due to government funding of research, a great deal more interest is being generated presently at universities. A few universities have maintained excellent programs in this area and are still producing a few students. These programs must be encouraged and supported by all who are concerned with the shortage of talent in this field.

There are certain steps which can be taken to increase the pool of talent available in the microwave area. This will require very close cooperation among government agencies (particularly DoD), industry and universities and will require additional support from government and industry to achieve.

Microwave engineering is a rather specialized area and very few, if any, colleges and universities offer a specialty in this field at the undergraduate level. This is because the amount of time which students spend in a typical undergraduate program (four years, 128 credit hours) is inadequate to allow for much specialization, particularly in microwaves. I believe that a minimum of one year of additional training is required for average stud-

(continued on page 21)

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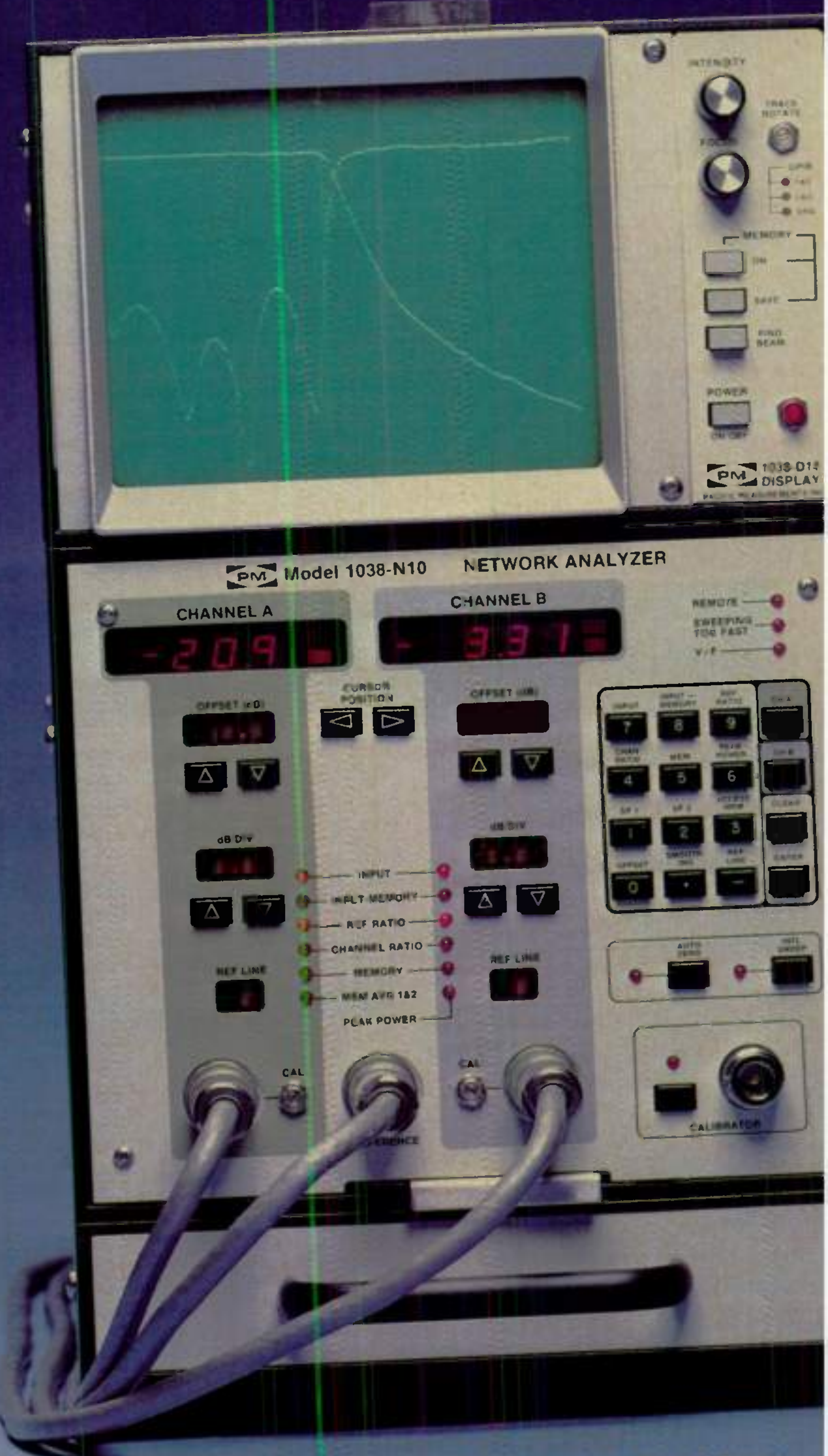

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CIRCLE 13 ON READER SERVICE CARD

Amplifiers

• Ultra Low Noise • Wide Dynamic Range
• Custom Design

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

CASE DIMENSIONS:
(Others Available)

	L (in.)	W (in.)	H (in.)
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A	3.375	1.875	0.465
H	3.75	2.60	1.95
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*Standard this model; others may be specified.
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E&C MICROWAVE BULLETIN

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

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

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Electrically Conductive Pressure Sensitive Tape

ECCOSHIELD® PST is a series of electrically conductive pressure-sensitive tapes useful in RF shielding and many other electrical and electronic applications. Aluminum foil is used as the tape backing. When applied to a metal surface, electrical contact is made to the metal from the adhesive side and into the backing. Thus, electrical continuity is made through the tape. ECCOSHIELD PST is available in two types, namely ECCOSHIELD PST-P and PST-C.

ECCOSHIELD PST-P is tape with a unique perforated design. The center third of the tape's width is solid metal foil, i.e. non-perforated. The outer third on each side of the center is perforated in such a way that uncoated metal integral with the backing appears on the adhesive side. ECCOSHIELD PST-P is particularly useful in sealing gaps in shielded enclosures, cabinets and devices.

ECCOSHIELD PST-C uses a conductive pressure-sensitive adhesive. Conductivity is supplied by metal particles embedded in the adhesive in such a way that when the tape is applied to a metal surface, the particles contact both the metal surface and the foil backing. Although ECCOSHIELD PST-C can be used for sealing seams in shielded rooms, cabinets, etc., it is well adapted to wrapping components, coax or the flanges of waveguide. Insertion loss values for all products are approximately the same. For most applications, one half inch (1.3 cm) overlap is sufficient. More overlap gives more adhesion and slightly improved insertion loss.

Circle No. 51 on Reader Service Card

E&C Shielded Anechoic Chamber for Testing Automotive Emissions

This large microwave anechoic chamber is being used by Nissan Motor Co., Ltd. for study of rf noise pollution by automotive systems. The chamber was erected near Yokohama by Emerson & Cuming Japan K.K. It is sufficiently large to accept an automobile with all systems operating. External rf noise is excluded from the interior of the chamber by metallic shielding, and the energy-absorbing pyramids that line the walls reduce to essentially zero all reflections of signals generated inside the chamber. In the resulting rf-quiet environment, sensitive and precise studies can be made of the rf noise emission of ignition, alternators, regulators, seat-belt interlocks, radios, tape decks, switches, and warning systems. Japanese pollution-control standards are much more demanding than those in the U.S., and the Nissan chamber permits measurements of automotive r emissions to frequencies as low as 7 MHz.

Thin, Flexible Absorber Suits Many Environments

ECCOSORB AN is a series of thin (1/4" to 4-1/2") microwave absorbers available in many variants to suit many environments. Available as flat sheets or custom blankets, it is easily cut, contoured, and bonded to radomes, antennas, and other structures. In general, the material reduces radar reflectivity to -17 db or better over the S, C, A, B, and X radar bands.

ECCOSORB AN — the basic material — is not weatherproof and should be used only indoors.

ECCOSORB AN-W is sealed in impervious neoprene-coated fabric for resistance to fuel and weather. The fabric is self-extinguishing and complies with MIL-C-20696.

ECCOSORB AN-P relies on use of a closed-cell foam for environmental resistance, and is not coated. It is especially thin (7/16" to 1-3/16") and lightweight.

ECCOSORB ANP-ML offers the same performance as ECCOSORB AN-P. In addition, it has an electrically conductive surface on the back. This means it can be applied to either a conducting or non-conducting surface, and the reduction in microwave reflectivity will be the same.

Circle No. 52 on Reader Service Card

E&C Research Contract Fuels Energy Search

In his message on energy, President Carter has emphasized exploitation of the Country's abundant coal and shale resources to lessen dependence on imported oil.

E&C has made a modest contribution to this goal by completing shipment of a load of simulated coal to the Marshall Space Flight Center of the National Aeronautics and Space Administration.

The simulated coal is not intended to keep NASA hearths warm this winter. Instead, it is being used by NASA scientists in a unique radar experiment.

The Marshall Space Flight Center is supporting the Department of Energy by finding ways to make coal extraction more efficient. Specifically, it is developing a radar which can scan the coal seam in a mine and determine the thickness of the seam on a continuous basis. This information, fed to a mining machine enables the machine to cut away only coal and avoid cutting into the shale behind the coal. The advantages are reduced contamination of the coal, reduced risk of sparks or of weakening the supporting walls of the mine shaft.

Because coal is a natural absorber, the system must be able to detect a very weak back-wall signal. It is desirable to have a standard material with similar dielectric properties to coal to calibrate the radar detector.

Numerous tests have shown these dielectric properties to be: $K = 3.8$ and $\tan d = 0.08$, at 3 GHz, for real coal taken from the Bruceton Mine in Pennsylvania.

Based on these tests, E&C fabricated and tested a number of blocks of simulated coal of various thicknesses, with dielectric constants and loss tangent close to the real values. These will help Marshall Flight Center continue the experimental program which may one day lead to the unusual sight of radar in a coal mine.

Use the enclosed reply card if you would like to know more about E&C's microwave materials research and measurement capabilities and services.

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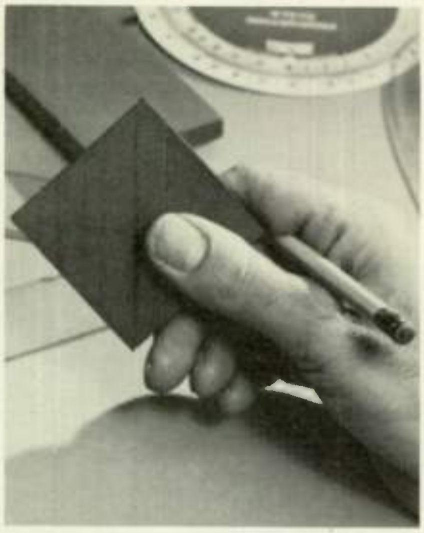
Thin Ferrite Absorber For 50MHz to 15GHz



ECCOSORB NZ is a series of thin absorbing materials for use in the frequency range from below 50 MHz to above 10 GHz. ECCOSORB NZ-2 is broadbanded; other NZs are relatively narrow-band, for the lower end of the frequency range.

All ECOSORB NZ materials are sintered ferrites available as square tiles approximately 2.36″x2.36″. Tiles can be bonded to flat or moderately curved conductive surfaces. Usage is approximately 26 tiles per square foot. The tiles are excellent for use in high-temperature, high power, outdoor and space environments. Eccosorb NZ-31 (50 MHz to 3 GHz) can be used to reduce ground plane reflections in chambers used for evaluation of computer systems.

Circle No. 54 on Reader Service Card

Microwaves in Medicine, Maybe E&C Can Help

Microwaves are definitely useful in detecting cancerous tumors, medical researchers have found.

The technique is based on the increased body radiation at the site of a malignancy. Although natural body microwave emissions are much less intense than body heat, today's radiometers are sensitive enough to do the job.

Microwaves may also be used to treat cancers. Physicians naturally are reluctant to use human patients in this investigation, but the prospect is encouraging enough that E&C's Microwave Products Division occasionally is asked to produce dielectric material "models" which simulate parts of the human body in their response to electromagnetic radiation. We welcome inquiries in this field.

High Dielectric Constant Stock with Improved Isotropy

Isotropy, as applied to dielectric constant, is the state of having the same dielectric constant in all directions. Materials which are not isotropic (anisotropic) may present serious application problems, especially where dielectric constant control is critical.

The achievement of isotropy in resins loaded with powders to raise the dielectric constant is a difficult manufacturing problem involving many factors such as mix proportions, shape and size of loading particles, and mixing techniques. After many years of effort, Emerson & Cuming is pleased to report substantial progress with this problem. The resulting product is STYCAST® HiHiK, which is offered as rod, bar, and sheet stock with a dielectric constant range of 3.5 to 23.

STYCAST HiHiK is used for machined parts of various kinds — matching transformers, tapered transitions, dielectric spacers, etc. It is used to shrink the size of antennas and other radiating devices, and in radome fabrication. It is readily machined with carbide tools or by grinding.

The color of STYCAST HiHiK varies from off-white at low dielectric constants to brown at the high end of the range. The specific gravity also increases from 2 to 3 as the dielectric constant increases. Temperature range of use is from −50°C to +150°C. Thermal expansion coefficient is well matched to that of aluminum and brass.

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nts with a B.S. degree to be able to contribute in this field. Most of the microwave companies, however, generally are not willing (there are exceptions) to invest in the training of fresh B.S. graduates and usually look for and hire "experienced" people. This, however, does not help in increasing he pool of available talent. Universities on the other hand can train students in this field but only if (1) the students go on to graduate school and work toward at least an M.S. or higher degree and (2) there are faculty members at the particular school who are actively involved in research and teaching in this field and have adequate laboratory facilities and equipment to be able to provide the proper training.

I therefore feel that industry, government agencies and universities should work closely to achieve the above objectives if there is truly an interest in increasing the pool of available talent.

Industry can contribute toward this n many ways. Some of these are cited below:

- Industry must be willing to invest in the training of B.S. graduates. This can be done by providing any of the following:

  On-the-job training and continuing education. Industry should not expect a B.S. graduate to start contributing the first day on the job.

  Subsidizing students to obtain advanced degrees. This can be done, for example, by hiring new B.S. graduates and sending them to a university for one year to obtain an M.S. degree in microwave engineering. Bell Laboratories, for example, does this in their so-called One-Year-On-Campus (OYOC) Program. Even though some students may not necessarily return to the sponsoring company, if enough companies did this, all of them would benefit in the long run.

  Donating fellowships funds to universities with active programs in microwaves and stipulating that such funds be used to attract graduate students into the microwave area. At this time a fellowship of $10,000/year would be adequate and very helpful in attracting a graduate student into the field.

- Industry must get more involved with universities on a regular and long-term basis and must communicate with undergraduate students. This can be achieved by doing any of the following:

  Sponsoring long-range research grants at universities and with faculty members who are actively involved in the field.

  Hiring faculty members as consultants and getting them involved in real-world problems. This, by the way, also helps to keep some excellent faculty members at universities to train the students.

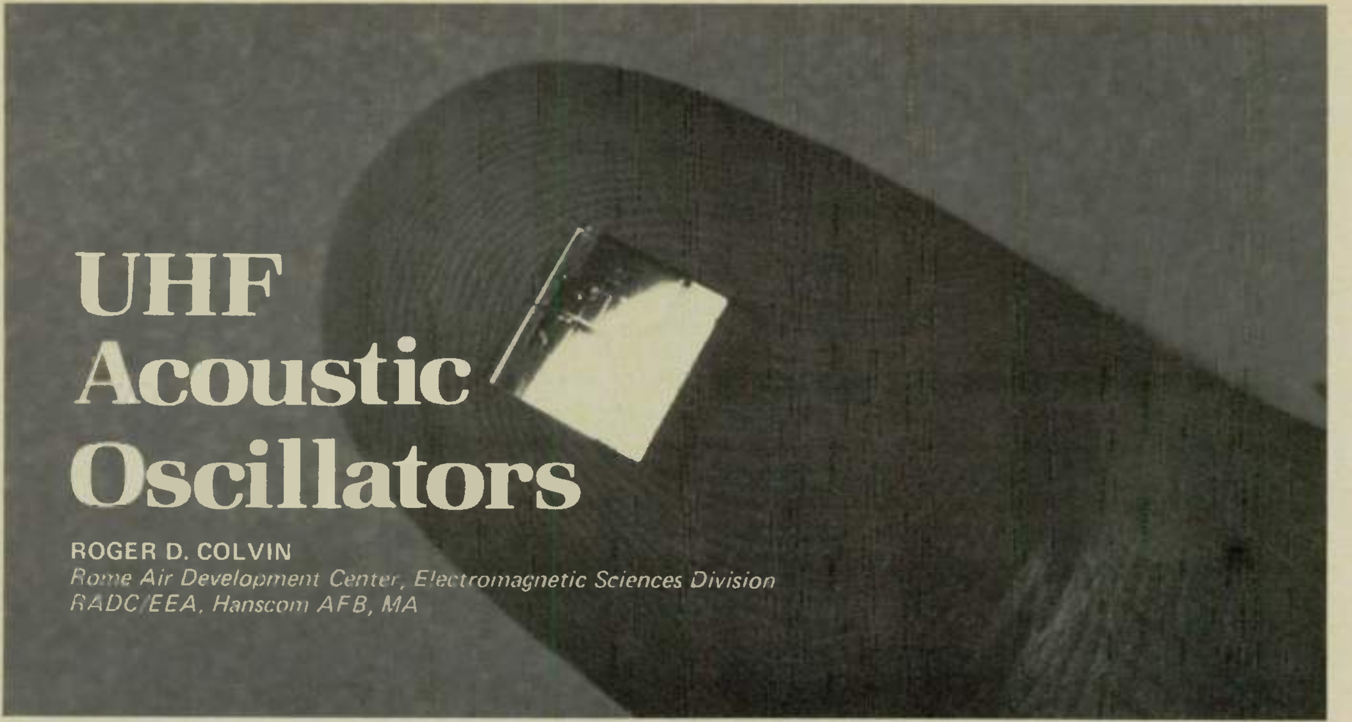
  Providing universities with equipment and facilities to help them establish experimental laboratories.

  Establishing endowed chairs at universities to help them attract top talent to their faculties in this field.

  Having technical personnel visit universities on a regular basis and give lectures to students on the challenging problems and exciting opportunities in the microwave field.

As to government agencies, particularly DoD ones, I must admit that they have certainly done much better than industry in this regard. Were it not for research support from these agencies, there would be no programs at universities in microwaves. Look what happened to instructional programs in microwave tubes when research funding from DoD dried up. They disappeared, and now it is extremely difficult and costly to turn them on again. I hope we have learned a good lesson from this. Government agencies, in general, have been providing long-range research support and this is essential to the survival and improvement of the few programs that exist at univerties. Government agencies have also been encouraging university-industry cooperation and joint programs and this is a step in the right direction. It is hoped that this type of support will be continued and expanded as it is essential to instructional programs. One area where the federal government can help immensely is to provide tax incentives to companies to support research at universities and donate equipment to them.

In closing, I believe that microwave engineering is very essential to ou communications, radar, defense and other systems and we cannot afford tc be second to anyone in this field. It behooves us to make certain that the pool of available talent is sufficient tc meet the need. With close cooperation among universities, industry anc government agencies, we can meet thi challenge. With proper support anc programs from industry and government agencies, I feel the universitie will respond effectively.



UHF Acoustic Oscillators

ROGER D. COLVIN
Rome Air Development Center, Electromagnetic Sciences Division
RADC/EEA, Hanscom AFB, MA

Surface Acoustic Wave (SAW) oscillators are practical from 100 MHz to 1500 MHz and can be in the form of a delay line or resonator. High overtone bulk acoustic resonators on non-piezoelectric substrates operate from 1 GHz to 10 GHz with a Q better than quartz. The two SAW approaches and the high overtone bulk resonator are compared with each other and with a multiplied 5 MHz standard crystal oscillator for UHF and microwave applications. UHF acoustic oscillators give size, weight, cost and power reductions.

INTRODUCTION

The motivation for a high fundamental frequency oscillator is the elimination of multipliers and associated filters. These multipliers and filters cause an unnecessary penalty in size, weight, power and cost. A recent application at 840 MHz dramatically demonstrated this. Compared to the previous system based on a multiplied 21 MHz crystal oscillator, there was an 11:1 decrease in size, a 6:1 decrease in power dissipation, and a substantial increase in output power.[1,2] Another example shows a 3 to 1 cost advantage in production for an oscillator at 1030 MHz using a SAW delay line at 515 MHz and a crystal at 172 MHz.[3]

A surface acoustic wave is launched by an interdigital transducer (IDT). The frequency is proportional to finger spacing and is limited only by photolithography capabilities for making the IDT. SAW oscillators are practical with fundamental frequencies from 100 MHz to 1500 MHz.

Another promising technology is oscillators made from high

Invited paper presented at the Society of Photo-Optical Instrumentation Engineers' (SPIE's) 24th Annual Technical Symposium, Seminar 2, July 28-August 1, 1980, San Diego, CA.

Editor's Note: Part II of this Special Report will appear in a subsequent issue. Such aspects of UHF acoustic oscillators as temperature effects, aging, such considerations as fast warm up, acceleration and vibration and some concluding remarks will be presented.

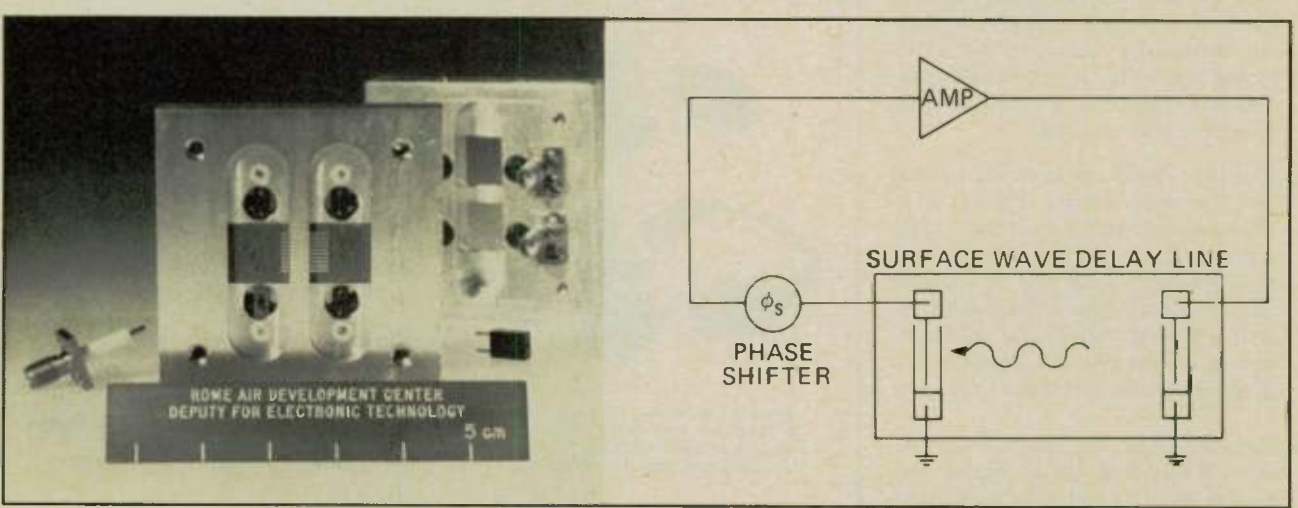


Fig. 1 Left—Photograph of five typical SAW delay lines that could be adapted for use in an oscillator.
Right—Schematic diagram of SAW delay line used as an oscillator.

(continued on page 24)

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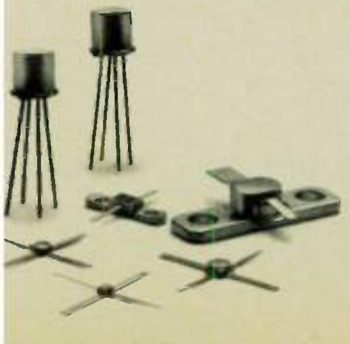
AT-0017	1.5dB	25dB	60MHz
UHF			
AT-0045	1.5dB	13dB	500MHz
AT-0025A	2.0dB	12dB	500MHz
AT-0025	2.5dB	11dB	500MHz
BIPOLAR SMALL SIGNAL LOW NOISE TRANSISTORS UP TO 4 GHz (70 mil pkg)			
AT-4680	2.8dB	8.8dB	4.0GHz
AT-4690	3.0dB	9.5dB	4.0GHz
AT-4641	3.5dB	7.5dB	4.0GHz
AT-4642	4.0dB	7dB	4.0GHz
AT-2645A	3.0dB	11dB	2.0GHz
AT-2645	3.5dB	11dB	2.0GHz
BIPOLAR SMALL SIGNAL LOW NOISE TRANSISTORS UP TO 4 GHz (100 mil pkg)			
AT-4880	2.8dB	8.8dB	4.0GHz
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 (TYP)	12dB	4GHz
AT-8060 Chip AT-8061	2.8dB (TYP) 2.5dB (TYP)	8dB 9dB	12GHz 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.**
AT-3850	+20dBm	4.0	9dB	3GHz



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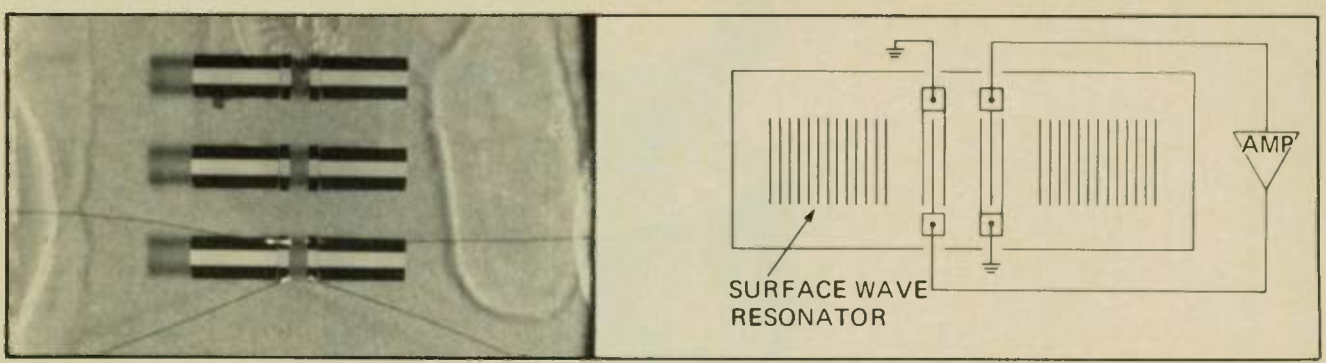

Fig. 2 Left—Photograph of three typical two-port SAW resonators.
Right—Schematic diagram of SAW two-port resonator used as an oscillator.

overtone bulk acoustic waves. Present devices use a zinc oxide interdigital transducer on non-piezoelectric single crystals allowing a much higher Q than quartz. These devices produce useful resonances in the range 1 GHz to 10 GHz. Any resonance may be used from an available comb of resonances which may cover an octave or more. This is attractive for frequency hopping. SAW oscillators can also produce a comb of frequencies by using a delay line with thinned or broadband transducers.

APPLICATIONS

The first applications of these oscillators have been in systems that do not require ultra-stability with changes in temperature. A prime example is the local oscillator of a radar. The stability requirement is only pulse to pulse and not for hours or days. Thus a relatively temperature-sensitive oscillator is acceptable. Other examples are missile and rocket systems, and data links that are expendable or have a short useful life. The new generation of gigabit logic using GaAs and Josephson Junctions will need clocks at microwave frequencies. The above representative examples demonstrate the utility of oscillators that do not require ultra-stability. In addition, they are inherently low cost due to monolithic construction, do not suffer phase noise degradation due to multiplier chains, and have inherently better vibration sensitivity.[5,6]

Ultra-stable UHF acoustic oscillators have been fabricated that meet the requirements of future military systems. These include but are not limited to GPS, JTIDS (class III), SEEK TALK, SINCGARS, and other TDMA systems. However, these are laboratory prototypes, and no one oscillator has met all the requirements simultaneously. This is a relatively new technology with major improvements being made almost daily. A second approach to ultra-stability involves the hybrid combination of acoustic oscillator with a rubidium or cesium source. Rubidium and cesium oscillators are phase locked to a 5 MHz crystal to achieve short-term stability. If this crystal were replaced with a SAW or high overtone bulk resonator operating at or near the atomic frequency there would be a 3.5 watt power saving and 1.6 pound weight saving in a typical case.[4] More important, however, would be the benefit of a higher output frequency. Instead of getting 5 MHz, the output would be at the UHF resonator frequency (a factor of 100 to 1000 higher) thus elimi-

TABLE I

Device	Material	Q_L	F_o (GHz)	$F_o{*}Q_L{*}10^{-13}$	Temperature Coefficient of Delay (PPM/°C)	
					Measured	Calculated
(13)	H.O.B.[1] Spinel (111)	14926	2.1311	3.18	32.07	28
(13)	H.O.B. YAG (100)	7899	3.4439	2.72	37.78	41
(13)	H.O.B. Diamond (111)	2697	2.5885	.70	7.40	8
(13)	H.O.B. Sapphire	6454	7.6623	4.94	33.19	34
(13,14)	H.O.B. $LiTaO_3$	≈ 10^4	3.00	3.00	Longitudinal	≈ 46
(13,15)	H.O.B. $LiTaO_3$				shear	0
(16)	Conventional bulk quartz	10^5	0.100	1.00		0
(17)	SAW[2] resonator	48,000	0.160	0.77		0
(18)	SAW resonator	5-10,000	0.300	0.15-0.30		0
(2)	SAW resonator	6000	1.43	0.86		0
(18)	SAW delay line	2000	0.300	0.06		0
(19)	SAW delay line	2973	0.401	0.12		0
(20)	SAW delay line	2000	1.400	0.28		0

1) H.O.B. — High Overtone Bulk
2) All SAW devices are on quartz

Table I — Device Q is a function of frequency and material. A good figure of merit is the product Q times frequency (Q*F). First order Temperature Coefficient of Delay is also given.

(continued on page 26)

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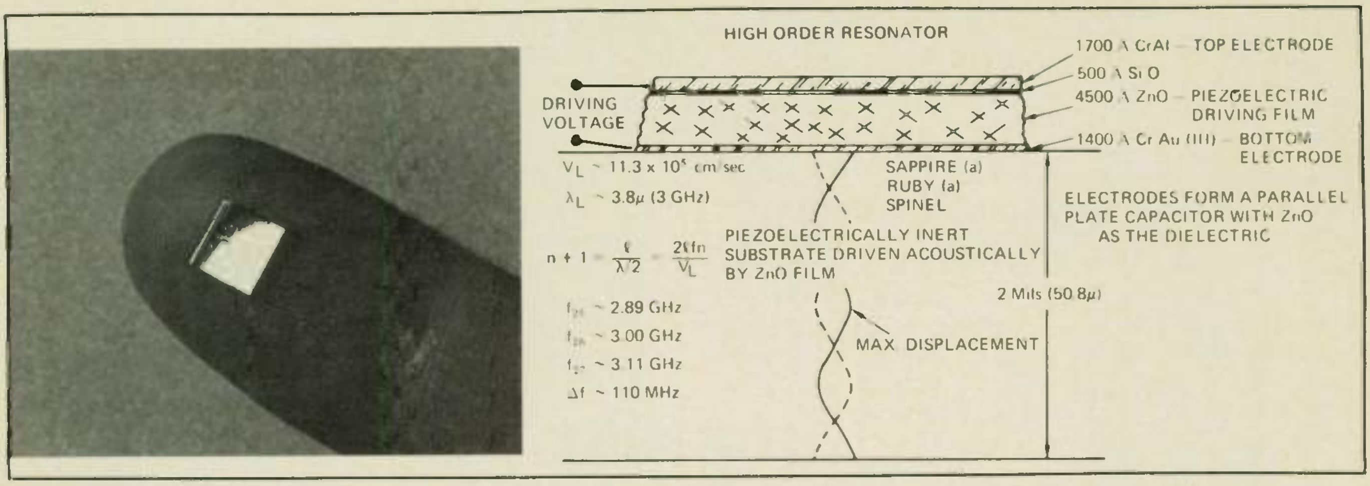


Fig. 3 Left—Photograph of a typical high overtone bulk acoustic resonator resting on a person's fingertip. Nearly all of the visible metal is bonding pads. The active area is too small to see. (Photo courtesy Westinghouse R&D Center.)
Right—Schematic diagram of a high overtone bulk acoustic resonator. With one transducer on top, it is a one-port resonator. With the addition of a transducer on the bottom, it becomes a two-port resonator. The data in this paper is for a two-port resonator (Ref. 13).

nating the need for external multipliers and filters.

BASIC PRINCIPLES

The delay line oscillator as shown in Figure 1 consists of an amplifier, phase shifter and SAW delay line. The conditions for oscillation are ADLP = 1 (III-1), and $\theta_A + \theta_{DL} + \theta_p = 2\pi m$ (III-2), where A, DL and P are the gains, and θ_A, θ_{DL}, and θ_p are the phases of the amplifier, delay line and phase shifter respectively, and m is an integer. The phase condition (III-2) determines the frequencies of oscillation while the frequency response of the delay line, using (III-1), suppresses oscillation at all but one of the possible oscillation frequencies. The spacing between possible adjacent oscillation frequencies is $1/\tau$, where τ is the total loop delay (typically the delay line contributes more than 99 percent of the total delay). The phase shifter is sometimes needed because of the inability to specify the insertion phase of the delay line.[7]

Conversely, a comb spectrum (many simultaneously available frequencies) may be desired. This phenomenon occurs when the curvature of the delay line passband is inverted relative to the normal (convex) form, and also intimately involves the non-linearity of the saturated amplifier.[8] The stability of this overmoded oscillator with temperature is as good as the temperature coeffi-

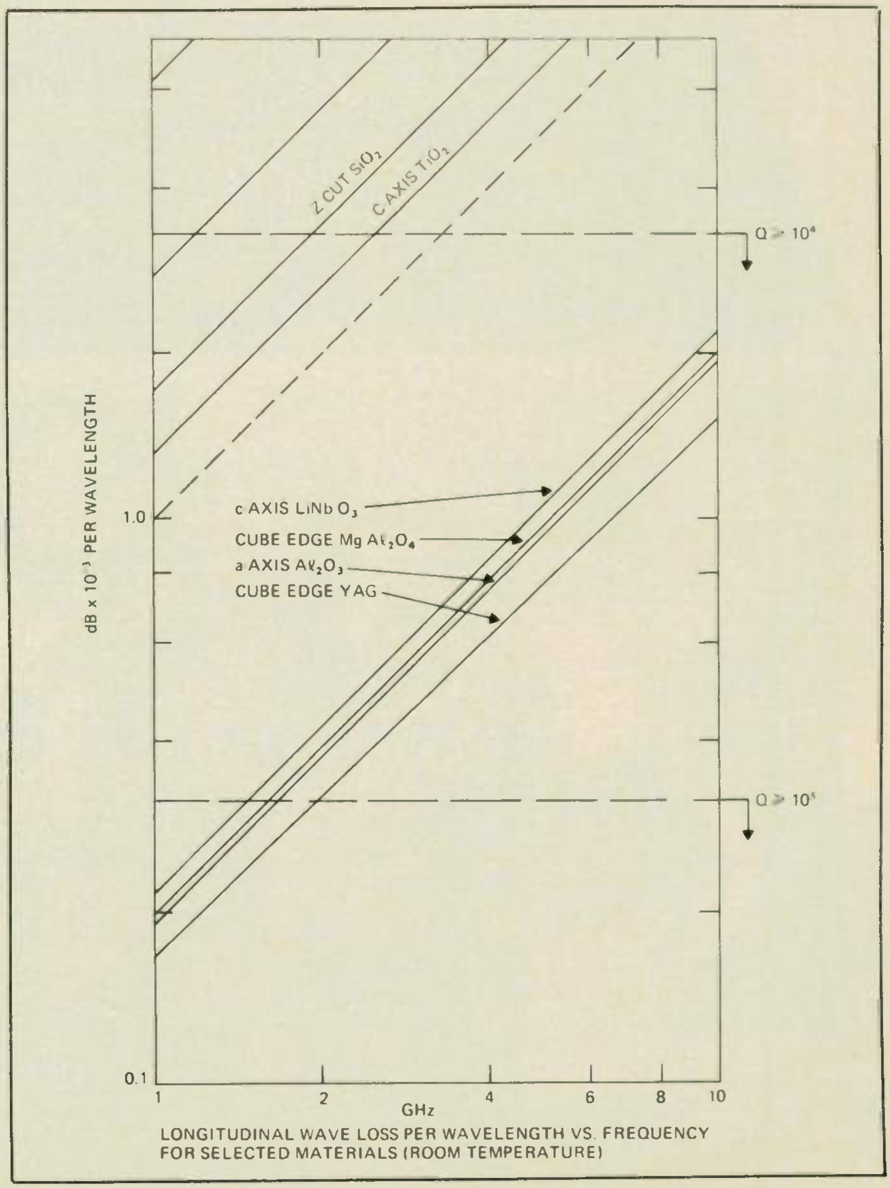
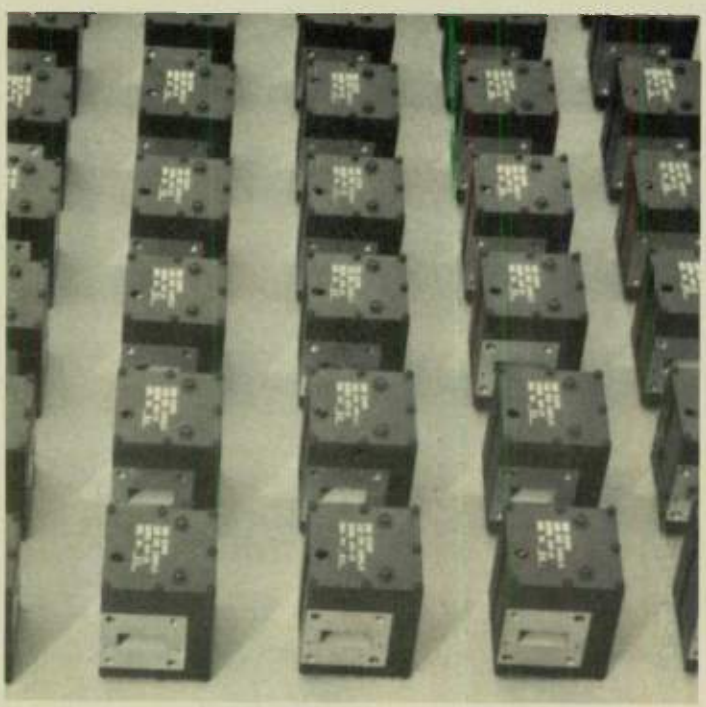


Fig. 4 4-Longitudinal acoustic wave loss per wavelength versus frequency for selected materials at room temperature (Ref. 13).

(continued on page 29)

high speed ferrite switches



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Switching Time:	20 KHz Min. (40,000 operations per second)
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Tel: (213)822-0800 Telex 65-2448 TWX 910-343-6469 cient of delay (TCD) of the delay line. If more stability is desired, the oscillator can be injection locked to a more stable oscillator. This combined device is called a mode locked SAW oscillator (MLSO).[9,10]

The surface wave resonator based oscillator is conceptually a simpler device. The loop gain and loop phase conditions (III-1 and III-2) must still be met, but the resonator has only one very narrow passband. Thus there is only one possible oscillation frequency. The resonator may be viewed as a resonant cavity with standing acoustic waves which are tapped into with the SAW interdigital transducers (IDT). **Figure 2** shows one type of two-port. There are two other basic configurations: 1) two-port, with input and output IDT's outside the cavity; 2) one-port, with a single IDT used as a resonant impedance.[11] In addition, there are several other possible configurations.[12] However, the configuration in **Figure 2** is the most promising since it requires no external circuitry (i.e. bridges or other balancing circuits) and has a low insertion loss. Either the resonator or delay line oscillator can be voltage tuned over a limited range.[7]

The high overtone bulk resonator shown in **Figure 3** is fundamentally different from conventional 5 MHz quartz resonators. First, the electrodes are interdigital rather than a continuous film, and second, only the area under the transducer is active (a very small area) rather than the whole surface. Thus mounting can be more rugged and simplified. Finally, the configuration shown uses a piezoelectric transducer material (ZnO) allowing the substrate to be a non-piezoelectric with less propagation loss and higher device Q. The interdigital electrodes described here should not be confused with the interdigital transducers of a SAW device. Here the electrodes form a parallel plate capacitor with ZnO as the dielectric. The frequency response of the transducer is determined by its overall thickness, and the electrodes are interdigitated only to aid impedance matching. The resonator may be either a one-port, as shown in **Figure 3**, or a two-port made by adding an identical transducer on the opposing surface. All the data in this paper is for a two-port configuration. **Figure 4** shows the acoustic loss vs frequency for several candidate materials. Note SiO_2 is quartz, Al_2O_3 is sapphire, and $MgAl_2O_4$ is spinel.[13] Performance of these materials is listed in **Table I** and explained in the next section in the context of short term stability. Analogous to the conventional 5 MHz resonator, many overtone resonances are available. In **Figure 3** the resonances are spaced by 110 MHz. This is a practical upper limit with spacings down to 5 MHz being more typical. The ZnO transducer has a broad frequency response; the example in Ref. 13 shows usable resonances over nearly an octave, 6 to 10 GHz, with a Q of 4500. Q's greater than 5000 are typical and have been fabricated to 20,000 for the frequency range of 1 to 10 GHz.

SHORT TERM STABILITY

The most direct comparison of acoustic devices used for oscillators can be obtained by examining **Figure 5** which shows equivalent circuit Q as a function of frequency. For attenuation, $a = 1.09\ F^2$ (in nepers per centimeter, F in GHz) has been used for ST,X Quartz. For physical size o the devices, length is expressed in microseconds, and velocity is 0.3159×10^6 cm/sec. For a *delay line*, the equivalent value of Q is related to the group delay, τ_g, through $Q = \pi f \tau_g$. (IV-1). For the unloaded *resonator*,

$$Q = \left[\frac{2\pi f \tau}{\sinh(2av\tau)}\right]\left[1 + \frac{2R_G/Z_o}{\tanh(av\tau)}\right]^{-1} \qquad \text{(IV-2}$$

where τ is the effective delay between grating reference planes

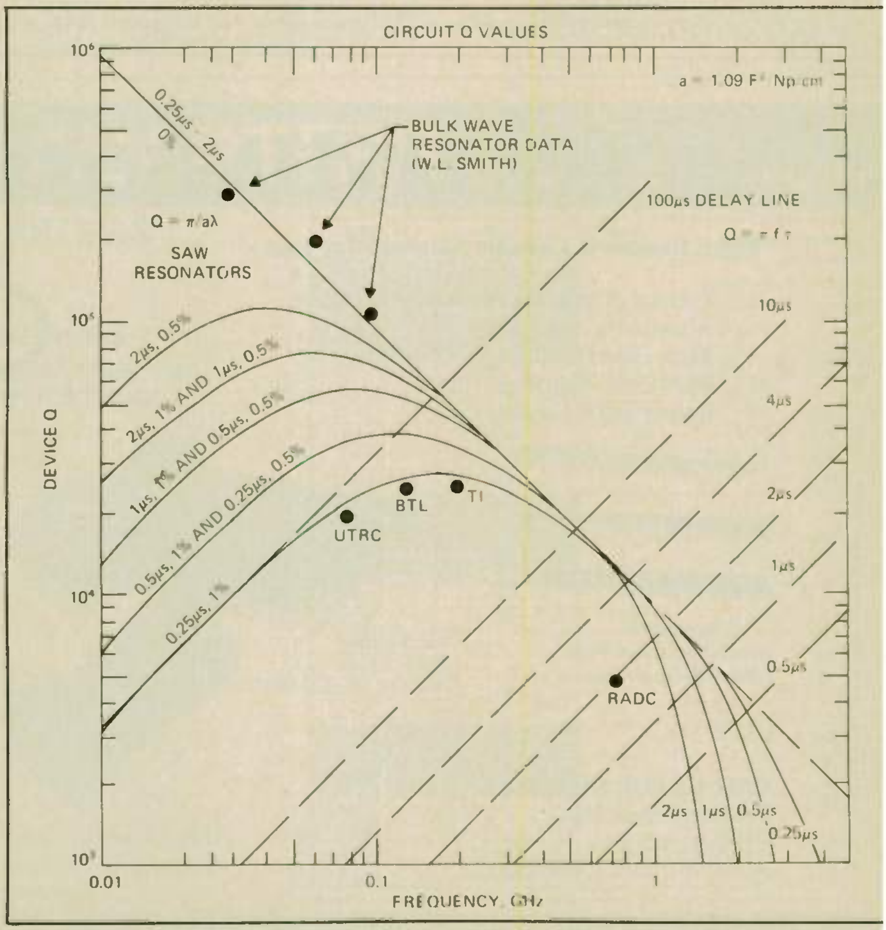
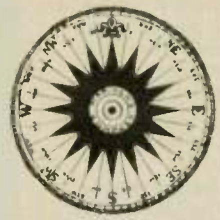


Fig. 5 Comparison of circuit Q values of bulk resonators, SAW resonators, and SAW delay lines vs frequency. The dots are experimental values. (Ref. 22)

Around the Circuit



PERSONNEL

Henry Pessah was appointed Manager of Engineering for Cablewave Systems, Inc., where he will direct product design. . .At the Solid State Microwave Division of Varian Associates, **Jack Keyes** was named Assistant General Manager. . .Promotions at California Eastern Laboratories Inc. include **Marvin E. Groll** from East Coast Sales Mgr. to V.P., Sales and **Russell E. Mills**, from Sales Engineer to Eastern Regional Sales Manager. . .EEV Canada Ltd. appointed **David Clissold** as Deputy General Mgr. and **Bob Parkes** as Sales Mgr.-Western Region. . . Magnum Microwave Corp. appointed **William D. Heichel** as Director of Advanced Development. . .**Trevor Lambert** joined Adams Russell Co. as V.P. of Corporate Development, a new post. . .**Richard F. Huelskamp** was named AN/MLQ-34 (TACJAM) Program Manager at the Western Div. of Sylvania Systems Group. . .Sanders Associates, Inc.-Microwave Div. announced the appointment of **Robert J. Quagan** as Mgr. of New Products and Advanced Technical Planning.

CONTRACTS

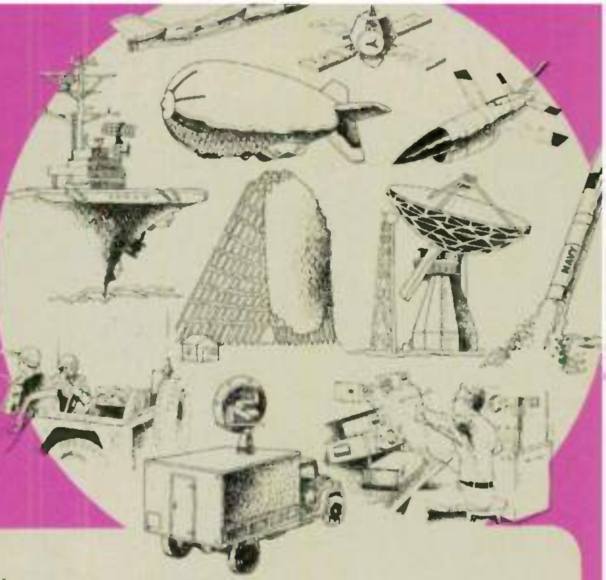
Alpha Industries, Inc., Millimeter Div., began delivery of prototypes under a $750K contract from the **Sperry Div.** of **Sperry Corp.** for initial development of mm-wave missile seeker components. . .**California Microwave, Inc.** received a $3.1M contract from **AT&T** Long Lines Dept. for some 1,000 CA42 transmitting amplifier systems. . .US Naval Air Systems Command granted an additional $2.2M contract to **Sanders Associates - Microwave Div.** for the third production lot of mini ECM devices, called Primed Oscillator Expandable Transponders (POET). . .**Anaren Microwave, Inc.** received a contract for over $6M from **Racal-Decca Defense Systems (Radar) Ltd.** for advanced ESM receivers to be used by the Danish Naval Materiel Command. . .**Acrian, Inc.** received a $2.5M order from **ITT Avionics Div.** for transistors to be used in ground TACAN equipment manufactured for the Federal Aviation Administration.

INDUSTRY NEWS

The Board of Directors of **IEEE** approved an increase in basic membership dues to $43, to $12 for US regional assessment, to $12 for students and to $22 for students transferring to higher grade membership. New fees become effective with 1981 dues billing. . .**Omniyig, Inc.** moved its operations into 8000-sq. ft. in a new building at 3350 Scott Blvd. in Santa Clara, CA and has acquired three acres at International Business Park, San Jose, CA where a 30,000-sq. ft. building is planned for future expansion. . .**Sawtek, Inc.** and **Rockwell International** have announced an agreement for Sawtek to acquire most of the assets of Rockwell's surface acoustic wave (SAW) business now located in Newport Beach, CA. Sawtek will move its acquisition to its Orlando, FL base. . .With the acquisition of **Tellite Corp., Electronized Chemicals Co.** (a div. of **High Voltage Engineering Corp.**), has broadened the selection of its low-loss clad laminate and dielectric sheet line. ECC now offers both Tellite® and Polyguide® product lines manufactured at Tellite's Whippany, NJ plant. . .**The Narda Microwave Corp.** announced that it filed a registration statement on Sept. 22, 1980 with the SEC for a proposed offering of 325K shares of common stock to be sold by Narda. . .**M/A-COM's** acquisition of **Valtec Corp.**, was consummated following approval of the transaction by stockholders of both companies. . .MA/COM has also announced agreements in principal with both Microwave Power Devices of Hauppauge, NY and Power Hybrids, Inc. of Torrance, CA under which each would become an operating subsidiary of MA/COM. . .**California Microwave, Inc. Co. (CMIC)** completed the acquisition of **Satellite Transmission Systems, Inc. (STS)**. CMIC purchased 800K outstanding STS shares for an initial payment of $2.3M ($1.7M cash and 44.2K shares) to acquire STS. . .**Tracor, Inc.** and **MBAssociates** (**MBA**) jointly announced the completion of the merger of MBA into a wholly owned subsidiary of Tracor, on Sept. 3, 1980. Tracor will issue .3125 of one share of Tracor common stock for each of MBA's 1.2M shares, outstanding. . .**Sperry Corp.** has signed a letter of intent to purchase **RCA's Avionics Systems Div.** Sperry plans to continue business at RCA's Van Nuys office with the existing work force. . .A new strategic business unit of **GTE Lenkurt**, for fiber optic communications systems, has been formed. Arthur R. Kraemer was appointed V.P.-General Mgr. of the **GTE Lenkurt Fiber Optics Div.** The new operation will be located first at GTE Lenkurt's present San Carlos headquarters, but will relocate to its own 65,000-sq. ft. plant in Mountain View, CA.

FINANCIAL NEWS

Avantek, Inc. reported operating results for the third quarter ended Sept. 6, 1980 of net sales of $13.7M, net income of $1.8M or earnings per share of 43¢. This compares with 1979 quarterly net sales of $9.6M, net income of $1.0M, or earnings per share of 28¢. . .For the nine months ended August 3, 1980, **Microdyne Corp.** reported net sales of $17.15M net income of $2.48M or 90¢ per share. This compares with 1979 nine-month net sales of $12M, net income of $1.7M or 76¢ per share. . .**Aydin Corp.** announced net sales of $22.2M, net income of $1.49M or 65¢ per share for the period ended March 29, 1980. This compares with first quarter 1979 results of net sales of $13.5M, net income of $863K or 38¢ per share. . .For the year ended June 30, 1980, **California Microwave, Inc.** reported sales of $38M, net income of $158K or 8¢ per share. During the comparable four quarters of 1979, sales were $40M, net income was $2.3M or $1.17 per share. . .For its fiscal year ended June 30, 1980, **Radiation Systems, Inc.** reported sales of $7.65M, net earnings of 836K or $1.06 per share. For 1979, results were sales of $5.65M, net earnings of 666K or 88¢ per share. . .**Sanders Associates, Inc.** reported year-end results for the period ended July 25, 1980 of net sales of $281.1M, net income of $18.5M or $2.65 per share. For 1979, net sales were $164M, net income was $15.3M or $2.44 per share. . .**Scientific-Atlanta, Inc.** and its subsidiaries reported year-end results for the period ended June 30, 1980 of net sales of $192.0M, net earnings of $12.7M or $1.31 per share. This compares with 1979 fiscal net sales of $129.76M, net earnings of $7.59M or 89¢ per share.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Some Recent Near-Field Antenna Measurements at NBS

C. F. STUBENRAUCH and A. C. NEWELL
Electromagnetic Fields Division
National Bureau of Standards
Boulder, CO

NTRODUCTION

This paper discusses three measurements recently completed at National Bureau of Standards (NBS) using near-field techniques. The first was a planar scan of a prototype microstrip array of a type used in satellite-borne synthetic aperture radars. Of special interest in this measurement was the requirement for far-field phase. In addition, the array was so large that the entire near-field pattern could not be measured with a single scan. Comparisons to far-field measurements performed at New Mexico State U., Physical Science Laboratory (PSL) will also be presented.[1,2]

The second topic consists of recent results obtained with probe corrected measurements made on a cylinder. Here comparisons to measurements made using planar scanning will be presented. Some results illustrating the importance of probe correction will be given.

The final section describes a hybrid technique which employs both planar and cylindrical scanning to allow sidelobes to be measured to greater angles off boresight than permitted by either planar or cylindrical scanning above. Essentially this technique determines the main beam and first few sidelobes with a planar scan and the far sidelobes with a cylindrical scan in which the axis of the scan cylinder is approximately coincident with the boresight of the antenna.

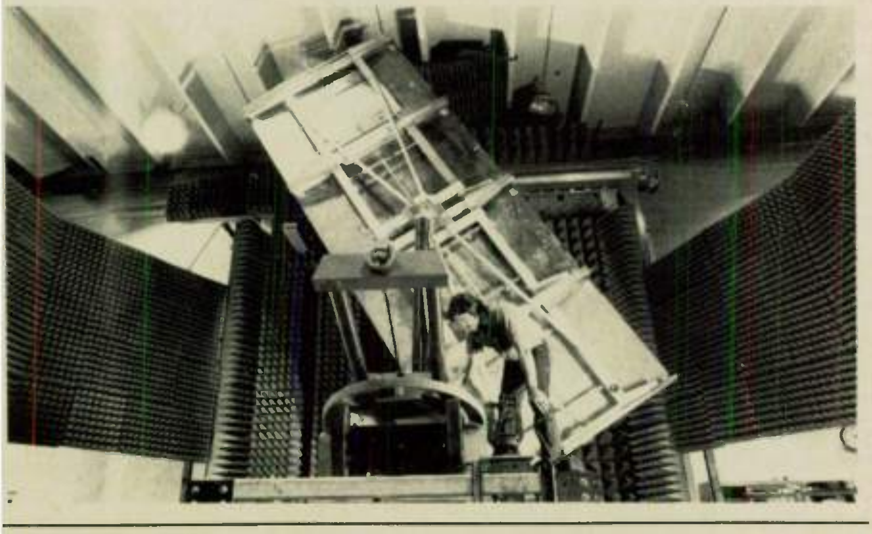

Fig. 1 Rear view of antenna showing 3-axis rotator mount with antenna partially rotated in ϕ.

PLANAR SCAN OF A MICROSTRIP ARRAY ANTENNA

Planar-near field scanning is the primary antenna measurement tool employed at NBS. It is the technique of choice for pattern measurements of high-gain, narrow-beam antennas. It is also useful for gain measurements of antennas whose Rayleigh distance (2 x aperture^2 /wavelength) is too great to permit the use of an extrapolation technique.

The measurement of a large microstrip phased array for space borne synthetic aperture radar (SAR) applications presented some unique problems and also provided a comparison between far-field patterns obtained with conventional techniques and those calculated from near-field data.[3,4] In addition to the comparison between patterns, it was desired to determine the effects of mechanical deformation of the array.

Of particular importance for the ultimate application was the determination of the far-field phase pattern over the −8 dB beamwidth of the main lobe. This type of measurement is essentially impossible using conventional far-field techniques. Thus, one of the goals was to evaluate the feasibility of using near-field techniques for far-field phase determinations.

The comparison was performed on an array of four engi-

The far-field pattern calculated from this data is shown in **Figure 7**, along with the results of the planar scan.

This same data has also been processed without probe correction, i.e., it is assumed the probe measured the field at a point. These results are shown in **Figure 8**.

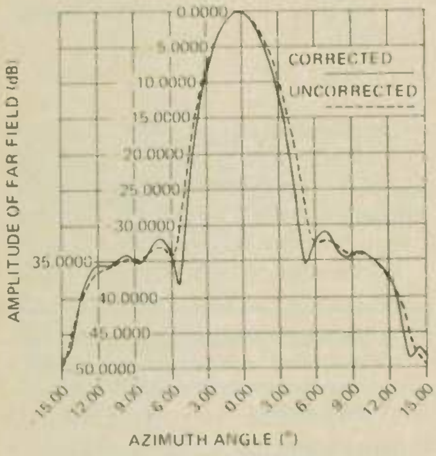

Fig. 7 Comparison of far-field patterns obtained from planar and cylindrical scans for X-band constrained lens antenna.

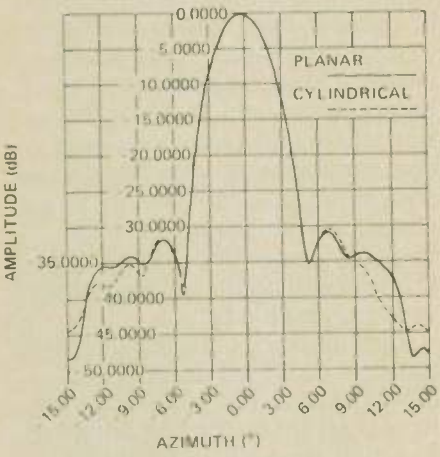

Fig. 8 Comparison of far-field patterns obtained from a cylindrical scan of an X-band constrained lens antenna and calculated both with and without probe correction.

HYBRID PLANAR – CYLINDRICAL SCANNING

One of the limitations of planar scanning was certain applications is that reliable far-field patterns are obtained only over an angular region defined by the edges of the aperture and the scan plane as shown in **Figure 9**. This implies that very large scan planes are required to determine far-field patterns over regions approaching a hemisphere.

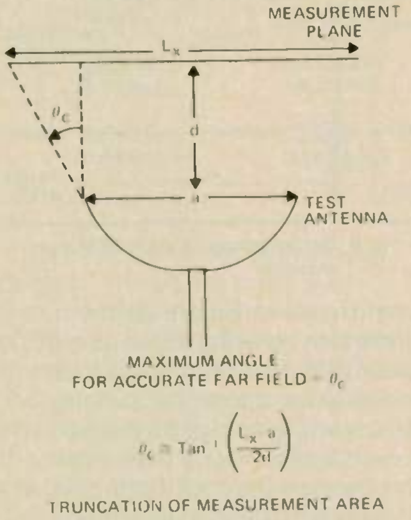

Fig. 9 Schematic relationship between scan length and maximum angle to which far-field patterns can be accurately determined.

In order to extend the region over which valid far-fields may be determined, it was proposed to perform a cylindrical scan of the antenna oriented with its boresight direction coincident with the cylindrical scan axis in order to determine the radiation pattern in the far-sidelobe region, and to measure the pattern in the main beam and first few sidelobes using planar near-field techniques. Pattern information may thus be obtained in all directions except for a conical region centered on the cylindrical scan axis and lying in the rear hemisphere of the antenna. **Figure 10** illustrates the scan surfaces for this hybrid technique.

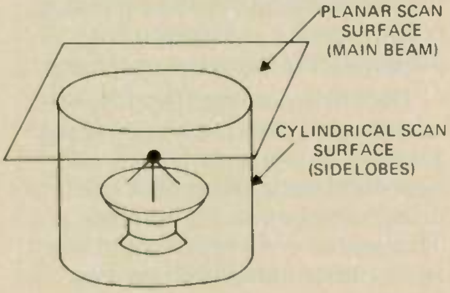

Fig. 10 Hybrid planar-cylindrical scanning. Main beam region is determined from a planar scan. Sidelobes are determined from a cylindrical scan.

The success of this system depends on whether the scan cylinder surrounding the antenna can be truncated in the direction of the main beam of the test antenna. In order to study the feasibility of such a technique, cylindrical scans were made on a 16 wavelength diameter reflector antenna oriented with the boresight axis parallel to the scan axis. Tests were made using several types of probes, including open ended waveguides, small standard gain horns and a horn whose axis was tilted with respect to the normal to the scan axis.

The coordinate systems for the far-fields obtained from the two cylindrical scans are revealed as in corresponding points on the reflector rim and corresponding cuts in the two systems. For example, the elevation component, azimuth cut for A⩾0 obtained from the cylindrical main beam (CMB) scan corresponds to the azimuth component in the plane A = 90° with E⩾0 obtained from the cylindrical sidelobe (CSL) scan.

Comparisons of amplitude contour plots obtained with CMB and CSL scans indicate that agreement is very good over common regions of validity. Thus it is seen that it is indeed feasible to obtain more complete patterns using the hybrid planar cylindrical near-field scanning technique.

CONCLUSION

Recent near field scanning work at NBS has been discussed. Planar scanning still remains a primary tool for pattern measurement. Cylindrical scanning is useful in many applications where planar cannot be used. Results presented show that the hybrid planar/cylindrical scanning promises to be suitable for measurements where more complete patterns are needed.

ACKNOWLEDGMENT

The work reported in this paper* is the result of effort on the part of many people at National

(continued on page 42)

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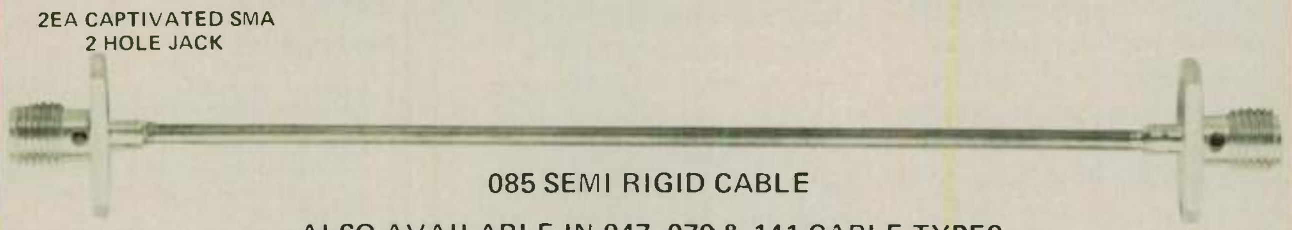

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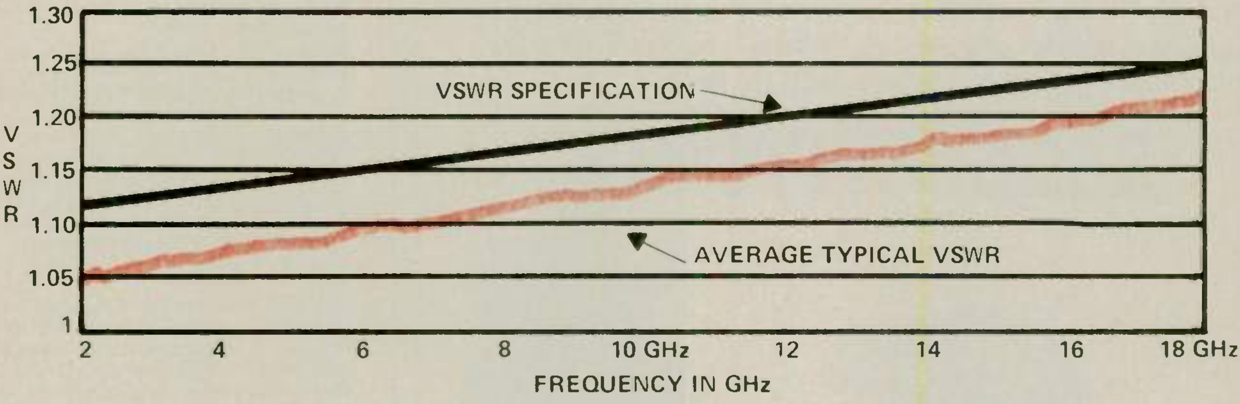

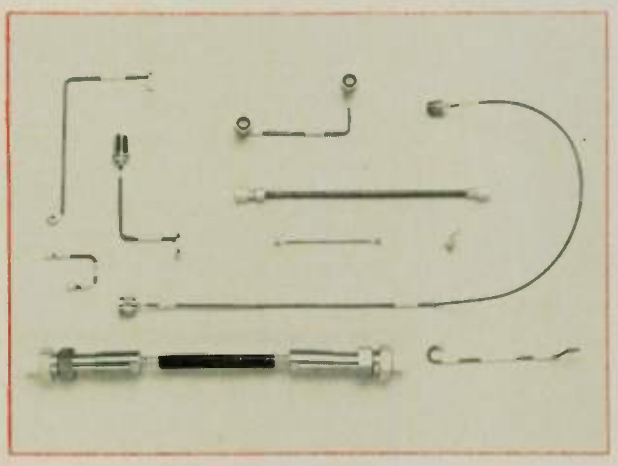

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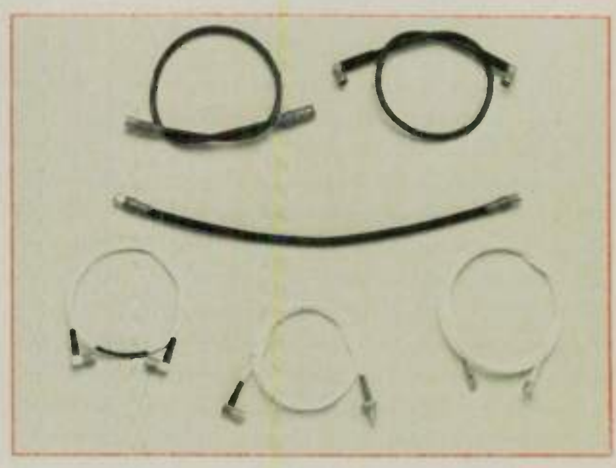

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(from page 40)

Bureau of Standards. In particular the work of Dr. Arthur D. Yaghjian is acknowledged. The support of Dr. Ramon C. Baird is much appreciated. Finally, the authors wish to thank Dr. Keith Carver of New Mexico State University for material relating to the microstrip antenna comparisons.

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Carl F. Stubenrauch received the B.S. and M.S. degrees in electrical engineering from the University of Illinois and the PhD. degree from the University of Michigan in 1972. Since 1972 he has worked at the National Bureau of Standards, Boulder Laboratories, where he has worked on near-field measurements. Most recently he has been involved with research on cylindrical scanning. He is currently an Electronics Engineer with the Electromagnetic Fields Division.

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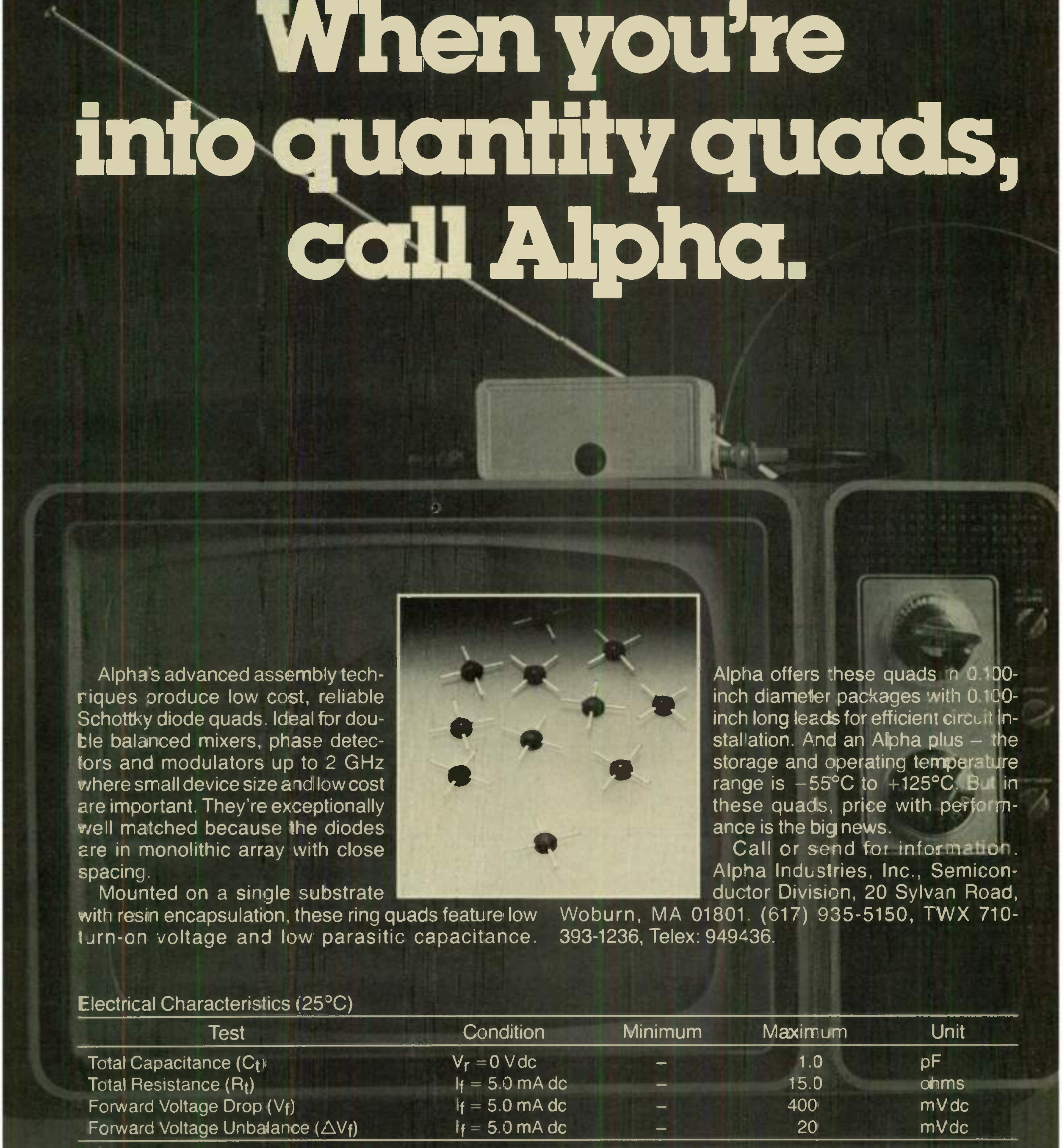

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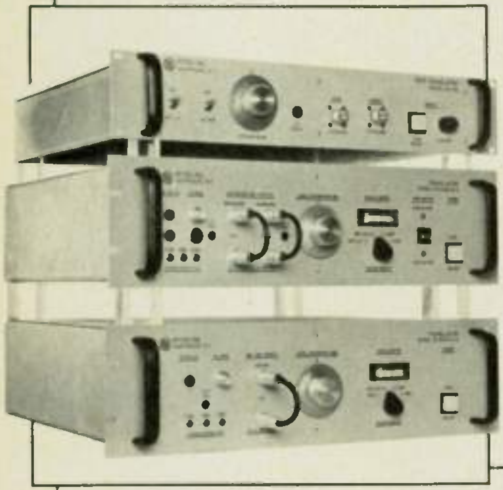

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			In	Out	
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UP-6-12	5.925-6.425	11.7-12.2	23	20	5.775
UP-6-14	5.925-6.425	14.0-14.5	23	20	8.075
UP-8011	3.7-4.2	5.925-6.425	23	23	2.225
UP-4-12	3.7-4.2	11.7-12.2	23	20	8.0
UP-4-14	3.7-4.2	14.0-14.5	23	20	10.3
DN-12-4	11.7-12.2	3.7-4.2	20	23	8.0
UP-12-14	11.7-12.2	14.0-14.5	20	20	2.3
DN-12-6	11.7-12.2	5.9-6.4	20	23	5.775
DN-14-4	14.0-14.5	3.7-4.2	20	23	10.3
DN-14-6	14.0-14.5	5.925-6.4	20	23	8.075
DN-14-12	14.0-14.5	11.7-12.2	20	20	2.3
DN-14-10	14.0-14.5	10.95-11.20	20	20	3.05
DN-14-11	14.0-14.5	11.45-11.70	20	20	2.55
DN-10-4	10.95-11.20	3.70-3.95	20	23	7.25
DN-11-4	11.45-11.70	3.95-4.20	20	23	7.50
DN-4245	(10.95-11.20) (11.45-11.70)	3.7-4.2	20	23	(7.25) (7.50)
DN-10-4WB	10.95-11.70	3.45-4.20	20	23	7.5
DN-10-4HO	10.95-11.70	4.20-3.45	20	23	15.15

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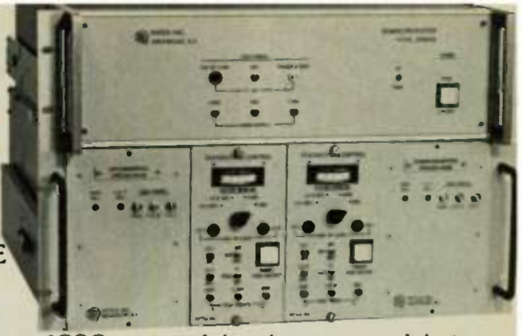

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Tunability —	Second local oscillator only	Second local oscillator only	First local oscillator only	First local oscillator only
Frequency Sense —	No inversion	No inversion	No inversion	No inversion
Tuning Range —	500 MHz	500 MHz	500 MHz	250-1000 MHz
Input Characteristics:				
Frequency —	50-90 MHz 100-180 MHz optional	50-90 MHz 100-180 MHz optional	3.7-4.2 GHz	10.95-11.2 GHz 11.45-11.7 GHz 10.95-11.7 GHz 11.70-12.2 GHz
Input Level —	−20 dBm	−20 dBm	−20 dBm	−20 dBm
Input Impedance —	75 ohms	75 ohms	50 ohms	50 ohms
Return Loss —	26 dB minimum	26 dB minimum	23 dB minimum	20 dB minimum
Output Characteristics:				
Frequency —	5.925-6.425 GHz	14.0-14.5 GHz	50-90 MHz (100-180 MHz optional)	50-90 MHz (100-180 MHz optional)
Bandwidth —	40 MHz, 80 MHz optional	40 MHz, 80 MHz optional	40 MHz, 80 MHz optional	40 MHz, 80 MHz optional
Impedance —	50 ohms	50 ohms	75 ohms	75 ohms
Return Loss —	23 dB	20 dB	26 dB	26 dB
Level —	−5 dBm, up to +30 dBm with optional output amplifiers	−5 dBm, up to +20 dBm with optional output amplifiers	+10 dBm nominal, +20 dBm optional	+10 dBm nominal, +20 dBm optional
Transfer Characteristics:				
Noise Figure —	12 dB typical	12 dB typical	10 dB typical, 12 dB maximum, as low as 1.5 dB with optional amplifier	10 dB typical, 12 dB maximum, as low as 4 dB with optional amplifier
Gain —	15 dB nominal	15 dB nominal	30 dB	30 dB
Image Rejection —	80 dB minimum	80 dB minimum	80 dB minimum	80 dB minimum
Level Stability —	±.25 dB at constant temperature ± 5 dB 0-50°C ±1 dB with optional amplifier	± 25 dB at constant temperature ±.5 dB 0-50°C ±1 dB with optional amplifier	±.25 dB at constant temperature ± 5 dB C-50 C ± 1 dB with optional amplifier	± 25 dB at constant temperature ±.5 dB 0-50 C ±1 dB with optional amplifier
Frequency Response —	40 MHz at .5 dB 36 MHz at 4 dB 20 MHz at 2 dB	40 MHz at .5 dB 36 MHz at .4 dB 20 MHz at .2 dB	40 MHz at .5 dB 36 MHz at .4 dB 20 MHz at .2 dB	40 MHz at .5 dB 36 MHz at 4 dB 20 MHz at .2 dB
Group Delay — (±18 MHz)	Less than .03 ns/MHz linear Less than .01 ns/MHz² parabolic Less than 1 ns peak-to-peak ripple	Less than .03 ns/MHz linear Less than .01 ns/MHz² parabolic Less than 1 ns peak-to-peak ripple	Less than .03 ns/MHz linear Less than .01 ns/MHz² parabolic Less than 1 ns peak-to-peak ripple	Less than .03 ns/MHz linear Less than .01 ns/MHz² parabolic Less than 1 ns peak-to-peak ripple
Intermodulation Distortion — (third order)	At −20 dBm output 50 dBc	At −20 dBm output 50 dBc	With two −40 dBm input signals 60 dBc	With two −40 dBm input signals 60 dBc
AM/PM Conversion —	<1°/dB to −5 dBm	<.1°/dB to −5 dBm	.1°/dB to +5 dBm output	.1°/dB to + 5 dBm output
Gain Slope —	<.02 dB/MHz maximum	<.02 dB/MHz maximum	<.02 dB/MHz maximum	<.02 dB/MHz maximum
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Clad Laminates of PTFE Composites for Microwave Antennas

G. R. TRAUT
Lurie Research & Development Center
Rogers Corporation, Rogers, CT

Copper-clad or specially backed laminates based on composites of PTFE fluorocarbon polymer with non-woven glass fiber or with high dielectric constant ceramic fillers offer combinations of properties valuable for microwave antennas. Uniformity of dielectric constant, isotropy, thermal coefficients, stability, low loss tangent, and thickness uniformity are important to the designer. Those building antennas are concerned with such characteristics as chemical resistance, low moisture absorption, strain relief, formability, machineability, and bondability. Conversion techniques to optimize component performance are discussed. It is important to have convenient test methods for dielectric constant that allow close control of the base material by the producer or close monitoring of dielectric constant so that antenna pattern artwork can be adjusted. A rigid non-destructive test method is summarized. The situation for producers of microwave printed circuit antennas should improve with laminators working for closer control of critical properties in existing products as well as development of new products better able to meet the demands for antenna applications.

INTRODUCTION

Valuable combinations of properties for microwave antennas are available in two types of poly (tetrafluorethylene), PTFE-based laminates with metal foil or plate cladding. Efficient reinforcement with random glass microfibers provides low dielectric constant and low loss in one type. The other is ceramic filled for high dielectric constant. Important characteristics are considered under two categories:

Design and Engineering

- Uniformity of dielectric constant
- Isotropy of dielectric constant
- Thermal effects on electricals
- Coefficient of thermal expansion
- Uniformity of thickness
- Stability to environment

Fabrication

- Chemical resistance
- Strain relief on etch
- Machinability
- Formability
- Bondability

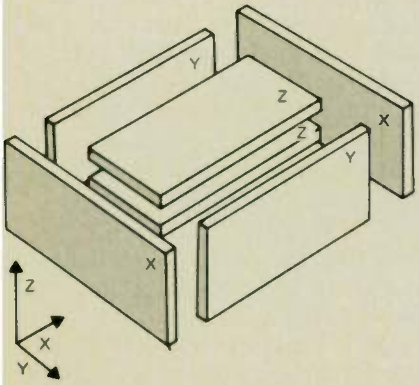

Fig. 1 Schematic for cutting dielectric constant specimens at various orientations from heavy thickness panel.

TABLE 1

X-BAND DIELECTRIC CONSTANT VERSUS MAJOR AXIS ORIENTATION OF ELECTRIC FIELD IN RT/DUROID 6010

Specimen Identification	Dielectric Constant		
	X direction	Y direction	Z direction
A	10.64	10.69	10.61
B	10.80	10.67	10.24
C	10.60	10.74	10.34
Average	10.68	10.70	10.40

The critical property of dielectric constant can be monitored by use of an empirically calibrated test fixture on a small area that is etched foil free.

With materials available, printed circuit antenna techniques should extend to some interesting new applications.

DESIGN AND ENGINEERING CHARACTERISTICS

Uniformity of Dielectric Constant

Dielectric constant uniformity is easily the materials property most critical to determining the performance levels that can be specified for most antennas.

The ±.02 dielectric currently supplied as standard in random glass microfiber-PTFE laminates is often adequate. Pattern compensation for very critical designs becomes practical with the Quick Test fixture to be discussed later.

Isotropy of Dielectric Constant

Isotropy of dielectric media is preferred for workable design computations. Anisotropy in composites is increased by the following:

- Difference between fiber and polymer matrix
- Degree of fiber orientation
- High volume fraction of fiber
- Fiber diameter and length
- Variation of fiber through the thickness
- Orientation of non-spherical fillers
- Uneven of layered filler distribution through laminate thickness

The stripline resonator test method described in ASTM D-3380, "Standard Method of Test for Permittivity (Dielectric Constant) and Dissipation Factor of Plastic Based Microwave Substrates," gives a value mostly based on a Z (thickness) direction E field. It is useful for measuring the degree of anisotropy when a heavy thickness panel can be cut into test specimen pairs as shown in **Figure 1**.

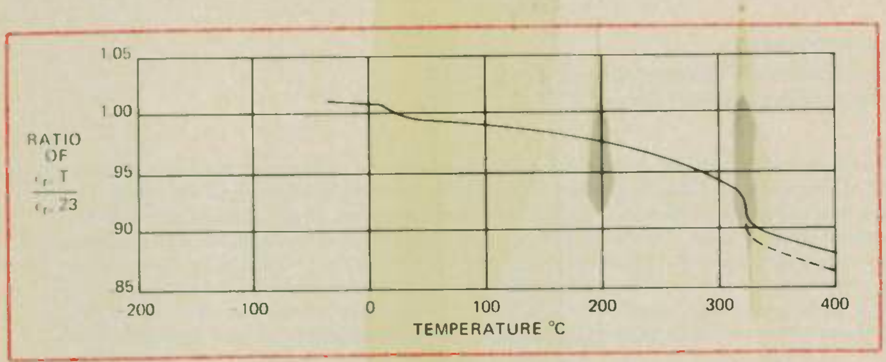

Fig. 2 Typical curves showing temperature effect on dielectric constant, ϵ_r of random glass-PTFE laminate.
Solid line is 2.33 ϵ_r material, dashed line is 2.20.

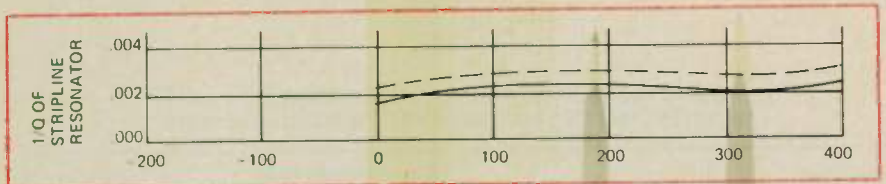

Fig. 3 Typical curves showing temperature effect on 1/Q of a 20 ohm Z_0 stripline resonator in random glass-PTFE laminate.
Solid line is 2.33 ϵ_r material, dashed line is 2.20.

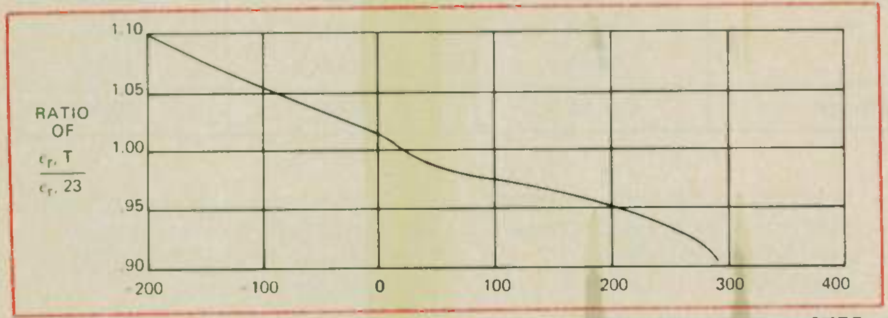

Fig. 4 Typical curve showing temperature effect on dielectric constant, ϵ_r of ceramic-PTFE laminate, 10.5 ϵ_r material.

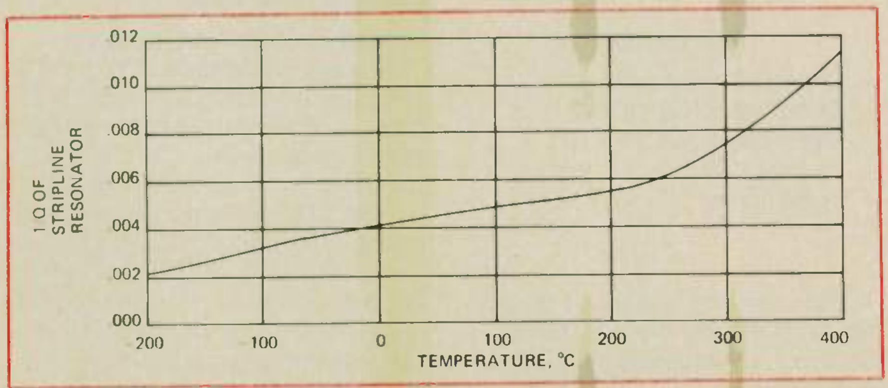

Fig. 5 Typical curve showing temperature effect on 1/Q of a 20 ohm Z_0 stripline resonator in ceramic-PTFE laminate, 10.5 ϵ_r material.

The data in **Table 1** shows a high degree of isotropy for RT/duroid 6010 microwave circuit laminate based on ceramic filled PTFE.

The uniform and low concentration of reinforcing glass microfibers in XY planes in RT/duroid 5870 laminate result in low anisotropy as illustrated by **Table 2**. The X,Y/Z isotropy index of 1.04 is significantly lower than the 1.09 index cited for woven glass-PTFE laminates of similar fiber content. Fine fiber size with uniform loading account for this.

Thermal Effects on Electrical Properties

Thermal expansion of polymer lowers the dielectric constant of PTFE composites. PTFE, a crystalline polymer, shows a slight step change in density in the 19°C region due to a crystalline lattice rearrangement and a large change at the 327°C crystalline melt. The amorphous phase shows a glass-to-rubber transition at about 130°C that appears as a gradual change in the thermal expansion coefficient.

Measurement of thermal effects on dielectric properties at microwave frequencies are observed in a 10 GHz, two-node stripline resonator assembly from two cards of the material. The resonator is capacitively coupled to probe lines and that region of the assembly is clamped between heated blocks. The remaining area is between water-cooled blocks. Resonant frequency and Q of the assembly is determined at a series of temperature settings. See **Figures 2, 3, 4** and **5**.

Both types of laminate show little change in lossiness over the temperature range. The dielectric constant changes are reversible and reflect the known PTFE transitions.

DIELECTRIC CONSTANT VERSUS MAJOR AXIS IN RT/DUROID 5870 NONWOVEN FIBER-PTFE COMPOSITE

Test Method	Dielectric Constant		
	X direction	Y direction	Z direction
1 MHz fluid displacement cell ASTM D1531	2.428	2.430	2.330
10 GHz stripline resonator ASTM D3380	2.452	2.432	2.347

Antenna designers must anticipate the temperatures to be encountered by a unit in normal service.

Coefficient of Thermal Expansion

In addition to the effect on dielectric constant, thermal expansion can have undesirable mechanical effects. Both the random fiber-PTFE and the ceramic-PTFE composites possess low thermal expansion in the plane of the sheet as can be seen in Table 3. Design out problems with mismatch to metal supports are solved by bonding circuit boards, by use of thick metal clad laminates or by solder reflow to a support.

The relatively large Z (thickness) direction expansivity poses other mechanical problems. Assemblies with rivets or screws can oosen after heat induced stress and creep. Spring-loaded screws or the like, allow expansion with minimal change in stress level.

Thickness Uniformity

The laminator must continuously monitor panel thickness uniformity since excessive variation is early warning of production problems. Extra close tolerances are available where this is mportant for a design.

STABILITY TO ENVIRONMENT

In selecting materials for an antenna, the designer must be concerned with such environmental factors as heat aging, UV, humidity cycling, vibration, thermal shock, air friction, and even long-term ocean submersion.

PTFE possesses a high melt point (327°C) and even melted retains its shape. Thermal degradation begins to be rapid at about 440°C. Prolonged service at temperatures up to about 260°C or in sunlight has little detectable effect, even without added stabilizers.

The polymer's low moisture permeability, low surface energy and the embedment of individual fibers of limited length or filler particles in the polymer matrix prevents the wicking mechanism for failure in weathering or cycling humidity.

The low modulus and good extensibility of both composite types resist damage by mechanical or thermal shock.

TABLE 3

COEFFICIENTS OF THERMAL EXPANSION OF PTFE COMPOSITES

Composite	RT/duroid 5880 Random glass-PTFE			RT/duroid 5870 Random glass-PTFE			Woven glass-PTFE			RT/duroid 6010 Ceramic-PTFE		
Diel. constant	2.20 ± .02			2.33 ± .02			2.55 ± .04			10.5 ± .25		
CTE, m/m/K	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
−70 to 10 C	85	83	112	32	59	67	66	35	135	19	21	24
10 to 25 C	72	109	449	23	61	435	16	18	378	54	53	73
25 to 75 C	21	51	261	19	47	218	19	14	217	20	20	14
75 to 150 C	20	33	269	11	31	273	26	41	285	16	18	13
150 to 250 C	24	42	504	10	28	470	28	61	461	15	16	26

FABRICATION CHARACTERISTICS

Chemical Resistance

The continuous PTFE matrix of the composites resists solvents and reagents. The ceramic filler or the glass microfiber are insoluble in organic solvents. The penetration of strong inorganic solvents is limited by the small size of fiber or filler particles isolated in the PTFE matrix.

Processing these composites should raise no concern about selection of special materials for cleaning, photo resist removal, etching or plating. Contamination

Where a corrosion-resistant plating such as gold is desired, the preferred procedure is to photo mask, plate gold, remove the mask, and etch away the exposed copper foil to avoid exposure of the copper-PTFE bond to plating solution.

Strain Relief

The heat used in lamination of foil clad PTFE composites results in annealing of copper foil to high ductility. Unfortunately, cooling leads to a strained condition between foil and substrate. The foil/substrate thickness ratio determines the degree of strain borne by the substrate. Strain relief when foil is removed by etching leads to a dimension change.

It has been found that comparatively low fiber concentrations in random composites largely control the X, Y thermal expansivities to about the same degree as woven fiber-PTFE composites with more fiber.

The strain relief problem for antenna patterns requiring tight dimensional control can be resolved in one of three ways.

- Determine the X and Y strain reliefs for the given pattern density, substrate thickness and foil thickness, allowing time for viscoelastic response of the composite after etching.
- Use a double mask and etch procedure to permit most strain relief to occur before the second exact final pattern mask is used.
- Work with laminate clad on the ground plane side with thick metal.

Machinability

The random glass-PTFE composites machine easily with low tool wear since the fibers are softer than steel, of fine diameter and in low concentration. Excess wear is avoided by keeping tool speeds down and feed rate up to cut a chip rather than scrape. Frictional heating can soften the composite enough to promote its sliding over the tool edge resulting in edge rounding.

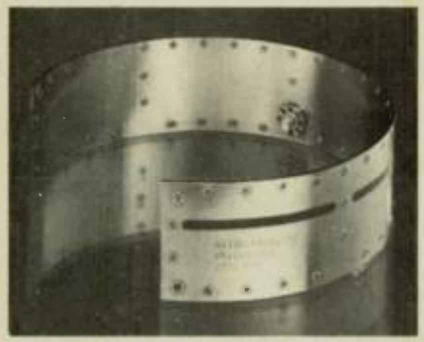

Fig. 6 A Wraparound^{TM} missile waistband antenna built by Haigh-Farr, Inc. from random fiber-PTFE laminate.

Even though the ceramic-PTFE composite is soft and cuts readily, carbide tools are needed because of the filler hardness.

Both types of composites are readily machined by lathe turning, drilling, milling and sawing. Good edges are easily obtained by shear, by punch and die and even by a sharp-edged model maker's knife.

Formability

The ceramic filled and random fiber reinforced composites both offer a high degree of formability where curved printed circuit antennas are required. The random fiber composite has an advantage over woven or continuous filament composites. Discontinuous fiber in a comparatively soft polymer matrix accommodates such bending with stress relaxation accelerated by heat while the board is held in the formed shape. The dead soft annealed condition of copper foil on the laminates minimizes the likelihood of cracks or breaks in a pattern.

A critical telemetry antenna in a formed shape is shown in **Figure 6**. The advantage of formability is combined with consistency, accurate electrical properties, stability under environmental extremes of temperature, shock and vibration; and resistance to exposure to solvents, fuels, salt spray and even prolonged sea water submersion.

The ceramic-PTFE laminates are even more formable. With proper heat forming fixtures, compound surfaces should also be feasible.

Bondability

Protective covers for antennas or cover panels for stripline divider networks are preferably bonded rather than clamped or riveted to keep performance variations minimal. Such bonded assemblies have been discussed before.[1]

A few thermoplastic polymer film types combine the electrical properties, melting point and adhesion to PTFE acceptable for a bonded circuit. A broader range of adhesive materials may be used by preparing the PTFE laminate surface with a commercially available Na etch treatment.

Alternately, direct bond by fusing the exposed PTFE laminate surfaces above 327°C with mild clamping pressure. Direct bonded antenna assemblies can withstand air friction heating to extremes where adhesive systems would fail. Problems created by dielectric constant differences between adhesive and substrate, especially with ceramic filled PTFE laminates are avoided. The extremely high melt viscosity of the PTFE (above 1 billion poise) combined with flow restraint afforded by fiber or filler makes it feasible without the expected distortion.

In one case distortion-free direct-bonded assemblies may be produced with two RT/duroid 6010 ceramic-PTFE laminate printed circuit boards that are 2 inches square, .050 inch thick with copper foil pattern over about 3% of the area. The assembly between plates with locating pins, foil enveloped to exclude air, is clamped at 100-140 psi, heated to 380° to 390°C for about 15 minutes and cooled while clamped.

In another case a 42 x 6 x 0.093 inch microstrip pattern on RT/duroid 5870 random fiber-PTFE laminate for a waistband telemetry antenna is bonded in curved shape with a .031 inch cover panel. The boards are clamped around a steel ring by a thin steel band hydraulically tensioned to provide a 50 psi normal stress. The assembly is oven heated for a 1-hour soak at 388°C in a nitrogen purged atmosphere to accomplish the direct bond.

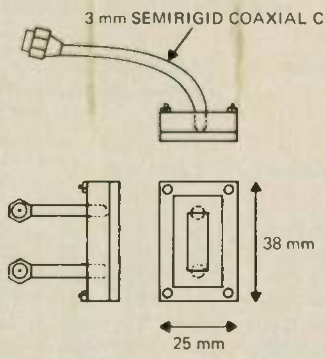

Fig. 7(a) Typical Quick Test fixture for X-band non-destructive testing of microwave circuit boards for dielectric constant.

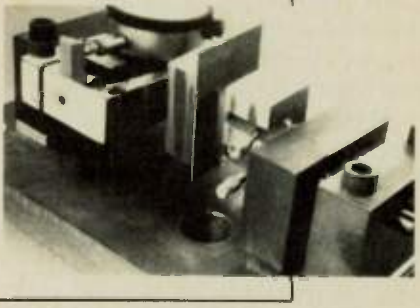

Fig. 7(b) Quick Test fixture and specimen clamped in vise.

A QUICK TEST METHOD FOR DIELECTRIC CONSTANT

A semi-destructive method for monitoring dielectric constant[2] requires only a small panel area etched free of copper on the panel to be measured. In process inspection for sorting or for selection of adjusted artwork patterns and detailed surveys of dielectric constant variation within a panel are possible.

TABLE 4

CALIBRATION DATA FOR A TYPICAL "QUICK TEST" FIXTURE

Specimen	Thickness mm T	Dielectric constant K	Resonant Frequency in GHz	
			observed F	predicted F
A	3.153	2.2372	9.387	9.392
B	1.551	2.2372	9.735	9.744
C	0.775	2.2372	10.053	10.047
D	0.354	2.2372	10.313	10.315
E	3.132	2.3578	9.257	9.237
F	1.549	2.3578	9.582	9.574
G	0.766	2.3578	9.851	9.853
H	0.370	2.3578	10.054	10.052
I	3.139	2.4891	9.041	9.065
J	1.532	2.4891	9.407	9.397
K	0.776	2.4891	9.610	9.624
L	0.370	2.4891	9.803	9.802
M	3.151	2.5953	8.935	8.925
N	1.539	2.5953	9.242	9.251
O	0.780	2.5953	9.447	9.437
P	0.377	2.5953	9.614	9.615

Polynomial from regression analysis:

$$\begin{aligned} F^{-2} = {} & -.019480 + .0055769T + .032089/T - .0099282/T^2 \\ & + (.023723 - .0047265T - .029210/T + .0087782/T^2)K \\ & + (-.0046290 + .0010714T + .0064858/T - .0019125/T^2)K^2 \qquad (1) \end{aligned}$$

The fixture (Figure 7) consists of a one-wavelength (2 node), X-band stripline resonator element embedded in the center of a dielectric card fastened to a metal block and fitted with coaxial probes that capacitively couple through the card to the resonator element. The resonator clamped against a laminate with ground plane backing has a resonant frequency that is a function of the dielectric constant and dielectric thickness of the specimen.

Before such a Quick Test fixture can be useful in comparing dielectric constants of unknowns, it must be calibrated against a series of known specimens covering the range of dielectric thicknesses and dielectric values to be encountered in service. The example of Table 4 shows actual T, K and F data used to derive the coefficients of the 12 term polynomial of equation 1 by curvilinear regression analysis.

NEW DIRECTIONS FOR MICROWAVE PRINTED CIRCUIT ANTENNAS

New circuit board materials and fabrication techniques will lead to some interesting extensions of printed circuit techniques into antenna applications. A few come to mind.

- *Size Reduction* — High dielectric constant laminates that resemble random fiber-PTFE laminates permit reduced antenna size for a given performance, important on vehicles crowded with new systems. Printed circuit techniques become feasible for some lower frequency applications.
- *Higher Temperature Capability* — Direct bonded antenna assemblies will allow greater air speeds in missiles.
- *Non-Planar Printed Circuit Patterns* — Development of random fiber-PTFE composites in compound curves such as ogive or hemisphere shapes could also lead to use of printed circuit techniques for radiating patterns on radomes.

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2. Traut, G. R., "Electrical Measurements of Microwave Circuit Board Materials," *Proceedings of the 13th E/EIC*, IEEE Pub. No. 77CH1273-2-E2 (1977), pp 39-44.

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INTRODUCTION

Domestic and international communications satellites now in orbit operate in the frequency bands of 4 GHz (downlink) and 6 GHz (uplink). Because all of these systems share the same allocated spectrum in each band with terrestrial microwave links, problems of frequency coordination in the face of potential mutual interference can become most severe. Locations near large metropolitan areas are particularly difficult to coordinate, and many users of private stations have been forced to utilize very remote sites or provide artificial shielding (e.g., deep pits) to assure acceptable performance. The number of domestic earth stations in the United States is increasing rapidly and while most of these will be receive-only installations, they should be capable of good quality interference-free reception, and the new transmit stations must not interfere with those already built or authorized.

Satellites in the future may be expected to be spaced even closer together than today. When adjacent satellite interference is combined with terrestrial microwave interference, it is quite likely that these future satcom systems will be limited as much by interference noise as they are presently limited by thermal noise.[1]

This paper describes a new earth station antenna design which for a small sacrifice in aperture efficiency produces sidelobe gain performance (G) vastly superior to the present day criteria of $G = 32 - 25 \log \theta$. Recent measurements on a full-scale, 7.6 meter antenna of this type have shown that in the mandatory 6 GHz transmit band where microwave coordination is most difficult, the $32 - 25 \log \theta$ sidelobe criteria can be improved upon by 10 to 15 dB. Out to the first 5° or so from the main beam, where adjacent satellite interference is the major problem, the $25 \log \theta$ fall off can be improved to $50 \log \theta$.

DESIGN

Present day high aperture efficiency earth station antennas are limited in their ability to produce low sidelobes primarily due to scattering from aperture blocking obstacles such as the subreflector and its support spars, and by the near-uniform illumination required to achieve high aperture efficiency. By backing off slightly on the uniform illumination, that is, by introducing a sharp taper at the edge of the main dish, conventional shaped Cassegrain antennas can just meet the FCC/INTELSAT mandatory sidelobe envelope provided they take advantage of certain exceptions that are permitted.

These exceptions permit a peak sidelobe to exceed the required value of $G = 32 - 25 \log \theta$ (where θ is in degrees and sidelobe gain G is in dBi) by as much as 6 dB, provided that the peak sidelobe in question falls below the required value when averaged with adjacent peaks on either side of it (or if that doesn't work, with the two adjacent peaks on either side of it). This is the FCC recommendation.[2] INTELSAT allows 10% of the sidelobe peaks to exceed the $32 - 25 \log \theta$ criteria.[3]

Figure 1 shows a generalized sketch of the major contributors to sidelobe levels in various angular regions surrounding an antenna. In the near-in region, that is within 10° of the main beam, the principal contributors are scattering due to aperture blockage and the choice of edge taper for the main reflector. To eliminate aperture blockage the offset configuration of **Figure 2** was used. Rays travelling between feed, subreflector, and main reflector are free from blockage of any kind. The illumination taper, controlled by choice of feed beamwidth, was set at about −15 dB for the 4 GHz receive band and −20 dB for the 6 GHz transmit band. In addition, only about 90% of the main reflector was illuminated on a geometric ray basis in order to further reduce spillover. Actually, there is considerable energy in this "unilluminated" ring due to the finite diameter of the subreflector in wavelengths.

The far out sidelobes, that is, sidelobes greater than 10° beyond the main beam, have two additional contributors. These are spillover of feed radiation past the subreflector, and spillover of

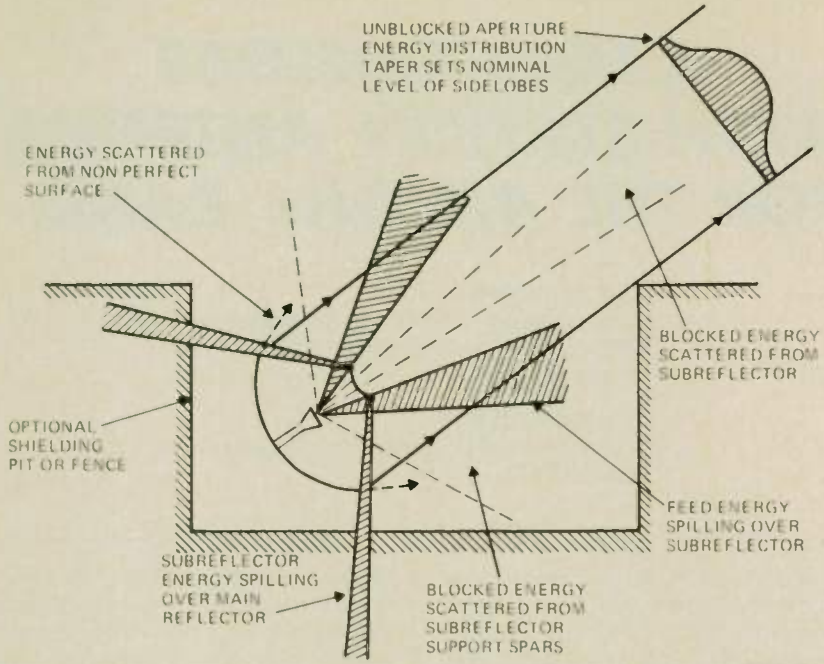

Fig. 1 Antenna sidelobe contributors.

subreflector radiation past the main reflector. These are most important when considering terrestrial interference. **Figure 1** shows one method that has been used in the past to eliminate such contributions, namely, pit or fence shielding.

Since pit shielding mainly reduces the effects of reflector spillover, it follows that one does not actually have to surround the entire antenna with absorber.[4] Reasonably equivalent results should be obtained if absorbing panels are attached to the rims of the reflectors themselves. For the main reflector this could be done regardless of whether an offset design was used or not. For the subreflector, however, an absorbing shield would greatly increase the near-in sidelobes for a conventional antenna due to the increase in aperture blockage. For the offset design of **Figure 2**, there is no such penalty. Note also that an attached shield absorbs spillover both above and below the subreflector, which is an improvement over the pit arrangement shown in **Figure 1**

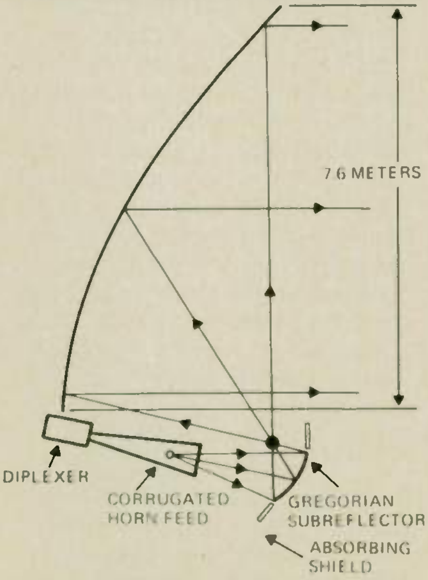

Fig. 2 Low sidelobe offset reflector antenna.

The main reflector illumination for a conventional prime focus offset antenna is not rotationally symmetric. As such, fairly high cross polarization lobes appear in the plane normal to the offset plane. The peak off-axis cross polarization level depends upon the F/D ratio of the main reflector and the offset angle of the center ray,[5] but typically might fall only 20 dB or so below the main beam co-polarization level. With a dual reflector offset antenna, the geometry and curvature of the subreflector can be varied such as to produce a rotationally symmetric main reflector illumination as well as a relatively large effective F/D ratio.[6]

A second way of viewing the special geometry used to minimize off-axis cross polarization is to consider the subreflector and main reflector as a two mirror beam waveguide system. It can be shown that for certain mirror curvatures and orientations the cross polarization fields generated by each mirror can be made to cancel.[7] The finite diameter of the mirrors and the spacing between them prevents exact cancellation, but a significant amount of cancellation can be achieved in a practical situation.

On-axis cross polarization level is limited by the feed and by the cross polarization characteristics of the antenna at the other end of the link. The total system on-axis cross polarization level can usually be adjusted to an extremely low value via an adjustable differential phase shifter provided in the feed. Worst case cross polarization peaks for the offset feed alone when swept continuously over each band were about −40 dB relative to the co-polarization peaks, with an average approaching −50 dB.

A Gregorian optics system was chosen over a Cassegrain for the following reasons. First, if the two systems are compared on the basis of a given feed horn, equal subreflector diameters, and equal spacing from feed horn to subreflector, then the Gregorian system will have a somewhat larger main reflector included angle. This means less main reflector spillover because of the lower subreflector pattern gain. Second, feed spillover past the upper edge of the Gregorian subreflector falls along the beam axis where it has little effect on the large sidelobes generated by the aperture illumination itself. Spillover past the lower edge occurs far off axis and essentially governs the sidelobe level in this region. For a Cassegrain system the spillover regions are reversed with respect to the top and bottom of the subreflector. Thus, for the Gregorian system a subreflector absorbing shield can be extended as far as desired past the lower edge of the subreflector without danger of

(continued on page 56)


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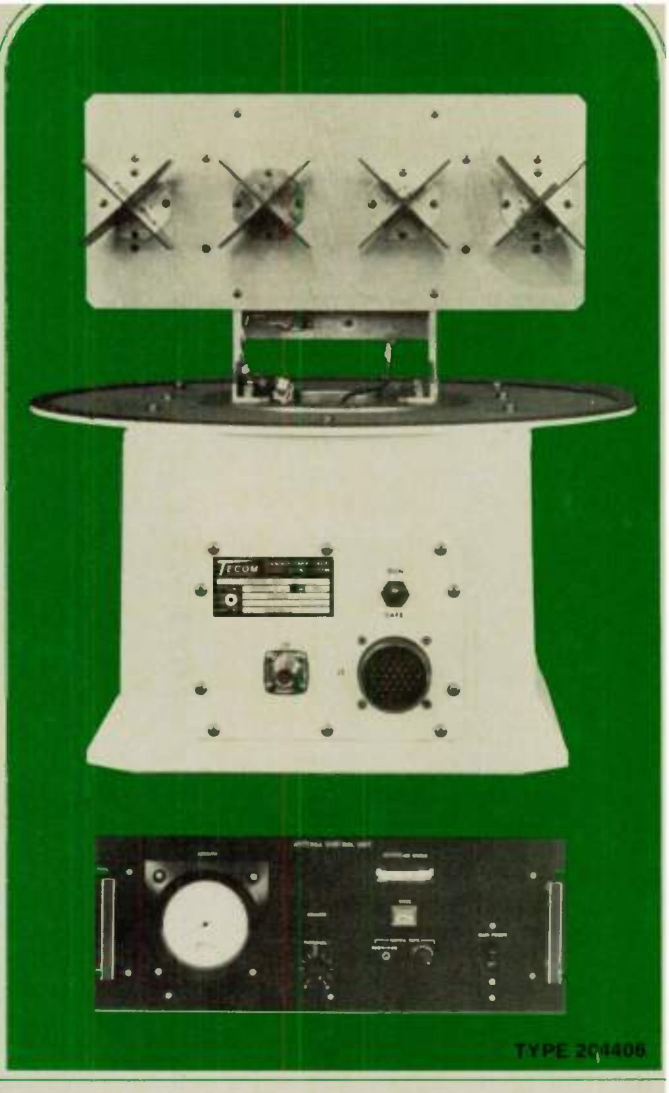
TYPE 204406

introducing aperture blockage. The shield could even be extended to connect the lower edge of the subreflector to the feed horn, thus completely absorbing far-out feed spillover sidelobes. Third, the feed is located closer to the bottom edge of the main reflector for the Gregorian system, thus resulting in a lower main reflector and a more compact antenna overall.

One particular difficulty with any dual band design that must be allowed for in the selection of a feed horn is the shift in feed phase center with frequency. Without the masking effect of aperture blockage the resulting defocusing effect is more noticeable in an offset design. Wide angle feeds generally have less phase center shift with frequency than narrow angle feeds. However, the effective focal length is also smaller if a wide angle feed is used, and generally speaking, the higher the effective focal length the less the effect of a feed phase center shift. Thus, the two effects are somewhat self-cancelling. If a high magnification factor and a short prime focal length are used to achieve a high effective focal length, then as stated previously, the main reflector spillover will be reduced somewhat by virtue of the lower subreflector pattern gain. This means a relatively large feed horn such as was used here. The larger feed horn also has superior feed patterns and lower off-axis cross polarization peaks relative to a smaller one, and its narrower beamwidth results in the subreflector spillover occurring closer to the main beam where it has less effect on the overall pattern envelope. The longer horn length also brings the feed ports out directly at the equipment hub, thus avoiding the necessity of having to add a section of lossy waveguide.

TABLE I

OFFSET REFLECTOR PERFORMANCE PREDICTIONS

EFFICIENCY FACTOR	**4 GHz**	**6 GHz**
Illumination (taper, phase)	−1.48 dB	−2.22 dB
Spillover (sub)	− .24	− .09
Spillover (main)	− .03	− .01
Cross Polarization	− .03	− .02
Surface Tolerance (.025″ rms)	− .05	− .11
Blockage	0	0
Feed (with diplexer)		
SWR	− .07	− .04
Dissipative	− .20	− .10
Total:	−2.10	−2.59
Efficiency	62%	55%
Gain (D = 7.6 m)	48.0 dB	51.0 dB

NOISE CONTRIBUTOR	**TEMPERATURE**
Main Beam @ 10° Elevation	15° K
Sub Spillover	16°
Main Spillover	1°
Surface Tolerance	1°
Feed	12°
T_{ant} @ 10°	45° K
T_{ant} @ 30°	35° K

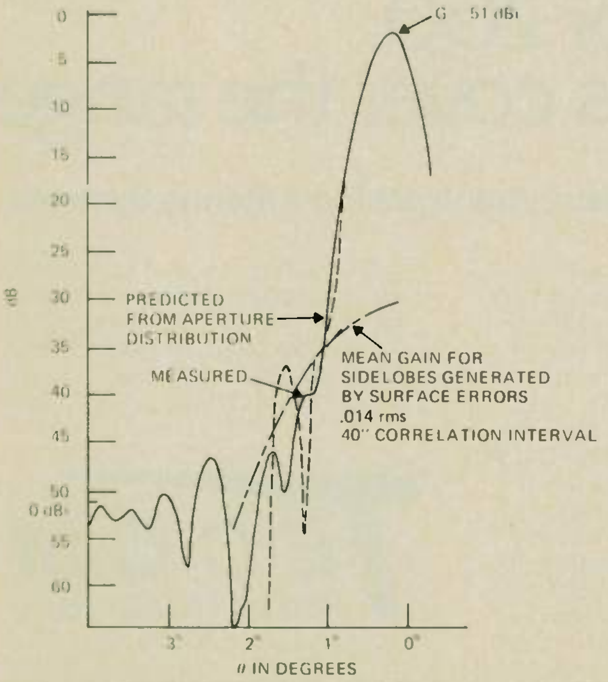

Fig. 3 Expanded elevation plane — 6175 MHz.

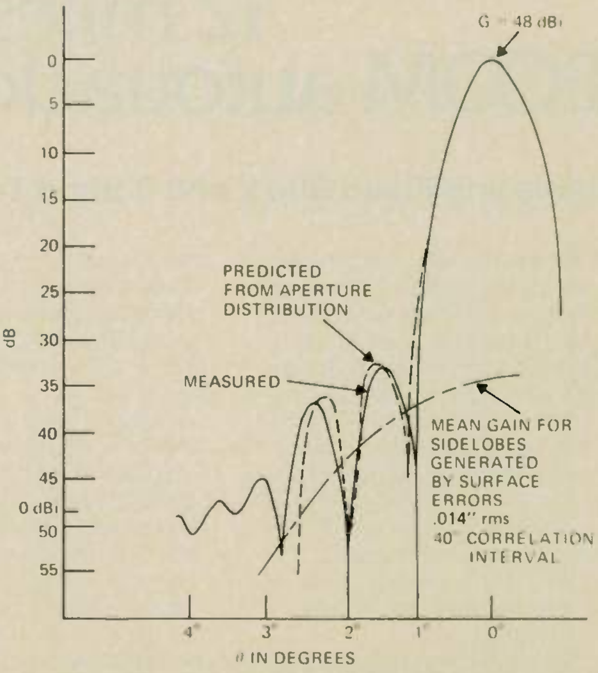

Fig. 4 Expanded elevation plane — 3950 MHz.

the final design. The sidelobe performance predictions are shown in **Figures 3** and **4**.

EXPERIMENTAL RESULTS

A full scale 7.6 meter offset antenna was built and tested. **Figures 3** and **4** show the measured transmit and receive band expanded elevation cuts. The first sidelobe is seen to be about -39 dB for transmit and -33 dB down for receive. These levels may be compared to a -16 dB first sidelobe level typical for a conventional shaped Cassegrain antenna.

When compared to theoretical predictions, the patterns are seen to exhibit a somewhat random departure about the expected values. This is particularly true for the transmit band. Some of this variation may be due to a slight misalignment of the subreflector which was not optimized experimentally. However, the most likely explanation is that it is due to the presence of sidelobes generated by surface errors. Plotted in **Figures 3** and **4** are dotted lines representing the calculated mean gains for sidelobes generated by an rms surface tolerance of .014" and a correlation interval of 40". The .014" rms was obtained by combining final alignment data, structural deflection calculations for the antenna on its test mount, and panel manufacturing errors. The 40" corresponds roughly to the minimum separation between panels. The level for these surface error generated sidelobes is seen to be relatively high for the transmit band. It is important to note here that very low tolerances must be achieved or the low sidelobes inherent in the design will be masked out.

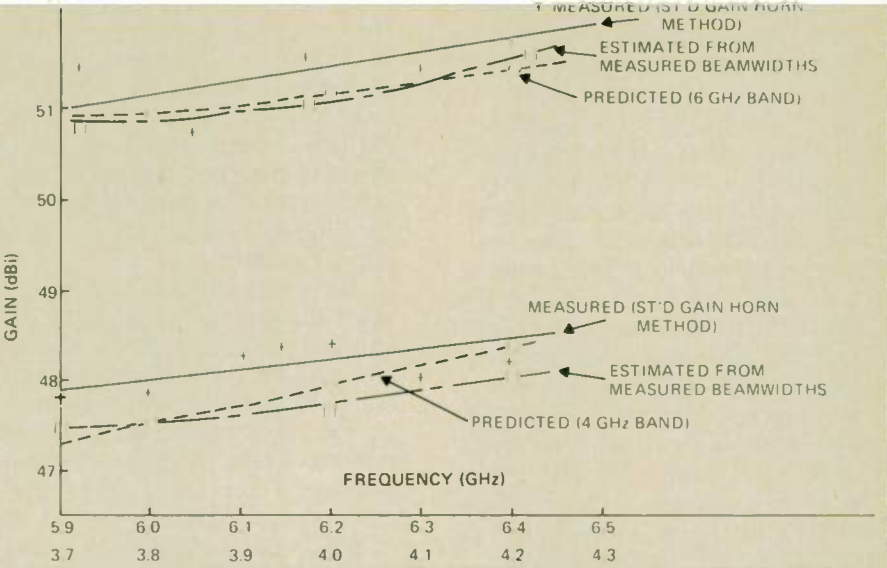

Fig. 5 Measured gain for 7.6 meter offset antenna.

Radiation patterns were measured for the transmit and receive bands in both the elevation and azimuth planes. Undoubtedly, range reflections caused some perturbations in these patterns, particularly around the back of the antenna where the main beam faced a parking lot and building while the true backlobe faced the transmitting source with a gain level approximately 70 dB below the main beam. The elevation plane patterns, therefore, may be somewhat more accurate far out than the azimuth plane patterns, since the beam was pointed upward away from possible reflections for this case. However, the azimuth patterns are also considered to be reasonably accurate, except possibly for the extreme backlobes.

Clearly, the transmit band patterns have the best sidelobe performance. This was expected since the aperture illumination taper was greatest at this frequency. Aperture efficiency was, of course, lower in the transmit band as can be seen in **Figure 5**. The sidelobe envelopes approximate a 50 log θ rather than a 25 log θ fall-off in the near-in region out to 5°. The fall-off rate is at least 40 log θ out to 16°. The peak sidelobe envelope is at least 10 dB and quite often 15 dB or more below the FCC/INTELSAT criteria for all values of θ. Again, it should be noted that this is the actual peak envelope performance without the sidelobe averaging or 10% exceptions allowed by FCC/INTELSAT.

The receive band performance is also considerably better than the FCC/INTELSAT criteria even on a peak basis, but the lower aperture illumination taper has clearly deteriorated the performance relative to the transmit case. The receive aperture efficiency is higher, being about 62% vs about 55% for transmit.

Although the transmit band is, in general, the more difficult band to coordinate and constitutes the only mandatory INTELSAT sidelobe requirement,[3] it is felt that an even greater trade-off of aperture efficiency for low sidelobe performance further. It should also be noted that while more taper in the receive band will reduce the aperture efficiency, it will also improve the noise temperature slightly due to reduced spillover energy absorption in the subreflector shield. Thus, for low noise temperature systems, the G/T loss may not be that serious.

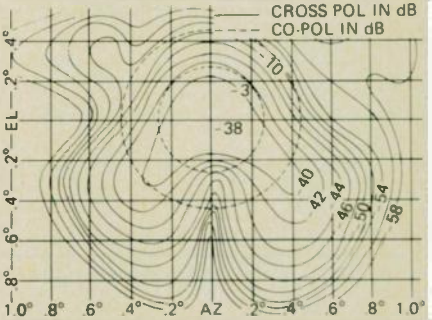

Fig. 6 Measured cross polarization levels for 7.6 meter offset antenna — 6175 MHz.

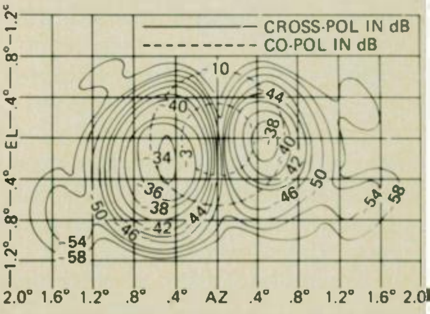

Fig. 7 Measured cross polarization levels for 7.6 meter offset antenna — 3950 MHz

Measured cross polarization data for the transmit and receive bands is shown in **Figures 6** and **7** in the form of contour maps about the beam axis. **Figure 7** shows the classic diagram to be expected for an offset system, with two lobes appearing along the azimuth axis normal to the plane of the offset. The peaks (-34 dB) are very low due to the special offset geometry employed and the low cross polarization level of the feed. The transmit band cross polarization contours of **Figure 6** show an even lower worst case value (-38 dB), but it is an on-axis peak. This could be due to the offset antenna, but it could also be due to the boresight antenna, which in this case was a simple 6′ prime focus dish with a hook feed.

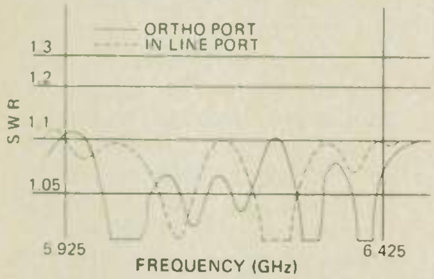

Fig. 8 Measured SWR vs frequency-transmit band.

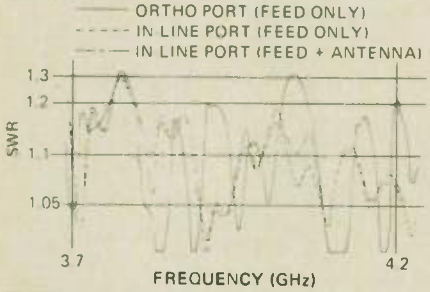

Fig. 9 Measured SWR vs frequency-receive band.

Finally, the measured return loss (SWR) of the antenna is shown in **Figures 8** and **9**. Note that the SWR of the feed when installed in the antenna (**Figure 9**) is exactly the same as when measured out of the antenna. Absent is the ripple normally superimposed on the feed's SWR characteristic due to echo from a conventional subreflector.

The corrugated horn feed and diplexer was developed specially for use with the offset antenna when working US domsat satellites. It is a dual linearly polarized feed with adjustable polarization. It is capable of independent polarization oreintation for each band for Faraday rotation compensation, and permits adjustment to match the satellite and earth station antenna axial ratios for highest possible on-axis polarization isolation.

The elevation axis platform rotates along an azimuth track on friction pads. Jack screw drives are used for both axes, with spacers used to center the elevation jack screw range about the nominal look angle of the satellites of interest. The present range of elevation angle adjustment is 10° to 60°. Any azimuth sector can be covered, but relocation of the azimuth screw jack drive is required each time a 10° sector is traversed. The antenna is of all aluminum construction with stainless steel hardware. The absorbing shields are supported by simple extensions of the back-up structure and are of a layered foam construction protected by a thin plastic cover. The foam is a closed cell type that does not absorb water, but all edges are coated with an epoxy paint for added protection. Any absorber panel can be easily replaced without interrupting operations in the event of severe environmental damage.

Figure 10 shows the final wheel and track configuration.

Fig. 10 Low sidelobe antenna — final configuration.

SUMMARY

A full-scale, 7.6 meter satellite earth station antenna employing offset geometry and absorbing shields has been built and tested. The peak sidelobe envelope in the critical 6 GHz transmit band is 10-15 dB lower than present FCC/INTELSAT requirements over the full range of aspect angles. First sidelobes are approximately -30 dB in the receive band and -35 to -40 dB in the transmit band. Worst case off-axis cross-polarized peaks are more than 30 dB below the co-polarized peak in both bands. The penalty in aperture efficiency to achieve this performance is only about .75 dB when compared with the most efficient conventional antennas. Dual-polarized feed ports, transmitters, and receivers are all located at ground level within a short distance of each other for all antenna pointing angles.

ACKNOWLEDGEMENTS

The development of this antenna was carried out under the sponsorship of the Communications Products Technology Center of GTE Laboratories as part of their continuing program in satellite communications R&D. The antenna was designed and built by GTE International Systems Corporation and Sylvania Systems Group Eastern Division as part of their continuing effort to supply new and improved satellite communications earth terminals to customers throughout the world. The authors would like to acknowledge the many valuable contributions made to the project by management and members of the technical staff of the above organizations. A special acknowledgement should also be given to H&W Industries of Cohasset, Mass. who designed and manufactured the structure in a very short period of time and to tolerances exceeding the original specifications.

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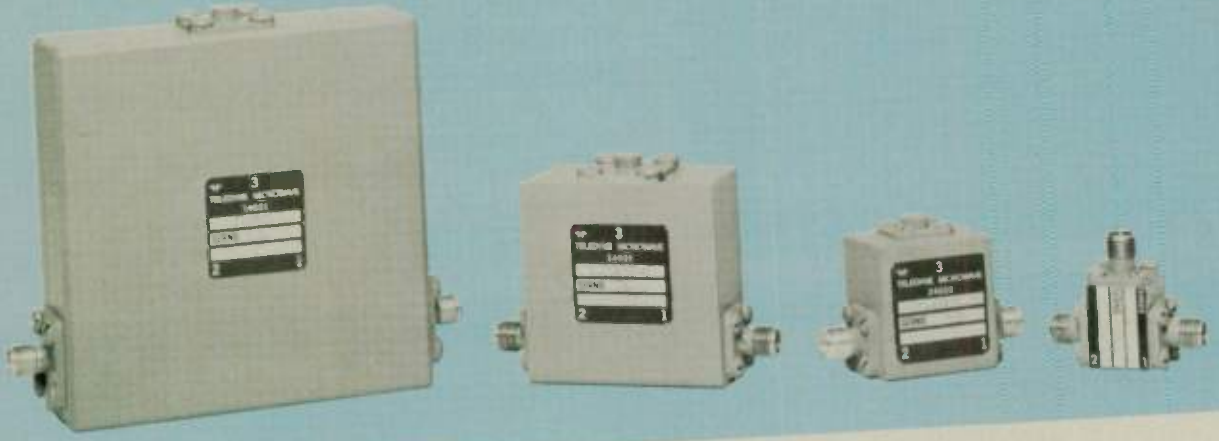
STANDARD DESIGNS

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.)	Height	Size Width	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.)	Height	Size Width	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.)	Height	Size Width	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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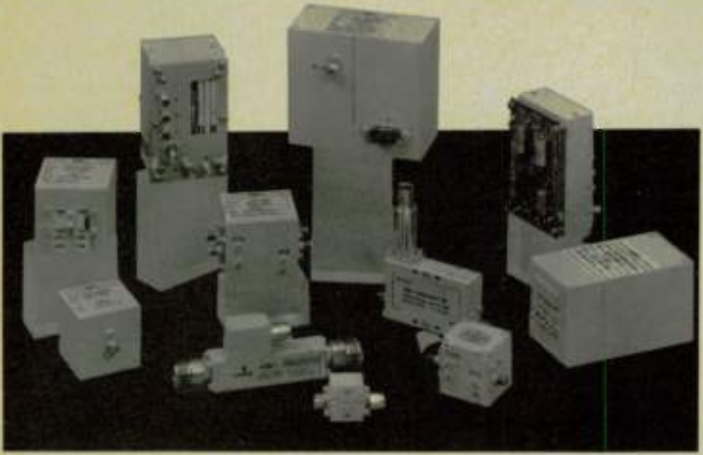

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MODEL:	Frequency Range (GHz)	Power Output Min. (mW)	Power Variation vs. Frequency	Spurious Signals: Harmonic Min.	Non-Harmonic Min.	Residual FM, 1 Hz—30 kHz	Frequency Stability: Vs Temperature	Vs Power Supply	Vs. Load Variation	Hysteresis
SDYX-3038	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

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MODEL:	Frequency Range (MHz):	Power, Min. (mW): Leveled	Power vs. Frequency	Unleveled	Power vs. Frequency	Spurious Signals: Harmonic Min.	Non-Harmonic Min.	Residual FM: in 1 Hz-30 kHz Band	Amplitude Control: Full Output	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	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.

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		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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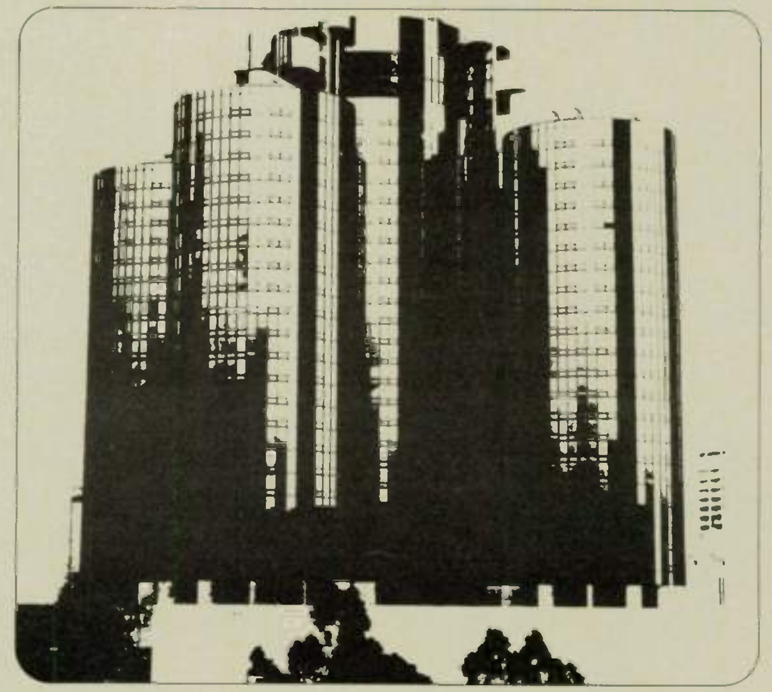

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A New Load Pull Measurement Technique Eases GaAs Characterization

DAVID ZEMACK
Microwave Semiconductor Corp. *
Somerset, NJ

INTRODUCTION

Designers of microwave active devices are constantly lacking device characterization data when large signal operation is encountered. Without such data, one must rely on experience and on the bench trial and error experiments to extract performance. Results obtained in this manner tend to be less reliable and even unusable when specifications get tougher. The load pull measurement technique is a systematic experiment that can serve as a characterization routine.

Large signal characterization of active devices at microwave frequencies is needed generally whenever output power and efficiency are key design goals. Load pull characterization can be used to predict performance and enable circuit design. Practical usage of this method is increasing. It was first used by Belohoubek et al[1] in 1969 to solve interstage matching problems. In 1972, a 1-2 GHz, 10 W linear amplifier was reported.[2] In 1974, automatic capacity for contour mapping was developed in RCA.[3]

Load pull characterization has been used in wideband GaAs FET amplifier design. Methods proposed by Takayama[4] and others were used to design wideband internal matched amplifiers.

The following are a few examples of load pull uses:

- Synthetic load lines (for maximum power, efficiency, phase, etc.)
- Performance trade-off
- Frequency equalizing
- Sensitivity to load changes (power, intermodulation, dissipation, etc.)
- Alternate network solutions
- Interstage matching

This paper introduces a load pull measurement technique, performed by a substitution method. This method uses a two-section load. A fixed section is duplicated to enable impedance measurements. A variable section is used to control performance. This method provides capability and simplicity lacking in many other methods. It can be used at very high power levels, and under pulsed conditions. Used to characterize a 1 W X-band GaAs FET it proved to be accurate up to 12

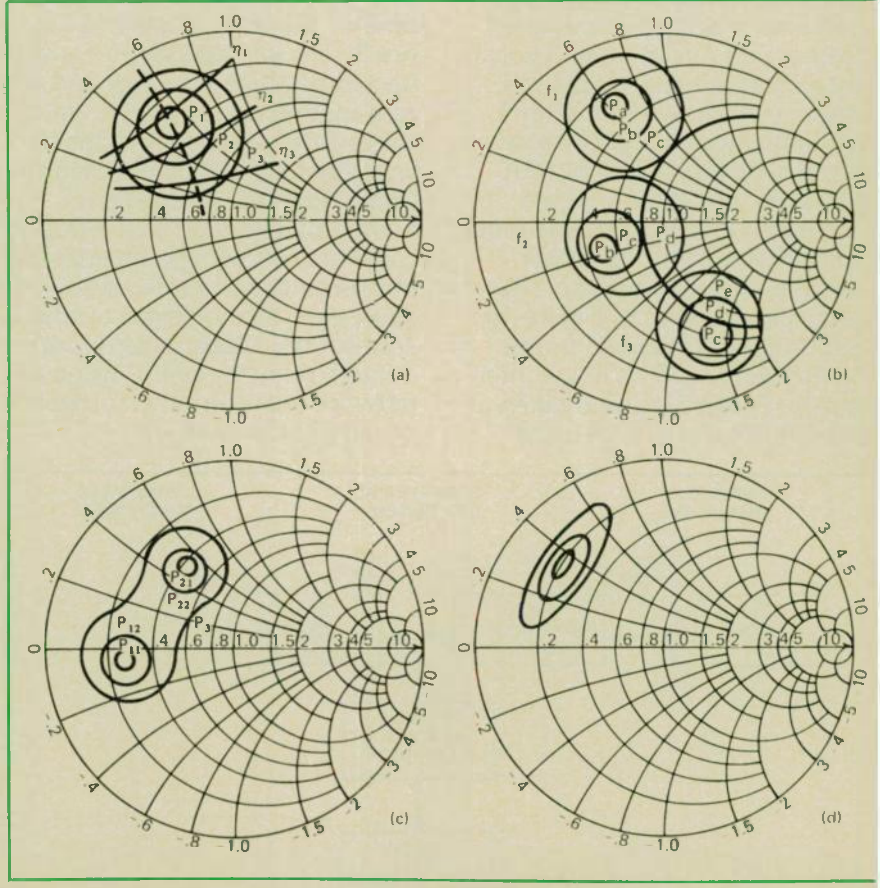

Fig. 1 (a) Power efficiency gradient; (b) Wideband load determination; (c) Double maxima; (d) Load sensitive device.

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* Author on sabbatical leave from Rafael, Israel.

GHz using available manual equipment.

PRINCIPLE OF LOAD PULL CHARACTERIZATION

Load pull characterization is basically a multiple experiment conducted on a single device. The device performance is recorded under variable load conditions. Load pull is performed at a single frequency. The load is changed, performance observed, and loci of impedances for a constant parameter (power, efficiency) are recorded. These loci form closed contours much like elevation lines. At the top, a single value optimum impedance is found. For wideband characterization, the band can be divided and load pull measurements can be taken at discrete frequencies within the band. Since impedance loci form closed contours, it is sufficient to record a limited number of representative points to map a given contour.

Loads for optimum power, efficiency, intermodulation and other parameters are not identical. Contours around those optimum points will point out gradient lines and sensitivities. Typical contours obtained via load pull mapping are shown in **Figure 1**. Each impedance contour represents a different power output level, with a maximum power output occurring within the inner contour. If power output contours are superimposed on efficiency contours, as in **Figure 1a**, then trade-offs between power and efficiency can be made intelligently. Power contours taken at different frequencies give the mapping in **Figure 1b**, which aids the design for optimum frequency performance. A constant power output load can be derived, resulting in a constant gain and impedance realizability. Double maxima as shown in **Figure 1c** can occur from uncontrolled harmonic loading. A typical load-sensitive device will have the kind of contours shown in **Figure 1d**. It should be kept in mind that the assumption of device characterization by its terminating impedances is not universally valid. The effect of impedance load at harmonics, reference plane errors and the tendency to oscillate tend to obscure mapping data.

LOAD PULL SUBSTITUTION METHOD

The method developed to characterize power FET's uses a substitution technique. The load in this method is formed by two sections, one fixed section, the other variable. The fixed portion is connected between the device and a double pole, single throw symmetrical RF relay. This section is duplicated at the other pole of the relay, shown in **Figure 2**. The variable section is connected between the relay and the terminating power meter. When this port is connected to the device, the load can be changed to attain desirable performance. Switching the relay to the duplicated arm allows for impedance measurement at a reference plane equivalent to the device output connection. Measurements conducted, point by point, using a network analyzer or a slotted line are straightforward.

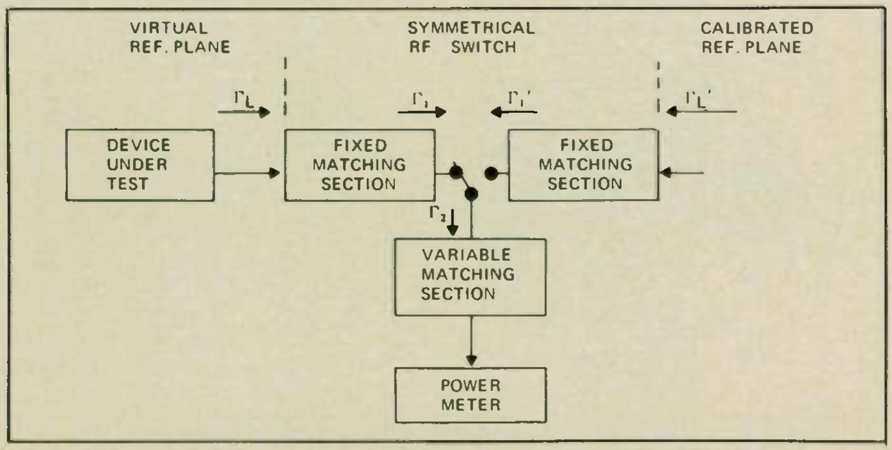

Fig. 2 Load pull substitution method.

In a practical application, the desired evaluation bandwidth is covered by four equally separated frequency points and power and efficiency recorded for three power contours at each frequency. With eight points for each impedance contour, the total number of impedance data points is 96. Before use of this method, the conventional approach required tuning the device, then disassembling the circuit and measuring impedances at each frequency. By this old process one would obtain a single data point at a time, requiring at least one for each frequency. Contour plotting was impractically difficult, so one tried to tune to as near an optimum as possible.

The impedance range covered by the variable portion of the load is limited by circuit dissipation. Losses of 1 dB permit contours having load SWR of up to about 9:1. In general, load circuit covering a SWR range of V is possible if circuit losses (in dB) satisfy:

$$L_A \leqslant 10 \log \frac{V+1}{V-1}$$

Relay symmetry affects accuracy of load duplication at the substituting arm. An HP8761A relay was tested for symmetry using an automatic network analyzer. Results for S_{11} and S_{21} are shown in **Table 1**.

The error caused by the small asymmetry of the relay could be calculated directly using two sets of S parameters for the two relay positions.

The reflection coefficient defined at the relay port, Γ_1'should be differentiated to find the measurement uncertainty.

$$\Gamma_1 = S_{11} + \frac{S_{21}{}^2\Gamma_2}{1-S_{22}\Gamma_2}$$

Γ_2 – Variable load reflection coefficient

Sij – Relay S parameters

$$\Delta\Gamma_1 = \Delta S_{11} + \frac{2\,S_{21}\Gamma_2}{1-S_{22}\Gamma_2}$$

$$\Delta S_{21} - \frac{S_{21}{}^2\Gamma_2{}^2}{(1-S_{22}\Gamma_2)^2}\,\Delta S_{22}$$

(continued on page 66)

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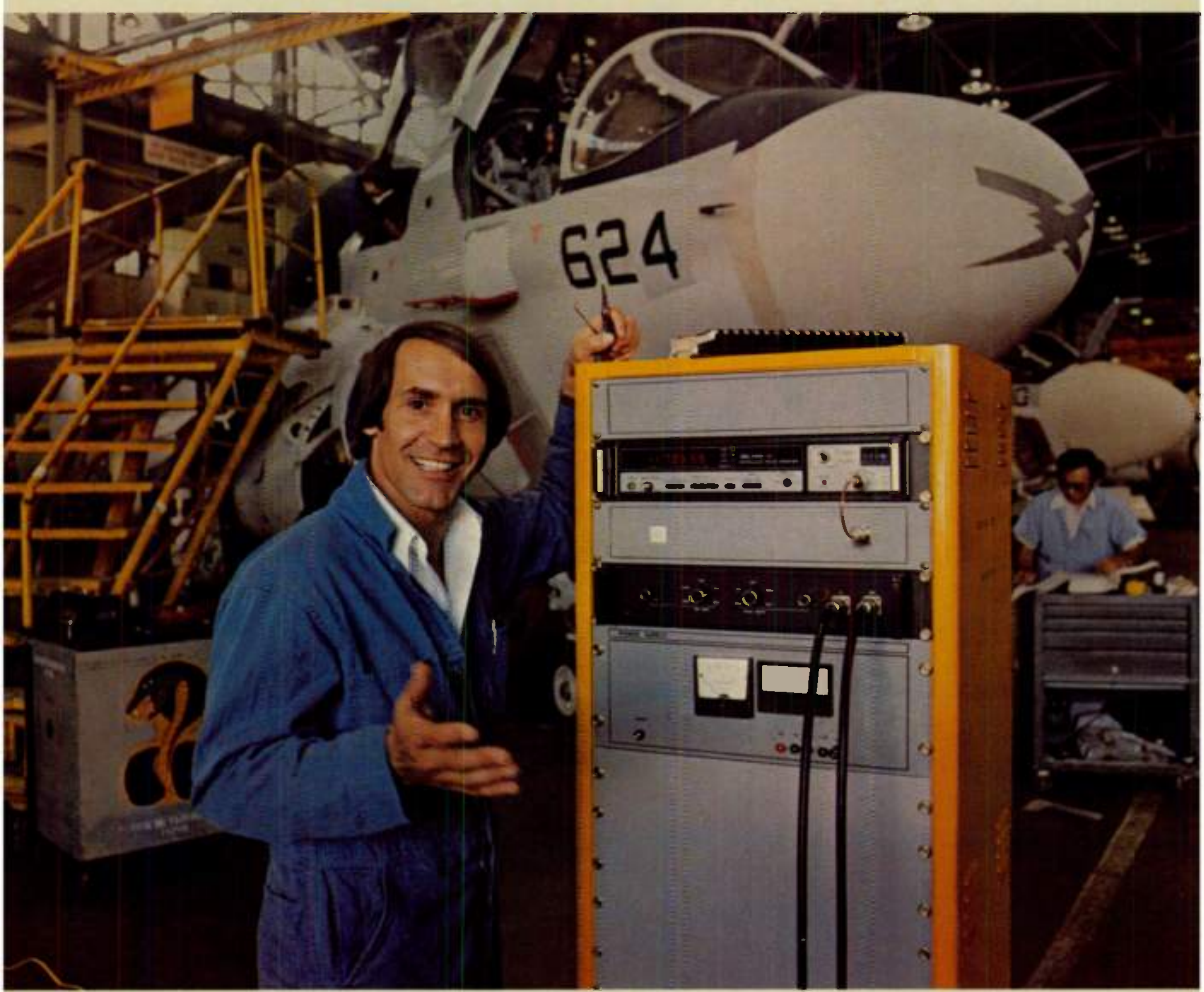

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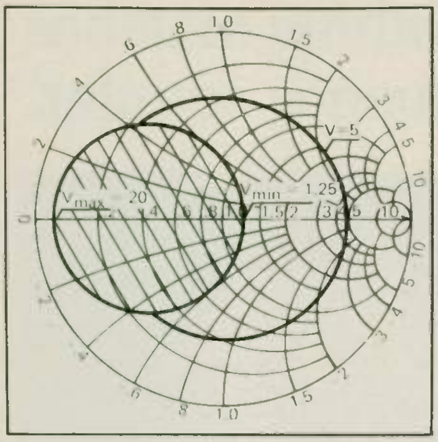

Fig. 3 Partial fixed matching.

Using the small reflection approximation:

$$|\Delta\Gamma|=|\Delta S_{11}|+2|\Gamma_2|\,|\Delta S_{21}|+|\Gamma_2|^2\,|\Delta S_{22}|$$

From **Table 1**, the largest deviations between the relay S parameters are:

$|\Delta S_{11}|\simeq|\Delta S_{22}|\simeq 0.007$ and

$|\Delta S_{21}|\simeq 0.0037$.

For $|\Gamma_2|=0.7$ the worst case uncertainty would be ±0.016. Assuming that the fixed portion of the network is identically duplicated, this should be the expected measurement error. Repetitive operation of the relay was found to give reproducible performance, within the tolerances described.

For power FET's, load impedances lower than 5 ohms are seldomly encountered. To obtain low impedance loading contours limited by circuit losses, partial matching at the fixed portion of the load should be considered. Using a quarter-wave section of transmission line having characteristic impedance Z_o, mapping is possible between V_{max} and V_{min} (maximum and minimum SWR circles) according to:

$$V_{max} = V \cdot \left(\frac{50}{Z_o}\right)^2$$

$$Z_o < 50$$

$$V_{min} = \left[\left(\frac{50}{Z_o}\right)^2 \cdot \frac{1}{V}\right]^{\pm 1}$$

$$V_{min} > 1$$

TABLE 1

SYMMETRICAL RELAY PORTS MEASUREMENTS

	S_{11}		S_{21}	
MHz	dB	ANG	dB	ANG
5000	−30.9	105	−0.06	− 30
6000	−27.3	− 82	−0.22	−107
7000	−26.7	120	−0.19	175
8000	−30.6	− 82	−0.05	95
9000	−30.5	76	−0.22	18
10000	−28.0	− 13	−0.20	− 60
11000	−30.6	4	−0.49	−137

	S_{11}		S_{21}	
MHz	dB	ANG	dB	ANG
5000	−32.8	102	−0.06	− 29
6000	−30.7	− 81	−0.19	−106
7000	−27.5	130	−1.18	176
8000	−33.8	− 65	−0.06	96
9000	−32.4	89	−0.16	19
10000	−28.3	− 7	−0.26	− 59
11000	−30.7	− 21	−0.56	−136

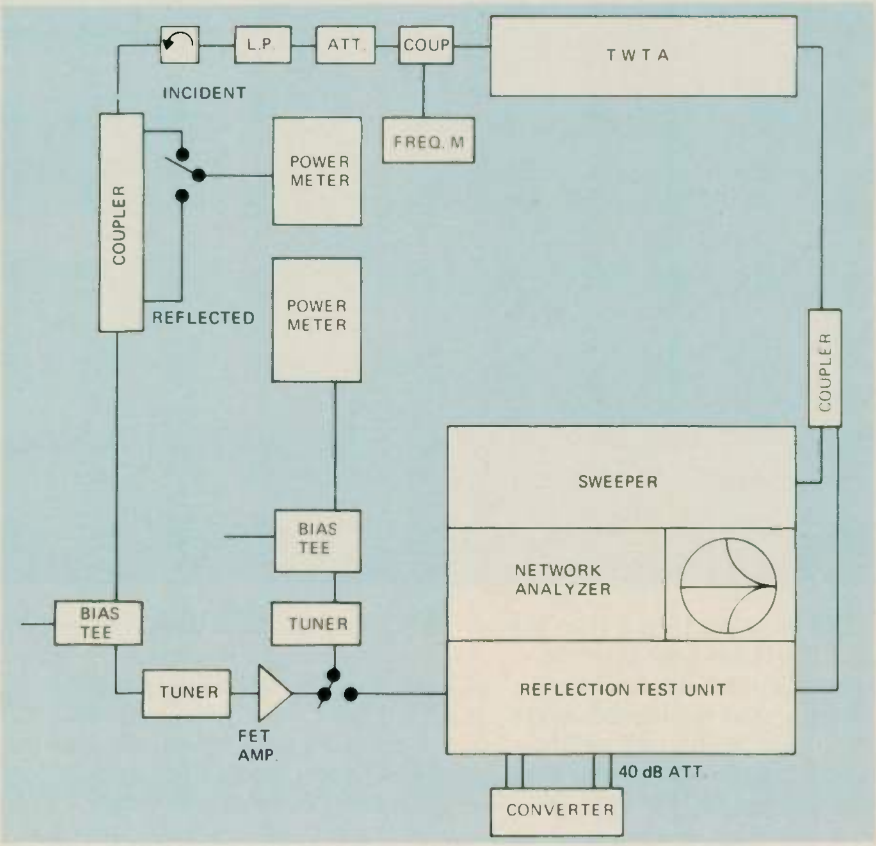

Fig. 4 Set-up for load pull measurements.

This is depicted in **Figure 3**. The variable section is limited to a SWR of 5. Using a 25-ohm quarterwave line at the fixed section, local contour mapping within the shaded circle is possible.

Using the obtained impedance data to design a circuit can be completed by measuring the realized load impedance. Keeping the same procedure for reference plane calibration and associated transition will result in reduction of realization errors.

Mapping of power contours on a Smith chart for the MSC 88104 was carried out using the set up described in **Figure 4** and presented in **Figure 6**. The tuner used for the variable section was

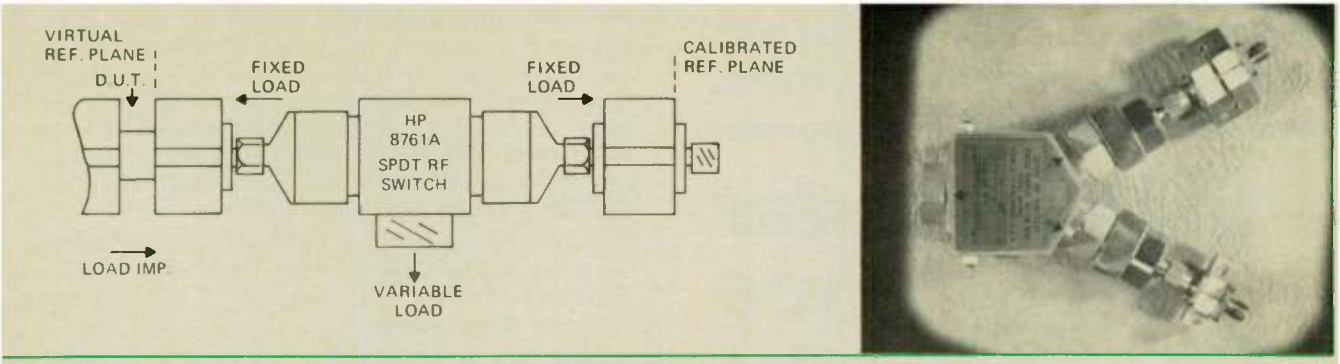

Fig. 5 Device and substitution section.

a single stub tuner composed of a Narda Model 3753B phase shifter and a shorted stub tuner. Total circuit losses in the 4 - 8 GHz band were 1.2 dB (SWR of 7:1).

The device mounting and substitution section are described in Figure 5. By placing a connector at the device symmetrical reference plane and using a network analyzer it was possible to ensure the 7:1 SWR coverage. By changing the variable load and alternatively connecting the two symmetrical ports to the analyzer, substitution errors were measured. The results were in agreement with those calculated.

CONCLUSIONS

This load pull substitution measurement technique offers a practical way to obtain the needed insight to operate active devices under large microwave signal conditions. When used to characterize a GaAs FET for the 4 to 8 GHz band, it was found to be accurate within ±5%.

This accuracy could be improved and extended in frequency by using computer-aided error correction methods. Using the semi-automatic network analyzer (Reference 6) it would simplify the sophistication needed to calibrate and store tuner data (Reference 3). This method is amenable to further refinements for improved load impedance evaluations. Used for oscillator design, power and frequency contours were recorded to enable high power wideband tuning (Reference 7). Harmonic tuning suggested in Reference 8 would be more effectively practiced, using a diplexer at the tuning port. Very importantly, pulsed operation of device that seem impossible using the method described in Reference 4 can be evaluated. With the separating switch, CW measurement of impedances does not interfere with high power pulsed operation of the active device (including single port devices). The suggested method could be used at the input of a device as well as the output, however, input impedance measurements described in Reference 9 could be more straightforward.

Availability of load pull data enables optimum design to exploit device properties. In the case of the GaAs FET measured, it suggests a very high usable operation bandwidth.

ACKNOWLEDGEMENTS

The author would like to thank Dr. Ira Drukier for his encouragement and support. The author also wishes to thank A. Kadosh from M.O.D. Israel, for his technical assistance at an earlier stage.

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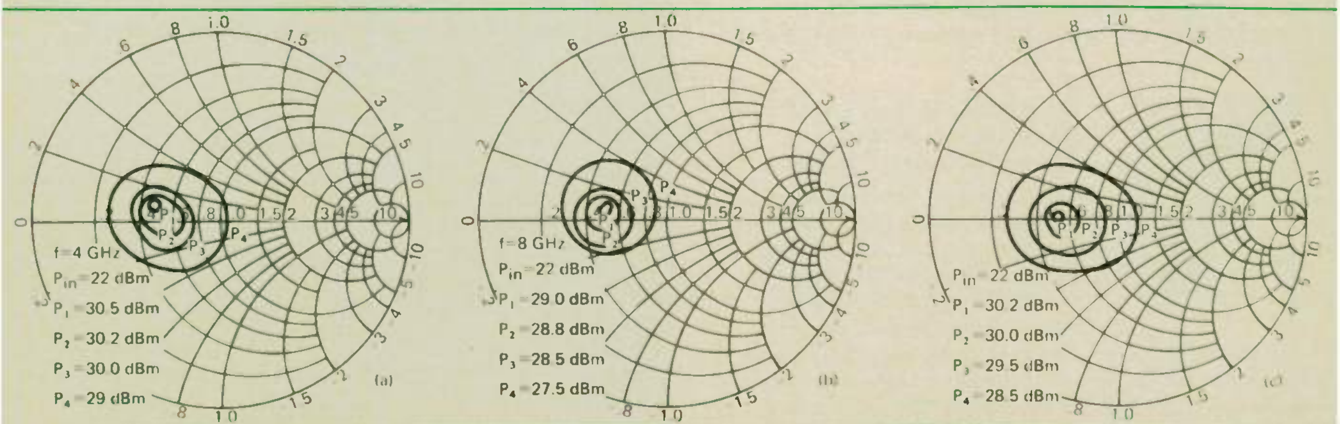

Fig. 6 Load pull contours for MSC 88/04 device – (a) 4 GHz; (b) 6 GHz; (c) 8 GHz.

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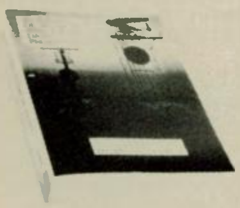

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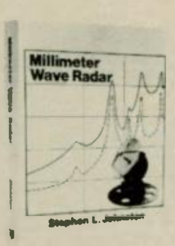

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Transition from Metal to Dielectric Waveguide

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A transition from metal waveguide to a dielectric waveguide is described. An important aspect of the transition is that no dimensions are critical, making manufacture inexpensive.

INTRODUCTION

The literature at present is notably short of detailed information on the manufacture and performance of transition from a metal to a dielectric waveguide. Such a transition has been developed and tested and is described. The development work was done in the X-band because of the greatly improved ease of manufacture of components, and then scaled and tested in the E-band. It was decided to standardize the dielectric waveguide (nominally 0.9 x 0.4″ for X-band and 0.122 x 0.61″ for E-band).

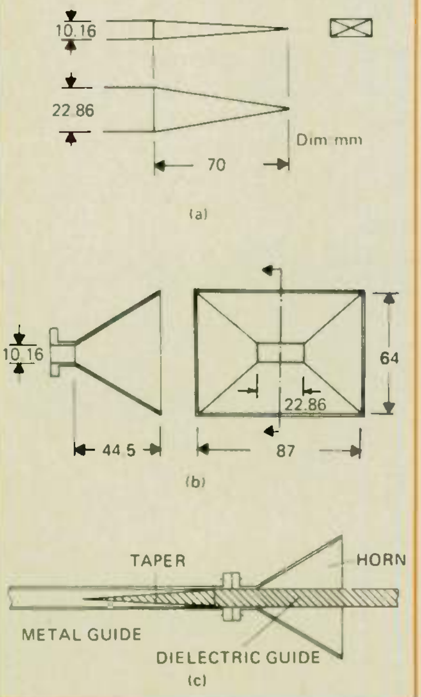

Fig. 1 (a) Dielectric taper, (b) Inside dimensions of the X-band horn in mm and (c) Assembly of the transition.

The transition consists of two regions, that can be identified as follows: firstly, there is a transition from air-filled to dielectric-filled waveguide (subsequently called the "taper") and secondly the mechanism whereby the wave is launched from the metal-boundary dielectric waveguide to the air-boundary dielectric guide (the "horn").

THE TAPER

The transition from air-filled to dielectric waveguide was examined first. **Figure 1(a)** shows the structure of a taper which is wedge-shaped in both the E- and H-planes. Two tapers fitted back-to-back, with a zero length of guide between them, was fitted inside the standard X-band guide. The return loss for this "double transition" was found to be in excess of 18 dB over the band 8-12 GHz. The insertion loss due to the two transitions (this is dissipation loss only, in view of the high return loss) is shown as the solid curve in **Figure 3(b)**. This performance was considered satisfactory.

LAUNCHING HORN

The transition from metal- to dielectric-waveguide is achieved by means of the launching horn shown in **Figure 1(b)**, for X-band. A variety of horn designs were tested and, while it was found that the horn length is not critical, it is necessary for the horn to have a wide flare. The assembly of the transition is shown in **Figure 1(c)**.

Figure 2 shows the forward transmission coefficient of two horns connected with lengths of "plexiglas" ($\epsilon_r = 2.6$, $\tan\delta = 57 \times 10^{-4}$) dielectric guide, of length 250, 360 and 700 mm respectively. In the case of the 700 mm long guide, the insertion loss increases linearly with frequency. For the guides of lengths 250 and 360 mm, however, the loss is constant to about 10 GHz, and then

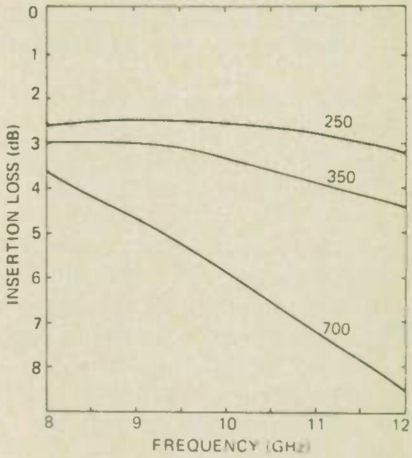

Fig. 2 Insertion loss vs. frequency for various lengths of line. Linelengths shown in mm.

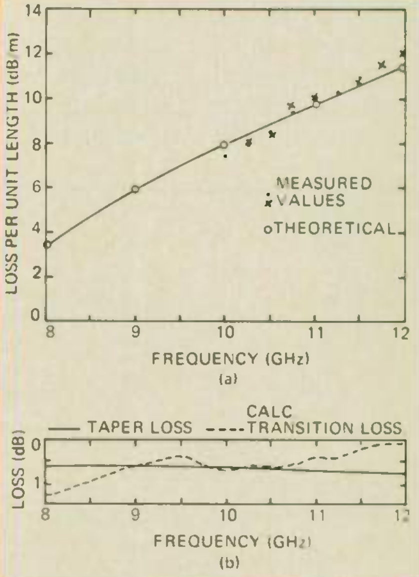

Fig. 3 Loss per unit length for dielectric guide (a), calculated: —o— ; measured: xx & ●●. (b): measured loss in the dielectric tapers ——— ; calculated transition loss: - - - - - .

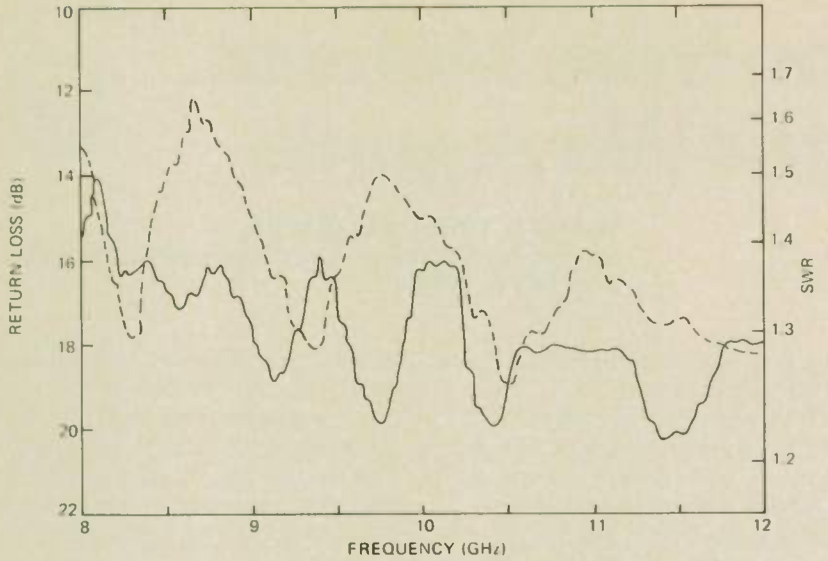

Fig. 4 Return Loss and SWR response for X-band transition with two types of dielectric taper: ——— both E and H Tapers; - - - - - H Taper only.

increases linearly with frequency. In the latter part, the correlation between the three guides is good. It is thought that at frequencies below 10 GHz on the shorter lines, the horns become coupled, causing the observed deviation. From this information, it is suggested that the horn coupling can be avoided if the length of the dielectric guide is more than about 20 wavelengths at the operating frequency.

The information in the curves was used to calculate the loss per unit line length, total loss in the guided section of the 700 mm long guide and thus the loss due to each transition. **Figure 3(a)** shows the loss per unit length of the straight dielectric waveguide section, as compared to a theoretical value.[1] **Figure 3(b)** shows the resultant difference between the total measured loss and the loss for the guide only, and compares this to the measured loss in the two transition tapers.

The return loss for the completed transition is shown in **Figure 4** for two cases. The solid line curve was obtained with the transition shown in **Figure 1(a)** while the dotted curve was obtained with a simplified transition, being tapered in the H-plane of the dielectric guide only. Both cases give acceptable and very similar performances. This result is of importance, as when applied to an E-band dielectric guide, it becomes very difficult to manufacture an E-plane taper because of the small size.

MILLIMETER-WAVE EXPERIMENTS

The horn previously described for use at X-band, was scaled for use in the E-band (80-85 GHz). The dimensions of the horn are shown in **Figure 5(a)**, and is shown assembled in **Figure 5(b)**.

Figures 6 and **7** show curves of frequency vs insertion loss and return loss respectively, for a dielectric waveguide constructed of Teflon ($\epsilon_r = 2.057$, $\tan\delta = 6 \times 10^{-4}$). Using the same assumption as in launching horn section, for loss, a theoretical loss curve is obtained for the dielectric guide, as shown in **Figure 6**. This would put the loss due to the transitions at less than 0.5 dB per transition, although clearly, this is a maximum value occurring only at a number of frequencies.

The return loss is in close agreement with that found for the X-band case where an H-plane taper only is used.

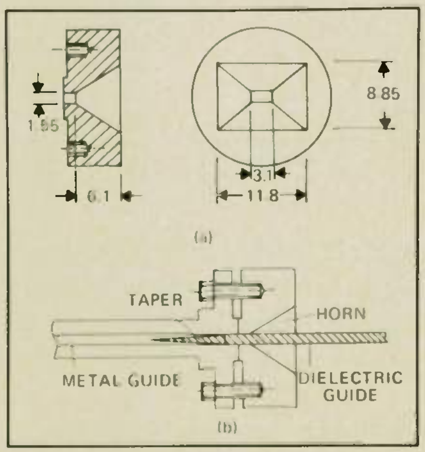

Fig. 5 Inside dimensions of the E-band launching horn in mm (a), and (b) the assembled transition.

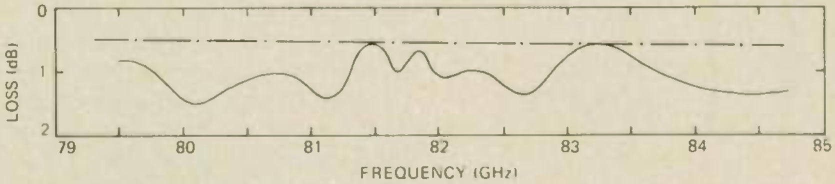

Fig. 6 Insertion Loss vs. frequency for the E-band transition and 86mm long Teflon guide ——— Total insertion Loss; —— • —— Calculated loss for the dielectric only.

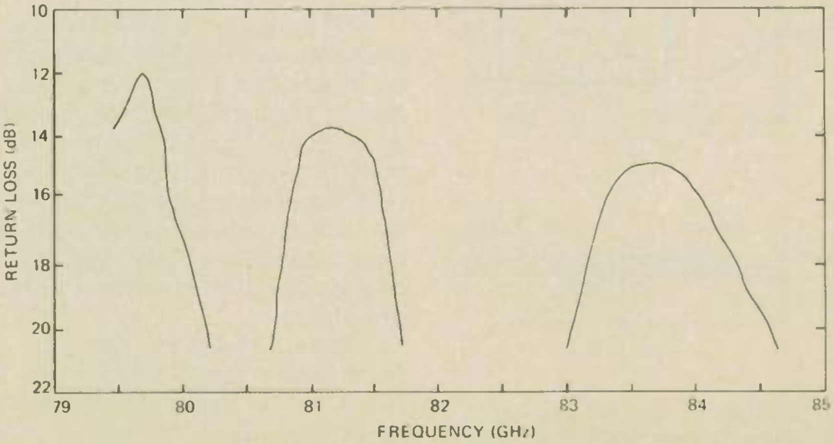

Fig. 7 Return Loss for E-band waveguide to dielectric transition.

(continued on page 74)

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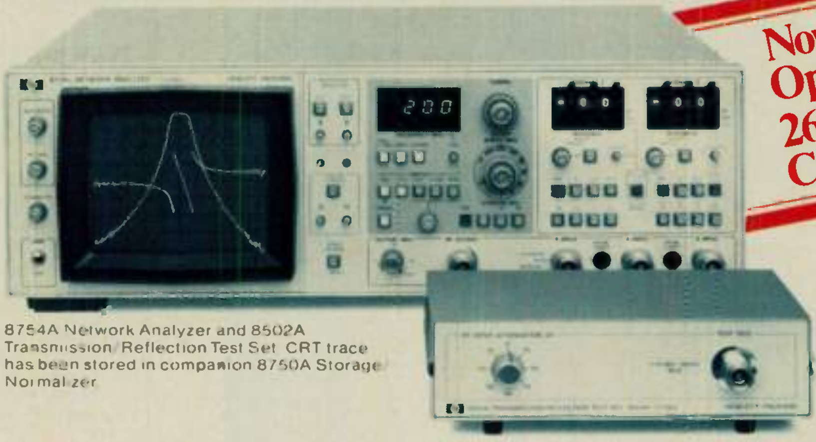

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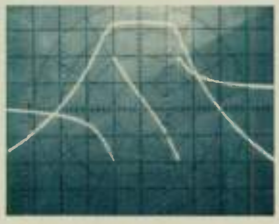

Measure loss, gain and phase shift using the 11850 Power Splitter ($675). Completely identify filter passbands and skirt characteristics without misleading harmonic or spurious responses.

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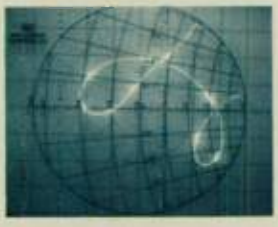

Measure and display impedance in polar form, with crystal markers to give precise frequency data. Test sets are available for both 50 and 75Ω systems.

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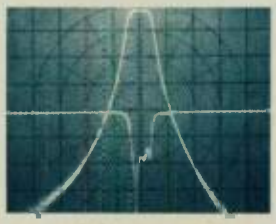

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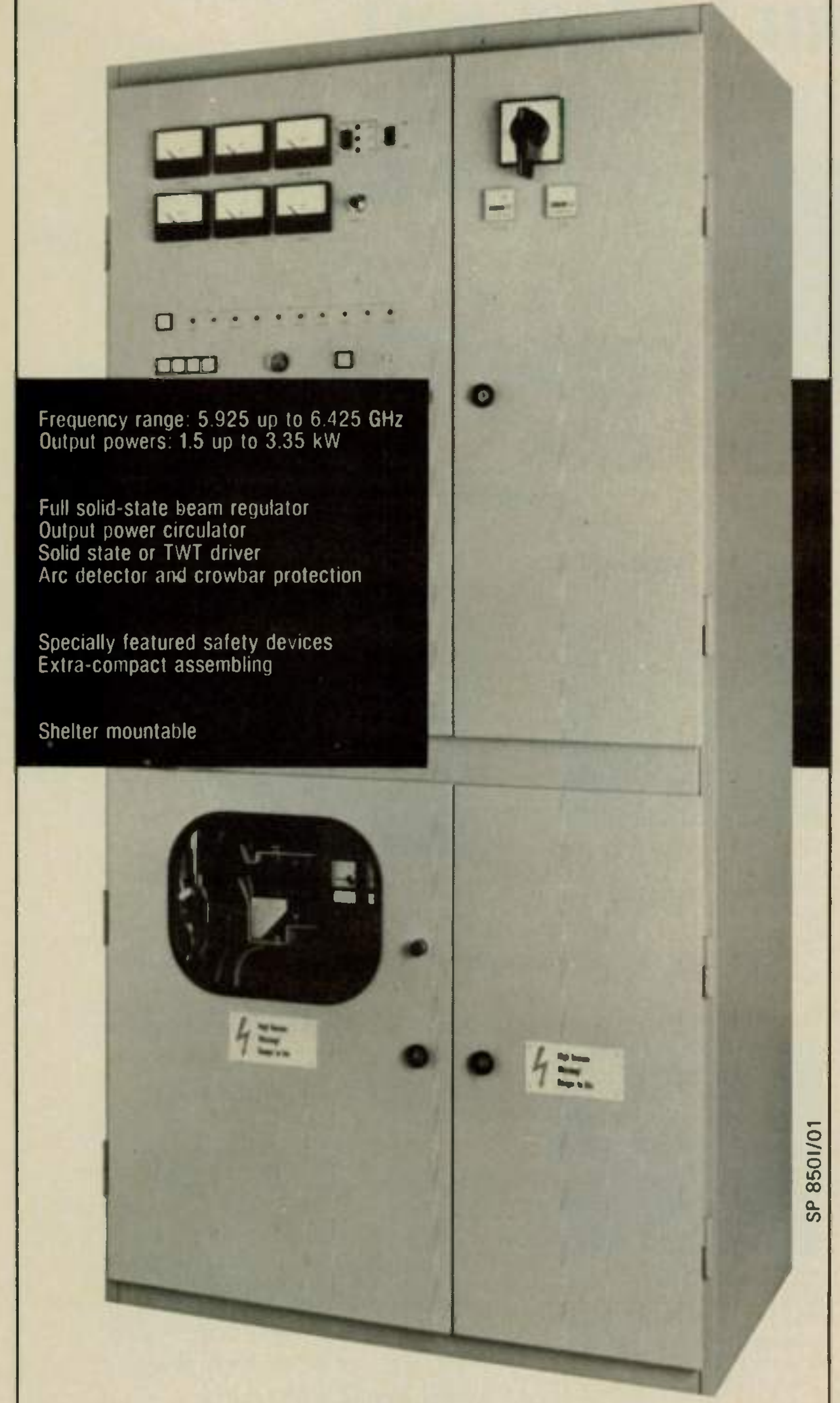

(from page 72) DIELECTRIC

CONCLUSION

A metal- to dielectric-waveguide transition has been described. The transition was first modelled at X-band and the scaled dimensions applied to the E-band. Losses of less than 0.5 dB per transition can be obtained, while none of the parameters are critical. A very good return loss has been observed.

ACKNOWLEDGEMENT

The work reported here was funded by grants DAAG-29-77G-0111 and N000 14-79-C-0424.

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Trang N. Trinh was born on November 28, 1956 in former South Vietnam. He received his B.S.E.E. from Wilkes College, Pennsylvania in 1978, and is working toward his M.S. degree at the University of Illinois, Urbana, in the area of millimeter-wave integrated circuits. Mr. Trinh is a student member of IEEE and Sigma Xi.

Scalar Analyzer Plug–in Automates Swept Measurements

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The Pacific Measurements, Inc. Model 1038/N-10 plug-in together with their Model 1038/D-14 mainframe completely automates swept measurements of insertion loss, gain, return loss and absolute power. The microprocessor-based 1038/N-10 functions are fully controllable by either IEEE-STD-488 Bus commands, front panel key pad, or individual function controls.

In conjunction with an appropriate sweeper and standard TMI detectors, measurements from 1 MHz to 26.5 GHz are accommodated. Waveguide detectors together with PMI cable adapters extend the range to over 100 GHz. With an input power range of +16 to -60 dBm, a full 76 dB of dynamic range is provided.

When used with a frequency-proportional-to-voltage sweep, the 2000-point memory stores calibration data for the entire sweep range and permits the displayed frequency end points to be chosen arbitrarily without recalibration. Horizontal centering and adjustment of the display width to full screen size for the full sweep range or a portion of that range is automatic for sweepers with voltage ranges between -10 and +20 V. An auto-zero feature compensates for low-level drift during retrace times.

Display sensitivities range from 0.1 to 10 dB/div. for both channels; an additional 0.05 dB/div. scale is available for the B channel. Resolution is 0.002 dB for the B channel and 0.02 dB for the A channel. Offsets from +40 to -60 dB in 0.1 dB increments may be set into both channels and the reference line may be set at any major horizontal graticule line. Frequency markers are displayed as upward spikes in the display. A downward spike cursor in the display identifies the point for which data is displayed on the LED readouts for both channels. Cursor position may be controlled via the Bus or by front panel controls.

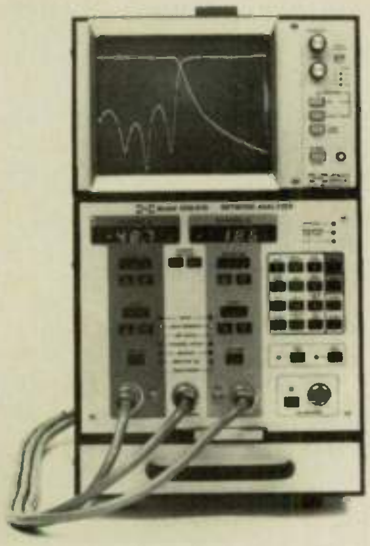
A 10 mW ± 1.5% calibration signal is available at the front panel. Harmonics in the signal are 50 dB below the fundamental and the source impedance is 50 ohms. Overall instrument accuracy is shown in the table.

The PMI balanced detectors for use with the 1038/N-10 are flat within ± 0.5 dB to 18 GHz, ± 1 dB to 26.5 GHz. The detectors are temperature compensated and calibration data is provided with each for absolute power measurements.

A 16-key digital pad is provided for selecting channels and functions and two special function keys are available for user-defined functions. A front panel flashing light feature indicates the status of every key pad entry routine until it is completed.

The 1038/N-10's standard software package includes application programs for all common sweep generators and calculators.

Model 1038/N-10 Plug-in.



1038/N-10 with 1038/D-14 Mainframe.

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TABLE I

KEY SPECIFICATIONS

Input Power	+16 to –60 dBm
Display Sensitivity	
A Channel	0.1, 0.2, 0.5, 1.0, 2.0, 3.0, 5.0, 10.0 dB/div.
B Channel	Same as A plus 0.05 dB/div. scale
Reference Offset	+40 to –60 dB in 0.1 dB increments
Calibration Signal	1 mW ± 1.5% @ 50 Ω
Accuracy	± 0.1 dB/10 dB; 0.3 dB max @ –40 dBm ± 0.4 dB max. @ –50 dBm, ± 1.0 dB max. @ –60 dBm and ± 0.5 dB @ +16 dBm
Horizontal memory	2000 points/channel

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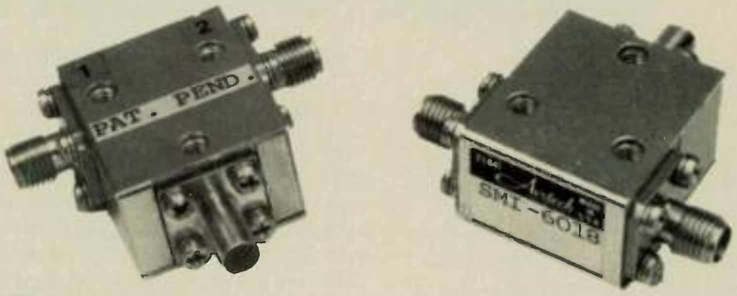

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Microwave circulators and isolators are generally available with insertion loss as low as .10 dB across a 10-20% bandwidth. As the passband is increased, however, the insertion loss increases and other electrical performance tends to degrade. Circulators and isolators of conventional design are limited to 66-75% bandwidth due to the frequency sensitivity of the ferrite junction, low field loss at the low end of the passband, and higher moding at the high end of the passband. While there are isolators available which perform over 100% bandwidth, these devices do not function as circulators.

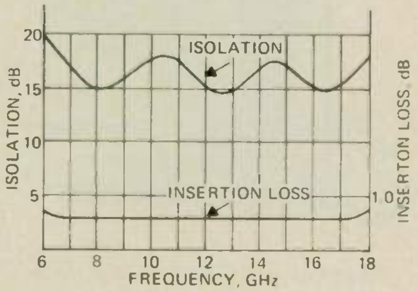

Fig. 1 SMI 6018 insertion loss and isolation.

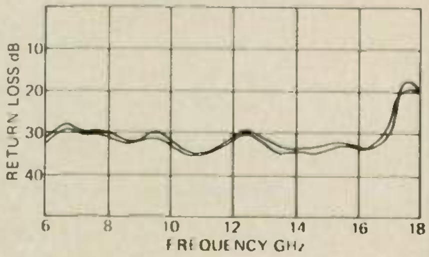

Fig. 2 SMI 6018 return loss.

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Figures 1 and 2 illustrate the characteristics of a 6-18 GHz circulator employing the Surface Mode™ design. This performance holds over a temperature range of −20° to +65°C. Some degradation occurs if the range is expanded to −55°C to +105°C. Mechanically, this device is 0.88" x 1.01" x 0.62" thick exclusive of connectors and it weighs 2 oz. **Figure 3** illustrates the performance of a 2-6 GHz model which measures 1.58" x 1.61" x 0.73" thick and weighs 6.0 oz. In addition to the 2-6 GHz and 6-18 GHz bands, other models are available to cover the 8-20 GHz range.

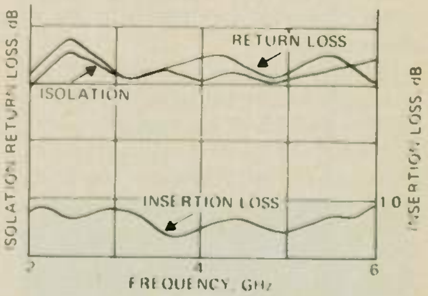


Fig. 3 SMI 2060 characteristics.

Because of their broadband characteristics, low insertion loss and small size, Surface Mode™ circulators and isolators are ideally suited to electronic warfare equipment as well as the instrument applications.

Circle 112 on Reader Service Card

Microwave Products

Instrumentation

SWEEP GENERATOR COVERS 10 MHz - 2 GHz

Model 610D sweep generator produces 20 mW over the 10 MHz to 2 GHz frequency range. Using an internal closed-loop leveling circuit, instrument holds variations in output power to less than ± 0.3 dB across the full band. A front-panel slope control compensates for test-circuit cable losses and maintains a flat output at the test point. Heterodyne circuit sweeps continuously across the full band at rates varying from 10 ms to 100 s per sweep. For ATE applications, option available which can be programmed for use on IEEE-488 bus with 10,000-point resolution. Also features broadband F_1 to F_2 sweep, a ΔF narrowband sweep, 3 CW frequencies, variable and crystal-controlled harmonic markers. Price: Mainframe – $1985, (610D) plug-in (6109D) – $5250; GPIB programmability option 16 – $1100. Del: 60 days. **Wiltron Co., Mountain View, CA. Walt Baxter, (415) 969-6500.** Circle 120.

METER SPANS VIDEO-UHF

Model LN-70 logarithmic amplifier provides 70 dB dynamic range measurements and is designed to operate with conventional sweep generators, displays and detectors covering from video to high microwave frequencies. Full dynamic range of model is +20 to -50 dBm. Offset control on front panel enables measurement of gain or loss to 0.1 dB resolution. Measurements presented on digital readout; powering is from 115/230 Vac, 50/60 Hz, with a power consumption of less than 15 W. Price: $595. **Texscan Corporation, Indianapolis, IN. Raleigh B. Stelle, (317) 357-8781.** Circle 116.

NOISE GENERATOR

A broadband, solid state noise generator, Model 7618, covers the 1-18 GHz frequency range with SWR of 1.2 max., from 1-12.4 GHz; 1.3 Max., from 12.4-18 GHz. Guaranteed excess noise ration (ENR) flatness of better than ± 1 dB; maximum ENR is 15.9 dB. Accuracy of the model is assured by 100% calibration with NBS approved noise calibration system. ENR uncertainty is worst case – not root sum of squares (RSS). Instrument requires 28 V at < 20 ma, and it can also be operated from a "stand alone", regulated power supply. Noise output connector is SMA female; power input connector is BNC female. **Eaton Corp., Electronic Instrumentation Div., City of Industry, CA. William Pastori, (213) 965-4911.** Circle 118

FREQUENCY EXTENDER PUSHES RANGE TO 50 MHz - 1.25 GHz

Model 2373 is a frequency extender which pushes 110 MHz spectrum analyzer frequency sweepwidths from 20 Hz per division to the full 50 MHz to 1.25 GHz. Coupled with the spectrum analyzer, this extender forms a measuring system over the 30 Hz to 1250 MHz frequency range, with an ability to measure narrow spectra to 5 Hz resolution. Price: $19,500. Avail: 30 days. **Marconi Instruments Div., Marconi Electronics Inc., Northvale, NJ. (201) 767-7250.** Circle 119.

(continued on page 78)

FREQUENCY DOUBLER EXTENDS SIGNAL GENERATOR OUTPUT FROM 1280-2560 MHz

Use of the HP11721A frequency doubler extends signal generator output frequency from 1280-2560 MHz. CW and FM-modulated signals will reproduce little distortion and with fairly predictable conversion loss. At drive levels greater than +10 dBm, for instance, conversion loss is less than 15 dB. Software routines for programmable applications also available. Price: $285. Del: 4 wks. **Hewlett-Packard Co., Palo Alto, CA. (415) 857-1501.** **Circle 117.**

ATTENUATION MEASUREMENT SYSTEM EXCEEDS 100 dB

Model VM-4A is a microprocessor-controlled dual channel receiver which makes rapid, single-step insertion-loss measurements in excess of 100 dB from 0.01-18 GHz. Resolutions of 0.1, 0.01, or 0.001 dB and all other functions are controlled either through its front panel or the IEEE-488 interface bus. Instrument can also be used to calibrate output attenuator of signal generators with typical sensitivity better than -100 dBm to 15 GHz and -90 dBm from 15-18 GHz. Typical measurements can be made by model at a rate of 5 frequencies per second, depending upon dynamic range and resolution. Parallel IF substitution improves accuracy; dual set of binary step attenuators improves stability of internal reference. Two microprocessors are used to operate local oscillator phase locked loop system and to provide adaptive signal filtering, along with system control and data functions. **Weinschel Engineering, Gaithersburg, MD. Julian D. Parker, (301) 948-3434.** **Circle 149.**

Hardware

MINI-TORQUE WRENCH FOR CONNECTORS

A miniature, lightweight torque wrench, Part No. 2098-0299-54, assures proper coupling for connector series. Size: 4½" L, supplied with 2 interchangeable heads. Torque is preset at 8 in. lb. Price: $89 per unit. Del: stock to 4 wks. **Omni Spectra, Inc., Microwave Connector Div., Waltham, MA. Ernest J. DeVita, (617) 890-4750.** **Circle 148.**

(continued on page 79)

ERRATUM

In the Contract News Report by Eliot D. Cohen (*Microwave Journal*, November, 1980, p. 38) the description of S-band power bipolar transistor development should have read as follows:

S-BAND POWER BIPOLAR TRANSISTOR DEVELOPMENT

Microwave Semiconductor Corporation (Contract No. N00173-78-C-0019) is continuing work on the development of high power 3.1-3.5 GHz transistors. Recently, a new run of large single cell devices yielded power outputs of up to 9.25 watts peak (50 microsecond pulses, 10% duty factor) with 6.7 dB gain and a collector efficiency of 30% at 3.5 GHz. This represents a power output of 1.75 watt over cell design goal and a substantial improvement in collector efficiency compared to previous device runs. Eight of these cells have been combined to produce a single device amplifier with approximately 60 watts of peak power output across the 3.1-3.5 GHz band. Gain and collector efficiency are approximately 5.5 dB and 30%, respectively, for the multi-cell device. The devices use ion implanted bases and diffused emitters.

Devices

MAGNETRON COVERS 94-96 GHz; EMPLOYS Sm-Co MAGNET

A lightweight, M-band fixed frequency pulse magnetron, Model MG5200, operates in the 94-96 GHz frequency range. This tube has an expected life of over 750 hrs. and samarium cobalt magnet structure reduces weight to only 1.8 kg (3 lbs., 15 oz). Unit operates at short pulse lengths down to 4 ns with a pulse duration of 50 ns. Anode voltage (peak) is 13 kV; anode current (peak) is 7.0 A output power is 3 kW; and duty cycle lasts 0.0002 s. Size: 152.5 mm x 108 mm x 76.5 mm, maximum (6" x 4¼" x 3"). **EEV Inc., Elmsford, NY. T. Soldano, (914) 592-6050. Circle 121.**

SILICON BIPOLAR TRANSISTOR FOR 4.3 GHz BAND

Model HXTR-4101 is a NPN silicon bipolar transistor for fixed frequency oscillator applications. Device output is guaranteed to be 19 dBm minimum and typically is 20 dBm at 4.3 GHz frequency band. At higher frequencies, output is typically 17 dBm at 6 GHz and 12 dBm at 8 GHz; unit usable to 10 GHz. Collector-base voltage is 15 V; collector current is 30 mA. Device employs ion implantation techniques and Ti/Pt/Au metallization in it's manufacture. Chip provided with dielectric scratch protection over its active area. Comes in rugged, metal/ceramic hermetic package, and meets MIL-S-19500 environmental requirements and MIL-STD-750/883 test requirements. Price: $39, 1-9 qty.; $28.50 for 100-249 pieces (US). Del: from stock. **Hewlett-Packard Co., Palo Alto, CA. (415) 856-1501. Circle 122.**

MONOLITHIC UHF PREAMPLIFIER

A monolithic, general purpose ultra-high frequency preamplifier, SL 955, operates from dc to 1 GHz. Intermodulation reference for the model has been set at 40 dB, which permits it to handle strong signals without interference from adjacent communications channels. Defined gain of the device has been set at 22 dB. Unit operates from a single 5 V power source and dissipates only 30-70 mW in operation. Its signal handling characteristics make it suited to UHF circuitry and CATV applications. Available in 8-PIN DIP configuration. Price: $2 for 10,000 qty.; $8.95, 100 qty. **Plessey Semiconductors, Irvine, CA. Dennis Chant, (714) 540-9979. Circle 123.**

Materials

LOW LOSS CLAD LAMINATES

Di-Clad 870 and 880 are low loss microwave laminates composed of Teflon® and woven fiber glass. Materials feature dissipation factor of 0.0015, max. Features dielectric constant of ± 0.02, with uniform performance. Size: 16" L x 36" W. Weight: 1 oz. rolled cu is stand. cladding, optional are 1/2 and 2 oz. cladding. **Keene Corporation, Chase-Foster Laminates Div., Bear, DE. Frank Yoerg, (302) 834-2100. Circle 126.**

RFI CONDUCTIVE CAULKING COMPOUNDS & SEALERS

ECCOSHIELD® VY and VY-C are single-component electrically conductive formulations designed for RF shielding applications. Properly caulked structure will exhibit insertion loss in excess of 100 dB. Material has volume resistivity of about 0.001 ohm-cm. Density for ECCOSHIELD VY is 4.9 gr/cc; for ECCOSHIELD VY-C, 1.4 gr/cc. **Emerson & Cuming, Canton, MA. Jeanne B. O'Brien. (617) 828-3300. Circle 125**

(continued on page 80)

ALUMINA THIN FILM CIRCUIT SUBSTRATES

A line of thin film metallized substrates made of highly polished alumina, Minimum Inclusion Polish and Process (MIPP) substrates, offer 1 microinch surface finishes and high density circuit patterns with excellent definition. These materials come in chrome/gold or moly/gold with line tolerance of ± .001" ± 1/10, and chrome/copper/gold or chrome/copper with line tolerances of ± .003" ± 3/10; other substrates available are chrome/copper/nickel/gold and tantalum nitride in combination with other metallizations. Size: 1" x 1", 1" x 2", 2" x 2". ½" x ½", ½" x 1" with .010", .015", .025", and .005" thickness available. The .005" thick materials are suited for complex subsystem packages. All substrates lack burrs or protrusions which cause premature breakdowns of thin film capacitor dielectric materials. Price: for 1" x 1" x .025" substrate, metallized with chrome/gold on all sides and edges, $19.50 in 100 qty. **Tekwave, Inc., New Hyde Park, NY. (516) 328-0100.** Circle 127.

CIRCULAR CONTACTS SUPPRESS STATIC BUILD-UP

A series of circular contacts have been designed to suppress static build-up due to delayed grounding. New configuration is a soft compressible knitted metal and rubber combination mounted on a metal or rubber washer. Metal washers have a clearance hole for application with a fastener; the rubber washers have pressure-sensitive backing. Both are designed to maintain full and resilient contact pressure over long periods of compression. Size: 0.625" O.D. with .25" thickness and a #6 clearance hole; and 0.875" O.D. with .187" thickness of adhesive-backed rubber. **Metex Corporation, Electronic Products Div., Edison, NJ. John Severinsen, (201) 287-0800.** Circle 124.

Antennas

ANTENNA SYSTEMS COVER 18.36-19.04 GHz BAND

A line of microwave antenna systems spans the 18.36-19.04 GHz range fixed point-to-point band. These high performance shielded parabolic antennas range from 2 to 4 ft. in diameter, and come with a full line of rectangular waveguide components. Antennas are center-fed and have continuous polarization orientation. Both the 2 and 4 ft. models conform to Part 94 requirements and Standards A and B of the FCC code. A TEGLAR™ radome and vertical tilt mount come as standard equipment. White or aviation orange color. **Andrew Corporation, Orland Park, IL. (312) 349-3300.** Circle 114.

12 FT, 3.66 M ANTENNA

A 3.66 meter, 12 ft. antenna operates over the 3.7-4.2 GHz band and 11.7-12.2 GHz frequency range. Gain for model is 41 dB @ 4 GHz and 51 dB @ 12 GHz. SWR maximum is 1.25; beamwidth degrees at midband are (−3 dB) 1.4° at 4 GHz; 0.48° at 12 GHz. Temperature wind load plus ice-survival is −60° to 125°F (−51° to +52°C) at 100 mph (160 km/hr) with 1.0" radial ice or 125 mphr (201 km/hr) with no ice. Reflector is constructed of high precision fiberglass; back-up structure is aluminum; mount is steel, and feed is copper. Employs a mount type with elevation over azimuth orientation capability of 360° on a central axis, with 10° - 65° elevation adjustment. Weight: 500 lbs. Del: 30 days, installation time: 2 men/2 hrs. **Microdyne Corporation, Ocala, FL. (904) 687-4633.** Circle 115.

Components

PIN PACKAGED, DIGITAL ATTENUATOR

DAP-1024 is a digital attenuator which provides 4 bits of attenuation with attenuation values of 3, 6, 12 and 24 dB for the 935-1260 MHz band. Component offers a maximum insertion loss of 3 dB, SWR of 1.5 maximum and a switching capability of 500 ns, maximum. Accuracy of the unit is ± 0.5 dB from 0-24 dB, and ± 1 dB from 25-42 dB. Temperature stability ranges from −54°C to +82°C is 0.5 dB maximum from 0-24 dB and 0.7 dB maximum from 25-42 dB. RF to control isolation for the model is 60 dB minimum; RF power is +20 dBm maximum,and input power is ± 1 V at ± 10 ma per bit. Size: for 24 pin, hermetically sealed header package: 1.4" x 0.810" x 0.375". Price: $300 per unit. **Engelmann Microwave Co., Montville, NJ. Carl Schraufnagl, (201) 334-5700.** Circle 135.

UHF AND INTEGRATED DUAL ISO-FILTER

Model 103600027 is a UHF dual iso-filter which employs current integration techniques. Filter covers the 494-554 MHz frequency range with an insertion loss of 1.3 dB maximum. Rejection at 614 MHz and 438 MHz is greater than 40 dB, and both input and output SWR remain below 1.3 for all load conditions. Both single and dual iso-filters span bandwidths as wide as 70% from 500 MHz to 18 GHz, and consist of a sharp cut-off comb-line filter and two high performance ferrite isoaltors integrated on a common ground. Phase linearity and loss variation options also available. Price $1.395. Del: 8-12 wks. ARO. **Eaton Corp., Addington Microwave Components, Sunnyvale, CA. Jim Wilson, (408) 738-4940.** Circle 130.

2850-3150 MHz BAND

A high speed diode limiter, Model LT-1026, operates in the narrow frequency band, 2850-3150 MHz. Unit has an insertion loss of 0.50 dB maximum and SWR of 1.25 maximum. Isolation is 45 dB minimum and power capability is 60 kW peak; 10 W-average and flat leakage is 40 mW maximum. Model has 0.10 ergs spike leakage and turn-on-time of 6 ns, maximum; recovery-time of 20 ns, maximum. Available with SMA type female connectors. Size: 2.5" x 1.25" x 0.38". **Triangle Microwave, Inc., East Hanover, NJ. James Beard, (201) 884-1423.** **Circle 138.**

SMA SWEEP RIGHT ANGLE ASSEMBLIES

A line of SMA sweep right angle assemblies include plug/plug (Part No. 795976) and plug/jack (Part No. 705979-001) units. Typical SWR is 1.2:1 to 18 GHz. Components use CT. 141-50 semi-rigid cable for the right angle bend; SMA plugs use cable center as the center contact. Come completely gold plated. Optional assembly combinations include: plug/receptical; jack/receptical; and jack/printed circuit. **Cablewave Systems, Inc., North Haven, CT. Steven Raucci, Jr., (203) 239-3311.** **Circle 132.**

TERMINATION INSENSITIVE MIXER FOR .5-.8 GHz BAND

A Termination Insensitive Mixer (TIM) covers the .5-.8 GHz range and operates with 0 dBm LO drive. This biasable mixer, MD-165, provides 9 dB typical conversion loss with a 0 dBm LO drive. Model also features 1 dB compression point of 2 dBm and 3rd order intercept of +7 dBm. TIM offers flat conversion loss regardless of sum frequency match, and predictable 3rd order intermodulation performance even into high IF mismatch. Price: $575, flatpack version; $650, SMA connectorized version. Avail: from stock. **Anzac Division, Adams Russell, Burlington, MA. (617) 273-3333.** **Circle 128.**

1500 MHz TV BANDPASS FILTER

Type 3710 is a bandpass filter suited for L-band TV channels #1-#15 (channel #1 spans 1429 to 1435 MHz and channel #15 spans 1513 to 1519 MHz). Unit has isolation of 30 dB ± 10 MHz and typical loss of 1.5 dB with typical SWR of 1.5 (15 dB return loss). Fittings are type N, 50 ohms. Price: $650. Del: 4 wks. **Microwave Filter Co., Inc., East Syracuse, NY. Emily Bostick, 1-800-448-1666 (toll-free) or (315) 437-3953.** **Circle 139.**

COAXIAL TERMINATION OFFERS 25 W

Model 9525 is a 25 W coaxial termination which operates from dc to 8 GHz and dissipates 25 W average power. SWR for unit is 1.1 max. at 1.0 GHz; 1.25 max. at 4 GHz and 1.35 max. at 8 GHz. Size: 1.75" L, connector is SMA male. Price: $85, small qty. Del: from stock. **Arra, Inc., Bay Shore, NY. Mike Geraci, (516) 231-8400.** **Circle 133.**

2-18 GHz BAND

A standard line of compact filters using press-in SMA connectors or 50 PIN feedthroughs with dimensions: 2.0" x 1.0" x .563"; 1.8" x .53" x .30" and 1.3" x .5" x .30". Components offer rejections of 40 65 dB, insertion loss of .7-1.5 dB and bandwidths of up to 1 GHz depending upon the number of sections used. Units all are rugged and built to conform to MIL-E-5400 Class II. Options include alternate connector locations and/or group-delay compensation. **Omniyig, Inc., Santa Clara, CA. (408) 988-0843.** **Circle 137.**

NON-GROUNDED RF FEEDTHROUGH

An insulated panel mount consisting of nylon washers for isolating the connector body from the mounting board comes fabricated to fit in a .250" D hole in a panel with a .031" minimum thickness. Components is a non-grounded RF feedthrough. **RF Components Div., Sealectro Corporation, Mamaroneck, NY. (914) 698-5600.** **Circle 141.**

SMA ATTENUATORS SPAN 3.0 GHz BAND

A series of 50-ohm, coaxial SMA attenuators, AT-53/SMA, are available in 1-9 dB in 1 dB steps and 10-20 dB in 2 dB steps. Attenuation accuracy for the models are 0.5 dB from dc to 2.5 GHz, and 1 dB from 2.5-3.0 GHz. Components have SWR is less than 1.35 at 3 GHz, averaging 1.2 over the band. Models can dissipate 0.25 W, CW or 250 W, peak power. Design utilizes gold plated connectors and high reliability MIL resistors in silver-plated housing. Size: 0.4" D. x 1.5" L. Del: stock to 30 days ARO. Price: $15, each FOB. **Elcom Systems, Inc., Boca Raton, FL. Leonard Pollachek, (305) 994-1774.** **Circle 129.**

(continued on page 82)

120° ANALOG PHASE SHIFTER

Model PQ-117 is an analog, multi-octave 120° phase shifter which operates over the 100-500 MHz frequency band. Unit has an insertion loss of 3.5 dB, maximum, amplitude ripple of ±0.5 dB, maximum and SWR of 1.6, maximum. RF input power for model is 1 W CW, maximum and bias voltage is +4 to +20 V dc. Phase shifter has a -54° to +85° C temperature range and comes with SMA female connectors. Size: 16 3/4" x 4 3/8" x 3/8". **Triangle Microwave, Inc., East Hanover, NJ. (201) 884-1423.** Circle 147.

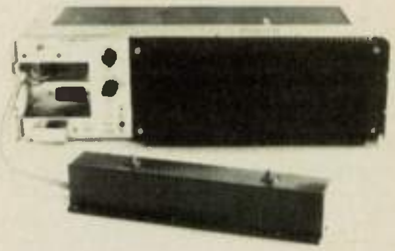
WR-229 SAT-COM SWITCHES COVER 3.7-4.2 GHz BAND

A line of ultra-low noise satellite communication waveguide switches, WR-229, cover the 3.7 to 4.2 GHz frequency range. Typical performance of the units is 1.04 SWR; 0.01 dB insertion loss; and 90 dB isolation. Switches may be used in earth stations for low noise amplifier and HPA systems and for numerous worldwide satellite communications systems. **Logus Manufacturing Corp., Deer Park, NJ. (516) 242-5970.** Circle 136.

TUNABLE BANDPASS FILTER COVERS 6.5-7.2 GHz BAND

A tunable bandpass filter, #201975, uses remote tuning by a digital command over the 6.5-7.2 GHz band. Unit can operate remote to the command center and responds to TTL and BCD logic inputs. Accuracy of ± .15 MHz is maintained from either direction and 1,000 positions of calibration are offered. At 3 dBBw, range is 17-19 MHz; at 30 dBBw, range is 32-39 MHz; and at 60 dBBw, range is 64-70 MHz. Insertion loss for model is 3 dB maximum and SWR is 1.5 at fo. Filter has power requirements of +15 Vdc, -15 Vdc or 5 Vdc. A type N female connector is available and unit can be rack mounted. Price: $6,400 for 1. Del: 12-14 wks. ARO. **Coleman Microwave Co., Edinburg, VA. (703) 984-8848.** Circle 134.

HIGH-EFFICIENCY SERIES OF TWT's



A line of high-efficiency traveling wave tubes with power supply (VPW-2859) are designed for digital and analog communication systems. These components extend from C to K_u-band – VTJ-2677E5 (5.9-7.1 GHz); VTH-2678B3 (7.1-8.5 GHz); and VTX-2679B2 (10.7-14.5 GHz). All TWT's are of double-depressed collector design, have low AM/PM conversion, and low 3rd-order intermodulation products. Minumum saturated power output is 20 W, with efficiency at saturation typically greater than 32%. Weight: of TWT's, 2 lbs, achieved via use of permanent magnet focussing stack constructed of Samarium-cobalt magnets. **Varian Associates, Electron Device Group, Palo Alto, CA. (415) 493-4000.** Circle 140.

BOOSTING ACOUSTIC WAVES DELAY LINES

A series of multireflection boosting acoustic wave (BAW) delay lines combines focusing of acoustic waves and boosting of selected echoes to achieve delays of up to 100 µs (at 1 GHz) in a 10 cm long package and delays of up to 10 µs (at 1.4 GHz) in a TO8 case. These delays are 2 to 3 times longer than conventional BAW delay lines with similar insertion loss. **Thomson-CSF Components Corp., Special Products Div., Clifton, NJ. (201) 779-1004.** Circle 131.

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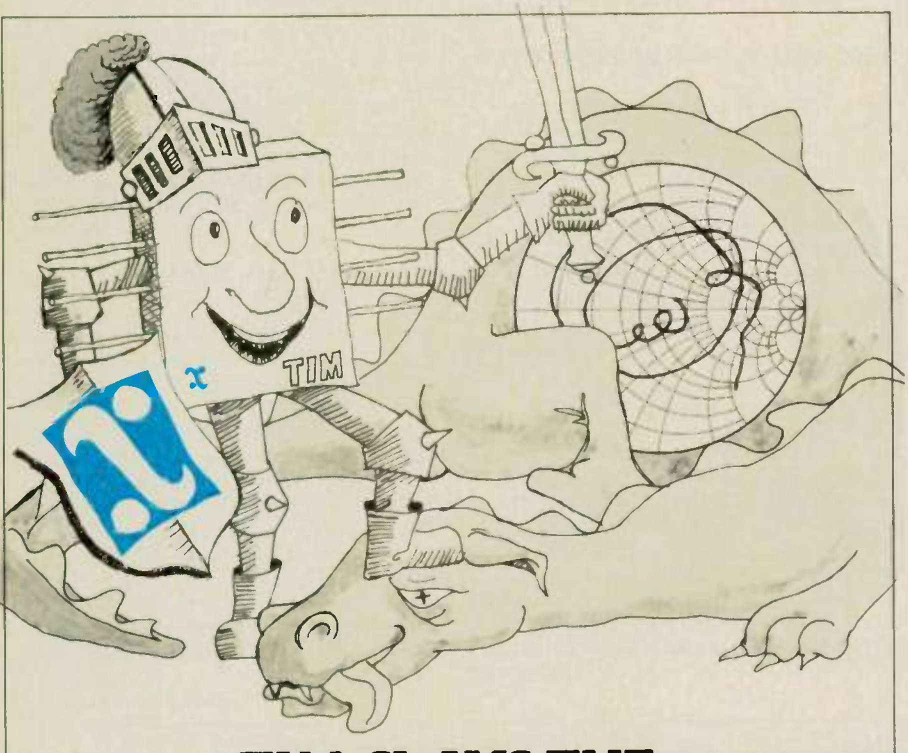

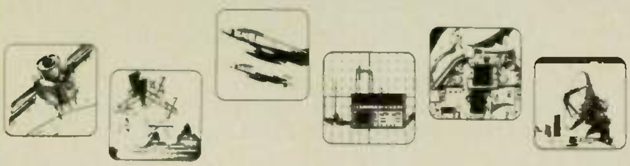

Microwave Professionals

■Component Design
■Product Line Management

Teledyne Microwave, located on the San Francisco Peninsula, is a major supplier of microwave components and subsystems to the military and commercial communications markets.

We are presently seeking candidates for two key Product Line Management positions in our Ferrite Components and Filter/Multiplexer product lines. Applicants should have a BSEE plus five years progressively responsible design and management experience in either of the above areas.

Design engineering positions are also available in Ferrites, Filters and Voltage Controlled Oscillators. Candidates for these positions should have a BSEE plus two or more years related experience.

Interested individuals are invited to submit their resume including salary history to Professional Employment Department, Teledyne Microwave, 1290 Terra Bella Avenue, Mountain View, CA 94043 or call collect (415) 968-2211.

TELEDYNE MICROWAVE

The Laboratory of Nuclear Studies at Cornell University has an opening for a

PHYSICIST / ELECTRICAL ENGINEER RESEARCH ASSOCIATE

to participate in MICROWAVE SUPERCONDUCTIVITY R/D directed at application to High Energy Electron Accelerators.

Ph.D. in Physics or Engineering required. Some experience in low temperature and microwave work highly desirable but not necessary. Two-year initial appointment with long-term possibilities. Salary commensurate with experience. Apply by letter to:

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We have a ground floor opportunity in RF Engineering for an individual with at least 10 years experience in RF/Microwave Integrated Circuit Design, working in frequencies through 20 GHz.

Your qualifications should include BS in EE or Physics and an extensive background in solid state component design. You should be a well rounded technical specialist with proven management skills as you will assume a key technical and management role in proposal development and project management.

We offer an excellent starting salary and comprehensive benefits including dental insurance, 100% tuition paid in advance . . . and a relocation package which includes settling-in assistance.

Please forward resume, including current compensation, to Professional Employment, ITT Avionics Division, 390 Washington Avenue, Nutley, New Jersey 07110.

ITT AVIONICS DIVISION

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(from page 82) NEW PRODUCTS

POWER RESISTOR AND TERMINATION SERIES

The HDA series of power resistors and terminations offer resistance values ranging from 25-200 ohms and power ratings from 10-250 W CW. Units cover the dc-1 GHz and to dc-4 GHz frequency range and maximum SWR is 1.3 to 1.4, depending on model. Configurations are offered with single or dual leads and with or without the flange for heat sinking. **Hybrid Design Associates, Inc., Chandler, AZ. David Perling, (602) 96109614.** **Circle 156.**

HIGH PERFORMANCE SWITCHES

The N-series of high-speed, (rise and fall times of < 20 ns) absorptive, SPST switch-driver assemblies covers the 0.5-18 GHz frequency range. Isolation is greater than 80 dB; insertion loss is 1.5 dB, SWR is 1.5. Units have an RF power rating of 1 W average, and the control logic is TTL compatible. Size: 1.25" x 2" x 0.5", with SMA connectors. Del: 90 days. **Hyletronics Corp., Littleton, MA. (617) 486-8911.** **Circle 145.**

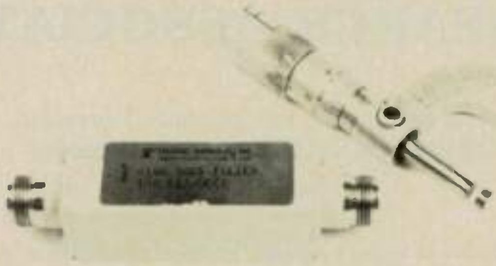
WR-137 SATELLITE COMMUNICATION SWITCHES

A series of WR-137 satellite communication switches meet critical requirements of various European domestic satellite programs and national security systems. Performance specifications include: 0.025 dB insertion loss; 90 dB isolation, minimum, and 10 kW CW, maximum power handling capability. **Logus Manufacturing Corp., Deer Park, NY. (516) 242-5970.** **Circle 146.**

COAXIAL RF FUSES

Models FL 50, FL 75 are coaxial RF fuses designed for use in the dc to 1500 MHz frequency range. Units contain subminiature fuse elements rated at 1/16 A or 1/8 A, in either 50 or 75 ohm structures. Components have insertion loss of less than 2.3 dB; and a typical SWR of 1.3, 1.7, maximum, over the band. BNC or TNC connectors are furnished. Price: $10.60 (BNC option), FOB. Del: stock to 30 days ARO. **Elcom Systems, Inc., Boca Raton, FL. Leonard Pollachek, (305) 994-1774.** **Circle 144.**

RUGGED HIGHPASS FILTER LINE



A line of rugged highpass filters, THP, cover the 100 MHz to 1500 MHz frequency range. Filters are available in 3 to 7 sections, and are 0.1 dB ripple lumped-element Tchebyscheff designs. Insertion loss is typically 0.5 to 1.0 dB with passband roll-off dependent upon required cutoff frequency and number of sections. Filter housings are fabricated from a single block, designed for production machining. **Telonic Berkeley, Laguna Beach, CA. Adam Reed (714) 494-9401.** **Circle 142.**

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New Literature

BULLETIN ON PARABOLIC ANTENNA WIND FORCES AND LOADS

Bulletin 1015F provides information for the system designer on the physical and windload characteristics of parabolic microwave antennas. Literature contains calculations and data required to determine antenna wind loading. Also includes graphs depicting windload coefficients, table of antenna weights and center of gravity locations with and without ice loading. **Andrew Corporation, Orland Park, IL.** (312) 349-3300. Circle 101.

CATALOG ON SMA IC LAUNCHERS

An 8-page catalog, No. 203A, gives product information on a line of hermetically sealed SMA microwave IC launchers. Brochure includes launcher descriptions, electrical, environmental, and mechanical specifications and outline drawings. Sliding contact and high temperature (250°C) versions are included. **Cablewave Systems, Inc., North Haven, CT. Steve Raucci Jr.,** (203) 239-3311. Circle 102.

IF/RF COMPONENT CATALOG

A 16-page IF/RF component catalog provides quick reference tables of key specifications and engineering design aids which delineate MIC and connectorized versions of solid state switches, programmable step attenuators and voltage controlled attenuators as well as connectorized models of high-power switches, coaxial relays and phase shifters. Booklet includes frequency, switching speed, isolation, insertion loss, RF power, SWR, dc power, control logic and termination specifications. Definitions, performance notes, quality assurance testing parameters, interface suggestions, and a spurious response nomograph are also provided. **Daico Industries, Inc., Compton, CA. (213) 631-1143.** Circle 103.

ATTENUATOR AND TERMINATION CATALOG

Catalog 811 is a 32-page listing of product information on a line of coaxial attenuators and terminations, minimum loss pads, multicouplers, double balanced mixers, and RF fuses. **Elcom Systems, Inc., Boca Raton, FL. (305) 994-1774.** Circle 104.

NOISE SOURCE CATALOG

A line of noise products, including solid state noise sources to 40 GHz, diode chips, and programmable noise instruments are covered. Basic broadband types, high output level modules, and precision thermal noise standards are also shown. **Micronetics, Inc., Norwood, NJ. (201) 767-1320.** Circle 105.

TELEMETRY RECEIVER BROCHURE

A 21-page pamphlet on Model 1200-MR details the features of this microprocessor controlled telemetry receiver. This two-color brochure discusses its applications and provides a general description, block diagrams and specifications. Detailed specifications for individual RF tuners, first and second IF filters and other receiver components are also provided. **Microdyne Corporation, Rockville, MD. (301) 762-8500.** Circle 106.

SCHOTTKY BARRIER MIXER BROCHURE

Brochure B-4211B describes low, medium and high barrier Schottky barrier mixer lines designed for optimum performance at various LO drive levels. Literature provides specifications and performance characteristics for the diodes. **Microwave Associates, Burlington, MA. (617) 272-3000.** Circle 107.

TECHNICAL BULLETIN ON MINI HYBRID AND DIRECTIONAL COUPLERS

A series of directional and miniature 90° hybrid couplers for applications from 2.6 to 17 GHz are described in a technical bulletin. Literature covers product specifications (electrical and mechanical) for the small, lightweight (0.5 oz., typical) stripline components. **Omni Spectra, Inc., Microwave Component Div., Merrimack, NH. (603) 424-4111.** Circle 108.

RF CONNECTOR CATALOG

A 60-page RF connector catalog (CX-9) gives complete electrical and mechanical specifications of a line of Conhex® subminiature RF connectors. Literature catalogs MIL-C-39012, series SMB and SMC, 50-ohm slide and 75-ohm Conhex connectors. **Sealectro Corporation, RF Components Div., Mamaroneck, NY. (914) 698-5600.** Circle 109.

CHIP INDUCTOR SERIES APPLICATION NOTE

A two-color application note describes "Series C" chip inductors. This 6-page pamphlet describes the fabrication and mounting and termination of the inductors. It discusses their mutual coupling, shock and acceleration and power handling characteristics and ground plan proximity effects. Supplementary data sheets provide full electrical and mechanical specifications. **Hull Corporation, Thinco Division, Hatboro, PA. (215) 675-5000.** Circle 110.

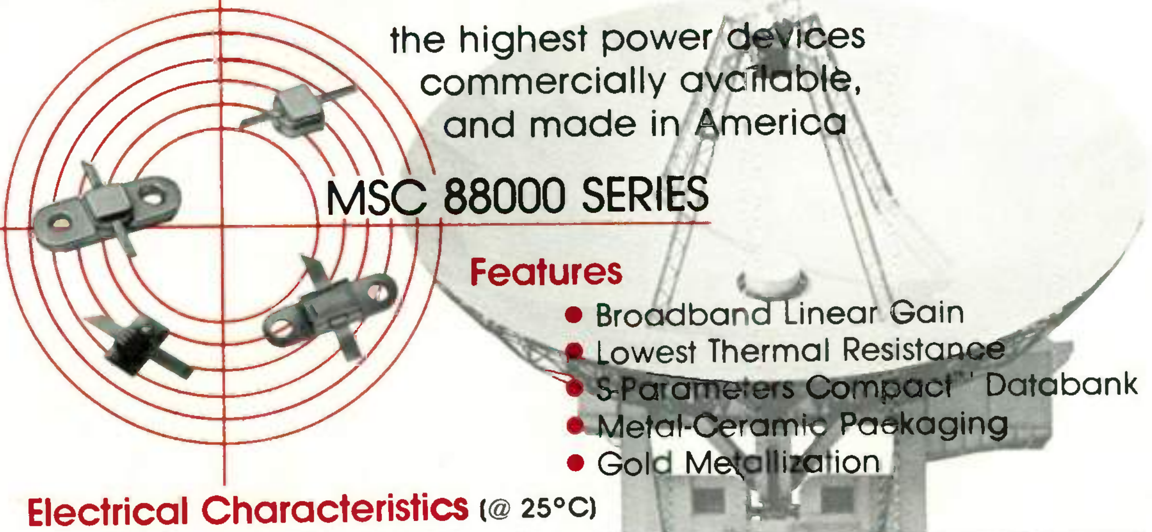
DATA SHEETS ON GaAs FETs

GaAs FET models VSF-9320 and VSF-9330 are featured in two data sheets. Each device is a 0.5 μm gate low noise device for C through K_u band applications and each will handle in excess of 500 mW. The VSF-9320 offers lower noise figure and higher gain than the VSF-9330. Complete specifications are provided by the data sheets. **Varian Associates, Solid State Microwave Div., Santa Clara, CA. (408) 988-1331.** Circle 111.

Revised

Power GaAs FETs

the highest power devices
commercially available,
and made in America



MSC 88000 SERIES

Features

- Broadband Linear Gain
- Lowest Thermal Resistance
- S-Parameters Compact™ Databank
- Metal-Ceramic Packaging
- Gold Metallization

Electrical Characteristics (@ 25°C)

MODEL NUMBER	TEST FREQ (MHz)	POUT$^{(1)}$ TYP (W)	POUT$^{(1)}$ MIN (W)	PIN (mW)	Vds NOM (V)	Idss NOM (mA)	θcc$^{(2)}$ TYP (°C/W)	PACKAGE TYPE
C-BAND SERIES								
MSC 88000	6000	0.060	0.050	8	8	90	45	FLIP-CHIP HERMETIC
MSC 88001	6000	0.200	0.175	40	8	150	35	FLIP-CHIP HERMETIC
MSC 88002	6000	0.400	0.350	90	9	300	25	FLIP-CHIP HERMETIC
MSC 88004	6000	1.000	0.800	200	9	700	20	FLIP-CHIP HERMETIC
MSC 88012	6000	3.700	3.500	800	10	2000	7	FLIP-CHIP HERMETIC
X-BAND SERIES								
MSC 88100	12000	0.060	0.050	16	8	90	45	FLIP-CHIP CARRIER
MSC 88101	12000	0.200	0.175	56	8	150	35	FLIP-CHIP CARRIER
MSC 88102	12000	0.400	0.350	125	9	300	25	FLIP-CHIP CARRIER
MSC 88104	12000	1.000	0.800	280	9	700	20	FLIP-CHIP CARRIER
Ku-BAND SERIES								
MSC 88199	15000	0.030	0.025	6	8	70	40	FLIP-CHIP CARRIER
MSC 88200	15000	0.110	0.100	25	8	120	35	FLIP-CHIP CARRIER
MSC 88201	15000	0.250	0.200	70	8	160	29	FLIP-CHIP CARRIER
MSC 88202	15000	0.450	0.400	140	9	325	23	FLIP-CHIP CARRIER
MSC 88204	15000	0.900	0.800	316	9	675	15	FLIP-CHIP CARRIER

NOTE (1) Power Output at the 1 dB Gain Compression point is defined as the point where further increases in input power cause the output power to decrease 1 dB from the linear portion of the curve.

NOTE (2) Thermal Resistance determined by Infra-Red Scanning of Hot-Spot Channel Temperature at rated RF operating conditions. Reference MSC Application Note TE-212

YOUR TOTAL MICROWAVE RESOURCE

The MSC series of GaAs FETs are designed for linear power amplifiers and for oscillator applications from 2-14 GHz. Higher frequency state-of-the-art devices are also available. Please call or write for a complete GaAs FET Product Data Packet, and the MSC 24-Page Product Guide.

MICROWAVE SEMICONDUCTOR INC.
an affiliate of SIEMENS
100 School House Road
Somerset, New Jersey 08873, U.S.A.
(201) 469-3311 TWX (710) 480-4730 TELEX 833473

CIRCLE 2 ON READER SERVICE CARD

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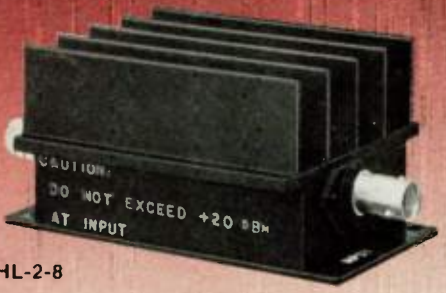
1W AMPLIFIERS

0.05-1200 MHz from $199

- Broadband ... each model multi-octave (see table)
- High linear output ... up to 30 dBm (1 W)
- Gain ... available from 16 dB to 27 dB
- Very flat gain response ... ±1 dB
- Connectors ... BNC Std; SMA, TNC, N available
- Compact ... 3.75" × 2.60" × 1.92" (ZHL-A Models)
  4.75" × 2.60" × 2.22" (ZHL Models)
- Self-contained heat sink
- One-week delivery



ZHL-2-8

If your application requires up to 1 watt for intermodulation testing of components ... broadband isolation ... flat gain over a wide bandwidth ... or much higher output from your frequency synthesizer or signal/sweep generator ... MiniCircuits' ZHL power amplifiers will meet your needs, at surprisingly low prices. Five models are available, offering a selection of bandwidth and gain.

Using an ultra-linear Class A design, the ZHL is unconditionally stable and can be connected to any load impedance without amplifier damage or oscillation. The ZHL is housed in a rugged ⅛ inch thick aluminum case, with a self-contained hefty heat sink. BNC connectors are supplied; however, SMA, TNC and Type N connectors are also available. Of course, our one-year guarantee applies to each amplifier.

So from the table below, select the ZHL model for your particular application now ... we'll ship within one week!

ZHL-1A

MODEL NO.	FREQ. MHz	GAIN dB	GAIN FLATNESS dB	MAX. POWER OUTPUT dBm 1-dB COMPRESSION	NOISE FIGURE dB	INTERCEPT POINT 3rd ORDER dBm	DC POWER		PRICE	
							VOLTAGE	CURRENT	$ EA.	QTY.
ZHL-32A	0.05-130	25 Min.	±1.0 Max.	+29 Min.	10 Typ.	+38 Typ.	+24V	0.6A	199.00	(1-9)
ZHL-3A	0.4-150	24 Min.	±1.0 Max.	+29.5 Min.	11 Typ.	+38 Typ.	+24V	0.6A	199.00	(1-9)
ZHL-1A	2-500	16 Min.	±1.0 Max.	+28 Min.	11 Typ.	+38 Typ.	+24V	0.6A	199.00	(1-9)
ZHL-2	10-1000	15 Min.	± 1.0Max.	+29 Min.	18 Typ.	+38 Typ.	+24V	0.6A	349.00	(1-9)
ZHL-2-8	10-1000	27 Min.	±1.0 Max.	+29 Min.	10 Typ.	+38 Typ.	+24V	0.65A	449.00	(1-9)
ZHL-2-12	10-1200	24 Min.	±1.0 Max.	+29 Min.*	10 Typ.	+38 Typ.	+24V	0.75A	524.00	(1-9)

Total safe input power +20 dBm, operating temperature 0° C to +60° C, storage temperature −55° C to +100° C, 50 ohm impedance, input and output VSWR 2:1 max.

*+28.5 dBm from 1000-1200 MHz

For detailed specs and curves, refer to 1980/81 MicroWaves Product Data Directory, Gold Book, or EEM

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