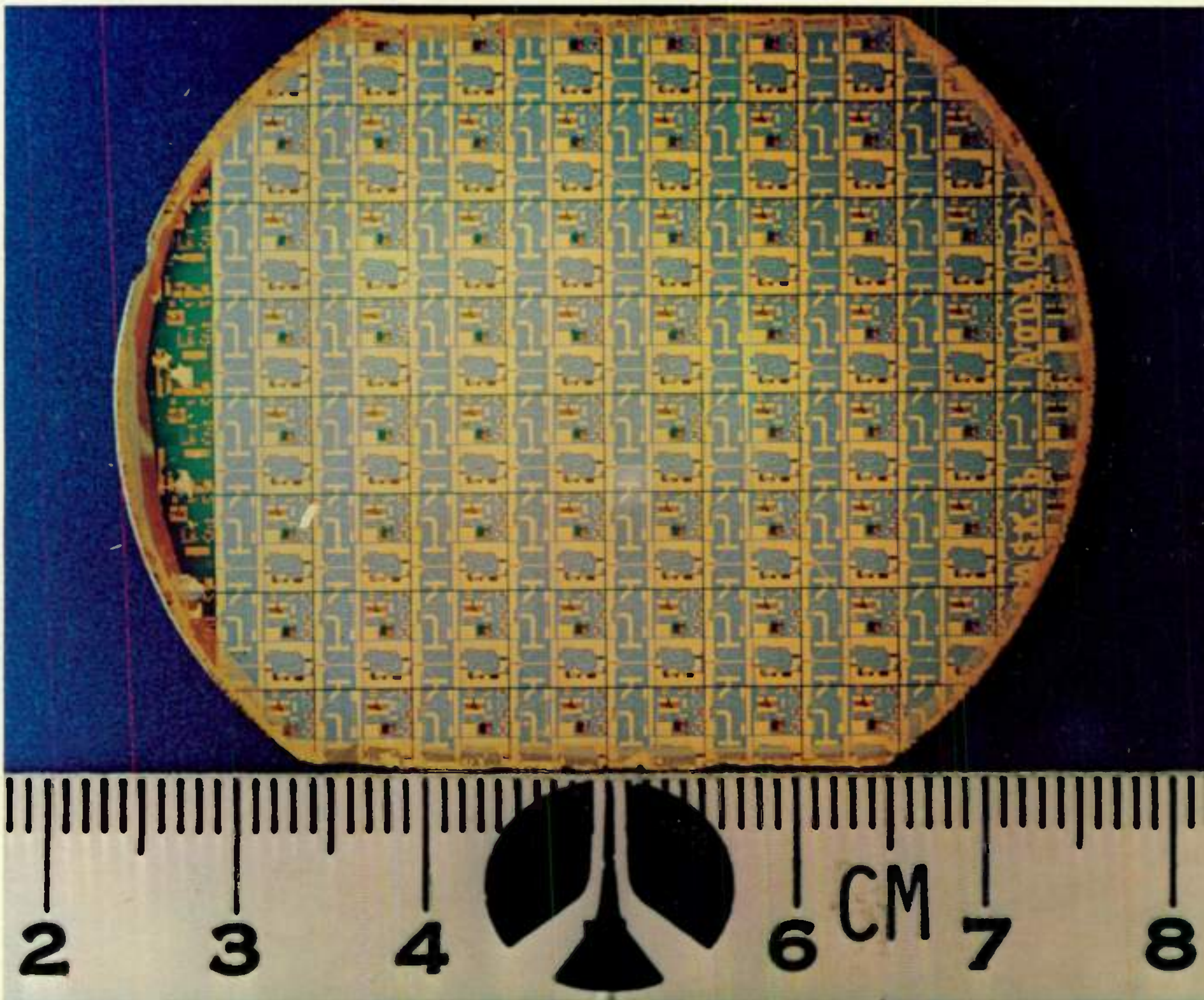
microwave
JOURNAL

INTERNATIONAL EDITION □ VOL. 24, NO. 3 □ MARCH 1981



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- Monolithic Microwave Receiver
- High Performance Radar Transistor
- 94 GHz Image Guide Circuits

horizon house

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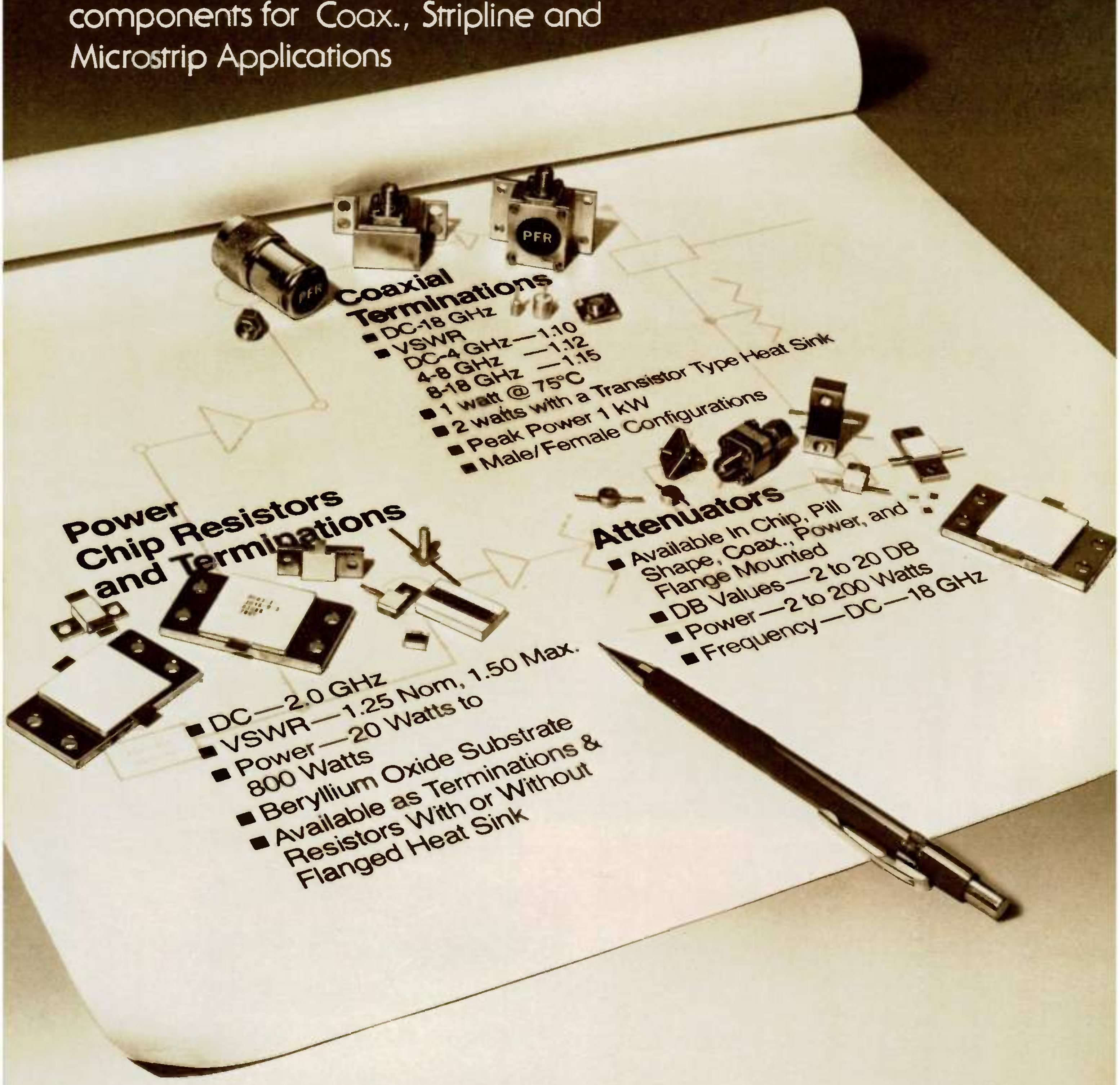
KDI PYROFILM has more to offer in microwave resistive components for Coax., Stripline and Microstrip Applications



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P80-4

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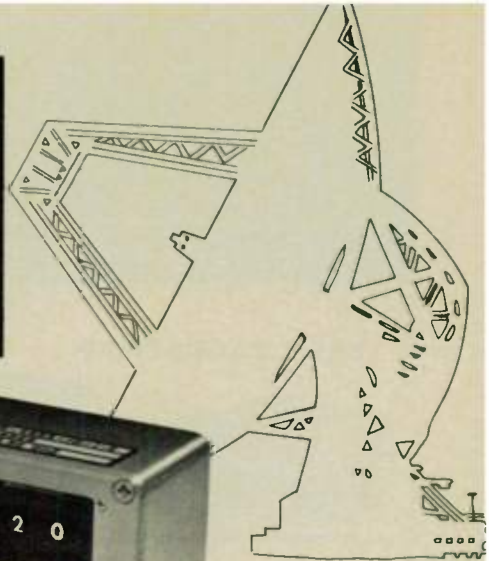

Featuring a thumbwheel frequency selection, low phase noise, 10 MHz frequency steps, 5 MHz input reference and options for 10 MHz and 100 MHz input reference.

GENERAL SPECIFICATIONS

Reference Input - Frequency:	5 MHz standard, 10 MHz and 100 MHz options
Power:	0±3 dBm
Frequency Step Size:	10 MHz
Frequency Stability:	Same as reference input
Spurious Outputs - Inband:	-70 dBc
Outband:	-55 dBc
Power Output Variation - Frequency:	±1.5 dB
Temperature:	±1.5 dB
DC Power:	+20V at 700 mA
Operating Temperature:	0 to 50°C
Weight:	23 oz.
Connectors - RF:	SMA female
DC:	Solder filter

Model Number	Output Frequency (GHz)	Power Output (Min.) (dBm)
PLS-3742-10	3.7-4.2	+13
PLS-4449-10	4.4-4.9	+13
PLS-4853-10	4.8-5.32	+13
PLS-6570-10	6.55-7.05	+10
PLS-7075-10	7.0-7.55	+10
PLS-7277-10	7.2-7.7	+10

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Over 96 models covering 2 kHz to 4.2 GHz

FROM **$9.95** (6-49)

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For complete specifications and performance curves, refer to
1980-81 MicroWaves Product Data Directory   1980-81 EEM   1980-81 Gold Book, Vol. 2

Model	Freq. range (MHz)	Min. isol-dB (Mid-band)	Max. insert. loss-dB (Mid-band)	See notes below	Price (Qty.)
2-WAY 0°					
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°					
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°					
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

Model	Freq. range (MHz)	Min. isol-dB (Mid-band)	Max. insert. loss-dB (Mid-band)	See notes below	Price (Qty.)
3-WAY 0°					
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°					
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°					
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°					
PSC-8-1	0.5-175	20	1.1		$68.95 (1-5)
PSC-8-1-75	0.5-175	20	0.8	1	$69.95 (1-5)
PSC-8A-4	5-500	18	1.8		$89.95 (1-5)
PSC-8-6	0.01-10	23	1.1		$79.95 (1-5)
ZFSC-8-1	0.5-175	20	1.1	10	$89.95 (1-4)
ZFSC-8-1-75	0.5-175	20	1.0	1,10	$90.95 (1-4)
ZFSC-8375	50-90	25	1.3	1,10	$119.95 (1-4)
ZFSC-8-4	0.5-700	20	1.5	10	$129.95 (1-4)
ZFSC-8-6	0.01-10	23	1.1	10	$109.95 (1-4)
16-WAY 0°					
ZFSC-16-1	0.5-125	18	1.6	11	$174.95 (1-4)
24-WAY 0°					
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
10. BNC connectors standard. TNC available at $10 additional cost. SMA at $25 additional cost
11. BNC connectors standard. TNC available at $20 additional cost. SMA available at $45 additional cost
12. BNC connectors standard. TNC available at $35 additional cost. SMA available at $65 additional cost
13. BNC connectors (not available for ZAPDQ-4). TNC available. (SMA (3MM) and Type N on request. Add $5 per unit.)
    Please specify connectors

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MICROWAVE JOURNAL is published monthly by Horizon House, 610 Washington Street, Dedham, MA 02026. Controlled circulation postage paid at Burlington, VT. Postmaster: Please send Form 3579 to MICROWAVE JOURNAL, 610 Washington Street, Dedham, MA 02026 microwave JOURNAL

VOLUME 24, NUMBER 3
USPS 396-250
MARCH 1981

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ON THE COVER: MMIC circuits fabricated on 2" diameter GaAs wafer. Circuit reticle includes K_u-band preamplifier, FET mixer, wideband amplifier and process monitoring pattern. Photo courtesy of Rockwell International.

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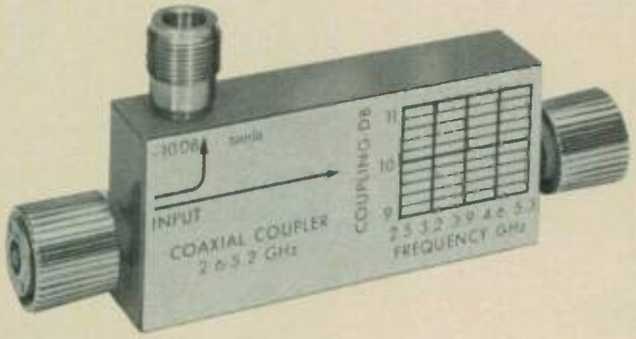
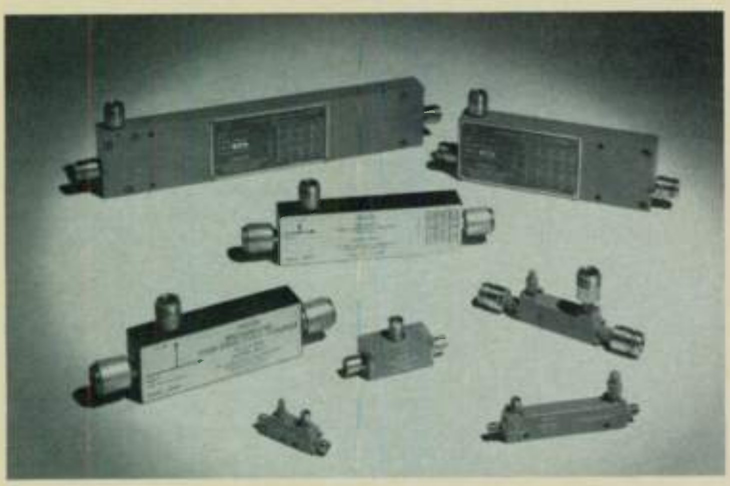
All of today's best couplers have one thing in common. . . they all have the same name. Narda.



No-nonsense specs..reliability..repeatability . . . at no extra cost



There are over 150 different catalog items in the Narda line of directional couplers . . . from stock. They operate over multi-octave and octave as well as over extremely broadband frequency ranges from 50 MHz to 26.5 GHz. We offer the smallest couplers and the broadest band widths available. (We also custom make specials).

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Coming Events

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

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," includes such topics as CAD and measurement techniques, microwave and mm-wave solid-state devices, IC's, etc. Contact: Al Clavin, Hughes Aircraft Company, Bldg. 268/A-55, Canoga Park, CA 91304. Tel: (213) 702-1778.

27TH ANNUAL TRI-SERVICE RADAR SYMPOSIUM JUNE 23-25, 1981

Sponsors: US Navy and DoD agencies. Place: The Naval Postgraduate School Monterey, CA. Theme: Development and operation of military radar systems. DoD security clearance through SECRET and a need-to-know endorsement will be required for attendance at the Symposium. Contact: Radar Symposium Coordinator, Environmental Research Institute of Michigan, P.O. Box 8616, Ann Arbor, MI 48107.
Tel: (313) 994-1200, ext. 324.

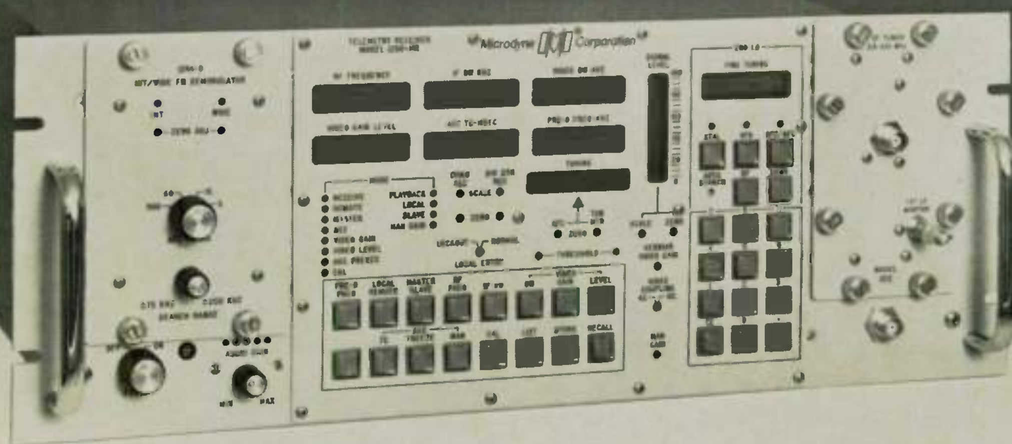
20TH GENERAL ASSEMBLY OF THE INT'L UNION OF RADIO SCIENCE AUG. 10-19, 1981

Sponsors: Int'l Union of Radio Science (URSI) US Nat'l Committee (USNC). Place: Hyatt Regency Hotel, Washington, DC. Symposia Sessions: Millimeter and Submillimeter Waves, Remote Sensing, Mathematical Models of Radio Propagation, Interaction of Electromagnetic Waves with Biological Systems, plus meetings of General Assembly Commissions. Contact: R. Y. Dow, Exec. Sec. of the 1981 URSI General Assembly Organizing Comm., National Academy of Sciences, 2101 Constitution Ave., N.W., Washington, DC 20418.
Tel: (202) 389-6478.

6TH INT'L CONF. ON INFRARED & MM WAVES DEC. 7-12, 1981

Call for Papers. Sponsors: IEEE MTT-S and IEEE Quantum Electronics and Applications Society. Place: Carillon Hotel, Miami Beach, FL. Topics: Millimeter sources, devices or systems, mm and sub-mm propagation, atmospheric physics and propagation, plasma interactions and diagnostics, guided propagation and devices, etc. Submit 35- or 40-word abstract by June 30, 1981 to Mr. K. J. Button, Program Chairman, MIT Francis Bitter Nat'l Magnet Lab, 170 Albany St., Cambridge, MA 02139.
Tel: (617) 253-5561.

the telemetry receiver your computer really understands



Microdyne's New 1200-MR

Both remotely and manually controllable, the 1200-MR double conversion receiver is the first to anticipate and meet the many telemetry requirements of the 1980's. Consider just some of the features:

- IEEE-488 or optional RS-232 interface
- Keyboard entry for manual control
- Discrete tuning ranges, voltage controlled from 215 MHz to 4.2 GHz
- AM, FM, PM and Bi-Phase Demodulation Modes
- DC to 5 MHz video Baseband response
- Synthesized LO's, phase locked to a common 5 MHz reference, with 1×10^{-7} stability
- Up to seven internal 2nd IF filters, switch selectable with BW's up to 10 MHz
- Ruggedized design allows installation on aircraft, land vehicles, ships and submarines

For free technical brochures describing the 1200-MR receiver, and/or the 3200-PC and 3200-PC(10) Diversity Combiners call or write: Microdyne Corporation, 627 Lofstrand Lane, Rockville, Maryland 20850. Telephone (301) 762-8500.

Microdyne Corporation®

Now - Extremely fast fade rate combiners for dramatic BER and SNR improvements

The new 3200-PC and 3200-PC(10) are the first and only commercial Pre/Post-D Diversity Combiners offering the following unique features:

Fast Fade Rates — Optimal Ratio Combining maintained with two randomly phased RF signals that vary up to 20 dB in relative amplitude at fade rates up to 20,000 c.p.s.!

AM/AGC Combining — AM Function insures Optimal Ratio Combining when fade rates exceed limited receiver AGC response times.

BER and SNR Improvements — Dramatic BER reductions and SNR improvements under severe multipath, flame attenuation and pseudo-random noise conditions.

Receivers Required — Two 1200-MR receivers are used with the 3200-PC Combiner. Two 1100-AR or similar type receivers, with 10 MHz and appropriate logic outputs are used with the 3200-PC(10) Combiner.

Replaces Other Combiners — The 3200-PC(10) replaces Microdyne 3300-C or similar type 10 MHz input combiners with BER and SNR limitations.

Ruggedized Design — Both combiners are ideally suited for ground stations and installation on aircraft, mobile vehicles, surface ships and submarines.

HP: EXPERIENCE IN MICROWAVE TECHNOLOGY

A CHOICE SELECTION:

High Performance at a low price with HP's new 8559A

Look at the performance you get for only $12,775: Frequency coverage from 10 MHz to 21 GHz; flat frequency response, ± 3 dB to 21 GHz; −111 to +30 dBm measurement range; distortion products are >70 dB down; 1 kHz to 3 MHz resolution bandwidths; digital frequency readout with typically better than 0.3% accuracy.

All this in a rugged, lightweight plug-in for the HP 182T display. Easy to use, too. You simply tune to the signal, set frequency span (resolution and sweep time are automatically optimized), and then set the amplitude reference level. It's HP's new budget-minded spectrum analyzer. Reader Service No. 64

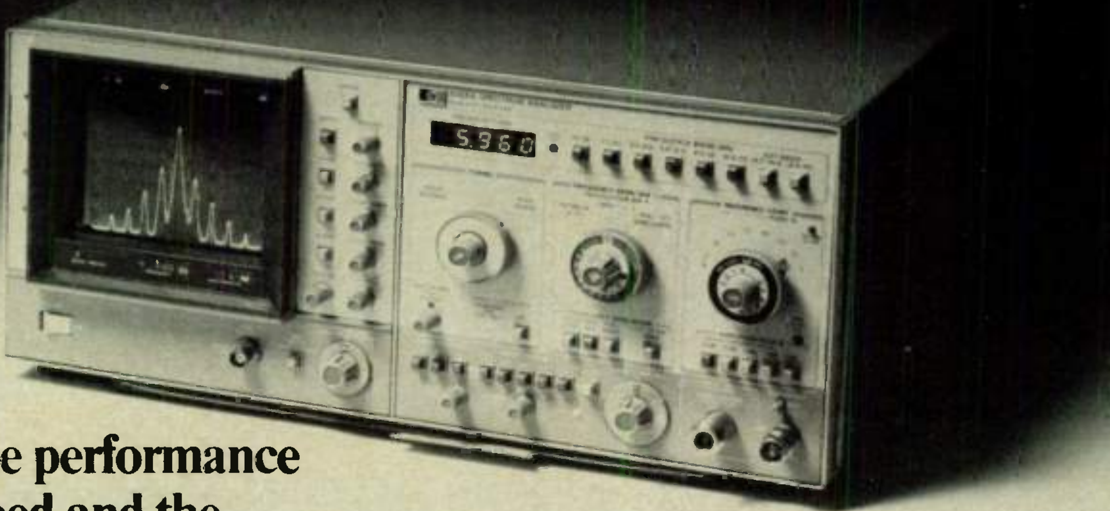
Modularity means value with the HP 8555A.

Buy only what you need for your current microwave requirements; you can add different RF tuning plug-ins or companion instruments as your needs expand. The HP 8555A RF Tuning Unit covers 10 MHz to 18 GHz (extendable to 40 GHz), has a ± 2 dB frequency response, and narrow resolution of 100 Hz. These features combine to provide you with an accurate and sensitive microwave signal analyzer. The 8555A with the 8552B RF Section and installed in the 141T Variable Persistence Display Section costs $17,950.

When your applications require input overload protection, elimination of multiple responses, or 100 dB harmonic distortion measurement range, add the HP 8445B Automatic Preselector. For wide dynamic range swept response measurements to 1.5 GHz, just add the 8444A Tracking Generator. For versatile coverage at audio, VHF, UHF and microwave frequencies, this modular family offers value for present and future needs. Reader Service No. 65

53104

HP's family of microwave spectrum analyzers.



Get the performance you need and the convenience you want with HP's 8565A.

Covering 10 MHz to 22 GHz and extendable to 40 GHz, this microwave spectrum analyzer gives you the combination of wide dynamic range, fully-calibrated measurement capability plus ease of operation. Frequency response is within ± 1.2 dB to 1.8 GHz and ± 3dB at 18 GHz. Resolution bandwidths from 1 kHz to 3 MHz are standard, with 100 Hz resolution available as an option. From 1.7 to 22 GHz, there's a built-in preselector which permits measurement of distortion products as small as 100 dB down. The 8565A is easy to operate too. Just set three controls: tuning frequency, frequency span and amplitude reference level. Resolution, video filtering and sweep times are automatically set. Bright LED's in the CRT bezel give you all pertinent operating conditions in easy view. The price for all this performance and convenience is $22,200; add $800 for the 100 Hz resolution option. Reader Service No. 66

For more information on these outstanding values in microwave spectrum analysis, call your local HP sales office or write to 1507 Page Mill Rd., Palo Alto, CA 94304.

DESIGNED FOR HP-IB SYSTEMS

For today's and tomorrow's most demanding needs, choose the HP 8566A.

The 8566A defines the state-of-the-art in microwave spectrum analyzer performance: 100 Hz to 22 GHz coverage, −134 to +30 dBm range, 10 Hz resolution bandwidth throughout (with correspondingly low L.O. phase noise), and counter-like frequency accuracy. The level of performance, flexibility and convenience of the 8566A brings unparalleled capability to microwave spectrum analysis. Perhaps even more significant, this performance is essential to realize the benefits of *automatic* spectrum analysis which the 8566A can deliver when under computer control via the HP Interface Bus. Complicated, time-consuming measurement routines, including ones that previously were impractical, can now be accurately executed with minimum operator involvement when the advanced microwave and digital technologies contained in the 8566A are applied. Price of the 8566A is $54,500; a system comprised of the 8566A, 9825T Computer, printer and software package costs $71,635. Reader Service No. 67

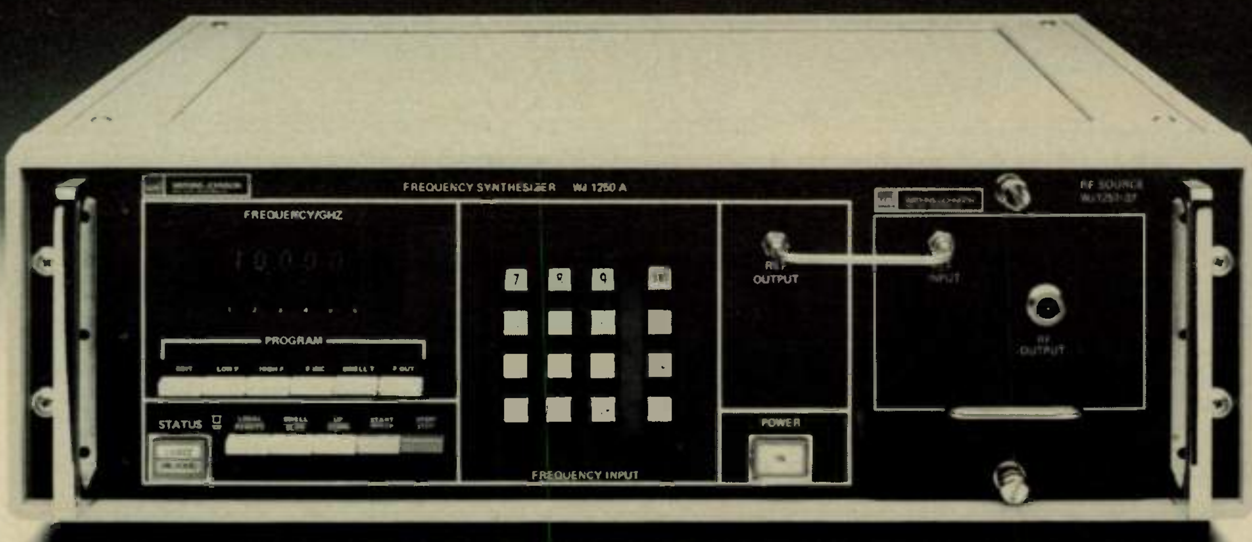
Domestic U.S. prices only.

HEWLETT PACKARD

New Low Frequency Performance

~~0.1~~ 0.01 to 18 GHz Coverage With Watkins-Johnson's WJ-1292 Microwave Synthesizer

The Heart of Your Microwave System



Standard Features:
- Single unit covers 0.01 to 18 GHz
- Digital sweep
- 100 kHz resolution
- Standard computer interface
- 1×10^{-9}/day stability

Typical Options:
- Extension to 40 GHz
- IEEE 488 bus compatibility
- 10 Hz resolution
- Leveling

Custom system designs have been supplied to meet many critical needs. For detailed specifications on Watkins-Johnson synthesizers and system capabilities, contact the W-J Field Sales Office in your area or phone SSE Division, Applications Engineering, in Palo Alto, California at (415) 493-4141, ext. 2218.

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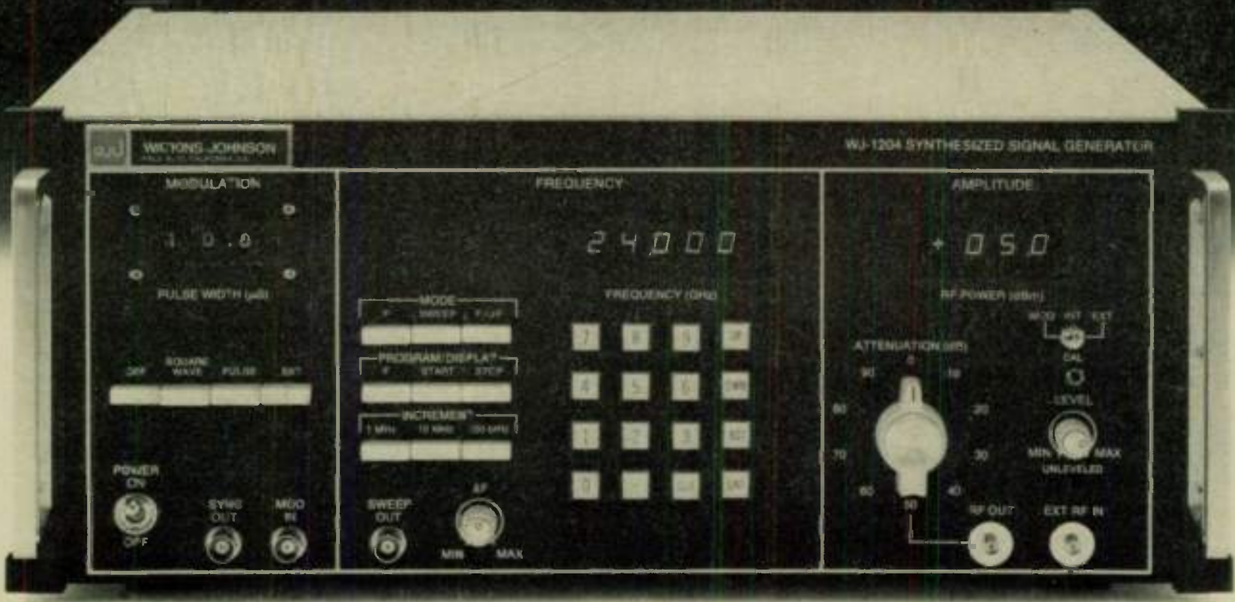

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Standard Features:
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Publisher's Note: This month's Sum Up is provided by our Associate Editor, V. G. Gelnovatch. Mr. Gelnovatch is currently director of the Microwave and Signal Processing Devices Division of the Electronics Technology and Devices Laboratory, ERADCOM. He has assembled the contributed articles on solid state topics which are featured in this issue.

GaAs – A TECHNOLOGICAL CATCH-22

The current "darling" of the microwave community is the monolithic microwave IC MMIC technology, building on a firm foundation established by discrete GaAs devices in the 1970s. This keynote report takes a sobering look at some of the conflicting boundary conditions that the industry faces in the inevitable technological shake out before GaAs becomes a household word and suggests some strategy which could ease the pain.

Sum Up

MMIC LINEAR AMPLIFIERS – DESIGN AND FABRICATION TECHNIQUES

Linear MMIC circuit technology has progressed to the point where complete microwave receivers can be fabricated on a single GaAs chip. The front cover demonstrates just such accomplishment. This paper will discuss such issues as MMIC design principles, material technology, circuit fabrication, some pertinent examples of the art and concludes by predicting some future trends.

MONOLITHIC MICROWAVE GaAs POWER FET AMPLIFIERS

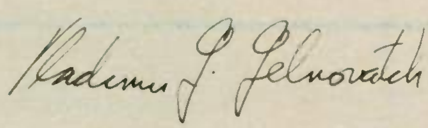
Recent advances in the development of the monolithic power GaAs FET amplifiers are presented. Single ended, push-pull and paraphase amplifiers are compared. Fabrication and characterization of passive matching circuit components such as inductors and capacitors are discussed. Future performance improvements and potential system applications are projected.

A HIGH PERFORMANCE S-BAND RADAR TRANSISTOR

First attempts at L-band phased array solid state modules generated 10 W from four silicon bipolar power transistors. This paper describes an S-band high performance pulsed power transistor developed for phased array and ECM applicators. It utilizes an implanted base, arsenic emitter, P moats, two layer refractory gold metallization and advanced matching circuitry and has yielded over 90 W at 3.1 GHz with over 40% efficiency.

MILLIMETER-WAVE InP GUNN DEVICES: STATUS & TRENDS

The Indium Phosphide (InP) Gunn device offers superior performance as a wideband low noise amplifier, low noise local oscillator, self-mixing oscillator, and low to medium power transmitter source in the mm wave region. Its development and advances are primarily driven by military systems requirements and developments spanning missile and projectile guidance, high resolution radars, intercept secure communications and EW/ECM functions.



Workshops & Courses

RADAR TECHNOLOGY SEMINAR

Sponsor: IEEE/AESS
Site: Hilton Hotel, Huntsville, AL
Date: April 20, 1981
Fee: $125, IEEE member; $140, nonmember
Lecturer: Dr. Eli Brookner, Consulting Scientist
Subjects: Radar systems, signal processing, solid-state tubes, etc.
Contact: Dr. Eli Brookner, Raytheon Company Wayland, MA 01778 Tel: 358-2721, ext. 2366

MICROWAVES FOR MANAGERS

Sponsor: Microwave Training Institute
Date: April 22-24, 1981
Location: Microwave Training Institute, Palo Alto, CA
Fee: $495
Seminar Leader: Al Scott, Mgr. of Adv. Development, Varian MTD
Topics: Survey of microwave systems and devices, financial aspects and future trends.
Contact: Microwave Training Institute, Box 11534, Palo Alto, CA 94306, (415) 969-7363

26TH SPUTTER AND PLASMA ETCHING SCHOOL

Sponsor: Materials Research Corp. (MRC)
Site: Holiday Inn, Palo Alto, CA
Date: April 29 - May 1, 1981
Fee: $395, full program; $125 - basics, day only
Lecturer: Dr. Eric Kay, IBM San Diego Labs
Contact: Rosemay McPhillips, MRC Orangeburg, NY 10962 Tel: (914) 358-2022

RF TECHNIQUES AUTOMATIC GROUP WORKSHOP

Call for Workshop Papers

Sponsors: Automatic RF Techniques Group, MTT-11.
Site: Bonaventure Hotel, Los Angeles, CA
Date: June 18-19, 1981
Topic: Panel discussion on mm-wave network analyzers, both automatic and manual versions. Submit 500 to 1000-word summary with illustrations (2 copies) by April 13, 1981.
Send papers to: R. H. Swartley, General Electric Space Div., Rm U2312, P.O. Box 8555, Philadelphia, PA 19101. Tel: (215) 962-3904.

GaAs Technology in the 80s

WILLIAM R. WISSEMAN
Central Research Laboratories
Texas Instruments Inc.
Dallas, TX

William R. Wisseman *is manager of the Advanced Microwave Components in the Central Research Laboratories at Texas Instruments Incorporated. He is responsible for the development of GaAs power and low noise FET's, hybrid and monolithic microwave integrated circuits, and high speed digital circuits.*

Dr. Wisseman received the Bachelor of Nuclear Engineering degree from North Carolina State University in 1954 and the Ph.D. degree in Physics from Duke University in 1959. He joined the Central Research Laboratories at Texas Instruments in 1960. He is Chairman of the Microwave Devices Technical Committee of the IEEE Electron Devices Society.

GaAs microwave and high speed digital technologies have come of age. The "future" is finally here for GaAs. Why is this happening now? People who have worked in this field for a number of years have seen three primary areas of device activity: Gunn diodes, IMPATT diodes (flat profile and Read type), and FET's. While there is a continuing interest in both Gunn and IMPATT diodes, the number of companies involved in their development is relatively small. These devices clearly are important for some applications, but they have not had a major impact on microwave systems.

The GaAs FET is a far more versatile device than either the Gunn or the IMPATT diode since it is superior for use in both medium power and low noise microwave circuits at frequencies up to 20 GHz and possibly as high as 30 GHz. In addition, relatively complex high speed digital circuits operating at clock rates of up to 4 GHz have been demonstrated. Even more important, in my opinion, is the recent development of monolithic microwave integrated circuits (MMIC's). MMIC's can easily be fabricated on GaAs since the semi-insulating substrate used for fabrication of planar FET's (on suitably doped active regions) can also serve as the dielectric for microstrip or coplanar transmission lines.

The fact that the GaAs FET is a versatile device with many applications is, of course, central to the current GaAs revolution and has attracted many companies previously not involved in GaAs technology development. Further, the FET has a relatively simple structure from a materials point of view. Initially, FET's were fabricated in active layers grown on semi-insultating substrates by vapor or liquid phase epitaxy. It was found, however, that direct ion implantation of a suitable species into the substrate, followed by a high temperature anneal, provides high quality active layers with superior intraslice uniformity and slice-to-slice reproducability. Several companies are now developing capabilities to prepare round substrates, up to 3 inches in diameter, of the quality required for ion implantation. The availability of such substrates, large by GaAs standards, allows application of techniques used for Si processing with a corresponding potential decrease in cost of both discrete devices and IC's.

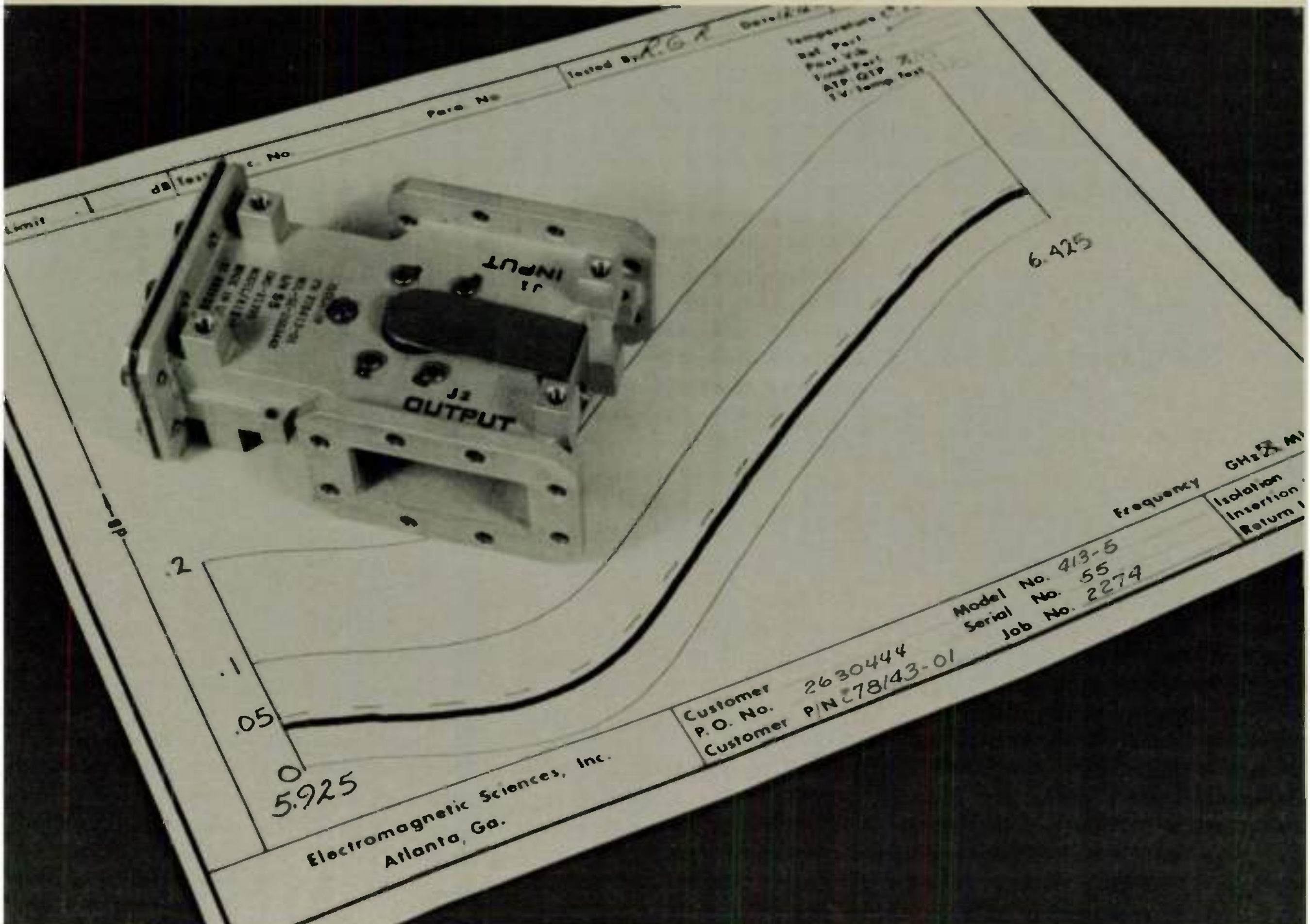
Where will the major volume impact of GaAs technology be? I don't believe it will be in the digital IC area. Application of GaAs IC's for high speed data processing will be important for special cases, primarily military, where relatively low circuit densities are required. GaAs is competing head-to-head with Si technology for digital applications, however. Experts in the field disagree as to what speed advantage GaAs offers, and some even question that it offers any advantage. Certainly, advanced Si processing technology may overcome, to a large measure, the GaAs mobility advantage. The other advantage GaAs has is the semi-insulating substrate, but this becomes less significant at LSI and VLSI circuit densitites. Consequently, I believe GaAs technology will play an important, but limited role for digital IC's.

The situation is completely different for microwave circuits. Except for Si IMPATT's at millimeter-wave frequencies above a few GHz. In fact, GaAs technology is making inroads down to frequencies of 1 GHz or even lower for some applications. Discrete GaAs devices, both low noise and power, have demonstrated the superiority of GaAs technology. These devices are beginning to have substantial impact on the microwave industry.

I believe that the real future for GaAs technology - the area that has the greatest growth potential - is in monolithic microwave integrated circuits. A few years ago the practicality of GaAs MMIC's was in question due to the cost of GaAs substrates. Was it practical to put passive components and transmission lines on GaAs when they might consume most of the area? This question was recently raised again in a recent article (*Microwaves,* December 1980, pp. 54-61), where it was concluded that some circuits, particularly power amplifiers of the type described in the paper by H.Q. Tserng and V. Sokolov in this issue, are not practical in MMIC form because of the high GaAs substrate cost.

(continued on page 18)

low loss lightweight Isolators



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I disagree with this conclusion. With the availability of large, round GaAs wafers and the use of ion implantation to fabricate active layers, the cost of processing GaAs wafers can be reduced substantially along a learning curve of the type so well established in Si processing. This presupposes a volume requirement, of course. There is already evidence the volume requirement for discrete FET's will be sufficient to substantially reduce GaAs wafer processing cost. This cost reduction will impact the cost of MMIC's, for which FET's are the primary yield-determining components.

The question then becomes, "What is the trade-off between MMIC processing cost and the cost of equivalent hybrid circuits using discrete devices?" Putting passive components such as inductors and capacitors on GaAs will be practical in production if material and processing uniformity is sufficient to eliminate much of the assembly and engineering expense incurred for hybrid IC's. The reduction in the number of interconnections would also give improved reliability. At this time it is not clear at what point it would be cost-effective to move from the use of one large MMIC chip to several MMIC chips or discrete FET's and other components. Determining this point is one of the goals of major R&D efforts now under way at several companies. There are potentially large volume requirements for GaAs microwave technology (e.g., phased array radars and expendable jammers) that will become practical only if GaAs MMIC's are able to bring the cost now projected for hybrid circuits down to an affordable level.

In any case, it is clear that GaAs MMIC technology is going to have a major impact on the microwave industry. GaAs MMIC's will become sufficiently important during the 80s that companies will need to have this capability to be cost-competitive as suppliers of microwave components. At the present time, most of the development of GaAs technology in the United States, particularly MMIC and digital IC's, is carried out by large companies that have major capital commitments to equipment-intensive semiconductor processing and substantial GaAs R&D efforts. On the other hand, most microwave circuits are now supplied by relatively small companies using discrete devices in hybrid configurations. During the 80s the nature of our industry will change: either small companies will establish MMIC capability, or the large systems companies will rely more and more heavily on their in-house capability to support microwave circuit requirements.

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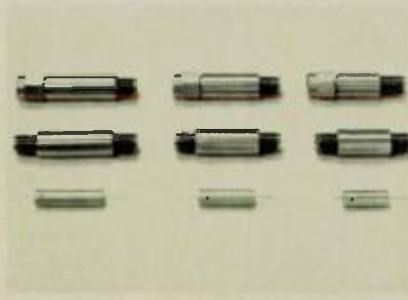

STANDARD DETECTORS

Omniyig Model #	Freq. Range (GHz)	k Factor	T_{ss} (dBm)
	Tunnel		
DT0D1P	0.1- 0.5	800	−50
DT2C1P	1.0- 2.0	800	−50
DT9A1P	2.0-18.0	450	−48
	Schottky*		
DS1C1N	0.5- 1.0	2000	−54
DS6A1N	8.0-16.0	1500	−52
DS9A1N	2.0-18.0	1000	−51

*Bias = 100 - 200 μamp

STANDARD LIMITERS

Omniyig Model #	Freq. Range (GHz)	Ins. Loss (dB)	Lkg. Pwr. (dBm)**
	Pin		
PL0E1	0.1-0.5	0.5	+20
PL2D1	1.0-2.0	0.6	+20
PL4C1	4.0-8.0	1.2	+18
	Schottky Turn-on		
SL0E1	0.1-0.5	0.5	+15
SL1E1	0.5-1.0	0.7	+15
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OFC-290	3.7-4.2	0.5	40
OFI-190	2.0-4.0	0.75	60
OFI-200	4.0-8.0	0.75	60
OFI-210	8.0-12.0	0.75	60
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OML-104	2.09-2.15	2.5	30
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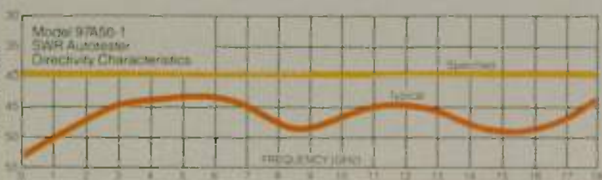

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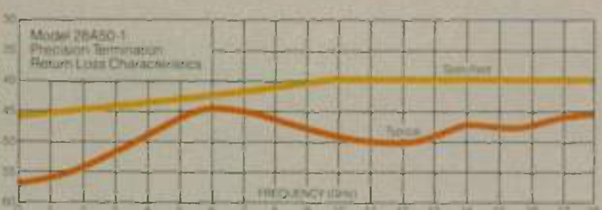

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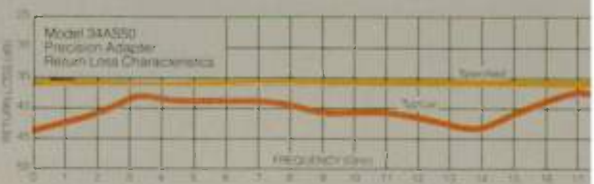

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GaAs – A Technological Catch-22

DR. JOHN T. MENDEL
Hughes Aircraft Co.
Industrial Electronics Group
Torrance, CA

Everywhere within the technical community we hear the familiar refrain "as soon as the market develops the price of GaAs devices and monolithic circuitry will drop dramatically." From the marketplace we hear, "as soon as the price becomes competitive the demand will grow dramatically." Although these two statements are by no means incompatible or mutually exclusive, they do pose a fundamental and formidable dilemma for the GaAs industry. This dilemma will probably have more influence in shaping the future course of this fledgling industry than all of the scientific endeavors currently in progress. In the evolutionary history of all technologies, economics has traditionally played the dominant role and will continue to do so in any free economy. Only those technologies survive and prosper which inherently possess a "compelling" economic justification. In the following discussion the word "compelling" is the key to understanding and accurately predicting the future role of GaAs in the cosmic scheme of the universe.

It is relatively easy to compile an impressive list of real applications of GaAs devices and circuitry. Furthermore, it can be shown that in each application GaAs has actually demonstrated superior performance even in laboratory models of early design. Certainly, with this kind of evidence, no one can doubt the economic potential of this highly versatile compound semiconductor. If we analyze each one of these applications from a total market viewpoint, we can conclude that the dollar potential is quite substantial. However, this is specious logic which leads to completely erroneous conclusions.

To better understand the economic forces at play, it is instructive to briefly review the silicon industry which is well documented with volumes of factual data. First of all, consider the staggering size of this industry — in 1980 sales of $13 billion for just the active devices — not the vast array of computers and black boxes that resulted from vertical integration. Discretes alone account for $3 billion of the total, the remainder being IC's. The slope of the sales curve for silicon suggests that within a short time this industry will rival the traditional giants of our national economy — steel, automobiles and oil. We are witnessing a true revolution in the electronics industry which is unlike anything else in our history both in scope and in its effect on our culture. The technical world will never be the same again. The most alarming aspect of this change is the incredibly short time span in which it occurred.

Why is the size of the silicon business fundamental to understanding GaAs? Simply because it puts into perspective the enormous forces at work. If we assume that 20% of the sales volume of silicon devices goes into continuing research and development (a reasonable assumption considering the pace of this industry) the current level of this type of activity is $2.6 billion annually. It is very difficult for most of us to fully comprehend the implications of this monumental R & D effort. We grew up in an era where the R & D effort associated with a new technology was an order of magnitude less. The numbers of scientists, engineers, technicians, and support personnel were minuscule by comparison to the present silicon levels. The equipment and facilities were likewise modest and almost insignificant alongside that which is becoming commonplace in the silicon arena.

If we assume that real progress is directly correlated to the magnitude of investment in terms of people and facility resources, then we must conclude that GaAs cannot challenge silicon in its traditional markets unless some profound changes occur. The present combined industry and government dollar support for GaAs R & D is approximately 2% of the dollar support for R & D in silicon. Although future events could alter the GaAs investments significantly, the level will remain a few percent, which means that the nature of this effort will always be quite modest. The GaAs effort must be focused

(continued on page 26)

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in those areas where it is truely unique, i.e., doesn't compete with silicon, but instead performs a very necessary function not addressed by silicon. These unique targets are not likely to be big markets like those enjoyed by a silicon microprocessor and consequently the investments in R & D will be correspondingly small. In short, there is nothing on the horizon which is going to alter the basic structure of semiconductor investment strategy and consequently we must forecast future developments with this assumption as a central tenet.

"UNIQUE" GaAs APPLICATIONS

Two very important and basic areas of application of GaAs technology are microwaves and optoelectronics (primarily fiber optics and integrated optics). In both of these applications the conflict with the silicon industry is relatively minor and should not present any serious obstacle to future growth. In fact, the microwave applications of GaAs supplied the original impetus to the pioneering effort of exploiting the advantages of low noise GaAs FET's. Bipolar silicon transistors are limited by the fundamental physics to the low end of the microwave spectrum leaving the higher frequencies completely open to any other semiconductor technology capable of doing the job. Fortuitously, the inherent properties of GaAs make it an ideal candidate for both transmitters and low noise receivers in the microwave region and the progress in this area has been very impressive indeed. Particularly remarkable are the noise figures of practical devices of 0.6 dB NF at 4 GHz and 1.3 dB at 12 GHz with excellent results up to 30 GHz. The very high electron mobility of GaAs is fundamental in achieving this outstanding performance which alone could justify all of the R & D expenditures for all work done on GaAs to date. Noise figure is so basic to any measure of merit of a microwave system that minimizing this parameter is worth the investment so long as good results are forthcoming.

At the other end of the microwave system, the power amplifier, GaAs FET's promise some very attractive advantages over existing electron beam amplifiers. Initially, the driving force was the hope for greatly improved life and reliability. As is well understood in the military, the major cost of ownership of a microwave system is the downtime caused by the output tube failures. Some of these are predictable and can be prevented with scheduled replacement but many failures are the result of marginal reliability which necessitates redundancy and other costly compromises. With the theoretical life and reliability projection for GaAs it was believed possible to effect almost an order of magnitude improvement — which in

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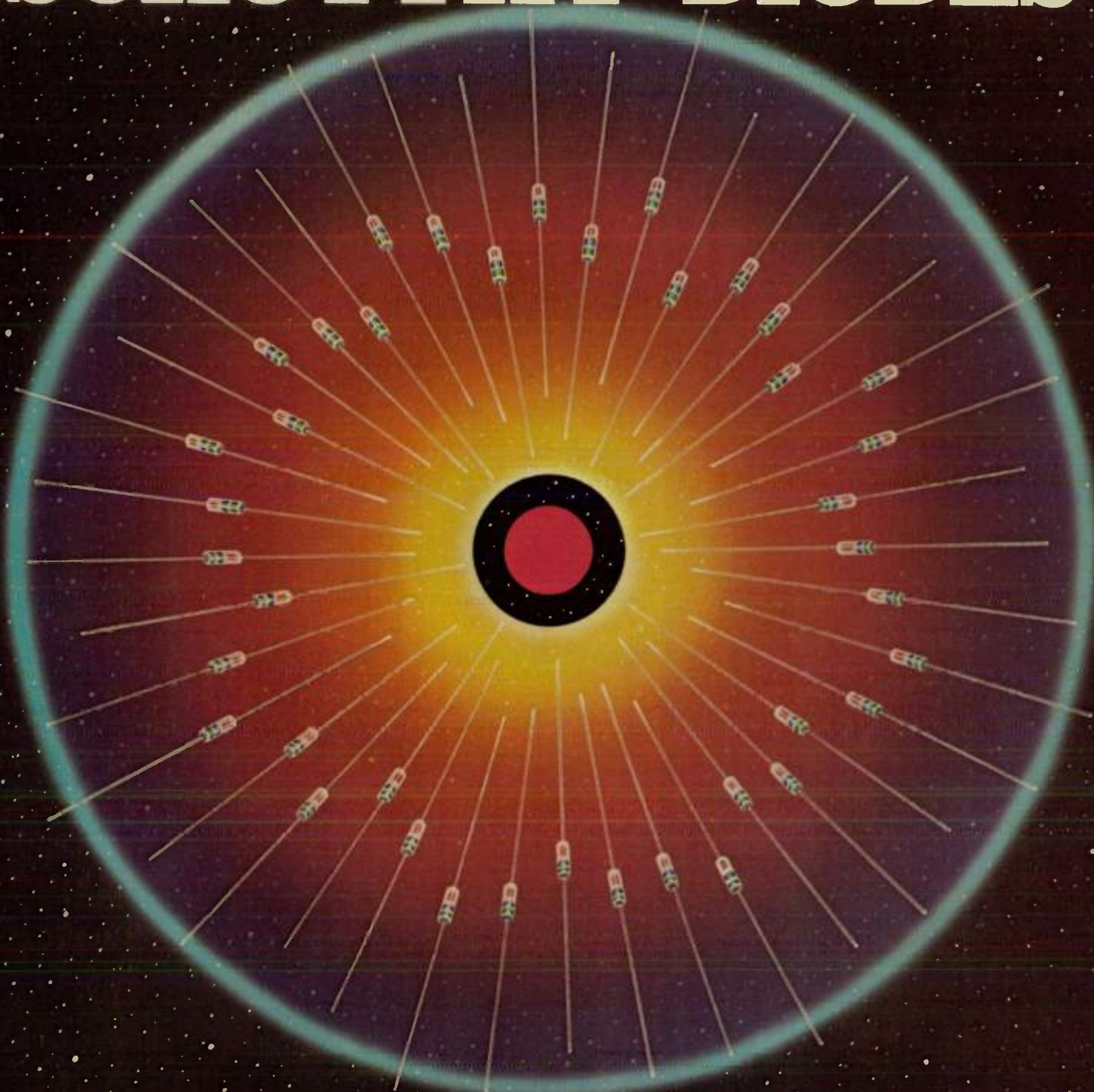
SCHOTTKY DIODES



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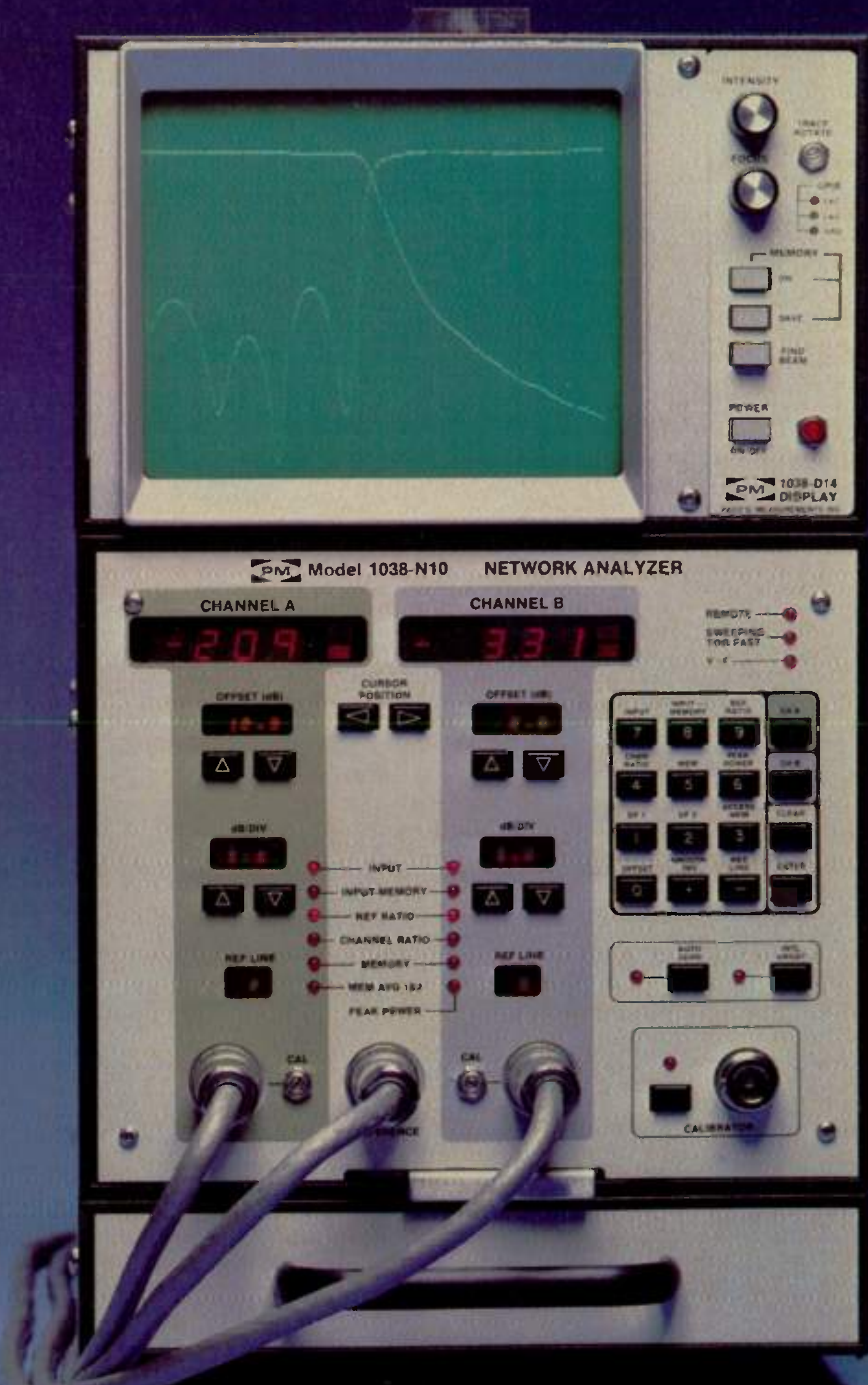

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CIRCLE 21 ON READER SERVICE CARD

from page 26)

urn would result in enormous dollar savings. These potential benefits have not been well documented with real case histories since the data base is now only embryonic. It remains to be seen exactly how this aspect will spur the investments necessary to displace tubes from their established markets.

Over and above the considerations of life and reliability, GaAs offers advantages of simplicity and small size. The simplicity issue is not confined to the active device itself but includes also the power supply and other circuitry necessary to operate the device. The high voltage power supply and the grid modulator associated with TWT's and klystrons involves a very complex and failure-prone array of highly stressed parts. The failure statistics are very unfavorable just because of the large parts count and the hostile environment of any high voltage circuit. In contrast to this unfavorable situation, the low voltage supplies associated with GaAs FET's should present very few problems. The small size of a GaAs FET amplifier offers the powerful advantage of implementing in a practical manner the active array concept — where each element of the antenna is fed by its own transmitter whose phase is precisely controlled. For aircraft and missiles, this technique could be the wave of the future, but not before a tough competition with existing electron tubes. On the basis of raw power and conversion efficiency, tubes are difficult to beat. An electron beam in a vacuum interacting with a high impedance copper circuit is a combination which inherently possesses high thermal capacity, excellent conversion efficiency, and relative freedom from anomalous effects. Some of the advantages of the tube approach become even more apparent at the higher frequencies where thermal problems severely limit the power from a solid-state amplifier. Much progress needs to be made with the programs now under way in GaAs before we see many real system examples. However, with the promise of new and innovative system concepts made possible by GaAs, the industry will vigorously pursue these objectives in the immediate future.

Formidable problems notwithstanding, GaAs does indeed offer some important rewards to the microwave community which apparently cannot be achieved by other means. Why then can't a substantial and healthy industry exist with these applications serving as a base? Simply because the entire microwave market is quite small and shows few indications that it will change. If GaAs were to successfully penetrate all of those microwave sockets where a clear need exists, the total annual device and monolithic circuit sales would still be quite modest, the order of several hundred million dollars (as a point of reference all klystron sales for 1980 were $95 million). Even though the microwave industry serves as the foundation of a substantial part of the electronics industry as a whole, it is by itself a small specialty busi-

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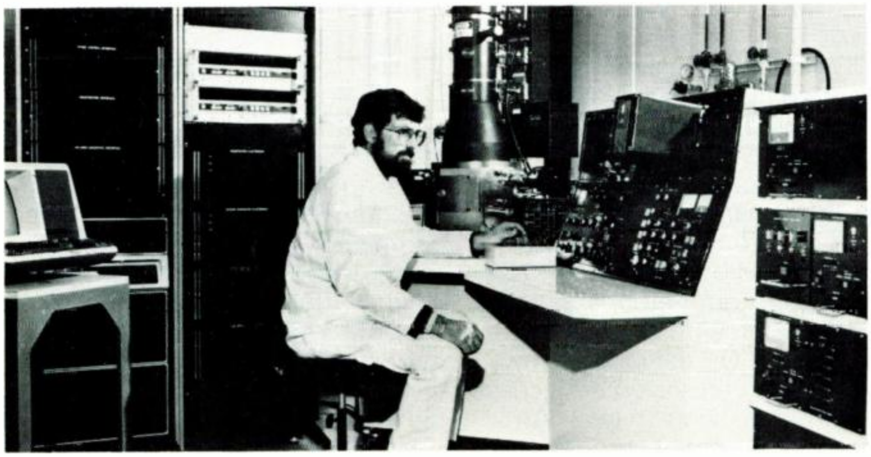

Fig. 2 Direct write E-beam lithography machine.

ness. Witness the great difficulty many aerospace companies are experiencing in their attempts to hire qualified microwave engineers. Very few major universities and colleges even offer a curriculum which emphasizes this discipline, primarily because of lack of student and faculty interest. Our educational institutions predict the present trend will continue and that industry itself must assume responsibility for training in this area. This state of affairs is neither alarming nor depressing but does reflect the realities of a situation which many forecasters choose to neglect.

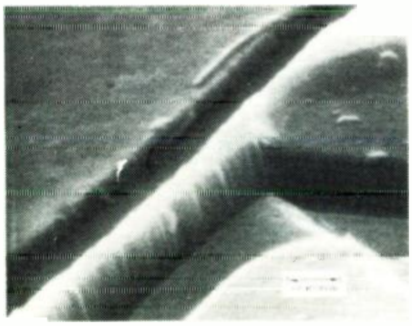

Fig. 1 A portion of the recessed gate structure of a 0.5 micron gate length low noise FET. This device is fabricated by direct write E-beam lithography.

CAPITAL – INTENSIVE GaAs PROCESSING

The silicon IC industry is just now beginning to experience the very high costs of the "next generation" of processing equipment. The impact of these costs has already had a profound effect on the nature of the industry in terms of mergers and acquisitions. To finance the implementation of fine line lithography, totally new dry processing techniques and E-Beam mask production have caused more than one company to seek a wealthy partner capable of supporting such huge expenditures. Even substantial companies such as Fairchild and Signetics have followed this course.

Unfortunately, this advanced generation of processing equipment is where one starts in the GaAs business. Low noise FET's have been available with submicron gate lengths for several years (see **Figure 1**). Direct writing on wafers using E Beam machines is a well developed technique. GaAs vapor phase epitaxial and metal organic CVD are sophisticated processes compared to what is commonly used in the silicon industry. Liquid encapsulated Czochralski high pressure crystal pullers appear to be a basic necessity-if material problems are to be brought under control. Diagnostic tools such as a well developed SIMS capability along with deep level transient spectroscopy are fundamental to a serious approach to research and development. These are only a few examples of the exorbitant tuition fees required to join the fraternity. One can argue that by judicious short cuts you may avoid the expense of a complete capability and, in fact, good work has been accomplished with very modest facilities. However, as the various techniques mature this capital situation is going to become more burdensome regardless of the style of the organization. With the rapid evolution of new equipment, the obsolescence of existing equipment will occur too fast for reasonable amortization. This expenditure, in all probability, will never be recovered and must still be regarded as an initiation fee associated with a new technology.

Figure 2 illustrates the elaborate equipment installation associated with a direct writing E-Beam machine for development work and prototype production. This machine will accurately and consistently define a 0.25 μm gate for a low noise FET and is also useful for the maskless definition of small circuits. Although

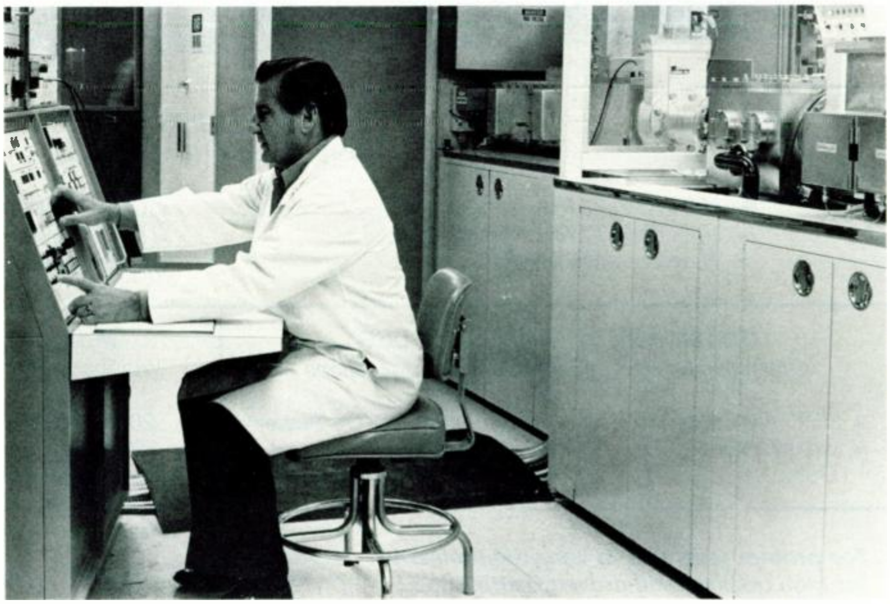

Fig. 3 Four hundred KeV ion implantation machine.

several advanced silicon processing facilities employ similar machines in a production environment, their cost is borne by a huge product throughput.

A 400 KeV ion implantation machine is shown in **Figure 3**. Because of the high voltage capability and other special features, the cost of this installation is several times that of typical silicon implantation equipment. The deep implants required for some FET devices necessitates the higher voltage which adds considerably to the cost.

Since substrate material characteristics determine device performance, many GaAs development organizations feel that a high pressure LEC crystal puller as shown in **Figure 4** is the key to future progress. Because of the unusual height of this installation, a special laboratory room must be available. Excellent silicon wafer material is readily supplied by several reliable sources which eliminate the need for this type of equipment for those working on silicon devices and integrated circuits. Even if they choose to grow their own crystals such an elaborate installation would not be required.

Fig. 4 High pressure Czochralski crystal puller.

At present, the lure of an exciting new field with a very promising future has encouraged the larger companies to make the initial investments. However, this favorable investment climate cannot exist over an extended period without the development of a genuine viable market. This is particularly true when there are other pressing demands for this same capital. The time constant during which the investors are patient is due to run out in the immediate future. When this happens there will be the usual retrenchment and only those products with an established economic base will be continued with adequate support.

The foregoing is basic economics but has been largely ignored by those playing the GaAs art. Some are too busy exploring new phenomena to pay close attention to the business picture and incorrectly believe that those issues will resolve themselves. The real danger is that when the business issues are addressed the adjustments will be too sudden and too drastic. It would behoove us all to initiate the sensible reductions without the forcing function of a financial crisis. We could plan these to be gradual, and based on real data as opposed to speculation. Such responsible action would lend credibility to the fraternity and could only improve the investment climate.

MAJOR PROBLEMS AND POTENTIAL SOLUTIONS

The kindest description of the current effort in GaAs is chaotic. The scope of the activity is overwhelming in view of the limited resources being applied. A plethora of small government device and circuit contracts aimed at the cutting edge of the technology typify the outside support available. Internally, many companies are investing heavily in a wide range of exploratory efforts to stay abreast of the fast pace of the industry. Very little thought has been given to a long-range investment strategy. The most vocal proponents of GaAs have embarked on a messianic

(continued on page 32)

crusade which has created expectations which are not likely to be satisfied. They spend most of their energies in going from conference to conference describing new "break-throughs." Although well intentioned, this type of promotion is already becoming counter-productive. Many serious proposals to pursue fundamental problems can't get funding because they are perceived as mundane and behind the art. The literature abounds with articles describing ambitious projects and alleged progress along a broad front. If one were to assess the technology from reading these articles, the impression would tend to overly optimistic conclusions. The groundwork is being laid for an inevitable backlash which can only hurt the industry in terms of continued support.

What is desperately needed is a systematic and fundamental attack on the basic material and processing problems. Long-range plans must be formulated which are realistic and well supported and which will lead to continuity of effort. It is very debilitating for those doing the work to exist in a highly volatile and disorganized environment which is characterized by rapidly shifting priorities. Real progress will only come with long term, dedicated, focused efforts.

The number of qualified experts capable of major contributions to the art are very few indeed. Only a handful of universities have research programs of any substance and these are guided by a very small faculty group. The growth of the GaAs industry, even if monetary constraints were removed, would be seriously limited by the supply of good people and this supply system is not likely to change in the near future. The available resources need to be applied with more care and precision in defining their mission if we hope to improve our performance.

To be more specific in suggesting how to bring order out of chaos, some bold judgments are in order. Because of the paucity of real data, these judgments may prove to be imperfect. However, the alternative of continuing along with no strategy is almost a guarantee of poor results.

- The first recommendation is to give higher priority to fundamental studies such as impurity control, epitaxial techniques, ohmic contacts, ion implantations, etc. At present, we are too enamoured of gadgets because these can be used to win government contracts and to supply material for publication.
- Dedicate the digital MSI work toward a new front end signal processors such as prescalers, frequency synthesizers, code generators, etc. Such circuitry would have immediate impact on radar receivers and would perform functions which would be difficult, if not impossible, to accomplish with existing technologies. A corollary to this thrust would be a move away from the main-frame computer business and other applications of a similar sort.
- Emphasize microwave analog devices, both discrete FET's and monolithic circuits. In this arena low noise FET's and power FET's have already made a significant contribution to the art. However, excessively optimistic objectives such as low cost monolithic transmitter/receiver modules should be carefully reassessed. We should first concentrate on performance with regard to the monolithic effort. The cost can only come down through the well established principles of the learning curve.
- Time order our objectives. Currently we are chasing everything with equal vigor. Obviously there are some near term requirements which should receive the bulk of our attention and some long term programs which sould survive with lower priority. In this manner we could accelerate the successful application of GaAs in real systems.
- Put high speed LSI on the bottom of the priority list. The likelihood that GaAs is going to prevail in this arena is remote and the current maturity of the technology is such that effort along these lines will not be productive (except to generate new benchmarks).

The term GaAs suggests a single technology based solely on this one compound semiconductor. In actual fact, the ternary and quaternary compounds such as InGaAs and InGaAs/InP will displace GaAs in many applications. We are already witnessing this trend in optoelectronics where it is important to vary the band gap of the semiconductor to accommodate different wavelengths of light. This inevitable proliferation of the base materials will put an additional strain on the available resources.

The foregoing is not intended as a negative prognosis for the future of GaAs in military systems. In view of its remarkable attributes and high leverage on system performance, economic justification is no obstacle to continued investments for such applications. Most of these systems require state-of-the-art devices to achieve superiority in the field and for this reason GaAs has much to offer.

Dr. John T. Mendel is Assistant Group Executive/Director of Technology, Industrial Electronics Group, Hughes Aircraft Company. Prior to joining Hughes he worked for the Bell Telephone Laboratories, Murray Hill, New Jersey in the Electronics Research Department. Dr. Mendel received the B.S.E.E., M.S.E.E., and Ph.D. degrees from Stanford University.

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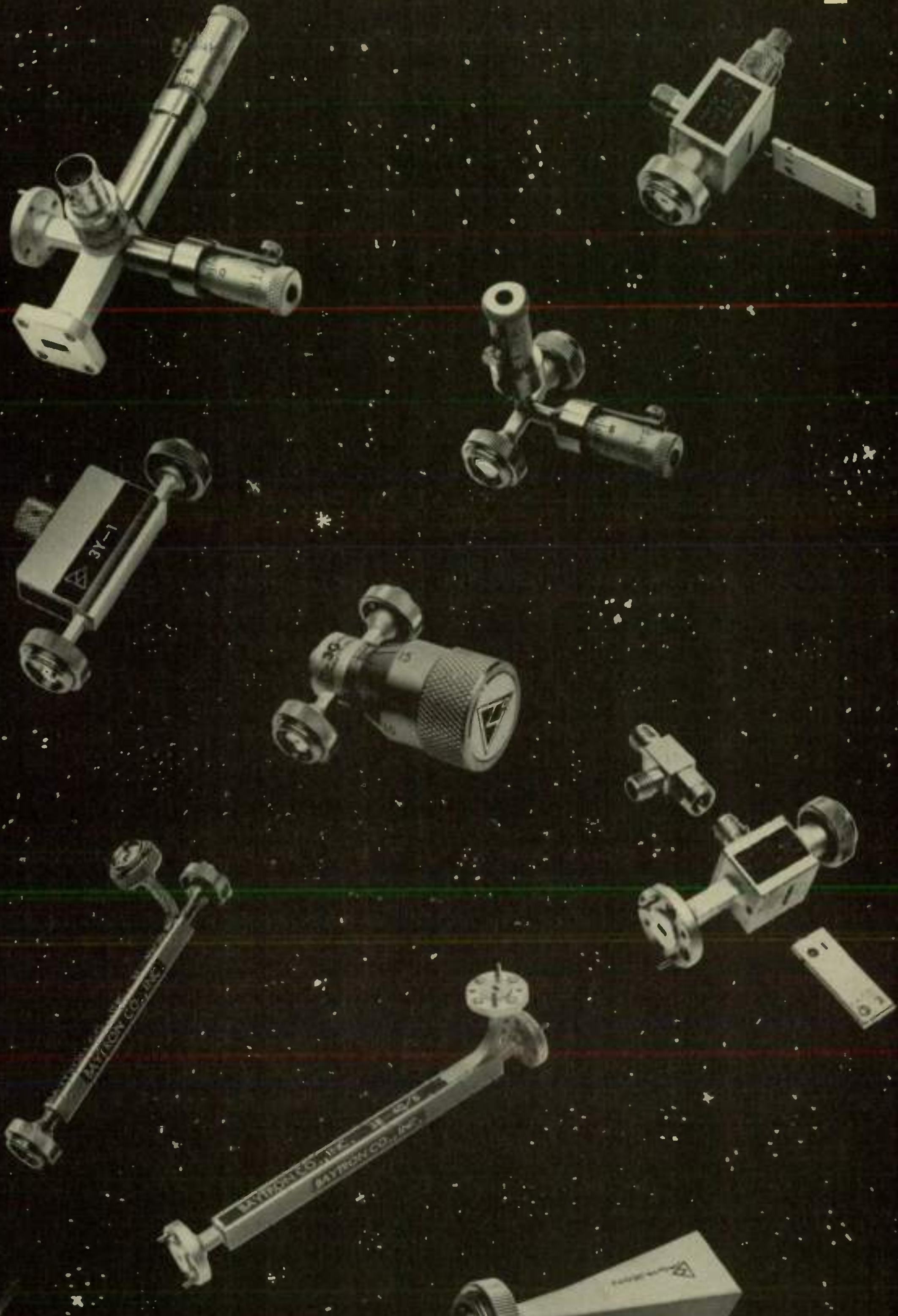

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Around the Circuit

PERSONNEL

At Keene Corp.'s Chase-Foster Laminates Div., **Michael Johnson** has been named Marketing Mgr., Electronics. . .**Frank Carroll** was appointed a Sales Engineer at Narda Microwave Corp. NY. . .Diamond Antenna & Microwave Corp. announced the return of **H. S. Tiger** as Chief Engineer. . .**John G. David** was appointed Mgr. of Automatic Test Equipment Affairs in the Marketing Dept. at RCA Automated Systems. . .**Thomas C. Cahill** joins RLC Electronics as Regional Sales Mgr. . .Eaton Corp.'s Electronic Instrumentation Div. appointed **Del Black** as So. CA District Mgr. . .**Irwin Drangel** has been promoted from Product Marketing Mgr. for Advanced Materials Div. of Material Research Corp. to Dir. of Marketing while **Ross Stander**, former Marketing Dir., assumes the new position of Dir. of Plasma Etching. . . **Jesse R. Lien**, V.P. - Engineering of GTE, has been elected a Fellow of the IEEE. Mr. Lien, also Pres. of GTE Labs, was chosen for his "leadership in electronics research and engineering". . .**James N. Finley** was promoted to Dir. of Field Marketing and **William F. Marvin** to Dir. of Central Marketing for the Applied Technology Div. of Itek Corporation. . .**Terry L. Miller** was promoted from Mgr., MW Materials Product Line to Div. Mgr. of the MW Materials Div. of Rogers Corp. . .**Ron Potter** joined the mktg. dept. of Tecom as Mgr., Adv. Programs.

CONTRACTS

Adams-Russell has been selected to provide CATV services for Lexington and Hudson, MA and the Village of Lynbrook, Nassau County, NY. . .**Hughes Aircraft Co.** was awarded a $54M contract from the Army Electronics R & D Command (ERADCOM) for production of 48 AN/TPW-36 mortar locating radars. . .**Itek Corp.'s Applied Technology Div.** received a $32.7M contract from the USAF for ALR-46/69 radar warning systems, spares and related test equipment. . .**Cincinnati Electronics Corp.** was awarded a $7.7M contract from the Naval Training Equipment Center for the 15E34A ECM Signal Practice Trainer Device. . .**Hazeltine Corporation** received a fixed price contract for $15.7M from the Electronic Systems Div. of the USAF Systems Command for development of engineering models for the USAF Airborne Comm. Systems, SEEK TALK.

INDUSTRY NEWS

CIT Alcatel (subsidiary of **Compagnie Générale d'Electricité**) reached an agreement with **Laser Diode Labs** (subsidiary of M/A-COM) under which they will share technology, production techniques and markets for electro-luminescent diodes, laser diodes and photodetectors in the 300-1600 nm range. . .**Cablewave Systems** announced that they will represent the **Spinner Company** of Munich, W. Germany in the US. . .**Weinschel Engineering Co., Inc.** appointed **Arva Hudson Inc.** as Weinschel's authorized sales rep. for the Washington/Oregon area. Arva Hudson offices are located at: P.O. Box 1512, Bellevue, WA 98009, Tel: (206) 455-0773 and 8700 S.W. 26th Avenue, Portland, OR 97219, Tel: (503) 245-9589. . .**Metex Corp.** announced the sale of its electronic shielding product line and related business assets to **Chomerics, Inc.** Terms of the sale include $3.0M paid to Metex in cash and $3.0M by a 5-year, secured note; additional payments amounting to between $2.2M and $3.7M will be paid over the next 10 years. . .**Loral Corp.** announced the acquisition of **KSW Electronics Corp.** of Burlington, MA. KSW will become a part of Loral's **Frequency Sources** subsidiary and be combined into **Frequency's GHz Div.** in Chelmsford, MA. Dr. Jerome Hartke, President of KSW, will be General Mgr. of the combined operations, and David Weinhold, presently Gen. Manager of GHz, will be Asst. Gen. Manager.

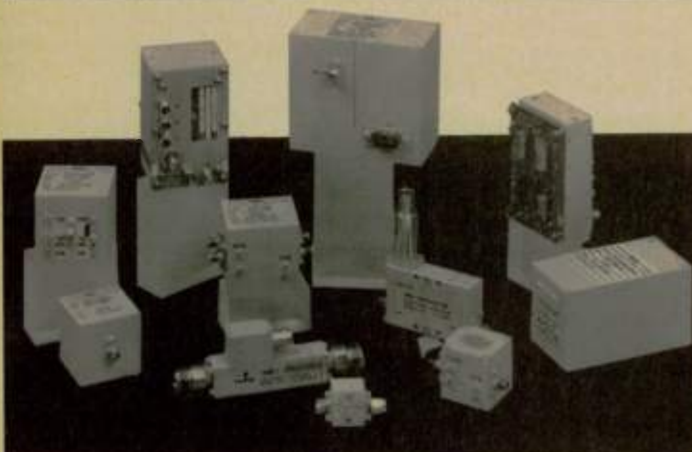
NEW MARKET ENTRY

Amplifonix, a new company which makes cascaded and custom hybrids, has occupied a design and production facility in Bristol, PA. Some 30 catalog items will be manufactured for kHz to 500 MHz applications, with deliveries to begin in 2-4 wks. Contact: Dr. Art Riben, President, Amplifonix, 221 Rt. 13, Bristol, PA 19007. Tel: (215) 788-2350.

FINANCIAL NEWS

The Narda Microwave Corp. reported half-year results for the period ended December 31, 1980. Six-month net sales were $11.9M, net income was $735K and earnings per share were 55¢. In 1979, half-year net sales were $8.45M, net income was $425K or 38¢ per share. . .**AEL Industries, Inc.** reported net income of $405K or 21¢ per share on sales of $15.8M in the third quarter ended November 28, 1980. This compares with 1979 quarterly results of net income $741K or 39¢ per share on sales of $12.5M. . .**Varian Associates, Inc.** reported annual results for the year ended September 30, 1980 of sales of $620.8M, net earnings of $22.1M or $2.77 per share. This compares with 1979 annual sales of $493M, net earnings of $8.58M or $1.13 per share. . .**Alpha Industries, Inc.** reported third quarter sales for the period ended December 31, 1980 of $7.6M, net income of $730K or 30¢ per share. This compares with 1979 quarterly net sales of $5.6M, net income of $469K or 24¢ per share. . .**Adams Russell Co., Inc.** announced first quarter net sales of $10.7M, net income of $814K or 25¢ per share for the period ended January 4, 1981. This compares with 1979 first quarter net sales of $7.96M and net income of $529K or 19¢ per share. . . **Watkins-Johnson Co.** reported unaudited results for fiscal year 1980 ended December 31, of sales of $132.8M, net earnings of $7.1M or $2.23 per share. This compares with fiscal year 1979 sales of $127.64M, net earnings of $7.25M or $2.32 per share. . .**Scientific-Atlanta, Inc.** reported six-month results for the period ended December 31, 1980 of sales of $120.6M, net earnings of $7.9M or 75¢ per share. This compares with 1979 half-year sales of $85.97M, net earnings of $5.2M or 55¢ per share. . . **EPSCO, Inc.** announced 1980 year-end net income of $936K or 96¢ per share on net sales of $16.0M for the period ended December 31, 1980. In fiscal year 1979, net income was $1.24M or $1.35 per share on net sales of $13.28M. . .**Sage Laboratories, Inc.** announced net earnings for the six months ended December 27, 1980 of $141K or 32¢ per share on revenues of $1.36M. For the comparable period of 1979, net earnings were $101K or 23¢ per share on revenues of $1.0M. . .**M/A-COM, Inc.** announced annual results for the period ended September 27, 1980 of net sales of $322.48M, net income of $24.9M or 77¢ per share. For year-end 1979, net sales were $227M, net income was $13.2M or 46¢ per share.

Systron-Donner Advanced



Systron-Donner's setting the standards for:

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

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

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

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

YIG DRIVERS

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

VOLTAGE-TUNED OSCILLATORS

MODEL:	Frequency Range (MHz):	Power, Min. (mW): Leveled	Power 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[1]	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[1]	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.

Components: Update 1981

YIG-TUNED FILTERS

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

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

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

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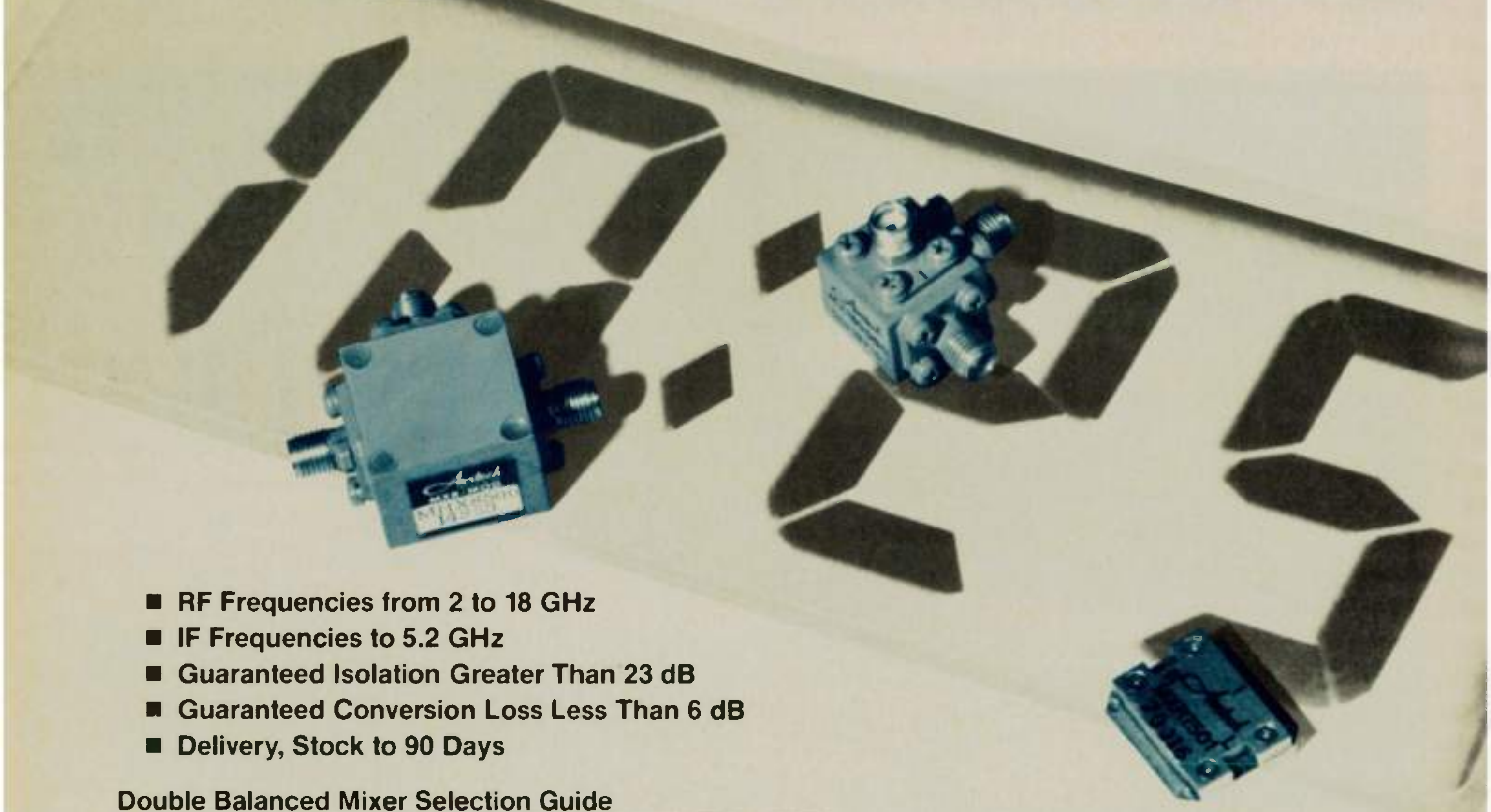

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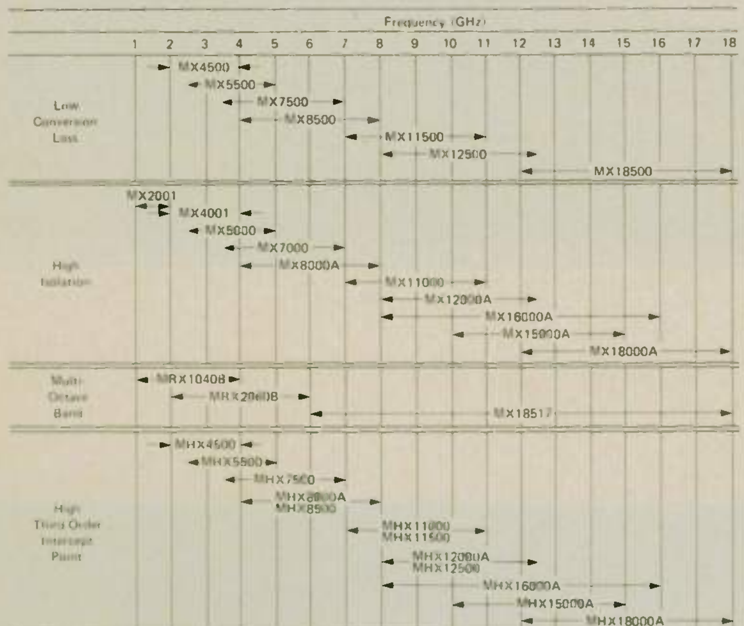

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MMIC Linear Amplifiers–Design and Fabrication Techniques

D. R. CH'EN, D. R. DECKER,
W. C. PETERSEN, and A. K. GUPTA
Rockwell International
Microelectronics Research and Development Center
Thousand Oaks, CA

INTRODUCTION AND TECHNOLOGY DESCRIPTION

The beginning of an era of cost effective MMIC's (monolithic microwave integrated circuits) with their integration of high performance GaAs FET's and associated circuitry is upon us. This new technological approach[1,2] to microwave circuitry will make possible applications heretofore not technically and/or financially feasible. In this paper, the main focus will be directed toward linear amplifiers although most circuit design rules, GaAs materials requirements, and device fabrication technology are applicable to the generalized MMIC approach.

MMIC circuit design principles and device layout procedures will be presented first. Details of materials growth and characterization which make possible the realization of GaAs MMIC amplifiers will be covered in the next section. Circuit fabrication techniques including a planar, ion implanted, GaAs MMIC fabrication process will be outlined. Circuit design iteration procedures and actual examples of an ultra wideband amplifier and an RF preamplifier will be presented. The final section will summarize the highlights of the MMIC linear amplifier technology and attempt to

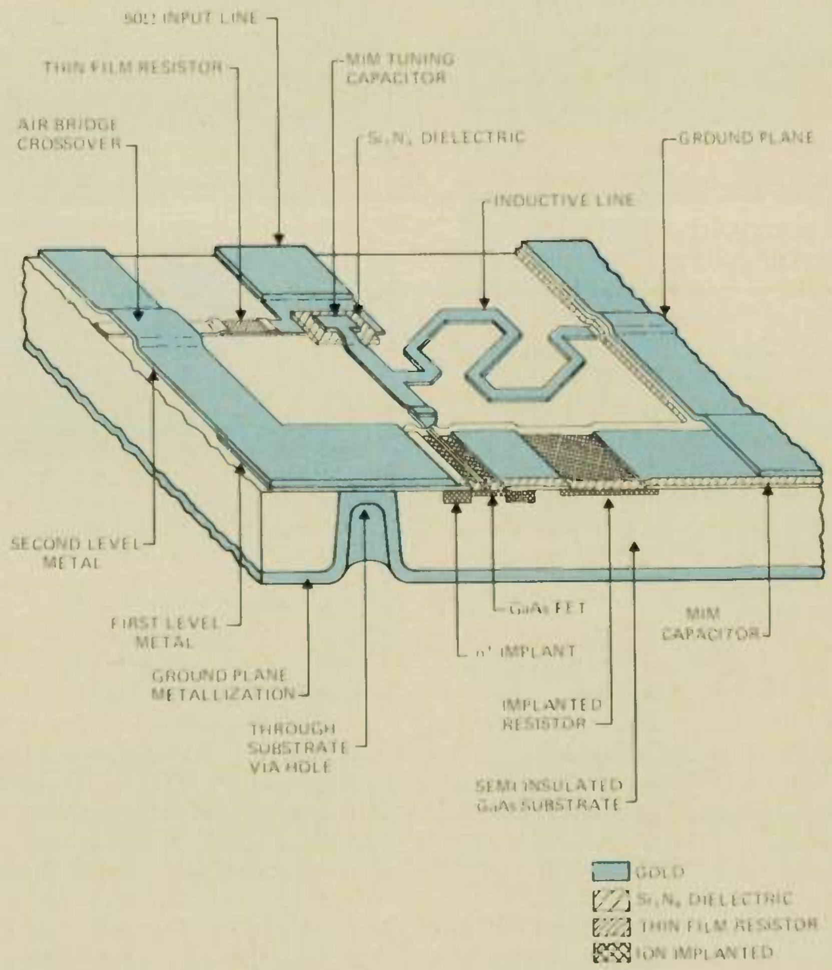

Fig. 1 Cross section of MMIC chip.

project the direction of future trends.

LINEAR MMIC DESIGN PRINCIPLES

The design of MMIC's is mainly accomplished through the use of computer-aided design (CAD) techniques which utilize models of the active devices and passive components to compute the predicted circuit performance. The accuracy and, consequently, the usefulness of these design techniques is directly related to the accuracy and completeness of the device and circuit element models upon which the analysis is based. Since this is the foundation upon which further analysis and designs are based, excellent models must be developed for the active GaAs FET's[4] and the circuit elements.

The structure of typical MMIC circuit elements may be seen in the cross section shown in **Figure 1**. Ion implantation is used to form the FET active layers and resistors. Metal-insulator-metal (MIM) capacitors (~125 pF/mm^2) are used as tuning elements for RF bypassing. High impedance transmission lines give inductive reactance over the desired band. Thin film resistors may be used for improved temperature stability. The primary transmission mode for complex amplifier design is microstrip, and either edge or through substrate via grounding (**Figure 2**) is used as needed. Plated air bridges may be used for low capacitance crossovers or beam lead fabrication. The substrate thickness may range between approximately 100 and 250μm depending on frequency and required power dissipation capability.

The impedance of microstrip transmission lines of various widths may be calculated from standard formulae for a given substrate thickness and a dielectric constant of ϵ_r = 12.9 for GaAs. Circuit impedances as high as about 110 ohms and 90 ohms can be realized with practical linewidths for 250μm and 125μm thickness substrates respectively. The loss per unit length of such narrow transmission lines can be computed, but measured values are more accurate since they account for all factors involved, including such variables as metallization roughness. A Q of ~ 125 through X-band is attainable.

Examples of both ultra wide band and narrow band MMIC amplifier designs have been chosen to demonstrate the progress of a typical design cycle. Both of these amplifiers are constructed using microstrip circuitry with 250μm substrate thickness. The narrow band design is a first iteration whereas the ultra wide band amplifier is a second iteration.[5]

The narrow band amplifier is designed to operate as a preamplifier in the 10 to 15 GHz band. A single stage, common source design with a small source inductance to improve input match at minimum noise comprises this amplifier. Series C, shunt L tuning at both input and output provide dc blocking and simple bias injection. MIM capacitors are used to tune input and output and to bypass the shunt induc-

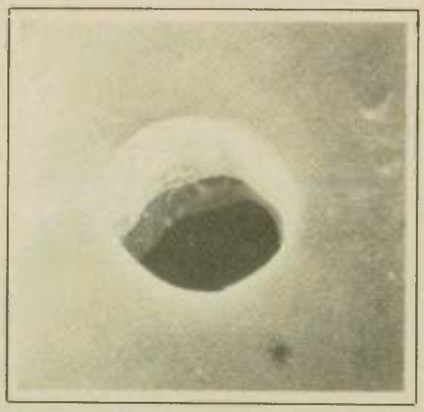

Fig. 2 Scanning electron micrograph of through-substrate via hole on a 500 μm thick substrate.

tors which are used for bias injection. The GaAs FET is a single 150μm wide finger with a nominal gate length of 0.7 μm.

The ultra wideband amplifier is designed to operate across the band from 100 MHz to 10 GHz. This amplifier is designed with four FET stages of which two provide active matching at input and output and the other two provide most of the gain. Therefore, the configuration of the four stages is common-gate, common-source, common-source, common-drain from input to output respectively. The first two stages are tuned for minimum noise. On-chip bias networks with MIM bypass capacitors are provided for all FET's. A scanning electron micrograph of the ultra wideband amplifier is shown in **Figure 3**.

MATERIAL TECHNOLOGY

The preferred MMIC fabrication technology has evolved toward the basic ion implanted (I.I.) GaAs FET process technology pioneered by Rockwell International.[3,6] This is primarily due to the superior device parameter uniformity and reproducibility offered by the I.I. method. This technique, however, puts strong constraints on the properties of the semi-insulating (S.I.) GaAs substrate material.

Well behaved S.I. GaAs ingots with resistivities of $\sim 1 \times 10^8$ ohm-cm can be grown by the horizontal Bridgman and the liquid encapsulated Czochralski (LEC) techniques. Ion implanted active FET layers with electron mobilities of ~ 4500 cm^{2}v^{-1}s^{-1} for 1×10^{17} cm^{-3} doping concentration can be prepared using either type of substrate material. A historical difficulty of control in the preparation of S.I. GaAs substrates has been a serious impediment to the development of monolithic circuitry. Various qualification procedures which assess the ability of the S.I. substrates to withstand high-temperature processing have been employed on an empirical basis to circumvent this problem. A preselection test for bulk S.I. GaAs substrates involves qualification of the entire GaAs ingot by sampling the front and rear of each boule. Extensive data has shown that all wafers within the ingot are qualified when samples from both ends pass the qualification tests.

The LEC crystal growth technique using the in-situ GaAs synthesis capability of a high pressure puller, with Si background impurity concentration, in the high (10^{14}) to low (10^{15})cm^{-3} range, offers approximately an order of magnitude higher purity crystals than the Bridgman method.[7] The etch pit density, which

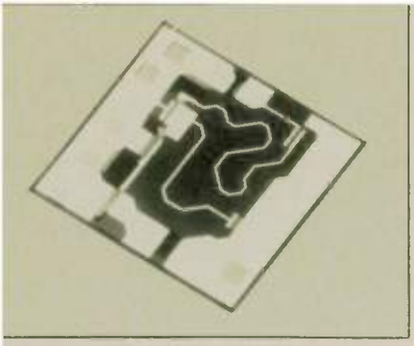

Fig. 3 Scanning electron micrograph of ultrawideband MMIC amplifier with 2.5 mm sq. chip size and 250 μm thick substrate.

ndicates degree of crystal disor-ler, is in the 10^3-$10^5 cm^{-3}$ range. This is one to two orders of mag-nitude higher than the etch pit lensity of Bridgman crystals. However, no clear correlation has been established between the tch pit density and device per-ormance and yield in GaAs. Ad-anced diameter control tech-niques have been developed for LEC crystal growth which per-nits the growth of boules with ize uniformity within ± 1 mm of a 2" diameter ingot.

In contrast, the limited size nd irregular shapes of the typical Bridgman wafers are very unde-irable for device manufacturing. Actual MMIC circuits fabricated on a 2" diameter LEC GaAs wafer re shown on the cover of this ssue. In this photograph, an ar-ay of circuits is fabricated from he same mask set. The circuit rray includes the narrowband preamplifier and ultra wideband mplifier. The ultra wideband mplifier is shown in the scan-ning electron micrograph of Fig-ure 3. Presently, both 2" and 3" diameter LEC ingots are being rown by Rockwell and other aboratories.

High quality semi-insulating GaAs grown by the LEC method has demonstrated feasibility for on implantation in both un-doped and chromium doped rystals. Active layer uniformity ssessed by FET pinchoff voltage (V_p) mapping on one quadrant of a 3" diameter LEC wafer using 100 keV Si implant reveals im-portant differences between Bridgman and LEC substrates as hown in Figure 4. Both wafers show good V_p uniformities; how-ever, the LEC slice shows higher uniformity with only 3.7% vs 7.6% scatter at one standard de-viation from the mean. The data positions represented by an "X" indicate areas either near the slice edge or shadowed by clips during processing. Please note that long range variations in V_p are much more evident in the Bridgman sample than in the LEC sample. The difference in the average V_p of the two types of materials is typical. The long range variation in V_p, which impact device yield for large MMIC chips, are in the range of ± (3-5) % for the LEC material.

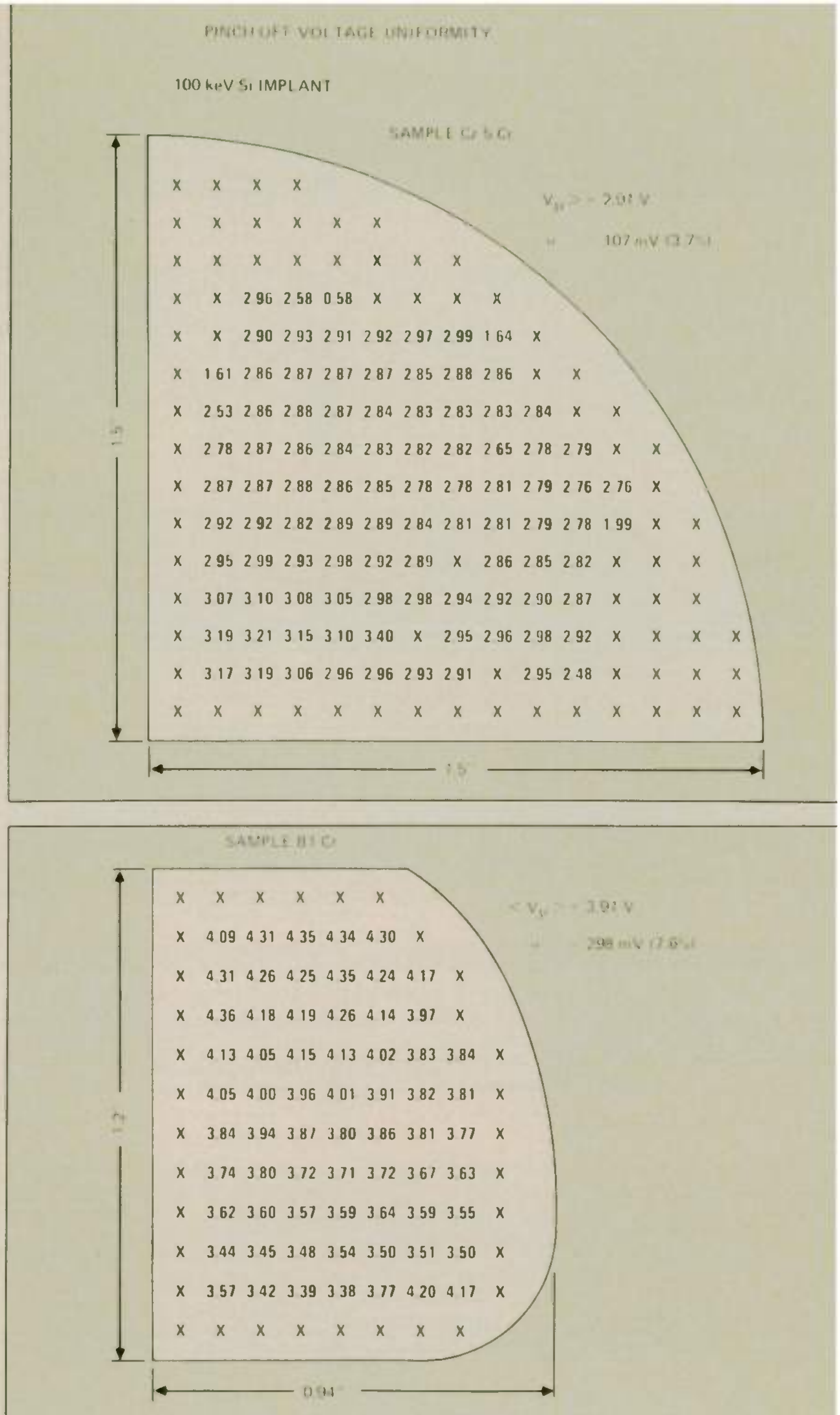

Fig. 4 FET pinch off voltage, V_p, mapping for LEC and Bridgman wafers.

In summary, both the Bridg-man and the LEC grown sub-

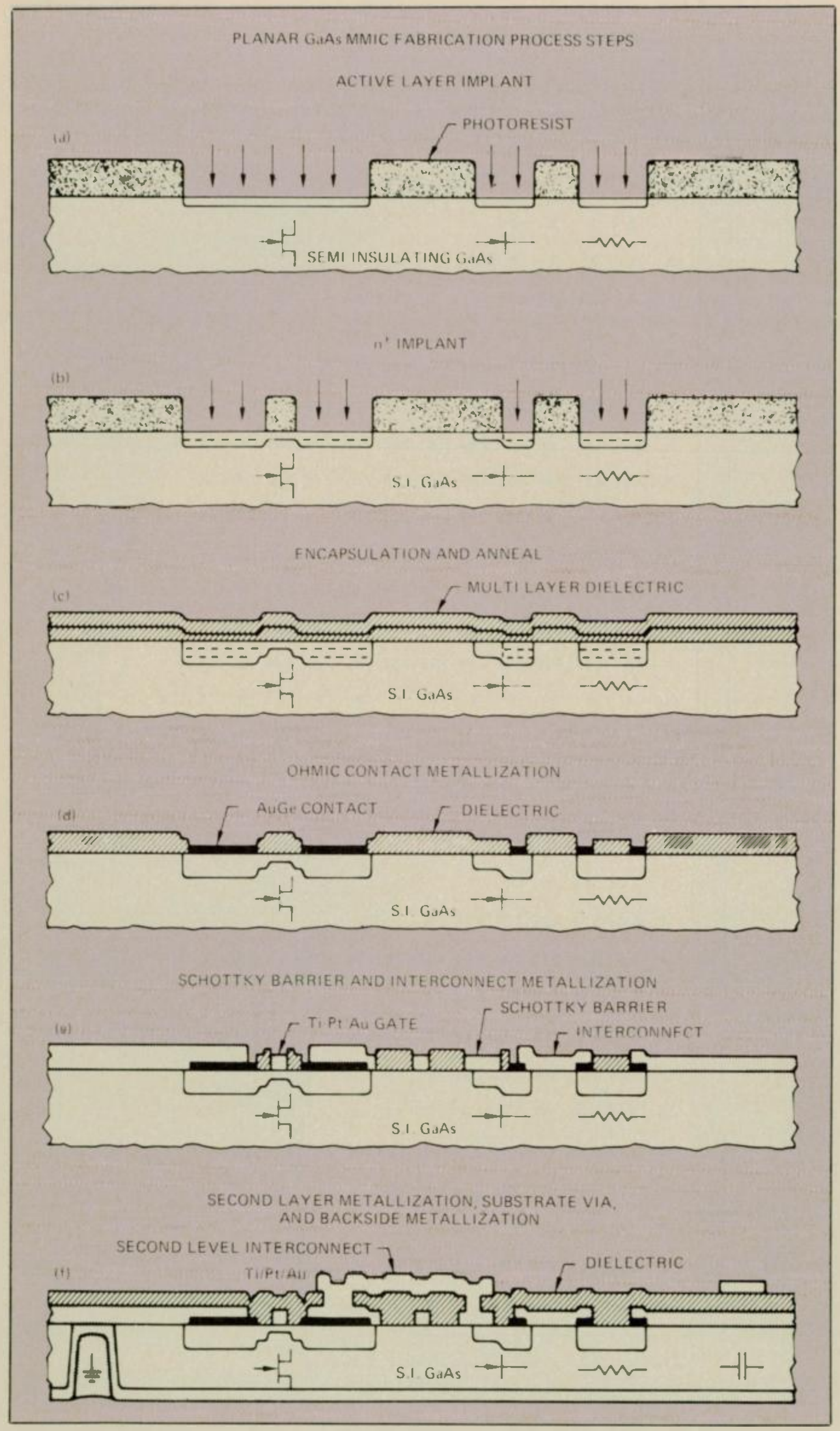

Fig. 5 Planar GaAs MMIC fabrication process steps.

strates are useful for MMIC fabrication. Most researchers feel that the LEC material has the greater long term potential; however, only limited quantities of S.I. LEC material are commercially available at the present time. It is interesting to note that the Metals Research Corporation, manufacturer of the large 10 kg capacity high pressure LEC crystal puller, has to date, sold seven $750K pullers dedicated to GaAs with a combined growth capacity of 560 kg of 3''-diameter S.I. GaAs ingots per month. With reasonable yields, this capacity may easily support the MMIC and other GaAs device requirements in the foreseeable future.

CIRCUIT FABRICATION TECHNIQUES

Conventional photolithography is a well established technology offering such advantages as parallel processing of large wafers using equipment originally developed for Si wafer processing. The main limitation of photolithography is in the fine line resolution, which is limited to a minumum dimension of 0.7-1.0μm for MMIC fabrication. This lower limit is sufficient to allow the use of standard photolithography in all masking levels except in the definition of submicron gates which can be defined by direct wafer writing using an electron beam lithography (EBL) machine. An added advantage of EBL is that it uses a computer to store the patterns to be generated and, therefore, provides a fast circuit editing capability.

In designing a complex MMIC, it is essential to have a multilayer interconnect scheme with low parasitic capability. Currently, two-level interconnections are used on X-band MMIC's with plasma deposited silicon nitride as the crossover insulator. Parasitic capacitances may be reduced further by incorporating gold-plated air-bridge in MMIC fabrication technology. A by-product of the air bridge technology is the ability to fabricate beam leads for all off-chip connections. The beam lead approach to off-chip interconnection is highly desirable in the MMIC process technology since it eliminates the need for wire bonds. To put the discussed key MMIC fabrication techniques in perspective, a step by step description of an actual process flow is outlines.

Figure 5 illustrates the Rockwell process to fabricate a planar GaAs MMIC chip incorporating an FET, a Schottky barrier diode, a bias resistor, and an MMIC capacitor. For illustrative purposes, a two-implant device fabrication process will be described. Fabrication of the device wafer from a qualified, S.I. GaAs substrate is initiated by a photo-resist operation to define the device and cir-

(continued on page 44)

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100BD	50-150	540	110	8	0.7
150BD	50-150	540	100	7	1.0
200BD	150-250	550	110	7	0.7
250BD	150-250	550	100	6	1.0
300BD	250-350	550	110	7	0.7
350BD	250-350	550	100	6	1.0
400BD	350-500	560	100	6	0.7
★ 450BD	350-500	560	80	5	1.0

* V measured at 500 µA I_R ** V measured at 3 mA I_F

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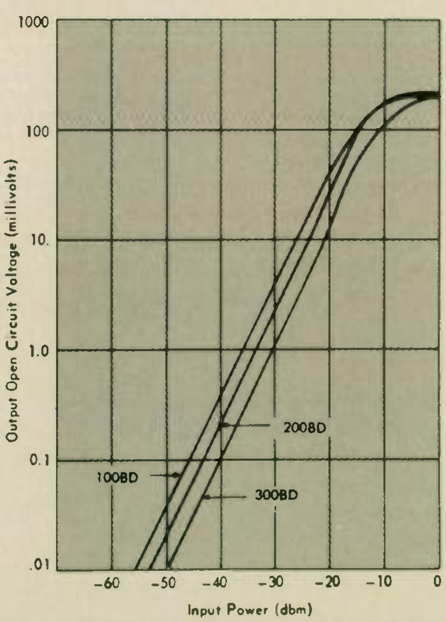
TYPICAL VALUES

DIODE TYPE	TEST FREQUENCY	TSS*	Figure of Merit $\gamma/\sqrt{R_v}$	Video Resistance $R_v\,\Omega$
100BD	2GHz	-58 dbm	300	400
	4GHz	-56 dbm	750	400
	8GHz	-52 dbm	75	400
	16GHz	-47 dbm	40	400
150BD	2GHz	-59 dbm	230	120
	4GHz	-57 dbm	195	120
	8GHz	-52 dbm	100	120
	16GHz	-46 dbm	55	120
200BD	2GHz	-55 dbm	110	80
	4GHz	-54 dbm	100	80
	8GHz	-51 dbm	100	80
	16GHz	-45 dbm	85	80

*2MHz Bandwidth

TYPICAL DETECTOR RESPONSE CURVES



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$$P_{TSS} = \frac{2.5\sqrt{4kTB\,(NF)}}{M} \text{ in watts}$$

where k = 1.38×10^{-23} joules /°K
T = temperature in °K
B = bandwidth of detector-amplifier combination in H_z
NF = noise figure of the amplifier (expressed as a ratio)
M = figure of merit of the diode

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cuit areas requiring the low dose implants such as that required for the active channel of an FET. This is followed by a shallow Se or Si implant as illustrated in **Figure 5**, step a. Additional localized implants such as an n+ implant suitable for device contact areas or Schottky-barrier diode are carried out in a similar manner as shown in **Figure 5**, step b. The localized implantation steps are followed by the encapsulation of the slice with Si_3N_4 and annealing at 850°C for 30 minutes in H_2 atmosphere, step c. This high temperature simultaneously anneals the two implants and converts the shallow implanted areas, ∿ 2000 Å, into FET active channel layers with pinchoff voltages dictated by the implant conditions (∿ 3V for small signal MMIC amplifiers). In contrast to the shallow active area implants, the n+ implant at a higher dosage is desirable for ohmic contacts and low value resistors. Additional implantation can be incorporated before the high temperature step 5c if required.

High performance GaAs FET's require ohmic contact resistance in the low $1 \times 10^6\ \Omega\ cm^2$ range. Device ohmic contacts are defined in step d with standard photolithographic techniques. After the alloying of the AuGe/Ni ohmic contact areas at 450°C, a photoresist operation is again performed to define the Schottky barrier metallization for the FET's and diodes. Ti/Pt/Au is selected for its reliable Schottky barriers as well as for the first layer circuit interconnections, step e. High melting point refractory metal gates have been shown to be many times more resistant to electrical transient burnout than Al structures. A dielectric layer is then deposited on the entire wafer as insulation for the second level interconnections and dielectric for the circuit MIM capacitors. Via holes etched through the dielectric layer are used for interconnections between the two metallizations. Ti/Pt/Au is also selected for the second level metallization. In the final series of finishing steps gold metallization for the circuitry is plated up for low transmission losses, the wafer is thinned, the substrate via holes are cut, and backside metallization is deposited, step f. **Figure 1** shows a cross-sectional view of such a completed circuit.

DESIGN EVALUATION

Evaluation of the narrow and wideband amplifier circuits described earlier is part of the overall MMIC design cycle. Initial results give an indication of design performance and help to guide subsequent circuit optimization. Since circuit "tweaking" is extremely difficult in the MMIC technology, performance analysis must rely on a combination of measurements and upgraded computer modeling. Microwave evaluation of the integrated chip involves testing for all performance goals and identifying contributions of individual subcircuits.

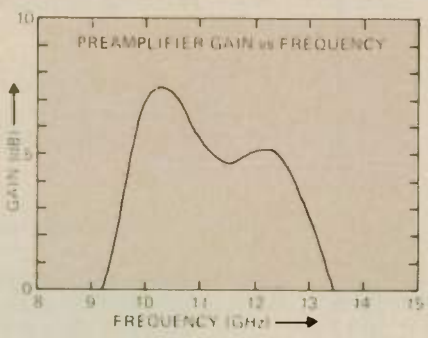


Fig. 6 Measured MMIC preamplifier gain vs frequency.

Initial measurements of the gain of the preamplifier circuit are shown in **Figure 6**. The gain is above about 5 dB from 10 to 12.5 GHz with a peak gain of about 7.5 dB at 10 GHz. The input and output return loss are nominally about 9 ± 4 dB across the same band. Analysis of these results has uncovered an extraneous source of stray capacitance. Continued development of this circuit is expected to flatten the gain and increase the center frequency by about 10 to 20%.

Characterization of the ultra wideband amplifier has disclosed several important features of the design performance. Thorough dc measurement and precise biasing of each FET of this multistage amplifier appear to be the key to achieving the designed performance. The measured gain from 500 MHz to 10 GHz for this amplifier is shown in **Figure 7**. It

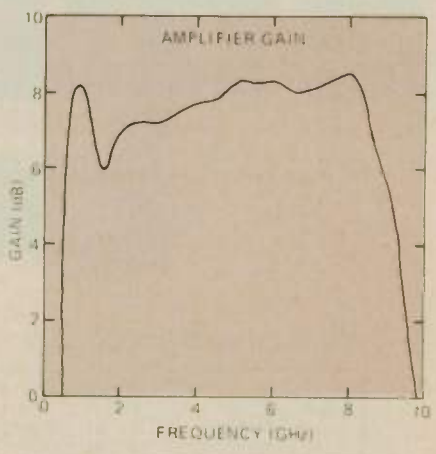


Fig. 7 Measured MMIC ultrawideband amplifier gain.

was necessary to adjust the value of one resistor to obtain this result. The measured input and output return loss for this amplifier are shown in **Figure 8**. Use of the active matching approach may be seen to result in excellent matching results (SWR ≅ 1.5:1) across very wide bandwidth with concurrent small chip size. Continuing development efforts on this amplifier are anticipated to realize 10 dB gain across the full bandwidth from 100 MHz to 10 GHz. Cascading of these amplifiers for higher gain is also very practical as a result of the excellent match achieved.

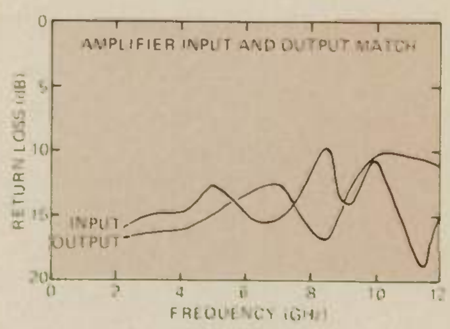
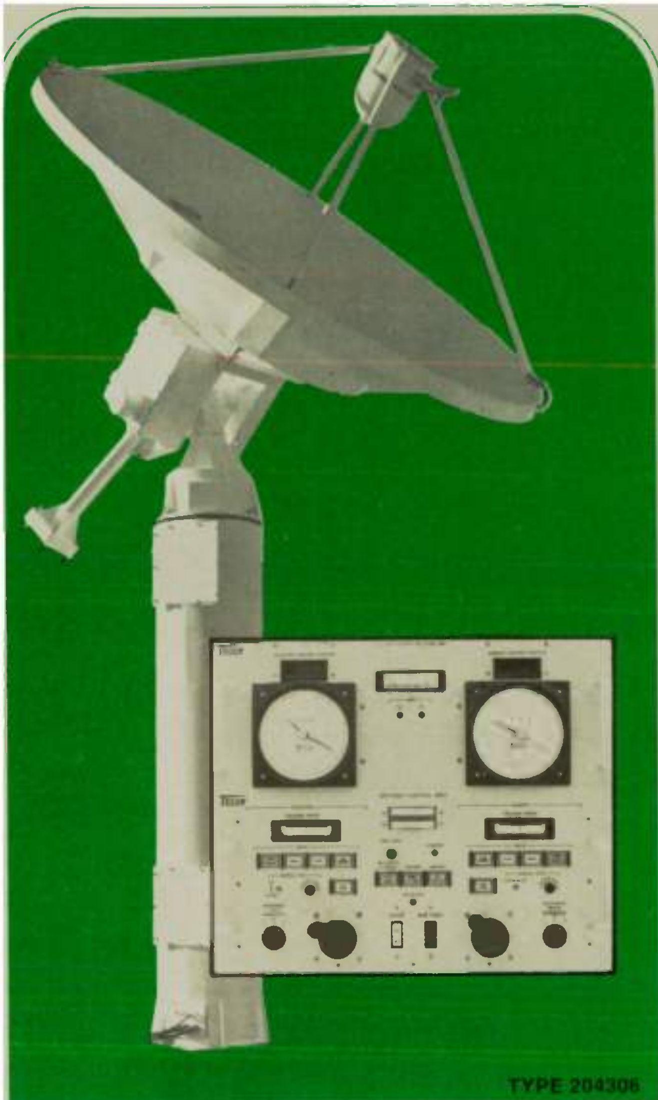


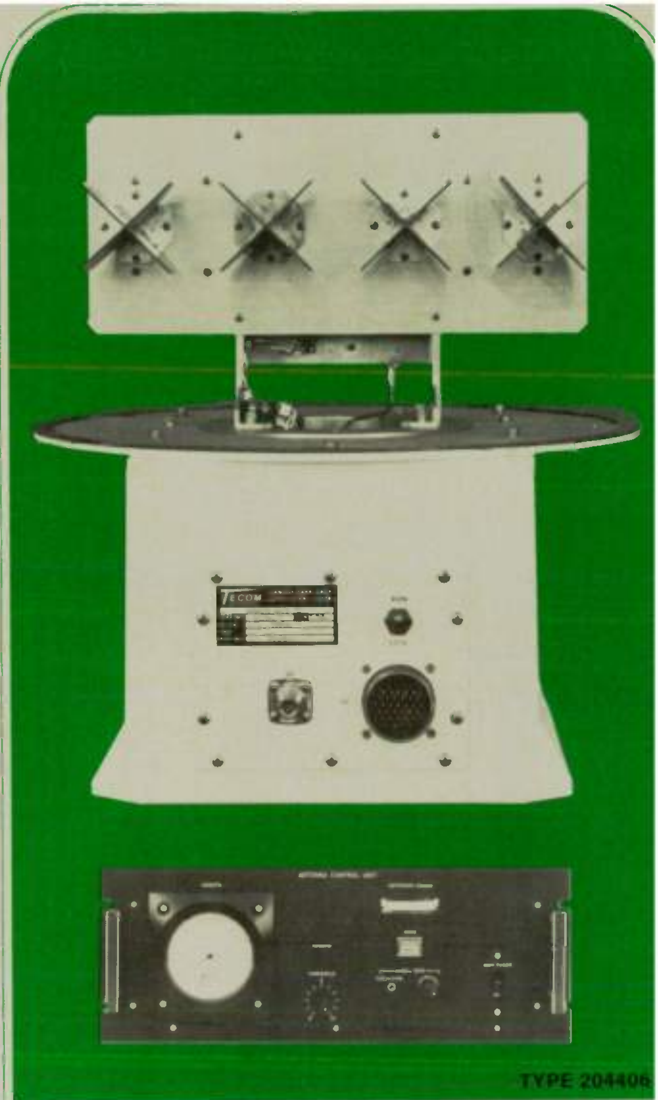
Fig. 8 Measured MMIC ultrawideband amplifier match.

FUTURE TRENDS

The MMIC fabrication approach is extremely difficult to circuit tune or tweak. This is a

(continued on page 48)


TYPE 204306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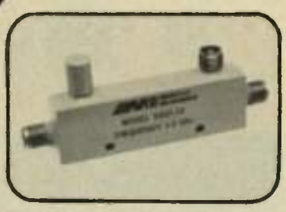

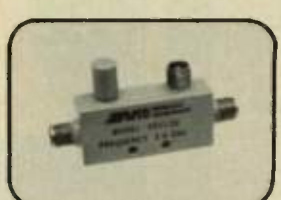

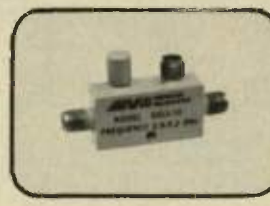

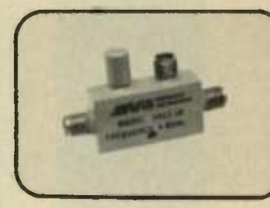

SPECIFICATIONS

MMI Model (1)	5010-6	5010-10	5010-20
Frequency Range (GHz)	ALL ARE 1-2		
Coupling in dB*	6 ± 1.00	10 ± 1.25	20 ± 1.25
Frequency Sensitivity in dB	± 0.60	BOTH ARE ± 0.75	
Directivity dB min.	BOTH ARE 25		27
VSWR max.	1.15	BOTH ARE 1.10	
Insertion Loss** dB max.	ALL ARE 0.20		

MMI Model (1)	5011-6	5011-10	5011-20
Frequency Range (GHz)	ALL ARE 2-4		
Coupling in dB*	6 ± 1.00	10 ± 1.25	20 ± 1.25
Frequency Sensitivity in dB	± 0.60	BOTH ARE ± 0.75	
Directivity dB min.	ALL ARE 22		
VSWR max.	ALL ARE 1.15		
Insertion Loss** dB max.	ALL ARE 0.20		

MMI Model (1)	5012-6	5012-10	5012-20
Frequency Range (GHz)	ALL ARE 2.6-5.2		
Coupling in dB*	6 ± 1.00	10 ± 1.25	20 ± 1.25
Frequency Sensitivity in dB	± 0.60	BOTH ARE ± 0.75	
Directivity dB min.	18	BOTH ARE 20	
VSWR max.	ALL ARE 1.25		
Insertion Loss** dB max.	ALL ARE 0.25		

MMI Model (1)	5013-6	5013-10	5013-20
Frequency Range (GHz)	ALL ARE 4-8		
Coupling in dB*	6 ± 1.00	10 ± 1.25	20 ± 1.25
Frequency Sensitivity in dB	± 0.60	BOTH ARE ± 0.75	
Directivity dB min.	18	BOTH ARE 20	
VSWR max.	ALL ARE 1.25		
Insertion Loss** dB max.	ALL ARE 0.25		

DIMENSIONS
(See Engineer Drawing Above)

All dimensions are in inches

	5010		5011		5012		5013	
A	ALL ARE 0.51		ALL ARE 0.51		N/A		N/A	
B	ALL ARE 0.94		ALL ARE 0.34		N/A		N/A	
C	ALL ARE 1.95		ALL ARE 1.35		ALL ARE 1.15		ALL ARE 1.15	
D	ALL ARE 0.65		BOTH ARE 0.60	0.65	BOTH ARE 0.60	0.65	BOTH ARE 0.60	0.65
E	ALL ARE 0.30		ALL ARE 0.30		ALL ARE 0.30		ALL ARE 0.30	
F	ALL ARE 1.35		ALL ARE 0.75		ALL ARE 0.56		ALL ARE 0.61	
G	N/A		N/A		ALL ARE 0.57		ALL ARE 0.57	

Average Incident Power - 50 Watts *Also includes frequency sensitivity. **Excluding coupled Power.

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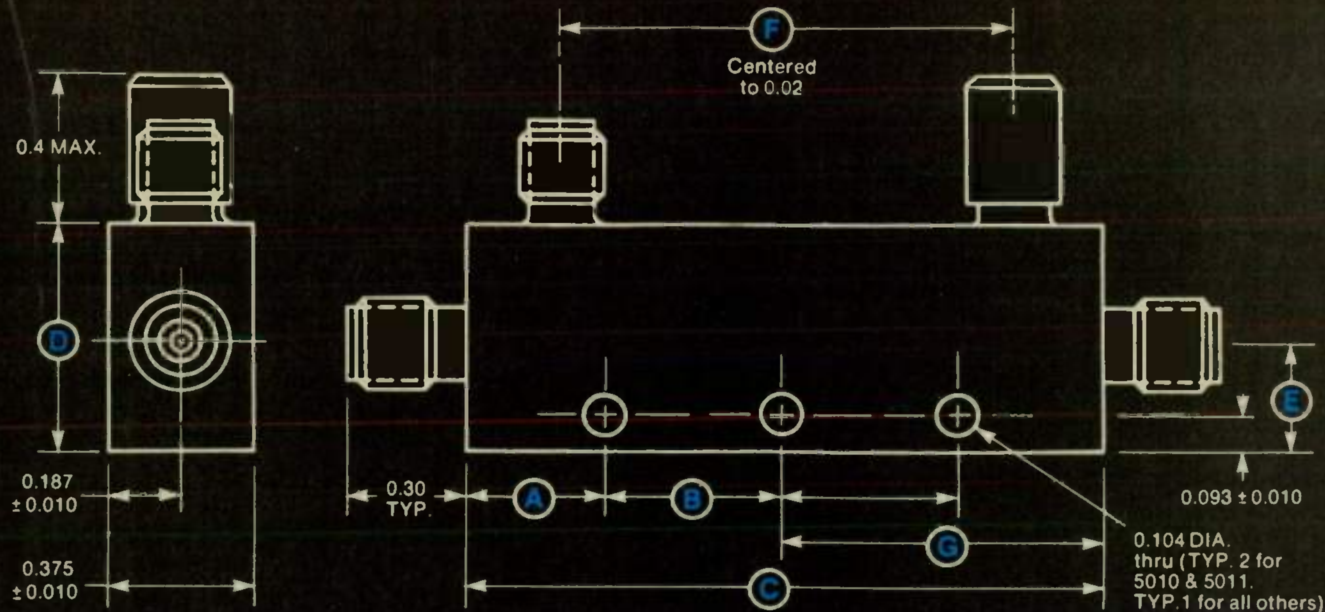

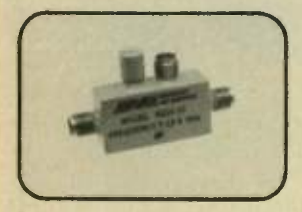

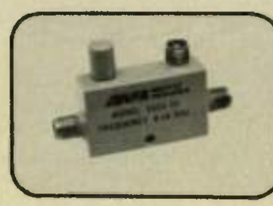

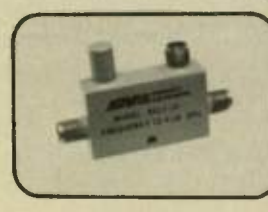

5014-6	5014-10	5014-20
ALL ARE 7-12.4		
6 ± 1.00	10 ± 1.25	20 ± 1.25
ALL ARE ± 0.50		
15	BOTH ARE 17	
ALL ARE 1.30		
ALL ARE 0.40		

5015-6	5015-10	5015-20
ALL ARE 7-18		
6 ± 1.00	10 ± 1.25	20 ± 1.25
± 0.60	BOTH ARE ± 0.75	
BOTH ARE 12		15
ALL ARE 1.40		
ALL ARE 0.50		

5016-6	5016-10	5016-20
ALL ARE 8-16		
6 ± 1.00	10 ± 1.50	20 ± 1.25
± 0.60	BOTH ARE ± 0.75	
BOTH ARE 12		15
ALL ARE 1.40		
ALL ARE 0.50		

5017-6	5017-10	5017-20
ALL ARE 12.4-18		
6 ± 1.00	10 ± 1.00	20 ± 1.00
ALL ARE ± 0.50		
ALL ARE 15		
ALL ARE 1.40		
ALL ARE 0.40		

N/A	
N/A	
ALL ARE 1.15	
BOTH ARE 0.60	0.65
ALL ARE 0.30	
ALL ARE 0.36	
ALL ARE 0.57	

N/A	
N/A	
ALL ARE 1.25	
BOTH ARE 0.75	0.80
ALL ARE 0.30	
ALL ARE 0.77	
ALL ARE 0.63	

N/A	
N/A	
ALL ARE 1.25	
BOTH ARE 0.75	0.80
ALL ARE 0.30	
ALL ARE 0.77	
ALL ARE 0.63	

N/A	
N/A	
ALL ARE 1.25	
BOTH ARE 0.75	0.80
ALL ARE 0.30	
ALL ARE 0.77	
ALL ARE 0.63	

(1) 5000 Series Couplers available with removeable termination. Add suffix "R" to model number.

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major benefit as well as a liability. The disadvantage lies in the fact that in order to obtain an acceptable circuit yield without the benefit of final tweaking of each individual chip the device and circuit design need to be somewhat insensitive to parameter variations. Thus, MMIC amplifiers can be expected to require a longer development phase in order to perform at the leading edge in noise figure and gain. The lower gain per stage, however, is easily made up with additional stages since the FET's are cheap circuit elements. A major advantage of this technology, however, is the same "no circuit tweaking necessary" philosophy that made Si integrated circuits so successful at lower frequencies. Hundreds of devices can then be fabricated in a parallel process on each GaAs wafer. The devices are then dc probed and sample tested at RF frequencies. If a chip functions to specifications, it is kept; otherwise, it is discarded. In this manner, thousands of circuits can be made at much lower unit cost than the present MIC approach where each circuit is individually assembled and tweaked.

To accomplish this goal, however, the production volume of MMIC amplifiers must be large enough to justify the substantial capital equipment requirements, and to establish a high yield manufacturing procedure. For example, it is projected that a complex transceiver chip 10mm X 10mm in size with transmit and receive capabilities, such as a phased array radar module, could be made at a cost of approximately $5-$50/chip. The cost is projected for a volume of 10^5 chips/year assuming reasonable yields at the end of two years of volume production. Thus, the initial commercial MMIC amplifiers are expected to be of custom designs where special systems requirements warrant the premium price. (Some examples would include extremely wideband amplifiers, circuits where extremely well-balanced devices are essential, and applications where size, weight, and reliability are of primary consideration.) As the MMIC process technology and device market volume improve, the next impact of the MMIC technology will be made on microwave systems. Large phased array systems and direct satellite TV are two obvious examples where volumes of 10^5 chips per year are possible. At that time, the standard MMIC amplifiers and components will be replaced by the more cost effective MMIC parts. However, extremely high performance, highly tuned circuits will still be difficult to replace by the MMIC technology. As the frequency increases, the circuit matching elements decrease in size, thus MMIC amplifiers become more attractive. However, the gain, noise, and power characteristics of the active devices rapidly degrade with higher frequency. It is expected that MMIC amplifiers using nominal present day half-micron gate GaAs FET technology can perform through K_a band (26.5-40 GHz). Improved FET's using exotic materials such as modulation doped layers may extend the MMIC amplifier technology through Q-band (40-60 GHz). New devices such as permeable base transistors (PBT), heterojunction bipolar transistors (HJBT), and other devices yet to be developed could conceivably extend the MMIC amplifier technology through W-band (75-110 GHz) and beyond.

Power capabilities of MMIC amplifiers may be expected to be modestly lower than the discrete devices due to the lower yield of high power devices. However, this can be compensated by the use of phased array approaches where the power requirement of each individual module is modest and the total power of the system is obtained by spatial or optical combining.

The ultimate impact of the MMIC amplifier technology is as a part of a multifunctional capability chip, that is, combinations of amplifiers, mixers, oscillators, etc. to replace many present day subsystems such as a microwave receiver front end or a transmit/receive module on a single GaAs chip. As an example of how such a component may appear, an 8 GHz MMIC receiver front end is illustrated by the scanning electron micrograph of **Figure 9**. The chip, starting from the top left corner going clockwise, shows an 8 GHz RF amplifier followed by a mixer (top right). The bottom circuits starting from the right side going to the left are a VCO (lower right) and IF amplifier (lower left). The entire chip is 4 X 4mm in size.

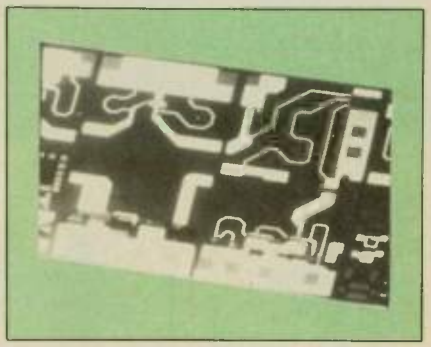

Fig. 9 Scanning electron micrograph of 8 GHz MMIC receiver front end chip.

In conclusion, extensive use of CAD methods for circuit optimization and analysis is required for MMIC designs. Accurate equivalent circuit models of the active and passive devices are used interactively with the circuit layout to complete the chip design. The philosophy that FET's are the most cost effective circuit elements make many low frequency circuit approaches, such as active impedance matching, feasible. Localized doping of selected semi-insulating GaAs substrates using ion implantation techniques is used to fabricate the required highly reproducible active devices. Silicon nitride is used for both the MIM capacitors and the dielectric layers between first and second level metallization. Ample capital equipment capacity for the growth of high quality S.I. GaAs substrate material is being installed. If the recent surge of interest in the MMIC amplifiers and multifunctional circuit technology continues so that the growth in R&D support of the materials, devices, and circuit design arenas is sustained, microwave systems design

(continued on page 50)

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REFERENCES

1. Ch'en, D. R., and D. R. Decker, "Monolithic Microwave Integrated Circuits — The Next Generation of Microwave Components," *Microwave Journal*, Vol. 23, No. 5, May 1980, pp. 67-78.
2. Ch'en, D. R., "Ion Implanted GaAs FET Devices and Circuits," *Asilomar Conference on Circuits, Systems, and Computers Tech. Dig.*, Nov. 1977.
3. Higgins, J. A., R. L. Kuvas, F. H. Eisen, and D. R. Ch'en, "Low Noise GaAs FET's Prepared by Ion Implantation," *IEEE Trans. ED-25*, June 1978, p. 587.
4. Pucel, R. A., H. A. Haus, and H. Statz, "Signal and Noise Properties of GaAs Microwave Transistors," in *Advances in Electronics and Electron Physics*, Vol. 38, New York: Academic Press, 1975.
5. Gupta, A. K., J. A. Higgins, and D. R. Decker, "Progress in Broadband GaAs Monolithic Amplifiers," *IEDM Tech. Dig.*, Dec. 1979.
6. Ch'en, D. R., and F. H. Eisen, "Ion Implanted High Frequency High Speed GaAs Integrated Circuits Technology," *J. Vac. Sci. Technology*, Vol. 16, No. 6, Nov./Dec. 1979.
7. Fairman, R. D., R. T. Chen, J. R. Oliver, and D. R. Ch'en, Growth of High Purity Semi-Insulating Bulk GaAs for Integrated Circuit Applications, *IEEE Trans. ED* Special Issue, to be Published Feb., 1981.
8. Pengelly, R. S., and D. C. Rickard, "Design, Measurement and Application of Lumped Elements Up to J-Band," *Proc. of 7th European Microwave Conference*, Copenhagen, 1977.
9. Immorlica, A. A., D. R. Decker, and W. A. Hill, "A Diagnostic Pattern for GaAs Material Development and Process Monitoring," *IEEE Trans. ED-27*, No. 12, Dec. 1980, pp. 2285-2291.
10. Decker, D. R., A. K. Gupta, W. C. Petersen, and D. R. Ch'en, "A Monolithic GaAs IF Amplifier for Integrated Receiver Applications," *IEEE MTT Symposium Digest*, May 1980, pp. 363-366.

Daniel R. Ch'en is Manager, Microwave Devices, at Rockwell International, Inc. He has a B.A., Physics, University of Oregon; Ph.D., Solid State Physics, University of California, Berkeley. Since joining Rockwell International in 1976, Dr. Ch'en has been in charge of the Microwave Devices Section of the Microelectronics Research and Development Center in Thousand Oaks, California. He spearheaded the development of an all ion implanted, GaAs FET and the successful transfer of this process to pilot production. He was instrumental in the GaAs digital integrated circuits (GaAs I.C.) program where ion implanted MESFET's are used to achieve pico second logic circuits with low power dissipations. His interests in microwave circuitry and devices led to the Monolithic Microwave Integrated Circuits (MMIC) programs at Rockwell International. Dr. Ch'en joined Avantek, Inc., Santa Clara, California in 1973 and was Senior Scientist and Manager of Device Development. He was responsible for the device materials aspects of the GaAs FET and Si bipolar transistor development. Prior to joining Avantek, Inc., Dr. Ch'en was active in microwave transistor development at the Central Research Laboratories, Texas Instruments, Inc., Dallas, Texas. He was involved in the development of an arsenic emitter diffusion process and its applications to Si microwave bipolar low noise and power transistors. He is a member of Phi Beta Kappa, American Physical Society, and the Electron Devices Society and the Circuits and Systems Group of IEEE.

D. R. Decker is a Member of Technical Staff, Microwave Devices, at Rockwell International. Dr. Decker received the B.S. degree in Physics from North Carolina State University and the M.S. degree in Physics and Ph.D. degree in Electrical Engineering from Lehigh University. He joined the Bell Telephone Labs. in Allentown, Pennsylvania, where he was engaged in research on harmonic generator circuitry. Later, he transferred to the Bell Labs. at Reading, PA, where he developed high power Si varactor diodes, PIN diodes and Ge, Si, and GaAs IMPATT diodes. In 1972, he joined Varian Associates in Palo Alto, CA, where he was engaged in research and development of high-efficiency GaAs IMPATT diodes, and low-noise and high-power GaAs FETs. In 1975, he joined Hewlett Packard in Palo Alto, CA, where he worked on low-noise and high-power GaAs FETs and circuits. In 1976, he joined the National Radio Astronomy Observatory in Charlottesville, VA, where he developed low noise millimeter wave receivers. In 1978, he joined the staff of Rockwell's Microelectronics Research and Development Center where he is presently engaged in the research and development of GaAs microwave devices and integrated circuits.

A. K. Gupta also is a Member of the Technical Staff, Microwave Devices Section, Rockwell Int'l. He received his B. Tech. degree in 1973 from the Indian Institute of Technology, Kampur, India, and his M.S. and Ph.D. degrees from Cornell University in 1975 and 1978 respectively. He joined Rockwell International-MRDC in 1978 and has been engaged in the development of GaAs monolithic microwave integrated circuits.

W. C. Petersen is a Member of Technical Staff, Microwave Devices Section at Rockwell Int'l. Dr. Petersen received his B.S. degree in Electrical Engineering in 1971 from New York University and his M.S. and Ph.D. degrees in Electrical Engineering in 1973 and 1976, respectively, from Cornell University. In 1976, he joined Varian Associates where he was engaged in the design and development of various microwave FET and bipolar amplifiers, including low noise, high power, and broadband limiting amplifiers. He is an author of several computer aided design programs used for both network analysis and synthesis. In 1979, he joined the Rockwell International Microelectronics Research and Development Center where he is presently engaged in the research and development of monolithic GaAs microwave integrated circuits. He is a member of Tau Beta Pi, Eta Kappa Nu, and the IEEE.

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MODEL NUMBER AMA–	FREQUENCY RANGE (GHz)	GAIN (dB) MIN	GAIN VARIATION (±dB)	NOISE FIGURE (dB MAX)	VSWR IN/OUT	POWER @ 1dB (dBm MIN)	POWER SAT. (dBm)	TYPICAL INTERCEPT POINT (dBm)
LOW NOISE AMPLIFIERS								
–0709A	.755-.985	30	0.50	2.0	1.25	+ 10	–	+ 20
–1020A	1.00-2.00	40	1.00	3.0	2.00	+ 25	–	+ 35
–1724A	1.70-2.40	24	1.00	2.0	1.25	+ 10	–	+ 20
–2040A8	2.00-4.00	40	1.00	3.5	2.00	+ 30	–	+ 40
–2652A2	2.60-5.20	30	1.00	4.2	2.00	+ 17	–	+ 27
–4450A	4.40-5.00	30	0.50	2.3	1.25	+ 10	–	+ 20
–2060A	2.0-6.0	40	1.70	6.0	2.00	+ 14	–	+ 24
–5964A	5.92-6.42	25	1.00	2.5	1.25	+ 10	–	+ 20
–4080A7	4.00-8.00	40	1.00	4.5	2.00	+ 27	–	+ 37
–70120A4	7.00-12.0	30	1.50	7.0	2.00	+ 13	–	+ 23
–117122A	11.7-12.2	30	0.50	4.0	1.25	+ 10	–	+ 20
–144152A	14.4-15.2	30	1.00	6.0	1.25	+ 10	–	+ 20
–80160A	8.0-16.0	30	2.00	9.0	2.00	+ 12	–	+ 22
–80181A	8.0-18.0	30	2.5	9.0	2.00	+ 12	–	+ 22
LIMITING AMPLIFIERS								POWER VAR ± dB
–1020L	1.0-2.0	40	1.0	3.5	2.0	–	+ 12	1.0
–1530L	1.5-3.0	40	1.0	4.0	2.0	–	+ 12	1.0
–2040L	2.0-4.0	40	1.0	4.5	2.0	–	+ 12	1.0
–2652L	2.6-5.2	40	1.0	5.5	2.0	–	+ 12	1.0
–2756L	2.7-5.6	65	1.0	6.0	2.0	–	+ 12	1.0
–2060L	2.0-6.0	40	2.0	6.5	2.0	–	+ 12	1.0
–4080L	4.0-8.0	40	1.0	6.5	2.0	–	+ 12	1.0
–70120L	7.0-12.0	40	1.5	8.0	2.0	–	+ 12	1.5
–80160L	8.0-16.0	30	2.0	10.0	2.0	–	+ 12	1.5
–80180L	8.0-18.0	30	2.5	10.0	2.0	–	+ 12	2.0
POWER AMPLIFIERS								
–0709B1	.755-.985	50	1.00	8.0	1.25	–	+ 39	–
–1020B	1.00-2.00	40	1.00	4.0	2.00	+ 30	+ 32	+ 40
–1720B	1.70-2.00	20	1.00	10.0	1.25	–	+ 39	–
–2040B	2.00-4.00	40	1.00	5.0	2.00	+ 29	+ 31	+ 39
–3742B	3.70-4.20	50	0.75	5.0	2.00	+ 34	+ 37	+ 44
–4450B2	4.40-5.00	47	0.50	5.5	1.25	+ 34	+ 36	+ 44
–5964B2	5.90-6.40	47	1.00	5.5	1.25	+ 31.5	+ 34	+ 41.5
–6471B	6.40-7.10	47	1.00	6.0	1.25	+ 29.5	+ 32	+ 39.5
–4080B	4.00-8.00	40	1.00	5.5	2.00	+ 27	+ 30	+ 37
–107117B	10.7-11.7	47	1.00	7.0	1.25	+ 29.5	+ 31	+ 39.5
–117122B	11.7-12.2	40	1.00	8.0	1.25	+ 27	+ 29.5	+ 37
–122127B	12.2-12.7	47	1.00	8.0	1.25	+ 27	+ 29.5	+ 37
–140145B	14.0-14.4	40	0.50	9.0	1.30	+ 25.5	+ 28	+ 35.5

1. Connectors are SMA F, unless otherwise requested.
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3. Frequency coverage: Models from 755 MHz to 18 GHz.

Monolithic Microwave GaAs Power FET Amplifier

HUA QUEN TSERNG and VLADIMIR SOKOLOV
Central Research Laboratories
Texas Instruments, Inc.
Dallas, TX

INTRODUCTION

The GaAs FET device processing technology has matured to the point that it is now feasible to combine active FET devices and passive matching elements (transmission lines, inductors, capacitors) on a single GaAs chip. Since the introduction of the first monolithic low-noise amplifier chip,[1] a great deal of emphasis has been placed on power amplifier development. For system applications (such as phased-array radar systems), the monolithic amplifier has significant size, weight and potential cost advantages over the hybrid MIC amplifiers. Table I summarizes the latest monolithic power FET amplifier results reported.[2-7] In addition to the power and gain performance, the chip sizes are also indicated. In this paper, design considerations for monolithic circuits in general and power amplifiers in particular are discussed. Circuit topologies, losses in matching elements, RF grounding and thermal resistance are among the topics considered. Characterization procedures pertinent for power FET amplifiers are also briefly described. Finally, some power FET amplifier circuits are given as examples for highlighting the design considerations discussed in this paper.

DESIGN CONSIDERATIONS

Circuit Topologies

For monolithic amplifier design, either a distributed approach or lumped-element approach can be used for impedance matching. For narrow bandwidths, the use of quarter-wave impedance transformers is the most straightforward approach, since conventional MIC technique can readily be applied. However, this matching scheme consumes too much GaAs substrate area especially at X-band and lower frequencies. For frequencies ≥ 20 GHz, the distributed approach appears to be suitable because of shorter wavelength. For the lumped-element matching approach, classical methods using discrete lumped LC elements can be applied.[8] Loop inductors, MIM and interdigital capacitors can be used which are formed on the same GaAs substrate as the active devices. The use of lumped-elemen[t] impedance matching tends to minimize the substrate area an[d] broaden the bandwidth, since t[he] circuit elements can be placed very close to the active device. While the design values of interdigitated and MIM capacitors generally agrees well with the e[x]perimental results, the loop inductors generally behaves in a semi-lumped fashion, especially for large loop sizes and at high frequencies. As a design rule an[d] to eliminate the impedance uncertainty, these inductors can b[e] treated as high impedance trans[-]mission lines. The characteristic impedance can be determined from the linewidth and substrat[e] thickness. For example, a Z_0 of

TABLE 1

MONOLITHIC POWER FET AMPLIFIER CIRCUITS SUMMARY

TYPE	PERFORMANCE	CHIP SIZE (mm)	COMPANY	REFERENCE
• Single-stage	9.5 GHz, 0.5 W, 4 dB	5 x 6.25	Raytheon	2
• Single-stage, 4-way combiner.	9.5 GHz, 2 W, 4 dB	4.75 x 6.13	Raytheon	3
• Two-stage, push-pull	9 GHz, 1.4 W, 12.3 dB	2 x 2	TI	4
• Single stage, paraphase	8.2 GHz, 0.1 W, 5 dB	2 x 2	TI	4
• Three stage	9.2 GHz, 0.4 W, 23 dB	1 x 4	TI	5
• Four stage	8.9 GHz, 1 W, 27 dB	1 x 4	TI	5
• Two stage	5.5-11 GHz, 0.6 W, 6 dB	2 x 5	Westinghouse	6
• Three-stage	2-7 GHz, CG-CS-CD, 8 dB good in/out SWR's	——	Rockwell	7

80 Ω is obtained for a width to height (W/h) ratio of ~ 0.19 on GaAs substrate. To conserve the space, the transmission line can be looped or meandered. Care must be exercised, however, to avoid undesirable parasitics due to proximity coupling.

- *Microstrip Transmission Lines on GaAs*

Since good quality semi-insulating GaAs has a loss tangent of about 0.0004[9], it is generally a very good approximation to neglect dielectric losses and consider metal losses only. One major factor which results in lowering of the unloaded Q of microstrip transmission lines incorporated in monolithic GaAs power FET circuits is that a relatively thin GaAs substrate whose ground plane side is soldered directly to a metal carrier must be used. Typical substrate thickness may be in the range of 0.1 to 0.2 mm (thicker substrates would result in higher thermal resistances and poorer power and efficiency performance due to inadequate heat sinking of the active devices). For microstrip the relation for the unloaded quality factor may be shown to be equal to $Q = K\sqrt{f}\,H/A(Z_o)$ where K = constant involving the conductivity of the conductor metal, H is the height of the microstrip substrate and A is the normalized attenuation factor as given by Schneider.[10] A is a function of the characteristic impedance, Z_o, of the line and includes the effects of the conductor thickness, t (in the derivation of A, t is assumed to be several skin depths). The function, A, evaluated for the case of microstrip on semi-insulating GaAs is shown in **Figure 1**. The numbers in parenthesis indicate the corresponding Q factors at 10 GHz. For high impedance lines, Q's of only 25-50 are theoretically realizable for microstrip lines on 0.1 mm thick substrates. Note that if the substrate thickness is doubled, then for the same characteristic impedance Q is almost doubled as seen from the expression for the quality factor shown in **Figure 1** (A also has a weak dependence on H and therefore Q does not exactly increase by a factor of 2).

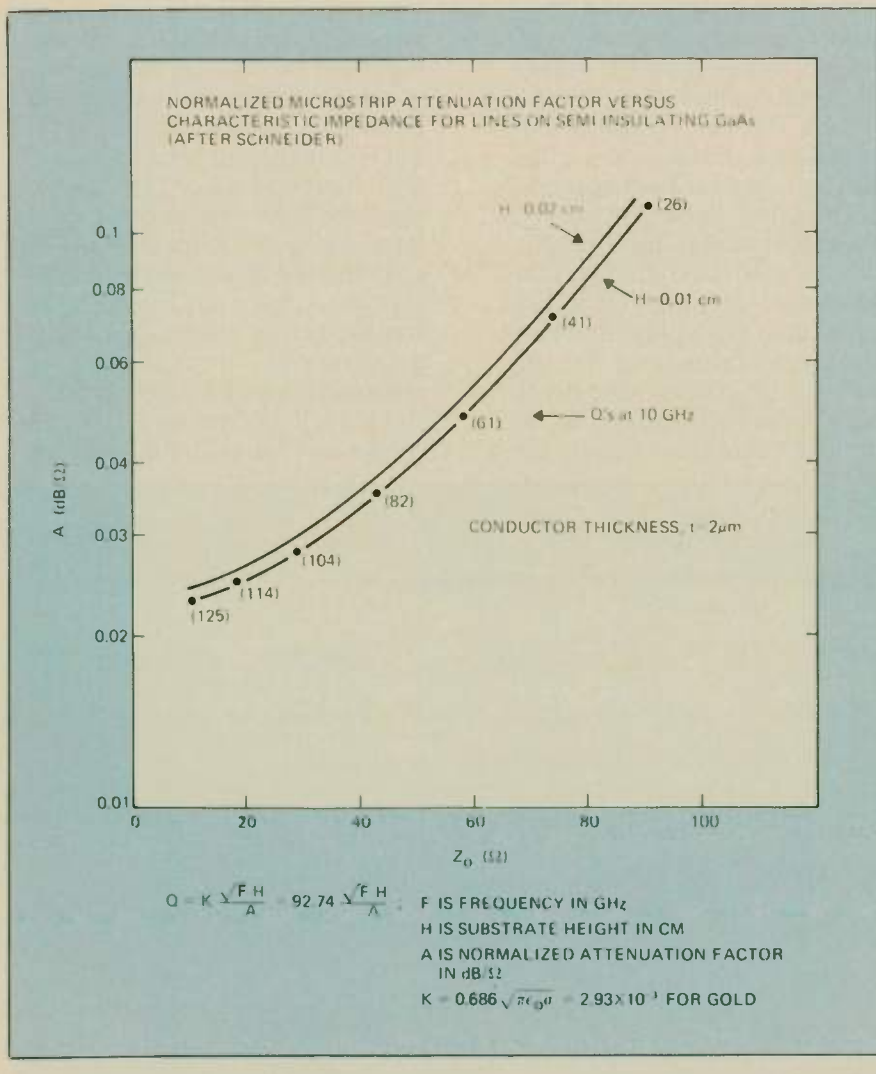

Fig. 1 Unloaded Q factor for microstrip on semi-insulating GaAs.

At 10 GHz, two skin depths in gold (~ 1.6 μm) is about the limit in metal thickness that can be "lifted-off" by photoresist in FET (discrete or monolithic) device processing. Consequently, to minimize loss, a thicker layer of gold is often achieved by plating up the conductor pattern originally defined by the metal lift-off technique.

- *Inductors*

To estimate the Q of inductors, one can start by considering the Q of a short section of high impedance microstrip line. It can be shown that for the case of losses dominated by conductor losses the transmission line expression for the unloaded Q factor, $Q = \beta/2\alpha$, closely approximates the familiar expression for the Q of an inductor, $Q = \omega L/R$. For the case of a high impedance line, L and R are just the inductance and resistance per unit length respectively. Thus treated as a lumped inductor or as a short piece of line the Q's are very nearly equivalent. For example, on 0.1 mm thick GaAs a strip track width of only 25 μm corresponds to a 74 Ω microstrip line. Its inductance per unit length ($L = Z_o/v_{ph}$) is approximately 7 nH/cm, and from **Figure 1**, Q at 10 GHz for a short length of such a line is 41. For a 12 μm trackwidth the inductance per unit length is only 8.3 nH/cm yet its Q is down to 26.

The above theoretical considerations are generally confirmed by experiment. Q's for single loop inductors with trackwidths of 18-25 μm on 0.1 mm GaAs

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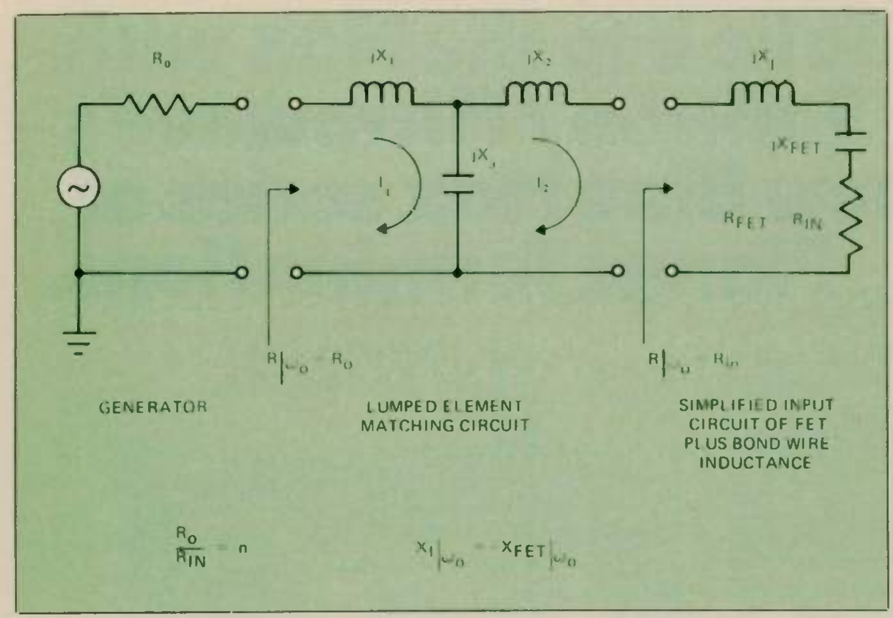

Fig. 2 Example of lumped element impedance matching to simplified input equivalent circuit of FET.

substrates and metallization thickness of 1.5 μm or greater typically fall in the range of 20-40 in X-band.

• *Capacitors*

In GaAs monolithic circuits, overlay MIM (metal-silicon-nitride-metal) or interdigital capacitors fabricated on the GaAs chip are employed. For both types of capacitors with values of less than about 3 pF, the normal dominant losses occur in the metal plates or fingers through which the displacement current must pass. The equivalent resistive element is in series with the capacitance so that the Q is given by $(\omega C \cdot R_{ac})^{-1}$. Q's at 10 GHz for such capacitors fall in the range of 40-80 with interdigital types having somewhat better values. For such type of capacitors the Q's can be measured by standard techniques used for evaluating varactors (e.g. as described by DeLoach.[11]

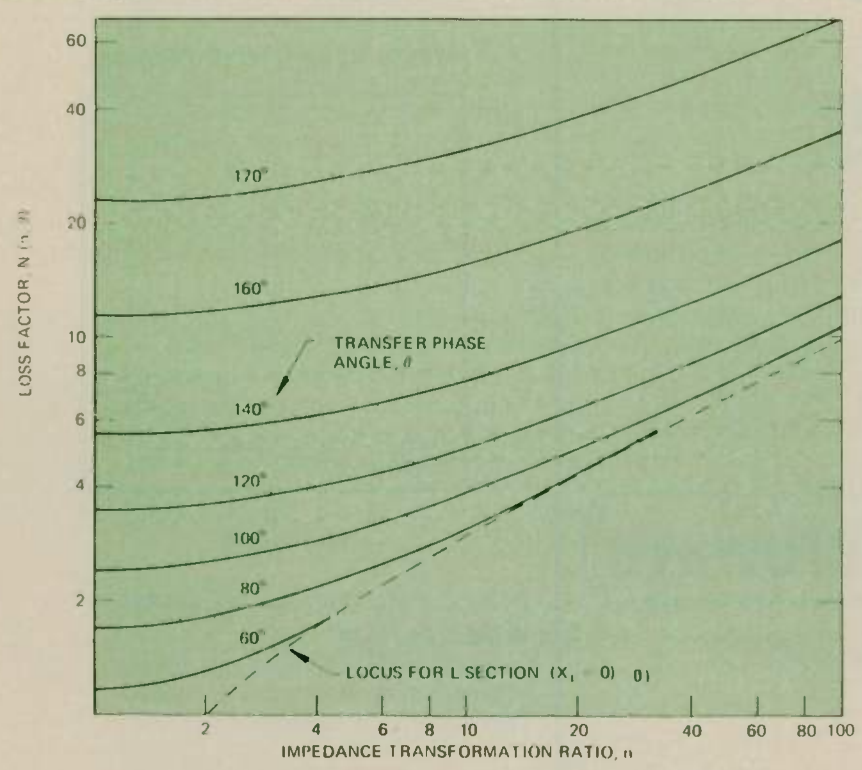

Fig. 3 Loss factor, B (η,θ) for lumped element T-matching network.

Capacitors with large values (> 3 pF) are mostly of the overlay type. Preliminary indications from several laboratories generally indicate Q values at 10 GHz for these capacitors in the 20-40 range. It is believed that for such capacitors leakage between plates at the periphery or through the dielectric also contribute to the losses and account for the lower Q factors.

• *RF Losses in a Typical Monolithic Impedance Matching Network*

Figure 2 shows an often used configuration (as shown in Figure 1 for matching between real impedances R_o and R_{in} using lumped elements. Assume, for example, as in Figure 6 that this network is used to impedance match to the input equivalent circuit of a power FET having an input resistance R_{in}, from a source resistance R_o with $R_{in} < R_o$, and $R_o = 50\ \Omega$. Further, let $R_o = nR_{in}$, where n is the impedance transformation ratio. Note that in Figure 2 the gate capacitance of the intrinsic FET is resonated with bond wire inductance to bring the input impedance to a real value, R_{in}, at the center band frequency, f_o. The circuit efficiency for power transfer through the network at f_o can be approximated in a fairly straightforward manner using well established formulas for the case of small losses, i.e., for reasonable values of the element Q's (> 10). Figure 3 shows the loss factor,[12] B, plotted for values of $1 \leq n \leq 100$ and $\cos^{-1}(n^{-1/2}) \leq \theta < 180°$.

It should be emphasized that all of the loss considerations mentioned above assumed nominal characteristics for the components involved. In the practical development of monolithic circuits much higher losses are sometimes incurred because of abnormal processing or fabrication. A GaAs substrate with a significant doping "tail" from the active layer may result in dielectric circuit losses which are so great that they practically render the monolithic amplifier useless. Poor nitride deposition, or excessively thin metal can make capacitors have the dominant

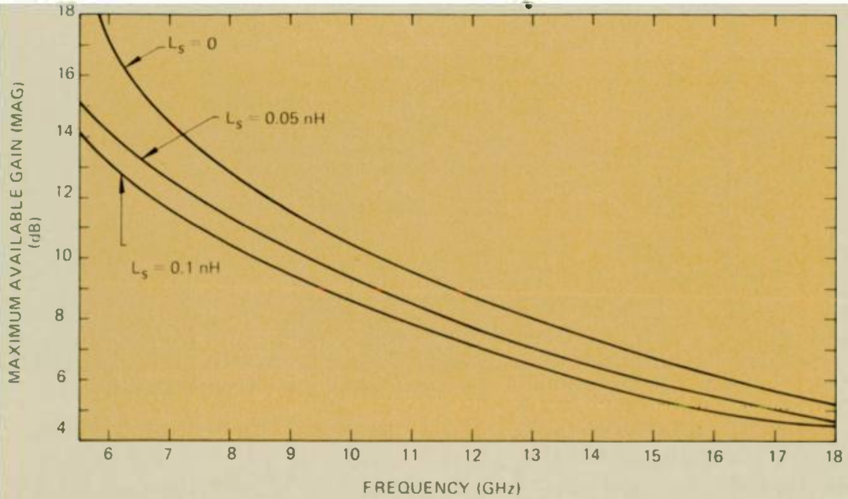

Fig. 4 Effect of source lead inductance on the maximum available gain of a 300 μm gatewidth FET.

nd overwhelming loss. Obviousy these losses are not intrinsic o monolithic technology and an be controlled by careful creening and fabrication procedures.

RF Grounding

Providing good RF ground to ommon source-operated power FET's at microwave frequencies an be a difficult problem for liscrete devices, not to mention he challenge it provides in the lesign of power FET monolithic ircuits. In the latter case, active levices may be located away rom the chips edge, making edge rounding with bonding wire impractical due to excessive source ead inductance. **Figure 4** shows he deleterious effect that source ead inductance has on the maxinum available gain of a 300 μm atewidth FET. The curves were omputed from a simplified quivalent circuit of such a deice. At 10 GHz, a 0.1 nH source ead inductance causes a 1.3 dB eduction in MAG. For larger atewidth devices the problem is ompounded by the fact that it is lifficult to present (because of ayout) exactly the same source ead inductance to all cells. Consequently, not only is the MAG legraded by the inductance but t also degrades because of elecrical asymmetry resulting in oorer cell combining efficiency.

A straightforward approach to RF grounding, at least in principle, is to connect the chips topide ground metallization with the underside metallization (solder joint interface) and chassis ground by means of plated through holes or vias etched in the GaAs. This technique is electrically very sound, but requires extra back-side processing, and mounting precautions. The vias must be in close proximity of each FET and must ensure suppression of any transmission line effects on the top ground metallization in the frequency band of interest.

For less complex monolithic circuits where the FET's can be located next to the chips edge, fine gold mesh can be used to connect the chassis ground to appropriate ground terminals on the top side. Such mesh can provide significantly less than 0.1 nH inductance to ground.

Another approach is to confine the RF ground currents to the top of the chip by means of a suitable circuit design. Monolithic push-pull power amplifiers achieve this objective by realizing a virtual ground between the push-pull pairs. If the push-pull pair share a common source metallization, then current at the fundamental frequency flows between the push-pull pairs and is confined to the chips surface. Effective source-lead inductance can be minimized by locating the FET pair close to each other.

Substrate Thickness

Based on the experience with discrete FET's most monolithic power FET circuits are designed for fabrication on GaAs substrates having a final thickness about 0.1 mm. For FET's incorporated in monolithic circuits the thermal resistance is similar to the discrete case as most of the heat flow is confined to a vertical path whose width is comparable to the width of the FET structure.

This fact can be substantiate qualitatively by liquid crystal temperature measurements mad on operating devices incorporated in monolithic circuits. For a typical 1.2 mm gatewidth discrete FET, a substrate thickness of 0.1 mm results in a thermal resistance of about 45°C/W for well soldered (heat sunk) devic In terms of power performance this corresponds to roughly a 0 dB difference in output power between CW operation and sho pulse (⩽ 200 ns), low duty cyc (⩽ 10 percent) operation where in the channel temperature is essentially the ambient room temperature.

Thicker than 0.1 mm substrates are also possible for implementation in power FET monolithic circuits. As discusse earlier, thicker substrates result in lower microstrip and inducto losses, and also are advantageou from the point of view of great mechanical strength. Saturated output power measurements made on 600 μm discrete FET's fabricated on 0.1 mm and 0.2 mm substrates indicate that less than 0.4 dB in the maximum output power is lost for FET's the thicker substrate. Consequently, it is quite feasible that because of the better Q factors and greater strength, substrate thicknesses between 0.1 and 0.2 mm can be practical for monolithic power FET applications.

MONOLITHIC POWER AMPLIFIER CIRCUITS

Characterization Procedures

In a monolithic power amplifier circuit, the Q's of the passiv components can be determined from conventional measuremen techniques. Loss considerations for these components were discussed above. During the early design stage of the monolithic amplifier, additional characterization techniques as described below can be used for design evaluation. This is especially true when the experimental results fall short of theoretical predictions.

To isolate the active device performance from the matching circuit losses (either dissipative or mismatch losses), discrete FET's cut from the amplifier chip can be used for power-gain evaluation and impedance measurement (S-parameter and load-pulling measurements). For the power-gain evaluation, conventional hybrid MIC technique can be used. If the discrete device performance proves to be satisfactory, the S-parameters of the individual stages, including input/output matching networks, can then be measured to determine the quality of the impedance matching at a certain reference plane between stages. Alternatively, the interstage matching network between any two FET's can be evaluated by cutting off the input matching circuit of the first stage and the output matching network of the second stage. External broadband hybrid MIC matching networks are used for gain-power determination. Such a structure — a cascade of two common-source FET's with monolithic interstage matching — has recently been described.[13] Because of the flexibility in tuning of the external hybrid MIC matching circuits, the monolithic interstage matching network can readily be evaluated. Another possible qualitative evaluation scheme for monolithic power GaAs FET amplifier circuit is to use the light emission property of FET's under RF operating conditions.[14] Since the emitted light intensity can be correlated with FET RF input drive levels, it can be used to investigate the interstage matching of a multistage monolithic amplifier.[5] Care must be exercised, however, in interpreting the light-emission results. FET's having high gate-drain breakdown voltage do not emit light as readily as lower gate-drain breakdown FET's under similar dc bias and RF drive levels. The threshold for light emission must be compared with discrete FET's cut from the same slice as the amplifier chip for the evaluation to be unambiguous.

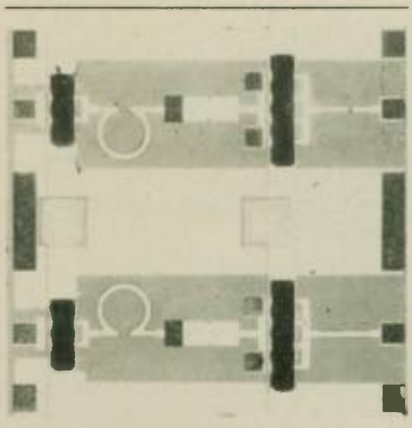

Fig. 5 A two stage monolithic push pull amplifier.

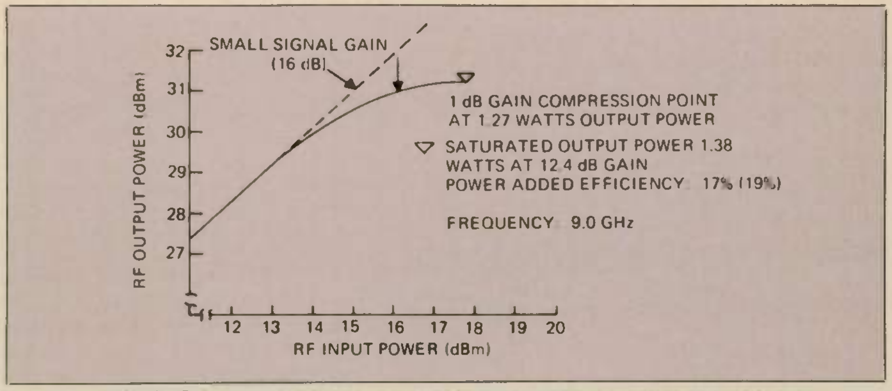

Fig. 6 Gain-compression characteristic for a 1.4 W monolithic amplifier.

Power FET Amplifier Circuits

Several practical monolithic GaAs power FET amplifier circuits will be described in this section. Single-ended, push-pull and paraphase amplifiers are described. Results of external circuit modifications of monolithic amplifiers for other than intended frequency band of operation are also covered.

- *Two-Stage, 1.4 W Monolithic Push-Pull Amplifiers*

Figure 5 shows a two-stage push-pull amplifier[4] chip. The chip dimensions are 2.0 mm x 2.0 mm. This was one of the earliest monolithic amplifiers developed in our laboratory. The series inductors and capacitors are monolithically integrated on the chip while the shunt inductors are realized with 25 μm diameter bonding wire. (This procedure allowed some flexibility in initial studies.) The output stage consists of a pair of 1.2 mm gate-width FET's, while the input stage utilizes a pair of 600 μm FET's with each stage operating in the push-pull mode. The input and output ports of the chip are designed to interface with a pair of 50 Ω antiphase transmission lines or, more simply, a 100 Ω balanced line. To test the amplifiers, external baluns are needed at input and output. For this purpose 180° hybrid rings fabricated on 0.6 mm thick alumina are used.

Figure 6 shows the gain-compression characteristic for one of the push-pull amplifiers. At 9.0 GHz, an output power of 1.4 W with 12 dB gain is achieved. The small-signal gain is 16 dB with a 1 dB gain compression point of 1.2 W. At the saturated output power, the power added efficiency is 19%. The 1 dB bandwidth is about 1.2 GHz.

- *Three Transistor X-Band Paraphase Amplifier*

To further show the flexibility of realizing fairly sophisticated monolithic circuits, a three-tran-

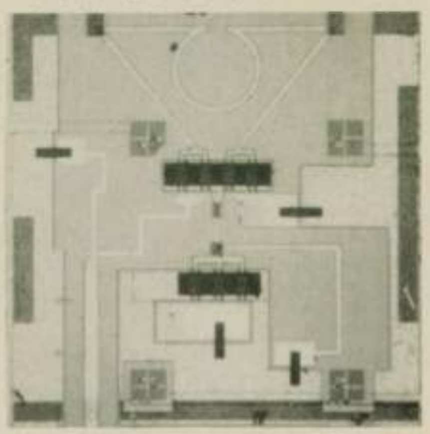

Fig. 7 Microphoto of paraphase amplifier.

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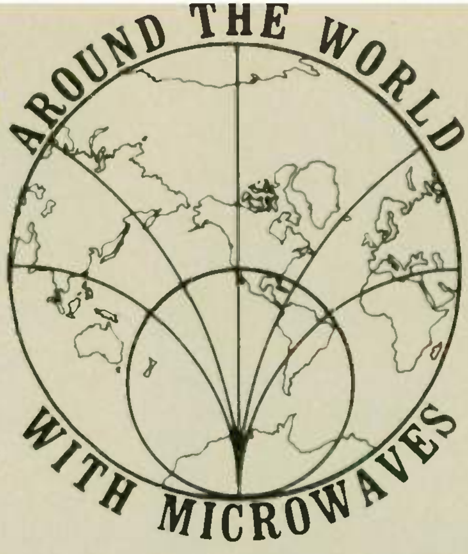

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sistor monolithic X-band paraphase amplifier was developed as shown in **Figure 7**. This active "balun" circuit will replace the input 180° hybrid ring so that the push-pull amplifier can be driven from a single unbalanced

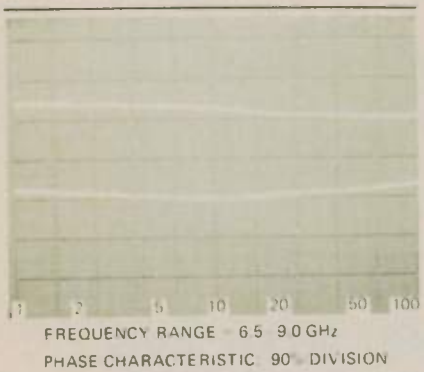

Fig. 8 Phase characteristic for paraphase amplifier – output of differential pair.

transmission line. To date we have tested the paraphase amplifier alone. The GaAs chip size for this circuit is 2.0 mm x 2.4 mm.

Figure 8 shows the insertion phase characteristic for the two outputs of the differential FET pair. The phase tracking of the 180° characteristic is accurate to within about ± 20° over the frequency range of 6.5 to 9.0 GHz. The gain characteristic for the two outputs tracks within ± 0.75 dB over this frequency range and is +3 dB at 8 GHz (note that a passive balun would show 3 dB loss).

Work is now underway to further optimize the paraphase chip and use it to drive the two-stage push-pull amplifier. It is expected this combination would produce a 1.4 W, 15 dB gain monolithic amplifier with an unbalanced input and a balanced push-pull output. Such an amplifier would be useful in any application requiring a balanced drive as, for example, in the case of a dipole antenna.

- *Multistage Single-Ended Amplifiers*

A single-ended, multistage design aimed at phased-array radar applications has produced encouraging results. Two completed amplifier chips, one a three-stage and one a four-stage, are shown in **Figure 9**. Each chip is 1 mm x 4 mm. Details of amplifier design and fabrication were published elsewhere.[5] **Figure 10** shows the RF performance of the four-stage amplifier at two input power levels. With -3 dBm input, an output power of 800 mW with 32 dB gain was achieved at 8.7 GHz with a power-added efficiency of ~ 15%. An output power of ~ 1 W with 27 dB gain was obtained at 8.9 GHz with a +3 dBm input. The power-added efficiency was 17%.

The circuit topologies were flexible enough to allow external bond wires to be used as shunt inductors for amplifier operation at C- or S-bands. **Figure 11** shows the gain-frequency response of a four-stage monolithic amplifier that was modified by using external bondwire inductors. An output power of 2 W with 28 dB gain and 36.6% power-added efficiency was achieved at 3.5 GHz. The 1 dB bandwidth was approximately 1 GHz.

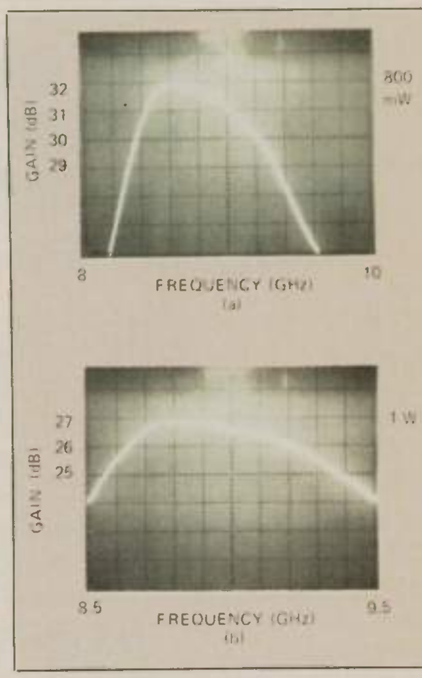

Fig. 10 Gain-frequency response of a four-stage monolithic amplifier
(a) RF input = -3 dBm
(b) RF input = +3 dBm.

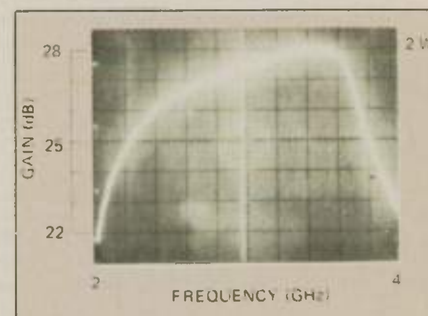

Fig. 11 Performance of a four-stage modified monolithic amplifier: RF input = +5 dBm.

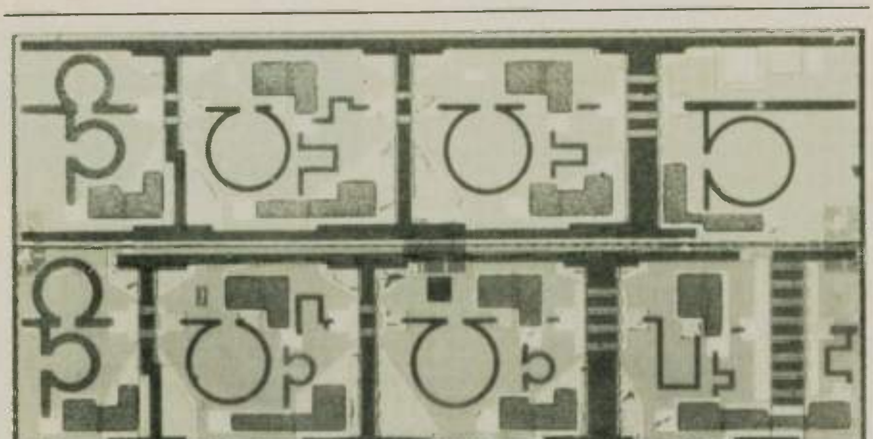

Fig. 9 Circuit layout of three- and four-stage amplifiers; chip size for each amplifier: 1 mm x 4 mm.

CONCLUSIONS

The design approaches used in the fabrication of monolithic microwave GaAs power FET amplifiers are presented. Design considerations as well as characterization procedures are discussed. Some power amplifier circuits are described along with their performance results. As the monolithic processing technology becomes more mature, improved amplifier performances in terms of output power, gain, bandwidth, efficiency and upper fre-

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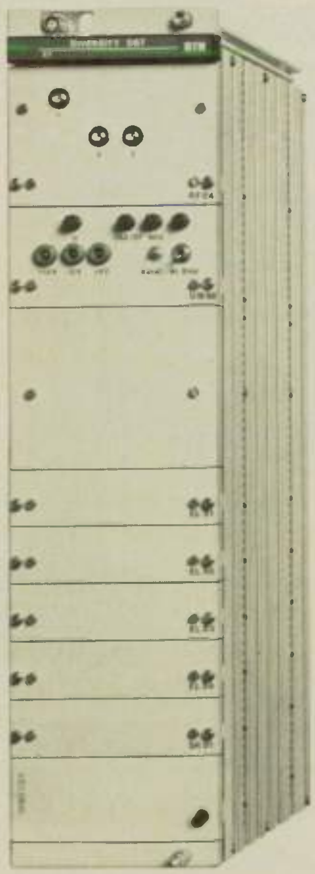

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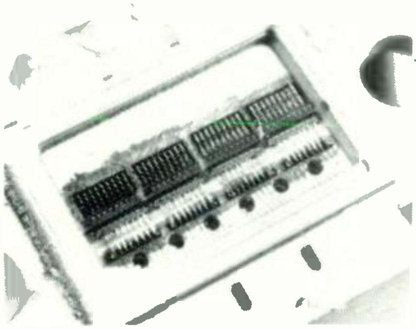

Fig. 1 Experimental four-cell 90 W S-Band radar device.

A high performance S-Band pulsed power transistor has been developed which provides a level of performance adequate for use in solid-state phased-array radar and ECM systems. This transistor is the result of several years[1] of continuous support and encouragement for this and related projects from ERADCOM, BMDATC and NRL, whose support is gratefully appreciated. Even though several of these contracts did not directly relate to the described effort, critical technological advancements developed under each one were "spun-out" and applied to the S-Band radar device.

Solid-state phase-array radar has been an industry-wide dream for more than a decade. Just recently, with the successful operation of PAVE-PAWS, AN-TPS-59 and the Belgian B3D radar, the feasibility of large solid-state phased arrays has been demonstrated at UHF and L-Band. Until now, there has been no microwave power transistor available which could be used in such a system at S-Band (2.7-3.5 GHz).

Solid-state systems can provide a level of versatility, performance and reliability unattainable with tube type systems for both ECM and radar.

Output powers of up to 90 W have been obtained from laboratory prototype multicell power transistors (**Figure 1**) under long pulse conditions (100 μs, 10%) at 3.1 GHz and 70 watts at 3.5 GHz with 400 MHz instantaneous bandwidth, 6 dB gain and 40% efficiency (**Figure 2**). Forty-five watts with similar gain and efficiency has been obtained from a half-size device (**Figure 3**) suitable for large-scale production.

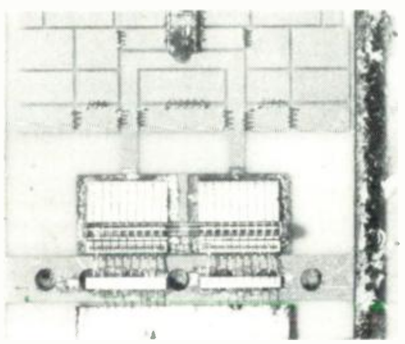

Fig. 2 Two-cell 45 W S-Band radar device.

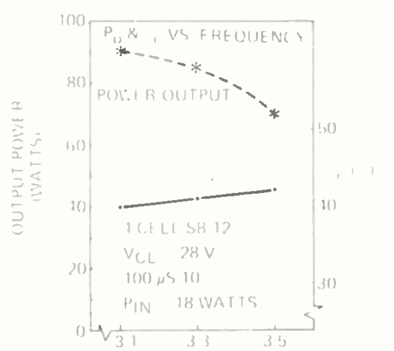

Fig. 3 RF performance of four-cell device.

The basic cell design for the S-Band devices is the designated SB-12. This cell is unique in its design in that the active area of the cell has a very high aspect ratio. The cell dimension is 37.5 μ (1.5 mil) long and 2184 μ (86 mil) wide. The cell contains 360 emitter fingers interdigitated between 361 base fingers. The total emitter periphery is 25.6 mm (1007 mils) per cell and the emitter width is 1.25 μ. The pitch (center-to-center emitter spacing) is 6 μ. Each cell is capable of producing about 22 watts in S-Band.

The base is formed by ion-implantation and is surrounded by a break-down voltage enhancing P^- guard ring. Emitter ballasting is provided by a diffused silicon resistor structure which provides an individual ballast resistor for each emitter finger pair. The emitter is formed by an arsenic diffusion from a doped polysilicon (DOPOS) source. This DOPOS layer remains on the emitter and provides permanent emitter-base junction protection.

The metallization is a two-layer refractory gold system. First layer metal is pattern plated to a thickness of 1.2 μ and then covered with silox. Contact openings are then etched and the second layer metallization (bonding pads and feeder bars) is pattern plated to a thickness of 5 μ. This two-layer system reduces the resistance and inductance and parasitic capacitance of the feeder bars and bonding pads. There are nine base pads and eight emitter pads per cell.

The internal matching circuitry designed for this device is unique. It is based on a concept developed at RCA by Belahoubek et al.[2] The concept is shown in the schematic diagram, **Figure 4**. In this circuit configuration, the shunt inductor is not returned to ground as is done with conventional internally matched devices. Instead, the shunt inductor returns directly to the base bonding pad of the transistor. This concept, called the "direct-

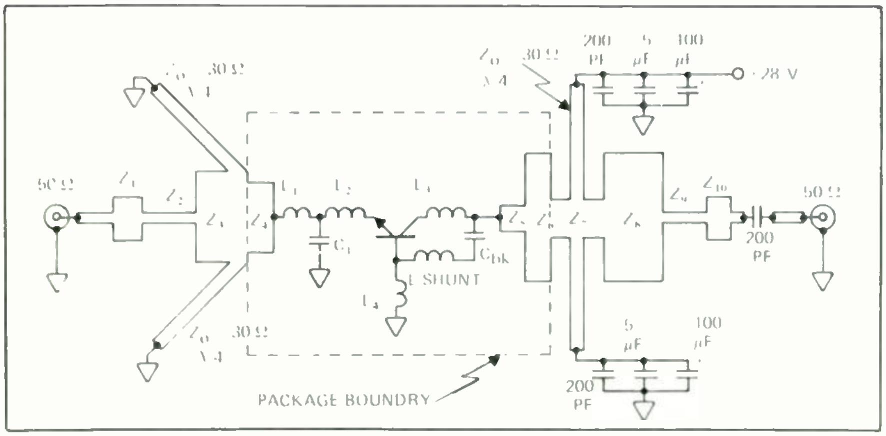

Fig. 4 Internal and external matching circuitry for four-cell device.

return shunt inductor," allows the shunt inductor elements to be evenly distributed along the width of the transistor. This is of critical importance as the device widths approach or even exceed $\lambda/4$. Realization of the shunt inductor is facilitated by the use of a special silicon chip called a "monolithic shunt inductor" or MSL. This chip contains the dc blocking capacitor for the shunt inductor, and special printed inductor stripes deposited over a thick polysilicon dielectric. The polysilicon dielectric process was developed under an NRL contract (N0014-75-C-0405). The MSL chip greatly facilitates assembly and adjustment of the devices. The shunt inductor also provides a critical impedance transformation at the collector and allows broadband operation which would be impossible without its presence.

The rest of the internal matching elements are used to form conventional low-pass type impedance transformers. The external microstrip matching elements provide additional impedance matching.

The bias circuits for high power pulsed devices are especially critical. It is the external bias circuits which determine to the greatest extent the transient behavior of the device. The intrinsic rise time of these devices is in the nanosecond range, as determined by the amplifier bandwidth. However, the peak collector current can exceed 8 amperes. Providing such a current step on a few nanoseconds notice while still maintaining a good RF circuit is a formidable problem indeed. The result of this abrupt current step in the emitter choke is an inductive kickback which inhibits normal emitter current flow. This transient effects must die out before maximum output power can be produced and is therefore the primary factor preventing the device from exhibiting its intrinsic rise time. Also, the collector choke and the shunt inductor blocking capacitor form a parallel resonant circuit which may ring and produce collector modulated AM sidebands if excited with a fast enough current transient (i.e., fast device turn on). The internal inductance and resistance of the first charge-storage capacitors in the collector circuit determines the "stiffness" of the collector supply to these fast rising pulses. In practice it has been found that 5-10 µf of Z5U barium titinate chip capacitors are the only kind that provide acceptable power supply stiffness, and then only if they are connected directly to the "cold" end of the collector bias chokes.

The long pulse microwave performance of these devices is excellent, far beyond what has been available in the past. Even state-of-the-art GaAs devices do not perform as well and are much more difficult to use due to their pulsed bias requirements. The silicon bipolar devices are operated in Class "C" and can be supplied with constant dc bias and pulsed with RF drive. Also the 24-28 V operating voltage of the silicon bipolar is more compatible with typical system requirements than the 8-18 V required by GaAs FET's.

Most phased-array radar applications require long pulses to produce maximum energy on target. The silicon device has been designed for a pulse width of 100 µs and duty factors up to 30% with virtually no droop. Longer pulses or even CW operation can be accommodated at re-

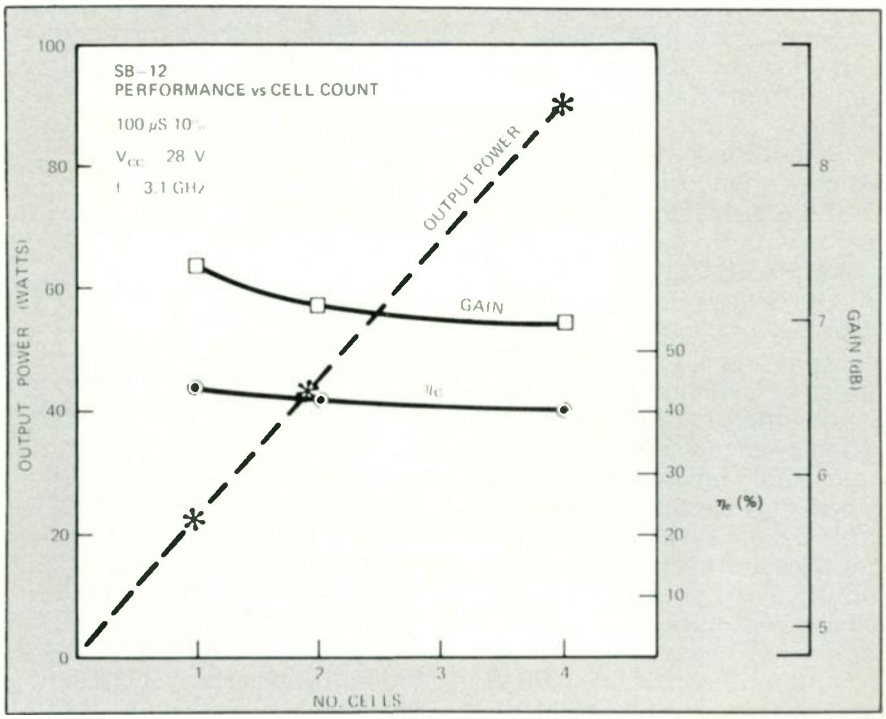

Fig. 5 Cell combining results for SB-12.

(continued on page 66)

duced peak power (about 2 dB lower for the CW case). Typical intrapulse phase shift is about 20°, a value which is compatible with typical system requirements.

The thermal resistance of the two cell SB-12 has been measured under both long pulse and CW conditions with the aid of nematic liquid crystals. The liquid crystal technique is believed to be much less susceptible to measurement errors then the more conventional infra-red technique. The thermal resistance to the hottest spot has been found to be 2.1°C/W for the two-cell device under 100 μs, 10% pulsed conditions and 3.8°C/W under CW conditions at a junction temperature of 171°C. Coupled with the high operating efficiency of these devices, typical peak junction temperatures under normal RF operating conditions are in the range of 140° to 160°C.

Devices of various power levels can be made by parallel combining different numbers of cells with almost no loss of performance, **Figure 5**. When cells are parallel combined with the right type of distributed circuitry, cell combining "losses" are virtually non-existent. The only penalty of adding more cells is the difficulty of assembly and the additional cost associated with lower yields. There is, however, an electrical limit which prevents cell combining to arbitrary levels. This is the electrical width of the microstrip package. The package will become non-propagating at a width of $\lambda/2$ and in practice it is difficult to achieve good performance much past a width of $\lambda/4$.

Extensive testing has been done under load mismatch tests on the 2-cell, 45-watt devices. It has been found the devices will typically withstand a 3:1 SWR without failure and a 2:1 SWR without oscillation in a proper test circuit.

In any case, when oscillations do occur, they are exactly at the resonant frequency of the collector bias choke and the parallel combination of C_{ob} and the internal blocking capacitor. These

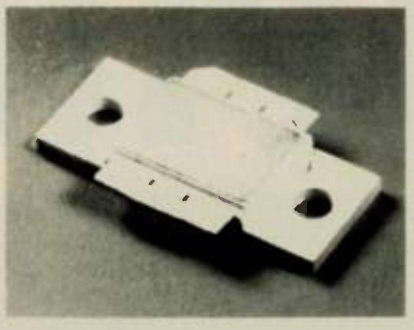

Fig. 6 90 W device in hermetic package.

oscillations produce AM sidebands, sometimes with remarkably low distortion.

The internal matching circuit for the device input is a low-pass structure and is designed to produce minimum reflected power. A return loss in excess of 20 dB has been obtained from both the 2- and 4-cell devices over the band of 3.1-3.5 GHz. Experimental work done on a 1-cell device has produced 18 watts over the full band of 2.7-3.5 GHz with efficiency in excess of 45% over the full 800 MHz bandwidth.

The 4-cell device is housed in a cofired ceramic hermetic package (**Figure 6**). The smaller devices are at present assembled in non-hermetic thin-film packages.

CONCLUSION

Prototype silicon bipolar devices have been fabricated which provide excellent microwave performance in S-Band. These devices are adequate for use in state-of-the-art solid-state phase array-radar and ECM systems.

REFERENCES

1. Contract numbers of the transistor work are: DAAB07-74-C-0280 40 W/2 GHz; DAAB07-77-C-2689 Kapton Interconnect; DAAB07-77-C-0431 Monolithic MMT; DAAB07-77-C-0283 5 W/5 GHz; DAAB07-77-C-2730 12 W/5 GHz; DAAB07-77-C-2730 12 W/5 GHz; N0014-75-C-0405 NRL Monolithic Development.
2. Presser, A., F. Sechi, E. Belahoubek, "S-Band Solid State Power Amplifiers," *ECOM Report*, ECOM-72-0225-F, August 1974.

George W. Schreyer received the B.S.E.E. degree from California State Polytechnic College, Pomona in 1973. Since then he has been employed at TRW Semiconductors. He is responsible for the development of state-of-the-art microwave power transistors in the frequency range of .5 to 5 GHz.

quency limit of operation (~ 30 GHz) are expected. The future generation of the monolithic power amplifier family will find important microwave system applications where size, weight, reproducibility and protection cost are important design considerations.

ACKNOWLEDGEMENTS

The partial support of the Office of Naval Research and the Air Force Avionics Laboratories for the work reported here is gratefully acknowledged. The authors also wish to thank their colleagues at Texas Instruments for their contributions to the work described in this paper, particularly, F. H. Doerbeck and W. M. Duncan for supplying the epitaxial GaAs, H. M. Macksey and R. E. Williams for amplifier processing, S. R. Nelson for device characterization. Special thanks are due to W. R. Wisseman for his constant encouragement.

REFERENCES

1. Pengelly, R. S., and J. A. Turner, "Monolithic Broadband GaAs FET Amplifiers," *Electronic Letters*, Vol. 12, No. 10, 1976, pp. 251-252.
2. Pucel, R. A., P. Ng, and J. Vorhaus, "An X-Band GaAs FET Monolithic Power Amplifier," in 1979 *MTT-S Internat. Microwave Symp. Dig.*, April/May 1979, pp. 387-389.
3. Pucel, R. A., "Performance of GaAs MESFET Power Combiner," *Microwave Journal*, March 1980, pp. 51-56.
4. Sokolov, V., and R. E. Williams, "Development of GaAs Monolithic Power Amplifiers in X-Band," *IEEE Trans. Electron Devices*, Vol. ED-27, June 1980, pp. 1164-1171.
5. Tserng, H. Q., H. M. Macksey and S. R. Nelson, "Design, Fabrication, and Characterization of Monolithic Microwave GaAs Power FET Amplifiers," *IEEE Trans. Electron Devices*, February 1981.
6. Degenford, J. E., R. R. Freitag, D. C. Boire and M. Cohn, "Design Considerations for Wideband Monolithic Power Amplifiers," Paper No. 22, 1980 GaAs IC Symposium, Las Vegas, Nevada.
7. Chen, D. R., and D. R. Decker, "MMIC's – The Next Generation of Microwave Components," *Microwave Journal*, May 1980, pp. 67-78.
8. Tserng, H. Q., "Design and Performance of Microwave Power GaAs FET Amplifiers," *Microwave Journal*, June 1979, pp. 94-100.
9. Courtney, W. E., "Complex Permittivity of GaAs and CdTe at Microwave Frequencies," *IEEE Trans. on Microwave Theory and Techniques*, Vol. MTT-25, No. 8, August 1977, pp. 697-701.
10. Schneider, M. V., "Microstrip Lines for Microwave Integrated Circuits," *Bell System Technical Journal*, Vol. No. 5, May-June 1969, pp. 1421-1444.

(continued on page 67)

1. DeLoach, B. C., "A New Microwave Measurement Technique to Characterize Diodes and an 800 GHz Cutoff Frequency Varactor at Zero Volts Bias," *IEEE Trans. on Microwave Theory and Tech.*, Vol. MTT-12, January 1964, pp. 15-20.
2. Everitt, W. L., and G. E. Anner, "*Communication Engineering*," McGraw-Hill Book Company, New York, 1956.
3. Crescenzi, E. J., Jr., et al. "High-Gain Monolithic GaAs FET Integrated Circuits for Application to X and K_u-Band Amplifiers," Paper No. 29, 1980 GaAs IC Symposium, Las Vegas, Nevada.
4. Tserng, H. Q., W. R. Frensley, and P. Saunier, "Light Emission of GaAs Power MESFETs Under RF Drive," *Electron Device Letters*, February 1980, pp. 20-21.

Hua Quen Tserng (M '70) received the .S. degree in electrical engineering from lational Taiwan University, Taipei, Taiwan, ı 1962, and M.S. and Ph.D. degrees in elec-ɪical engineering from Rice University, louston, Texas, in 1966 and 1968, respec-vely. He joined Texas Instruments Incor-orated, Dallas, Texas, in 1968 as a member f the technical staff of the Central Research aboratories. From 1968 to 1968, he re-earched thermal physics and characteriza-on of semiconductor devices and from 969 to 1975, he worked on GaAs IMPATT iodes for high-power, high-efficiency mi-rostrip oscillator and amplifier applications. ince 1975, he has been involved with the esign and fabrication of microstrip and ıonolithic GaAs power FET amplifiers and scillators.

Vladimir Sokolov received his B.S. de-ree in Science Engineering from Northwest-rn University, in 1968, and his M.S. and 'h.D. degrees in Electrical Engineering from he University of Wisconsin, in 1970 and 973 respectively. From 1974 to 1975 he vas employed as a Senior Engineer at North-op Corporation, Electronics Division, De-ense Systems Department, where his work ncluded microstrip circuit design and evalu-tion of microwave hardware for ECM ap-lications. In 1975 he joined Texas Instru-nents as a Member of the Technical Staff f the Central Research Laboratories where e is presently engaged in microwave meas-rements and circuit design, as related to ıonolithic and hybrid GaAs FET amplifiers.

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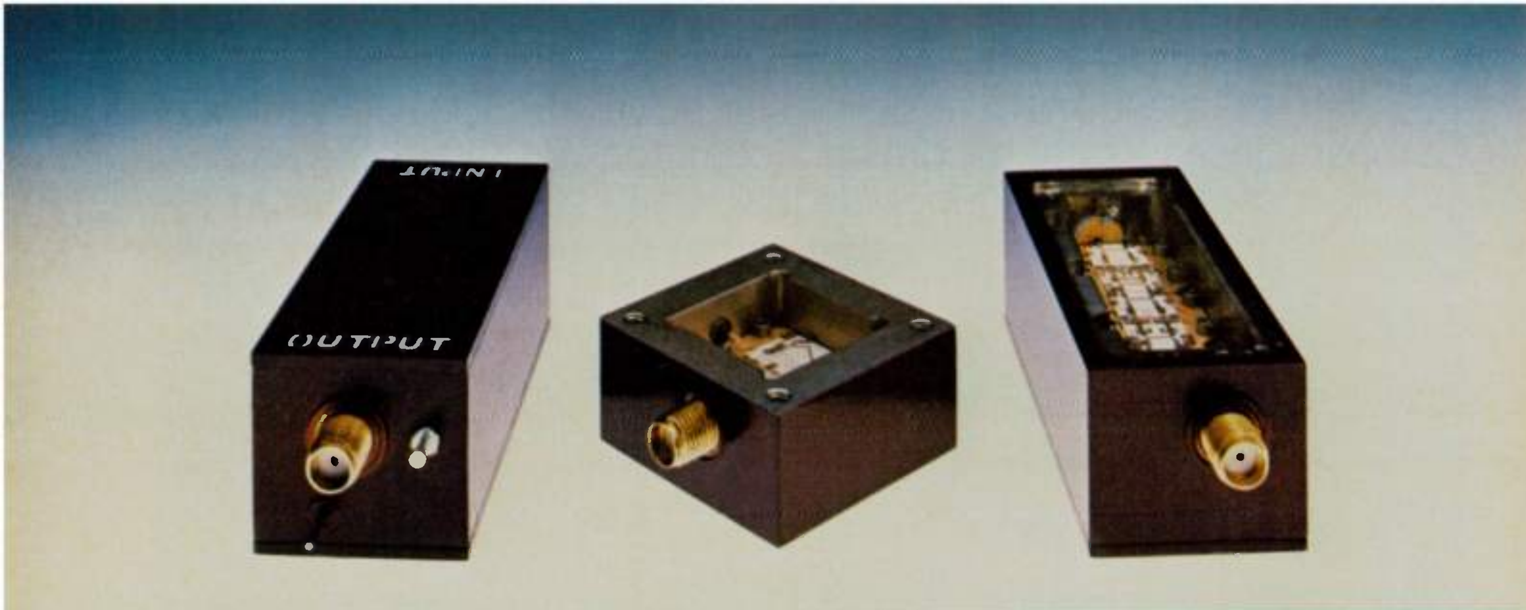

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	SDA 117122-01	11.7–12.2	30	3.5	+13	+23
Broad band	SDA 2080-13	2–8	34	6.0	+18	+28
	SDA 80180-05	8–18	24	7.5	+10	+20
Medium power	SDA 2040-13	2–4	38	6.5	+21	+30
	SDA 4080-17	4–8	38	6.0	+21	+30
	SDA 80124-17	8–12.4	32	7.5	+21	+30

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mm-Wave InP Gunn Devices: Status and Trends

L. WANDINGER
USA Electronics Technology and Devices Laboratory
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INTRODUCTION

Since its introduction a decade ago, the InP Gunn device has rivaled the GaAs Gunn device in performance and system applications. Its potential as high power pulsed sources for microwave applications has been demonstrated at 16 GHz with a peak power of 15 W at 10% duty cycle.[1] Since 1972 the Army has spearheaded the development of InP oscillators for the millimeter-wave region. In recent years, significant advances have been made in extending the frequency range of InP Gunn devices into the 94 GHz range, increasing CW power output and conversion efficiency steadily. This paper traces the advantage of InP for millimeter-wave components, recent progress in InP Gunn device development, initial systems applications and future trends.

ADVANTAGES OF InP

The key scattering and transport properties which are responsible for the superior performance of InP versus GaAs Gunn devices are tabulated in Table 1. It was shown,[2] that the dominant speed limitation of hot-electron effects in GaAs is not determined by the intervalley scattering rate, which is faster, but by the rate with which electrons can gain or lose energy in the central valley of the energy band structure. The same conclusion applies to InP since evidence suggests that the Γ - L scattering is even faster than the Γ - X scattering.[3] Photo emission data[4] show that the intervalley relaxation time $\tau_{L\Gamma}$,

TABLE 1

ADVANTAGES OF InP

		GaAs	InP
Higher Frequency Limit	Central valley dynamics:	f≈100 GHz	2f
	Energy relaxation time due to collisions	6×10^{-12}	3×10^{-12}s
	Acceleration-deceleration time for electron to gain or lose E_s	1.48×10^{-12}s	0.75×10^{-12}s
	Intervalley relaxation time		2.50×10^{-13}s
Higher Efficiency η	Higher v_p:v_v ratio	2.4	4.0
Transfer Mechanism and η less T dependent	E_{Γ}-L 0.31eV in GaAs E_{Γ}-L 0.6 eV in InP	Efficiency degrades by 0.2% per °C	 0.05% per °C
Lower Noise	Noise proportional to $D(E)/\mu(E)$ Low D in InP at fields above threshold	at E/E_{th}=2 142 cm²/s	 72 cm²/s
Thermal Conductivity		0.54 W/cm°C	0.68 W/cm°C
Threshold Field	At f<20 GHz, $L_a\geq10\mu m$ Increased power dissipation precludes CW operation	3.5 kV/cm	10.5 kV/cm
Active Region Length	Experimental evidence	L_a	≈$2L_a$

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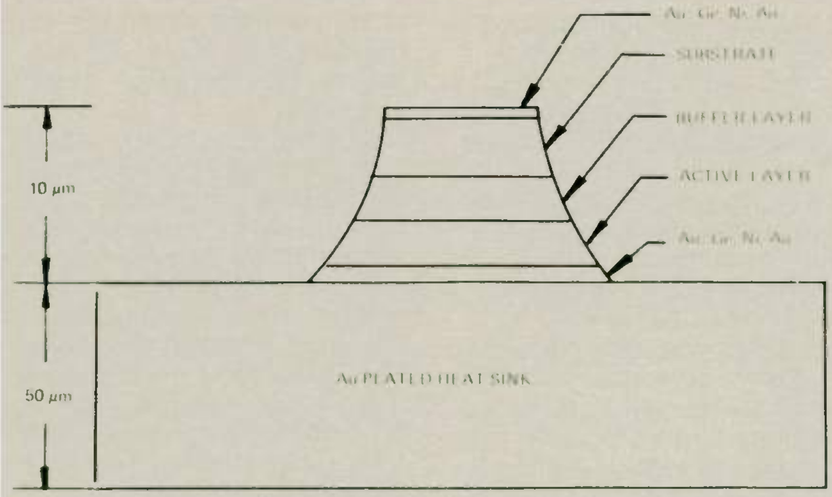


Fig. 1 InP Gunn device structure.

which is the average time for an electron to be scattered from the L-valley to the central- or Γ-valley, is ≅ 2.5×10^{-13}s.

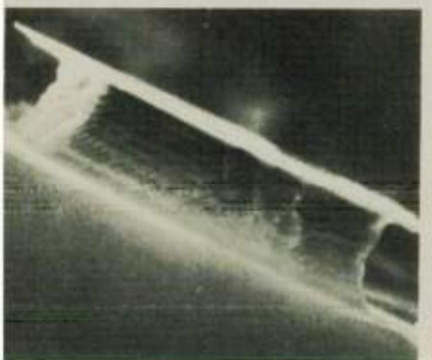


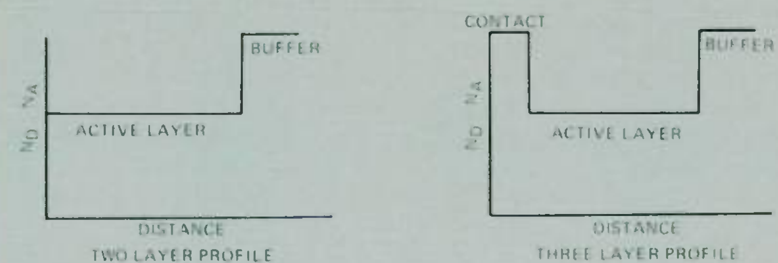
Fig. 2 InP mesa, thickness 10 μm (1600 x).

Two time constants govern the central valley dynamics: The energy relaxation time τ_e due to collisions[5] and the acceleration deceleration time τ_{ad} required for an electron to gain or lose the energy E_S separating Γ-valley from L-valley.[6] Table 1 shows that the values of these time constants for InP are both smaller by a factor of 2 than those for GaAs. This leads to the conclusion that InP should be about twice as fast as GaAs or the ultimate frequency limit for InP should be twice as high as for GaAs.[7] Since τ_{ad} decreases with increasing field strength, the speed of hot electron devices increases with increasing field. The three times higher threshold field of InP is clearly a decisive factor in this category. The frequency limit of GaAs Gunn devices is placed at about 100 GHz.

The peak-to-peak-valley ratio[8,9] is an important parameter for the efficiency of Gunn oscillators. The efficiency is proportional to $(v_p - v_v) / (v_p + v_v)$,[10] and a high peak-to-valley ratio is clearly desirable. As Table 1 shows, InP has a clear advantage over GaAs in this category. With increased temperature, the peak-to-valley ratio and consequently the device efficiency are reduced in general. However, the electron transfer in InP is much less temperature sensitive, due to the large Γ - L energy separation. A detailed analysis[11] shows that in InP the efficiency degrades less rapidly with T, a valuable property with operating device temperatures as high as 225°C.

Noise in Gunn devices is proportional to D/μ where D is the electron diffusion coefficient and μ is the negative differential mobility. It was shown[12] that above threshold the noise decreases with increasing field. In addition, the characteristics of polar scattering and intervalley scattering at fields above threshold were shown to lead to a low diffusion coefficient in InP. Consequently, lower noise is an inherent property of InP because of its higher threshold field.

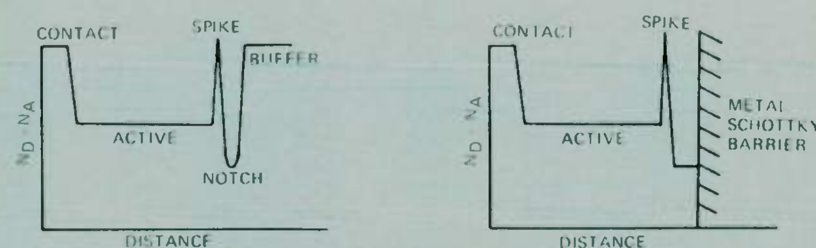
The higher threshold field in InP (three times GaAs) which



SPECIFICS FOR 94 GHz DOPING PROFILE

N_C 1 3×10^{17} cm^{-3} N_A 6 8×10^{15} cm^{-3} N_B 1 2×10^{17} cm^{-3}

L_C 0.75 1.0 μm L_A 1.6 2.1 μm L_B 3 4 μm



TWO ZONE CATHODE PROFILES

SPECIFICS FOR 94 GHz TWO ZONE CATHODE DOPING PROFILE

N_C 1 3×10^{17} cm^{-3} N_A 6 8×10^{15} cm^{-3} N_B 1 2×10^{17} cm^{-3}

L_C 0.75 1.0 μm L_A 1.2 1.6 μm L_B 3 4 μm

N_S 0.7 2×10^{17} cm^{-3} N_N 1×10^{15} cm^{-3}

L_S 0.05 μm L_N 0.2 0.3 μm

Fig. 3 Different doping profiles with specifics for 94 GHz InP Gunn devices.

proved so advantageous for low noise and upper frequency limit is the biggest drawback of InP for low frequency devices due to greatly increased power dissipation in the thicker active layers preventing CW operation. At higher frequencies, the active region length in InP is twice that of GaAs[13] which is a technological advantage in fabricating millimeter-wave devices. Finally, the thermal conductivity of InP at room temperature is 0.68 W/cm °C versus 0.54 W/cm °C for GaAs, a 25% advantage.

DEVICE TECHNOLOGY

The fabrication of high efficiency, low noise mm-wave InP Gunn devices requires optimization of active layer doping profile, device geometry, and above all, cathode contacts while striving for good thermal design, metallurgical stability and device reliability.

A typical InP Gunn device structure is shown in **Figure 1**. It consists of the various epitaxial layers, alloyed Au: Ge, Ni, Au contacts and plated gold heat sink to reduce thermal resistance and facilitate chip bonding and packaging. The mesa structure is formed by chemical etching. The device is mounted in an N-34 package with cross ribbon bonded top contact. Thermal resistance of 94 GHz devices ranges between 40 - 50 °C/W of which less than one third is contributed by the InP mesa itself.

Series resistance due to a thick substrate degrades device efficiency. At millimeter wave frequencies, skin effect losses and their influence on radial variations of the microwave voltage caused by the confinement of RF currents are serious contributors to reduced device efficiency. The skin depth for a 94 GHz InP Gunn device is about 10 μm. Substrate thinning to skin depth level has improved device performance dramatically. A SEM photograph of a super thin InP Gunn mesa is shown in **Figure 2**.

OSCILLATORS

InP Gunn oscillators for 60 GHz and 94 GHz have been developed. Two-layer, three-layer and two-zone cathode device structures whose detailed doping profiles are shown in **Figure 3** have been used. The two-layer devices showed slight current limiting with direct metal contact as cathode and yielded the highest efficiencies at 60 GHz and 94 GHz. It resembles the previously discussed constant current cathode. As expected, the three-layer ohmic cathode devices had significantly lower efficiency.

The two-zone cathode structure is a complex profile consisting of buffer-notch-spike-active-contact layers. The notch doping and length are designed to assure a rapid rise of the electric field across this zone, thereby accelerating the electrons to high energies. Since the highly doped narrow spike reduces the electric field rapidly, the energetic electrons retain much of their energy during transit of the spike. Thus, hot electrons are injected into the active region effectively reducing the cathode dead space.

At 60 GHz, a coaxial-waveguide circuit[14] as shown in **Figure 4** produced the best power levels and efficiencies. In this circuit, a coaxial line is terminated on one end by the InP Gunn device and on the other end by a multi-section low pass filter dc biasing network. A reduced height opening provides both coax-to-waveguide coupling and impedance transformation to full height waveguide. Center conductor length and diameter are varied for circuit optimization. A dielectric tuning rod allows limited tuning of about 1 GHz.

TABLE 2

RF PERFORMANCE OF MILLIMETER-WAVE InP GUNN OSCILLATORS

	CW				PULSED					
	f (GHz)	P_o (mW)	η (%)	t* (μm)	Pulse Width (μs)	Duty Cycle	f (GHz)	P_o (mW)	η (%)	t* (μm)
Two-Layer Devices	56.5	194	4.7	50	0.25	0.10	54.5	860	4.8	50
	57.2	195	6.5	30	0.25	0.10	67.8	135	7.0	20
	61.1	123	3.0	40	0.25	0.10	89.9	68	5.1	20
	83.8	49	5.7	20	0.25	0.10	99.0	24	6.0	20
	89.5	125	3.3	10	0.50	0.01	90.3	236	4.3	10
	96.4	73	2.1	10	0.25	0.10	71.5	99	8.4	20
	105.8	35	1.5	20						
Three-Layer Devices	57.2	120	1.9	50	0.25	0.10	57.1	220	3.7	30
	94.1	63	1.3	20	0.25	0.10	66.7	175	3.3	40
	100.0	36	0.8	20	0.15	0.06	63.0	100	0.8	50
					0.50	0.01	93.3	52	0.8	40
					0.25	0.10	100.3	14	0.2	40
Two-Zone Cathode Devices	57.5	32	0.9	40	0.50	0.10	57.0	130	1.6	20
	94.5	20	0.5	40	0.50	0.10	88.2	34	0.6	40
Combiner Two diodes Dual Radial Line Circuit	91.8	97	100.0 Combining Efficiency.			Initial results with low power devices to demonstrate feasibility, not optimized.				

t* = mesa thickness

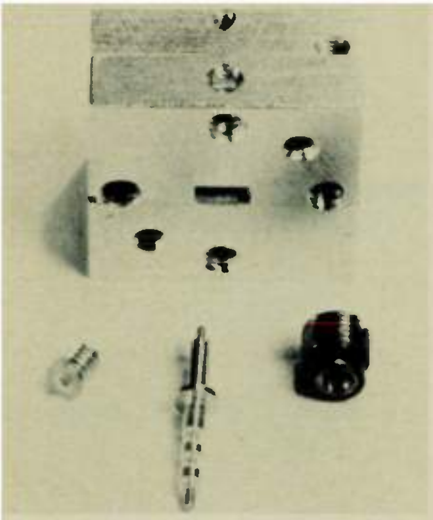


Fig. 4 60 GHz coax-waveguide circuit.

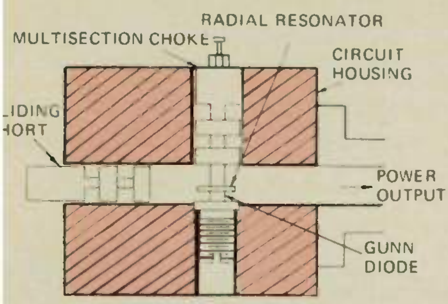


Fig. 5 94 GHz radial line resonator.

At 94 GHz, the familiar resonant disk or radial line circuit as shown in **Figure 5** was used exclusively. The oscillator frequency is primarily determined by the diameter of the disk, its distance from the wallguide wall and to a lesser extent by the thickness of the disk and the post diameter and length above it. The diode is mounted in the waveguide wall and a similar bias feed-through as described earlier is used. A sliding short provides impedance matching and optimum coupling location, $(2n + 1/4)\lambda_g$ behind the diode, resulting in maximum power output. The performance of the various InP Gunn structures is summarized in **Table 2**.

Both CW and peak power results are reported. Overall, the best CW power levels and efficiencies have been obtained with two-layer direct metal contact devices. In the 94 GHz region, the best device produced a power output of 125 mW with 3.3% efficiency at 89.5 GHz. This dramatic improvement in performance at this frequency resulted from minimizing skin effect losses and series resistance losses by thinning the device to 10 μm. As expected, the three-layer ohmic contact devices show lower performance levels. The results for the two-zone cathode devices are preliminary since only non-optimum doping profiles have been available.

Devices under pulsed conditions show marked increases in performance due to the lower operating temperature. The best results are 860 mW at 54.5 GHz and 236 mW at 90.3 GHz. In the pulsed mode, the highest efficiency was 8.4%. Regular CW rather than specially designed devices were used for these measurements.

InP Gunn devices are inherently broadband devices. A reduced height waveguide resonator was used to demonstrate the mechanical and electronic tuning capabilities of InP Gunn oscillators at 60 GHz. This oscillator was tuned mechanically from 52 GHz to 64 GHz with power variation less than 2.5 dB. Varactor tuning covered a range of 3.5 GHz.

AMPLIFIERS

The broadband negative resistance characteristics of an InP Gunn device together with its low noise properties are ideal for the development of low noise InP Gunn reflection amplifiers in the millimeter-wave region. It has been shown[15] that the device effective noise temperature ratio T_{eff}/T_o, also called the noise measure M, approaches a limit

$$M_{min} = \frac{q}{k}\frac{D(E)}{\mu(E)}$$

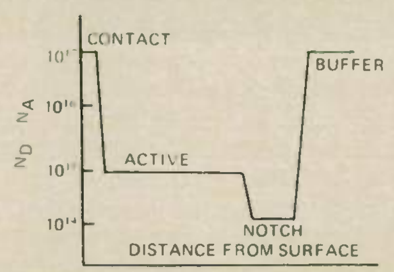
Where q is the electronic charge, k is Boltzmann's constant, T is the absolute temperature, D(E) is the electron diffusion coefficient and μ(E) is the differential negative mobility, both field dependent quantities. At approximately twice threshold field, D(E) of InP is only one-half that of GaAs.[16] The more commonly used noise figure F is related to M by the following equation

$$F = 1 + M(1 - 1/G)$$

with G as the power gain.

A low noise measure requires a low nL product and a uniform field distribution over most of the device which can be achieved with a cathode notch structure as shown in **Figure 6**. This structure has been used to fabricate InP Gunn amplifiers. Coaxial-waveguide circuits as discussed previously were predominately used for the amplifiers. The noise measure decreased steadily with increasing nL products and reached a minimum of 7.8 dB for nL between $1\text{-}2 \times 10^{11}\,cm^{-2}$. This might be an inherent limit of the n-type notch contact structure due to added series resistance. Improvements in the noise measure can be achieved by the use of a p-type notch profile. An ultimate noise measure of 4-dB for Gunn amplifiers in the 40-60 GHz region is projected.

A typical gain response and noise figure plot of a single stage InP Gunn reflection amplifier for the upper end of this band is shown in **Figure 7**. A gain of 6-8 dB with noise figures between 10-11 dB represent typical num



IDEALIZED DOPING PROFILE

SPECIFICS FOR 40-60 GHz NOTCH PROFILE

N_C	$1\text{-}3 \times 10^{17}$	cm^{-3}	N_A	$0.8\text{-}1.0 \times 10^{15}$	cm^{-3}
L_C	0.75-1.0	μm	L_A	2.0-3.5	μm
N_N	$3\text{-}5 \times 10^{14}$	cm^{-3}	N_B	$1.0\text{-}2.0 \times 10^{17}$	cm^{-3}
L_N	1.4-1.8	μm	L_B	3-4	μm

Fig. 6 InP cathode notch device for amplifi

Fig. 7 Gain and noise figures of 56.5 GHz amplifier.

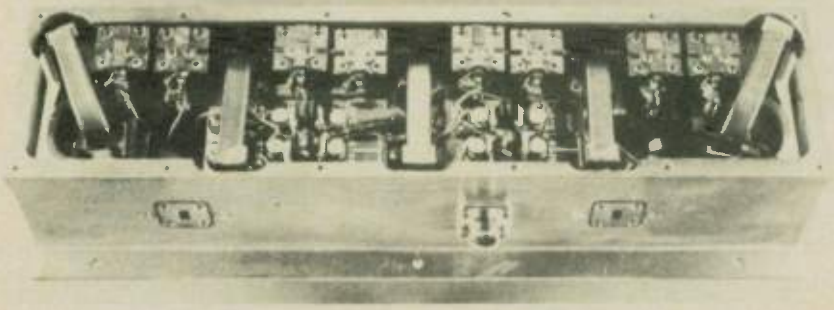


Fig. 8 Full band 26.5 - 40 GHz 8-stage InP Gunn diode amplifier.

bers. Between 40-60 GHz, full band operation of the amplifier is presently not possible because of the lack of full band circulators. An amplifier with 15 dB saturated gain, 100 mW saturated power output, a bandwidth of 4 GHz and a maximum noise figure of 15 dB at 60 GHz is feasible with existing technology.

In a recent development,[18] a full band InP Gunn diode amplifier for the 26.5-40 GHz band with a gain of 35 dB and a maximum noise figure of 16.5 dB was demonstrated, **Figure 8**. The dc power supply and regulator are included in the lower half of amplifier housing. This amplifier was developed as a direct replacement for a TWT amplifier with similar electrical characteristics and identical form factor for surveillance and target acquisition applications. It met or exceeded the TWTA performance and offers the additional advantages of longer lifetime and better reliability.

FUTURE TRENDS

The ultimate potential of InP Gunn devices will be further explored by continuing work in the following areas

- Two-zone cathode refinement
- Improving thermal resistance of the 10 μm device structure with silver contacts and diamond heat sinks
- Higher power devices for pulsed applications with the required low loss, low impedance circuits
- Use of combiners to achieve higher powers
- Investigation of 100-200 GHz InP Gunn oscillators
- Incorporation of InP Gunn's into mm-wave IC's

CONCLUSION

The state-of-the-art, recent advances and future trends of mm-wave InP Gunn oscillators and amplifiers have been described. Most significant are the results which show that InP has surpassed GaAs in this area by a factor of 2:1 in output power and a factor of about 3:1 in efficiency, at 94 GHz. The real benefit of low noise, high performance InP Gunn devices will become even more obvious as operating frequencies are pushed to 140 GHz and higher where no other semiconductor device with similar performance characteristics for low noise application is available. The potential of InP Gunn devices for pulsed operation through the millimeter-wave frequency range and increased power output through combining is just beginning to be tapped. The benefits of millimeter-wave IC's are just beginning to emerge.

ACKNOWLEDGEMENTS

The author would like to thank Drs. F. B. Fank and J. D. Crowley, from Varian, and Dr. Y. Chang, from TRW, for material provided for this paper. Thanks are also due D. Rubin, NOSC, Project Monitor of the Navy amplifier programs for permission to include amplifier data. Experimental data for this paper was obtained from work performed by Varian under Contracts No. DAAB07-78-C-2940, DAAK20-79-C-279, DAAK20-79-C-280, and N00123-77-C-0459.

REFERENCES

1. Irving, L. D., J. E. Pattison, and W. Braddock, "Improved Mean Power and Long Pulse-Width Operation of InP TEO's in J Band," *Electron. Lett.* Vol. 14, 1978, pp. 116-117.
2. Rees, H. D., "Time Response of the High-Field Electron Distribution Function in GaAs," *IBM J. Res. Develop.* Vol. 13, 1969, pp. 537-542.
3. Fawcett, W. and D. C. Herbert, "High-Field Transport in Indium Phosphide," *Electron. Lett.* Vol. 9, 1973, pp. 308-309.
4. James, L. W., "Parameters of Electron Transfer in InP," *J. Appl. Phys.* Vol. 44, 1973, pp. 2746-2749.
5. Glover, G. H., "Study of Electron Relaxation Times in GaAs and InP," *J. Appl. Phys.* Vol. 44, 1973, pp. 1295-1301.
6. Kroemer, H., "Hot-Electron Relaxation Effects in Devices," *Solid State Electronics* Vol. 21, 1978, pp. 61-67.
7. Ridley, B. K., "Anatomy of the Transferred-Electron Effect in III-V Semiconductors," *J. Appl. Phys.* Vol. 48, 1977, pp. 754-764.
8. Fawcett, W. and G. Hill, "Temperature Dependence of the Velocity-Field Characteristic of Electrons in InP," *Electron. Lett.* Vol. 11, 1975, pp. 80-81.
9. Fawcett, W., A. D. Boardman, and S. Swain, "Monte Carlo Determination of Electron Transport Properties in Gallium Arsenide," *J. Phys. Chem. Sol.* Vol. 31, 1970, pp. 1963-1990.
10. Hilsum, C., "Simple Graphical Method for Calculating the Efficiency of Bulk Negative-Resistance Microwave Oscillators," *Electron. Lett.* Vol. 6, 1970, pp. 448-449.
11. Hilsum, C., "New Developments in Transferred-Electron Effects," *Proc. 3rd Cornell Electr. Engr. Conf.*, 1971, pp. 1-9.
12. Hammar, C. and B. Vinter, "Diffusion of Hot Electrons in N-Indium Phosphide," *Electron. Lett.* Vol. 9, 1973, pp. 9-10.
13. Paxman, D., "Indium Phosphide as a New Material for Microwave (Transferred-Electron Effect) Oscillators," *Acta Electronica* Vol. 15, 1972, pp. 245-252.
14. Hamilton, R. J., R. D. Fairman, S. I. Long, M. Omori, and F. B. Fank, "InP Gunn-Effect Devices for Millimeter-Wave Amplifiers and Oscillators," *IEEE Trans. MTT-24*, 1976, pp. 775-780.
15. Thim, H., "Noise Reduction in Bulk Negative-Resistance Amplifiers," *Electron. Lett.* Vol. 7, 1971, pp. 106-107.
16. Bauhahn, P. E., G. I. Haddad, and N. A. Masnari, "Comparison of the Hot Electron Diffusion Rates for GaAs and InP," *Electron. Let.* Vol. 9, 1973, pp. 460-461.
17. Sitch, J. E. and P. N. Robson, "The Noise Measure of GaAs and InP Transferred Electron Amplifiers," *IEEE Trans. ED-23*, 1976, pp. 1086-1094.
18. Wolfert, P. and J. D. Crowley, "Design and Fabrication of Solid State Amplifier for 26-40 GHz," NOSC Contract No. N66001-79-C-0283, Aug. 1980.

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The back diode is a highly doped, alloyed junction diode that operates on the principle of quantum-mechanical tunneling. It is in actuality a special case of the Esaki tunnel diode, with the PN junction doped into degeneracy.

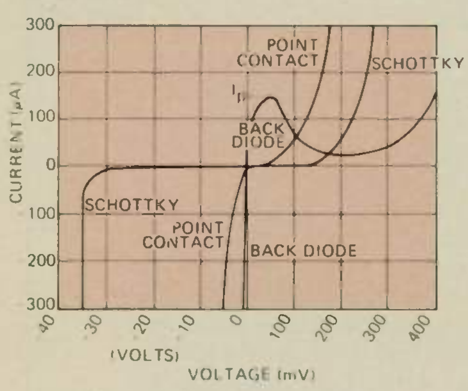


Fig. 1 Typical current — voltage characteristics.

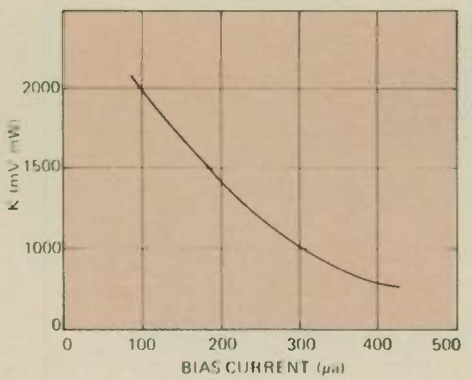


Fig. 2 8 GHz typical Schottky barrier diode SWR vs bias.

The diode is essentially a Zener at the origin. If this point is accepted, then the I-V curve (**Figure 1**) makes it obvious that the diode's RF impedance is unusually low, current sensitivity unusually high, and its temperature coefficient is better by several magnitudes than conventional diodes.

The name "back or backward diode" derives from the fact that the easy flow of current takes place in the negative rather than the positive region of the I-V curve. If the n region is considered to be the anode and the P region to be the cathode then biasing may be applied as if it were a conventional diode.

A Schottky diode in the frequency range 4-8 GHz has a sensitivity (K) of 1500 mV/mW compared to K=850 mV/mW for a back diode. However, for a K of 1500 a Schottky diode needs to be biased at approximately 100 μa. At this bias, the SWR is typically 5.0:1 and at a power level of 0 dBm it is 8.0:1 to 10.0:1. With 450 μa bias, a SWR of 2.0 is possible but K is reduced to 600 mV/mW (**Figure 2**).

A back diode at zero bias, on the other hand, has a typical SWR of 2.0:1 which can be maintained at a maximum of 2.5:1 up to 0 dBm while sustaining a sensitivity of 850 mV/mW.

Schottky barrier detectors looking into an open circuit are available with temperature sensitivity typically of 3.0 dB @ 100 μa, 2.0 dB @ 250 μa, and 1.0 dB @ 450 μa over −55°C to +85°C temperature range. Back diode detectors are available with a maximum sensitivity variation of ± 0.5 dB over the same temperature range and tracking accuracy vs temperature for a pair of detectors can be held down to ± 0.25 dB.

It is interesting that while a 1.0 dB temperature sensitivity may be acceptable with 450 μa bias, the Schottky's effective "K" is reduced to considerably *less* than that of the back diode (**Figure 3**).

It should also be pointed out that a back diode inherently has a low 1/f noise corner and low impedance. This

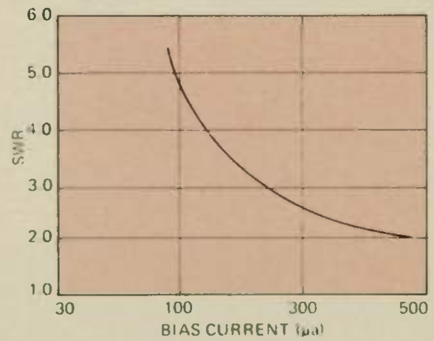


Fig. 3 Typical K vs bias.

impedance matches nicely with the amplifier circuitry resulting in a better overall S/N ratio performance and offering inherent wideband capability.

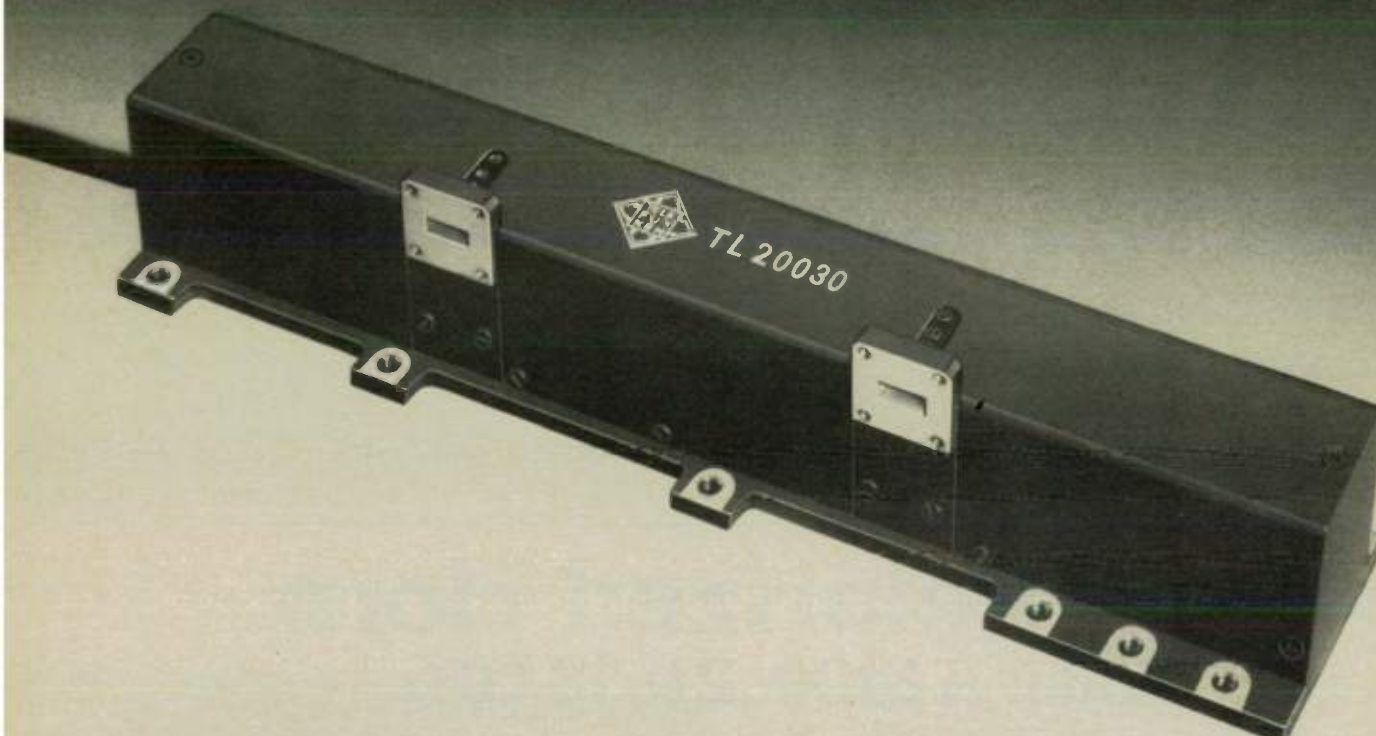
In summary, it can be readily seen that in *system applications* where *overall parameters* need to be optimized, the advantages of the back diode compared to the Schottky barrier diode should be considered.

AEG-TELEFUNKEN

Future oriented

TL 20030

for Satellite Communications in the 20 GHz Band



In the foreseeable future the growing requirement for transmission channels in satellite communications will not be met by the transmission systems for the 4 GHz and 12 GHz bands. Consequently a further frequency band around 20 GHz was allocated.

With the TL 20030, therefore, AEG-TELEFUNKEN have already developed the next generation of satellite traveling-wave tubes.

The tube, fitted with a two-stage collector, achieves an overall efficiency of 38%. It weighs 900 g approximately. In the design of the tube a dispenser cathode proven in other space programmes was chosen.

The development of the TL 20030 was based on proven technologies. A life expectation, which is usually far in excess of the specified seven years, may thus be safely assumed.

Technical data:

Frequency range	18.5 ... 21.5	GHz
Efficiency	38	%
Gain	50	dB
Power output	22	W
Weight appr.	900	g

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Tubes

SUBMINIATURE 250 W X-BAND MAGNETRON

Model E3469 is a subminiature, 250 W pulsed magnetron utilizing Sm-Co technology which weighs 2 oz. and has a volume less than 1 cu. in. The tube has a peak output of 250 W at an operating voltage of 850 V, will operate at pulse lengths between 20 ns and 2 μs at a duty cycle of 30 to 1, and can be positively or negatively pulsed. A fast warm-up cathode permits unit to be fully operational within 1.5 s after switch-on, and it has excellent pulse stability (leading edge jitter of about 1.5 ns). **EEV, Inc., Elmsford, NY. Tom Soldano, (914) 592-6050.**

Circle 172.

K_u-BAND SPACE TWT

A space-qualified, traveling-wave tube for operation at K_u-band, the WJ-3710, provides a nominal saturated output power of 25 W with a small signal gain of 60 dB across the 12-16 GHz frequency range. Unit meets life and reliability demands of continuous operation for up to 10 years in space. Options such as mounting-hole positions variations and choice of coaxial or waveguide outputs are offered. **Watkins-Johnson Company, Palo Alto, CA. S. B. Witmer, (415) 493-4141.** **Circle 173.**

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Si TUNING VARACTOR CHIPS

A series of silicon abrupt junction microwave tuning varactor chips, #MA-45200C, provides 50 MHz Q's of 600 to 5500 and capacitance ratios of 4.5 to 9.0. Typical CT-4 capacitance ranges from 0.6 to 8.2 pF. Mounting may be either substrate-down or flip-chip. Chips are suitable for applications from VHF through K_u-band. **Microwave Associates, Inc., Burlington, MA. (617) 272-3000.** **Circle 170.**

LOW NOISE COMMUNICATION TRANSISTOR

The LT-4700 is a low noise, small signal and high performance transistor for front-end receivers. Device features forward insertion gains of 15 dB at 1 GHz and 21 dB at 500 MHz, and typical noise figures of 1.6 dB at 1 GHz and 1.1 dB at 500 MHz. Unit is housed in a hermetic, low-parasitic, high frequency 100 sq. mil package and has a maximum storage temperature of 200 C. Price: $18 in 100 qty. Del: 4-6 wks. **TRW RF Semiconductors, Lawndale, CA. Gene Brannock, (213) 679-4561.** **Circle 171.**

Cable

TEFLON-FOAM HELIAX CABLE

Type FT5-50 HELIAX® is a 7/8", 50 Ω coaxial cable permitting continuous operation up to 200° C (392° F). The Teflon® foam dielectric offers attenuation characteristics comparable to air-dielectric cables without the need for pressurization. An annularly corrugated outer conductor, in conjunction with the connector "O" ring seals, provides a longitudinal moisture block. Teflon® jacket provides resistance from corrosion and abrasion. **Andrew Corporation, Orland Park, IL. (312) 349-3300.** **Circle 169.**

Systems

400 W LINEAR AMPLIFIER SYSTEM

Model #A1CAL is a linear amplifier system which offers 56 dB gain and up to 400 W PEP (300 W CW) into 50 Ω over the 222-403 MHz frequency range. The unit is complete with all power supplies, protective circuitry (automatic excess SWR shutdown), blowers and cabinets to provide a complete, fully protected and operational system. Price: $39,000 per system. **Micon Inc., Microwave Control Co. Division, Brick, NJ. (201) 458-3000.** **Circle 175.**

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Model 3200-PC and 3200-PC (10) are pre/post detection diversity combiners which permit optimal ratio combining with two randomly phased RF signals that vary up to 20 dB in relative amplitude at fade rates up to 20,000 Hz. AM/AGC combiner functions offer BER reduction and SNR improvements under severe multipath, flame attenuation and pseudo-random noise conditions. **Microdyne Corp., Rockville, MD. (301) 762-8500.** **Circle 174.**

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IF LIMITER SERIES SPANS 10 - 250 MHz RANGE

A series of IF limiters, #PLM 1000, covers the 10-250 MHz frequency range with 10-20 MHz bandwidths. Dynamic range is 0-80 dB and output power is 0 dBm typical. Size: 1.5" x 1.8" x 0.65" package and 1.25" x 1.25" x 0.20" dip package. **Petrond Microwave Inc., San Jose, CA. Pete Lau, (408) 227-1764.** **Circle 160.**

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A series of SMA coaxial connectors are designed to be mechanically installed without soldering on semi-rigid cables. Installation requires less than .5 min. Attachments resist a minimum of 100 in. oz. of cable torque and provide a tensile strength greater than 70 lbs. The 50-ohm subminiature coax connectors can be used up to 18 GHz with a SWR (for the MIL-C-39012/92 plug) less than 1.035 + .005f (GHz). RF leakage is -90 dB at 2.5 GHz. Dielectric withstanding voltage is 100 V rms at sea level and insulation resistance is better than 5000 M Ω. Price: $1 per unit in production qty. **AMP Inc., Harrisburg, PA. Jim Pletcher, (717) 564-0100.** **Circle 161.**

(continued on page 84)

BROADBAND BIAS INSERTION UNIT FOR PULSE AND CW

An ultra broadband bias insertion unit, Model AVX-T, is designed for both CW and subnanosecond rise time baseband pulse applications. RF frequency range extends from 10 MHz to 5 GHz with a baseband pulse width range 200 ps to 50 ns. Series blocking capacitor has maximum voltage rating of 200 V while shunt inductor has maximum current rating of 1.0 A. Size: 1.5" x 1.1" x 0.9" in cast aluminum chassis, with SMA connectors. Price: $195 (U.S.) Del: 30 days ARO; FOB (from Ottawa). **Avtech Electrosystems Ltd., Ottawa, Ontario, Canada. W. J. Chudobiak, (613) 226-5772.**
Circle 164.

MULTI-MINI™ TWTA

The Multi-Mini™ traveling wave tube amplifier is a self-contained unit with 8 pulsed or CW mini TWT's for phased array applications. Provision for an external synchronization signal, makes it possible to operate more than one Multi-Mini TWTA so that all TWT's in the system achieve phase and gain tracking. Component uses 115 Vac (400 Hz, 3 phase) and consumes 2500 W in the 8-tube configuration. Size: 15.75" L x 11.00" W x 5.51" H. Weight: 40 lbs. **Varian Associates, Palo Alto, CA. (415) 493-4000.**
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ZERO-BIASED BACK DIODES

Model 23200BD is a stripline packaged zero-biased back diode which provides tangential signal sensitivity @ 10 GHz (2 MHz bandwidth) of 52 dBm. Open circuit voltage sensitivity is 1200 mV/mW and figure of merit is 100. Peak current is 150 to 250 μa and capacitance is .7 pF, maximum. Price: $20, 1-24 qty.; $11.90, 1000-4999 qty. Del: 30-60 days. **Custom Components, Inc., Lebanon, NJ. Charles Blaine, (201) 236-2128.** **Circle 159.**

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Series 727 is a line of super power dummy loads designed in accordance with MIL-D-3954 for L through K_u-band applications. Dissipation ratings for L-band models go to 25 kW, average, 15 MW, peak. C-band types up to 10 kW, average, 1.3 MW, peak and K_u-band loads up to 0.5 kW, average, 160 kW, peak are offered. S, X and X_L loads with comparable ratings are also available. Dissipative material is high-temperature glossy ceramic, conforming to MIL-D-3954. Terminations are finished in high-temperature black enamel, and equipped with standard cover flanges to mate with applicable AN type waveguide. **Micronetics, Inc., Norwood, NJ. Gary Simonyan, (201) 767-1320.** **Circle 176.**

SUBMINIATURE PROGRAMMABLE ATTENUATOR

Model PA-5010 is a subminiature programmable attenuator which occupies less than 3 cu. in. of space and provides 0-127 dB of attenuation in 1 dB steps. Frequency range is dc - 1300 MHz, per cell accuracy is 0.2 dB or 1% at 1000 MHz and SWR is 1.5 at 1000 MHz. Attenuator is available with control voltages of 26.5 Vdc, 12.0 Vdc or 5.0 Vdc and connectors are SMA type. Price: $390, 1-9 qty. Del: 8 wks., ARO. **Texscan Corporation, Indianapolis, IN. Raleigh B. Stelle, (317) 357-8781.** **Circle 155.**

THROUGH-HOLE MOUNTED SMA CABLE JACK

Models 55-610-3702 and 55-610-3703-31 are direct solder type bulkhead cable jacks for use on cable-wired cabinets or for through-bulkhead systems. The former is designed for .085" semi-rigid cable, while the latter is used for .141" semi-rigid cable. Connectors incorporate a threaded bushing for through-hole bulkhead mounting, complete with rubber O-ring gasket and lock washer. Size: .750" L, overall. **Sealectro Corp., RF Components Div., Mamaroneck, NY. (914) 698-5600.**
Circle 154.

SMA FLANGE CONNECTOR

An SMA edge connector, Model 6921, incorporates "floating" clamping plates designed to prevent solder joint failure and speed and simplify MIC package assembly. Connectors are designed for operation from dc to 18 GHz, and meet all requirements of MIL-C-39012. Connector bodies are passivated stainless steel, clamping plates are brass, nickel plated. Center conductors and replaceable pins are Be-Cu, Au plated. These pins are offered in bifurcated, tabs, standard SMA and machinable blank configurations. Price: $9.47 each, 100 qty. Del: from stock. **EMC Technology, Inc., Cherry Hill, NJ. Steve Rollin, (609) 429-7800.**

Circle 165.

DOUBLE BALANCED MIXER SPANS 4-9 GHz RANGE

The M-8935 is a high level, double-balanced mixer which operates over the 4-9 GHz frequency range. IF bandwidth is 60 MHz to 3.0 GHz. At an LO drive of +22 ± 1.5 dBm, maximum conversion loss ranges from 7 dB to 10 dB depending on RF and IF bandwidths employed; 1 dB compression point is +15 dBm; and 3rd order intercept is +26 dBm (5-7 GHz). Price: $425, 1-4 qty. Del: Stock to 4 wks. ARO. **Western Microwave, Sunnyvale, CA. Richard Sanders, (408) 734-1631.**

Circle 167.

TVRO POWER DIVIDERS FOR 3.7 - 4.2 GHz BAND

A line of TVRO in-phase power dividers is designed for the 3.7-4.2 GHz communications band. The Model D-3742 is available with 2, 4 and 8 outputs. Low insertion loss, SWR (1.25 maximum) and good isolation (20 dB minimum) are featured. Price: $50, per unit. Del: Stock to 4 wks., in small qty. **RLC Electronics, Inc., Mt. Kisco, NY. (914) 241-1334.**

Circle 153.

LINEARIZED DIODE ATTENUATOR

A linearized diode attenuator, Model TG 1044, operates over the 8-18 GHz range with an attenuation range of 60 dB minimum and insertion loss of 3.5 dB maximum. SWR is 2.0, maximum, and switching time is 400 ns, max. Frequency flatness is ±1.7 dB to 30 dB, ±3.0 dB to 60 dB; linearity is ±0.25 dB to 30 dB, ±0.5 dB to 60 dB. Temperature stability is ±1.5 dB from -54 C to +80 C and RF power is 10 dBm maximum. The dc voltage is ±15 V @ +50 mA and control voltage is 0 to +10 Vdc; response is monotonic. **Triangle Microwave, East Hanover, NJ. James Beard, (201) 884-1423.**

Circle 157.

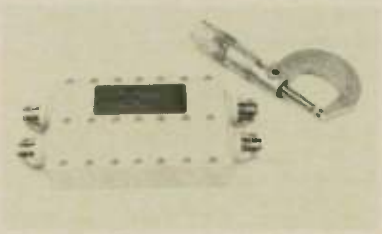
(continued on page 86)

(from page 85) NEW PRODUCTS

TUNABLE BANDPASS FILTER

Part #201675 is a tunable filter with a tuning range of 7.1 to 8.4 GHz; 3 dB bandwidth of 80 MHz nominal; 0.2 dB bandwidth of 38 MHz minimum and 35 dB bandwidth of 310 MHz maximum. The small sized unit has an insertion loss of 0.7 dB maximum with SWR 1.5:1 maximum. Price: $850 per unit, small qty. Del: 6-8 wks. ARO. **Coleman Microwave Co., Edinburg, VA. Ken Coleman, (703) 984-8848.** **Circle 144.**

CONTIGUOUS BAND MULTIPLEXERS



A series of 2 to 5-channel contiguous band multiplexers with up to 7 sections per channel are offered for the 50-1500 MHz range. Multiplexers are 0.1 dB ripple Tchebysheff designs. Typical triplexer unit might have passbands of 100-200 MHz, 200-400 MHz, and 400-1000 MHz. Upper section can be either a bandpass or a highpass filter, the lower, a bandpass or lowpass filter. Units have a typical insertion loss of 0.2-0.3 dB, with a crossover insertion loss less than 5.0 dB, for operating temperatures from −20°C to +50°C. **Telonic Berkeley, Subsidiary of Berkeley Industries, Laguna Beach, CA. Adam Reed, (714) 494-9401.** **Circle 156.**

DOUBLE BALANCED MIXER FOR 2-8 GHz BAND

Model MD-177 is a double balanced mixer which covers the 2-8 GHz frequency band. It features 5 dB typical, 8.0 dB maximum conversion loss, 23 dB typical L-R isolation and is capable of operating at 0 dBm starved LO without bias. Units are designed for extreme military environments and can be supplied screened to MIL-STD-883. Available in a hermetic 3 pin module or SMA connectorized module which can double as a module test fixture. Price: $250, 1-5 qty. of module type; $325, in connectorized version. Avail: from stock. **Adams Russell Co. Inc., Anzac Division, Burlington, MA. Mark Rosensweig, (617) 273-3333.** **Circle 143.**

SPDT SWITCH FOR 2 - 12.4 GHz BAND

Model S-B25 in a PIN diode SPDT switch which offers a minimum of 60 dB isolation and 2.5 dB maximum insertion loss over the full 2-18 GHz frequency range. 10-90% rise and fall times are 50 ns, maximum. Drivers are integral and require +5 Vdc at 75 ma and −5 Vdc at 20 ma, plus logic for TTL operation. The maximum SWR in the "on" position is 1.30 and the operating power is limited to 1 W CW maximum. Operating temperature range is −55° to +85°C and it is suited for applications which include environmental parameters of MIL-E-5400R. Size: 1.1" x 1.1" x 0.50", plus SMA female type connectors and bias terminals. Price: $350, 1-9 qty. Del: 60 days. **Engelmann Microwave Co., Montville, NJ. Carl Schraufnagl, (201) 334-5700.** **Circle 145.**

THIN-TRIM® CAPACITOR LINE

Expanded line of Thin-Trim® capacitors includes four series from smallest, the 9402, which measures .125" x .125" x .040" T to the largest, the 9900, which is .300" x .300" x .080"T. A wide selection of capacitance values provide a broad range of adjustments — from #9401-0 which has a .25-.7 pF range to #9917, with a 20-100 pF adjustment range. Capacitors may be used at frequencies up to 5 GHz, depending on model. Insulation resistance is 10^6 M Ω; working voltage is 250 Vdc. Price: 50¢-$1.05 in 10,000 qty. Del: stock to 4 wks. **Johanson Manufacturing Corp., Boonton, NJ. Eric Fagerlund, (201) 334-2676.** **Circle 146.**

DIODE SWITCHES COVER .1-18 GHz

Six new series of single pull, single throw diode switches are offered for the .1-18 GHz frequency range in bandwidths up to 9:1. Broadband isolations of 45 dB and 70 dB are available with and without drivers in switching speeds of 15 and 350 ns. Size .69" x .75" x .5" without driver; 7/8" x 1 1/2" x 1/2" with driver. Price: from $135. Del: from stock. **Norsal Industries, Central Islip, NY. Norman Spector, (516) 234-1200.** **Circle 152.**

50 Ω CARTRIDGE TERMINATIONS

A series of 50 ohm cartridge terminations which operate in the dc to 18 GHz frequency range at an SWR of 1.35:1 maximum from 12.4 to 18 GHz is offered. Model PCL 3-125-3 weighs less than 2 g and will dissipate 3 W of average power; PCL15-250-3 is a 15 W model. Price: $7.70 each in 3 W unit in 100 qty.; $9.95 each for 15 W termination in 100 qty. Avail.: from stock. **KDI Pyrofilm Corporation, Whippany, NJ. Al Arfin, (201) 887-8100.**
Circle 147.

PASSIVE POWER DIVIDER/COMBINERS FOR 3.7 - 4.2 GHz BAND

Series PDR-4200 are passive power divider/combiners featuring 2, 4, and 8-way phase coherence (0°) optimized for the 3.7-4.2 GHz band of satellite downlink receiver systems. Series features 0.70-0.9 dB typical insertion loss, 20 dB port-to-port isolation and 1.3:1 maximum SWR. Power divider/combiners are bilateral and designs minimizes number of internal soldered connections for improved reliability and elimination of in-band SWR, phase and amplitude perturbations. Units are packaged in shielded plated metal cases and equipped with type N RF connectors. Price: $95-$175, in single qty. according to model. Del.: 60 days ARO. **Avantek, Inc., Santa Clara, CA. Ken McKean, (408) 727-0700.**
Circle 148.

HERMETIC SMA BULKHEAD FEEDTHROUGH ADAPTOR

Part No. 705627-101 is a hermetic SMA bulkhead feedthrough adaptor employing a 50 ohm solder-in Kovar glass seal and welded contacts. It has a SWR of 1.25:1 maximum from 2-18 GHz. Mating face is SMA jack (female) on both ends in accordance with MIL-C-39012B. Price: $7.82 per unit, 1,000 qty. Avail.: stock. **Cablewave Systems, Inc., North Haven, CT. Steven Raucci Jr., (203) 239-3311.** Circle 149.

GaAs FET AMPLIFIER SERIES COVERS 6-18 GHz BAND

Series N6226S are GaAs FET amplifiers which cover the 6-18 GHz frequency range with SWR of 2:1, maximum. Model N6226A-10 has maximum NF of 8 dB, minimum 9 dB small signal gain, gain variation of ± 1 dB maximum and power output of + 10 dBm, minimum. Typical current at + 12 Vdc is 120 mAdc. For Model N6226S-16, NF is 8 dB, maximum, small signal gain is 43 dB, min., gain variation is ± 2.0 dB, max. and power output is + 10 dBm, min. Typical current at + 12 Vdc is 600 mAdc. Amplifier series uses thin-film microstripline construction and conforms to MIL-E-5400/MIL-E-16400 requirements. Model N6226A-10 measures 1.15" x 1.0" x .6" and N6226S-16, 3.1" x 1.0" x .6", both exclusive of SMA connectors which are standard. **Narda Microwave Corp., Sunnyvale, CA. Gary Gianatasio, (408) 735-7500.** **Circle 177.**

LINE OF COAX RF POWER TRANSFER STANDARDS

Series 1103 is a line of coaxial RF power transfer standards offering accurate calibration of terminating and feedthrough power meters. The frequency range of 0.1-18.0 GHz is covered in six models. Less than 1% total error in transfer of calibration factor to an unknown is achieved, depending upon SWR of the secondary standard. Stability is better than ± 0.5%. High connector repeatability and low SWR is insured by using 14 mm (0.1 to 8.0 GHz) and 7 mm (8.0 to 18.0 GHz) precision connectors. The SWR is typically 1.15 and a thermal time constant of approximately 3 hours minimizes drift during measurement. Adjustable stand permits a high and axial rotation for proper alignment and engagement of precision connectors. Input SWR, equivalent source SWR and calibration factors at three frequencies (NBS traceable) are furnished with each unit. **Weinschel Engineering, Gaithersburg, MD. Julian D. Parker, (301) 948-3434.**
Circle 158.

720 MHz IF-BPF FOR EARTH STATIONS

Model 3636-720-20 is an IF bandpass filter for earth stations. Center frequency is 720 MHz, bandwidth is 20 MHz. Selectivity is 30 dB min. ± 30 MHz. Connectors are the SMA type. **Microwave Filter Company, Inc., East Syracuse, NY. Emily Bostick, (315) 437-3953.** Circle 151.

Advertising Index

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New Literature

SIGNAL GENERATOR/SIGNAL SOURCE SHORT FORM CATALOG

An 8-page catalog (P-80) describes the upgraded "E" Series of signal generator/signal source for the 0.8 to 21 GHz frequency band. Catalog highlights features of each product with performance curves, block diagrams and specifications. Photographs are also provided. Catalog includes a Specifications Summary Chart for the 26 models. Additional units, such as solid state modulators, spectrum analyzers and calibrated antennas also are listed. **Polarad Electronics, Inc., Lake Success, NY. Ed Feldman, (516) 328-1100.** **Circle 137.**

MILLIMETER-WAVE COMPONENT CATALOG

A complete line of millimeter-wave components is described in a 40-page catalog which includes attenuators, directional couplers, frequency meters, calorimeters, loads, tunable detector mounts, bi-directional switches, horns/lenses, E-H tuners, 90 bends, adjustable shorts and phase shifters, polarization duplexors, reflectometers, hybrid tees, flange transitions, waveguide tapers, twists and other components. Booklet includes photographs of various components as well as mechanical dimensions, and key electrical performance specifications. **Thomson CSF Electron Tube Division, Clifton, NJ. A. Laconti, (201) 779-1004.** **Circle 140.**

MICROWAVE COMPONENT PRODUCT LINE CATALOG

A 22-page, 2-color catalog describing a complete line of microwave components, including coaxial switches, waveguide switches, dummy loads, crystal detectors, bolometers, RF micropotentiometers and solid state noise diodes and sundries is offered. Each product section includes photograph(s), performance characteristics and schematic diagrams. **Micronetics, Inc., Norwood, NJ. Gary Simonyan, (201) 767-1320.** **Circle 133.**

BROCHURE ON AUTOMATED POWER RATIO MEASUREMENT

AN-17 is a brochure describing how to reduce the steps taken in automated power measurement using the model 1045 RF Power Meter. Measurements of RF power in both mW and dBm terms is discussed as is the use of the power meter under control of an intelligent calculator. A separate section on programming the instrument is included. **Pacific Measurements, Inc., Sunnyvale, CA. Ed Mendel, (408) 734-5780.** **Circle 136.**

RF AND MICROWAVE FILTER LINE CATALOG

A comprehensive, 40-page brochure describes an RF and microwave filter product line, consisting of 23 types of filters from 20 MHz - 12 GHz including new standard high-pass and subminiature types. Each series of filters is covered by a description, photo, and chart of electrical and environmental specifications. Catalog is organized into sections on filter selection, frequency and bandwidth tolerance curves, passband relationships and passband relationship curves. **Telonic Berkeley, Berkeley Industries Subsidiary, Laguna Beach, CA. Adam Reed, (714) 494-9401.** **Circle 139.**

CATALOG OF MICROWAVE TELEVISION FILTERS

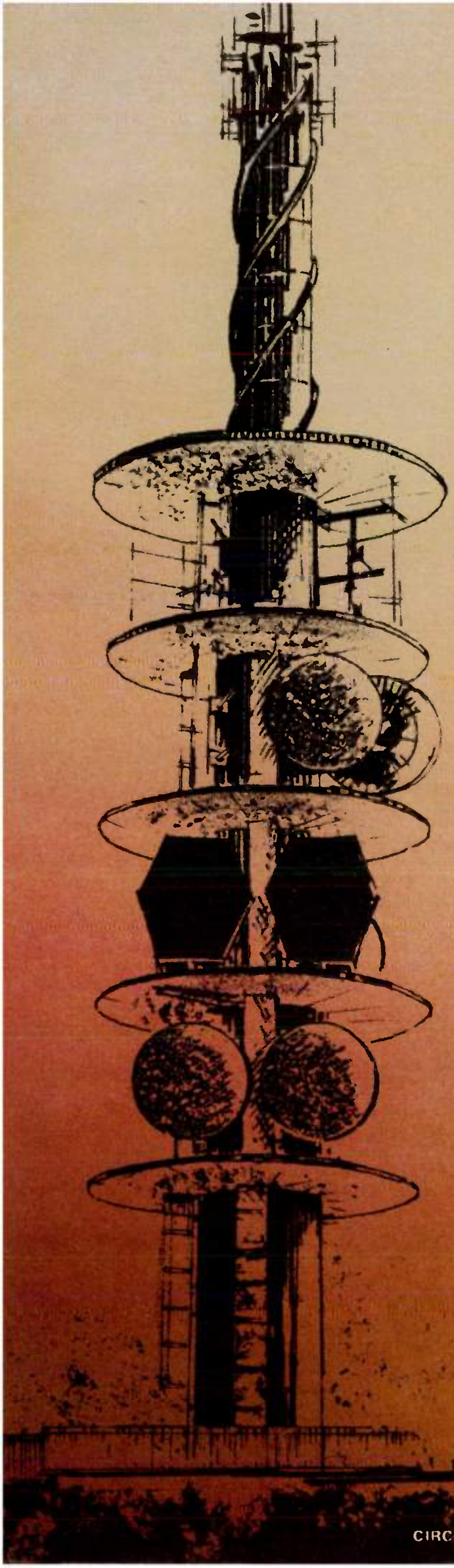
=MTV/81 is an eight-page pamphlet which describes filters for cars Bands, MDS and earth stations. A bandpass filter for 3.7-4.2 GHz frequency range, single transponder band pass fillers, IF band pass fillers from 70 MHz to 1500 MHz and traps for eliminating terrestrial interference are included. Each product is treated with performance curves, key electrical specifications and a photograph. **Microwave Filter Company, Inc., E. Syracuse, NY. Emily Bostick, (315) 437-3953.** **Circle 134.**

CATALOG ON COMPONENTS AND ASSEMBLIES

Catalog '79 in a 42-page, comprehensive listing of attenuators, bias tees, bi-phase modulator, directional couplers, comparators, detectors, dc blocks and bias tees, discriminators, duplexers, filters, hybrids, limiters, levelers, balanced mixers, mixer-detectors, modulator, phase shifters, power dividers, SSB generators, subassemblies and switches for applications from 0.1-18 GHz. Each product category is treated with photographs, performance specifications and mechanical dimensions. **Triangle Microwave, East Hanover, NJ. (201) 884-1423.** **Circle 141.**

CATALOG ON PROGRAMMABLE ATTENUATOR PRODUCT LINE

The 3200 brochure details a programmable attenuator product line designed for OEM use in the dc to 2 GHz range. Complete specifications, attenuation curves and outline configurations are provided. **Weinschel Engineering, Gaithersburg, MD. Julian D. Parker, (301) 948-3434.** **Circle 142.**



MSC

GaAs FET Power Amplifiers

Products for Terrestrial Radio Systems

MSC 98100 SERIES

Electrical Characteristics (@ 30°C)

Model Number	Frequency Range (MHz)	Small Signal Gain (dB)	Power Output (dBm) Minimum @ 1 dB Comp.	Power Output (dBm) Minimum @ Saturation
MSC 98101R	3600-4200	32	30.0	31
MSC 98111R	3600-4200	37	33.0	34
MSC 98121R	3600-4200	41	37.0	38
MSC 98102	4400-5000	31	30.0	31
MSC 98103R	5925-6425	30	30.0	31
MSC 98113R	5925-6425	35	33.0	34
MSC 98123R	5925-6425	39	37.0	38
MSC 98104R	6425-7125	28	30.0	31
MSC 98114R	6425-7125	32	32.3	33
MSC 98124R	6425-7125	36	35.5	36
MSC 98105R	7125-7725	26	30.0	31
MSC 98115R	7125-7725	30	31.5	32
MSC 98125R	7125-7725	33	34.5	35
MSC 98106	7900-8400	27	30.0	31

NOTES (1) Higher gain options available (MSC 98700 series).
(2) Recommended supply voltage for best efficiency V_D = + 10Vdc regulated.
(3) Alternate supply voltage V_D = + 12 Vdc minimum with internal regulation.

YOUR TOTAL MICROWAVE RESOURCE

Custom designed amplifiers with higher power outputs and optimization of band-width and/or efficiency are available. Please call or write for a complete GaAs FET Product Data Packet.

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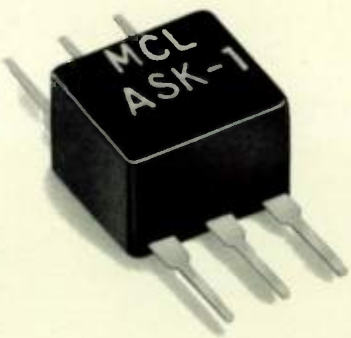
CIRCLE 2 ON READER SERVICE CARD

Shown actual size

the shrinker

the worlds smallest and lowest priced flatpack mixer **shrinks size and cost.**

The ASK-1 from Mini-Circuits $5.95 (10-49)



Mini-circuits
Model ASK-1/Plastic Case

Until now, the smallest mixer flatpack available was 0.510 by 0.385 inches or 0.196 sq. inches.

Now, Mini-Circuits introduces the ultra-compact ASK series, measuring only 0.300 by 0.270 inches or 0.081 sq. inches, more than doubling packaging density on a PC board layout.

Utilizing high production techniques developed by Mini-Circuits, the world's largest manufacturer of double-balanced mixers, the ASK-1 is offered at the surprisingly low price of only $5.95 (in 10 quantity).

Production quantities are available now for immediate delivery. And, of course, each unit is manufactured under the high quality standards of Mini-Circuits and is covered by a one-year guarantee.

ASK-1 SPECIFICATIONS

FREQUENCY RANGE:
RF, LO: 1-600 MHz;
IF: DC-600 MHz

CONVERSION LOSS:
One Octave from Bandedge: 8.5 dB Max.
Mid-Range: 7.0 dB Max.

ISOLATION:
L-R: 45 dB Typ.; L-I: 30 dB Typ.

ABSOLUTE MAXIMUM RATINGS:
Total Input Power: 50 mW
Total Input Current, peak: 20 mA
Operating Temperature: −55°C, +100°C
Storage Temperature: −55° to +100°C
Pin Temperature (10 sec): +260°C

WEIGHT: .35 grams (.01 ounces) *CASE:* Plastic

Mini-Circuits
A Division of Scientific Components Corp.
World's largest manufacturer of Double Balanced Mixers
2625 East 14th Street, Brooklyn, New York 11235 (212)769-0200
Domestic and International Telex 125460 International Telex 620156

CIRCLE 3 ON READER SERVICE CARD

52 REV. ORIG.