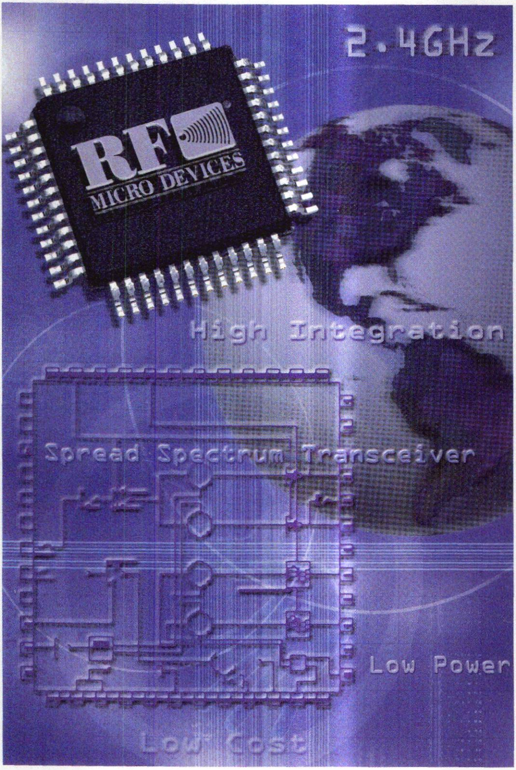
microwave JOURNAL
EURO-GLOBAL EDITION

OCTOBER 1999
VOL. 42, NO. 10



COMMUNICATIONS AND PCNs

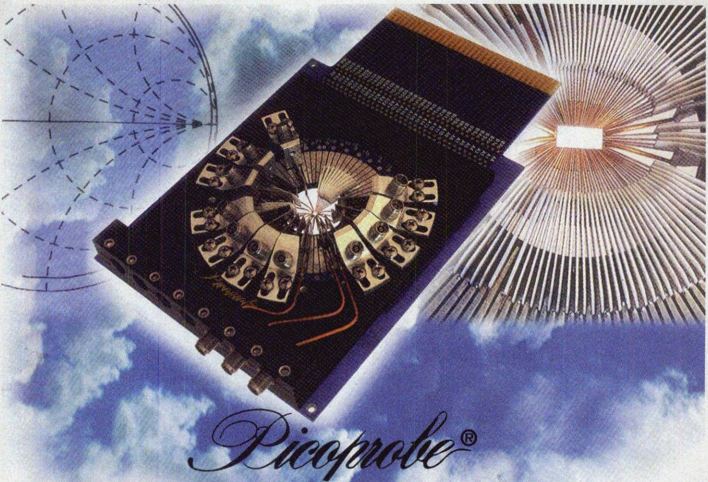
UNDERSTANDING OFFSET 8-PSK MODULATION FOR GSM EDGE

DIGITAL PREDISTORTION TECHNIQUES FOR RF POWER AMPLIFIERS WITH CDMA APPLICATIONS

VECTOR SIGNAL MEASUREMENT FOR 38 GHZ DIGITAL RADIO APPLICATIONS

CONTENTS, P. 10

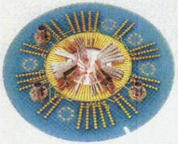
horizon house®



Picoprobe elevates probe cards to a higher level...

(...110 GHz to be exact.)

For 17 years GGB Industries, Inc., has blazed the on-chip measurement trail with innovative designs, quality craftsmanship, and highly reliable products. Our line of custom microwave probe cards continues our tradition of manufacturing exceptional testing instruments.



Through unique modular design techniques, hundreds of low frequency probe needles and a variety of microwave probes with operating frequencies from DC to 40, 67, or even 110 GHz can be custom configured to your layout.

Our patented probe structures provide the precision and ruggedness you require for both production and characterization testing. And, only Picoprobe® offers the lowest loss, best match, low inductance power supplies, and current sources on a single probe card.

Our proven probe card design technology allows full visibility with inking capability and ensures reliable contacts, even when probing non-planar structures.

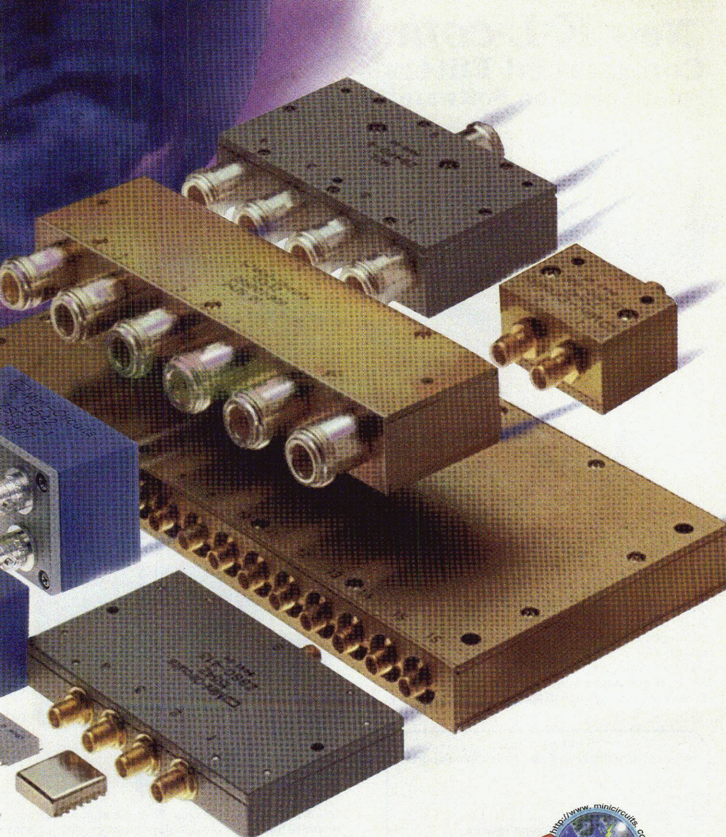
Not only do you get all the attractive features mentioned, but you get personal, professional service, rapid response, and continuous product support--all at an affordable price so your project can be completed on time and within budget.

Typical Specs	10GHz	20GHz	40GHz
Insertion Loss	0.6 dB	0.8 dB	1.3 dB
Return Loss	22 dB	18 dB	15 dB

For technical assistance, custom product designs, or off-the-shelf delivery, call GGB Industries, Inc., at (941) 643-4400.

GGB INDUSTRIES, INC. • P.O. BOX 10958 • NAPLES, FL 34101

Telephone (941) 643-4400 • Fax (941) 643-4403 • E-mail email@ggb.com • www.picoprobe.com



Calibrate Your Vector Network Analyzer *ACCURATELY!*

PROPERLY CALIBRATED **vector network analyzers (VNAs) are essential for accurately determining the one- and two-port network characteristics of RF and microwave devices. TRL/LRL calibration is one of the most accurate VNA calibration methods available.**

MAURY MICROWAVE's **comprehensive line of coaxial and waveguide TRL/LRL VNA calibration kits provide accurate, stable and precise calibration standards that ensure accurate evaluation of VNA performance.**

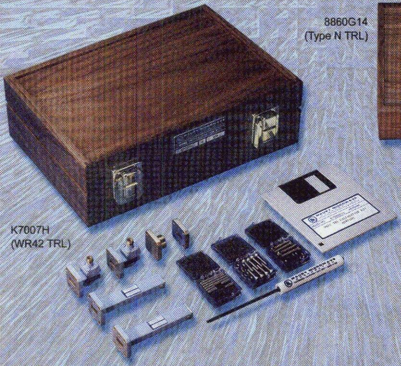
TRI-KITS **– MAURY offers a variety of coaxial "TRI-KITS" that are ideal for performing TRL/LRL, short-open-load-thru (SOLT), and one-port calibrations for gated measurement. Available connector types are:**

- 2.92mm (K)
- 3.5mm (also used for SMA testing)
- Type N
- 7-16
- 14mm (formerly GR900)
- 7mm (APC7)

2660A
(7mm TRL)

WAVEGUIDE **TRL kits are available in all common, standard rectangular sizes from WR430 (1.7 to 2.6 GHz) through WR22 (33 to 50 GHz). If you require a specially configured calibration kit, please contact our Sales Department.**

8860G14
(Type N TRL)



K7007H
(WR42 TRL)

For more information about these and other fine Maury products, contact our SALES DEPARTMENT at the numbers below.

MAURY MICROWAVE CORPORATION

Visit us on the World Wide Web at
http://www.maurymw.com

2900 Inland Empire Blvd. • Ontario, California 91764, USA • Tel: 909-987-4715 • Fax: 909-987-1112
Email: maury@maurymw.com

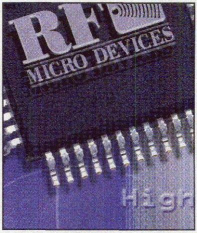
microwave JOURNAL®

OCTOBER 1999 • VOL. 42, NO. 10

FEATURES

TECHNICAL FEATURES

[Continued on page 12]



ON THE COVER

A transceiver chipset for 2.4 GHz direct sequence spread spectrum applications is featured on this month's cover

Cover art courtesy of RF Micro Devices

Microwave Journal (USPS 396-250) (ISSN 0192-6225, International Edition: ISSN 0192-6217, Euro-Global Edition) is published monthly by Horizon House Publications Inc., 685 Canton St., Norwood, MA 02062. Periodicals postage paid at Norwood, MA 02062 and additional mailing offices.

POSTMASTER: Send address corrections to *Microwave Journal*, PO Box 3256, Northbrook, IL 60065-3256, Subscription information (847) 291-5216. This journal is issued without charge upon written request to qualified persons working in that part of the electronics industry, including governmental and university installation, that deals with VHF through light frequencies. Other subscriptions are: domestic, $100.00 per year, two-year subscriptions, $150.00; foreign, $165.00 per year, two-year subscriptions, $310.00; back issues (if available) and single copies, $10.00 domestic and $20.00 foreign.

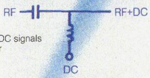
BPA INTERNATIONAL

Horizon House also publishes *Telecommunications*® and *Journal of Electronic Defense*

Posted under Canadian international publications mail agreement #0738654

BIAS TEES

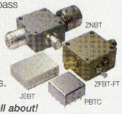
From $25^{95}



Easily combines RF+DC signals for your modulation or test requirements.

Now up to 500mA DC current 100kHz-6GHz

With Mini-Circuits Bias-Tees, you can DC connect to the RF port of an active device without effecting its RF properties...modulate a laser, apply DC to an amplifier output, and more! Using statistical process control plus combining magnetics and microstrip, large DC currents may pass through the Bias-Tee without saturation and degradation of performance. At 1/3 to 1/4 the price of competitive units, these new Bias-Tees are available in surface mount, pin, and connectorized models. So why wait, solve your connection problems with Mini-Circuits Bias-Tees.



Mini-Circuits...we're redefining what VALUE is all about!

Model	Freq (MHz)	Insertion Loss (dB Typ.)			Isolation (dB Typ.)			VSWR (Typ.)	Price $ ea
	F_L-F_U	L	M	U	L	M	U	U	1-9 qty.
▲ZFBT-4R2G	10-4200	0.15	0.6	0.6	32	40	50	1.13:1	59.95
▲ZFBT-6G	10-6000	0.15	0.6	1.0	32	40	30	1.13:1	79.95
▲ZFBT-4R2GW	0.1-4200	0.15	0.6	0.6	25	40	50	1.13:1	79.95
▲ZFBT-6GW	0.1-6000	0.15	0.6	1.0	25	40	30	1.13:1	89.95
▲ZFBT-4R2G-FT	10-4200	0.15	0.6	0.6	N/A	N/A	N/A	1.13:1	59.95
▲ZFBT-6G-FT	10-6000	0.15	0.6	1.0	N/A	N/A	N/A	1.13:1	79.95
▲ZFBT-4R2GW-FT	0.1-4200	0.15	0.6	0.6	N/A	N/A	N/A	1.13:1	79.95
▲ZFBT-6GW-FT	0.1-6000	0.15	0.6	1.0	N/A	N/A	N/A	1.13:1	89.95
★ZNBT-60-1W	2.5-6000	0.2	0.6	1.6	75	45	35	1.35:1	82.95
■PBTC-1G	10-1000	0.15	0.3	0.3	27	33	30	1.10:1	25.95
■PBTC-3G	10-3000	0.15	0.3	1.0	27	30	35	1.60:1	35.95
■PBTC-1GW	0.1-1000	0.15	0.3	0.3	25	33	30	1.10:1	35.95
■PBTC-3GW	0.1-3000	0.15	0.3	1.0	25	30	35	1.60:1	46.95
•JEBT-4R2G	10-4200	0.15	0.6	0.6	32	40	40	-	39.95
•JEBT-6G	10-6000	0.15	0.7	1.3	32	40	40	-	59.95
•JEBT-4R2GW	0.1-4200	0.15	0.6	0.6	25	40	40	-	59.95
•JEBT-6GW	0.1-6000	0.15	0.7	1.3	25	40	30	-	69.95

L = Low Range M = Mid Range U = Upper Range

NOTE: Isolation dB applies to DC to (RF) and DC to (RF+DC) ports.

▲SMA Models, FT Models Have Feedthrough Terminal ★Type N, BNC Female at DC

■Pin Models •Surface Mount Models

Mini-Circuits®

US 102 INT'L 103

CIRCLE READER SERVICE CARD

P.O. Box 350166, Brooklyn, New York 11235-0003 (718) 934-4500 Fax (718) 332-4661 For quick access to product information see MINI-CIRCUITS CATALOG & WEB SITE

The Design Engineers Search Engine Provides ACTUAL Data Instantly From MINI-CIRCUITS At: ***http://www.minicircuits.com***

ISO 9001 CERTIFIED

F 164 Rev B

microwave JOURNAL®

FEATURES

TUTORIAL

TECHNICAL FEATURE

PRODUCT FEATURES

DEPARTMENTS

Press run for this issue is 58,523 copies

Printed in the USA

STAFF

Publisher/Editor: Harlan Howe, Jr.
Associate Publisher: Edward Johnson
Managing Editor: Amy E. Norcross
Technical Editor: Frank M. Bashore
Staff Editor: Christina M. Sciammacco
Editorial Secretaries: Allison Greco
Gayl Sanzi
Consulting Editor: Howard I. Ellowitz
Consulting Editor: Theodore S. Saad
Consulting Editor: Peter Staecker
Int'l Correspondent: Martin Streetly
Int'l Staff Editor: Steve McClelland
Assistant to the Publisher: Kristen Dednah
Traffic Manager: Edward Kiessling
Traffic Administrator: Michelle Carletti
Production Manager: Robert Bass
Production Assistant: Judy Wiklund
Art Director: Robert Pike
DTP Coordinator: Janet A. MacDonald
Graphic Designer: Sachiko Stiglitz
Graphic Design Group:
Sandra Deneault
Sara Keating
Andrew Ross

EUROPE

Deputy Publisher: Sam Baird
Office Manager: Eugenie Hardy
Sales Manager: Gareth Watson

CORPORATE STAFF

Chairman & Executive Officer: William Bazzy
President: William M. Bazzy
VP Finance & Operations: Charles A. Ayotte
VP Group Publishing: William Waller
Corporate Vice President: Joan B. Egan

Executive Editorial Office:
685 Canton Street, Norwood, MA 02062
Tel: (781) 769-9750
Fax: (781) 769-5037
e-mail: mwj@mwjournal.com
www.mwjournal.com

European Editorial Office:
46 Gillingham Street, London SW1V 1HH, England
Tel: Editorial: +44 171 596 8730 Sales: +44 171 596 8740
FAX: +44 171 596 8749

- .047" Cable Maximum Diameter
- .13" Minimum Bend Radius
- .38" Preferred Bend Radius
- -65 / +105°C Temperature Range

Now, over **40,000** QMI Cable Assemblies are in stock at **Richardson Electronics**.

In stock, fully specified Assemblies with selected lengths and Connector combinations. Data sheets available at **www.qmiinc.com**.

Connector Specifications at: QMIINC.COM	Impedance Nominal (Ohms)	Capacitance Nominal (pf/FT)	Velocity of Propagation, Nominal (%)	Relative Shielding (dB Min)	Insulation Resistance (Megohms Min)	Dielectric Withstanding Voltage (VRMS Min.)	Electric Delay (ns/FT)	Electric Delay (ps/Inch)	Max. Pulse RF Power (Watts)*	F (in GHz)	Max. CW Watts
SMA.604	50	31.40	70.5	-100	1000	1000	1.44	120	1250	1 2 4 6 12 18	33 24 18 16 13 10
MCX.604	50	31.40	70.5	-100	1000	1000	1.44	120	500	0.5 1 2 4 6	45 33 20 17 13
MCXRT.604	50	31.40	70.5	-100	1000	1000	1.44	120	500	0.5 1 2 4 6	45 33 24 18 16

*Into a 50 OHM System, with duty cycle less than CW rating.

MADE IN THE USA

Tensolite

QMI® Microwave Interconnects

A CARLISLE Company

301 Ballardvale St. Wilmington, MA 01887

1-800-362-FLEX

FAX: (978) 988-9393

www.qmiinc.com Email: sales@qmiinc.com

"Do it Yourself" - call QMI for cable and connector price and availability. Selected options and lengths in stock for immediate delivery from QMI's Worldwide Distributor:

Richardson Electronics

Engineered Solutions

1-800-RF-POWER

1999 International Semiconductor Device Research Symposium (ISDRS '99)
December 1–3, 1999
Charlottesville, VA

Sponsors: IEEE MTT and ED Societies. Topics: Fundamental concepts in novel devices and advanced processing technologies, including new material and device characterization, microwave and millimeter-wave devices, microelectrical mechanical systems, nanoelectronics and optoelectronics. Contact: Lori Tawney, conference coordinator (804) 924-3744 or e-mail: engineering-outreach@virginia.edu. Additional information is available at www.ee.virginia.edu/~isdrs/.

54th ARFTG Conference
December 2–3, 1999
Atlanta, GA

Sponsors: The Automatic RF Techniques Group (ARFTG). Topics: Characterization of broadband access technologies, automated microwave and RF measurements, simulation tools and associated products including network analysis, calibration techniques, on-wafer measurements, power and noise. For exhibition information, contact: Leonard Hayden (503) 601-1580 or e-mail: Leonard@cmicro.com. Additional information is available at www.arftg.org.

Sixteenth Annual IEEE Semiconductor Thermal Measurement and Management Symposium
March 21–23, 2000
San Jose, CA

Sponsors: Components, Packaging and Manufacturing Technology Society of the IEEE and the National Institute of Standards and Technology. Topics: New developments relating to the thermal characterization of electronic components, subsystems and systems, including generation and removal of heat from within semiconductor devices, measurement of device temperatures and simulation of device and system thermal behavior. Contact: Bonnie Crystall, conference manager, C/S Communications Inc., PO Box 23899, Tempe, AZ 85285 (520) 323-2870, fax (520) 323-2803 or e-mail: cscom@indirect.com.

2000 International Conference on GaAs Manufacturing Technology
May 1–4, 2000
Washington, DC

Call for papers. Topics: Compound semiconductor manufacturing, 150-mm conversion, cycle time reduction, CIM tools for manufacturing environmental impact and cost management; processing, lithography, gate formation, low capacitance crossovers, high and low dielectric constant materials, failure mechanisms and module integration issues; test and reliability, high speed, high volume and low cost testing; device technologies, yield enhancement (MESFET, pHEMT, HBT, HFET, PIN) and thermal enhancement; and optical devices and materials and packaging. Send: original abstract with supporting data and 45 copies. Send to: Bruce Bernhardt, Motorola, MD EL-720, 2100 East Elliot Rd., Tempe, AZ 85284 (408) 413-4427. Submissions also can be sent electronically in PDF format to abstractsubmission2000@gaasmantech.org. **Deadline: November 1, 1999.** Additional information is available at www.gaasmantech.org.

50th Electronic Components and Technology Conference
May 21–24, 2000
Las Vegas, NV

Sponsors: IEEE Components, Packaging and Manufacturing Technology Society and Electronic Industries Alliance. Topics: New developments in electronics technology, including advanced packaging, components and RF, connectors and contacts, education, interconnections, manufac-

turing, materials and processing, modeling and simulation, optoelectronics, and quality and reliability. Contact: Michael McShane (512) 933-6403, fax (512) 933-5844.

Fifth International Workshop on Finite Elements for Microwave Engineering
June 8–9, 2000

Sponsors: Worcester Polytechnic Institute, the University of Florence and Ansoft Co. Topics: Application areas of antennas and scattering problems, microwave electronics and the finite element method. Contact: J.F. Lee, Worcester Polytechnic Institute, e-mail: jinlee@ece.wpi.edu or R. Lee, Ohio State University, e-mail: lee@ee.eng.ohio-state.edu. Additional information can be found at www.ece.wpi.edu/~jinlee.

2000 IEEE Radio Frequency Integrated Circuits (RFIC) Symposium
June 11–13, 2000
Boston, MA

Sponsors: MTT-S. Topics: Highly integrated ICs and system IC solutions in the RF/microwave frequency range, including semiconductor technology; mixed-signals, cellular/PCS/ISM, receiver, transmitter, and microwave and mm-wave ICs; multifunction ICs and multichip modules; RF/microwave subsystems; integrated filters and antennas; and packaging, testing and reliability. Contact: Christian Kermarrec (781) 937-1217 or e-mail: christian.kermarrec@analog.com. Additional information is available at www.ims2000.org.rfic.htm.

2000 IEEE MTT-S International Microwave Symposium and Exhibition
June 11–16, 2000
Boston, MA

Call for papers. Sponsors: IEEE MTT-S. Topics: Advancement and application of RF and microwave theory and techniques, including analysis and design; components and assemblies; passive and active microwave technology; frequencies greater than 30 GHz; fabrication, integration and test; and applications. Electronic submissions are highly recommended via www.ims2000.org. For hard copy submissions, send to: International Microwave Symposium c/o LRW Associates, 468 Walden Trail, Waxhaw, NC 28173 (704) 841-1915. Send: author registration form, including 30- to 50-page abstract, and four-page summary. **Deadlines: December 3, 1999 (electronic submissions), November 29, 1999 (hard copy submissions).** For symposium information, contact: Peter Staecker, technical program chair (781) 861-7643, fax (781) 863-5751 or e-mail: p.staecker@ieee.org. For exhibition information, contact Kristen Dednah, Horizon House Publications, 685 Canton St., Norwood, MA 02062 (781) 769-9750, fax (781) 769-5037 or e-mail: kdednah@mwjournal.com. Additional information is available at www.ims2000.org.

ARFTG Conference
June 15–16, 2000
Boston, MA

Sponsors: ARFTG and IEEE MTT-S. Topics: Issues in nonlinearity characterization for RF and microwave components, subsystems and systems, including digital mobile (CDMA and GSM), PCS and third-generation wireless technology, local multipoint distribution systems, multichannel multipoint distribution systems and other broadband wireless access systems, digital cable and broadcast television, low earth orbit satellite and other satellite communications systems, wireless local loop applications and wireless local area networks. Contact: Mike Fennelly, Roos Instruments Inc., 2285 Martin Ave., Ste. C, Santa Clara, CA 95050 (978) 258-4101 or e-mail: mfennelly@roos.com. Additional information is available at www.ims2000.org/arftg.htm.

WORKSHOPS & COURSES

Principles of Modern Radar

■ **Topics:** Basic radar principles, techniques and technology, including antennas, transmitters, receivers, signal processing, Doppler polarization and reflectivity measurements. Fee: $1295.
■ **Site:** Atlanta, GA
■ **Date:** November 1–5, 1999
■ **Contact:** Continuing Education, Georgia Institute of Technology, Atlanta, GA 30332 (404) 894-2547 or e-mail: conted@gatech.edu.

LTCC Measurement and Testing for Wireless Applications

■ **Topics:** Measurement and testing of low temperature co-fired ceramic (LTCC) technology, including reproducible dielectric measurements at frequencies above 1 GHz, modeling of tape processes and phase equilibria data for electrode/ceramic interactions.
■ **Site:** Gaithersburg, MD
■ **Date:** November 4–5, 1999
■ **Contact:** Steve Freiman or Carolyn Sladic, National Institute of Standards and Technology (301) 975-6119 or e-mail: stephen.freiman@nist.gov.

Digital Wireless Telecommunications: An Introduction

■ **Topics:** Analog and digital cellular technologies, applications and regulatory status in the US and Europe; PCS trends; and mobile, LEO and MEO satellite systems. Fee: $1125.
■ **Site:** Washington, DC
■ **Date:** November 15–17, 1999
■ **Contact:** P.J. Mondin, George Washington University Continuing Engineering Education Program, 2029 K St. NW, Suite 200, Washington, DC 20052 (800) 424-9773 or e-mail: pj@ceep.gwu.edu.

Basics of Wireless for Nonengineers

■ **Topics:** Wireless terminology; microwave, satellite, cellular/PCS and WLL systems; the history of telecommunications; and key players in the wireless industry. Fee: $795.
■ **Site:** Reston, VA
■ **Date:** November 16–17, 1999
■ **Contact:** Comsearch Center for Technical Training, 2002 Edmund Halley Dr., Reston, VA 20191 (800) 318-1234 or e-mail: info@comsearch.com.

Frequency Synthesis Technology and Applications in Wireless Systems

■ **Topics:** Direct digital, direct analog and digital signal processing principles; phase noise theory and testing; and simulation and practical considerations of CAD tools. Fee: $1250.
■ **Site:** Orlando, FL
■ **Date:** December 1–3, 1999
■ **Contact:** Besser Associates, 201 San Antonio Circle, Bldg. E, Mountain View, CA 94040 (650) 949-3300, or e-mail: info@bessercourse.com.

HF Communication Technology: Advanced Techniques

■ **Topics:** Traditional and modern approaches to high frequency (HF) communications system design and operation; HF direction-finding technologies; and ionospheric and HF channel variability. Fee: $1445.
■ **Site:** Washington, DC
■ **Date:** December 6–10, 1999
■ **Contact:** P.J. Mondin, George Washington University Continuing Engineering Education Program, 2029 K St., NW, Ste. 200, Washington, DC 20052 (800) 424-9773 or e-mail: pj@ceep.gwu.edu.

RF and Wireless Component Design Using Electromagnetic Simulation

■ **Topics:** Solutions to complex geometries, discontinuities, transistors in multilayer structures, planar antennas and calibration structures, and choosing the appropriate CAD package.
■ **Site:** Denmark
■ **Date:** December 9–10, 1999
■ **Contact:** Continuing Education Institute-Europe, PO Box 910, S-612 25 Finspong, Sweden, +44 122 175 70 or e-mail: cei.europe@cei.se. Additional information is available at www.cei.se.

Self-study Radar Course

■ **Topics:** Radar principles, functions and parameters, the radar equation, target detection, tracking and track-while-scan, radar hardware, signal processing and case studies. Textbook included. Fee: $384
■ **Contact:** IEEE Customer Service Dept., 445 Hoes Lane, PO Box 1331, Piscataway, NJ 08855 (800) 678-4333 or e-mail: customer-service@ieee.org.

We make noise...

To make your products quiet!

Noise Com is the global provider of Noise Generators, Noise Sources, Noise Power Ratio Test Sets, Noise Diodes and specialized Noise Test Solutions.

For more information about our products, applications or how we may solve your testing needs, contact us:

Noise Com
E. 64 Midland Avenue, Paramus, NJ 07652
Phone: (201) 261-8797 Fax: (201) 261-8339
Email: info@noisecom.com
Web Site: http://www.noisecom.com

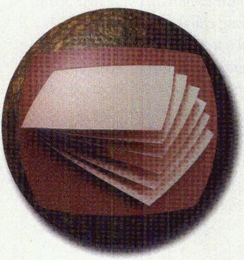
NOISE/COM

NOW THERE'S A
WHOLE WORLD OF LAMINATES FOR A
UNIVERSE OF HIGH FREQUENCY, HIGH PERFORMANCE
APPLICATIONS. ALL UNDER ONE ROOF.

INTRODUCING ROGERS
ULTRALAM®1000 WOVEN GLASS PTFE LAMINATES.

With the introduction of new **ULTRALAM®1000** Woven Glass PTFE Laminates for base station antenna and power amplifier applications, Rogers extends its capabilities to offer competitively priced laminates. And Rogers Express℠ next-day shipping service is available for customers who need laminates right away.

ULTRALAM®1000 materials are available in up to 4'x10' sheets, making them ideal for large panel antennas. Standard thicknesses include 0.020"



(.5mm), 0.031" (.75mm), and 0.062" (1.5mm) for dielectric constants of 2.17, 2.50, and 3.0.

ROGERS HAS IT ALL.

For more than 30 years, Rogers has led the industry in the design and manufacture of high frequency and high performance printed circuit board laminates for RF and microwave applications. Today, we offer the broadest product range on the market, whether you are designing cellular and PCS base station antennas, power amplifiers, LNB's for direct broadcast systems, patch antennas, or high speed digital circuits. More design engineers and purchasing managers are turning to the convenience of a single source to meet their needs.

WORLDWIDE SERVICE AND DELIVERY.

With an additional new laminate manufacturing plant in Ghent, Belgium, Rogers has further extended its ability to serve global customers. With offices in the U.S., Belgium, Japan, Hong Kong, and Taiwan, you're never far from the source. In fact, many products can be shipped next-day via Rogers Express℠. And as always, Rogers Technical Support Specialists are available to answer your questions and help you choose the right laminates for your design challenges.

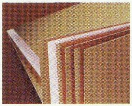
CONTACT US TODAY.

To learn more about Rogers high frequency and high performance laminates, including ULTRALAM®1000 material, call a Materials Specialist today at 480-961-1382, or visit our web site at **www.rogers-corp.com/mwu**.

Either way, you'll discover that doing business with Rogers makes a world of difference.

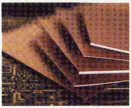
ROGERS

SINCE 1832



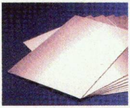
RO4000®

• Ability to laminate multilayer hybrid circuits in a single lamination cycle • Easier and less costly to fabricate • Improved performance



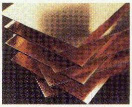
RO3000™

• Outstanding electrical performance
• Uniform mechanical properties over a range of dielectric constants



TMM®

• Stable electrical and mechanical performance vs temperature
• Can be manufactured using standard PCB fabrication techniques



RT Duroid®

• Reinforced PTFE laminates
• Superior electrical characteristics
• Low dissipation factor
• Highly predictable performance

Microwave Materials Division, 100 S. Roosevelt Avenue, Chandler AZ 85226 • Fax: 480-961-4533

TECHNICAL FEATURE

DIGITAL PREDISTORTION TECHNIQUES FOR RF POWER AMPLIFIERS WITH CDMA APPLICATIONS

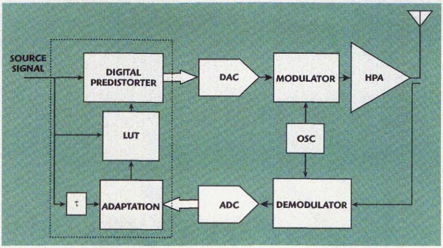
Power amplifiers (PA) used in the next-generation wireless communication systems based on spread spectrum techniques must exhibit exceptional linearity. This linearity must be achieved without sacrificing efficiency to a great extent. Digital predistortion techniques have been shown to improve the linearity of PAs for narrowband applications. In this article, digital predistortion is applied to both GaAs and laterally diffused metal oxide semiconductor (LDMOS) amplifiers with narrowband and wideband input signals. The efficacy of the digital predistortion under various input signal peak-to-average power ratios is also considered.

With the increasing importance of spectral efficiency in mobile communications, linearity of the RF PA has become a critical design issue for non-constant-envelope digital modulation schemes.[1] This issue is particularly significant in spread spectrum applications such as CDMA and wideband CDMA (W-CDMA) base stations, where the peak-to-average ratio of modulated RF signals can vary over a range of 3 to 12 dB. The concern for linearity is primarily due to the stringent restrictions on intermodulation products and out-of-band power emission requirements. Furthermore, amplification of multicarrier (multichannel) signals requires adequate amplifier linearity in order to avoid significant cross modulation. Additionally, for bandwidth-efficient modulation the amplifier nonlinearity can produce substantial signal distortion and, hence, increased bit error rates (BER).[2]

Linearity is achieved, in part, through the use of more linear amplifiers such as class A amplifiers, and by operating the amplifier backed off from the saturation range so that the signal level is confined to the linear region of the amplifier characteristics. However, this approach results in low DC-to-RF conversion efficiency, which is particularly costly in base station applications. Furthermore, low DC-to-RF conversion necessitates high current oper-

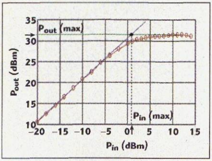
[Continued on page 24]

FRANK ZAVOSH, MIKE THOMAS, CHRIS THRON, TRACY HALL, DANIEL ARTUSI, DAVID ANDERSON, DAVID NGO AND DAVID RUNTON
Motorola Semiconductor Product Sector, Networking and Computing Systems Group
Tempe, AZ



▲ *Fig. 1 An adaptive digital predistortion system schematic.*

Fig. 2 Limitation of the predistortion algorithm. ▼



ating points, resulting in undesired thermal effects.

A viable alternative to low efficiency linear amplifiers is the application of a linearity technique to more efficient amplifiers such as class AB or class C PAs. A number of linearization techniques have been reported in recent years, including Cartesian feedback, adaptive baseband predistortion, envelope elimination and restoration (EER), linear amplification with nonlinear components/combined analog locked loop universal modulator and feedforward.[3–5] Although these techniques have been shown to improve linearity in certain applications, many of them suffer from limitations in bandwidth, precision or stability. Any linearization technique considered for third-generation (3G) cellular base station applications must contend with input signals exhibiting both wide bandwidth and large peak-to-average ratios.

One technique that can potentially compensate for PA nonlinearities in such an environment is adaptive digital predistortion. In this approach, since the predistortion is implemented digitally, a greater degree of precision can be achieved when computing the predistortion coefficients. Also, unlike analog systems, there is no concern for stability in adaptive digital predistortion schemes. Finally, with the availability of high speed digital signal processors (DSP), adequate million instruction per second (MIPS) levels are available to treat the wideband signals found in today's advanced spread spectrum systems.

ADAPTIVE DIGITAL PREDISTORTION

The simplified schematic of an adaptive digital predistortion system is shown in ***Figure 1***. A fully adaptive digital predistortion system requires the addition of a predistortion circuit consisting of a digital predistorter and look-up table (LUT) to the transmission path in addition to a feedback path consisting of a demodulator, analog-to-digital converter (ADC) and adaptation circuit for updating the LUT. Most common implementations of digital predistortion utilize standard DSPs. Such processes typically operate with a wordlength of 16 or 32 bits, which provides sufficient accuracy for most applications. In specific applications, application-specific ICs (ASIC) are designed to implement the predistorter system, providing flexibility in controlling wordlength and power consumption.

The functionality of digital predistortion can be best described by representing the signal at various points in the system as baseband complex envelopes. The block diagram assumes that all components of the system except the predistorter and high power amplifier (HPA) have a linear response and, hence, can be ignored in the analysis. The predistorter is equivalent to a nonlinear circuit with gain expansion response that is the inverse of the PA gain compression (AM/AM) response, and a phase rotation that is the negative of the PA phase rotation (AM/PM). Hence, in the most ideal case, the following relationships hold for all levels of input power:

$$|F(x_i)| \bullet |G(x_i|F(x_i)|^2)| = K$$

$$\Phi_F = -\Phi_G$$

where

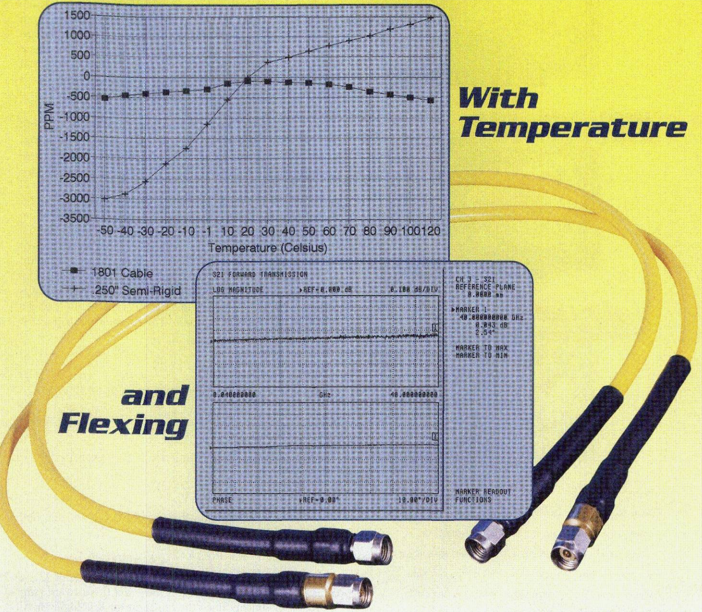
x_i = amplitude of the input signal
F = complex voltage gain of the predistorter
G = complex voltage gain of the PA

For a practical PA, however, these relationships can be achieved only up to the saturation point of the amplifier, as shown in ***Figure 2***. For any instantaneous input power greater than $P_{in(max)}$, the PA will not provide any additional headroom to compensate for the AM/AM nonlinearity response. Therefore, the peak-to-average ratio of the input signal will determine how close to saturation the PA can operate and still behave linearly once the predistortion coefficients are applied. Note that for spread spectrum applications with a high number of users, even with predistortion, the PA would have to operate substantially backed off from the optimally efficient operating point to avoid substantial spectral regrowth. Furthermore, as is evident by the data plot, the type of compression also can determine how well the predistortion algorithm will perform. In the case of hard compression (that is, a sharp transition from linear to saturation mode), there won't be adequate headroom for the predistortion to compensate for the PA nonlinearities. However, in the case of soft compression (a slow transition from linear to saturation mode), the PA can provide a few decibels of gain in the compression region to allow for the predistortion algorithm to perform well. Note that soft vs. hard compression is primarily a function of process technology.

Early implementations of digital predistortion were based on a point-

[Continued on page 26]

New Phase Stable Coaxial Cable Assemblies



IW has developed a new series of low loss, phase stable cables (diameters from 0.1" to 0.480") which exhibit excellent stability under both temperature changes and repeated flexing. Now, when you need flexible cable assemblies with smaller diameters, lighter weight, lower insertion loss and enhanced electrical stability, come to the technology leader with the broadest line to solve your most demanding requirements for both military and commercial applications.

Just give us a call or visit us at www.insulatedwire.com

Since 1970 ... Specialists in the manufacture of high-performance microwave transmission lines.

20 East Franklin Street • Danbury, CT 06810
Tel: 203-791-1999 • Fax: 203-748-5217
e-mail: iwconn@insulatedwire.com
www.insulatedwire.com

MICROWAVE PRODUCTS DIVISION

KNOW IW

CIRCLE 67 ON READER SERVICE CARD

by-point mapping LUT from the input drive to the desired PA drive. This method required a large LUT and suffered from low accuracy due to residual noise. The more recent digital predistortion approach capitalizes on the fact that most PAs have amplitude and phase characteristics that are phase invariant with respect to the input signal. This assumption allows the predistortion to be applied as a gain and phase multiplication to the input signal based only on its amplitude.[6–7] It is important to note that proper operation of the linearizer in such a system is based on the assumptions that the amplifier is memoryless and that the signal is not filtered before the PA.[12]

The key components of the digital predistorter system are shown in ***Figure 3***. The measurement of the input magnitude V_i provides the index to the LUT and subsequent multiplication with the LUT gain coefficient to provide the predistortion input V_d. The values designated as G and F depict the complex voltage gains of the PA and predistorter, respectively, at a specific power level. By basing the indexing on input power $|V_i|^2$, a higher proportional number of LUT levels are assigned to the higher power levels where PAs exhibit their most nonlinear behavior, hence, enhancing the LUT resolution at these levels. The following equations describe the important relationships depicted in the block diagram. Each complex gain is only a function of its input magnitude. The relevant signal powers

$$x_d = |V_d|^2$$
$$x_i = |V_i|^2$$

are used to express the PA output and input voltages

$$V_o = V_d \bullet G(x_d)$$
$$V_d = V_i \bullet F(x_i)$$

The forward path transfer function is then expressed as

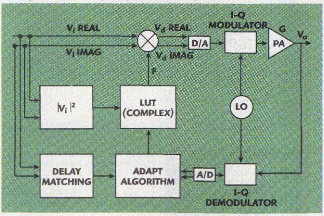
$$\frac{V_o}{V_i} = K$$

where K is the target gain through the LUT and PA, and is expressed by

$$K = F(x_i) \bullet G(x_i\,|F(x_i)|^2)$$

When the predistortion is optimized, the value of K is a constant over all values of input level and the forward path is completely linear. Since the equation for K is highly non-

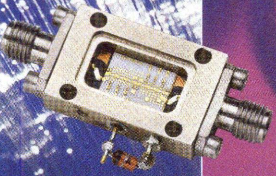
Fig. 3 A basic adaptive predistortion system.

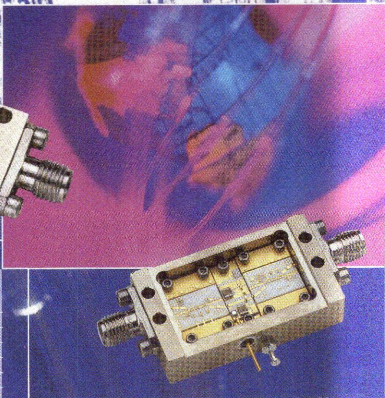


[Continued on page 28]

AMPLIFIERS

10 MHz to 18 GHz Ultra-Broadband for Fiberoptic and Telecommunications





MODEL NUMBER	FREQ. RANGE GHZ	GAIN dB MIN	NOISE FIG. dB MAX	GAIN FLATNESS +/-dB	1dB COMP. PT. dB MIN	3RD ORDER ICP TYP.	VSWR IN/OUT MAX	DC CURRENT MA
JCA008-201	.01-8.0	25	*5	2.0	0	10	2.0:1	175
JCA008-202	.01-8.0	24	*5	2.0	5	15	2.0:1	200
JCA008-203	.01-8.0	22	*5	2.0	10	20	2.0:1	225
JCA008-301	.01-8.0	35	*5	2.5	0	10	2.0:1	300
JCA008-302	.01-8.0	34	*5	2.5	5	15	2.0:1	325
JCA008-303	.01-8.0	32	*5	2.5	10	20	2.0:1	350
JCA0010-201	.01-10.0	24	*5	2.0	0	10	2.0:1	175
JCA0010-202	.01-10.0	22	*5	2.0	5	15	2.0:1	200
JCA0010-203	.01-10.0	20	*5	2.0	10	20	2.0:1	225
JCA0010-301	.01-10.0	34	*5	2.5	0	10	2.0:1	300
JCA0010-302	.01-10.0	32	*5	2.5	5	15	2.0:1	325
JCA0010-303	.01-10.0	30	*5	2.5	10	20	2.0:1	350
JCA0012-201	.01-12.0	23	*5	2.0	0	10	2.0:1	175
JCA0012-202	.01-12.0	21	*5	2.0	5	15	2.0:1	200
JCA0012-203	.01-12.0	20	*5	2.0	10	20	2.0:1	225
JCA0012-301	.01-12.0	33	*5	2.5	0	10	2.0:1	300
JCA0012-302	.01-12.0	31	*5	2.5	5	15	2.0:1	325
JCA0012-303	.01-12.0	30	*5	2.5	10	20	2.0:1	350
JCA0118-201	.1-18.0	22	**5	2.5	3	13	2.0:1	200
JCA0118-202	.1-18.0	20	**5	2.5	5	15	2.0:1	250
JCA0118-203	.1-18.0	20	**5	2.5	7	17	2.0:1	300
JCA0118-301	.1-18.0	31	**5	2.5	3	13	2.0:1	250
JCA0118-302	.1-18.0	29	**5	2.5	5	15	2.0:1	300
JCA0118-303	.1-18.0	29	**5	2.5	7	17	2.0:1	350

* Noise Figure is specified above 300 Mhz

** Noise Figure is specified above 500 Mhz

- Ideal for Fiberoptic, Telecommunications, and Test Equipment
- Drop-in Style Packages
- Multi-Octave Operation
- Compact Size
- Competitively Priced

DELIVERY IN 2-4 WEEKS ARO

JCA TECHNOLOGY

4000 Via Pescador, Camarillo, CA 93012
(805) 445-9888 Fax: (805) 987-6990
email: jca@jcatech.com • www.jcatech.com

linear and a closed-form solution is not possible, the problem can be solved iteratively by minimizing an error function given by

$$e_g(F) = V_o(F) - K\,V_i$$

The error function is simply the difference between the target output power and the measured output power during a specific iteration. This equation can be solved using an iterative technique such as Newton's method. However, since this method is computationally intensive, a simpler technique such as the Secant method is generally applied. A further refinement can be added to the solver by applying a method such as weighted least squares to provide greater accuracy at the high signal levels where the PA is most nonlinear.

The accuracy of the predistortion technique discussed previously is predicated on how well the gain function G matches the actual response of the PA. In general, G is obtained either through processing of empirical data or by developing a theoretical model of the PA based on a traveling-wave tube (TWT) amplifier approximation. The most common TWT approximation represents the PA with a normalized AM/AM and AM/PM response expressed as[6–8]

$$M(\rho) = \frac{2\rho}{1+\rho^2}$$

$$\Phi(\rho) = \frac{2\Phi_0\rho^2}{1+\rho^2}, \quad \Phi_0 = \frac{\pi}{6}$$

where

ρ = amplitude of the PA input signal

In the empirical approach, the AM/AM response is obtained by sending a training sequence through the PA and measuring the P_{in} vs. P_{out} response using a power meter. The type of training sequence used can vary greatly in both spectral and statistical distribution. The AM/PM response can be obtained by inputting a single RF tone into the PA and measuring the phase shift using a high frequency scope. Alternatively, the PA output can be downconverted and the rotation in the output constellation measured. A curve-fitting technique (such as cubic spline) is used to fit a polynomial function to the measured AM/AM and AM/PM response. The functions obtained are used in the predistortion algorithm discussed previously. In an alternative empirical technique, the demodulated PA output is compared to the baseband input signal to estimate the AM/AM and AM/PM characteristics.[3,9]

HARDWARE SETUP

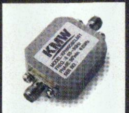
In this article, measurement results were emphasized over pure simulated results due in part to the fact that simulated results do not compensate for any memory effects exhibited by the PA or LO feedthrough and I and Q amplitude and phase imbalances caused by the quadrature modulator.[10–11] These effects can substantially alter the behavior of the modeled vs. measured results. Secondly, since an open-loop system was utilized, only measured data can provide insight into the accuracy of the PA transfer functions used in the predistortion algorithm.

[Continued on page 30]

Contactless Phase Shifters: Designed for Reliability Under All Conditions

KMW's rugged phase shifters feature phase accuracy in any conditions.

KPH90OSCL000



KPH90OSCL001

■ Features

1. Reliability

Thanks to the non-contact structure, you can get remarkably stable Phase even under hard environmental conditions such as Temperature, Humidity and Vibration.

2. Low Insertion Loss

Using Dielectric material with high "Q" results low Insertion Loss.

3. Linearity

Phase is linearly varied by controlling rotated angle of axis which is co-centered with transmission line.

4. High Power Handling Capability

Low IMD with non-contract structure.

Product Code No.	A type : KPH90OSCL000 B type : KPH90OSCL001		
Frequency Range	~ 1GHz	1 ~ 2GHz	2 ~ 3GHz
Insertion Loss (max.)	0.15dB	0.25dB	0.35dB
VSWR (max.)	1.25 : 1	1.25 : 1	1.25 : 1
Incremental Phase Shift	90 degree min. @ 2GHz		
Electrical Delay	125 psec min.		
Nominal Impedance	50 ohm		
I/O Port Connector	SMA(F) / SMA(F)		
Average Power Handling	20W @ 2GHz		
Temperature Range	-30°C ~ +60°C		
Dimension (inch)	A type : 1.496*1.102*0.470, B type : 1.225*1.102*0.470		

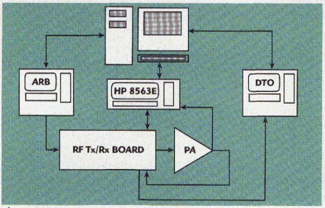
SMD type is also available.

13131 East 166th Street, Cerritos, CA 90703-2202
1-800-8320-KMW • www.kmwinc.com
tel: 562-926-2033 • fax: 562-926-6133

KMW
RF & Microwave Products

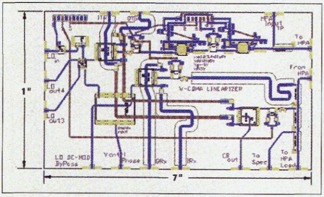
To provide a platform in the lab to accurately measure PA characteristics and gauge the PA response to predistortion, careful consideration was given to the setup of the RF portion of the system. A simple block diagram of the lab setup is shown in ***Figure 4***. In this setup, both the RF transmit and receive chains are included on a board specifically designed for this analysis. A direct-conversion scheme was used to simplify the system and reduce the number of RF components that can potentially produce nonlinear effects.

The system board consists of various off-the-shelf vendor-supplied components. A Mini-Circuits amplifier (VNA-25) is used to amplify the LO power source to the I/Q modulators. Two Motorola GaAs driver amplifiers (MRFIC1817) are used to provide the needed input power for different HPAs under test. Gain range is achieved with the use of Alpha variable attenuators (AV102-12), creating flexibility throughout the test system. Passive I/Q modulators from RF Prime (RFIQ-2000) are used in the direct-conversion system, thereby removing bias requirements and improving repeatability in comparison. In order to maintain the received I and Q channels in quadrature, a KDI phase shifter (SQ 0003) is used.



▲ *Fig. 4 Lab setup for digital predistortion PA linearization.*

▼ *Fig. 5 The RF Tx/Rx board layout.*

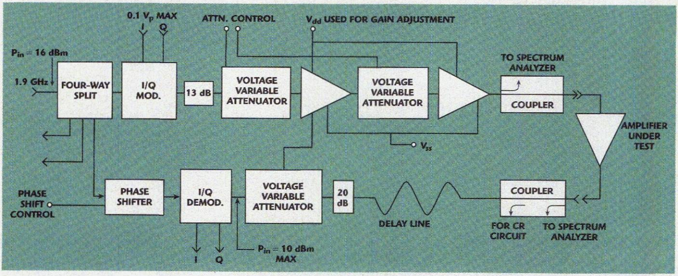


The PA module is set up on a separate fixture with input and output ports tied back to the main RF board. This configuration allows for simple and rapid analysis of various PA circuits. The baseband signals are generated via a PC and transferred to an arbitrary waveform generator (ARB), which operates as the digital-to-analog converter (DAC). To eliminate any limitations in dynamic range due to the signal-to-noise ratio of the DAC, an ARB with a 14-bit DAC is used. A digital test oscilloscope (DTO) is used to perform the analog-to-digital (A/D) conversion and pass the data to the PC for further analysis. The DTO has the capability to oversample the received data in order to enhance the accuracy of the measurements. A PC-controlled spectrum analyzer is interfaced with the PA input and output ports to evaluate the gain and adjacent-channel power (ACP) response of the amplifier. Note that in a fully adaptive digital predistortion system, the ARB and DTO would be replaced with DAC and A/D circuits and the functionality of the PC would be performed by a DSP board. This configuration provides the ability to perform real-time training of the system and updating of the LUT in the predistortion system.

The layout of the RF board is shown in ***Figure 5***. The board consists of a transmit chain, receive chain and carrier recovery system. The board receives baseband I and Q channels from the ARB, outputs the modulated RF carrier to the PA board, receives the PA RF output and outputs the demodulated baseband I and Q signals to the DTO. In addition, ports are provided for the LO input signal, carrier recovery LO bypass, LO feedthrough compensation circuit and spectrum analyzer output.

The transmit (Tx) and receive (Rx) chain components are shown in ***Figure 6***. The input LO signal is passed

▼ *Fig. 6 Components of the RF Tx and Rx chains.*



[Continued on page 32]

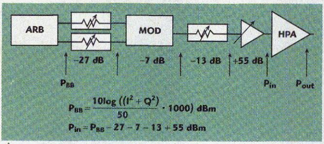


Fig. 7 Forward path gain and loss values.

through a four-way splitter to provide signals for the modulator, demodulator bypass and carrier recovery circuit. The chain of voltage-controlled driver amplifiers and attenuators provides a linear response over a range of 50 to 60 dB as required in most CDMA and W-CDMA systems. In the receiver chain, an attenuator is used to adjust the RF power level entering the demodulator to maintain circuit linearity. In addition, a carrier recovery circuit based on reverse modulation is included as well as a bypass LO signal with external phase adjustment.

The developed RF system provides a highly linear response in both transmit and receive chains over a wide bandwidth, assuring that any nonlinear behavior observed is a function of the PA circuit only. However, some level of LO feedthrough and amplitude and phase imbalance in the quadrature modulator still exists, which can result in some degradation of system performance. The LO feedthrough can be compensated for by combining an LO signal with proper amplitude and phase level to the modulated signal at the input of the PA.

Since the predistortion coefficients applied to the input signal are determined as a function of the instantaneous PA input power, it is necessary to accurately measure any gain or loss in the forward path of the system from the I and Q output ports of the ARB to the PA input port. The gain and loss of all forward path components are carefully measured to accurately translate the power of the baseband signal to the input of the PA, as shown in ***Figure 7***. Note that all components (except for the GaAs driver amplifier) are fixed loss elements in the system. The combination of driver amplifiers and voltage-controlled attenuators is the only adjustable element in the forward path and is used to vary the HPA operating point in the study of the digital predistortion algorithm. The forward-path element loss/gain information is added to the predistortion algorithm to properly adjust for the input power of the HPA when test simulations are performed.

RESULTS

The first task in developing a predistortion algorithm for a given PA is to obtain an accurate estimate of the PA transfer function. In this analysis, the AM/AM and AM/PM response of the PA is obtained empirically. In obtaining the gain and phase response, two important parameters should be considered: what measurement technique to utilize (that is, what equipment to use) and what input signal to use as the training sequence. Equipment accuracy as well as the bandwidth and peak-to-average ratio of the input training data may have some impact on the accuracy of the measured response.

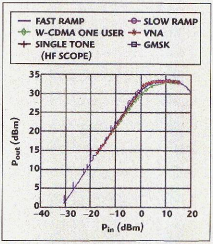
For these experiments both a GaAs PA (Motorola MRFIC1818 – 2 W) and an LDMOS PA (Motorola MHW19338 – 4 W) were considered. The GaAs PA tends to exhibit a hard compression response; the LDMOS exhibits more of a soft compression response. A number of input training signals are used in conjunction with the described system. Specifically, a number of digital baseband signals were constructed and sent through the RF board for upconversion and amplification. The baseband signals used included a fast ramp function, slow ramp function, constant-envelope Gaussian minimum-shift keying (GMSK) and single-user W-CDMA signal. These signals exhibit a wide range of peak-to-average ratios and modulation bandwidths.

The AM/AM response was measured using a power meter, and the AM/PM response was measured by downconverting the PA output and measuring the phase shift in the output constellation using the DTO. Additionally, two other measurements were

[Continued on page 34]

conducted using a high frequency (HF) digital scope and a vector network analyzer (VNA) with single-tone RF signals as the input. In both cases the power meter was used to measure the AM/AM response. The AM/PM response for the HF scope was obtained by measuring the phase difference between the input and output of the PA as it is displayed on the scope. In the case of VNA, the phase of S_{21} was used to obtain the AM/PM response.

Figure 8 shows the AM/AM response of the MRFIC1818 GaAs PA using the various techniques discussed previously. Excellent agreement is achieved between the various measurements. The AM/PM response of the same PA is shown in ***Figure 9***. Although all of the signals exhibit similar trends, large differences in the relative values are obtained. For these measurements, there appears to be a correlation between the peak-to-average ratio of the signal used and the AM/PM response, with the small peak-to-average ratio signals at the top and the large peak-to-average signals at the bottom of the graph. The LDMOS PA's AM/AM and AM/PM responses are shown in ***Figures 10*** and



▲ *Fig. 8 The GaAs PA's measured AM/AM response.*

Fig. 9 The GaAs PA's measured AM/PM response. ▼

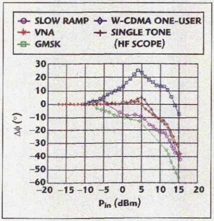
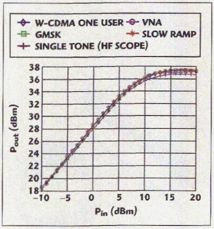
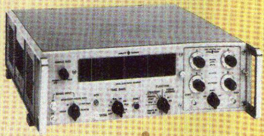


Fig. 10 The 4 W LDMOS PA's measured AM/AM response. ▼



[Continued on page 38]



EVERYTHING YOU'D EXPECT FROM THE COMPANY THAT INVENTED THE COUNTER.

STARTING AT **$1,575***

AND LESS.

HP 53181A FREQUENCY COUNTER

Performance
10 digits of resolution per second

Frequency Range
225 MHz and 1.5, 3, 5 and 12.4 GHz additional channel options

Measurements
Up to 200 measurements per second

Ease of Use
One button frequency measurements

Price
Starting as low as $1,575*

MORE DIGITS, LESS MONEY.

Ever since we developed the first frequency counter, we've been improving on it. Now we're even improving on the price.

Starting at just $1,575, the HP 53181A gives you an amazing 10 digits of resolution per second. Buy just the performance you need—the HP 53181A has 225 MHz bandwidth and 1.5, 3, 5, and 12.4 GHz additional channel options. And for ease of use, you get a high-visibility display and one-button frequency measurements. What you don't get are complicated features you don't want or need.

The HP 53181A frequency counter. It may be more than you'd expect for the price. But not less than you'd expect from HP.

For more information about the HP 53181A frequency counter, help selecting the counter that's right for you, or for a free booklet titled ***8 Hints for Making Better RF Counter Measurements***, call your local HP sales office or one of the numbers listed below.

*U.S. list price

Australia 13-1347 Ext. 2902 • Austria (0660) 8004 • Belgium (02) 778-3417 • Finland (90) 8872 2100 • France 1 69 82 41 14
Germany (07031) 14-6333 • Hong Kong 2599-7070 • India (11) 647-2311 • Ireland (01) 2844 633 • Italy (02) 92 122 241
Korea (2) 769-0800 • Malaysia (3) 290-0213 • Netherlands (020) 547 6222 • New Zealand (0800) 738-378 • Norway 47 2273 5759
Philippines 894-1451 Local 2022 • PRC (10) 505-0149 • Singapore 290-6375 • Spain (91) 631 1323 • Sweden (08) 444 22 77
Switzerland (01) 735 7200 • (022) 780 4485 • Taiwan 080-212-535 • Thailand (2) 254-6720 • United Kingdom 01344 366666

HEWLETT PACKARD
Expanding Possibilities

Silicon Germanium (SiGe), Stanford Microdevices' latest RF semiconductor process, offers benefits not attainable by conventional silicon-bipolar technologies: lower noise figures, lower power consumption, high output power at high efficiency, and high integration level.

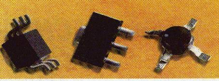
As part of a series of Stanford Microdevices' initiatives to apply silicon germanium technology to a broad spectrum of communications applications, we are now offering the wireless market devices built using a patented silicon germanium manufacturing process. As these devices enter the marketplace, consumers will benefit from cellular phones, pagers, and other wireless communications devices that have extended battery life, carry out multiple functions, and are smaller, lighter, and less expensive.

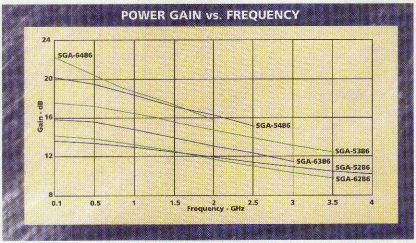
PRODUCT SELECTION GUIDE

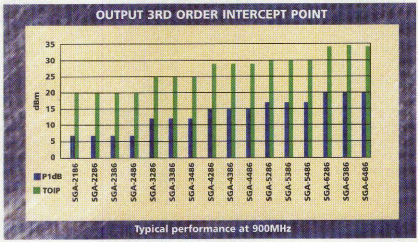
General Purpose Amplifiers

Part Number	Vd (V)	Id (mA)	3dB BW	P1dB (dBm)	IP3 (dBm)	Gain@ 1 GHz	Gain@ 2 GHz	NF 50 Ohm
SGA-2186	2.2	20	DC-5.0	+7.0	+20.0	10.5	10.2	4.1
SGA-2286	2.2	20	DC-3.5	+7.0	+20.0	15.0	14.0	3.2
SGA-2386	2.7	20	DC-2.8	+7.0	+20.0	17.4	16.4	2.9
SGA-2486	2.7	20	DC-2.0	+7.0	+20.0	19.6	18.0	2.5
SGA-3286	2.7	35	DC-3.6	+12.0	+26.0	14.8	13.4	3.5
SGA-3386	2.5	35	DC-3.6	+12.0	+25.0	17.4	16.2	3.0
SGA-3486	2.9	35	DC-2.0	+12.0	+25.0	21.5	19.4	2.6
SGA-4186	3.2	45	DC-6.0	+15.0	+29.0	10.4	10.2	4.6
SGA-4286	3.2	45	DC-3.5	+15.0	+29.0	13.8	12.6	3.3
SGA-4386	3.3	45	DC-2.5	+15.0	+29.0	17.0	15.2	2.8
SGA-4486	3.2	45	DC-2.0	+15.0	+29.0	19.0	16.8	2.5
SGA-5286	3.5	60	DC-4.0	+17.0	+30.0	13.5	12.7	4.1
SGA-5386	3.6	60	DC-3.2	+17.0	+31.0	17.3	16.0	3.5
SGA-5486	3.5	60	DC-2.4	+17.0	+31.0	19.7	18.0	2.8
SGA-6286	4.2	75	DC-3.5	+20.0	+34.0	13.8	12.4	3.9
SGA-6386	5.0	80	DC-3.0	+20.0	+34.5	15.4	13.8	3.8
SGA-6486	5.2	75	DC-1.8	+20.0	+34.0	19.7	16.7	2.9

SGA 2000 through 4000 series are also available in SOT-363
SGA 5000 and 6000 series are also available in SOT-89 & SOT23-5

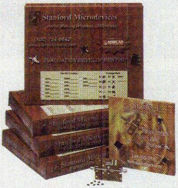






Stanford Microdevices produces the highest performance products utilizing cutting edge technology at the lowest possible cost. All Stanford MMICs are 100% tested and qualified annually to ensure reliable field performance even under the harshest environments, making Stanford Microdevices a favorite among major OEMs worldwide. Over the past five years Stanford Microdevices has become the preeminent leader in the design and manufacturing of GaAs, LDMOS and SiGe amplifier and switch products.

ALSO COMING SOON!
DISCRETE SiGe HBTs and LOW NOISE SiGe MMICs



Call for Evaluation Kit
1-800-764-6642

FEATURES

- Low Cost
- SiGe HBT Technology
- Low Power Consumption
- High Linearity
- Industry Standard Packages

Stanford Microdevices

1-800-764-6642
Dept. SGMJ1
Visit our web site at
www.stanfordmicro.com/sige

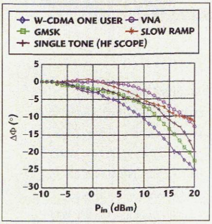
DISTRIBUTED BY:

AVNET electronics marketing
800-332-8638 www.em.avnet.com

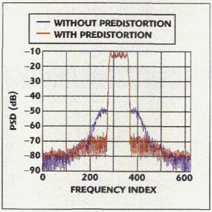
Richardson Electronics
Engineered Solutions
800-348-5580 www.rfpowernet.com

For performance, reliability and value, count on Stanford Microdevices.

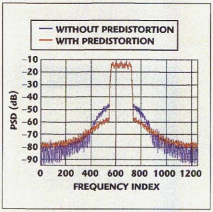
CIRCLE 162 ON READER SERVICE CARD



▲ *Fig. 11 The 4 W LDMOS PA's measured AM/PM response.*



▲ *Fig. 12 Theoretical PSD of the GaAs PA with and without predistortion for one-user W-CDMA modulated signals.*



▲ *Fig. 13 The theoretical PSD of the GaAs PA with and without predistortion for 256-user W-CDMA modulated signals.*

11, respectively. Once again, the AM/AM responses are well correlated while the AM/PM responses deviate greatly. Note that no correlation is observed between the signal's peak-to-average ratio and the AM/PM response as in the GaAs case. The different methods used in obtaining AM/PM response should provide bounds on the values to be used in the algorithm. This limitation was necessary since an accurate measurement of the PA phase response proved to be difficult.

Data for the various PA characteristics obtained from the measurements were added to the digital predistortion algorithm developed in MatLab.® Since for both GaAs and LDMOS PAs considered the deviation in the various data sets was mainly in the AM/PM response, in theory the algorithm is able to compensate for the phase variation in all cases. In performing the simulations, the PA operating point is varied by adjusting the driver amplifier gain until the optimal ACP response is obtained. This operating point is a function of the peak-to-average ratio of the PA as well as the PA transfer function used in the simulation.

Both two-tone and W-CDMA modulated signals were considered. ***Figure 12*** shows the simulated power spectral density (PSD) results obtained for the GaAs PA using a one-user W-CDMA signal with a peak-to-average ratio of 5.2 dB. The theoretical results predict a 20 dB improvement in ACP. The driver amplifier gain is set to +31 dB for this simulation. Since the transfer function obtained in this analysis was computed at only one frequency (1.9 GHz), the simulator does not account for any frequency dependency of the gain curve and, hence, only a frequency index is shown. However, for all the theoretical and experimental studies conducted, the bandwidth of the modulated signal was narrow enough so that the GaAs PA exhibits a flat gain response over the entire range. ***Figure 13*** shows the results of a second simulation for the same PA operating point with a 256-user W-CDMA input signal. The peak-to-average ratio of this signal is 10.5 dB and, as expected, a smaller ACP improvement of only 10 is observed.

[Continued on page 43]

PureSource.

Your new source

for maximum

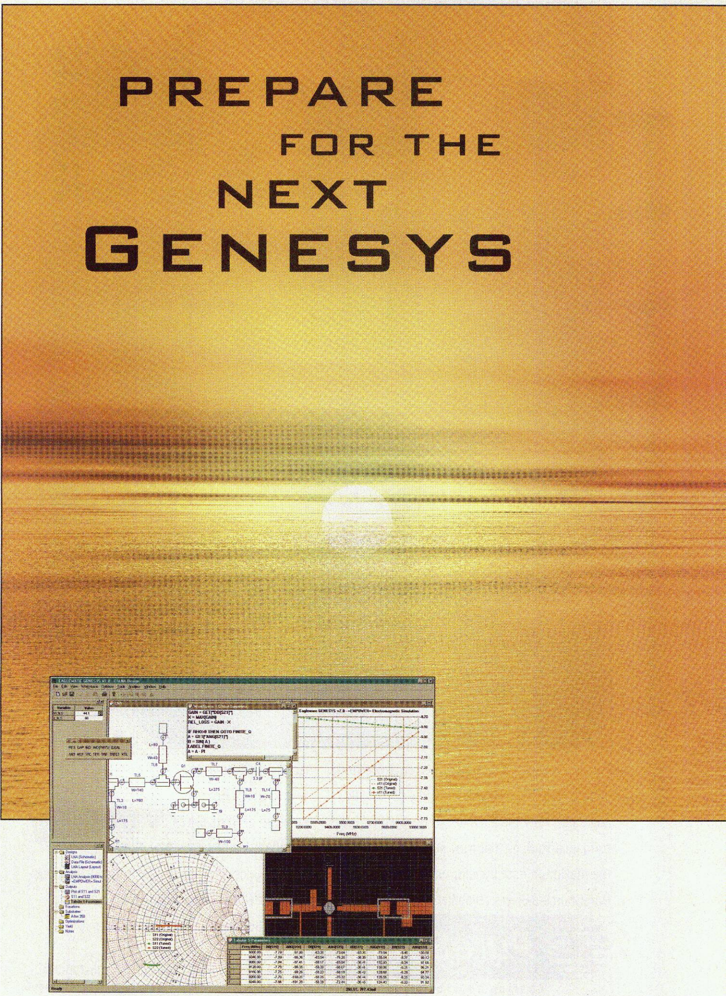
data transfer.

You'll never get the optimum performance from your system if your DRO has to be constantly adjusted. Now there's a new line of high performance sources that truly allow your system the maximum data transfer you want. PureSource delivers reliability without cutting back on performance. How reliable? How's ten years of trouble-free operation. Maintenance-free. Plus low microphonics, low phase jitter and low spurious products. Get the data transfer you demand. Let PureSource help take you to the max.

PureSource

Lasting reliability at last.

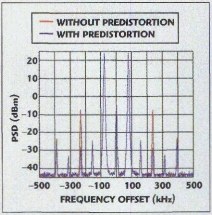
A Microwave dB product • Tel: 805-499-0410
Fax: 805-498-0054 • **www.microwavedb.com**


PREPARE
FOR THE
NEXT
GENESYS

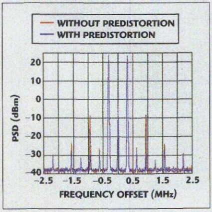
Once an optimal operating point is obtained through simulation, the predistorted signals are loaded onto the ARB to evaluate the measured response of the PA. As in the simulation case, the various PA transfer functions obtained previously were used in the measurement and the results were compared. As expected, different levels of ACP improvements were obtained for the various transfer functions. The GaAs PA transfer function that yielded the best measured ACP performance is a composite of the AM/AM data from the GMSK measurement and AM/PM data from the VNA measurement. For all the measurement results presented, this composite transfer function is used in the predistortion algorithm.

To better understand the bandwidth dependency of the predistortion algorithm, both the two-tone and modulated signal measurements are carried out for three different bandwidths. **Figure 14** shows the PSD of the PA output for a two-tone signal with 150 kHz tone separation (signal peak-to-average = 3 dB, P_{in} = –4 dBm, P_{out} = 27 dBm). To generate this signal, the function $\cos(\omega_1 t)$ was generated at baseband and used as the I input to the modulator with the Q signal set to zero. The frequency ω_1 determines the tone spacing. Since the modulator is designed for balanced input, the imbalanced signal produces a large LO leakage, which is depicted as a tone at the center of the figure. The results indicate a reduction of 20 dB in the third-order intermodulation (IM3) levels and a 2 to 3 dB reduction in the fifth-order intermodulation (IM5) levels. These results are in line with previously reported data.[3,8] **Figures 15** and

[Continued on page 46]



▲ *Fig. 14 Measured PSD of the GaAs PA with and without predistortion for two-tone input signal, 150 kHz tone spacing.*

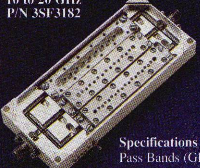


▲ *Fig. 15 Measured PSD of the GaAs PA with and without predistortion for two-tone input signal, 0.6125 MHz tone spacing.*

If You Need to Switch

Don't Fight It !!

3 Channel Switch Filter Bank
10 to 20 GHz
P/N 3SF3182



Specifications

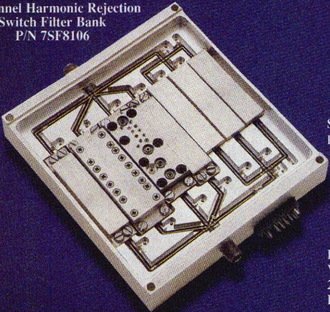
Pass Bands (GHz)	10.3 - 11.7 15.8 - 17.7 18.8 - 19.7
Insertion Loss	6.0 dB max
Rejection (DC-24 GHz)	70 dB min
Switching Speed	200 ns max

SP4T
PIN Diode Switch
2.0 to 18 GHz
P/N 4S3068

Specifications

Frequency Range	2.0 - 18 GHz
Insertion Loss	2.9 dB max
Isolation	55 dB min
VSWR	2.0:1 max
Switching Speed	50 ns max

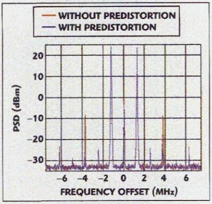
7 Channel Harmonic Rejection
Switch Filter Bank
P/N 7SF8106



Specifications

Pass Bands (GHz)	0.5 - 0.8 0.8 - 1.3 1.3 - 2.0 2.0 - 3.5 3.5 - 6.0 6.0 - 10.4 10.4 - 18.0
Insertion Loss	6.0 dB max
VSWR	2.0:1 max
2nd Harmonic Reject.	**50 dBc min**
Harmonics	**65 dBc max**

MVS *Microwave & Video Systems, Inc.*
mvsmicro@worldnet.att.net
87B Sandpit Road
Danbury, CT 06810
TEL (203) 792-7474
FAX (203) 792-7475



▲ *Fig. 16 Measured PSD of the GaAs PA with and without predistortion for two-tone input signal, 2.5 MHz tone spacing.*

Fig. 17 Measured PSD of the GaAs PA with and without predistortion for 300 kHz wide modulated signal. ▼

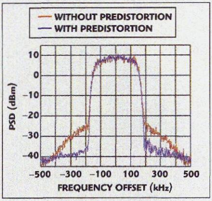
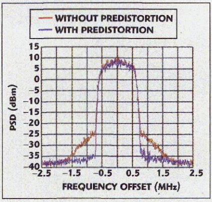
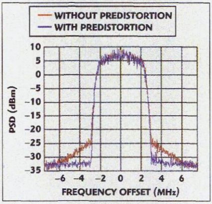


Fig. 18 Measured PSD of the GaAs PA with and without predistortion for 1.25 MHz wide modulated signal. ▼



16 show the two-tone response of the PA for tone spacing of 612.5 kHz and 2.5 MHz, respectively. The results are similar to the 150 kHz case, however, for the 2.5 MHz tone spacing, a slight degradation in the IM3 results can be observed.

Figure 17 shows the measured PSD of the GaAs PA output for a 1.9 GHz modulated carrier with a modulated bandwidth of 300 kHz with and without predistortion applied to the baseband signals (signal peak-to-average = 5.2 dB, P_{in} = −4 dBm, P_{out} = 27 dBm). An improvement of approximately 15 dB is observed in the ACP of the predistorted signal for the same level of output power.



▲ *Fig. 19 Measured PSD of the GaAs PA with and without predistortion for 5 MHz wide modulated signal.*

Fig. 20 Theoretical PSD of the 4 W LDMOS PA with and without predistortion for one-user W-CDMA modulated signals. ▼

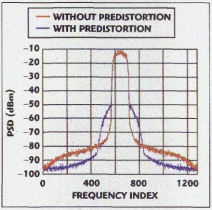
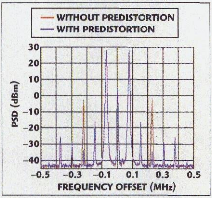
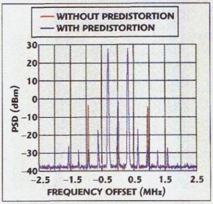


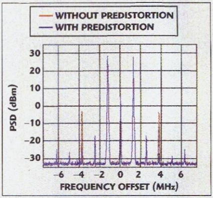
Fig. 21 Measured PSD of the 4 W LDMOS PA with and without predistortion for two-tone input signal, 150 kHz tone spacing. ▼



The measured PSD for 1.25 and 5 MHz bandwidth signals is shown in ***Figures 18*** and ***19***, respectively. As the bandwidth of the modulated signal is increased the improvement in the ACP decreases. In the 5 MHz case, the ACP improvement has been reduced to 7.5 dB or half the 300 kHz bandwidth signal. This result could be due in part to the construction of the PA module, the memory effect of the amplifier, LO feedthrough, and phase and amplitude imbalance in the quadrature modulator, or some limitation of the predistortion algorithm.



▲ *Fig. 22 Measured PSD of the 4 W LDMOS PA with and without predistortion for two-tone input signal, 0.6125 MHz tone spacing.*



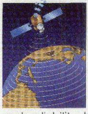
▲ *Fig. 23 Measured PSD of the 4 W LDMOS PA with and without predistortion for two-tone input signal, 2.5 MHz tone spacing.*

The analysis performed for the MRFIC1818 GaAs PA was repeated for the MHW19338 4 W LDMOS PA. As in the GaAs case, since the main difference in the measurements is in the AM/PM response, the theoretical results are consistent for a given operating point. The optimal operating point for the PA was obtained through simulation, and the results are shown in ***Figure 20*** for a signal peak-to-average of 5.2 dB and driver gain of 40 dB. As in the GaAs example, a 20 dB improvement in ACP is observed. For this PA, the optimal measured results were obtained using the VNA data set. The two-tone measured data for 150 kHz, 612.5 kHz and 2.5 MHz tone separation are shown in ***Figures 21***, ***22*** and ***23***, respectively (signal peak-

[Continued on page 48]

THE GLOBAL SOLUTION... AND BEYOND!

10MHz to 7GHz AMPLIFIERS from $99.95 (1-9 qty.)



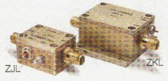
From amateur radio to cellular to satellite applications, with medium output power up to 17dBm, Mini-Circuits versatile ZJL and ZKL connectorized amplifiers offer the broad range of choices designers demand for achieving high system performance goals. Ultra-wideband models deliver **gain ranging from 9 to 40dB** and IP3 up to +32dBm. But beyond the performance and reliability built into these miniature 12V amplifiers lies another important feature, the low price...from only $99.95! Call now for fast delivery.

Mini-Circuits...we're redefining what VALUE is all about!

SPECIFICATIONS

Model	Freq (MHz)	Gain (typ) Midband (dB)	Gain (typ) Flat (±dB)	Max. P_{out}[1] (dBm)	Dynamic Range (Typ @2GHz[2]) NF(dB)	Dynamic Range (Typ @2GHz[2]) IP3(dBm)	I(mA)[3]	Price $ea. (1-9)
ZJL-5G	20-5000	9.0	±0.55	15.0	8.5	32.0	80	129.95
ZJL-7G	20-7000	10.0	±1.0	8.0	5.0	24.0	50	99.95
ZJL-4G	20-4000	12.4	±0.25	13.5	5.5	30.5	75	129.95
ZJL-6G	20-6000	13.0	±1.6	9.0	4.5	24.0	50	114.95
ZJL-4HG	20-4000	17.0	±1.5	15.0	4.5	30.5	75	129.95
ZJL-3G	20-3000	19.0	±2.2	8.0	3.8	22.0	45	114.95
ZKL-2R7	10-2700	24.0	±0.7	13.0	5.0	30.0	120	149.95
ZKL-2R5	10-2500	30.0	±1.5	15.0	5.0	31.0	120	149.95
ZKL-2	10-2000	33.5	±1.0	15.0	4.0	31.0	120	149.95
ZKL-1R5	10-1500	40.0	±1.2	15.0	3.0	31.0	115	149.95

NOTES:
1. Typical at 1dB compression.
2. ZKL dynamic range specified at 1GHz.
3. All units at 12V DC.



Mini-Circuits®

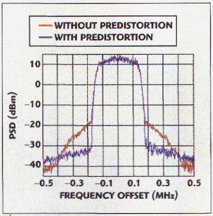
US 104 INT'L 105
CIRCLE READER SERVICE CARD

P.O. Box 350166, Brooklyn, New York 11235-0003 (718) 934-4500 Fax (718)332-4661 *INTERNET* http://www.minicircuits.com

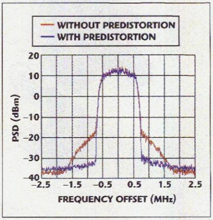
For quick access to product information see MINI-CIRCUITS CATALOG & WEB SITE • EEM • MICROWAVE PRODUCT DATA DIRECTORY • WWW.RFGLOBALNET.COM to-average = 3 dB, P_{in} = 3.5 dBm, P_{out} = 31.5 dBm). The improvement in IM3 is 30 dB for 150 kHz tone spacing and decreases to 20 dB for the 2.5 MHz tone spacing. Note that no improvement in IM5 is observed.

The PSD of the LDMOS PA output for modulated signals with bandwidths of 300 kHz, 1.25 MHz and 5 MHz is shown in ***Figures 24, 25*** and ***26***, respectively (signal peak-to-average = 5.2 dB, driver gain = 40 dB). An improvement in ACP of 12 dB is observed for the narrow-bandwidth signal and decreases to 10 dB for the wider-bandwidth signal.

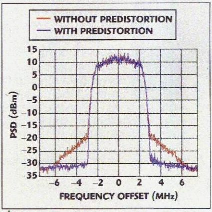
The results clearly indicate that the linearity of both GaAs and LDMOS technologies can be improved using digital predistortion techniques. Although the improvements observed in the measured results are not as good as the simulated results, the theoretical limits in ACP can be reached by improving the accuracy of the PA transfer function used in the predistortion algorithm. The PA AM/AM and AM/PM can be optimized further either theoretically or experimentally by performing multiple measurements and averaging the results. In addition, a closed-loop system can be used to dynamically update the LUT.



▲ *Fig. 24 Measured PSD of the 4 W LDMOS PA with and without predistortion for 300 kHz wide modulated signal.*



▲ *Fig. 25 Measured PSD of the 4 W LDMOS PA with and without predistortion for 1.25 MHz wide modulated signal.*

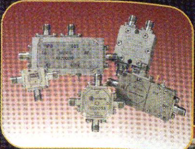


▲ *Fig. 26 Measured PSD of the 4 W LDMOS PA with and without predistortion for 5 MHz wide modulated signal.*

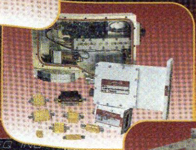
[Continued on page 50]

MITEQ

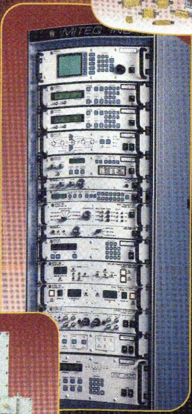
FROM COMPONENTS TO SYSTEMS

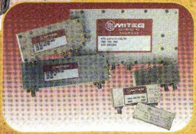


MIXERS TO 60 GHz
- Single-, double-, and triple-balanced
- Image rejection and I/Q
- Single-sideband, BPSK and QPSK modulators
- High dynamic range
- Active and passive frequency multipliers

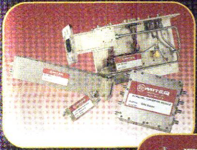


AMPLIFIERS TO 60 GHz
- Octave to ultra-broadband
- Noise figures from 0.35 dB
- Power to 10 watts
- Temperature compensated
- Cryogenic





INTEGRATED SUBASSEMBLIES TO 60 GHz
- Integrated up/downconverters
- Monopulse receiver front ends
- PIN diode switches
- Ultra-miniature switch matrices
- Missile receiver front ends
- Switched amplifier/filter assemblies



IF AND VIDEO SIGNAL PROCESSING
- Logarithmic amplifiers
- Constant phase-limiting amplifiers
- Frequency discriminators
- AGC/VGC amplifiers
- I/Q processors
- Digital DLVAs

SATCOM EARTH STATION EQUIPMENT TO Ka-BAND
- Synthesized up/downconverters
- Test translators
- LNA systems
- 1:N redundancy units
- INMARSAT products
- FM modems

FREQUENCY SOURCES TO 40 GHz
- Free-running VCOs/DROs
- Phase-locked cavity oscillators
- Phase-locked coaxial resonators
- Synthesizers for SATCOM
- Fast-tuning communication synthesizers

MITEQ

TEL: (516) 436-7400

FAX: (516) 436-7430

100 Davids Drive, Hauppauge, NY 11788

www.miteq.com

CONCLUSION

Based on empirical and analytical studies of the digital predistortion technique, improvement in the ACP response of digitally modulated RF carriers can be achieved for both narrowband and wideband signals. The degree of improvement observed, however, is a function of multiple system parameters, including the PA gain response (soft vs. hard compression), statistical distribution of the input signal (peak-to-average ratio), spectral distribution of the input signal (modulated bandwidth) and accuracy of the PA AM/AM and AM/PM functions used in the predistortion algorithm.

A variety of techniques were utilized in obtaining the PA transfer function with good correlation of the AM/AM response and poor correlation of the AM/PM response. The measured results indicate that the algorithm is sensitive to the PA AM/PM response and that an accurate measurement of this characteristic is difficult to obtain. However, with the limited accuracy of the described measurement, better than 10 dB of ACP improvement was observed for both GaAs and LDMOS PAs for input signals with 5 dB of peak-to-average ratio. The simulated results indicate that an additional 10 dB improvement can be obtained if a more accurate PA transfer function is used in the algorithm. ■

References

1. J.K. Cavers, "The Effect of Quadrature Modulator and Demodulator Error on Adaptive Digital Predistorters for Amplifier Linearization," *IEEE Transactions on Vehicular Technology*, Vol. 46, No. 2, May 1997, pp. 456–466.
2. E.G. Jeckeln, F.M. Ghannouchi and M. Sawan, "Linearization of Microwave Emitters Using an Adaptive Digital Predistorter," *27th European Microwave Conference Proceedings*, September 1997, pp. 336–340.
3. A. Lothia, P.A. Goud and C.G. Englefield, "Power Amplifier Linearization Using Cubic Spline Interpolation," *Proceedings of the 43th IEEE Vehicular Technology Conference*, May 1993, pp. 676–679.
4. P.B. Kenington, "Linearised RF Amplifier and Transmitter Techniques," *Wireless Systems International*, 1998.
5. B. Razavi, *RF Microelectronics*, Prentice Hall, 1998.
6. A.N. D'Andrea, V. Lottici and R. Reggiannini, "A Digital Approach to Efficient RF Power Amplifier Linearization," *IEEE Transactions*, 1997, pp. 77–81.
7. A.N. D'Andrea, V. Lottici and V. Reggiannini, "RF Power Amplifier Linearization through Amplitude and Phase Predistortion," *IEEE Transactions on Communications*, Vol. 44, No. 11, Nov. 1996, pp. 1476–1484.
8. I. Park, E.J. Powers and G. Xu, "Parallel Adaptive Predistortion for RF Power Amplifier Linearization," *Proceedings of the IEEE*, 1997, pp. 82–86.
9. L. Sundstrom, M. Faulkner and M. Johansson, "Quantization Analysis and Design of a Digital Predistortion Linearizer for RF Power Amplifiers," *IEEE Transactions on Vehicular Technology*, Vol. 45, No. 4, November 1996, pp. 707–719.
10. A.S. Wright and W.G. Durtler, "Experimental Performance of an Adaptive Digital Linearized Power Amplifier," *IEEE Transactions on Vehicular Technology*, Vol. 41, No. 4, November 1992, pp. 395–400.
11. M. Faulkner and M. Johansson, "Adaptive Linearization Using Predistortion-Experimental Results," *IEEE Transactions on Vehicular Technology*, Vol. 43, No. 2, May 1994, pp. 323–332.
12. A.A.M. Saleh and J. Salz, "Adaptive Linearization of Power Amplifiers in Digital Radio Systems," *Bell Systems Technical Journal*, Vol. 62, No. 4, April 1983, pp. 1019–1033.

Joint Venture Awarded $500 M from NATO

Air Command Systems International, a joint venture equally owned by Raytheon Co. and Thomson-CSF, has been awarded a contract valued at approximately $500 M from the North Atlantic Treaty Organization (NATO) Air Command and Control Management Agency for the NATO Air Command and Control System Level of Operational Capability 1 (ACCS LOC1). Under the terms of the contract, the NATO ACCS LOC1 program will provide NATO with a fully interoperable, common air operations command and control system to support all offensive and defensive air operations as well as military air traffic control, command and control resource management, and airspace management in Europe. The program will replace the existing NATO air command and control system (NATO Air Defense Ground Environment) implemented in the 1970s, and will also provide centralized command and decentralized execution capability through a combination of an in-place static backbone and a deployable ACCS component.

NATO intends to employ an evolutionary implementation of full ACCS capability, which will take place in increments known as LOCs. Each increment will be implemented through development and validation phases followed by a replication phase. The initial ACCS LOC1 program includes the development of core software, its validation at the system test and validation facility and four operational sites, and its subsequent replication at other operational sites. Contracts are expected to be awarded to four additional NATO nations, including Belgium, France, Germany and Italy, for validation sites.

Program Develops Global ATM Capabilities for Fighter Aircraft

Rockwell Collins and the US Air Force have introduced key technology to bring Global Air Traffic Management (GATM) capabilities to tactical fighter aircraft. The new technology includes a miniature modular digital radio (MMDR), fast I/Q processor (FIQP) and future air navigation software. The MMDR serves as a receiver/exciter and the FIQP serves as a waveform processor. When used together, the two components form the front end of a software-programmable radio.

The GATM capabilities developed by Rockwell Collins and the Air Force under the Future Air Navigation and Traffic Avoidance Solution through Integrated Communication/Navigation/Identification (FANTASTIC) program will be combined to demonstrate a typical GATM solution in the summer of 2000. As part of the FANTASTIC program, an impact study for the F-15 and F-16 fighter platforms is being conducted to develop and demonstrate potential long-term GATM solutions for tactical fighters. The study will identify requirements for each platform and potential solutions with an emphasis on commercial off-the-shelf components. Affordable retrofits providing compliance with civilian airspace navigation regulations with minimal impact also will be identified.

US Navy Awards Raytheon $414 M to Remanufacture Tomahawk Cruise Missiles

The US Navy has modified an existing contract with Raytheon Co. to remanufacture up to 624 Tomahawk cruise missiles to the latest Block III configuration. Launched from surface ships and submarines, Tomahawk is a long-range, subsonic cruise missile used for land-attack warfare. Block III adds a GPS guidance capability to Terrain Contour Matching and Digital Scene Matching Area Correlation guidance systems. Under the terms of the $414 M indefinite-quantity contract, the Navy will order the upgraded Tomahawks as needed. Work will be performed principally at the Raytheon Missile Systems business unit in Tucson, AZ, and is expected to be completed by October 2000.

In June 1998, Raytheon was awarded a cost-plus, fixed-fee contract for the engineering and manufacturing development (EMD) of a more versatile, lower cost version of Tomahawk designated Tactical Tomahawk. The Tactical Tomahawk will be capable of battle damage indication, inflight retargeting, loitering and mission planning from the launch platform. The award includes the firm pricing for 1343 missiles (valued at $800 M) delivered over five years. EMD is scheduled to be completed in 2002 and production is expected to begin in 2003.

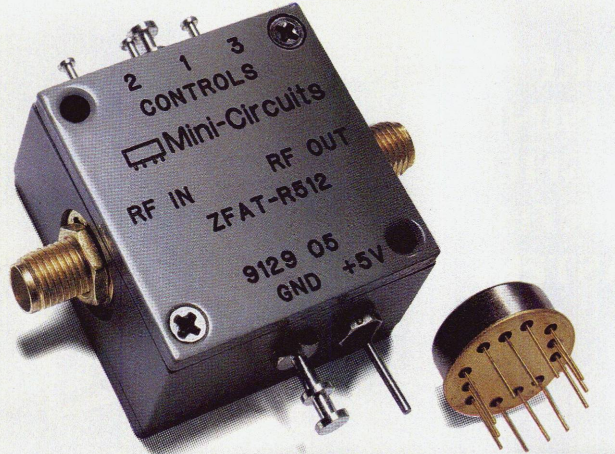
US Army's First Digitized Division Examined

The US General Accounting Office (GAO) has released a report, "Battlefield Automation: Performance Uncertainties Are Likely When Army Fields Its First Digitized Division" (GAO/NSIAD-99-150), which examines the progress of the Army's efforts to field a digitized division by 2000. Although the overall digitization effort involves more than 100 systems, the Army intends to field 16 high priority systems to three of the division's four brigades by December 2000 and field the first digitized corps by September 2004. In general, these 16 systems are command, control and communications systems intended to support decision-making by commanders in tactical operations centers at battalion, brigade, division and corps levels, including the Maneuver Control System and upgrades to mobile subscriber equipment and satellite communication systems. One of the systems, however, the Force XXI Battle Command, Brigade and Below (FBCB2), is an entirely new technology intended to accomplish the critical objective of sharing battlefield information with the thousands of soldiers outside of tactical information centers.

Though some systems were fielded as early as 1998, the acquisition status of other systems varies. For example, the Global Broadcast Service Transportable Ground Receive Suite was delayed because the contractor's initial design required too many terminal transit cases. The report identifies other significant uncertainties the Army will confront when the division is fielded at the end of 2000. Most importantly, the operational effectiveness and suitability of FBCB2 will be unknown, and the recent restructuring of the system's test and evaluation program will prevent full testing until at least 2002. Operational performance of other fielded systems will be unknown because the results of scheduled operational tests will not be completed by December 2000. In addition, automated data sharing within tactical centers will not have been demonstrated and whether digitization can achieve the expected increases in lethality and survivability is unlikely to be resolved any earlier than 2002 — after the FBCB2 initial operational test and evaluation are completed.

Iridium Tested as Potential F-16 Communication System

As reported in *C4I NEWS*, Lockheed Martin and AlliedSignal have entered into a cooperative agreement to test and demonstrate a two-way satellite communication system on a Lockheed Martin F-16 using Iridium's existing commercial system via an AlliedSignal AIRSAT 1. The objective of the agreement is to demonstrate the delivery of intelligence information to fighter pilots in near real time from anywhere in the world in an affordable manner. The proposed system ultimately could be integrated into the F-16, providing pilots with two-way voice and data communication to any command center, operating base or intelligence source in the world. The Lockheed Martin joint strike fighter team also could benefit from any advances made in the two-way militarized satellite communication field. Testing was scheduled to begin this summer to evaluate the operation of satellite communication technology in high speed fighter aircraft. A second test is scheduled for June 2000 to examine the integrity and security of the connection between the satellite and the aircraft. ■



DIGITAL STEP ATTENUATORS

up to 35dB
10 to 1000MHz

FROM **$5995**

TOAT-R512 ZFAT-R512 Accuracy (dB)	(+/-dB)	TOAT-124 ZFAT-124 Accuracy (dB)	(+/-dB)	TOAT-3610 ZFAT-3610 Accuracy (dB)	(+/-dB)	TOAT-4816 ZFAT-4816 Accuracy (dB)	(+/-dB)	TOAT-51020 ZFAT-51020 Accuracy (dB)	(+/-dB)
0.5	**0.12**	**1.0**	**0.2**	**3.0**	**0.3**	**4.0**	**0.3**	**5.0**	**0.3**
1.0	**0.2**	**2.0**	**0.2**	**6.0**	**0.3**	**8.0**	**0.3**	**10.0**	**0.3**
1.5	0.32	3.0	0.4	9.0	0.6	12.0	0.6	15.0	0.6
2.0	**0.2**	**4.0**	**0.3**	**10.0**	**0.3**	**16.0**	**0.5**	**20.0**	**0.4**
2.5	0.32	5.0	0.5	13.0	0.6	20.0	0.8	25.0	0.7
3.0	0.4	6.0	0.5	16.0	0.6	24.0	0.8	30.0	0.7
3.5	0.52	7.0	0.7	19.0	0.9	28.0	1.1	35.0	1.0

Price $ (1-9 qty) TOAT $59.95/ZFAT $89.95
bold faced values are individual elements in the units

Finally...precision attenuation accurate over 10 to 1000MHz and -55°C to +100°C. Standard and custom models are available in the TOAT(pin)- and ZFAT(SMA)-series, each with 3 discrete attenuators switchable to provide 7 discrete and accurate attenuation levels.

The 50-ohm components perform with 6μsec switching speed and can handle power levels typically to +15dBm. Rugged hermetically-sealed TO-8 units and SMA connector versions can withstand the strenuous shock, vibration, and temperature stresses of MIL requirements. TOAT pin models are priced at only $59.95 (1-9 qty); ZFAT SMA versions are $89.95 (1-9 qty).

Take advantage of this striking price/performance breakthrough to stimulate new applications as you implement present designs and plan future systems. All units are available for immediate delivery, with a one-yr. guarantee, and three-sigma unit-to-unit repeatability.

Mini-Circuits®

US 108 INT'L 109
CIRCLE READER SERVICE CARD

P.O Box 350166, Brooklyn, New York 11235-0003 (718) 934-4500 Fax (718)332-4661 *INTERNET* http://www.minicircuits.com

For detailed specs on all Mini-Circuits products refer to • 760- pg. HANDBOOK • INTERNET • THOMAS REGISTER • MICROWAVE PRODUCT DATA DIRECTORY • EEM

INTERNATIONAL REPORT

Martin Streetly, International Correspondent

Greece Signs Up for ERIEYE AEW&C Radar

Following a December 1998 announcement that Greece had selected an Embraer EMB-145 airframe fitted with Ericsson's ERIEYE radar and an Ericsson/Thomson-CSF North Atlantic Treaty Organisation (NATO)-compatible mission suite to fulfill its outstanding airborne early warning and control (AEW&C) aircraft requirement, Ericsson has announced that a formal contract covering the supply of four systems has been signed. Based on the EMB-145SA platform that Embraer developed for Brazil's Sistema de Vigilancia da Amazonia (SIVAM) region surveillance programme, the Greek EMB-145s will feature a revised mission workstation format, Thomson-CSF's DR 3000 electronic support system and NATO-compatible communications and identification friend-or-foe subsystems. The ERIEYE radar is also in service aboard the Swedish air force's S 100B airborne early warning aircraft, and the EMB-145/ERIEYE combination continues to be offered to a number of ongoing AEW&C programmes. As of press time, the first Greek system is scheduled for delivery during 2002.

Russian Radar Technology Showcased

The electronics industry in Russia has highlighted new radar technology at a number of recent trade shows, with emphasis on applications in the areas of combat aircraft fire control and missile guidance. At the Paris Air Show held in June, Tikhomirov Scientific Research Institute of Russia displayed its Epaulet phased-array antenna design that is intended to act as part of an interface subsystem between Western fire-control radars and Russian air-to-air missiles. The range of missiles involved includes the R-27 (AA-10 Alamo) and R-77 (AA-12 Adder), and the equipment takes the form of guidance antennas located on the sides of the host aircraft's fuselage or its wing roots.

At the Moscow Air Show held in August, Russian contractor Phazotron-NIIR displayed a prototype of its Sokol passive phased-array radar that is intended for use aboard multirole combat aircraft such as the Sukhoi S-37. Fitted with a 1 m diameter antenna array, Sokol utilises a novel antenna element arrangement that is claimed to significantly reduce costs. The radar is equipped with a single 2.5 kW liquid-cooled transmitter (an arrangement that could be superseded by a twin transmitter/single antenna at a later stage in its development). The system weighs approximately 270 kg and provides a detection range of 180 km against a moderate size radar cross-section target. In addition, the company has developed a low weight (75 kg) variant of the basic architecture designated the Pharaon system. The Pharaon system has a detection range of approximately 70 km and is intended for use aboard aircraft such as the Su-27 and Su-33.

Chapter 11 Filings Delay MSC Start-up

Following Iridium's filing for US Chapter 11 bankruptcy protection, the mobile satellite communications (MSC) sector suffered a second blow when ICO Global Communications filed Chapter 11 on August 27. Prior to filing for bankruptcy protection, ICO had raised $3.1 B to fund its 12-satellite constellation and required an additional $1.6 B to launch consumer services during the fourth quarter of 2000. However, the failure of a recent rights issue, the need to raise $600 M to meet immediate financial commitments and inconclusive refinancing negotiations between ICO and its major investors are believed to be the main drivers behind the company's request for court protection. European analysts also have suggested that poor marketing, high handset prices and increasing investor scepticism about the validity of the MSC concept are major factors behind the demise of both companies.

Australia Acquires AMSTAR and UK GPS Simulator

As part of its Project Ninox night-fighting, surveillance and target acquisition system upgrade programme, the Australian army has purchased 61 examples of the Australian Man-portable Surveillance and Target Acquisition Radar (AMSTAR) variant of Racal Defence Electronics' J-band (10 to 20 GHz) MSTAR sensor, which will replace its existing RASIT systems. AMSTAR leverages technology from the UK's MSTAR mid-life update effort and differs from the existing set in a number of respects, including the type of man-machine interface used and the detection range offered. In Australian service, AMSTAR will be used in the all-weather target detection and classification role, and a percentage of the new sensors are expected to be installed on the service's ASLAV-S wheeled armoured reconnaissance vehicles. The total programme value is $32.5 M and deliveries are scheduled to begin in 2001.

Australia's Department of Defence also has acquired a Global Positioning System (GPS) simulator from UK contractor Global Simulation Systems Ltd. Computer based, the new architecture accurately replicates signals from the entire 24-satellite GPS constellation as well as those from the Russian GLONASS satellite navigation system and a number of the augmentation systems currently being proposed for use with GPS. The new simulator was scheduled for installation at the Australian Defence Science and Technology Organisation's Tactical Surveillance Systems Division in Salisbury, South Australia in February 2000.

Rohde & Schwarz Launches New Antenna System

German contractor Rohde & Schwarz has launched a new antenna test system aimed primarily at the mobile telephone industry. The TS9970 measures the characteristics of integrated handset antennas via their auxiliary variables. The test item is mounted on a positioning system that can rotate in both the horizontal and vertical planes and measure the antenna's gain, sensitivity and three-dimensional radiation pattern. To simulate user impact on test pieces, the mounting assembly can be combined with an artificial head or body, with the entire measurement run performed in an anechoic chamber. Parameter measurements are performed automatically at given angular increments with the processed results displayed in either tabular or graphic form. The TS9970 is also suitable for use with a range of radio communications systems that use integral antennas including radio-controlled central locking systems for cars or wireless networks used with PCs.

Smart Label® Alliance Formed

Netherlands contractor Philips Semiconductors Inc. and Japanese automation specialist The Omron Corp. have entered into an agreement to work on the latest generation of smart label technology. Here, radio frequency transponders andread/write memories are laminated between layers of paper or plastic to produce low cost, consumable labels that can store information relating to a product, manufacturer or logistic process and transmit it to an appropriate read/write device at a rate of approximately 30 labels per second. More importantly, the reader and the label do not have to be in direct line-of-sight contact with each other. Under the terms of the agreement, Philips will supply Omron with smart label ICs that will work with Omron's range of 13.56 MHz label readers and transponders. The resultant technology package is suitable for all emerging applications including airport baggage handling, parcel tracking, library tracking and retail logistics. An Omron 13.56 MHz baggage label reader has been tested by British Airways and the company is currently testing retail and express parcel applications with smart labels containing Philips ICs. ■

First-half 1999 US Factory Electronics Sales Increase Nine Percent

According to the Electronic Industries Alliance, factory sales of electronics equipment in the US reached $244 B during the first six months of 1999, a nine percent increase over the same period in 1998. The telecommunications sector recorded the most significant growth with sales of $41.6 B, which exceeded sales of $35.3 B in the first half of 1998 by 18 percent. The other related products sector continues to drive the US economy forward with sales of $39.7 B in 1999, a 14.3 percent increase from last year's sales of $34.8 B. The remaining sectors (with the exception of industrial electronics, which dropped four percent) recorded moderate growth. The electronic components sector increased 7.6 percent from $67.4 B in 1998 to $72.5 B this year; the electromedical equipment sector grew 6.5 percent with $6.6 B in sales during the first half of 1999 compared to $6.2 B during the first half of 1998. Computers and peripherals sales increased 5.3 percent to $45.6 B from 1998's $43.3 B, defense communications rose 4.5 percent with $15.6 B in sales in 1999 compared to $15 B in 1998 and consumer electronics posted a 4.1 percent increase in sales to $4.4 B from $4.2 B.

FCC Authorizes Additional Carriers to Provide Air-to-ground Cellular Service

The Federal Communications Commission (FCC) has authorized seven additional cellular service providers to use AirCell Inc.'s unique, patented technology to provide air-to-ground advanced communications to general aircraft and regional airlines. The FCC order permits the cellular providers to offer service based on AirCell's proprietary technology, which re-uses existing cellular network spectrum and infrastructure to provide cellular-like service for airborne aircraft. Pine Belt Cellular Inc., XIT Cellular, ETEX Cellular Co. Inc., WESTEX Telecommunications Inc., Tennessee RSA No. 3 Limited Partnership, North Alabama Cellular LLC and Cellular Network Partnership are the companies included in the order, which brings the number of providers commercially offering AirCell's technology to 14.

A separate FCC order granted AirCell providers additional relief that will facilitate more rapid introduction of nationwide service. The order reduces the frequency notification distance from 270 kilometers (168 miles) to 151 kilometers (94 miles), clarifies the frequency coordination process and increases the number of available channels. AirCell's technology reduces the cost of airborne telephone service and provides access to a suite of advanced communications capabilities, including fax, e-mail and the World Wide Web, at faster speeds and at a fraction of the cost of other airborne phone systems.

Tenfold Growth Forecast for Millimeter-wave Device Market

Allied Business Intelligence Inc. has released a report, "Millimeter-wave '99 – Broadband Wireless Automotive Radar Markets, Opportunities and Forecasts," which predicts that total shipments of millimeter-wave devices will grow from 314,000 in 1999 to approximately three million in 2004. Although traditional point-to-point and backhaul applications are expected to represent 90 percent of millimeter-wave device shipments this year, less than five percent of the point-to-point millimeter radios sold are expected to be used to provide access to end users. During the next five years, local multipoint distribution system (LMDS) customer premise equipment is forecast to increase from one to 14 percent of the market share, and LMDS deployments are expected to be primarily point-to-point rather than multipoint.

The demand for broadband millimeter-wave satellite system receivers is expected to account for a major share of the market growth, comprising 43 percent of the millimeter device market by 2004. The automotive radar systems segment, which is expected to account for five percent of millimeter device shipments this year, continues to make strong strides in the trucking industry. Migration of the technology to the mass market is expected within five years and is forecast to account for 21 percent of millimeter-wave shipments in 2004. The total value of millimeter-wave device shipments in 1999 is expected to reach $28.1 M. For additional information, contact Andy Fuertes at Allied Business Intelligence (516) 624-3113 or e-mail: analysts@alliedworld.com.

Enhanced 911 Phase II Network Caller Location System Demonstrated

Rural Cellular Corp. and five participating partners, including CML Technologies, 911 Datamaster Inc., GeoComm Inc., Independent Emergency Services LLC (IES) and KSI Inc., have demonstrated a new technology for 911 service that enables police to automatically pinpoint the location of a wireless telephone user calling 911 for help, thereby speeding response time. Previewed at the 1999 International Association of Public Safety Communications Officials Conference, the Enhanced 911 Phase II network-based system operates without user intervention and is independent of the wireless provider and handset used. The system also employs traditional Public Safety Answering Point equipment and technology and requires the addition of only a limited amount of equipment to 911 dispatch centers. From 1994 to 1998, the number of wireless subscribers nearly tripled from 24 million to 69 million, and close to 36 million emergency calls (an average of 68 calls per minute) were made in 1998. By 2000, when wireless subscribers are expected to number approximately 100 million, 50 million emergency calls are forecast.

Wireless Network to be Installed in 21 African Countries

Alexander Resources International Inc. has entered into an agreement to provide voice, data, Internet and video broadcasting services throughout 21 countries in Africa. Under the terms of the agreement, Alexander is responsible for the installation and operation, including capital investment and ongoing operating costs, of Tele-Trade Centres in the member countries of the Common Market for Eastern and Southern Africa (COMESA). The COMESA region currently has approximately 4.4 million telephone lines, which generate \$2.2 B in annual revenues and service more than 380 million people. A great demand for services exists in the region: The official waiting lists in Tanzania and Egypt contain 112,200 and 1,173,600 names, respectively. These figures only include those individuals who have submitted an application, which means the actual waiting list is estimated to be five- or six-times longer. Tele-Trade Centres using very small aperture terminal satellite communications to support voice, data, Internet and video broadcasting services will be installed in the region's rural and urban areas. The major objectives of the network are to improve healthcare, education, employment and the overall quality of life in the region while increasing global connectivity and establishing a backbone for future expansion.

Ericsson to Install TDMA Networks in Argentina

Ericsson has been awarded two contracts with an aggregate value of more than \$400 M to supply national wireless networks to two newly licensed 1900 MHz operators in Argentina. Telecom and Telefónica currently operate TDMA 800 MHz networks in northern and southern Argentina, respectively, which were supplied by Ericsson. The new 1900 MHz networks will allow the two operators to support larger volumes of users and provide a platform for personalized services. Equipment deliveries from Ericsson are scheduled to begin in the second half of this year. Full network operation is expected to begin by the second half of 2000. ■

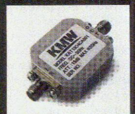
KMW Has Wide Range of Quality Attenuators To Handle All Your Needs

Designed by KMW for consistency and stability, these attenuators will be your first choice for building wireless communication system applications!

KAT1OO4SA000

KAT2OO4SA000

KAT1304CA000



KAT1304CA001

■ Step-Rotary Attenuators

Product Code No.	KAT1OO4SA000	KAT2OO4SA000	KAT1SO4SA000	KAT2SO4SA000
Operating Type	Break-Before-Make		Make-Before-Break	
Frequency Range	DC ~ 3GHz	DC ~ 3GHz	DC ~ 3GHz	DC ~ 3GHz
Insertion Loss (max.)	0.2dB	0.2dB	0.2dB	0.2dB
VSWR (max.)	1.15:1	1.15:1	1.15:1	1.15:1
Incremental Attenuation Range (dB)	0 ~ 1	0 ~ 10	0 ~ 1	0 ~ 10
Attenuation Step (dB)	0.2	1	0.2	1
Nominal Impedance	50 ohm		50 ohm	
I/O Port Connector	SMA(F) / SMA(F)		SMA(F) / SMA(F)	
Average Power Handling	2W @ 2GHz		2W @ 2GHz	
Temperature Range	-55°C ~ +85°C		-55°C ~ +85°C	
Dimension (inch)	1.93*1.56*1.51		1.93*1.56*1.51	

■ Continuously Variable Attenuators

Contactless Structure for High Power Handling Capability, up to 2W average @2GHz.

Product Code No.	A type : KAT13O4CA000 B type : KAT13O4CA001		
Frequency Range	DC ~ 1GHz	1 ~ 2GHz	2 ~ 3GHz
Insertion Loss (max.)	0.15dB	0.3dB	0.35dB
VSWR (max.)	1.25 : 1	1.25 : 1	1.25 : 1
Attenuation Range (max.)	4dB @ 1GHz	13dB @ 2GHz	25dB @ 3GHz
Nominal Impedance	50ohm		
I/O Port Connector	SMA(F) / SMA(F)		
Average Power Handling	2W @ 2GHz & 25°C, without Heat-Sink		
Temperature Range	-55°C ~ +85°C		
Dimension (inch)	A type : 1.496*1.102*0.470, B type : 1.225*1.102*0.470		

■ Fixed Coaxial Attenuators are available

N-type, SMA-type Connectors

CIRCLE 76 ON READER SERVICE CARD

13131 East 166th Street, Cerritos, CA 90703-2202
1-800-8320-KMW • www.kmwinc.com
tel: 562-926-2033 • fax: 562-926-6133

KMW

INDUSTRY NEWS

■ **Watkins-Johnson Co.**, Palo Alto, CA, has signed a definitive agreement to sell its **Telecommunications Group** business to **Marconi North America**, a subsidiary of **The General Electric Co. plc** of the UK. The pre-adjusted purchase price of $57.9 M, based upon a balance sheet, will be adjusted to the balance sheet at the date of closing, and the final transaction is subject to the approval of Watkins-Johnson shareholders.

■ **Noise Com's Wireless Telecom Group Inc.** has entered into a definitive agreement to merge **Boonton Electronics Corp.** into a wholly owned subsidiary. Under the terms of the agreement, each share of Boonton common stock will be converted into 1.4 shares of Noise Com common stock and an amount of cash equal to 0.175 times the closing price of Noise Com common stock on the closing date. The transaction, which is expected to be completed before December 31, is valued at approximately $7 M and subject to Boonton shareholder approval as well as other customary requirements.

■ **Mitec Telecom Inc.** has moved its operations to a state-of-the-art, 88,000-square-foot manufacturing facility geared for very large volume production. The new facility is located at 9000 Trans-Canada Highway, Pointe Claire, Quebec, Canada H9R 5Z8 (514) 694-9000, fax (514) 694-3814.

■ MMIC and MMIC assembly designer and manufacturer **Hittite Microwave Corp.** has relocated its operations to a new facility at 12 Elizabeth Drive, Chelmsford, MA 01824 (978) 250-3343, fax (978) 250-3373. The e-mail address is hmcsales@hittite.com.

■ RF and microwave filter and diplexer manufacturer **Luna Microwaves Inc.** has moved to a larger facility at 7610-V Rickenbacker Dr., Gaithersburg, MD 20879. Telephone and fax numbers remain unchanged.

■ **Trak Communications Inc.**, a **Tech-Sym** company, has opened a new filter design center, **Advanced Filter Solutions (AFS)**, in Frederick, MD. The new facility will be responsible for sales, design and development of a comprehensive line of RF filter products for the wireless industry.

■ **Centurion International Inc.** has increased its presence globally by opening a new manufacturing facility in Tijuana, Mexico; expanding its Asian management team and relocating offices to Seoul, South Korea; and building a new campus with corporate headquarters and a manufacturing facility in Lincoln, NE. In addition, Centurion has acquired **Sigma Wireless Technologies**' portable antenna division in Dublin, Ireland and relocated it to the company's operations in Aylesbury, UK.

■ New Zealand-based **Deltec** has changed its name and look to represent the company's growing presence in the global telecommunications industry. The newly named company, **Deltec Telesystems**, will continue to design, manufacture and market advanced base station antennas, filters and control systems and offer its line of Teletilt™ remote-controlled electrical downtilt antennas.

■ **CTS Corp.'s Electrocomponents** business unit, which designs and manufactures variable resistor, encoder and switch products, will be integrated with the company's **Resistor Products** business unit to form **CTS Resistor/Electrocomponents**. Simultaneously, CTS Electrocomponents' loudspeaker and electromechanical assembly products will integrate into CTS' **Automotive Products** business. All customer support personnel and manufacturing facilities will remain unaffected.

■ RF and microwave specialty component distributor **Richardson Electronics Ltd.**, LaFox, IL, has entered into an agreement with **Motorola Semiconductor Product Sector** to serve as its global RF, microwave and wireless components distributor. In related news, Richardson Electronics and **M/A-COM**, a division of **AMP Inc.**, have expanded their distribution agreement to include Taiwan. The distribution agreement will provide technical support and product availability to the wireless telecommunications, automotive, aerospace and defense markets.

■ **Unique Broadband Systems Inc.** has named Chilean-based **Telefonia Y Comunicaciones SA (TECOM)** a distributor of its broadband wireless equipment product line. Under the terms of the agreement, TECOM is responsible for purchasing equipment worth US$2.1 M over the length of the agreement, which expires December 31, 2000. The agreement is expected to increase sales and create brand recognition in the South American market.

■ **Tekmark Inc.**, Atlanta, GA, has selected **Diamond Advanced Components Inc.** to serve as North American distributor for its high quality quartz frequency control products to the computer, telecommunications, wireless data communications, CEM and other OEM markets.

■ **Hewlett-Packard Co. (HP)**, Palo Alto, CA, and **Ando Electric Co. Ltd.** of Tokyo have entered into a three-year agreement to develop and market test instruments for the emerging high bandwidth DWDM and SONET/SDH functional test market. The agreement does not apply to other HP and Ando products, which the companies will continue to market and sell independently worldwide. In related news, HP and **Integrated Measurement Systems' (IMS) Virtual Test Division** have entered into an agreement to offer virtual test software tools for verifying the compatibility of test programs with high performance semiconductor designs without using a prototype. The alliance is the culmination of a two-year relationship during which the companies collaborated on developing methods to enhance the IC testing process.

■ **IBM** and **Siemens Information and Communication Networks** have signed an agreement to apply next-generation system-on-a-chip products based on IBM's silicon

[Continued on page 66]

germanium (SiGe) process technology to high performance mobile network communication systems. Under the terms of the agreement, Siemen's **Communication on Air** business unit will gain access to IBM's SiGe technologies currently in development. SiGe technology is a process in which the standard silicon that forms the base of microchips is augmented with germanium to make the chips operate much faster with decreased power consumption and increased integration capabilities.

■ **American Microsystems Inc. (AMI)**, Pocatello, ID, has entered into an agreement with **Rambus Inc.**, Mountain View, CA, to license the company's Direct Rambus™ technology for clock generator devices. AMI will design and manufacture a family of Direct Rambus clock generator devices to support high bandwidth Rambus® memory systems for computers, communications and consumer products as well as other high performance electronic systems.

■ **Superconductor Technologies Inc.**, Santa Barbara, CA, has entered into a five-year agreement with **US Cellular Corp.** Under the terms of the agreement, US Cellular will acquire a minimum of 100 SuperFilter® systems over the next year and a minimum of 400 systems over the subsequent four years. In turn, Superconductor Technologies will issue US Cellular a warrant, subject to vesting provisions, providing for the purchase of up to one million shares of the company's stock at $4 per share.

■ **Gabriel Electronics Inc.**, Scarborough, ME, and **Endgate Corp.**, Sunnyvale, CA, have entered into a joint agreement to introduce a new generation of smaller and more attractive antennas for the expanding broadband wireless market. The two companies will jointly market and support FlatFire™ and GemFire™ products globally while cooperating in the development of new, integrated antenna solutions for a variety of applications.

■ **CoWare Inc.**, a provider of system-level design tools for complex system-on-a-chip development, and **Lucent Technologies** have entered into an agreement whereby Lucent will use the CoWare N_2C™ design software to minimize system-on-a-chip design time. In addition, Lucent plans to integrate some of its processor cores into the CoWare N_2C system so customers can quickly complete designs.

■ **Motorola Inc.** has presented Texas A&M University College of Engineering with a $500 K gift to support the college's future system-on-a-chip research and development programs. The donation, which is expected to be paid over five years, will support activities of the analog and mixed-signal research program and fund research assistantships in an effort to fill the critical need for more analog and mixed-signal engineers.

■ Solid-state power amplifier manufacturer **Comtech PST** has begun supplying a two-year warranty for the company's standard general-purpose and standard wireless-band series class A linear amplifiers. The warranty will apply to module (AM series) as well as instrument (AR series) amplifiers.

[Continued on page 68]

AROUND THE CIRCUIT

■ Wireless communications equipment manufacturer **Celwave**, a division of **Radio Frequency Systems Inc.**, has begun base station antenna production in Brazil's recently expanded kmP factory in Embu, a suburb of Sao Paulo. The facility is restricting its initial output to Brazil exclusively; export to other South American markets is being planned.

■ The Department of Defense Small Business Innovation Research (DoD SBIR) program has launched its first solicitation for FY 2000. The SBIR program is the largest source of early stage research and development funding available in the US for small, high tech companies. Qualifying companies must have 500 or fewer employees and be US owned and organized for profit. Information on solicitation topics and submission procedures can be found at www.acq.osd.mil/sadbu/sbir. Proposals will be accepted December 1, 1999 through January 12, 2000.

■ **Karl Suss** is celebrating its 50th anniversary. Founded in 1949, the company's current product range includes the world's fastest production mask aligners, spin coater product lines for high end application markets, bonders and test equipment.

■ **International Crystal Manufacturing (ICM)** has been approved by the North Texas Women's Business Council as a certified Women Business Enterprise (WBE). The certification will allow ICM to compete for business with corporations and agencies that recognize and support WBE.

■ **Sonoma Scientific** has received ISO 9001 certification.

FINANCIAL NEWS

■ **Andrew Corp.** reports sales of $186.1 M for the third quarter, ended June 30, compared to $204.2 M for the same period last year. Net income was $14.7 M (18¢/diluted share), compared to $24.6 M (28¢/diluted share) for the third quarter of 1998.

■ **REMEC Inc.** reports sales of $47.3 M for the second quarter, ended July 30, compared to $44.4 M for the same period last year. Net loss was $2.8 M (11¢/diluted share), compared to a net loss of $6.5 M (26¢/diluted share) for the second quarter of 1998.

■ **Watkins-Johnson Co.** reports sales for continuing operations of $34.9 M for the second quarter, ended June 25, compared to $26.8 M for the same period last year. Net income from continuing operations was $3 M (45¢/diluted share), compared to $563 K (7¢/diluted share) for the second quarter of 1998.

■ **Ansoft Corp.** reports sales of $6.9 M for the first quarter, ended July 31, compared to $5.2 M for the same period last year. Net loss was $893 K (8¢/share), compared to a net loss of $1.3 M (11¢/share) for the first quarter last year.

■ **Robinson Nugent Inc.** reports sales of $18.9 M for the fourth quarter, ending June 30, compared to $16.4 M

[Continued on page 70]

for the fourth quarter of 1998. Net income was $1.2 M (24¢/share), compared to a net loss of $2.5 M (52¢/share) for the same period last year.

■ **Superconductor Technologies Inc.** reports sales of $1.5 M for the second quarter, ended July 3, compared to $2.2 M for the same period last year. Net loss was $2.4 M (31¢/share), compared to a net loss of $2.2 M (28¢/share) for the second quarter of 1998.

CONTRACTS

■ RF engineering and system deployment service firm **LCC International Inc.** has signed a contract valued at approximately $115 M with XM Satellite Radio Inc. for the design and deployment of XM's terrestrial repeater network. The contract designates LCC as the prime contractor for the implementation of XM's supplemental terrestrial repeater sites. The repeater network will use direct satellite-to-receiver broadcasting technology to provide radio listeners with up to 100 channels of digital radio from coast to coast.

■ **Sanders**, a **Lockheed Martin** company, has been awarded a $43 M contract for continued production of millimeter-wave transceivers for the Longbow Hellfire Missile System. The missile system is deployed on US Army AH-64D helicopters and will be installed on UK Army WAH-64 Apache helicopters. Sanders will build 4200 transceivers for Lockheed Martin Millimeter-wave Technologies Inc., a Lockheed Martin subsidiary. Deliveries are scheduled to begin in April 2000 and are expected to be completed in February 2002.

■ **L-3 Communications' Global Network Solutions (GNS)** business unit has been awarded a $15 M contract to provide a complete private digital microwave voice and data network to the Egyptian National Railways (ENR) organization. Under the terms of the contract, GNS will install a private communications network that spans ENR's entire 6000-mile right-of-way, including site survey and facility installation work. In related news, L-3 Communications' Telemetry & Instrumentation (L-3 T&I) has awarded a contract to **EMP TrexCom** to supply three model 050 2.4-meter antenna systems to be installed in the Hebrides range facility for the Defense Evaluation Research Agency in the UK. The three systems are part of a $3.6 M contract received by L-3 T&I for the upgrade of the facility, which will support testing of the next-generation, high energy air-to-air missiles.

■ **Andrew Corp.**, Orland Park, IL, has been awarded a contract from Level 3 Communications to supply and install equipment shelters along the company's fiber-optic communications network in the US and Canada. Under the terms of the $14 M contract, Andrew will design, manufacture and install shelters at 96 sites along Level 3's US and Canadian route. All shelters are expected to be installed and operative by December 2000.

[Continued on page 72]

■ GPS and wireless antenna designer and manufacturer **Micro Pulse Inc.** has been awarded an 18-month contract valued at $3.4 M from San Diego, CA-based QUALCOMM Inc. to supply antennas for use on QUALCOMM's OmniTRACS® Mobile Information Management system. The fully integrated information management system provides two-way mobile communications, satellite tracking, and real-time messaging and position reporting between fleets and their operation centers.

■ **Signal Technology Corp.**, Danvers, MA, has received contracts totaling $971 K from Raytheon Systems Co. and Raytheon's suppliers to manufacture components, including isolators, mixers, limiters and limiter/filter assemblies, for the Patriot Missile System. The components will be produced at Signal Technology's California division in Sunnyvale, CA.

■ **Scientific-Atlanta Inc.**, Norcross, GA, has signed a multimillion-dollar contract with Telespazio SpA, a Telecom Italia Group company, to develop, manufacture and install the satellite ground terminals that form a major portion of the ground infrastructure network for Astrolink, a new global satellite system. Under the terms of the contract, Scientific-Atlanta will supply the Gateway Satellite Access Facility RF terminals and the Intersatellite Gateway Links comprising precision tracking antenna systems, front-end communications electronics and high speed modems. The contract covers the networks' first four regions: Europe, Asia, the Atlantic and North America. Astrolink commercial service is scheduled to begin in 2003 with full deployment planned for 2004.

■ **Berkeley Varitronics Systems Inc.**, Metuchen, NJ, has been awarded a contract by Motorola of Buenos Aires to provide CDMA test transmitters that will be used to aid in CDMA system build-out. In related news, Berkeley Varitronics Systems has been awarded a contract by World Access, Alpharetta, GA, for eight PCS 20 W class A Gator transmitters that will aid in rapid build-out of PCS networks. Financial details of both contracts were not disclosed.

■ **Chipscale Robotics Inc.**, Fremont, CA, has received an order from Coherent Inc. for a high accuracy DSH 5000 pick-and-place system for die stacking. The system will use both up- and down-looking optics for precision die stacking and inspection. Coherent will use the system in its manufacturing operations. Financial terms of the agreement were not disclosed.

PERSONNEL


▲ Thomas J. Scanio

■ TriPoint Global Communications Inc. has appointed **Thomas J. Scanio**, chief technical officer. Scanio has more than 25 years of experience in engineering design and management and, most recently, was VP, product development for the Antenna Control division of TriPoint's RSI group.

■ REMEC Inc. has appointed **Mark D. Dankberg** to serve on its board of directors. Dankberg is the founder, chairmen and CEO of ViaSat Inc.

■ **James E. Bunting** has been named CFO at SatCom Systems Inc. Most recently, Bunting was VP, CFO aNd COO at Intellicell Corp.


▲ John E. Warren III


▲ Glenn Fraser

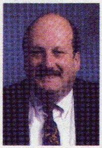
■ ANADIGICS has announced several new personnel appointments, including **Thomas C. Shields** as CFO, **John E. Warren III** as VP, human resources and **Glenn Fraser** as VP, RF Standard Products. Most recently, Shields was VP of finance and controller at Fisher Scientific Co.; Warren was VP, human resources at AlphaNet Solutions; and Fraser was director of the Wireless Business Unit at Fujitsu Microelectronics Inc.

■ Rodale Electronics Inc. has promoted **Vince Maida** to VP and director of operations. In addition, **Paul Ablequist** has been named VP, sales and marketing. Most recently, Maida was VP, engineering; Ablequist was VP, marketing for the EMS Division of Ultra Electronics plc.

■ Acoustic signal processing product manufacturer Micro Networks/Andersen Laboratories has appointed **Linda Plano** VP and business unit manager, frequency products. Most recently, Plano was head of the Electronic Materials and Microsystems Group at Sarnoff Corp.

■ Custom Microwave Inc. has appointed **Michael Kujawa** VP, business development. Kujawa has 17 years of experience in the SATCOM, aerospace and automated meteorology markets.

■ Smart antenna system provider Metawave Communications Corp. has appointed **Andy Merrill** VP, customer operations. Merrill has 15 years of experience in the cellular industry and, most recently, was field engineering manager of Motorola Inc.'s western region.


▲ David J. London

■ **David J. London** has been appointed VP, sales and marketing at Piconics Inc. Most recently, London served as VP at mm-Tech Inc.

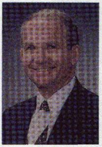

▲ Mark Fornier

■ Stellex-Phoenix Microwave has appointed **Mark Fornier** director of sales at its Phoenix Microwave operation. Fornier has more than 18 years of sales and marketing experience in the RF and microwave industry and, most recently, was marketing manager at M/A-COM's Aerospace and Defense business.

[Continued on page 74]

▲ Mark Jewell

■ Flexible waveguide manufacturer Quasar Microwave Technology Ltd. has appointed **Mark Jewell** sales and marketing director. Jewell has experience in RF and microwave sales in the international market, including Asia, Australia and Europe.



▲ Ron Desilets

■ **Ron Desilets** has joined Metclad International Corp. as North American sales and marketing manager. Desilets brings to the company 20 years of experience in microwave laminates and circuits.

■ CTS Corp. has named **John W. Cline** director of engineering for CTS Reeves Frequency Products. Prior to joining the company, Cline served as president of Oak Frequency Control Inc.

■ Tensolite-QMI has appointed **Will Jensen** director of sales and marketing. Jensen brings to the company sales and marketing management experience from companies that provide products and services to the wireless telecommunication marketplace.

■ Northrop Grumman Corp.'s Integrated Systems and Aerostructures sector has named **Frank Wagner** director and integrated product team leader for the F-14 program. Wagner has more than 20 years of F-14 experience and, most recently, was program manager for F-14 new programs at Northrop Grumman.

■ ARCOM Inc. has named **Dieter Kaiser** director of operations for its product line of mm-wave wireless components and subsystems. Kaiser brings to the company more than 20 years of high volume manufacturing experience and, most recently, worked at Whistler Corp.

■ Surface-mount technology and advanced packaging supplier Quad Systems Corp. has appointed **Jay DiGiovanni** director of software engineering. Most recently, DiGiovanni was director of systems engineering at CFM Technologies Inc.

■ Palomar Technologies has announced several new personnel appointments, including **Michael Criscuolo** as manager of customer service and **Gabriel Perez** and **Jerrol Olsen** as field service engineers. Criscuolo has 18 years of management experience at General Dynamics, Convair Division and Palomar Robotics Technologies; Perez most recently was a field service engineer at Devoltec; and Olson has 13 years of technical experience and electronics training with the United States Marine Corps.

[Continued on page 76]

■ **Leo Messier** has been appointed business unit manager for HELIAX® connector products at Andrew Corp. Messier has more than 30 years of operations and materials experience. Prior to joining Andrew, he was director of operations at Huber + Suhner Inc., North America and Amphenol RF/Microwave.

REP APPOINTMENTS

■ **Fujitsu Compound Semiconductor Inc.**, San Jose, CA, has named **Kruvand Associates Inc.**, Richardson, TX, to represent its microwave, lightwave and GaAs IC DataComm products in Arkansas, Louisiana, Oklahoma and Texas (excluding El Paso County). In the past 10 months, Fujitsu has added five new sales representative firms to cover more than 30 percent of the US.

■ **Advanced Semiconductor Inc.**, North Hollywood, CA, has appointed several European companies to represent its line of microwave and RF components, including **Semic RF Electronic GmbH** to cover Germany, Austria, Switzerland and Eastern Europe; **Novacom Microwave Ltd.** to cover the UK, Ireland and the Netherlands; and **Compomill AB** to cover Scandinavia.

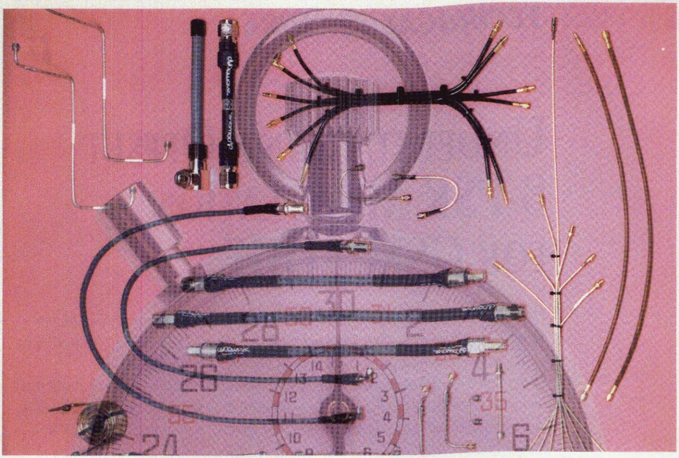
WEB SITES

■ **Aethercomm**, San Marcos, CA, has designed a new Web site containing information about the company's RF, microwave and millimeter-wave amplifiers, transmitters, receivers, components and ASICs for use by military, satellite communications and commercial wireless customers. The site can be accessed at www.aethercomm.com.

■ **Association Connecting Electronics Industries** has designed a new Web site dedicated to GenCAM,℠ the industry standard for printed board data transfer. The site is a one-stop source for information on the format, including CAD and CAM suppliers, accuracy checkers and the standard itself. The site can be accessed at www.gencam.org.

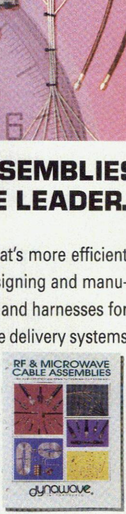
■ **Interstate Electronics Corp.**, a division of **L-3 Communications**, has designed a new Web site to discuss the release and other authoritative material related to the defense industry and GPS. The site, which can be accessed at www.rankin-group.com/iecpr, will highlight the company's developments and current products for the US Navy's Extended Range Guided Munition program and the US Army's new 155 mm Excalibur GPS receiver projectile.

■ **Microwave Solutions Inc.**, National City, CA, has designed a Web site containing product information on the latest amplifiers used in today's market, including high power, drop-in, broadband, communication, low noise and stocked. Press releases, key specifications, company information and purchasing information can be accessed at www.microwavesolutions.com.



WHEN YOU NEED YOUR CABLE ASSEMBLIES RIGHT AND RIGHT NOW, CALL THE LEADER.

To be more efficient and more competitive, call a company that's more efficient and competitive. Dynawave. For over ten years, we've been designing and manufacturing low cost, superior quality cable assemblies, delay lines, and harnesses for the wireless and military markets. Our on-demand and just-in-time delivery systems can satisfy the most stringent procurement requirements. And we can deliver prototypes, short runs, and high volume production with the same efficiency.



For high quality flexible, semi-rigid, delay lines, phase matched, and harnesses when you need them, call us today. Or send for a free brochure. Either way, it's time to switch to Dynawave.

dynawave INCORPORATED®

135 Ward Hill Ave., P.O. Box 8224, Haverhill, MA 01835 U.S.A.
Tel: 978-469-0555 / Fax: 978-521-4589 / E-mail: connect@dynawave.com / Website: www.dynawave.com

CIRCLE 34 ON READER SERVICE CARD

UNDERSTANDING OFFSET 8-PSK MODULATION FOR GSM EDGE

The evolution of the GSM standard for mobile communications toward higher data rates embodied by the enhanced data rates for GSM evolution (EDGE) uses a variation of an eight-phase-shift keying (8-PSK) modulation scheme. Understanding of the selected modulation technique and the reasons behind it is important because they drive design choices. This article describes 8-PSK and its derivation toward the form it takes in GSM EDGE. A complete GSM EDGE transmitter/receiver baseband architecture is discussed along with simulation results.

The need to expand mobile communications systems capabilities to encompass data as well as voice means that higher data rates will be transmitted without loosening bandwidth restrictions. This enhancement requires the use of spectrally more efficient modulation techniques, that is, modulation techniques that offer a higher throughput/occupied bandwidth ratio. An evolution of the current GSM standard to provide higher data rates is GSM EDGE (812.5 kbps) where the modulation scheme to be used is pulse-shaped (Gaussian) 3π/8 offset 8-PSK as opposed to GSM (270.8 kbps), which uses Gaussian minimum-shift keying (GMSK). One of the most remarkable differences between the two modulation formats is that GMSK has a constant amplitude or envelope and exhibits phase modulation; pulse-shaped 8-PSK exhibits both amplitude and phase variations.

8-PSK

Analog or digital modulation consists of varying the characteristics of a sinusoidal waveform u(t) (the carrier), be it amplitude, phase, frequency, polarization or a combination of these characteristics, according to the information being transmitted. In the case of digital modulation schemes, the information is in a digital format, usually a binary word (n bits), hence producing $M = 2^n$ possible words. Each symbol has a duration T and each bit has a duration T_b, where $T = nT_b$.

M-PSK is a digital modulation scheme where the information to be transmitted is conveyed onto the phase of the carrier. The expression for the modulated carrier u(t) is

$$u(t) = A(t)\cos(2\pi f(t)t + \phi(t)) \qquad (1)$$

and the phase of the carrier $\phi(t)$ is

$$\phi(t) = \sum_k \phi_k \delta(t - kT) \qquad (2)$$

where

$$\phi_k = \theta_0 + (2m+1)\frac{\pi}{m}$$

$$m \in [0 \to M-1]$$

[Continued on page 80]

ASHKAN MASHHOUR
Nokia Telecommunications
Camberley, Surrey, UK

ϕ_k is a set of M-ary words and $\delta(t)$ is a Dirac pulse. Therefore, the expression for the modulated carrier can be written as

$$\begin{aligned} u(t) &= A(t)\cos\left(2\pi f(t)t + \sum_k \phi_k \delta(t-kT)\right) \\ &= \sum_k A(t)\cos\left(2\pi f(t)t + \phi_k\right)\delta(t-kT) \\ &= \sum_k A\cos\left(2\pi ft + \phi_k\right)\delta(t-kT) \end{aligned} \quad (3)$$

Since amplitude and phase are constant in M-PSK, this expression can be expanded as

$$\begin{aligned} u(t) &= A\sum_k\left[\cos(\phi_k)\cos(2\pi f_c t) - \sin(\phi_k)\sin(2\pi f_c t)\right] \\ &\quad \bullet\delta(t-kT) \\ &= \sum_k\left[I_k\cos(2\pi f_c t) - Q_k\sin(2\pi f_c t)\right]\delta(t-kT) \end{aligned} \quad (4)$$

where

$I_k = A\cos(\phi_k)$
$Q_k = A\sin(\phi_k)$
f_c = carrier frequency

Traditionally, I_k and Q_k are referred to as the in-phase and quadrature components since u(t) can be decomposed as a sum of two quadrature waveforms $\cos(2\pi f_c t)$ and $\sin(2\pi f_c t)$. These components take their values in an M-ary alphabet formed by n bits ($M = 2^n$). This expression can be represented in the Fresnel plane (complex plane referring to a complex envelope representation of the signal).

For 8-PSK, $M = 8 = 2^3$ where n = 3. Therefore, each symbol is formed from three bits. A vectoral illustration of this technique is shown in ***Figure 1***, with $\theta_0 = 0$ and a Gray coding for mapping the bits to the symbols.

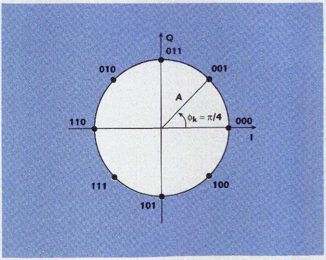
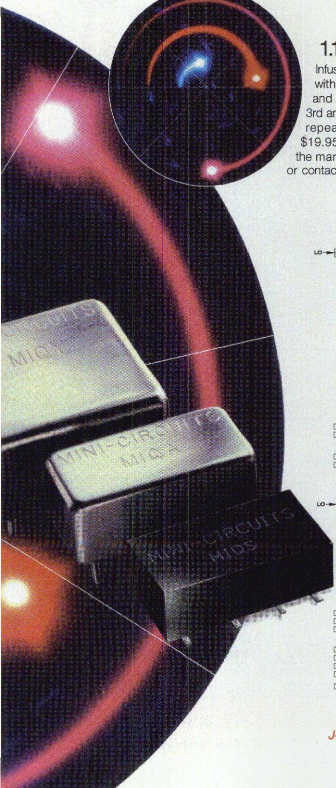


Fig. 1 An 8-PSK constellation diagram with Gray coding.

[Continued on page 83]

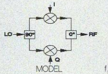
I&Q MODULATORS DEMODULATORS



1.15MHz to 1880MHz from $19.95 (qty. 1-9)

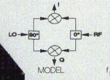
Infuse your cellular, spread spectrum, and communication system projects with the performance and reliability of Mini-Circuits I&Q modulators and demodulators. Surface mount and plug-in units feature excellent 3rd and 5th order harmonic suppression, low loss, and "skinny" 4.5 sigma repeatability unit-to-unit. With small quantity prices starting at only $19.95, these compact units truly are the next generation of value on the market today! Call Mini-Circuits for guaranteed 1 week shipment, or contact our applications department for custom designs at catalog prices.

Mini-Circuits...we're redefining what VALUE is all about!



I/Q MODULATORS

MODEL	FREQ. (MHz) f_L	f_U	CONV. LOSS (dB) $\bar{x}$	σ	CARRIER REJ. (-dBc) Typ.	SIDEBAND REJ. (-dBc) Typ.	HARM. SUPPRESS (-dBc) Typ. 3xI/Q	5xI/Q	PRICE $ Qty. (1-9)
MIQA-10M	9	11	5.8	0.20	41	40	58	68	49.95
MIQA-21M	20	23	6.2	0.14	50	40	48	65	39.95
MIQA-70M	66	73	6.2	0.10	38	38	48	58	39.95
MIQA-70ML	66	73	5.7	0.10	38	38	48	58	49.95
MIQA-91M	86	96	5.5	0.10	38	38	48	58	49.95
MIQA-100M	95	105	5.5	0.10	38	38	48	58	49.95
MIQA-108M	103	113	5.5	0.10	38	38	48	58	49.95
MIQA-195M	185	205	5.6	0.10	38	38	48	58	49.95
MIQC-38M	34	38	5.6	0.10	48	37	54	65	49.95
MIQC-88M	52	88	5.7	0.10	41	34	52	66	49.95
MIQC-176M	104	176	5.5	0.10	38	36	47	70	54.95
MIQC-895M	868	895	8.0	0.10	40	40	52	58	99.95
MIQC-1785M	1710	1785	9.0	0.30	35	35	40	65	99.95
MIQC-1880M	1805	1880	9.0	0.30	35	35	40	65	99.95
☐ MIQY-70M	67	73	5.8	0.20	40	36	47	60	19.95
☐ MIQY-140M	137	143	5.8	0.20	34	36	45	60	19.95
Surface Mount Models									
☐ JCIQ-88M	52	88	5.6	0.1	40	35	45	65	49.95
☐ JCIQ-176M	104	176	5.6	0.1	35	35	45	65	54.95



I/Q DEMODULATORS

MODEL	FREQ. (MHz) f_L	f_U	CONV. LOSS (dB) $\bar{x}$	σ	AMP. UNBAL. (dB) Typ.	PHASE UNBAL. (Deg.) Typ.	HARM. SUPPRESS (-dBc) Typ. 3xI/Q	5xI/Q	PRICE $ Qty. (1-9)
MIQA-10D	9	11	6.0	0.10	0.15	1.0	50	65	49.95
MIQA-21D	20	23	6.1	0.15	0.15	0.7	64	67	49.95
MIQA-70D	66	73	6.2	0.10	0.15	0.7	56	58	49.95
MIQC-38D	34	38	5.5	0.10	0.10	0.5	60	65	49.95
MIQC-60WD	20	60	5.3	0.10	0.15	1.0	55	67	79.95
MIQC-895D	868	895	8.0	0.20	0.15	1.5	40	55	99.95
☐ MIQY-1.25D	1.15	1.35	5.0	0.10	0.15	1.0	59	67	29.95
☐ MIQY-70D	67	73	5.5	0.25	0.10	0.5	52	66	19.95
☐ MIQY-140D	137	143	5.5	0.25	0.10	0.5	47	70	19.95
Surface Mount Models									
☐ JCIQ-176D	104	176	5.5	0.1	0.15	2	52	65	54.95
☐ JCIQ-895D	868	895	8.6	0.1	0.2	1	45	65	99.95
☐ JCIQ-1785D	1710	1785	8	0.2	0.2	2	50	65	99.95
☐ JCIQ-1880D	1805	1880	8	0.2	0.2	2	50	65	99.95

☐ NON-HERMETICALLY SEALED

MIQA case .4 x .8 x .4 in. MIQY case .8 x .8 x .4 in.
MIQC case .8 x .8 x .4 in. JCIQ case .9 x .8 x .25 in.

All Models Available in New J-LEAD Surface Mount Package. Consult Factory for Details.

J-LEAD

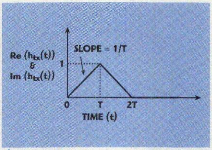
Mini-Circuits®

US 110 INT'L 111
CIRCLE READER SERVICE CARD

P.O Box 350166, Brooklyn, New York 11235-0003 (718) 934-4500 Fax (718)332-4661 *INTERNET* http://www.minicircuits.com

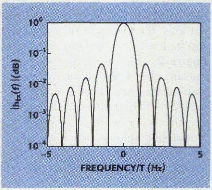
For detailed specs on all Mini-Circuits products refer to • 760- pg. HANDBOOK • INTERNET • THOMAS REGISTER • MICROWAVE PRODUCT DATA DIRECTORY • EEM

F 208 Rev A

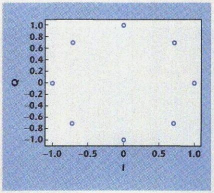


▲ *Fig. 2 The triangular filter's impulse response.*

Fig. 3 The triangular filter's frequency response. ▼



▼ *Fig. 4 An 8-PSK constellation diagram.*



PULSE SHAPING

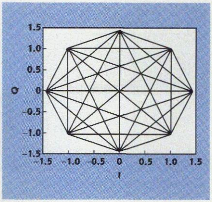
Considering the complex envelope of the signal $u_e(t)$ given by

$$u_e(t) = \sum_k \exp(j\phi_k)\delta(t - kT) \qquad (5)$$

the spectrum of this signal is represented as

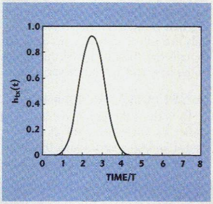
$$FT(u_e(t)) = U_e(f)$$
$$= \sum_k \exp(j(\phi_k + 2\pi fk)) \qquad (6)$$

Since ϕ_k has a random distribution, $U_e(f)$ also has a random distribution and can be regarded as having an infinite bandwidth. In practice, it is not tolerable to transmit such a signal since only a limited bandwidth is available. Therefore, the signal needs



▲ *Fig. 5 Trajectories for the triangular filter.*

Fig. 6 The GSM EDGE pulse-shaping filter's impulse response. ▼

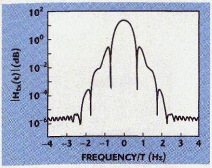


to be filtered in order to limit its spectrum. A useful filter is a triangular filter for which the time and frequency domain responses are shown in ***Figures 2*** and ***3***, respectively. (This filter can be derived easily.)

It is often mistakenly thought that 8-PSK signals' trajectories are linear transitions between one constellation point and the next. In fact, an 8-PSK signal as represented by its I and Q components has no trajectory as such because instantaneous phase changes occur between symbols at every T. ***Figure 4*** shows an 8-PSK constellation diagram. This filter produces linear monotonic trajectories, as shown in ***Figure 5***, from one symbol to the following symbol and it can be seen from its impulse response that the output depends on two consecutive symbols. (T is the period of a symbol.) The frequency response of the filter displays a reduced spectrum (–3 dB BW ≈ 0.32/T Hz).

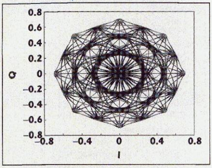
The proposed filter for GSM EDGE is a Gaussian-like filter for which the impulse and frequency response are shown in ***Figures 6*** and

[Continued on page 84]

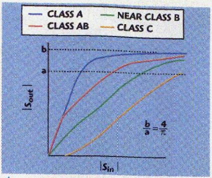


▲ *Fig. 7 The GSM EDGE pulse-shaping filter's frequency response.*

Fig. 8 The filtered GSM EDGE 8-PSK constellation. ▼



7, respectively. (The impulse response of the filter as it is defined in the European Telecommunications Standards

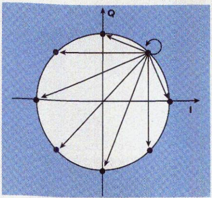


▲ *Fig. 9 Typical PA characteristics.*

Institute (ETSI) standards is discussed in ***Appendix A***.) It can be seen that the output of this filter is dependent on five consecutive symbols. The trajectory of the filtered I and Q signals is shown in ***Figure 8***. It is worth noting that the nonfiltered I and Q signals are of a constant amplitude although the filtered signal undergoes both phase and amplitude variations.

OFFSET PULSE-SHAPED 8-PSK

In both of the examples discussed earlier, the trajectory of the modulating data (I and Q) goes through the origin (I = Q = 0). In practice, power ampli-

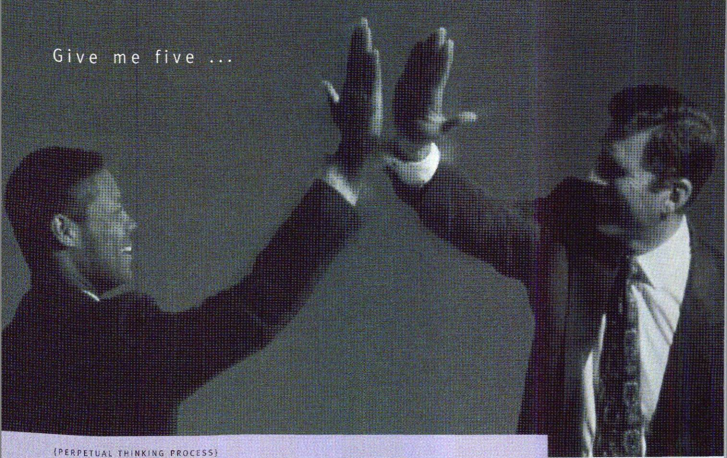


▲ *Fig. 10 All possible 8-PSK transitions.*

fiers exhibit a nonlinear characteristic not only for high power regions but also for low power regions, as shown in ***Figure 9***. This condition is especially true for class C amplifiers where the base-emitter junction threshold is required to start conducting before the amplifier kicks in. In other words, for modulation schemes such as 8-PSK, where the trajectory crosses the origin, nonlinearity at low power regions will distort the signal and, hence, produce spectral regrowth. ***Figure 10*** shows all

[Continued on page 87]


Looking for a diode supplier that's a bit more personal?



(PERPETUAL THINKING PROCESS)

INFINEON PRODUCTS

PMB2341 Single RF PLL
Frequency: Up to 2.5 GHz. Steps: Down to 5KHz.
Inband phase noise: -88 dBC/Hz @ 1KHz, fc=900MHz.
170 µs lock-in time; GPRS capability up to 5 slots;
2.7 to 4.5 V. BICMOS Technology; TSSOP 10 ($3x5\ mm^2$).

PMB2347 Dual RF/IF PLL
Frequency: RF 2.8 GHz. IF 500 MHz. Steps: Down to 5KHz.
Inband phase noise: -83 dBC/Hz @ 1KHz, fc=900MHz.
2.7 to 4.5 V; BICMOS Technology; TSSOP 20

PMB2335 Universal RF Mixer
(Succeeds Infineon's popular PMB2331)
Frequency: Up to 3GHz. 2.7 to 4.5 V.
Bipolar Technology B6HF; TSSOP 10 ($3x5\ mm^2$)

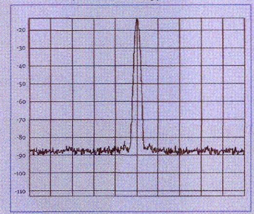
PMB2362 Dual LNA
Frequency: 900/1800MHz. 2.7 to 3.6 V.
Easy-to-handle 50 Ohm, extreme low NF.
Bipolar Technology B6HF; TSSOP 10 ($3x5\ mm^2$)

PMB2212 Direct Modulator with integrated Mixer and 40dB dynamic-range AGC
Frequency: 1.4 to 1.6GHz. 2.7 to 4.5 V.
Bipolar Technology B6HF; TSSOP 24
($6.5 \times 6.4\ mm^2$), 0.5 mm fine pitch.

Five for your success! Designed for a range of mobile applications, Infineon's new RF IC's offer dramatically improved performance in space-saving packages. These devices include single and dual PLL (Phase Lock Loop) frequency synthesizers, universal and dual-band RF-mixers/modulators/LNAs (Low Noise Amplifiers). All are fully compliant with standards like GSM (Global System for Mobile Communications), PCS (Personal Communication System), CDMA (Code Division Multiple Access), TDMA (Time Division Multiple Access) and PDC (Personal Digital Cellular).
Count on the company with experience. Count on Infineon, the world market leader in high frequency ICs. Mass quantities of Infineon's new RF ICs are available for Fall '99! Order today!

www.infineon.com/building-blocks

Measured Inband phase noise of PMB 2341:

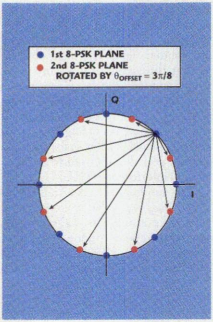


L(f_m)= -88 dBc/Hz @ 1KHz (fc=900 MHz)

Infineon technologies

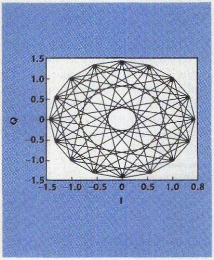
CIRCLE 66 ON READER SERVICE CARD

Never stop thinking



▲ *Fig. 11 Offset 8-PSK transitions.*

Fig. 12 The pulse-shaped (triangular) 3π/8 offset 8-PSK constellation. ▼

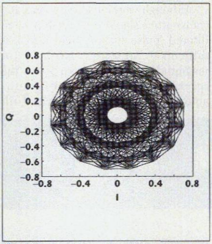


of the possible transitions from one symbol to the next.

It would be useful if the origin somehow could be avoided for the modulating data. One way of doing this is to offset the modulation scheme. In 8-PSK, the symbol at present time kT is $e(kT) = \exp(j\phi_k)$ and at time $(k + 1)T$ is $e((k + 1)T) = \exp(j\phi_{k+1})$, with $\phi_{k+1} \equiv \phi_k \bmod[\pi/4]$.

Continuously rotating the symbols by an offset $\theta_{offset} \equiv \pi/8 \bmod[\pi/4]$ prevents the signal from crossing through the origin. Hence, the transmitted signal becomes

$$u_{e\_offset}(t) = \sum_k \exp\left(j\left(\phi_k + k\theta_{offset}\right)\right)\delta\left(t - kT\right) \quad (7)$$



▲ *Fig. 13 The pulse-shaped (GSM EDGE) 3π/8 offset 8-PSK constellation.*

This condition is viewed as having two 8-PSK constellation planes offset by θ_{offset} and swapping from one plane to the other at every consecutive symbol time as shown in ***Figure 11***, where $\theta_{offset} = 3\pi/8$. This procedure can be illustrated using the triangular filter mentioned earlier and filtering the I and Q signals, where the benefit of rotating two 8-PSK planes leads to avoiding the center region of the constellation, as shown in ***Figure 12***. Applying the offset to the 8-PSK constellation and filtering it with the GSM EDGE pulse-shaping filter produces the output constellation shown in ***Figure 13***. Again, it can be seen that the trajectories no longer cross the origin.

One disadvantage of this procedure is that it may put strain on the detection for which the threshold margins are reduced. However, since there is a change in planes from one symbol to the next, the decision-making process in the receiver approximates that of an 8-PSK signal rather than, for example, a 16-PSK signal.

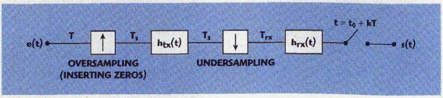
RECEIVER FILTER

In general, the baseband signal described previously is subsequently upconverted, transmitted via the transmission channel and demodulated in the receiver where a baseband signal is recovered. However, this example assumes that there is no up- or downconversion and that the transmission channel is ideal. In other words, to keep things simple, the analysis is performed at baseband according to the block diagram shown

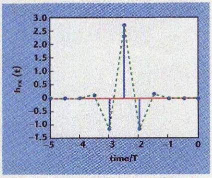
[Continued on page 88]

in **Figure 14**. (T = symbol period, T_s = sampling period (oversampling $\Rightarrow T_s \leq T$) and T_{rx} = sampling period going through the receiving filter. It is envisageable to have $T_s = T_{rx} = T_b$ (T_b = bit period) with appropriate zero padding.)

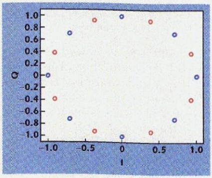
Although working at baseband, the transmitted signal, once it has been filtered (pulse-shaping filter $h_{tx}(t)$), is difficult to interpret. (Error vector magnitude can be used to assess the received signal.) Hence, it is desirable to convert the transmitted filtered signal back into a constellation as done initially, and then do the comparison. As can be seen in the transmitted signal, the main obstacle is that the signal at a given time t (and, more specifically, at the symbol sampling time kT) is dependent on several samples, or symbols (depending on the undersampling rate — recall the Gaussian filter spans over five symbol periods), referred to as intersymbol interference (ISI).



▲ *Fig. 14 The transmit/receive chain.*



▲ *Fig. 15 The zero-forcing GSM EDGE filter's impulse response.*



▲ *Fig. 16 The received constellation with no ISI.*

The aim here is to determine a receiver filter $h_{tx}(t)$ that will enable the received constellation diagram to be recovered. The derivation of the filter coefficients is explained in ***Appendix B***. The chosen filter here is an 11-tap finite impulse response filter exhibiting no ISI at the decision times (symbol period T). The response of the filter and the recovered constellation diagram are shown in ***Figures 15*** and ***16***, respectively.

CONCLUSION

This article has described an 8-PSK modulation scheme and some of its variations as well as its application to the GSM EDGE standard. It also explained a means of determining a complete baseband transmitter and receiver architecture. Additional information can be obtained from the author. ■

References

1. "Change Request A001, Rev. 1, Technical Specification GSM/UMTS: 05.04, Version 5.01 – SMG2 453/98," *ETSI*, November 1998.
2. John G. Proakis, *Digital Communications*, Third Edition, McGraw-Hill, New York, 1995.
3. B.P. Lathi, *Modern Digital and Analog Communication Systems*, Holt-Saunders International, New York, 1983.

Ashkan Mashhour *received his Diplôme d'Ingénieur from ENST Bretagne, France, and his MSc from University College London, UK, both in 1997. He then joined Nokia Telecommunications, Camberley, UK, where he currently works as an RF design engineer. He is involved in the development of new RF technologies and transceiver architectures for future-generation base stations. Mashhour can be reached at +44 (0) 1276 602 024 or Ashkan.Mashhour@ntc.nokia.com.*

[*Continued on page 90*]

APPENDIX A

GSM EDGE pulse shaping filter impulse response h_{tx}

$$h_{tx}(t) = \begin{cases} \prod_{i=0}^{3} S(t+iT) & \text{for } 0 \le t \le 5T \\ 0 & \text{elsewhere} \end{cases}$$

where

$$S(t) = \begin{cases} \sin\left(\pi \int_0^t g(x)dx\right) & \text{for } 0 \le t \le 4T \\ \sin\left(\frac{\pi}{2} - \pi \int_0^{t-4T} g(x)dx\right) & \text{for } 4T \le t \le 8T \\ 0 & \text{elsewhere} \end{cases}$$

$$g(t) = \frac{1}{2T}\left(Q\left(2\pi \bullet 0.3 \frac{t-\frac{5T}{2}}{T\sqrt{\log_e(2)}}\right) - Q\left(2\pi \bullet 0.3 \frac{t-\frac{3T}{2}}{T\sqrt{\log_e(2)}}\right)\right)$$

and

$$Q(t) = \frac{1}{\sqrt{2\pi}} \int_t^{+\infty} \exp\left(\frac{-x^2}{2}\right)dx = \frac{1}{2}\operatorname{erfc}\left(\frac{t}{\sqrt{2}}\right)$$

for GSM EDGE, $T \approx 3.69\ \mu s$

APPENDIX B

Derivation of the Receiver Filter h_{rx}

The input signal is the complex $3\pi/8$ offset 8-PSK signal $e(t)$

$$e(t) = \sum_k \exp\left(j\left(\phi_k + k\frac{3\pi}{8}\right)\right)\delta(t-kT) \qquad (A1)$$

This signal is then filtered by the Gaussian-like pulse shaping filter and filtered again by the receiver filter. The received signal $s(t)$ can be written as

$$\begin{aligned} s(t) &= e(t) \otimes h_{tx}(t) \otimes h_{rx}(t) \\ &= e(t) \otimes g(t) \quad \text{with} \quad g(t) = h_{tx}(t) \otimes h_{rx}(t) \end{aligned} \qquad (A2)$$

where $\otimes$ stands for convolution

To recover the transmitted signal (constellation), it is desirable to make $S(kT) = e(kT)$

$$\begin{aligned} s(kT) &= e(kT) \\ s(kT_s) &= \sum_n e(nT_s) g(kT_s - nT_s) \end{aligned}$$

at $t = kT$:

$$\begin{aligned} s(kT) &= \sum_n e(nT_s) g(kT - nT_s) \\ &= e(kT)g(kT-kT) + \sum_{nT_s \ne kT} e(nT_s) g(kT - nT_s) \\ &= e(kT)g(0) + \sum_{n \ne k} e(nT) g(kT - nT) \\ & \qquad \text{because } e(nT_s) = 0 \text{ for } nT_s \ne lT \\ &= e(kT)g(0) + \sum_{n,m \ne 0} e(nT) g(mT) \ \forall e(t) \end{aligned} \qquad (A3)$$

Hence, the condition to be satisfied to guarantee no ISI is

$$\forall k \in Z^{\circ} \begin{cases} g(0) = 1 \\ g(kT) = 0 \end{cases} \qquad (A4)$$

Note that it is not necessary to define the behavior of g at all $t = nT_s$

$$\underline{g(0)=1} \Leftrightarrow g(0) = \sum_n h_{tx}(nT_s) h_{rx}(0 - nT_s)$$

$$\Leftrightarrow \sum_n h_{tx}(nT_s) h_{rx}(-nT_s) = 1 \qquad \Rightarrow \text{if } h_{tx} \text{ is causal then } h_{rx} \text{ is not causal}$$

$$\underline{g(kT)=1} \Leftrightarrow \sum_n h_{tx}(nT_s) h_{rx}(kT - nT_s) = 0 \qquad \text{for } k \ne 0$$

This system of linear equations leads to a matrix equation. If the receiver filter is defined every T/m step, $h_{rx}(t)$'s impulse response will be defined by a set of 2n + 1 coefficients $b_{-2n}, b_{-2n+1}, \ldots, b_0$ and $k \in [-n \rightarrow +n]$. In other words, the value of g is specified at 2n + 1 points. This requires 2n + 1 samples of the transmitter pulse shaping filter $h_{tx}(t)$ $(a_0, a_1, \ldots, a_2)$ to be taken. Note that the receiver filter $h_{rx}(t)$ is noncausal here, hence the choice of negative indices. This type of filter is sometimes referred to as a zero-forcing filter. The set of equations can be written as

[Continued on page 92]

APPENDIX B (continued)

$$
\begin{array}{r}
k=-n \\ k=-n+1 \\ \\ \\ k=0 \\ \\ j \\ \\ \\ k=+n
\end{array}
\underbrace{\begin{bmatrix}
a_0 & 0 & \cdots & & & & & & & 0 \\
a_{-m} & a_{-m+1} & \cdots & a_0 & 0 & \cdots & & & & 0 \\
a_{-2m} & a_{-2m+1} & \cdots & a_{-m} & a_{-m+1} & \cdots & a_0 & 0 & \cdots & 0 \\
\vdots & & & & & & & & & \\
a_{-2n} & a_{-2n+1} & & & & \cdots & & & & a_0 \\
\vdots & & & & & & & & & \\
0 & \cdots & 0 & a_{-2n} & a_{-2n+1} & & \cdots & & & a_{-2n+jm} \\
\vdots & & & & & & & & & \\
0 & \cdots & & & & & 0 & a_{-2n} & \cdots & a_{-2n+m} \\
 & & & & & & & & & a_0
\end{bmatrix}}_{A}
\bullet
\underbrace{\begin{bmatrix} b_{-2n} \\ b_{-2n+1} \\ \\ \\ \vdots \\ \\ \\ b_0 \end{bmatrix}}_{h_{rx}}
=
\underbrace{\begin{bmatrix} 0 \\ \vdots \\ 0 \\ 1 \\ 0 \\ \vdots \\ \\ 0 \end{bmatrix}}_{x}
$$

or

$$A \bullet h_{rx} = x \qquad \text{(A5)}$$

The receiver filter h_{rx} coefficients are determined by multiplying Equation A5 by the inverse matrix A^{-1}, expressed as

$$h_{rx} = A^{-1} \bullet x \qquad \text{(A6)}$$

This result is applied to the GSM EDGE pulse shaping filter. If the receiver filter is defined every T/2 step, $h_{rx}(t)$ will be defined by a set of 11 coefficients ($b_{-10}, b_{-9} \ldots, b_0$) (the receiver filter $h_{rx}(t)$ is noncausal here). Taking 11 samples spaced T/2 from the pulse shaping filter $h_{tx}(t)$ ($a_0, a_1, \ldots, a_{10}$) leads to

$$
\begin{bmatrix}
a_0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{-2} & a_{-1} & a_1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{-4} & a_{-3} & a_{-2} & a_{-1} & a_0 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{-6} & a_{-5} & a_{-4} & a_{-3} & a_{-2} & a_{-1} & a_0 & 0 & 0 & 0 & 0 \\
a_{-8} & a_{-7} & a_{-6} & a_{-5} & a_{-4} & a_{-3} & a_{-2} & a_{-1} & a_0 & 0 & 0 \\
a_{-10} & a_{-9} & a_{-8} & a_{-7} & a_{-6} & a_{-5} & a_{-4} & a_{-3} & a_{-2} & a_{-1} & a_0 \\
0 & 0 & a_{-10} & a_{-9} & a_{-8} & a_{-7} & a_{-6} & a_{-5} & a_{-4} & a_{-3} & a_{-2} \\
0 & 0 & 0 & 0 & a_{-10} & a_{-9} & a_{-8} & a_{-7} & a_{-6} & a_{-5} & a_{-4} \\
0 & 0 & 0 & 0 & 0 & 0 & a_{-10} & a_{-9} & a_{-8} & a_{-7} & a_{-6} \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & a_{-10} & a_{-9} & a_{-8} \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & a_0
\end{bmatrix}
\bullet
\begin{bmatrix} b_{-10} \\ b_{-9} \\ b_{-8} \\ b_{-7} \\ b_{-6} \\ b_{-5} \\ b_{-4} \\ b_{-3} \\ b_{-2} \\ b_{-1} \\ b_0 \end{bmatrix}
=
\begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}
\qquad \text{(A7)}
$$

The filter determined in this manner has the impulse response shown previously. In this case, $a_0 = a_{-10} = 0$, hence, matrix A^{-1} is not defined. The inverse of a submatrix B of A where $B = A_{ij}$ with $(i,j) \in [1 \rightarrow 9]$ (that is, B is A with the first and last columns and rows removed) is required. Therefore, b_0, b_{-10} can be set to 0. The matrix A in Equation A7 becomes

$$
A \approx
\begin{bmatrix}
-0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 \\
0.031 & 0.001 & -0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 \\
0.706 & 0.260 & 0.031 & 0.001 & -0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 \\
0.706 & 0.927 & 0.706 & 0.260 & 0.0031 & 0.001 & -0.000 & 0.000 & 0.000 & 0.000 & 0.000 \\
0.032 & 0.261 & 0.706 & 0.927 & 0.706 & 0.260 & 0.031 & 0.001 & -0.000 & 0.000 & 0.000 \\
0.000 & 0.001 & 0.032 & 0.261 & 0.706 & 0.927 & 0.706 & 0.260 & 0.031 & 0.001 & -0.000 \\
0.000 & 0.000 & 0.000 & 0.001 & 0.032 & 0.261 & 0.706 & 0.927 & 0.706 & 0.260 & 0.031 \\
0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.001 & 0.032 & 0.261 & 0.706 & 0.927 & 0.706 \\
0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.001 & 0.032 & 0.261 & 0.706 \\
0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.001 & 0.032 \\
0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000
\end{bmatrix}
$$

$$
B^{-1} \approx
\begin{bmatrix}
1392 & 0 & 0 & -0 & 0 & -0 & 0 & -0 & 0 \\
-12288 & 34 & -0 & 0 & -0 & 0 & -0 & 0 & -34 \\
33598 & -111 & 5 & -0 & 0 & -0 & 0 & -6 & 1507 \\
-44240 & 154 & -10 & 3 & -1 & 1 & -3 & 46 & -12473 \\
33716 & -119 & 8 & -3 & 3 & -3 & 8 & -124 & 33796 \\
-12448 & 44 & -3 & 1 & -1 & 3 & -10 & 160 & -44348 \\
1507 & -5 & 0 & -0 & 0 & -0 & 5 & -116 & 33682 \\
-36 & 0 & -0 & 0 & -0 & 0 & -0 & 36 & -12319 \\
0 & -0 & 0 & -0 & 0 & -0 & 0 & -0 & 1395
\end{bmatrix}
$$

$$
h_{rx} = b =
\begin{bmatrix} 0 \\ 0 \\ -0.0032 \\ 0.1382 \\ -1.1359 \\ 2.7318 \\ -1.1366 \\ 0.1387 \\ -0.0033 \\ 0 \\ 0 \end{bmatrix}
\qquad
h_{tx} = a =
\begin{bmatrix} -0 \\ 0.0007 \\ 0.0315 \\ 0.2604 \\ 0.7057 \\ 0.9268 \\ 0.7057 \\ 0.2605 \\ 0.0315 \\ 0.0008 \\ 0 \end{bmatrix}
$$

The recovered signal exactly matches the transmitted $3\pi/8$ offset 8-PSK constellation since the channel is ideal.

VECTOR SIGNAL MEASUREMENT FOR 38 GHz DIGITAL RADIO APPLICATIONS

Broadband access using millimeter-wave digital radio technology has generated significant interest during the past several years. This technology is especially attractive for the implementation of a low cost, rapidly deployable last-mile interconnection solution between fiber-optic networks and service hubs. From a signal distribution point of view, two basic classes of radio systems exist: point-to-point and point-to-multipoint.

A point-to-point radio system is a dedicated link to provide short-haul voice and data communication between two business network centers. The licensed frequency spectrum allotted for short-haul radio links is 15, 18, 23, 26, 38 or 50 GHz. Data capacities range from a single DS-1 (1.544 Mbps) to DS-3 (44.736 Mbps).

A point-to-multipoint radio system provides voice and data communication services between multiple subscribers with a shared hub. The Federal Communications Commission has licensed the 27.5 to 28.35, 29.1 to 29.25 and 31 to 31.5 GHz bands for local multipoint distribution system (LMDS) service. Because of the availability of the wide bandwidth (850 MHz), very large downstream data capacity can be achieved.

With few exceptions, most millimeter-wave radio systems currently under development are based on digital communication implementation. Depending on the applications, various modulation schemes are being implemented from quadrature phase-shift keying (QPSK) to 64 quadrature amplitude modulation (QAM). Data rates range from T1 (1.544 Mbps) to DS-3 (44.736 Mbps), and a higher rate to 155 Mbps (OC-3).

Modern RF wireless communication systems use advanced vector signal measurement techniques to accurately measure the dynamic behavior of the RF subsystems and the integrated digital/RF systems. In the past, these types of tests were not performed at bandwidths above 7 MHz and millimeter-wave frequencies due to a lack of suitable test capabilities. This limitation has greatly curtailed the ability for transceiver manufacturers to speedily develop low cost, high performance transceiver products for digital radio applications. However, recent advances in wide-bandwidth vector signal analyzer (VSA) test equipment

[Continued on page 96]

G. SAMUEL DOW, JEFF YANG AND KUO-HSIUNG YEN,
TRW, Electronics Technology Division
Redondo Beach, CA
ROBERT MATRECI, ERIC SPOTTED-ELK, STEPHEN PETTIS AND LONG TRINH
Hewlett-Packard Co.,
Santa Rosa Systems Division
Santa Rosa, CA

- **Low Cost Machined Housing**
- **Low Intermod Construction**
- **High Volume Production Capability**
- **High Power Handling**
- **Symmetric and Asymmetric Pseudo Elliptic Designs**

For over 30 years, Lorch Microwave has supplied quality microwave components and sub systems to a diverse and ever changing electronics and communications industry. With new facilities and state-of-the-art equipment, dedicated personnel, and the introduction of new products, Lorch Microwave continues to keep pace with developing markets worldwide.

LORCH MICROWAVE

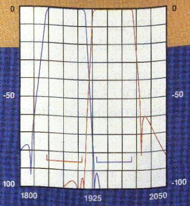
Helping your ideas take wing™

1725 N. Salisbury Blvd.
PO Box 2828
Salisbury MD 21802 USA
Phone 410-860-5100
Fax 410-860-1949
Web http://www.lorch.com
E-mail lorchsales@lorch.com

CIRCLE 80 ON READER SERVICE CARD

REAL WORLD solutions for Wireless Applications

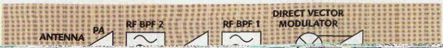
Lorch Microwave is now producing a full line of filters and diplexers specifically optimized for wireless applications. In addition to offering a wide range of standard designs covering the entire cellular and PCS spectrum, our engineers can assist you with developing custom filtering solutions. Contact sales so we may offer a solution to your wireless requirements today.



Example Performance:

WD-00007 FULL BAND PCS DIPLEXER

RX Passband Frequency: 1850-1910 MHz
TX Passband Frequency: 1930-1990 MHz



tones are no longer adequate to describe the performance and behavior of RF components and subsystems

dual-frequency conversion approach, as shown in ***Figures 1*** and ***2***, respectively. Direct frequency conversion has a simpler architecture; however, it requires a very linear millimeter-wave direct IQ modulator, which is a design challenge. On the other hand,

modulation accuracy are the modulator and output PA. For multilevel signaling, a linear quadrature modulator is required. Important properties of a linear quadrature modulator include good dynamic range with linear transfer characteristics, low I/Q gain imbalance and quadrature error, and low DC offset. It is often necessary to align the modulator by adjusting these input I and Q parameters, including possible correction for I/Q imbalance vs. baseband frequency.

Nonlinearity of a PA also degrades the transmitter's modulation accuracy by introducing AM/AM and AM/PM distortions. Traditionally, linearity of the PA is achieved by a backed-off mode of amplifier operation. Output power back off can range from 4 to 10 dB depending on the linearity requirements. Thus, for a 1 W linear transmitter, the PA requires 2.5 to 10 W output power capability. This capability significantly increases the radio equipment cost. In fact, developing a high output PA at an acceptable cost remains a major challenge to RF component suppliers.

Other impairments that could degrade the transmitter's modulation accuracy include interfering signals, close in spurs, LO feedthru and phase noise of frequency sources. The industry-wide standard to determine the modulation accuracy is EVM,[4] which measures the phasor difference between an ideal reference signal and the measured modulated signal. This parameter is an aggregated measure of the signal imperfections due to I/Q imbalance, PA nonlinearity, oscillator phase noise and filter imperfection in a single specification. The EVM specification allows circuit designers the flexibility to trade off different design approaches and permits system designers to know explicitly the hardware's capability.

A MILLIMETER-WAVE VECTOR SIGNAL MEASUREMENT SYSTEM

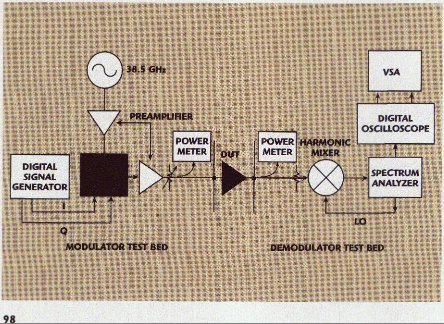
A millimeter-wave vector signal measurement system was configured to operate at higher Ka-band frequencies. It consists of a millimeter-wave modulator and a demodulator test bed. A functional block diagram of the complete vector signal measurement system is shown in ***Figure 3***. The demodulator test bed is essentially an HP 71000T wideband VSA system, which extends the measurement bandwidth of the HP 89410 VSA from 7 MHz to over 200 MHz.[1] The system has a maximum coax-input frequency of 26.5 GHz and can be extended to 110 GHz with external harmonic mixers. The LO for the harmonic mixer is provided by the output of the HP 70910A spectrum analyzer's internal LO source module.

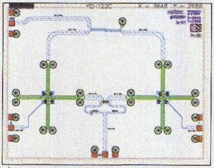
The modulator test bed includes an HP E4433B digital modulation signal source to generate a digital I/Q data stream and an HP 83650B frequency synthesizer to generate the LO for the modulator. The digital data stream was generated, intersymbol interference (ISI) filtered and passed through a digital-to-analog converter (DAC) to form a band-limited analog waveform for driving the millimeter-wave quadrature modulator.

The modulator used in this case is TRW's model YQH122C monolithic quadrature modulator. ***Figure 4*** shows a layout of the YQH122C MMIC. This monolithic high electron mobility transistor (HEMT) MMIC consists of two binary phase-shift keying (BPSK) modulators, a phase shifter and a power splitter connected to perform a vector modulator function. Each BPSK modulator is based on a double-balanced ring mixer structure,[5] which features good amplitude and phase balance. The quadrature modulator circuit performance was evaluated with a single-sideband frequency upconversion test. At 38.5 GHz, the measured conversion loss for the desired sideband is 9 dB with 20 MHz IF. The measured image rejection and carrier suppression are > 25 and > 30 dB, respectively. The overall system's data rate is limited by the digital signal generator to 12.5 Msps. Higher bandwidth signals are achieved using a VXI-based signal generator (based on a special option of the HP E6432A microwave synthesizer).

The first test is to measure the signal quality of the overall measurement system with the YQH122C modulator in place by connecting the output of the modulator test set to the input of the demodulator test set. Four different modulation formats were chosen: QPSK, offset QPSK (OQPSK), $\pi/4$ differential QPSK and 16QAM. The frequency synthesizer was set to 38.5 GHz. The I/Q digital data rate was set to 12.5 Msps along with a square-root raised cosine lowpass filter with α (excess bandwidth ratio) set to 0.5.

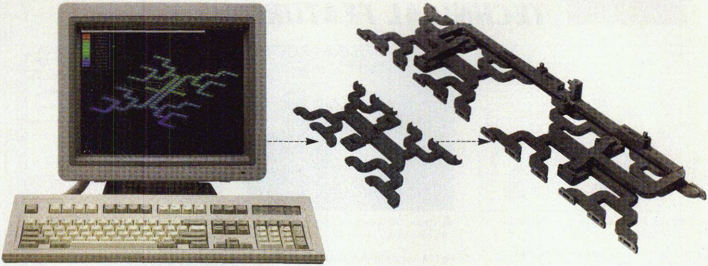
▼ *Fig. 3 The mm-wave VSA test bed block diagram.*

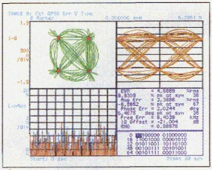




▲ *Fig. 4 The YQHI22C MMIC's layout.*

[Continued on page 102]





▲ *Fig. 5 Modulator output with QPSK modulation.*

Fig. 6 Modulator output with OQPSK modulation. ▼

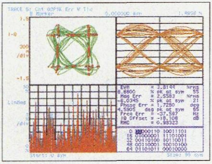


Fig. 7 Modulator output with π/4 differential QPSK modulation. ▼

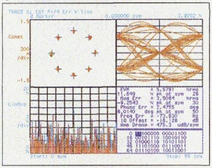
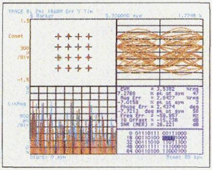


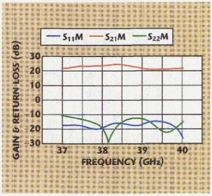
Fig. 8 Modulator output with 16QAM modulation. ▼



Figures 5, 6, 7 and ***8*** show four VSA output displays under four different modulation conditions. Each VSA display contains a vector or constellation diagram, eye diagram, error vector time display, error summary and symbol table. In all four cases, the symbols in the constellation diagrams have shown a small amount of spread. All eye diagrams show good eye openings. The average EVM ranges from three to 5.5 percent for these four cases. These levels of modulated signal accuracy should be adequate for most system applications. The measured EVMs also include contribution from the demodulator test set since no independent calibration is performed on the demodulator test bed.

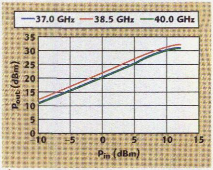
▲ *Fig. 9 The power amplifier module with bottom-side waveguide interfaces.*

Fig. 10 The PA module's small-signal performance vs. frequency. ▼



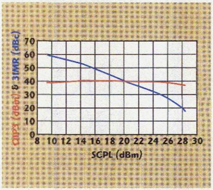
A 38 GHz 1 W PA MODULE

A vector signal measurement system was used to characterize TRW's HPA117 PA module, which operates from 37 to 40 GHz with a P1dB > 30.5 dBm across the full band. ***Figure 9*** shows a photograph of the PA module. Internal to the PA module are three APH309C MMICs. One PA module is used as a driver, and the output stage consists of two PA modules combined through Wilkenson couplers. The APH309C MMIC is a two-stage balanced amplifier design based on TRW's 0.15 μm InGaAs pseudomorphic HEMT (pHEMT) device technology. It delivers > 12 dB linear gain and has an output P1dB > 29 dBm. The PA module has built-in DC and control functions and requires only +6 V and –5 V supplies.



▲ *Fig. 11 The PA module's CW output power with V_d = +5.5 V.*

Fig. 12 The PA module's two-tone OIP3 and 3IMR performance at 38.5 GHz. ▼



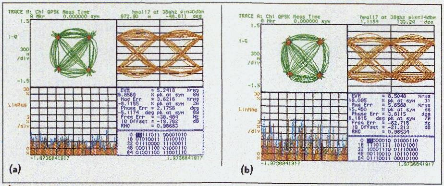
The input and output RF ports are standard WR-28 waveguide interfaces located on the bottom side of the housing. The module is designed for 37 to 40 GHz point-to-multipoint base station applications.

The small-signal performance of the HPA117 module is shown in ***Figure 10***. The unit has 21 to 23 dB linear gain across the 37 to 40 GHz band. The measured CW output power performance is shown in ***Figure 11***. P1dB at 37, 38.5 and 40 GHz is 30.7, 31.4 and 30.5 dBm, respectively. Power-added efficiency is approximately 11 percent. The measured two-tone output third-order intercept point (OIP3) and third-order intermodulation rejection (3IMR) performances are shown in ***Figure 12***. The measured OIP3 is approximately 40 dBm. A single carrier output power level (SCPL) of 26 dBm was achieved with a 3IMR level of 28 dBc.

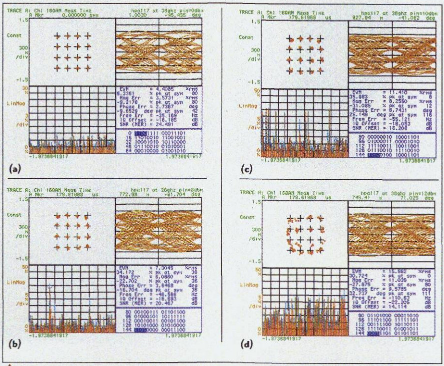
VECTOR SIGNAL MEASUREMENTS OF THE PA MODULE

An HPA117 PA module was then inserted into the vector signal measurement system. The first test used a

[Continued on page 104]



▲ *Fig. 13 The PA module driven with QPSK modulation at P_{in} of (a) 0 and (b) +14 dBm.*



▲ *Fig. 14 The PA module driven with 16QAM modulation at P_{in}/P_{out} levels of (a) 0/22.2, (b) 8/29.8, (c) 10/31.4 and (d) 12/32.4 dBm.*

TABLE I

PA MODULE LINEARITY PERFORMANCE

Input Power (dBm)	Single-tone CW Output Power (dBm)	Single-tone CW Gain Compression (dB)	Two-tone OIP3 (dBm)	Two-tone SCPL/3IMR (dBm/dBc)	16QAM EVM (% rms)
0	22.2	0	40.5	19/43	4.4
8	29.8	0.4	39.4	26.4/26	7.3
10	31.4	0.8	38.3	27.8/21	11.4
12	32.4	1.8	37.4	28.4/18	15.6

QPSK digital modulation waveform. The RF carrier was set to 38.5 GHz and the I/Q digital data rate was set to 12.5 Msps with α = 0.5. ***Figure 13*** shows the two VSA output displays corresponding to two input power levels of 0 and +14 dBm. A vector diagram displays the instantaneous output power behavior of the PA module. From these two vector diagrams, power compression is clearly evident at a P_{in} = +14 dBm drive level with the vector traces compressed around the corners along with symbol spreading occurring at the constellation points. The EVM also increased from 5.2 percent rms to 8.5 percent rms. This amplitude compression causes the frequency spectrum to spread into adjacent channels, which could create an adjacent-channel interference problem.

The PA module was further tested with a 16QAM digital modulation input. As before, the data rate was set to 12.5 Msps with α = 0.5. ***Figure 14*** shows the VSA displays at four different input power levels (0, +8, +10 and +12 dBm) and their corresponding CW output power levels. As the input power level increases, the symbol constellation becomes increasingly rounded with the symbol clusters increasingly spread out at their symbol locations. In addition, the eye diagrams start to show richer accumulation of noise at the decision line due to ISI. The closure of the eye opening makes signal detection at the receiver more difficult, thus resulting in higher system BER. The measured average EVM increased from 4.4 percent rms at P_{in} = 0 dBm to 15.65 percent rms at P_{in} = +12 dBm. It is worthwhile to note that the PA module maintains fairly good modulation quality at an output power of approximately 1 W. It is also interesting to compare the EVM results from QPSK and 16QAM modulation. As expected, the QPSK modulation clearly has a better modulation quality performance, leading to a higher output power capability.

Table 1 lists the PA module linearity performance measured using three different methods: a single-tone CW, two-tone intermodulation and a 16QAM vector signal. As the input power increases from 0 to +12 dBm, the single-tone CW measurement shows a 1.8 dB gain reduction, the two-tone OIP3 decreases by 2.9 dB and the 16QAM EVM increases from 4.4 percent rms to 15.6 percent rms. All three methods characterize PA linearity performance; however, only the vector signal method provides insight into the PA nonlinear behavior under digital modulation. It should also be noted that since the modulator test bed has not gone through an alignment or calibration prior to device test, the measurement was actually for a complete direct modulation

[Continued on page 106]


Sometimes it's hard just getting to work...
NEW MODEL!
MITEQ makes it easier to get the tools there!
Mobile Satellite Test Set
The Mobile Satellite Test Set provides a test translator and block downconverter in a single transportable package. This unit offers transmit to receive, receive to L-, or transmit to L-band frequency translations. Both translations are designed for a minimum of amplitude and delay distortion.
Model TLT/DNB-14-1
TLT Input . . . . 14.0 – 14.5 GHz
TLT Output . . . . 11.7 – 12.5 GHz
DNB Input . . . . 11.7 – 12.5 GHz
DNB Output . . . . . . 0.95 – 1.75 GHz
Model TLT/DNB-14-2
TLT Input . . . . 14.0 – 14.5 GHz
TLT Output . . . . 12.25 – 12.75 GHz
DNB Input . . . . 12.2 – 12.75 GHz
DNB Output . . . . . . 0.95 – 1.50 GHz
Model TLT/DNB-6-1
TLT Input . . . . 5.845 – 6.425 GHz
TLT Output . . . . 3.62 – 4.2 GHz
DNB Input . . . . 3.4 – 4.2 GHz
DNB Output . . . . . . 0.95 – 1.75 GHz
For additional information or technical assistance, please contact Chris Alfenito at (516) 439-9108 or e-mail calfenito@miteq.com
MITEQ
100 Davids Drive
Hauppauge, NY 11788
TEL.: (516) 436-7400 • FAX: (516) 436-7431/436-7430
www.miteq.com
AS OF NOVEMBER 1999, OUR NEW AREA CODE WILL BE 631
CIRCLE 127 ON READER SERVICE CARD

transmitter, which consists of a quadrature modulator, frequency source and PA module.

CONCLUSION

A 38 GHz vector signal measurement system has been demonstrated. Key to the system are a TRW Ka-band monolithic quadrature modulator and an HP 71000T wideband signal analyzer. The system is flexible in providing various digital modulation formats. The modulation quality of the test system is measured by EVM and is less than six percent rms. The system was used to characterize a 37 to 40 GHz 1 W PA module with QPSK and 16QAM digital modulation. The PA module linearity performance was measured and compared using three different methods: single-tone CW, two-tone intermodulation and vector signal measurement. The vector signal measurement test method allows sophisticated digital/RF parametric tests to measure the dynamic behavior of the RF system under digital test stimuli. The new test method provides the possibility for more meaningful product specification, trade-offs between digital and RF functions, and the development of a streamlined test methodology for future millimeter-wave digital radio RF product development. ■

References

1. "HP 71000T E72 Wideband Vector Signal Analyzer Installation and Operating Guide," Hewlett-Packard, February 1999. Also see "HP E3830 Series Wide Bandwidth Vector Signal Analysis Systems," (http://www.tmo.hp.com/tmo/datasheets/English/HPE3830.html).
2. "Using Vector Modulation Analysis in the Integration, Troubleshooting and Design of Digital RF Communications Systems," Hewlett-Packard Product Note 89400-8 (http://www.tmo.hp.com/tmo/Notes/English/5091-8687E.html).
3. "10 Steps to a Perfect Digital Demodulation Measurement," Hewlett-Packard Product Note 89400-14A (http://www.tmo.hp.com/tmo/Notes/English/5966-0444E.html).
4. "Using Error Vector Magnitude Measurements to Analyze and Troubleshoot Vector Modulated Signals," Hewlett-Packard Product Note 89400-14.
5. "A Monolithic Broadband Double Balanced EHF HBT Star Mixer with Novel Microstrip Baluns," *1995 IEEE MTT-S Digest*, pp. 119–122.

High Efficiency Power Amplifier Design Using GaAs HFETs

The computer-aided design and performance of high efficiency amplifiers operating in class AB/F at X-band are presented. The amplifiers employ state-of-the-art power heterostructure FET (HFET) devices. The design emphasis is on maximizing the output power and power-added efficiency. Two single-ended power amplifiers are designed using the developed and scaled small- and large-signal models of a 2.4 mm unit cell HFET to represent 4.8 and 9.6 mm gate width HFET devices. The amplifier employing a 4.8 mm HFET achieved a power-added efficiency of 53 percent at an output power of 2.5 W with 8 dB small-signal gain. The amplifier employing a 9.6 mm HFET achieved a power-added efficiency of 42 percent at an output power of 8 W with 7 dB small-signal gain. The design technique employed provides good agreement between measured and predicted results.

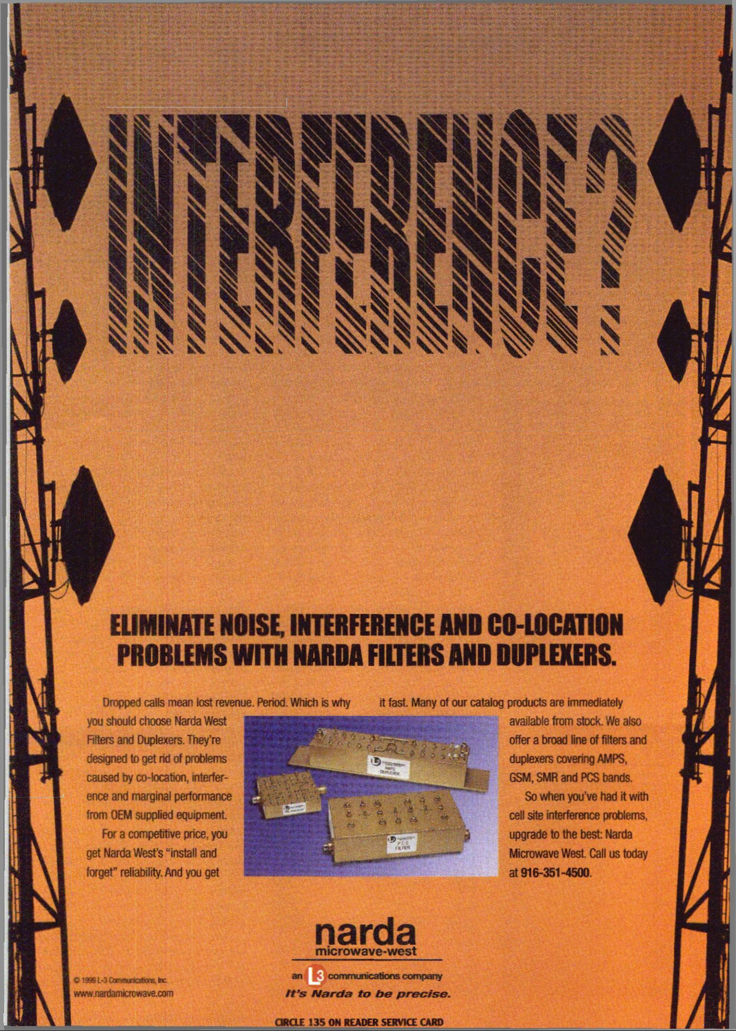
Solid-state power amplifiers (SSPA) are one of the key components of wireless communication systems. This critical component governs much of the systems' size, cost, performance and manufacturability. Differentiating factors such as frequency, bandwidth, supply voltage, output power, efficiency and mode of operation drive the requirements for SSPAs for both commercial and military systems.

Until recently, GaAs power MESFETs have been the prime devices employed in SSPAs at RF and microwave frequencies for a variety of wireless communication systems for both commercial and military applications. The main deficiency of these devices is their inability to achieve high power-added efficiency. Depending upon the application and frequency range, the output power requirement of communication systems varies from a few watts to a few hundred watts. For example, for phased-array-type applications power levels of up to 10 W may be sufficient, while for satellite uplink terminals several tens of watts are required. RF communication-type applications require narrow bandwidths while application areas such as electronic warfare and optical line drivers have ultra-wide bandwidth requirements.

For airborne, spaceborne and personal communications applications (that is, PCS and GSM), the DC-to-RF conversion efficiency of such SSPAs must be maximized. In particular, the SSPAs have a number of advantages over

[Continued on page 110]

A.S. Virdee
Filtronic Components Ltd.
Milton Keynes, UK
B.S. Virdee
University of North London,
School of Communications Technology and Mathematical Sciences
London, UK

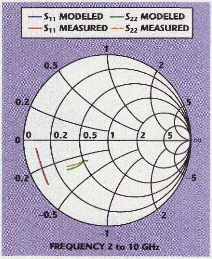

INTERFERENCE?
ELIMINATE NOISE, INTERFERENCE AND CO-LOCATION PROBLEMS WITH NARDA FILTERS AND DUPLEXERS.
Dropped calls mean lost revenue. Period. Which is why you should choose Narda West Filters and Duplexers. They're designed to get rid of problems caused by co-location, interference and marginal performance from OEM supplied equipment.
For a competitive price, you get Narda West's "install and forget" reliability. And you get it fast. Many of our catalog products are immediately available from stock. We also offer a broad line of filters and duplexers covering AMPS, GSM, SMR and PCS bands.
So when you've had it with cell site interference problems, upgrade to the best: Narda Microwave West. Call us today at 916-351-4500.
narda
microwave-west
an L3 communications company
It's Narda to be precise.
© 1999 L-3 Communications, Inc.
www.nardamicrowave.com
CIRCLE 135 ON READER SERVICE CARD

traveling-wave tube amplifiers (TWTA) employed in communication satellite applications. SSPAs are more robust and reliable, require only simple voltage supplies and are of lower mass and size. However, to date, SSPAs have seen little use in spacecraft payloads at frequencies above UHF. The main reason for this lack of use has been attributed to poor efficiency. Typical SSPA efficiencies are in the range of 20 to 30 percent, whereas TWTA efficiencies are approximately double this level. Such low SSPA efficiencies present power drain and thermal control problems onboard a spacecraft, which, in the eyes of payload system designers, outweigh the advantages of employing solid-state technology.

The SSPA RF integrated circuits (RFIC) also must achieve maximum output power and efficiency, which have a direct correlation to how much talk time in a personal-communication-type application is obtained per battery charge. These RFIC amplifiers are employed in the lower microwave frequency range in areas such as cellular phones and base stations operating in the 900 MHz and 1.8 GHz bands. Satellite communication services and wireless local area networks at L-band are also major users of RFICs. Therefore, any improvement in SSPA efficiency — even if only moderate — makes use of the amplifier much more attractive.

Recent developments in material growth techniques (such as molecular beam epitaxy and molecular chemical vapor deposition) and realization of novel device structures are beginning to change device capabilities in terms of higher output power and efficiency. These new state-of-the-art power GaAs HFET devices have structures that are based on heterojunctions comprising AlGaAs/GaAs, InGaP/GaAs and InAlAs/InGaAs. These devices offer high gate-drain and gate-source breakdown voltages, near-constant transconductance with gate bias down to pinch-off voltage and moderately high maximum channel current that enables high efficiency to be obtained.

In this article, high efficiency microwave IC power amplifiers operating in class AB/F[1] and employing 4.8 and 9.6 mm HFET power devices are designed at X-band using computer-aided design methods. The characterization of large gate width power devices is complex and the traditional technique for obtaining the devices' input and output impedances is the load pull power contour method.[2] However, the technique employed here for characterizing large gate width HFET power devices is to scale the developed small- and large-signal models of the 2.4 mm unit cell HFET. It is shown that this technique yields good agreement between measured and predicted results.



▲ *Fig. 1 De-embedded and measured S_{11} and S_{22} of the 2.4 mm unit cell HFET biased at $V_{ds} = 8$ V and $I_{ds} = 0.51_{dss}$.*

Fig. 2 The 4.8 mm HFET S_{11} and S_{22} modeled by scaling the 2.4 mm unit cell HFET biased at $V_{ds} = 8$ V and $I_{ds} = 0.5I_{dss}$. ▼

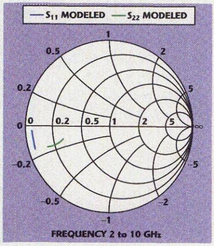
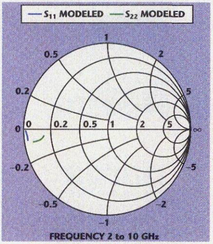


Fig. 3 The 9.6 mm HFET S_{11} and S_{22} modeled by scaling the 2.4 mm unit cell HFET biased at $V_{ds} = 8$ V and $I_{ds} = 0.5I_{dss}$. ▼



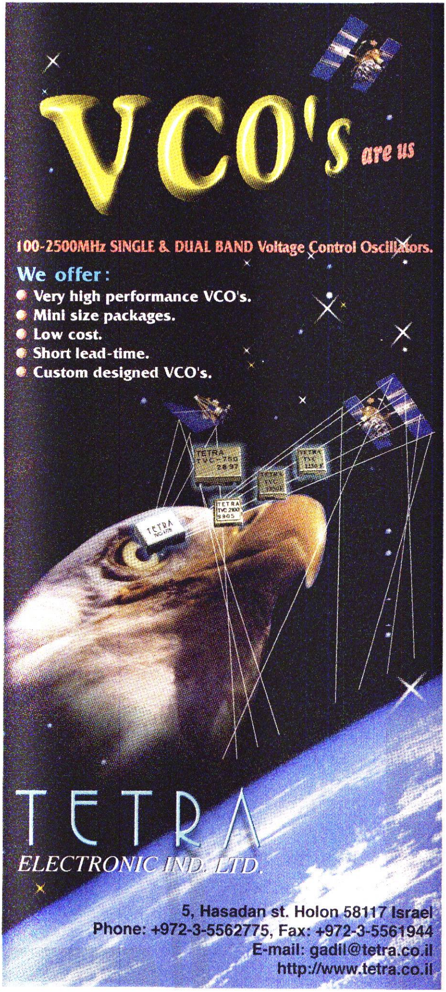
DEVICE CHARACTERIZATION AND MODELING

The design of power amplifier matching circuits differs in approach from low noise amplifiers for a number of reasons. The physical size of the 4.8 and 9.6 mm HFET power devices is large enough to require a distributed analysis.[3] In addition, the devices' inherently low terminal impedances make it difficult to measure and characterize them using conventional 50 Ω characteristic impedance network analyzers. Even if a perfect distribution network was available to characterize a multicell device, this method would lead to measurement errors because the device input and output impedances are considerably less than 50 Ω. Therefore, a single cell defined as the 2.4 mm unit cell HFET is employed and characterized in a 50 Ω system.

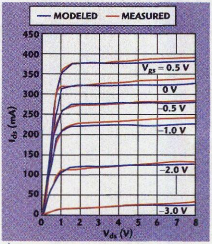
The 2.4 mm unit cell HFET was characterized by measuring the S parameters at a $V_{ds} = 8$ V and $I_{ds} = 0.25I_{dss}$ operating point in order to achieve the optimum power-added efficiency performance. The de-embedded[4] S parameters from the measurement fixture were employed to develop a small-signal model over 2 to 10 GHz. The 2.4 mm unit cell HFET was characterized for large-signal modeling by measuring the pulsed I_{ds}/V_{ds} and I_{ds}/V_{gs} characteristics. LIBRA® CAD software was employed to achieve an optimum fit to the de-embedded small-signal S parameters. ***Figure 1*** shows good agreement between the de-embedded and modeled S_{11} and S_{22}. ***Figures 2*** and ***3*** show S_{11} and S_{22} of the 2.4 mm unit cell HFET scaled by a factor of two to represent the 4.8 mm HFET and by a factor of four to represent the 9.6 mm HFET device, respectively.

Large-signal modeling was carried out by employing the Curtice-Quadratic,[5] Curtice-Ettenberg,[6] Statz[7] and TOM[8] large-signal models available in

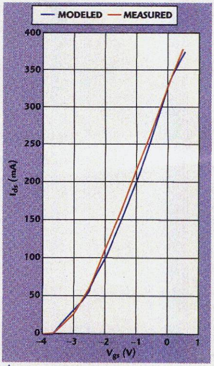
[Continued on page 112]



LIBRA. The latter models were optimized to achieve optimum fit to the pulsed I_{ds}/V_{ds} and I_{ds}/V_{gs} characteristics. The Statz large-signal model was determined to provide the optimum fit to the measured I_{ds}/V_{ds} and I_{ds}/V_{gs} characteristics of the 2.4 mm unit cell HFET, as shown in ***Figures 4*** and **5**, respectively. The Statz model introduces two important advances over previous device models. First, the model incorporates an improved analytic DC I-V formulation. Second, the model offers an improved charge model



▲ *Fig. 4 The 2.4 mm unit cell HFET measured and modeled I_{ds} vs. V_{ds} employing the LIBRA Statz large-signal model.*



▲ *Fig. 5 The 2.4 mm unit cell HFET measured and modeled I_{ds} vs. V_{gs} employing the LIBRA Statz large-signal model.*

[Continued on page 114]

representation of C_{gs} and C_{gd} as functions of both V_{gs} and V_{ds}. The Statz model modifies the Curtice-Ettenberg formulation by replacing the more computationally intensive hyperbolic tangent function with a truncated series representation. The Statz I_{ds} equation then becomes

$$I_{ds}\left(V_{gs}V_{ds}\right) = \frac{\beta\left(V_{gs} + \left|V_P\right|\right)^2\left(1 + \lambda V_{ds}\right)\left[1 - \left[1 - \frac{\alpha V_{ds}}{3}\right]^3\right]}{1 + b\left(V_{gs} + \left|V_P\right|\right)} \quad (1)$$

for $0 < V_{ds} < \frac{3}{\alpha}$

and

$$I_{ds}\left(V_{gs}V_{ds}\right) = \frac{\beta\left(V_{gs} + \left|V_P\right|^2\right)\left(1 + \lambda V_{ds}\right)}{1 + b\left(V_{gs} + \left|V_P\right|\right)} \quad (2)$$

for $V_{ds} \geq \frac{3}{\alpha}$

where

$\left[1 - \left[1 - \frac{\alpha V_{ds}}{3}\right]^3\right]$ = the truncated series representation of $\tanh(\alpha V_{ds})$

β = a model parameter

The equations provide unusually good control over the contour in the transition of $I_{ds} = f(V_{gs})$ as it goes from square law to linear behavior. As long as the quantity $b(V_{gs} + |V_p|)$ is << 1 (as it is when V_{gs} is close to pinch-off), then the behavior is square law since $I_{ds} = \beta(V_{gs} + |V_p|)^2$. However, when $b(V_{gs} + |V_p|)$ >> 1, then the expression is nearly linear since I_{ds} approaches

$$I_{ds} = \frac{\beta V_{ds} + \left|V_P\right|}{b}$$

The coefficient β is easily evaluated for any choice of b since

$$I_{ds} = \frac{\beta\left|V_P\right|^2}{1 + b\left|V_P\right|} \quad (3)$$

and

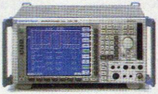
$$\beta = \frac{I_{dss}\left(1 + b\left|V_P\right|\right)}{\left|V_P\right|^2} \quad (4)$$

The described Statz function allows a broad latitude in I_{ds} vs. V_{ds} fitting by performing adjustments of the coefficients b and β. It can accommodate I_{ds} vs. V_{gs} behavior that varies from totally square law (b = 0) to totally linear (very large b). The model provides an excellent fit with measured data along the entire I_{ds}/V_{gs} curve and down to the curvature close to pinch-off. The latter fit enables amplifiers to be designed and operated in class AB mode. The developed small- and large-signal models of the 2.4 mm unit cell HFET then were appropriately scaled to represent the 4.8

[Continued on page 116]

The new mid-range prodigy (and the proud parents)

So you know all about spectrum analyzers from Rohde & Schwarz? Top of the range instruments for the most demanding requirements, superlative performance that naturally comes with a matching price tag? Then think again! And take a good long look at this box of tricks: small, light, extremely fast, big colour display, with a specification to blow the socks of all the opposition in the market for mid-range spectrum analyzers. Features like high-speed zero span? Built-in. GPIB, RS232 and printer interfaces? Standard. PC-compatible screenshots? At the touch of a button, no conversion software needed. 10 Hz to 10 MHz bandwidths? The complete range. Time-gated analysis? No extra charge. Plus a range of features not to be found in a rival mid-range analyzer for love or money. Such as the RMS detector, or statistic measurement functions like CCDF. Or highly selective FFT filters and the fast ACP measurement function. Not bad, you are thinking, but tell me about the price for such a parade of technology. Certainly we'll tell you about the price: very, very competitive. Just another feature. By the way our mid-range prodigy is called the FSP. You can find out all about the FSP on the Internet. Or give us a call.

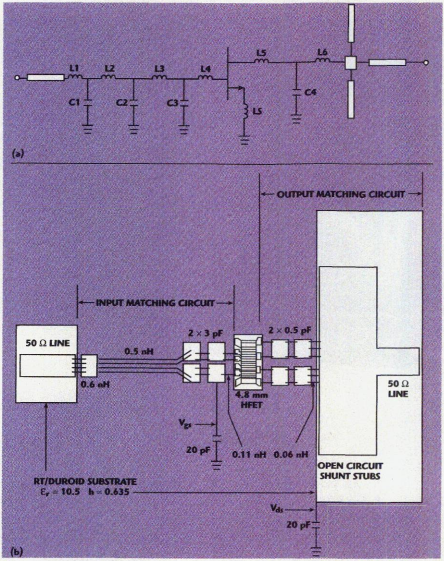


Discover more: www.fsp.rsd.de

ROHDE&SCHWARZ

Internet http://www.rsd.de · **TEL** · **Argentina** (1) 14 331 1685 · **Australia** (2) 97 48 01 55 · **Austria** (1) 6 02 61 41 · **Belgium** (2) 7 21 50 02 · **Brazil** (11) 55 05 21 77 · **Bulgaria** (59) 2 65 51 33 · **Canada** (see USA) **Chile** (2) 2 77 50 50 · **China** (10) 64 67 23 65 · **Czech Republic** (2) 24 32 20 14 · **Denmark** (43) 43 66 99 · **Finland** (58) 9 47 88 30 · **France** (1) 41 36 11 09 · **Germany** (180) 512 42 42 · **Greece** (1) 7 22 92 13 **Hongkong** (2) 5 07 03 33 · **Hungary** (1) 203-0282 · **India** (11) 4 61 52 85 · **Indonesia** (21) 2 52 47 88 · **Iran** (21) 8 73 02 82 · **Italy** (6) 41 59 81 · **Malaysia** (3) 7 03 5503 · **Mexico** (5) 6 66 63 33 **Netherlands** (30) 6 00 17 00 · **New Zealand** (4) 2 32 32 33 · **Norway** (23) 17 22 50 · **Pakistan** (51) 25 69 53 · **Philippines** (2) 8 13 29 31 · **Poland** (22) 6 35 06 87 · **Portugal** (1) 4 12 01 31 · **Romania** (1) 4 10 68 46 **Russian Federation** (095) 2 34 49 62 · **Saudi Arabia** (1) 4 65 44 78 · **Singapore** (2) 87 68 22 · **Slovenia** (61) 1 23 46 51 · **South Africa** (11) 786 3647 · **Spain** (1) 3 34 10 70 · **Sweden** (8) 6 05 19 00 **Switzerland** (31) 9 22 15 22 · **Taiwan** (2) 23 21 70 70 · **Thailand** (2) 6 43 13 30-9 · **Turkey** (216) 3 85 19 17 · **United Kingdom** (1252) 81 13 77 · **USA** Tektronix Tel. (800) 426 22 00, Fax (503) 2 22 15 42, http://www.tek.com · **Vietnam** (4) 8 34 61 86

CIRCLE 152 ON READER SERVICE CARD



▲ *Fig. 6 The 4.8 mm HFET power amplifier circuit (a) schematic and (b) layout.*

and 9.6 mm gate width HFETs in order to carry out the design of high efficiency power amplifiers.

HIGH EFFICIENCY AMPLIFIER DESIGN PROCEDURE

The design of high efficiency amplifiers employing the 4.8 and 9.6 mm HFETs is accomplished using LIBRA in order to optimize output power and power-added efficiency performance. In employing computer-aided design, accurately scaled small- and large-signal device models of the 2.4 mm unit cell HFET are required. An accurate scaled large-signal model of the device is required to design the output matching circuits for the amplifier. The predominant nonlinearities correspond to the drain source current I_{ds} and are fitted to the pulsed I_{ds}/V_{ds} and I_{ds}/V_{gs} measured characteristics of the 2.4 mm unit cell HFET device to the nonlinear Statz model. The Statz large-signal model achieved the best fit to the pulsed data and was employed in simulating the amplifier designs under large-signal conditions. In order to optimize the amplifier design for small-signal gain and input and output return loss, the scaled small-signal model of the 2.4 mm unit cell HFET device was used at the quiescent bias point.

4.8 MM HFET HIGH EFFICIENCY AMPLIFIER DESIGN

A single-ended amplifier design employing a 4.8 mm HFET device was carried out by initially optimizing the small-signal performance by using the small-signal model of the 2.4 mm unit cell HFET device scaled by a factor of two. This scale factor was used because the gate width ratio of the two devices was 2:1. ***Figure 6***

[Continued on page 118]

shows a circuit schematic and layout of the optimized amplifier design.

To achieve high efficiency, a class F mode of operation was employed where the harmonic distribution of energy is such that higher voltages and lower currents are produced at the output terminals of the device. For the ideal case, that is, for the ideal drain source voltage $v_{ds}(t)$ to be a square waveform, it must contain only odd harmonic voltage components given by[1]

$$v_{ds}(t) = v_{max}\left(\frac{1}{2} - \frac{2}{\pi}\sum_{n=1,3,n}^{\infty}\frac{1}{n}\sin n\omega t\right) \qquad (5)$$

and for the drain source current $i_{ds}(t)$ waveform to be a half sinusoid it must consist of even harmonic current components given by[1]

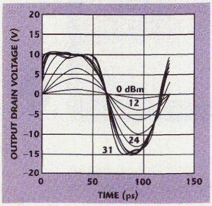
$$i_{ds}(t) = i_{max}\left(\frac{1}{\pi} + \frac{1}{2}\sin(n\omega t) - \frac{2}{\pi}\sum_{n=2,4,n}^{\infty}\frac{1}{n^2-1}\cos(n\omega t)\right) \qquad (6)$$

where

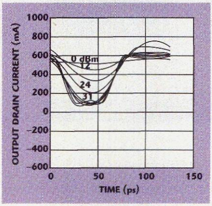
v_{max} = maximum drain source voltage under RF conditions

i_{max} = maximum drain source current under RF conditions

Large-signal simulation and optimization for output power and efficiency were carried out by employing a class F mode of operation by incorporating a close-in second-harmonic short circuit at the output matching circuit. Optimization of efficiency is shown in ***Figures 7*** and ***8***, which display the output drain voltage and current waveforms approaching square wave,[9] a condition for optimum efficiency as the input power is increased.



▲ *Fig. 7 The LIBRA-predicted output drain voltage waveform of the 4.8 mm HFET large-signal amplifier simulation.*



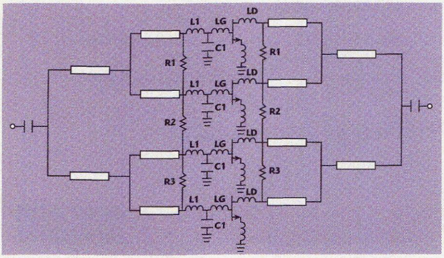
▲ *Fig. 8 The LIBRA-predicted output drain current waveform of the 4.8 mm HFET large-signal amplifier simulation.*

9.6 MM HFET HIGH EFFICIENCY AMPLIFIER DESIGN

A single-ended amplifier design employing four 9.6 mm HFET devices was carried out by initially optimizing small-signal performance using the small-signal model 2.4 mm unit cell HFET scaled by a factor of four. The scale factor of four was used because the gate width ratio of the two devices was 4:1. ***Figure 9*** shows a circuit schematic and layout of the optimized amplifier design. The input matching circuit consists of lumped element matching using lowpass networks close to the four devices. These elements offer the low impedance required to perform circuit matching to the low input impedance of the device. Lumped-element matching increases the impedance level so that further multiple transformations in impedance level to the system impedance of 50 Ω can be carried out by employing a divider network comprising two-section quarter-wave impedance transformers realized as microstrip elements.

The output matching circuit employs microstrip element matching because the impedance of the scaled 9.6 mm HFET device was higher than the input impedance and, therefore, requires no lumped-element matching. It also can be observed from the diagram that the four 9.6 mm HFET devices are combined using an in-phase power combiner network comprising two-section quarter-wave impedance transformers, which simultaneously combine and match the four devices. Initial values of the impedance transformers were calculated and further optimized using LIBRA. The isolation resistors labeled R_1, R_2 and R_3 were employed to terminate any odd modes[10] that may be generated by circuits of this complexity.

The small-signal-optimized single-ended amplifier employing 9.6 mm HFETs was optimized for large-signal performance. The LIBRA Statz large fitted model of the 2.4 mm unit cell HFET was scaled by a factor of four to represent the 9.6 mm HFET device. Large-signal simulation and optimization for output power and efficiency were carried out by employing a class F mode of operation similar to the 4.8 mm HFET



▲ *Fig. 9 The 9.6 mm HFET power amplifier circuit schematic.*

[Continued on page 120]

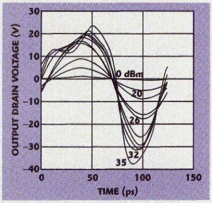
design. Optimization of efficiency also was confirmed as illustrated in ***Figures 10*** and ***11***, which show the output drain voltage and current waveforms approaching a square wave, a condition for optimum efficiency[1] as the input power is increased, respectively.

AMPLIFIER FABRICATION

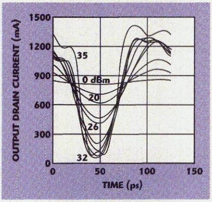
The 4.8 mm HFET single-ended power amplifier was constructed by employing lumped and microstrip elements. The input matching circuit consists of a three-section lowpass lumped-element network comprising low loss microwave chip capacitors and 1 mil diameter gold bond wire employed to fabricate the required inductors. The output matching circuit consists of a single-section lowpass lumped-element network comprising two low loss shunt-mounted capacitors and inductors realized by employing 1 mil gold wires. The final connection to the 50 Ω system impedance was carried out by employing microstrip elements fabricated on RT/Duroid softboard material with a dielectric constant ε_r of 10.5 and substrate thickness of 25 mils. The amplifier was fully assembled onto a machined gold-plated carrier made from copper tungsten composite material. All the components and substrates were soldered onto the gold-plated carrier.

The single-ended 9.6 mm HFET amplifier was fabricated using lumped and microstrip components. Its circuit layout is shown in ***Figure 12***. The lumped components comprised low loss microwave chip capacitors and inductors that were realized employing 1 mil gold wire of appropriate lengths. The microstrip circuits were realized on 10 and 25 mil alumina substrates. The 9.6 mm HFET amplifier was fabricated onto a highly precision machined gold-plated tungsten/copper carrier. The carrier incorporated very

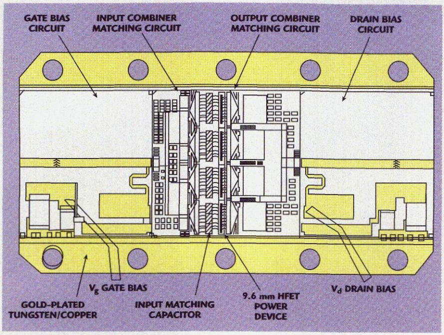
[Continued on page 122]



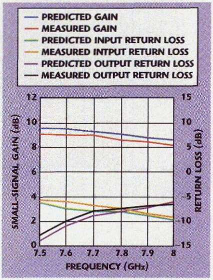
▲ *Fig. 10 The LIBRA-predicted output drain voltage waveform of the 9.6 mm HFET large-signal amplifier simulation.*



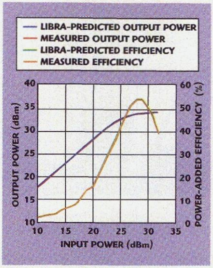
▲ *Fig. 11 The LIBRA-predicted output drain current waveform of the 9.6 mm HFET large-signal amplifier simulation.*



▲ *Fig. 12 The 9.6 mm HFET power amplifier's circuit layout.*



▲ *Fig. 13 The 4.8 mm HFET amplifier's LIBRA-predicted and measured small-signal gain and return loss.*

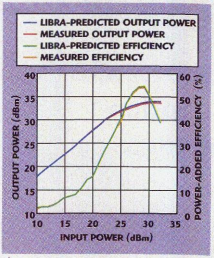


▲ *Fig. 14 The 4.8 mm HFET amplifier's measured and LIBRA-predicted output power and power-added efficiency at 7.5 GHz.*

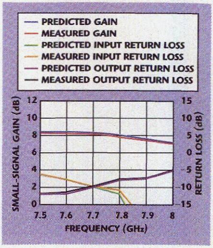
finely machined ribs onto which the 9.6 mm HFET devices and lumped matching capacitors were soldered. The positions of the machined ribs were calculated in order to realize the lumped-element inductor values for the input and output matching circuits.

AMPLIFIER MEASUREMENTS

The measured and predicted small-signal performance of the 4.8 mm HFET amplifier is shown in ***Figure 13***. The amplifiers were biased in class AB mode of operation at the V_{ds} = 8 V and $I_{ds} = 0.25I_{dss}$ quiescent operating point to achieve optimum power-added efficiency performance. The measured and predicted output power and efficiency performance at 7.5 and 8.0 GHz are shown in ***Figures 14*** and ***15***. An output power of 34 dBm (2.5 W) at 1 dB gain compression with 53 percent power-added efficiency has been achieved. The measured and predicted small-signal performance of the 9.6 mm HFET amplifier is shown in ***Figure 16***. The measured and predicted output power and efficiency performance at 7.5 and 8.0 GHz is shown in ***Figures 17*** and

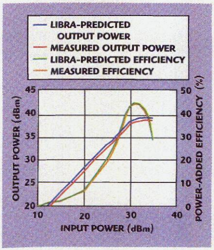


▲ *Fig. 15 The 4.8 mm HFET amplifier's measured and LIBRA-predicted output power and power-added efficiency at 8.0 GHz.*



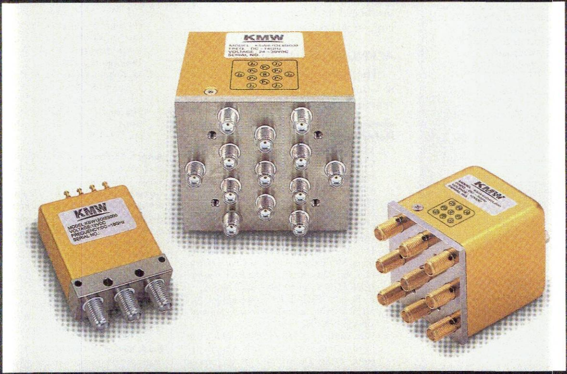
▲ *Fig. 16 The 9.6 mm HFET amplifier's measured and LIBRA-predicted small-signal gain and return loss.*

Fig. 17 The 9.6 mm HFET amplifier's measured and LIBRA-predicted output power and power-added efficiency at 7.5 GHz. ▼



[Continued on page 124]

Designed for Ultimate Quality



Your Complete Switching Solution from KMW

■ KMW new 6P7T switch is designed for W-CDMA IMT2000.

Product Code No.	KSW12O12S000	KSW67O42L000	KSW45O42L000
Switch Type	SPDT	6P7T	4PST
Frequency Range	DC ~ 3GHz	DC ~ 3GHz	DC ~ 3GHz
Insertion Loss (max.)	0.2dB	0.2dB	0.2dB
VSWR (max.)	1.15 : 1	1.15 : 1	1.15 : 1
Isolation (min.)	80dB	80dB	80dB
Operating Mode	Latching	Latching	Latching
Actuating Voltage /Current (max.)	12Vdc ± 10% /240mA (@ 12Vdc, 25°C)	12Vdc ± 10% /165mA (@ 12Vdc, 25°C)	12Vdc ± 10% /165mA (@ 12Vdc, 25°C)
I/O Port Connector	SMA(F) / SMA(F)	SMA(F) / SMA(F)	SMA(F) / SMA(F)
RF Power Handling	100W CW (@ 1GHz)	250W CW (@ 1GHz)	250W CW (@ 1GHz)
Dimension (inch)	1.339*1.575*0.528	2.441*2.177*2.165	1.626*1.874*1.626

Higher Frequency available, up to 18GHz
Power Handling Capability, up to 250W CW& 4KW Peak @1GHz

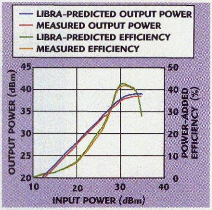
■ Available Options

Internal Termination, Indicator Circuitry, Suppression Diode, TTL Logic, Self De-Energizing Circuit, Various I/O Connector type, other Operating Voltage

■ 5 million life cycle SPDT switch available upon request.

13131 East 166th Street, Cerritos, CA 90703-2202
1-800-8320-KMW • www.kmwinc.com
tel: 562-926-2033 • fax: 562-926-6133
CIRCLE 77 ON READER SERVICE CARD

KMW
RF & Microwave



▲ *Fig. 18 The 9.6 mm HFET amplifier's measured and LIBRA-predicted output power and power-added efficiency at 8.0 GHz.*

18. An output power of 39 dBm at 1 dB gain compression with 42 percent power-added efficiency has been achieved.

CONCLUSION

In this article the design of high efficiency power amplifiers has been investigated using CAD techniques. The designs were conducted using state-of-the-art HFET devices and the technique of scaling was employed to permit the 2.4 mm unit cell HFET device to represent the 4.8 and 9.6 mm gate width HFETs. The 4.8 mm HFET amplifier achieved a power-added efficiency of 53 percent; the amplifier employing the 9.6 mm HFET achieved a power-added efficiency of 42 percent. Excellent correlation has been achieved between predicted and measured small- and large-signal performance.

ACKNOWLEDGMENT

The authors wish to thank Filtronic Components Ltd. for its permission to publish these results. ■

References

1. M.K. Kazimierczuk, "A New Concept of Class F Tuned Power Amplifier," *Proceedings of the Midwest Circuits and Systems Symposium (MCASS)*, June 1984, pp. 18–14.
2. S.C. Cripps, "A Theory For the Prediction of GaAs FET Load Pull Power Contours," *IEEE MTT-S Digest*, 1983, pp. 221–223.
3. D.E. Peck and D.F. Peterson, "A Measurement Method for Accurate Characterisation and Modelling of MESFET Chips," *IEEE MTT-S Digest*, 1981, pp. 310–312.
4. L. Besser, "Skillfull De-Embedding," *Applied Microwave and Wireless Journal*, 1994, pp. 86–94.
5. W.R. Curtice, "A MESFET Model for Use in the Design of GaAs Integrated Circuits," *IEEE Transactions on Microwave Theory and Techniques*, Vol. MTT-33, May 1980, pp. 448–456.
6. W.R. Curtice and M. Ettenberg, "A Nonlinear GaAs FET Model for Use in the Design of Output Circuits for Power Amplifiers," *IEEE Transactions on Microwave Theory and Techniques*, Vol. MTT-33, December 1985, pp. 1383–1394.
7. H.P. Statz, I. Newman, W. Smith, R.A. Pucel and H.A. Haus, "GaAs FET Device and Circuit Simulation in SPICE," *IEEE Transactions on Electron Devices*, Vol. ED-34, February 1987, pp. 160–169.
8. A.J. McCamant, G.D. McCormack and D.H. Smith, "An Improved GaAs MESFET Model for SPICE," *IEEE Transactions on Microwave Theory and Techniques*, Vol. MTT-38, June 1990, pp. 822–824.
9. C.J. Wei, Y.A. Tkachenko and J.C.M. Hwang, "Noninvasive Waveform Probing for Nonlinear Network Analysis," *Microwave Journal*, Vo. 37, No. 2, February 1994, pp. 122–126.
10. M. Kohno, T. Fujioka, K. Hayashi, Y. Itoh, Y. Ikeda, K. Seino and M. Yamanouchi, "High Efficient C-band 27 Watt Internally Matched GaAs FET For Space Applications," *IEEE MTT-S Digest*, 1994, pp. 273–276.

Avtar S. Virdee *received his BSc (Hons) degree in electrical engineering from the University of Leeds, UK and his MSc degree from the University of Cranfield, UK. His previous work experience includes two years with British Aerospace designing LNAs for spacecraft applications, six years with Plessey Microwave designing solid-state amplifiers for radar systems and four years with Electtronica UK Ltd. designing broadband amplifiers for EW systems. Currently, he is an R&D technical specialist in the field of solid-state amplifiers at Filtronic Components Ltd. Virdee's research interests are in the area of efficiency improvements of broadband solid-state power amplifiers.*

Bal S. Virdee *received his BSc (Hons) and MPhil degrees in electronic engineering from the University of Leeds, UK and his PhD in electronic engineering from the University of London, UK. He worked for Philips, Cambridge, UK, as a research and development engineer specializing in communication systems and at Leeds Metropolitan University and the Open University as a lecturer before he joined the University of North London. He was subsequently promoted to a senior lecturer position and now leads the Microwave Research Group. Virdee has developed and run professional short courses on microwave components and techniques, microwave communications systems and DRO design. He has also chaired technical sessions at the 1996 and 1998 Asia-Pacific Microwave Conference, New Delhi, India, and Yokohama, Japan, respectively.*

ULTRAFAST WIDEBAND MICROWAVE
LOGARITHMIC AMPLIFIERS

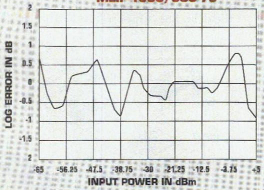
FEATURES

- Fast Recovery Time
- Low Output Noise for Increased Accuracy
- Improved Sensitivity Through Low Noise Figure Input Stages
- Custom Electrical Performance Available

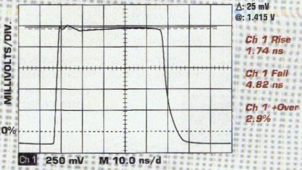
ELECTRICAL SPECIFICATIONS

Model Number	Center Frequency (MHz)	Operational Bandwidth (MHz, Min.)	Dynamic Range (dB, Min.)	TSS (dBm, Max.)	Log Linearity (±dB, Max.)	Video Flatness (±dB, Max.)	Rise Time (ns, Max.)	Recovery Time (ns, Max.)
MLIF-500/100-70	500	100	-70 to 0	-74	1	1.0	5	23
MLIF-750/500-60	750	500	-60 to 0	-67	1	1.5	2	12
MLIF-1000/300-60	1000	300	-60 to 0	-68	1	0.75	2	12
MLIF-1000/500-70	1000	500	-65 to +5	-72	1	2.0	5	25
MLIF-1500/500-60	1500	500	-60 to 0	-66	1	1.0	1.7	12
MLIF-1575/200-50	1575	200	-45 to +5	-53	1	1.0	1.5	10

LOG LINEARITY
MLIF-1000/500-70



PULSE RESPONSE
MLIF-1000/300-60



For additional information, please contact Boris Benger at (516) 439-9402 or e-mail bbenger@miteq.com.

NQA ISO 9001 REGISTERED COMPANY

MITEQ

100 Davids Drive • Hauppauge, NY 11788
TEL.: (516) 436-7400 • FAX: (516) 436-7430
www.miteq.com

CIRCLE 128 ON READER SERVICE CARD

TECHNICAL FEATURE

Impedance Measurements for High Power RF Transistors Using the TRL Method

Impedance measurements on high power RF transistors are always a problem because of the very low values and lead widths and because the devices may be in a push-pull configuration. Calibration kits to measure wide or balanced microstrip lines are difficult to build and provide poor accuracy. This article describes a way to accurately characterize high power RF transistors, even with wide leads and in a single-ended or push-pull configuration. The impedances of the transistor or the S parameters of the input and output test fixture are obtained using the thru-reflect-line (TRL) calibration technique in order to perform de-embedding or load-pull measurements. Different options of calculation are presented.

METHOD DESCRIPTION

Generally, high power transistor characterization consists of a measurement of the optimum source and load presented to the transistor by a given test fixture. This test fixture can be tuned at each individual frequency for best performance, or included in a load-pull bench as an impedance transformer. In all cases, the impedance of the test fixture (S_{22} of the input matching network and S_{11} of the output matching network) must be measured. In the case of a load-pull, all other S_{ij} parameters must be determined in order to perform de-embedding. To determine the S parameters, a break-apart test fixture is used and included in a calibration routine with a vector network analyzer (VNA), as shown in ***Figures 1*** and **2**.

If a TRL calibration is performed instead of a short-open-load-thru (SOLT) procedure, the only standard needed is a delay line. In this case, if the delay line is designed so that it has the same width as the transistor leads, the measurement will be accurate because width transitions are avoided, as well as coaxial-to-microstrip transitions, and the measurement system will be normalized to the impedance of the delay line, which will be lower than 50 Ω if

Fig. 1 The break-apart test fixture.

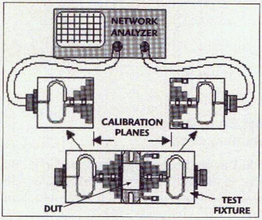
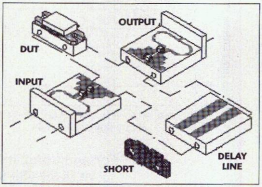
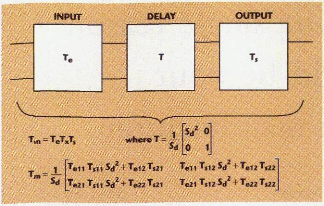


Fig. 2 Components of the test fixture.



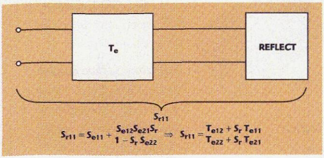
[Continued on page 128]

JEAN-JACQUES BOUNY
Motorola Semiconducteurs S.A.
Toulouse, France



▲ *Fig. 3 The T_m measurement.*

▼ *Fig. 4 The S_r measurement.*



the line is wide. In the case of a push-pull configuration, the delay line design is accomplished by printing two symmetric lines, making the impedance of the delay two-times the impedance of a single line. When the three measurements of the TRL calibration are completed, it is possible to calculate the error matrix corresponding to the input and output matching networks.

IMPEDANCE CALCULATION

To calculate the parameters of the error matrix, T parameters, which are cascadable, are used instead of S parameters. Translation between S and T parameters is described in ***Appendix A***. T_m is measured, as shown in ***Figure 3***, with the delay and thru to obtain T_{dij} (delay) and T_{tij} (thru) with $S_d = S_{21} = S_{12}$ of the delay line (equal to 1 in the case of the thru).

S_{rij} is subsequently measured, as shown in ***Figure 4***, where S_r is a reflecting termination (an open or short circuit). Ten relationships now exist to calculate the values of T_{eij} and T_{sij} (T parameters of the input and output test fixture, respectively) as a function of T_{dij}, T_{tij}, S_{rij}, S_r and S_d. After some mathematical calculations (detailed in ***Appendix B***), formulas are obtained where S_{s11} and S_{e22} are fully determined if S_d and S_r are presumed to be known. Note that S_d and S_r also could be calculated, however, some unknowns must be determined. For simplicity, suppose that S_d has been measured or simulated and that S_r is known (+1 for an open, or –1 for a short).

CALCULATION RESULTS

S_r and S_d now can be replaced by their values and S_{e11}, S_{ee22}, S_{s11} and S_{s22} can be obtained as functions of S_{rij}, T_{dij} and T_{tij}. $S_{e12}S_{e21}$ can be extracted from the S-parameter form of Equation A9, and the crossed term $S_{e21}S_{s21}$ can be extracted from Equation A18 knowing that it is equal to $1/T_{e22}T_{s22}$. If the input and output test fixtures are assumed reciprocal, $S_{e12} = S_{e21}$ and $S_{s12} = S_{s21}$ can be calculated as the square root of their respective products. T parameters then can be replaced by their S-parameter equivalents and the following S-parameter impedances can be obtained:

Input:

$$S_{e11} = \frac{S_{d11}S_{t21} - S_d S_{t11} S_{d21}}{S_{t21} - S_d S_{d21}}$$

$$S_{e22} = \frac{\left(S_{d11}S_{t21} - S_d S_{t11} S_{d21}\right) - S_{r11}\left(S_{t21} - S_d S_{t21}\right)}{\left(S_d S_{d11} S_{t21} - S_{t11} S_{d21}\right) - S_{r11}\left(S_d S_{t21} - S_{d21}\right)} \bullet \frac{S_d S_{t21} - S_{d21}}{S_{t21} - S_d S_{d21}}$$

$$S_{e12}S_{e21} = S_{r11}\left(1 - S_{e22}\right) - S_{e11}$$

Output:

$$S_{s11} = \frac{\left(S_{d22}S_{t21} - S_d S_{t22} S_{d21}\right) - S_{r22}\left(S_{t21} - S_d S_{d21}\right)}{\left(S_d S_{d22} S_{t21} - S_{t22} S_{d21}\right) - S_{r22}\left(S_d S_{t21} - S_{d21}\right)} \bullet \frac{S_d S_{t21} - S_{d21}}{S_{t21} - S_d S_{d21}}$$

$$S_{s22} = \frac{S_{d22}S_{t21} - S_d S_{t22} S_{d21}}{S_{t21} - S_d S_{d21}}$$

$$S_{s12}S_{s21} = S_{r22}\left(1 - S_{s11}\right) - S_{s22}$$

Crossed:

$$S_{e12}S_{s12} = S_{e21}S_{s21} = \frac{1 - S_d^2}{S_d} \bullet \frac{S_{d21}S_{t21}}{S_{t21} - S_d S_{d21}}$$

In this case, S_r is supposed to be an open; in the case of a short, the sign of S_{e22} and S_{s11} is opposite. Z_{in}^* and Z_{out}^* are given by

$$Z_{in}^* = Z_o \bullet \frac{1 + S_{e22}}{1 - S_{e22}}$$

$$Z_{out}^* = Z_o \bullet \frac{1 + S_{s11}}{1 - S_{s11}}$$

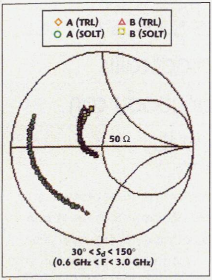
where Z_o is the normalization impedance of the system — the impedance of the delay line. It should be noted that the delay must be different from the thru (indeterminable if the delay is 0° or 180°), which means that the best case is when the delay is 90°. However, in a practical case, a delay line between 30° and 150° provides good accuracy.

PRACTICAL USE

Practical measurements are quite simple to implement, however, special attention must be paid to several points. First, when assembling the break-apart test fixture, the continuity of the ground must be very good. Second, if a quarter-wave delay line is used, it will transform the impe-

[Continued on page 130]

dance seen on one side (very low) to a very high impedance on the other side, and the transmitted signal will be very low. A lot of noise will be added on the measurements, and the obtained results may be unusable.



▲ *Fig. 5 SOLT and TRL measurements of the first two passive networks.*

Fig. 6 Difference between the real impedance presented to the device and that measured with a standard technique. ▼

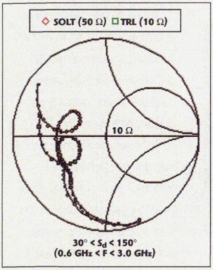


TABLE I

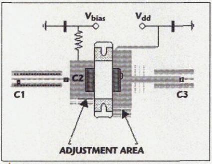
MRF18060 IMPEDANCES

Frequency (GHz)	Z_{in} (Ω)	Z_{out} (Ω)
1.70	0.60 + j2.53	2.27 + j3.44
1.80	0.80 + j3.20	2.05 + j3.05
1.90	0.92 + j3.42	1.90 + j2.90
2.00	1.07 + j3.59	1.64 + j2.88
2.10	1.31 + j4.00	1.29 + j2.99

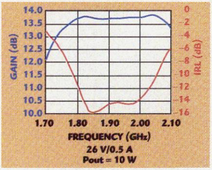
METHOD VERIFICATION

Two passive networks have been measured with a standard SOLT calibration and connector and with a TRL calibration and a 50 Ω delay line. ***Figure 5*** shows the results obtained between 0.6 and 3 GHz, which confirm that the method is valid over more than two octaves for a single delay line. Note also that even with a 50 Ω delay line, some differences exist as a result of the coaxial-to-microstrip transition.

A second set of measurements has been completed with a wide delay line (10 Ω). As shown in ***Figure 6***, there is a big difference between the real impedance presented to the device and the one measured with a standard technique.



▲ *Fig. 7 The optimized amplifier.*



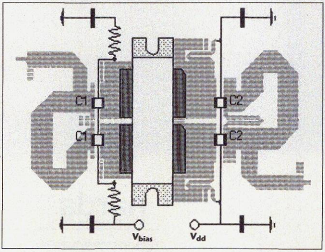
▲ *Fig. 8 The amplifier's gain and IRL vs. frequency at 10 W.*

TABLE II

MRF21120 IMPEDANCES

Frequency (GHz)	Z_{in} (Ω)	Z_{out} (Ω)
2.05	2.90 + j11.82	6.03 + j6.38
2.11	2.35 + j11.42	5.15 + j6.70
2.17	2.05 + j10.80	4.34 + j6.69
2.23	1.98 + j10.53	3.98 + j6.61

▼ *Fig. 9 The amplifier's layout.*



A DESIGN EXAMPLE

An amplifier was designed using this technique with a Motorola model MRF18060 60 W/1.8 GHz/26 V transistor. Impedances measured for 65 W and 13 dB gain at 1 dB compression are listed in ***Table 1***. A drawing of the optimized amplifier is shown in ***Figure 7***, where C1 = 1.8 pF, C2 = 1 pF and C3 = 10 pF. When the amplifier was assembled without any tuning, the results were 64 W, 12.2 dB gain and 47 percent efficiency at 1 dB compression. After adding adjustment areas at the input and output, the results became 66 W/12.7 dB gain/48.8 percent efficiency at 1.8 GHz, 67 W/12.7 dB gain/47.8 percent efficiency at 1.9 GHz and 67 W/12.8 dB gain/48.3 percent efficiency at 2.0 GHz. Gain and input return loss (IRL) are shown in ***Figure 8***.

A SECOND EXAMPLE

Another amplifier was built using a Motorola model MRF21120 120 W/2.1 GHz/26 V push-pull transistor. ***Table 2*** lists the measured impedances for 120 W/12.1 dB gain at 1 dB compression. The amplifier is shown in ***Figure 9***, where C1 = 1.8 pF and C2 = 4.7 pF. Before any tuning, the measurement results were 113 W, 11.6 dB gain and 45 percent efficiency at 1 dB compression. After a slight adjustment of the position of C1 and C2 (up and down), the results were 121

[Continued on page 132]

W/12.1 dB gain/47.6 percent efficiency at 2.11 GHz and 118 W/12.1 dB gain/46.6 percent efficiency at 2.17 GHz. Gain and IRL are shown in **Figure 10**. As in the previous example, results are very similar to those obtained when measuring the impedances in a narrow band, which demonstrates that the method is valid and accurate.

For designers with access to a VNA with TRL calibration capability, an alternative solution consists of using the internal calibration routine of the VNA and extracting the error parameters corresponding to S_{eij} and S_{sij}. In this case, the calibration can be verified by measuring the thru.

A NONINSERTABLE QUADRIPOLE

When a de-embedding solution is required, all parameters can be calculated with the presented method. However, a first calibration must be completed in the connector plane before the measurements are performed. The VNA routine also may be used and two successive calibrations performed: one in the connector plane (cal 1, error matrix M), and a second one (TRL) including the test fixture (cal 2, error matrix N). By using T parameters, the X_{ij} (S_{ij} parameters of the test fixture) may be calculated, as shown in **Figure 11**.

After some algebra, the input or output becomes

$$X_{11} = \frac{N_{11} - M_{11}}{M_{22}N_{11} - \Delta M}$$

$$X_{12} = \frac{M_{21}N_{12}}{M_{22}N_{11} - \Delta M}$$

$$X_{21} = \frac{M_{12}N_{21}}{M_{22}N_{11} - \Delta M}$$

$$X_{22} = \frac{M_{22}\Delta N - N_{22}\Delta M}{M_{22}N_{11} - \Delta M}$$

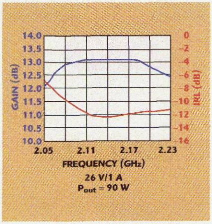
In a calibration set, S_{12} and S_{21} of the different error matrices are not known independently; however, $X_{12}X_{21}$ can be calculated as a function of $M_{12}M_{21}$ and $N_{12}N_{21}$. If the quadripole is assumed reciprocal, that value is equal to X_{21}^2 and X_{12}^2 such that

$$X_{12} = X_{21} = \pm\frac{\sqrt{(M_{12}M_{21})\bullet(N_{12}N_{21})}}{M_{22}N_{11} - \Delta M}$$

The sign then must be determined using an approximate value of X_{21}.

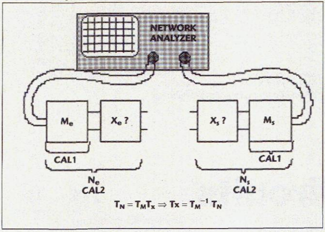
CONCLUSION

It has been shown that the TRL calibration technique can provide precise characterization of high power RF transistors, including impedances and board measurements for de-embedding. Examples show that this technique is much more accurate than standard techniques using coaxial SOLT calibration because measurements are done without any coaxial-to-microstrip transition or width transition and can be performed in a low impedance system. The only calibration standard required to be built is a delay line that can be used over more than two octaves. The use of the TRL method for impedance measurement allows the designer to build an optimized amplifier at the first pass, which drastically reduces the design's cost and cycle time. ■



▲ *Fig. 10 The amplifier's gain and IRL vs. frequency at 90 W.*

▼ *Fig. 11 X_{ij} determination.*



APPENDIX A

S and T Parameters

$$\begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = [S]\bullet\begin{pmatrix} a_1 \\ a_2 \end{pmatrix}$$

$$\begin{pmatrix} b_1 \\ a_1 \end{pmatrix} = [T]\bullet\begin{pmatrix} a_2 \\ b_2 \end{pmatrix}$$

where

$$[S] = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix}$$

$$[T] = \begin{pmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{pmatrix}$$

Figure A1 shows the parameter orientations.

S to T Translation

$$[T] = \frac{1}{S_{21}}\begin{pmatrix} -\Delta S & S_{11} \\ -S_{22} & 1 \end{pmatrix}$$

where

$\Delta S = S_{11}S_{12} - S_{12}S_{21}$

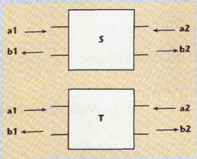
It should be noted that the expression for T_{11} as a function of S parameters is more complex than for T_{12}, T_{21} and T_{22}. For this reason, when there is a choice between two expressions, the one that does not contain T_{11} is chosen.

T to S Translation

$$[S] = \begin{pmatrix} \frac{T_{12}}{T_{22}} & \Delta T \\ \frac{1}{T_{22}} & -\frac{T_{21}}{T_{22}} \end{pmatrix}$$

where

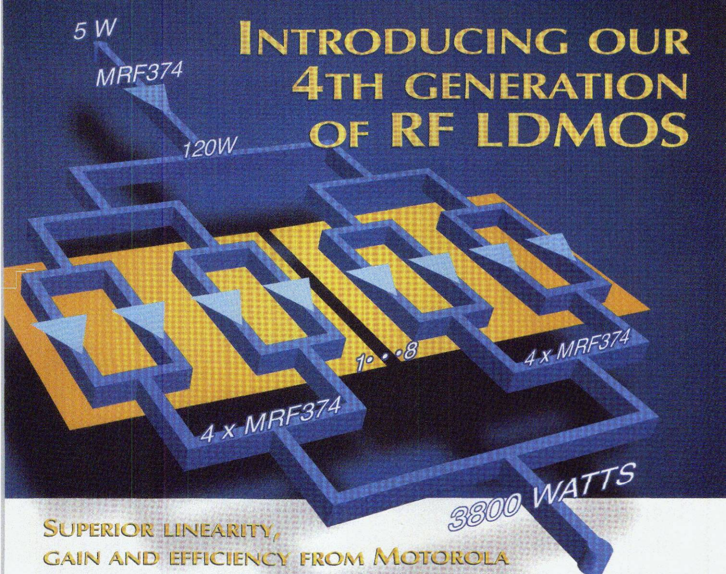
$\Delta T = T_{11}T_{22} - T_{12}T_{21}$



▲ *Fig. A1 S and T relationships.*

[Continued on page 134]

INTRODUCING OUR 4TH GENERATION OF RF LDMOS



SUPERIOR LINEARITY, GAIN AND EFFICIENCY FROM MOTOROLA

Device	Frequency	Operating Voltage	Output Power	Gain (Typ.)	Effic. (Typ.)	Package	Technology
MRF21120*	2170 MHz	28 Volts	120 Watts PEP	11.6 dB	36%	375D/2	LDMOS
MRF21120S*	2170 MHz	28 Volts	120 Watts PEP	11.6 dB	36%	375E/2	LDMOS
MRF19120*	1990 MHz	28 Volts	120 Watts PEP	11.5 dB	34%	375D/2	LDMOS
MRF19120S*	1990 MHz	28 Volts	120 Watts PEP	11.5 dB	34%	375E/2	LDMOS
MRF18090A*	1.8-2.0 GHz	26 Volts	90 Watts	12 dB	48%	465B/1	LDMOS
MRF18090B*	1.8-2.0 GHz	26 Volts	90 Watts	12 dB	45%	465B/1	LDMOS
MRF372*	470-860 MHz	28 Volts	180 Watts	14.5 dB	55%	375B/2	LDMOS
MRF373	470-860 MHz	28 Volts	60 Watts	14.7 dB	56%	360B/1	LDMOS
MRF373S	470-860 MHz	28 Volts	60 Watts	14.7 dB	56%	360C/1	LDMOS
MRF374	470-860 MHz	28 Volts	100 Watts PEP	13.5 dB	36%	375F/1	LDMOS
MRF1512T1	520 MHz	7.5 Volts	3 Watts	10.5 dB	55%	449/1 (PLD-1)	LDMOS
MRF1513T1	520 MHz	12.5 Volts	3 Watts	11 dB	55%	466/1 (PLD-1.5)	LDMOS
MRF1517T1	520 MHz	7.5 Volts	8 Watts	11 dB	55%	466/1 (PLD-1.5)	LDMOS
MRF1518T1	520 MHz	12.5 Volts	8 Watts	11 dB	55%	466/1 (PLD-1.5)	LDMOS
MRF166C	500 MHz	28 Volts	20 Watts	16 dB	55%	319/3	MOSFET
MRF166W	500 MHz	28 Volts	40 Watts	16 dB	55%	412/1	MOSFET
MRF141	175 MHz	28 Volts	150 Watts	10 dB	45%	211/2	MOSFET
MRF141G	175 MHz	28 Volts	300 Watts	14 dB	55%	375/2	MOSFET
MRF151	175 MHz	50 Volts	150 Watts	13 dB	45%	211/2	MOSFET
MRF151G	175 MHz	50 Volts	300 Watts	16 dB	55%	375/2	MOSFET
MRF171A	150 MHz	28 Volts	45 Watts	19.5 dB	70%	211/2	MOSFET
MRF275L	500 MHz	28 Volts	100 Watts	8.8 dB	55%	333/2	MOSFET
MRF275G	500 MHz	28 Volts	150 Watts	11.2 dB	55%	375/2	MOSFET

*Internally Matched/4th Generation LDMOS

Device	Frequency	Operating Voltage	Output Power	Hybrid Gain (Typ.)	Chan. Load Capacity	Noise Figure Maximum	Package
MHW7222A	750 MHz	24 Volts	+40 dBmV	22.3 dB	110	7.0 dB	714Y/1
MHW8222B	860 MHz	24 Volts	+38 dBmV	22.7 dB	128	7.0 dB	714Y/1

As digital standards dominate wireless communications, Motorola technology dominates the marketplace. And Future Electronics sets the standards for worldwide distribution of the components you need.

Motorola RF LDMOS technology makes high power, high frequency amplifier designs simpler, easier and more cost effective. The enhanced Motorola RF portfolio combines world leadership in submicron VLSI MOS technology with high volume manufacturing. That means an even wider breadth of RF products, including discrete medium and high power devices, power modules and Class A, ultra-linear amplifiers...only from Motorola and Future Electronics.

Far more than a worldwide leader in electronic components distribution, Future Electronics provides leading edge e-commerce supply chain solutions, state-of-the-art design centers, and one of the largest technical support teams with qualified engineers around the world. With an advanced partner like Motorola, we enable you to be even more competitive for generations to come.

DigitalDNA™ from Motorola

THE HEART OF SMART.

For online data sheets and a free Motorola RF data package go to www.future.ca/motorolarf or call 1-888-680-5892

FUTURE ELECTRONICS

APPENDIX B

Calculation Details

First, the 10 relations given by the measurements are

delay

$$S_d T_{d11} = T_{e11} T_{s11} S_d^2 + T_{e12} T_{s21} \quad (A1)$$

$$S_d T_{d12} = T_{e11} T_{s12} S_d^2 + T_{e12} T_{s22} \quad (A2)$$

$$S_d T_{d21} = T_{e21} T_{s11} S_d^2 + T_{e22} T_{s21} \quad (A3)$$

$$S_d T_{d22} = T_{e21} T_{s12} S_d^2 + T_{e22} T_{s22} \quad (A4)$$

thru

$$T_{t11} = T_{e11} T_{s11} + T_{e12} T_{s21} \quad (A5)$$

$$T_{t12} = T_{e11} T_{s12} + T_{e12} T_{s22} \quad (A6)$$

$$T_{t21} = T_{e21} T_{s11} + T_{e22} T_{s21} \quad (A7)$$

$$T_{t22} = T_{e21} T_{s12} + T_{e22} T_{s22} \quad (A8)$$

reflect

$$S_{r11} = \frac{T_{e12} + S_r T_{e11}}{T_{e22} + S_r T_{e21}} \quad (A9)$$

$$S_{r22} = \frac{-T_{s21} + S_r T_{s11}}{-T_{s22} + S_r T_{e12}} \quad (A10)$$

In addition, it is known that $S_{e22} = -T_{e21}/T_{e22}$ yields Z_{in}^* (conjugate of the transistor's input impedance), and $S_{s11} = +T_{s12}/T_{s22}$ produces Z_{out}^*.

Equations A11 to A20 are obtained by making some combinations between Equations A1 to A10 (for example, Equation A1 – Equation A5, Equation A1 – (S_d^2) Equation A5, Equation A2 – Equation A6, Equation A2 – (S_d^2) Equation A6, producing

$$S_d T_{d11} - T_{t11} = T_{e11} T_{s11} (S_d^2 - 1) \quad (A11)$$

$$S_d T_{d12} - T_{t12} = T_{e11} T_{s12} (S_d^2 - 1) \quad (A12)$$

$$S_d T_{d21} - T_{t21} = T_{e21} T_{s11} (S_d^2 - 1) \quad (A13)$$

$$S_d T_{d22} - T_{t22} = T_{e21} T_{s12} (S_d^2 - 1) \quad (A14)$$

$$S_d T_{d11} - S_d^2 T_{t11} = T_{e12} T_{s21} (1 - S_d^2) \quad (A15)$$

$$S_d T_{d12} - S_d^2 T_{t12} = T_{e12} T_{s22} (1 - S_d^2) \quad (A16)$$

$$S_d T_{d21} - S_d^2 T_{t21} = T_{e22} T_{s21} (1 - S_d^2) \quad (A17)$$

$$S_d T_{d22} - S_d^2 T_{t22} = T_{e22} T_{s22} (1 - S_d^2) \quad (A18)$$

$$S_{r11}\left(1 + S_r \frac{T_{e21}}{T_{e22}}\right) = \frac{T_{e12}}{T_{e22}} + S_r \frac{T_{e11}}{T_{e22}} \quad (A19)$$

$$S_{r22}\left(-1 + S_r \frac{T_{s12}}{T_{s22}}\right) = -\frac{T_{s21}}{T_{s22}} + S_r \frac{T_{s11}}{T_{s22}} \quad (A20)$$

Concerning the input, dividing Equation A15 by Equation A17 or Equation A16 by Equation A18, and Equation A11 by Equation A13 or Equation A12 by Equation A14 yields

$$\frac{T_{e12}}{T_{e22}} = \frac{T_{d11} - S_d T_{t11}}{T_{d21} - S_d T_{t21}} = \frac{T_{d12} - S_d T_{t12}}{T_{d22} - S_d T_{t22}}$$

$$\frac{T_{e11}}{T_{e21}} = \frac{S_d T_{d11} - T_{t11}}{S_d T_{d21} - T_{t21}} = \frac{S_d T_{d12} - T_{t12}}{S_d T_{d22} - T_{t22}} \quad (A21)$$

$$\Rightarrow \frac{T_{e11}}{T_{e22}} = \frac{S_d T_{d11} - T_{t11}}{S_d T_{d21} - T_{t21}} \bullet \frac{T_{e21}}{T_{e22}} = \frac{S_d T_{d12} - T_{t12}}{S_d T_{d22} - T_{t22}} \quad (A22)$$

Note that $S_{e11} = T_{e12}/T_{e22}$ is now calculated. These results are used in Equation A19 to obtain

$$S_r \frac{T_{e21}}{T_{e22}}\left(S_{r11} - \frac{S_d T_{d12} - T_{t12}}{S_d T_{d22} - T_{t22}}\right)$$

$$= \frac{T_{d12} - S_d T_{t12}}{T_{d22} - S_d T_{t22}} - S_{r11} \quad (A23)$$

S_{e22} is now fully determined if it is assumed that S_d and S_r are known (same for S_{e11}). Applying the same method to the output yields

$$S_r \frac{T_{s12}}{T_{s22}}\left(S_{r22} - \frac{S_d T_{d21} - T_{t21}}{S_d T_{d22} - T_{t22}}\right)$$

$$= -\frac{T_{d21} - S_d T_{t21}}{T_{d22} - S_d T_{t22}} + S_{r22} \quad (A24)$$

where S_{s11} and S_{s22} are fully determined if S_d and S_r are known.

S_d Calculation

Equation A21 is used to extract S_d, and the second-order equation becomes

$$S_d^2 (T_{t11} T_{t22} - T_{t12} T_{t21}) + S_d \bullet (T_{d21} T_{t12} + T_{d12} T_{t21} - T_{d11} T_{t22} - T_{d22} T_{t11}) + (T_{d11} T_{d22} - T_{d12} T_{d21}) = 0$$

Only an indetermination remains to be solved (which root to choose) to obtain the value of S_d.

S_r Calculation

In fact, S_r will not be calculated, but a way to extract S_{e22} and S_{s11} without knowing it will be determined. By dividing Equation A23 by Equation A24 to obtain S_{e22}/S_{s11} (= A) and dividing Equation A14 by Equation A18 to obtain $S_{e22} \times S_{s11}$ (= B), S_{e22} and S_{s11} are now calculated as

$$S_{e22} = \pm\sqrt{AB} \qquad S_{s11} = \pm\sqrt{\frac{A}{B}}$$

As before, the indetermination of the sign of the square root must be solved.

ADAPTIVE FEEDFORWARD LINEARIZATION FOR RF POWER AMPLIFIERS

The design of RF power amplifiers has become increasingly complex. With modern radio communications systems focusing on ever-higher data rates and better spectral efficiencies, these challenges to amplifier design will continue. Modulation schemes such as multilevel linear quadrature amplitude modulation (QAM) increase spectral efficiency yet their operating envelopes fluctuate, making this approach much more sensitive to the inherent nonlinear component of power amplifier behavior — the major source of nonlinear distortion in microwave transmitters. The traditional approach to the distortion problem is to back off the output power of a class A power amplifier until it operates within a linear region and distortion is reduced to an acceptable level (that is, where average output power is much smaller than saturation power). Unfortunately, this course of action increases cost and reduces efficiency for amplifier design.

"Adaptive feedforward linearization, while based on a concept developed many years ago, represents an optimized approach to solving the problem of IM distortion in multichannel, wideband applications."

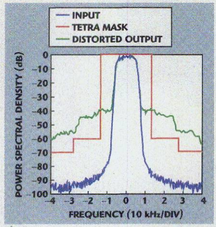
As supplementary stages are added to allow the amplifier to maintain transmitted power levels, more DC power is consumed. Further, with efficiency so critical for battery-operated systems and designs with limited enclosure space for heat dissipation, linearization of a power-efficient class AB amplifier is a much more desirable alternative to backing off output power. Class AB power amplifiers provide approximately 25 percent efficiency and are more power efficient than class A amplifiers, which only attain approximately five percent efficiency. Class AB amplifiers also exhibit gain roll off at low input powers and at saturation.

The industry continues to embrace linear modulation techniques such as quadrature phase-shift keying (QPSK), 64-state QAM (64QAM) and multicarrier configurations. As this trend continues, active linearization of the power amplifier will remain a key technology for reducing nonlinear distortions. The transmitted signal from one of these modern linear modulation schemes may exhibit a fluctuating envelope, which generates intermodulation (IM) distortion in the power amplifier. Today's digital communication systems typically use very narrow channel spacing and require better distortion performance than analog systems. Since most of the IM power appears as interference in adjacent channels, it is critical that these systems utilize a highly linear power amplifier.

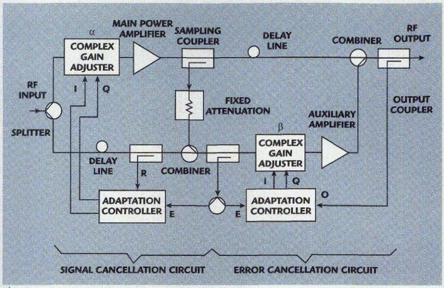
Unfortunately, power amplifiers are devices that exhibit both linear and nonlinear behavior, and these characteristics have a tendency to change over time due to repeated exposure to temperature changes, voltage variations,

[Continued on page 139]

SHAWN P. STAPLETON
Simon Fraser University,
School of Engineering Science
Burnaby, B.C., Canada



▲ *Fig. 1 The power spectra of a class AB power amplifier with π/4 DQPSK modulation.*



▲ *Fig. 2 Key components of an adaptive feedforward linearizer.*

channel changes and aging. Therefore, any robust linearization approach must incorporate the capacity for adaptability. Adaptive feedforward linearization represents just such an approach — one that has the distinct advantage of being able to handle wide bandwidths while continuously adjusting for component drift and power level changes.

DESIGN CHALLENGES

Power amplifier nonlinearity is typically characterized by amplitude-dependent gain variation (AM/AM) and amplitude-dependent phase shift (AM/PM). However, in addition to nonlinearities, RF amplifiers also possess memory, that is, the output signal depends on the current value of the input signal as well as previous input values spanning the memory of the amplifier.

Other design constraints are the result of regulatory bodies, which specify power spectral density masks defining the maximum allowable adjacent-channel interference (ACI) levels. For example, ***Figure 1*** shows the application of a mask specified by the trans-European terrestrial trunked radio (TETRA) standard that uses a π/4 differential QPSK (DQPSK) modulation format with a symbol rate of 18 kHz and channel spacing of 25 kHz. A class AB power amplifier operating at a back-off power of 3 dB is shown superimposed on the mask to illustrate how the distorted output falls outside the specification.

FEEDFORWARD LINEARIZATION

The idea of using negative feedback for linearizing amplifiers is not new. First described in 1927 by H.S. Black of Bell Telephone Laboratories,[1] the concept of feedforward is simple. If the amplifier output is reduced to the same level as the input, the difference between the input and output is only the distortion generated by the amplifier. Further, if this resulting distortion is then amplified using a different amplifier and subtracted from the original amplifier output, theoretically only a linear amplification of the input signal remains.

Figure 2 shows a schematic illustrating the key components of the feedforward linearizer circuit. Feed-

[Continued on page 141]


From Milliwatts to Megawatts
SPECIALIZED
Microwave Components
PRODUCT RANGE:
TRAVELING WAVE TUBES
MAGNETRONS
PASSIVE COMPONENTS
LOW NOISE AMPLIFIERS
INTEGRATED MICROWAVE ASSEMBLIES
COMPLETE FRONT ENDS
FOR:
AVIONICS
DEFENSE
COMMUNICATIONS
MEDICAL
INDUSTRIAL
CUSTOM DESIGN PRODUCT DEVELOPMENT
WORLD CLASS CUSTOMER & PRODUCT SUPPORT
Shopping for microwave products couldn't be easier. EEV is world renowned as the company with a wide range of components across the entire microwave spectrum. Now with the integration of solid-state activities EEV can offer even more innovative integrated solutions for your requirements.
EEV
A SUBSIDIARY OF THE GENERAL ELECTRIC COMPANY PLC OF ENGLAND
USA: EEV, Inc.
Telephone: (914) 592-6050
Toll Free: 1800 DIAL EEV
Facsimile: (914) 682-8922
E-mail: info@eevinc.com
CANADA: EEV Canada Ltd.,
Telephone: (905) 678 9811
Facsimile: (905) 678 7726
E-mail: info@eevinc.com
UK: EEV Ltd.,
Telephone: +44 (0)1245 493493
Facsimile: +44 (0)1245 492492
E-mail: info@eev.com
www.eev.com
CIRCLE 37 ON READER SERVICE CARD

forward linearization really utilizes two circuits: an input signal cancellation circuit and a distortion (or error) cancellation circuit. The incoming signal is split into two paths. The upper path, or signal-cancellation circuit, contains a complex gain adjuster and primary power amplifier. The signal-cancellation circuit's complex gain adjuster alters the amplitude and phase so that the input reference signal is cancelled from the primary power amplifier's output, leaving an error signal that contains both the linear and nonlinear components of the amplifier distortion.

The second path, or error-cancellation circuit, carries a replica of the primary output with the amplified signal plus distortion but with latency added to match the delay in the upper path. The distortion-only signal from the upper path is fed to the lower path. There the signal is amplitude and phase adjusted by a complex gain adjuster and combined with the delayed power amplifier's output, eliminating the distortion. The linear distortion component is due to deviations of the amplifier's frequency response from flat gain and linear phase.[2] Note that distortion from memory effects also can be compensated using the feedforward technique since these effects are included in the error signal.

Looking again at the diagram, the values for the sampling coupler and fixed attenuation should be chosen to match the gain of the primary amplifier. Variable attenuation is included in the circuit to enable the output level to be precisely adjusted to match the input reference, while the variable phase shifter adjusts the power amplifier output in an antiphase arrangement with the input reference. The delay line in the error-cancellation branch of the circuit is necessary for wide-bandwidth operation and compensates for the group delay of the primary amplifier by time aligning the power amplifier output and reference signals before they are combined. The error-cancellation circuit is used to suppress the distortion component of the power amplifier output, leaving only the linear-amplified component of its output signal. In order to suppress the distortion component of the signal, the gain of the power amplifier used in the error-cancellation circuit must be carefully chosen to match the sum of the effects of the sampling coupler, fixed attenuator and output coupler. Thus, the error signal is amplified to approximately the same level as the distortion component in the power amplifier output signal.

Since feedforward linearization is based on subtracting nearly equal quantities in the signal-cancellation loop, its major parameters must adapt to changes in the operating environment. In the mid-'80s and early '90s, many patents covering adaptive feedforward systems were filed. These patents encompass two general methods of adaptation, both with and without the use of pilot tones. The first is an adaptation based on power minimization;[3] the second is an adaptation based on gradient signals.[4]

The control scheme for power minimization adaptation is based on trying to adjust the complex-vector modulator in the signal-cancellation circuit. Theoretically, this process minimizes the measured power of the error signal in the frequency band occupied by the reference signal. The frequency range chosen for the error-cancellation circuit includes only the bands occupied by the distortion. Once the optimum parameters have been achieved, deliberate perturbations are required to continuously update the coefficients, which reduces the effects of IM distortion suppression.

Adaptive feedforward based on the use of gradient signals requires a continuous computation to estimate the gradient of a three-dimensional power surface. The surface for the signal-cancellation circuit consists of the power in the error signal. This power is minimized when the reference signal is completely suppressed, leaving only distortion. The surface for the error-cancellation circuit is the power in the linearizer-output signal, and the power is minimized when the distortion is completely suppressed from the primary power amplifier's output signal. Since the gradient is continually computed, no deliberate misadjustment is required.

[Continued on page 143]

High Performance and Low Cost Electromagnetic Simulation and Optimization Tools

From: Zeland Software, Inc., 39120 Argonaut Way, Suite 499, Fremont, CA 94538, U.S.A.,
Phone: 510-797-8109, Fax: 510-797-8241, E-mail: zeland@zeland.com, Web: http://www.zeland.com

Products:

IE3D Planar and 3D Electromagnetic Simulation and Optimization Package

FIDELITY Time-Domain FDTD Full 3D Electromagnetic Simulation Package

Applications:

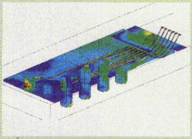
Microstrip, CPW, striplines, suspended-strip lines, coaxial Lines, rectangular waveguides, high speed digital transmission lines, 3D interconnects, PCB, MCM, HTS circuits and filters, EMC/EMI, wire antennas, microstrip antennas, conical and cylindrical helix antennas, inverted-F antennas, antennas on finite ground planes, and other RF antennas.

Features:

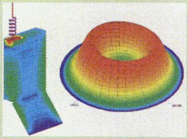
- MS-Windows graphic interface for interactive construction of geometry
- High efficiency and flexibility MOM and FDTD simulation engines
- Non-uniform automatic meshing and de-embedding
- Modeling 3D metallic and dielectric structures
- Built-in robust and efficient electromagnetic optimization
- Accurate modeling of metallic thickness, thin substrate and lossy dielectric materials
- Mixed electromagnetic simulation and nodal analysis for large scale simulation
- Cartesian and Smith Chart display of S-, Y- and Z-parameters, VSWR
- RLC parameter extraction compatible with SPICE
- 2D and 3D display of current distribution, radiation patterns and near field
- Calculation of antenna and scattering parameters including directivity, efficiency and RCS
- Current and near field animation

IE3D Simulation Examples and Display

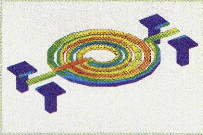
The current distribution on an AMKOR SuperBGA model at 1GHz created by the IE3D simulator



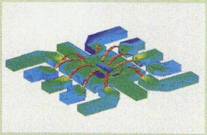
The current distribution and radiation pattern of a handset antenna modeled on IE3D



IE3D modeling of a circular spiral inductor with thick traces and vias

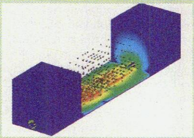


IE3D modeling of an IC Packaging with Leads and Wire Bonds

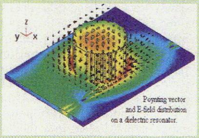


FIDELITY Examples

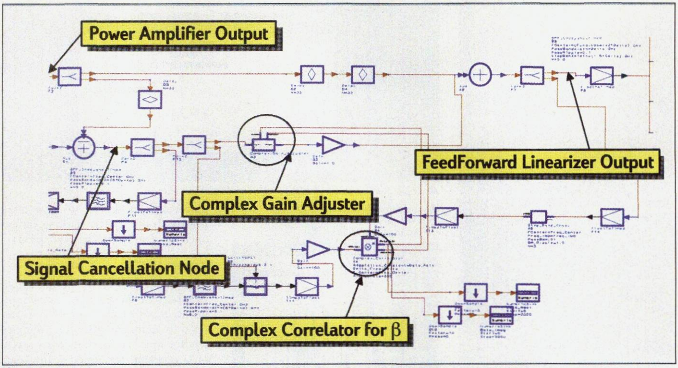
The near field and Poynting vector display on a packaged PCB structure with vias and connectors



FIDELITY modeling of a cylindrical dielectric resonator and the Poynting vector display



Zeland Software, Inc. provides excellent technical support and services.
Zeland Software, Inc. is also the north American exclusive representative for the LINMIC product from Jansen Microwave GmbH



▲ *Fig. 3 The feedforward error-cancellation loop based on the gradient-adaptation method created in HP ADS.*

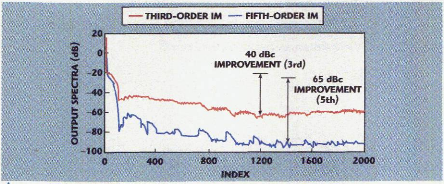
A GRADIENT ADAPTATION FEEDFORWARD LINEARIZER EXAMPLE

Figure 3 shows an example circuit schematic for the error-cancellation loop in a feedforward linearizer based on the gradient-adaptation method created by the Hewlett-Packard Advanced Design System (HP ADS). A rectangular implementation is used for the complex gain adjuster. The input is of a two-tone modulation with the following specifications: $K\alpha = -0.1$ adaptation rate and $K\beta = -0.01$ adaptation rate. A rectangular vector modulator is used, and the circuit operates at 5 dB back off from the 1 dB compression point. Ideal passive components are assumed.

When implementing this circuit, care must be taken in the choice of adaptation parameters. The best approach is to ensure that the signal-cancellation loop (α adaptation coefficient) has converged to within a small variance before the error-cancellation loop (β adaptation coefficient) begins to converge.

When gradient-based adaptation is used, delay must be added to the upper branch of the error-cancellation loop to ensure proper cancellation. If feasible, a bandstop filter may be incorporated after the output coupler to reduce the linear portion of the output signal. This configuration effectively speeds up the adaptation process. If the power minimization method is employed, then a bandpass filter is used to sample the output IM distortion.

[Continued on page 144]



▲ *Fig. 4 IM improvement at the feedforward linearizer output.*

Fig. 5 The resulting output using 5 dB back off at (a) the initial state and (b) after the coefficients have adapted. ▼

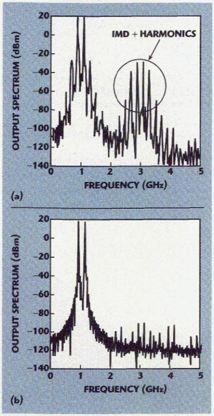


Figure 4 shows the level of improvement exhibited in both third- and fifth-order IM levels at the output of the feedforward linearizer in the first simulation. In the example, the signal-cancellation loop is allowed to converge before the error-cancellation loop is turned on to avoid instability. This condition can occur if close attention is not paid to the adaptation procedure. The error-cancellation loop takes more time to optimize than the signal-cancellation loop because of the order of magnitude difference in adaptation rates. Taking the example a step further, if the power amplifier is driven using 5 dB of back off, high levels of IM power and harmonics are generated. ***Figure 5*** shows the resulting output once the coefficients have adapted.

CONCLUSION

As the duties of RF power amplifiers become increasingly complex, innovative approaches must be developed to minimize distortion. Adaptive feedforward linearization, while based on a concept developed many years ago, represents an optimized approach to solving the problem of IM distortion in multichannel, wideband applications. The linearization example presented here demonstrates the kind of performance that can be achieved with feedforward linearization. System-level simulation provides a solid starting point for carrying out an implementation quickly since designed components can be integrated into the system to gauge the impact on overall performance. ■

References

1. H.S. Black, "Inventing the Negative Feedback Amplifier," *IEEE Spectrum*, December 1977, pp. 55–60.
2. H. Seidel, "A Microwave Feedforward Experiment," *Bell Systems Technical Journal*, Vol. 50, No. 9, November 1971, pp. 2879–2918.
3. M.G. Oberman and J.F. Long, "Feedforward Distortion Minimization Circuit," U.S. Patent 5,077,532, December 31, 1991.
4. J.K. Cavers, "Adaptation Behavior of a Feedforward Amplifier Linearizer," *IEEE Transactions on Vehicular Technology*, Vol. 44, No. 1, February 1995, pp. 31–40.

Shawn P. Stapleton *has 17 years of experience in RF and microwave circuit and systems design. He is currently a professor of electrical engineering at Simon Fraser University in Burnaby, British Columbia, Canada, as well as a consultant for HP EEsof. He has developed GaAs MMIC components, including mixers, amplifiers, frequency dividers and oscillators. His most recent projects include digital signal processing, mobile communications and RF/microwave systems.*

MICROWAVE MCM-C UTILIZING LOW LOSS LTCC AND PHOTO-PATTERNING PROCESSES

Microwave applications at frequencies in excess of 1 GHz, such as wireless devices, are well suited to ceramic construction. Other circuit fabrication technologies do not exhibit the same balance of low loss, precise geometries, cost and reliability. In addition, ceramic technology has the ability to provide greatly enhanced functionality by integrating buried passive components. A further requirement stems from the increasing use of flip-chip technologies, which provide compact assemblies with good microwave characteristics suitable for volume production. Many alternative technologies fail to provide the appropriate interconnect density and, in the case of polymer circuits, require an expensive under fill process. This article describes a new low loss low temperature cofired ceramic (LTCC) technology that, when combined with a photo-patterned thick-film technology, offers outstanding interconnect density and microwave performance. The ability to combine the efficiency of cofired ceramic with multiple out photo processing leads to low cost systems solutions involving multichip module with cofired substrate (MCM-C) technology. Data are presented to show the outstanding performance available both as microstrip lines and other circuit components, extending the application of LTCC into the 30 GHz and higher range of frequencies.

As frequencies increase toward 40 GHz for many applications, circuit technology and performance become increasingly critical. Line loss rises with frequency, making the loss characteristics of the technology particularly important. At the same time, dimensions decrease, making geometrical properties critical. Conventional technologies, with the exception of thin-film circuitry, struggle to meet these needs. However, thin-film technology, which is expensive to manufacture, is not suited to the newer volume requirements.

Lower microwave frequency circuits are often manufactured using conventional FR4 or similar laminate materials. Unfortunately, these materials exhibit excessive loss, which becomes particularly significant as frequencies rise. An additional problem is the poor dimensional stability of laminate materials, with both temperature and humidity having a significant effect on dimensions. Again, this problem be-

[Continued on page 148]

PETER BARNWELL,
MICHAEL P. O'NEILL
AND CHARLES SABO
Heraeus Inc., Cermalloy Division
West Conshohocken, PA
CHARLES FREE
Middlesex University
London, UK

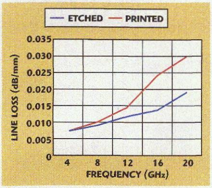
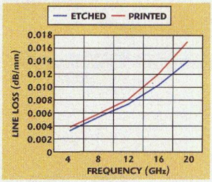


Fig. 1 Line loss with 96 percent alumina, 0.635 mm line width.

Fig. 2 Line loss with 99.5 percent alumina, 0.635 mm line width.



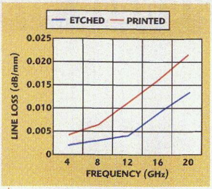
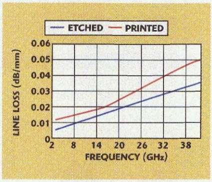


Fig. 3 Line loss with 99.6 percent alumina, 0.635 mm line width.

Fig. 4 Line loss for a 250 μm line, 99.6 percent alumina.



comes increasingly significant with increasing frequency. What is needed is a ceramic-based technology that can offer several advantages, including low dielectric loss; a precisely defined dielectric constant that is stable with frequency; precise, stable dimensions; excellent thermal management; integrated passive components; and low costs due to multiple out parallel processing.

Conventionally, ceramic technologies for high volume manufacture have used thick-film technology, sometimes in conjunction with LTCC. Unfortunately, the precision of the lines fabricated with thick-film technology, while capable of fabricating low loss lines, does not allow the fabrication of precise geometries for devices such as filters and couplers. Furthermore, conventional LTCC technology is high in dielectric loss (10^{-2}) and relatively high in dielectric constant (typically 8). These problems are unfortunate since the parallel manufacturing technology and integrated components available with LTCC offer a very cost-competitive technology.

A family of photo-patterned thick-film materials has been developed to address the lack of precision in thick-film technology. These materials offer excellent microwave performance. In conjunction with this, a novel low dielectric constant, low loss LTCC material has been developed that offers outstanding capabilities when used with the photo-patterned materials.

PHOTO THICK-FILM MEASUREMENTS

Photo-processed thick-film technology has been discussed extensively elsewhere[1,2] and will not be discussed in detail here. It consists of an etchable high density gold or silver conductor and a photo-sensitive, low loss dielectric. A full program of tests on microstrip lines using this technology on various substrates was performed recently and the results are presented.

It was decided to investigate microstrip lines using 96 percent, 99.5 percent and 99.6 percent alumina. The 96 percent alumina was (as fired)

Coors ADS96F, the 99.5 percent alumina was Coors roll compacted as fired and the 99.6 percent alumina was Coors, lapped to a surface finish of 10 µin. It is particularly significant to compare the performance of these different materials because they vary significantly in cost: The 96 percent alumina is the least expensive with the 99.5 percent alumina being approximately twice the cost and the lapped 99.6 percent alumina at least 10-times the cost. The different performance of the materials on these different cost substrates is considered to be vital data for a microwave designer.

At the same time the loss of etched lines was measured, direct printed lines were measured to provide a performance comparison between the two technologies. All etched lines were fabricated using Heraeus KQ500 gold; printed lines were fabricated using KQ550 gold. Due to the fine line printing capability of the KQ550, it was possible to realize lines with widths very similar to those of the etched lines.

The majority of the work was carried out on 0.635 mm (25 mil) thick alumina with measurements up to 20 GHz. A microstrip line width of 0.635 mm was used to produce a 50 Ω impedance. Above this frequency, thinner substrates are needed to ensure correct microstrip propagation, therefore, a 0.25-mm (10 mil) substrate thickness and line width was adopted. Measurements were made up to 40 GHz with these substrate dimensions. The measurements used both a direct pass through and a meander line on a 2 in^2 substrate. The substrate was then mounted in a Wiltron jig.

PHOTO THICK-FILM PERFORMANCE

The results obtained from the measurements described are shown as plots of loss in decibels per millimeter. ***Figures 1***, ***2*** and ***3*** show the results obtained with 96 percent alumina, 99.5 percent alumina and 99.6 percent lapped alumina, respectively. It can be seen immediately that, as expected, the etched lines show a significant performance advantage over the printed lines. However, this advantage is significant only above approximately 8 GHz and is relatively small for the 99.5 percent alumina. In all cases, the etched lines show excellent performance. Even on 96 percent alumina the etched lines show performance comparable with published figures for thin film.

These results could be interpreted as indicating that direct printed lines are acceptable as a general-purpose microstrip line technology at these frequencies. This capability is certainly the case for simple transmission lines. However, if these lines are used as part of a component, it is not just the loss that is significant, but also the geometrical precision. For example, if an edge-coupled filter is being fabricated, it is likely to require line widths and spacing of 75 µm or better. Even though it may be possible to achieve this goal by direct printing, the tolerance on the dimensions is likely to be on the order of 25 µm. This tolerance makes the performance of the resulting component subject to wide variations in bandwidth and center frequency. The etched line, on the other hand, has an edge tolerance of 1 µm and produces a far more stable and reproducible component.

Further conclusions can be drawn from these three plots. First, it can be seen that loss reduces with the higher purity, higher cost substrates. However, this improvement is a small difference only, making the lower cost substrates suitable for circuit fabrication. Second, the difference between the printed and etched line on the 99.5 percent material is smaller than with the other materials. This result is believed to be due to the nature of the substrate surface allowing high quality printing, but will be the subject of further evaluation. ***Figure 4*** shows a plot of loss vs. frequency for the thin, 250 µm line on 0.25 mm thick, 99.6 percent lapped alumina. It can be seen immediately that the line loss rises steadily with increasing frequency but is linear, indicating no problems with dispersion. Again, the loss is higher in the printed line compared to the etched line. Finally, the loss at 20 GHz is only 20 percent higher than for the wider 0.635-mm line. These results indicate excellent low loss behavior of the microstrip line on a thin alumina substrate.

LOW LOSS LTCC

Although the classic microstrip line on alumina discussed previously is of great interest, it is somewhat limited in the fabrication of complex circuits. What is needed is the ability to build multilayer patterns, incorporate resistors and other passive components and, hence, realize a complete structure. While this goal can be achieved using thick-film multilayer technology, the use of an LTCC process allows complex, low cost structures to be built in high volume. The reduction in processing steps with LTCC is significant and multiple out circuits can be fabricated readily. Unfortunately, as noted, LTCC tends to offer a high loss, high dielectric constant material that is not suitable for microwave interconnect.

As a result of these limitations, a new low loss dielectric material has been developed based on the KQ dielectric material referenced earlier. This tape can be fabricated in various fired thicknesses from 75 μm. The material allows the ready fabrication of structures where the microstrip line can be fabricated on top of the tape to produce the thin dielectric material required for operation at higher microwave frequencies. The process can be taken a step further with the fabrication of lines buried within the tape to form stripline and similar structures. With the inclusion of general interconnect and passive components, a complex integrated high performance structure can be readily built.

The low loss tape has been measured at X-band (8 to 12 GHz), yielding a dielectric constant of 3.94 and a loss factor of 5×10^{-4}. It can be seen that the required low loss is achieved together with the advantage of a low dielectric constant.

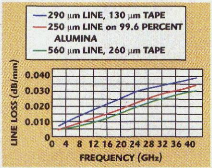
LTCC IN COMBINATION WITH PHOTO THICK FILM

In order to realize the structures allowable with the low loss LTCC, compatible materials of appropriate performance are required. The photo-patterned KQ materials discussed earlier prove ideal for this task. Even with a low dielectric constant of 3.94, a 75 μm tape thickness requires a narrow 150 μm line width for a 50 Ω impedance. Conventional LTCC processes can realize such line widths, but with poor tolerance. KQ photo processing can readily achieve such dimensions with excellent edge acuity.

Structures combining low loss LTCC and KQ photo-processed conductors have been built, allowing the use of a thin tape material with good connection to the ground plane. Two alternative versions of the structure were fabricated — one with a fired tape thickness of 130 μm and one with a fired thickness of 260 μm. The line widths were designed to provide a 50 Ω impedance (using the 3.94 dielectric constant), resulting in line widths of 290 and 560 μm, respectively. Loss was measured using a comparison between a straight through line 50 mm long in

[Continued on page 152]

Limited Space?
Your solution is Dow-Key's line of miniature electro-mechanical switches
Do you need a miniature switch for your matrices, your microwave radio or to select an alternating antenna? Do you need a miniature switch to bypass a circuit element or to act as a direct input to output insertion? Do you need a miniature switch to provide simultaneous reception and transmission of signals?
If you do, then Dow-Key's low cost, miniature switches, operating to 3 GHz, are your solution. The product line includes a SPDT failsafe switch, a DPDT Bypass switch, and a DPDT Transfer switch. Designed to be PCB mounted, these 50 ohm impedance switches can be hot switched at 10W CW to 3 GHz without performance degradation and can handle up to 50W CW at 1 GHz.
If unprecedented customer service, on-time delivery, and the highest quality switch products with unsurpassed reliability at the right price are your requirements . . .
DOW-KEY MICROWAVE is your solution.
DowKey® Microwave
CORPORATION
4822 McGrath Street
Ventura, CA 93003-5641
Tel: (805) 650-0260 • Fax: (805) 650-1734
Visit us at www.dowkey.com
A DOVER TECHNOLOGIES COMPANY
CIRCLE 32 ON READER SERVICE CARD



▲ *Fig. 5 Line loss for a 50 Ω KQ line on tape and alumina.*

comparison with a meander line of 110 mm. This procedure allowed for any losses in the interface with the Wiltron jig to be isolated.

Measurements of line loss are shown in ***Figure 5***. It can be seen immediately that the 290 µm line produces a loss of 0.039 dB/mm at 40 GHz, which is approximately 14 percent greater than the similar 250 µm line on 99.6 percent lapped alumina. The wider line on the thicker material produces a loss of 0.03 dB/mm at 40 GHz, 12 percent lower than on 99.6 percent alumina. These results are considered to be excellent and show the outstanding applicability of this technology to building microwave structures.

The small sizes that result allow the parts to be manufactured as multiple out circuits on a relatively large substrate. The photo-processing technique is also suitable for multiple out work, guaranteeing accurate alignment over a large surface area. These benefits offer mass production cost benefits similar to those found in integrated circuit and printed circuit board fabrication and make the technology ideal for economical high volume production as required by current telecommunications applications.

CONCLUSION

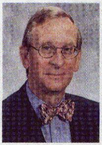
The performance of photo-processed thick-film conductors up to at least 40 GHz has been demonstrated and excellent results have been obtained. Using this knowledge, a low loss LTCC tape material with good microwave properties has been demonstrated. What is now needed is a fully integrated, cofireable LTCC system that allows the production of high performance components together with integrated passive components. The cost benefits resulting from such a structure will be considerable and research and development work is being directed into this area. The combination of these materials and processes will lead to the realization of compact, low cost, high performance microwave structures.

ACKNOWLEDGMENT

The authors would like to acknowledge Bill Lorelli and Jim Wood at Heraeus for their great assistance with LTCC structure fabrication. The support of Susan Munyon at Coors Ceramics has also been invaluable. Portions of this paper were presented at the International Conference and Exposition Exhibition on High Density Packaging and MCMs in Denver, CO, April 6–9, 1999. ■

References

1. P.G. Barnwell and J. Wood, "A Novel Thick-film on Ceramic MCM Technology Offering MCM-D Performance," *Proceedings of the Sixth International Conference on MCMs*, Denver, CO, April 1997, pp. 48–52.
2. P.G. Barnwell, C. Free, L. Chin and C. Aitchison, "A Novel Thick-film on Ceramic Microwave Technology," *Proceedings of the 1998 Asia Pacific Microwave Conference*, December 1998.



Peter Barnwell *received his BSc and PhD degrees in applied physics from City University, London, and has worked in the hybrid microelectronics industry for more than 30 years. His technical specialization has concentrated on RF and microwave properties of thick-film technology. Barnwell has published more than 70 technical papers, including several at the annual International Microelectronics and Packaging Society (IMAPS) Conference in the US. He is currently president of IMAPS Europe. In addition, Barnwell is business manager for Advanced Materials and Telecommunications Applications at Heraeus Inc., Cermalloy Division, where he has established new technologies in the marketplace and interfaced with both circuit manufacturers and systems companies.*

Michael P. O'Neill *received his BS degree in industrial engineering from Drexel University and has worked in the electronic materials industry for 14 years. He has held various positions in research and development, technical service, market development and sales with DuPont Microcircuit Materials. Currently, he is sales and marketing manager for Thick Film and Advanced Materials with Heraeus Inc., Cermalloy Division. O'Neill has authored or co-authored a number of papers on thick-film and LTCC materials and applications and is a member of IMAPS.*

Charles Sabo *received his BS and MS degrees in metallurgical engineering from Lafayette College and Purdue University, respectively. He spent three years as a member of the technical staff at the Microelectronics Circuits Division of Hughes Aircraft Co., and has been with Heraeus Inc.'s Cermalloy Division for the past 11 years in the position of senior quality assurance engineer and senior research metallurgist. Currently, he is technical service manager for Advanced Packaging responsible for the company's KQ and LTCC product lines. Sabo has co-authored eight papers dealing with material aspects of microelectronic packaging and is a member of IMAPS.*

Charles Free *is a principal lecturer and leader of the Communications Research Group at Middlesex University in the UK. He is the author of 50 technical and scientific papers and his current research interests are in dielectric measurements at microwave frequencies, microstrip antennas, high frequency MCM design, microstrip phase shifters and digitally controlled microwave oscillators.*

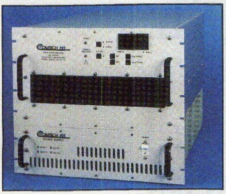
50 WATT GaAs FET POWER AMPLIFIER

Model ARD88258-50 operates over the 800 to 2500 MHz frequency band with 50 watts of output power (1 dB compression point). Gain is 47 dB minimum with a noise figure of 10 dB typical. An integral IEEE-488 interface provides full monitor and control of amplifier functions. Typical Intermodulation Distortion of <-30 dbc at 5o watts PEP. Size is 8.75"H x 19"W x 24"D.

Comtech PST Corp.
Melville, NY 11747 (516) 777-8900

CIRCLE 23 ON READER SERVICE CARD

250 WATT GaAs FET POWER AMPLIFIER SYSTEM

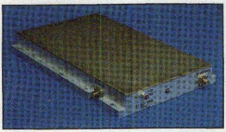


Model ARD1929-250 is a solid state, Class A RF power amplifier system operating in the 1000 to 2000 MHz frequency range with a power output of 250 watts (400 watts saturated) at the 1 dB compression point. It is broad-band and laboratory-quality, with a gain of 53 dB min. and 12 dB max.noise.

Comtech PST Corp.
Melville, NY 11747 (516) 777-8900

CIRCLE 24

MODEL AM19258-50



Model AM19258-50 operates over the 1000 to 2500 MHz frequency band with 50 watts of output power. Gain is 54 dB nominal with a small signal gain flatness of ± 3.0 dB.

Size is 18"L x 12"W x 1"H and operates over the 0 to +71°C baseplate temperature range.

Comtech PST Corp.
Melville, NY 11747 (516) 777-8900

CIRCLE 25 ON READER SERVICE CARD

A Transceiver Chipset for 2.4 GHz Direct Sequence Spread Spectrum Applications

The 2.4 GHz industrial, scientific and medical (ISM) band is coming of age, largely due to the coincidental emergence of three wireless local area network (LAN) standards. However, there are still relatively few products designed for this band that offer an attractive combination of performance, size and cost.

Wireless LAN systems have been hyped for many years with very limited success, but there are encouraging signs that this market will finally emerge. The segmentation of this market is still unclear since some of the standards appear to overlap. For example, the Home RF Working Group's shared wireless access protocol (SWAP) specification calls for 800 kbps and 1.6 Mbps data rates, while Bluetooth radios provide 1 Mbps with hopes to move to 2 Mbps later. The first IEEE802.11 wireless LAN specification was ratified in 1997 with a 2 Mbps maximum data rate but is quickly moving on to an 11 Mbps standard, a speed that clearly differentiates it from other alternatives. For the first time, a wireless LAN offers performance competitive with existing wired systems.

What will finally enable the market is the right combination of data rate and price. The existence of the 11 Mbps IEEE standard is a key step; however, the cost of a wireless LAN radio is still too high and will inhibit market growth. While wireless LANs will remain more costly than Ethernet hardwire networking, it is clear that, in many applications, mobility has great value.

The model RF2938 RF/IF transceiver IC forms the core of the wireless LAN radio design and offers high performance, low power and high integration at a cost that makes discrete designs inefficient and other integrated approaches expensive by comparison. Other applications, such as wireless modems and wireless local loop (WLL), will also benefit from the versatility and integration level of the RF2938 IC.

[Continued on page 156]

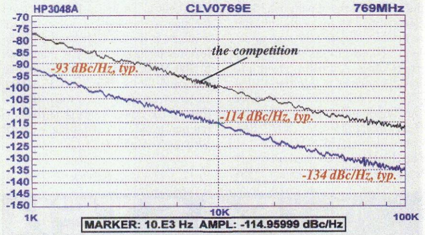
RF Micro Devices
Greensboro, NC

All VCOs should be this good . . .

Setting the standard for VCO performance.

Designing today's advanced radios is tough enough when you have VCOs that don't give you the margin you need. Our CLV line of patented ultra-low noise VCOs will give you that margin ... and more!

Part No:	Freq. Range:	V_{tune}	Φ_n at 10kHz	V_{supply}
CLV0769E	734-804	1-4	-112	5
CLV0815E	806-824	0.5-4.5	-113	5
CLV0945E	936-953	0.5-4.5	-114	5
CLV1320E	1295-1335	1-5	-113	5
CLV1525E	1500-1550	0.3-4.7	-110	5

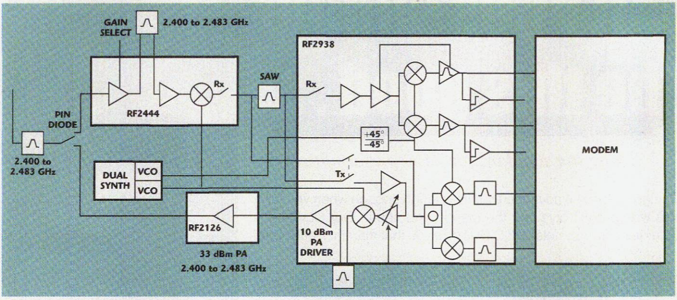


Learn more about Z-COMM's CLV product line by visiting our web site at http://www.zcomm.com/ for datasheets, outline drawings, tape and reel specifications, and application notes, as well as our complete product catalog and custom VCO inquiry form.

Come to the source ...

Z-COMM.

Z-Communications, Inc.
9939 Via Pasar • San Diego, CA 92126
(619) 621-2700 • Fax: (619) 621-2722
WWW: http://www.zcomm.com/



▲ *Fig. 1 A complete chipset for the 2.4 GHz ISM band.*

AN IEEE802.11 CHIPSET

Figure 1 shows a high performance, low cost, IEEE802.11-compliant transceiver chipset designed for direct sequence spread spectrum (DSSS) communication in the 2.4 GHz ISM band. The RF2938 transceiver IC is designed using a state-of-the-art 24 GHz BiCMOS process and utilizes a single conversion architecture to optimize the system performance/cost trade-off. In half-duplex mode, the RF2938 IC saves the cost of one IF surface acoustic wave (SAW) filter by switching a single filter between RX and TX modes. Full-duplex mode is also available.

Linear amplifiers and 95 dB of gain control are used in the RX signal path to preserve signal amplitude, however, internal high speed comparators also offer data-sliced digital outputs. The TX signal path has 15 dB of gain control to make the chipset more flexible, allowing the system designer to choose filters with various insertion losses. A 6 dBm power amplifier (PA) driver is integrated that can drive an antenna directly or drive various highly efficient GaAs heterojunction bipolar transistor (HBT) PAs, which can deliver 1 W of power.

The chipset was designed specifically for an IEEE802.11-compliant DSSS system using biphase-shift keying (BPSK), quadrature phase-shift keying (QPSK) or the complementary code keying (CCK) modulation scheme proposed for the 11 Mbps standard but, with built-in flexibility, it can be used for many other applications and is not confined to the 2.4 GHz band. Flexible features include a broad IF range (45 to 500 MHz) and user-programmable baseband filters (from 1 to 35 MHz). In short-range applications, the +6 dBm of RF power available at the output may avoid the need for an external RF power amplifier.

[Continued on page 158]

TABLE I

RF2444 LNA/MIXER KEY SPECIFICATIONS

Noise figure (dB)	2.3
IF range (MHz)	45 to 500
Gain settings (dB)	25 or 10
Cascaded noise figure (high gain) (dB)	4
Supply voltage (V DC)	2.7 to 3.6
Current consumption (mA)	21
Package	16-pin SSOP

SIGNAL PATH

The front end of the receive signal path starts with a 2 dB noise figure low noise amplifier (LNA). An N-type MOS (NMOS) π-attenuator is placed directly after the LNA and either passes the signal or attenuates it by 15 dB. The signal moves off chip to the image filter then back on to the mixer, which is a double-balanced differential mixer with an additional pre-amplifier at its input that boosts gain and improves noise figure.

The choice of IF ranges from 45 to 500 MHz should allow the system designer to select from a wide range of available SAW filters. The IF automatic gain control (AGC) amplifiers have 50 dB of gain range and the baseband AGC amplifiers have another 30 dB of gain range, providing a total of 80 dB of gain range controlled by a single pin. Adding in the 15 dB gain step in the LNA yields 95 dB of total gain variation. Separating the gain between the IF and baseband frequencies adds frequency diversity to the system, which reduces the chance of instabilities and improves power supply rejection.

The baseband signal path also has four programmable lowpass filters (LPF) (I and Q in RX and TX). The internal LPFs are active gmCs, which realize a five-pole Bessel filter. A Bessel filter was chosen as the optimum filter type for data systems due to the flat passband group delay and excellent step response. The 3 dB corner for these four filters ranges from 1 to 35 MHz, and all are programmed simultaneously by a single external resistor.

The linear, filtered baseband outputs of the RX signal paths are also fed into a data slicer, which gives out CMOS levels. These data slicers can be independently disabled if the analog outputs only are desired. The TX signal path starts by lowpass filtering the input bits with the five-pole gmC Bessel filter. The signal is then upconverted to IF and the I and Q channels are combined and moved off chip to the external SAW filter. The IF signal is then amplified prior to upconverting to RF. This amplifier provides 15 dB of variable gain to allow correction for all the various IF and RF filter losses. This gain also may be adjusted in real time if necessary. Finally, the RF signal is boosted to 6 dBm prior to going off chip to one of the GaAs HBT PAs.

THE RECEIVER

RX Front End

The RF2444 contains the RX front-end LNA/mixer for this chipset. The LNA comprises two stages: a common emitter amplifier stage with 13 dB power gain and an NMOS π-attenuator that has an insertion loss of 3 dB in the high gain mode and 17 dB in the low gain mode. The attenuator was placed after the LNA so that system noise figure degradation would be minimized. A single gain stage was used prior to the image filter to maximize the third-order intercept point (IP3), which minimizes the risk of large out-of-band signals jamming the desired signal. The LNA + attenuator noise figure is 2.3 dB and the input IP3 is –6 dBm in the high gain mode. ***Table 1*** lists key specifications for the RF2444 LNA/mixer.

The mixer on the RF2444 also comprises two stages. The first stage is a common emitter amplifier used to boost the total power gain prior to the lossy SAW filter. This stage also converts the single-ended signal to differential and improves the noise figure of the mixer. The second stage is a double-balanced mixer whose output is differential open collector. It is recommended that a current combiner is used (as shown in ***Figure 2***) at the mixer output to maximize conversion gain, but other loads also can be used. The current combiner is used to perform a differential-to-single-ended conversion for the SAW filter. C1, C2 and L1 are used to tune the circuit for a specific IF. L2 is a choke to supply

[Continued on page 160]

UNCOMPROMISING HIGH POWER MULTI OCTAVE PERFORMANCE

CUSTOM DESIGNED HIGH POWER N-WAY COMBINERS

UP TO 20:1 BANDWIDTH CAPABILITY.
FREQUENCIES FROM 2 - 2000 MHz.
HIGH POWER EXPERIENCE TO 50 kW.

High Power Components Since 1965

Let us design a solution to suit your combining application.

Werlatone's high power custom N-Way Combiners are available with as few as 2 inputs to as many as 16. Combiners, operating at VHF frequencies and above, feature efficient air or teflon dielectric designs to assure low loss and high average / peak power performance. Our precision Combiner structures guarantee repeatability and high reliability, coupled with excellent phase and amplitude balance.

WERLATONE
DECADES AHEAD

WERLATONE Inc. • P.O. Box 47 • Brewster, NY 10509 • Telephone: (914) 279-6187 • FAX: (914) 279-7404

CIRCLE 187 ON READER SERVICE CARD

DC current to the mixer and also can be used as a tuning element, along with C3, if necessary. The conversion gain of this mixer is

$$\text{Power Conversion Gain (dB)} = 10\log_{10}(R1) - 11 \text{ dB}$$

The mixer power conversion gain is +19 dB when R1 is set to 1 kΩ. The conversion gain can be adjusted up ≈ 5 dB or down ≈ 7 dB by changing the value of R1. Once R1 is chosen, L2 and C3 can be used to tune the output for the SAW filter. The mixer cascade single-sideband (SSB) noise figure is 10 dB and IIP3 is –18 dBm.

The cascade power gain of the LNA/mixer is 29 dB. After the insertion loss in the image filter (≈ 3 dB) and IF SAW filter (≈ 10 dB), there is still 16 dB of gain prior to the IF amplifiers so the 5 dB noise figure of the IF amplifiers should not significantly degrade system noise figure.

RX IF AGC/Mixer

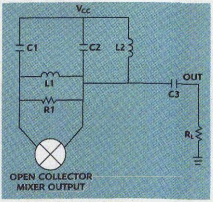
The front end of the IF AGC starts with a single-ended input and a constant gain amplifier of 15 dB. This first amplifier stage sets the noise figure and input impedance of the IF section, and its output is taken differentially. The rest of the signal path is differential until the final baseband output, which is converted back to single ended. Following the front-end amplifier are multiple stages of variable gain differential amplifiers giving the IF signal path a gain range of 0 to 50 dB. The noise figure (in maximum gain mode) of the IF amplifiers is 5 dB, which should minimally degrade the system noise figure. The IIP3 of the IF amplifiers is –68 dBm in maximum gain mode, and –8 dBm at minimum gain.

The IF-to-baseband mixers are double balanced, differential in, differential out types with 0 dB conversion gain. The LO for each of these mixers is shifted 90° so that the I and Q signals are separated in the mixers.

RX Baseband Amplifiers, Filters, Data Slicers and DC Feedback

At baseband frequency, multiple AGC amplifiers offer a gain range of 0 to 30 dB. Following these amplifiers are fully integrated gmC lowpass filters to further filter out-of-band signals and spurs that get through the SAW filter, anti-alias the signal prior to the analog-to-digital converter and band limit the signal and noise to achieve optimal signal-to-noise ratio. The 3 dB cutoff frequency of these LPFs is programmable with a single external resistor and continuously variable from 1 to 35 MHz. A five-pole, Bessel-type filter response was

Fig. 2 Current combiner for the mixer load.



[Continued on page 162]

chosen because it is optimal for data systems due to its flat delay response and clean step response. Butterworth- and Chebyshev-type filters ring when given a step input, making them less ideal for data systems.

The filter outputs drive the linear 500 mV p-p signal off chip, but also connect internally to a data slicer that squares up the signal to CMOS levels and drives this data signal off chip. This data slicer is a high speed CMOS comparator with 30 mV of hysteresis and self-aligned input DC offset. It can be independently disabled if only the linear outputs are desired.

DC feedback is built into the baseband amplifier section to correct for input offsets. Large DC offsets can arise when a mixer LO leaks to the mixer input and then mixes with itself. DC offsets also can result from random transistor mismatches. A large external capacitor is needed for the DC feedback to set the highpass cutoff, and this capacitor is re-used to set the DC input level for the self-aligned data slicer.

The receive signal path also has a received signal strength indicator (RSSI) output, which is the sum of both the I and Q channels. The RSSI has approximately 70 dB of dynamic range. ***Table 2*** lists key features of the RF2938 transceiver IC.

TABLE II

RF2938 TRANSCEIVER IC KEY FEATURES

IF (MHz)	45 to 500
Programmable baseband filters (MHz)	1 to 35
Cascaded Rx gain (dB)	to 90
Package	small 48-pin
Supply voltage (V DC)	3
Single IF SAW filter for half-duplex mode	
RF amplifier to 6 dBm (linear)	

LO INPUT BUFFERS

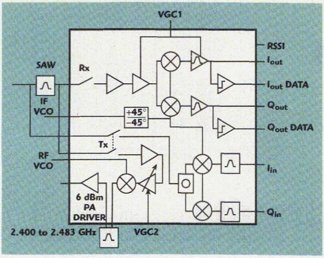
RF LO Buffer

The RF LO input has a limiting amplifier before the mixer on both the RF2444 (RX) and RF2938 (TX). This limiting amplifier design and layout are identical on both ICs, which will make the input impedance the same as well. Having this amplifier located between the VCO and mixer minimizes any reverse effect the mixer has on the VCO, expands the range of acceptable LO input levels and holds the LO input impedance constant when switching between RX and TX. The LO input power range is –18 to +5 dBm, which should make it easy to interface to any VCO and frequency synthesizer.

IF LO Buffer

The IF LO input has a limiting amplifier before the phase-splitting network to amplify the signal and help isolate the VCO from the IC. In addition, the LO input signal must be twice the desired IF. This requirement simplifies the quadrature network and helps reduce the LO leakage onto the RX_IF input pin (since the LO input is now at a different frequency than the IF). The amplitude of this input must be between –15 and 0 dBm. ***Figure 3*** shows a block diagram of the RF2938 transceiver IC in half-duplex mode.

▼ *Fig. 3 The RF2938 transceiver IC in half-duplex mode.*



TRANSMITTER

TX LPF and Mixers

The transmit section starts with a pair of five-pole Bessel filters identical to the filters in the receive section and with the same 3 dB frequency. These filters preshape and band limit the digital or analog input signals prior to the first upconversion to IF. These filters have a high input impedance and expect an input signal of 200 mV p-p (typ). Following these LPFs are the I/Q quadrature upconverter mixers. Each of these mixers is half the size and half the current of the RF-to-IF downconverter on the RF2444 IC. Recall that this upconverted signal may drive the same SAW filter (in half-duplex mode) as the RF2444 and, therefore, share the same load. Having the sum of the two baseband-to-IF mixers equal in size and DC current as the RF-to-IF mixer minimizes the time required to switch between RX and TX and facilitates the best impedance match to the filter.

TX Variable Gain Amplifier

The AGC after the SAW filter starts with a switch and a constant gain amplifier of 15 dB, which is identical to the circuitry on the receive IF AGC. This configuration was used (similar to the RX signal path) so that the input impedance remains constant for different TX gain control voltages. Following this 15 dB gain amplifier is a single stage of gain control offering 15 dB gain range. The main purpose of adding this variable gain is to give the system the flexibility to use different SAW filters and image filters with different insertion loss values. This gain also could be adjusted in real time if desired.

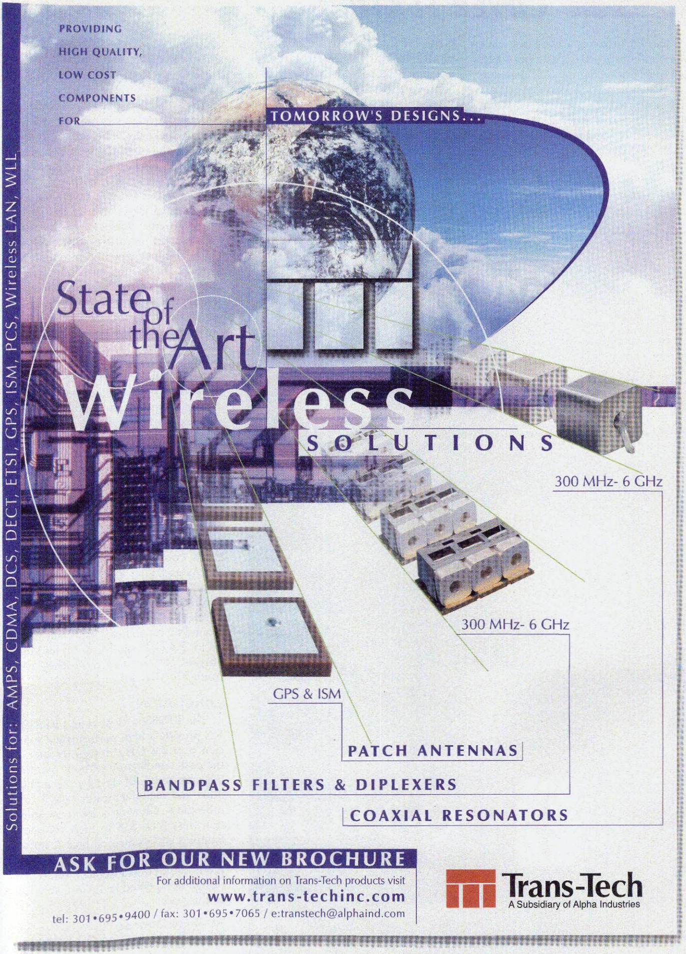
TX Upconverter

The IF-to-RF upconverter is a double-balanced differential mixer with a differential-to-single-ended converter on the output to supply 0 dBm peak linear power to the image filter. The upconverted SSB signal should have –6 dBm power at this point, and the image will have the same power. However, due to the correlated nature of the signal and image, the output must support 0 dBm of linear power to maintain linearly.

+6 dBm PA Driver

The SSB output of the upconverter is –6 dBm of linear power. The image filter has at most 4 dB of insertion loss while removing the image, LO, 2LO and any other spurs. The filter output supplies –10 dBm of input power to the PA driver.

[Continued on page 164]

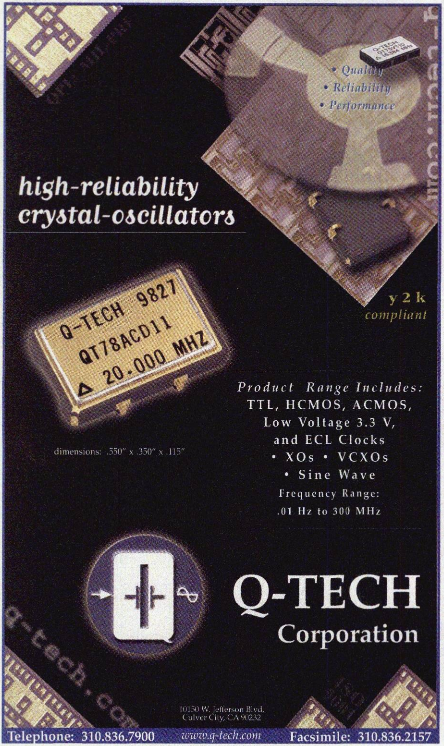


CIRCLE 178 ON READER SERVICE CARD

The PA driver is a two-stage class A amplifier with 10 dB gain per stage, is capable of delivering 6 dBm of linear power to a 50 Ω load and has a 1 dB compression point of 12 dBm. For lower power applications, this PA driver can be used to drive a 50 Ω antenna directly.

THE POWER AMPLIFIERS

There are currently several PAs for the 2.4 GHz band designed in the GaAs HBT fabrication facility. Since the RF2938 provides up to +10 dBm, not much more gain is required to achieve the +20 dBm for wireless LAN systems, and the RF2126 chip is a suitable choice. Offering 45 percent power-added efficiency at Vcc = 3.6 V, the RF2126 PA typically draws less than 200 mA at +20 dBm, though it can provide up to +30 dBm if required. The IC is supplied in a PSOP-8 package, which provides good thermal characteristics as well as a low inductance ground.



IC PACKAGES

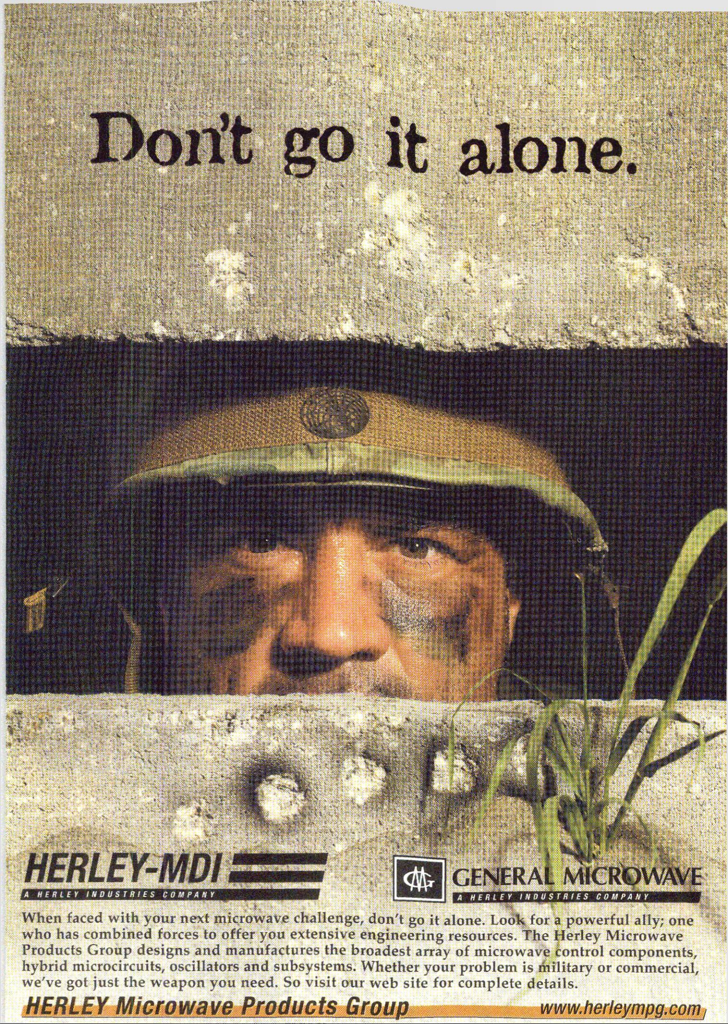
The RF2938, RF2444 and RF2126 ICs are supplied in new exposed dieflag packages. The dieflag is exposed on the bottom side of the package, which allows it to be soldered directly to the PCB. The use of this package has two major advantages: The thermal impedance of the package is greatly improved so that the junction temperature stays cooler. Thermal impedance improvements of 2× to 4× are not unusual. Though neither design needs this extra thermal conduction to operate properly, having more temperature control improves performance. In addition, the dieflag makes a very low inductance ground, which is very important for low power RF circuitry. The pads on the IC can be bonded directly to the dieflag, providing as many low impedance grounds as desired. Package pins are not required to be designated as grounds so they can be used for signals instead, thereby allowing more functionality in 16 pins than before. Each bondwire to ground has < 1 nH of inductance, and the common inductance from the top of the dieflag to the PCB ground is < 50 pH. Each common emitter amplifier (LNAs and PAs) and each section of circuitry has its own ground, thereby minimizing crosstalk between bondwires and circuit elements. This grounding capability is especially critical for 2.4 GHz signals, but is also important for the IFs since they can reach 500 MHz for this chipset.

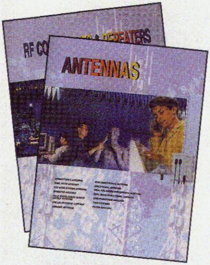
CONCLUSION

The RF2938, RF2444 and RF2126 ICs provide a high performance solution to a 2.4 GHz design, reducing the cost significantly without sacrificing versatility. All devices are monolithic and manufactured on high volume lines, allowing a low cost solution (less than $15 in high volume). Samples and evaluation boards for all products are available, and a complete 2.4 GHz transceiver reference design is expected to be available later this year.

RF Micro Devices,
Greensboro, NC (336) 664-1233.

Circle No. 302

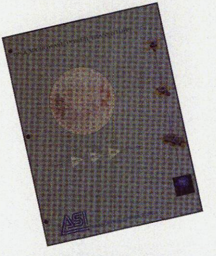

Don't go it alone.
HERLEY-MDI
A HERLEY INDUSTRIES COMPANY
GENERAL MICROWAVE
A HERLEY INDUSTRIES COMPANY
When faced with your next microwave challenge, don't go it alone. Look for a powerful ally; one who has combined forces to offer you extensive engineering resources. The Herley Microwave Products Group designs and manufactures the broadest array of microwave control components, hybrid microcircuits, oscillators and subsystems. Whether your problem is military or commercial, we've got just the weapon you need. So visit our web site for complete details.
HERLEY Microwave Products Group
www.herleympg.com



▲ Antenna and RF Component & Repeater Catalogs

The 104-page antenna catalog describes retractable, dual-band, inverted, cellular phone, ceramic, directional, reflector, yagi and patch antennas. The 106-page RF component and repeater catalog describes amplifiers, RF switches, attenuators, active mixers, bandpass filters, isolators, combiners, dividers and couplers.
Ace Technology Inc.,
Chatsworth, CA (818) 718-1534.

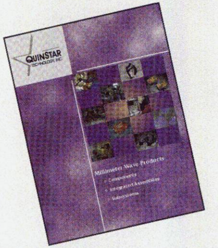
Circle No. 310



▲ RF & Microwave Power Transistor Catalog

This 30-page catalog details all of the company's standard silicon bipolar and MOSFET power transistors, including HF, VHF, UHF, pulsed avionics, pulsed radar, CW microwave, microwave oscillator and broadcast. Quality assurance and reliability standard information is included.
Advanced Semiconductor Inc. (ASI),
North Hollywood, CA (800) 423-2354
or (818) 982-1200.

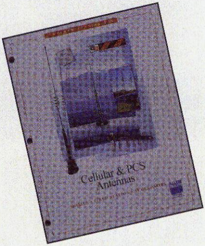
Circle No. 311



▲ Millimeter-wave Product Catalog

This 120-page catalog contains information on millimeter-wave products, including standard components, specialized RF signal generating, amplifying and conditioning components and fully integrated and customized assemblies and subsystems for digital and analog sensor, communications and test applications. Product photographs, specifications, outline drawings and model numbering information also are featured.
QuinStar, Torrance, CA (310) 320-1111.

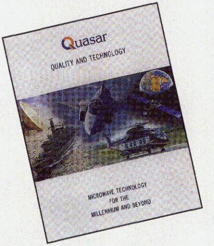
Circle No. 345



▲ Cellular/PCS Antenna Catalog

This 36-page catalog describes cellular, PCS and GPS products, including On-Glass® elevated feed, magnet and rooftop antennas as well as the fixed station Discreet™ planar, yagi, log periodic and omnidirectional antennas. Three new antennas, including a multiband omnidirectional indoor antenna, an enclosed coil cellular magnet-mount mobile antenna and a mini-magnet dual-band mobile antenna, are also featured.
Antenna Specialists,
a division of Allen Telecom Inc.,
Cleveland, OH (440) 349-8400.

Circle No. 313



▲ New Product Catalog

This 12-page catalog describes the company's full range of microwave waveguide products, including microwave attenuators, directional couplers, flexible/twistable waveguides, horns, load terminations, rigid waveguides, hybrid assemblies, tee junctions, coaxial and taper transitions, rotary vane attenuators, waveguide-tuned filters and diplexers.
Quasar Microwave Technology Ltd.,
Newton Abbot, Devon, UK
+44 (0) 1626 83 42 22.

Circle No. 334

▲ 1999–2000 Product Catalog

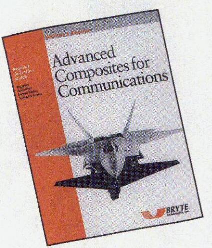
This product catalog describes state-of-the-art passive microwave components, including a variety of microwave adapters and connectors, flexible and semirigid microwave cable, three styles of coaxial contacts, precision phase shifters, terminations, shorts, caps, attenuators, and flexible and semirigid cable assemblies for test, commercial, space and military applications up to 50 GHz. Also featured are the patented mini-bend cable assemblies for use up to 40 GHz.
Astrolab Inc., Warren, NJ (732) 560-3800.

Circle No. 315

▲ Systems Integration Capability Brochure

This brochure contains information on the company's services, including research analysis, application software development, circuit and system design, and system integration as well as detailed descriptions of several products offered. A company history and client list also are provided.
B&B Technologies Inc.,
Albuquerque, NM (505) 345-9499.

Circle No. 316



▲ Advanced Composite Product Selection Guide

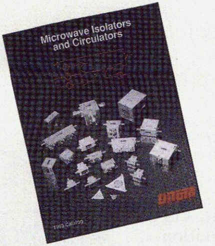
This four-page low dielectric composite product selection guide contains information on prepregs and liquid resins, film and paste adhesives, and bulk and film syntactic foams. Specified data include cure temperature, service temperature, glass transition temperature, neat resin moisture absorption, dielectric constant and loss tangent.
Bryte Technologies Inc.,
San Jose, CA (408) 776-0700.

Circle No. 317

▲ Quartz and Clock Oscillator Catalog

This 20-page catalog describes crystals and oscillators that are available in prototype-through-production quantities. Temperature and frequency tolerance and packaging are discussed. A part number guide and order forms are provided, and key specifications are listed.
Cal Crystal Lab Inc./Comclok Inc.,
Anaheim, CA (800) 333-9825
or (714) 991-1580.

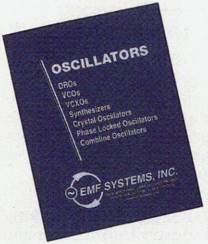
Circle No. 318



▲ Microwave Isolator and Circulator Catalog

This eight-page catalog details single-junction and dual-junction isolators and circulators. Single-junction devices include octave/broadband, electronic warfare/broadband and high performance/narrowband; dual-junction devices include octave/broadband and high performance/narrowband. Key specifications are listed and outline drawings are provided.
DITOM Microwave Inc.,
San Jose, CA (408) 727-1201.

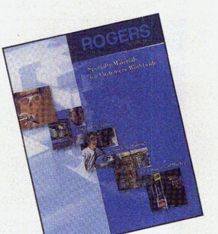
Circle No. 319



▲ Oscillator Catalog

This catalog contains information about a variety of oscillators including dielectric resonator oscillators, VCOs and voltage-controlled crystal oscillators as well as coaxial resonators and phase-locked oscillators. Frequency synthesizers, combline generators and special products are also detailed. Key specifications are listed and outline drawings are provided.
EMF Systems Inc.,
State College, PA (814) 237-5738.

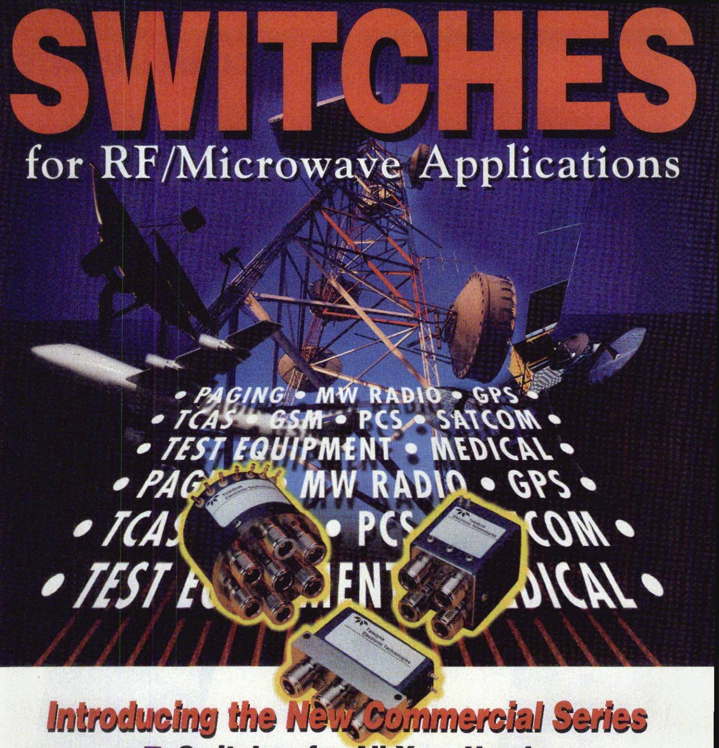
Circle No. 320



▲ Specialty Material Catalog

This 16-page catalog contains information on a variety of specialty materials, including PORON® urethane foam and silicon material, R/bak® compressible printing plate mounting products, ENDUR® elastomer components, NITROPHYL® floats, MPC® and RX® moldable composites, RO3000™ and RO4000® high frequency circuit materials, RT/duriod® and TMM® high frequency circuit materials, R/flex® flexible circuit materials and Induflex® laminates.
Rogers Corp., Rogers, CT (860) 774-9605.

Circle No. 336

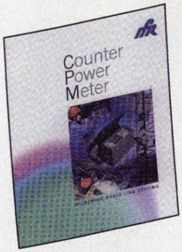

SWITCHES
for RF/Microwave Applications
• PAGING • MW RADIO • GPS •
• TCAS • GSM • PCS • SATCOM •
• TEST EQUIPMENT • MEDICAL •

▲ Product Reference Guide

This eight-page brochure describes RF and microwave silicon power transistors, transponders, cellular base stations and emitters for PCS/cellular, broadcast, SATCOM and radar applications. The company's capabilities in product design, wafer fabrication, die fabrication, assembly and test are discussed. Key specifications are listed.

GHz Technology Inc.,
Santa Clara, CA (408) 986-8031.

Circle No. 322

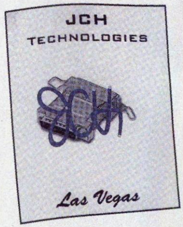


▲ 20/46 GHz Counter Power Meter Brochure

This six-page brochure describes the company's CPM 46 (46 GHz) and CPM 20 (20 GHz) counter power meters and their use in RF and microwave radio link installation and maintenance applications, including cellular network testing, local access radio, trunked radio and satellite communications. Key specifications and features are listed.

IFR Americas Inc.,
Wichita, KS (316) 522-4981.

Circle No. 323



▲ Cable Assembly Brochure

This four-page brochure describes a variety of cable assemblies, including coaxial, power, small computer standard/system interface, fiber-optic, patch, computer extension and Ericsson-type cables. Value-added services are listed and outline drawings are included.

JCH Technologies,
Las Vegas, NV (800) 773-2202
or (702) 639-4100.

Circle No. 324

▲ Commercial Filter and Selection Software Brochure

This six-page brochure describes the company's KeL-Com™ commercial filter selection software, which allows users to specify standard filters and submit requests for quotes directly to the factory. The software program generates response curves, outline drawings, tabular data and part numbers based upon user-defined filter parameters.

K&L Microwave Inc.,
Salisbury, MD (410) 749-2424.

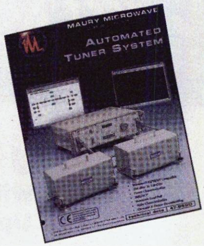
Circle No. 325

▲ Hermetic Laser Sealing and Packaging Brochure

This four-page brochure contains information about hermetic laser welding, electromagnetic interference shielding, RF interference shielding and general-purpose welding capabilities, which include production sharing and a typical 48-hour turnaround. The company's facilities and laser welding operations are also discussed.

Maryatt Technologies Inc. (MTI),
Sunnyvale, CA (800) 858-9353
or (408) 730-1907.

Circle No. 326

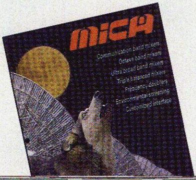


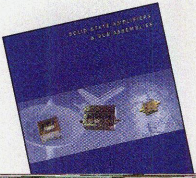
▲ Automated Tuner System Brochure

This 12-page brochure describes the newest features, options and applications available with the company's automated tuner system, including noise and power characterization, intermode/ACP measurements, swept-power load pull, harmonic source/load pull and on-wafer measurements. High matching range tuners specifically designed for the cellular/PCS frequency bands also are discussed.

Maury Microwave Corp.,
Ontario, CA (909) 987-4715.

Circle No. 327





and technical and purchasing information.
Microwave Solutions Inc.,
National City, CA (800) 967-4267
or (619) 474-7500.

Circle No. 330

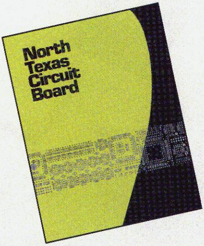
ultrabroadband mixers, triple-balanced mixers and frequency doublers is provided.
Mica Microwave,
San Jose, CA (408) 363-9200.

Circle No. 328

formation, specifications and outline drawings also are included.
Micro Substrates Corp. (MSC),
Tempe, AZ (602) 731-6230.

Circle No. 329

▲ **ComponentWorks™ Brochure**



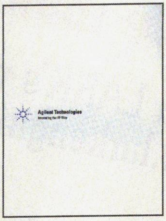
CATALOG UPDATE

▲ Thin-film Fabrication Technology Brochure

This four-page brochure contains information about the company's photomask requirements, standard metallizations, and standard processes and features. Standard substrate types and specifications as well as dimensions and tolerances are listed.

Applied Thin-Film Products (ATP), Fremont, CA (510) 661-4287.

Circle No. 314



▲ Company Backgrounder

This backgrounder describes the launch of Agilent Technologies, a diversified technology company launched as part of Hewlett-Packard Co.'s plan to strategically realign itself into two fully independent companies. A company profile, objective list and business overview are included.

Agilent Technologies, Palo Alto, CA (650) 857-4752.

Circle No. 312

▲ Cable Assembly Catalog

This 32-page catalog lists approximately 4000 stock cable assemblies featuring the company's line of coaxial connectors, solid center contacts, dual-wall tubing for strain relief and fabrication with more than 650 variations of standard connector interfaces. Custom assembly forms are included.

RF Connectors, a division of RF Industries, San Diego, CA (800) 233-1728 or (858) 549-6340.

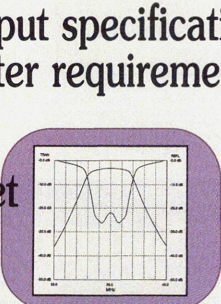
Circle No. 335

Step-by-step Filter Design At LARK we make it easy!

1 Go to LARK's web site, www.larkengineering.com

2 Input specifications of your filter requirements

3 Get



Instant gratification. That's what it's all about when you place your order using **Lark**'s unique software and internet access. Just get on line with **Lark**. Click the *GO! Interactive Design* icon, just like the one shown below, and you will be guided one step at a time through the design process. Once the part number comes up you can select additional information such as performance plots, specification sheets, and outline drawings.

Select from one of the most extensive product lines in the filter industry. **Lark** provides RF/Microwave spectrum filters from 100 kHz to 18 GHz utilizing structures such as lumped constant, tubular, ceramic, interdigital, combline and cavity. **Lark**'s mechanical packaging includes leadless surface mount and connectorized units with solder pins to Type N Connectors.

Lark Engineering is **ISO 9001** certified. We pride ourselves on being the leader in supplying RF and Microwave filters. We have coined the term **IMMEDIATE FILTER DESIGN** to describe how easy it is for you to get the optimum filter for your application. It's fast too! That's one good reason why major wireless communication systems worldwide use **Lark** filters.

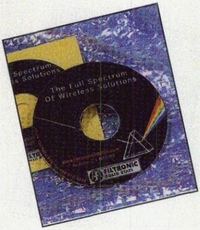
Find out how easy it is. Link up with **Lark** at **www.larkengineering.com** and we'll do the rest. Your design, your specs, your exact filter, **EASY! ORDER NOW...** quantity, price, and delivery will be E-mailed or Faxed to you within 24 hours.

INTERACTIVE DESIGN

Lark Engineering Co.™

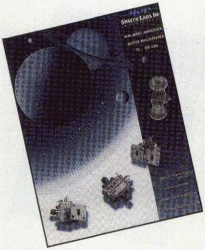
Div. Baier & Baier, Inc.
27282 Calle Arroyo • San Juan Capistrano, CA 92675
(949) 240-1233 • Fax: (949) 240-7910 • ISO 9001 Certified

CIRCLE 79 ON READER SERVICE CARD



▲ Wireless Solution CD-ROM

This revised CD-ROM, "The Full Spectrum of Wireless Solutions" (revision 2.1), features complete information on filtronic semiconductor, wireless, component and ferretec products.
Filtronic Solid State,
Santa Clara, CA (408) 988-1331.
Circle No. 321



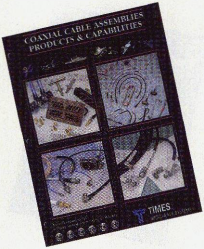
▲ mm-wave Amplifier Catalog

This six-page catalog details the company's capabilities in producing mm-wave amplifiers from 18 to 110 GHz and highlights low noise, power and general-pupose amplifiers as well as a full range of active frequency multipliers. Key specifications and photographs are provided.
Spacek Labs Inc.,
Santa Barbara, CA (805) 564-4404.
Circle No. 337

▲ High Frequency Connector Catalog

This 28-page catalog details the company's full line of custom and standard RF connectors and interface gages designed for a variety of microwave applications. Specifications and outline drawings are included.
SRI Connector Gage Co.,
Melbourne, FL (407) 259-9688.
Circle No. 338

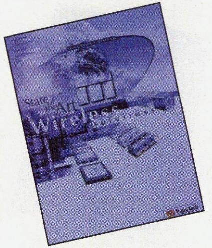
CATALOG UPDATE



▲ Coaxial Cable Assembly Product and Capability Catalog

This 28-page catalog describes coaxial cable assemblies for military and aerospace applications, Miltech® hermetically sealed cable assemblies and multiport broadband microwave interconnect systems. Electrical performance, operating environment specifications, mechanical installation envelopes and military specification qualifications are highlighted.
Times Microwave Systems, Wallingford, CT (203) 949-8427.

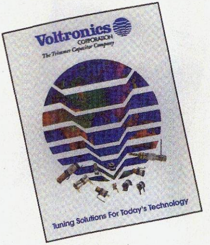
Circle No. 339



▲ RF and Microwave Ceramic Component Brochure

This brochure introduces the company's line of RF and microwave products for the wireless communication market. Design capabilities and current component technology for ceramic bandpass filters and diplexers, coaxial resonators and patch antennas are detailed. Specifications for typical products are also listed.
Trans-Tech, a subsidiary of Alpha Industries, Adamstown, MD (301) 695-9400.

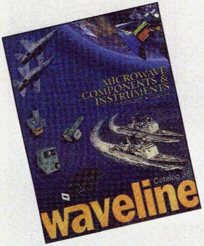
Circle No. 340



▲ Product Catalog

This 40-page catalog describes PTFE, glass, quartz, sapphire and air variable capacitors. Detailed information on the company's new line of solid dielectric trimmer capacitors designed for GHz frequencies with high Q, small size, low cost and high reliability is also included. Specifications are listed and outline drawings are provided.
Voltronics Corp., Denville, NJ (973) 586-8585.

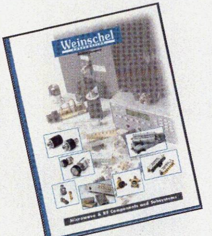
Circle No. 341



▲ Microwave Component and Instrument Catalog

This 96-page catalog features a complete description of the company's waveguide and coaxial products, including adapters, attenuators, circulators, crystal mounts, directional couplers, phase shifters, switches, terminations, transitions and tuners. Specifications and outline drawings are provided.
Waveline, West Caldwell, NJ (973) 226-9100.

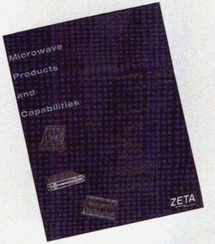
Circle No. 342



▲ 1999 Product Catalog

This 224-page catalog details wireless, RF and microwave products, including variable and step attenuators, programmable attenuators, resistive power splitters and dividers, fixed attenuators and terminations, precision adapters and connectors, blind-mate and Planar Crown® connector systems, directional couplers, phase shifters and SmartStep™ components and subsystems. Product photographs are included.
Weinschel Corp., Frederick, MD (800) 638-2048 or (301) 846-9222.

Circle No. 343



▲ Microwave Product and Capability Catalog

This 12-page catalog contains information on MICs, crystal-stabilized sources, multichannel sources, frequency multipliers, comb generators, frequency synthesizers, frequency converters, receivers and microwave subsystems, and other products specifically designed for use in missile guidance, ground support equipment, radar, satellite communications, data links and other applications.
Zeta, a division of Sierra Networks Inc., San Jose, CA (408) 434-3600.

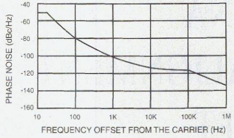
Circle No. 344

Phase-Locked Coaxial Resonator

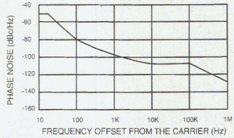
OSCILLATORS

TYPICAL PHASE NOISE

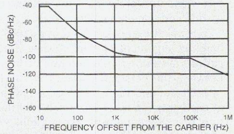
Phase Noise at 4 GHz



Phase Noise at 8 GHz



Phase Noise at 15 GHz



ELECTRICAL SPECIFICATIONS

Output frequency (Fixed)	4 to 15 GHz
Output power	+13 dBm, minimum
Output power variation	±1 dB, maximum
Input reference frequency range	1 to 20 MHz
Input reference power range	-3 to +3 dBm
Output spurious signals	-65 dBc minimum
Output harmonics	-50 dBc minimum
Output impedance	50 Ohm nominal
Load VSWR	1.5:1 nominal
DC voltage (Customer specified)	15, 20 or 24 V
DC current	600 mA typical

FEATURES

- 4-15 GHz with 1-20 MHz Input Reference
- Superior Phase Noise
- Compact Loop Design
- Competitive Performance in a Smaller Package
- 100% Environmental Screening

YEAR 3 WARRANTY

NQA ISO 9001 REGISTERED COMPANY

For further information, please contact Al Annarumma at (516) 439-9172 or e-mail aannarumma@miteq.com.

MITEQ

100 Davids Drive, Hauppauge, NY 11788
TEL.: (516) 436-7400 • FAX: (516) 436-9219/436-7430
www.miteq.com

CIRCLE 129 ON READER SERVICE CARD

A Microwave Antenna Path-Alignment Test Set

Microwave links require accurate path alignment to ensure proper operation. This process has traditionally required highly trained tower crews to physically align the antennas as well as ground technicians and complex and expensive test equipment to monitor the results. A new test set has been developed that simplifies this task at a low cost without compromising performance or accuracy. Tower installation crews now can perform the entire alignment process on the tower without the need for additional ground technicians or equipment. The associated system's radio equipment and waveguide feeds do not even need to be installed.

Fig. 1 Azimuth radiation pattern for a typical parabolic antenna. ▼

THE TRADITIONAL PROCESS

The traditional antenna alignment process requires the use of a transmitter and receiver located at each end of the microwave link. The transmitter generates the signal that passes through the transmission line to the antenna, which radiates the signal over free space to the receive antenna. If the antennas are optimally aligned, the largest concentration of signal (main beam) is emitted and received and maximum signal transfer is achieved. If the antennas are not aligned properly, the signal transfer is degraded and dynamic range is lost.

Several steps are involved in the process of antenna alignment in a microwave communications system. A voice communication link between the personnel inside the radio room of each site and the tower technicians located at each antenna is required using two-way radios or cellular phones. Some radio systems contain an order wire link for these communications; however, communications to each of the tower technicians still must be established.

Once this setup is completed the tower technicians may begin the adjustment of the azimuth (bearing) of the antennas (one at a time). Careful observation of the output power is necessary to distinguish each antenna's sidelobe to main-lobe response, as shown in ***Figure 1***. Once the maximum signal is achieved, the antennas are aligned for optimum elevation. Throughout this process communications between the two sites and between the tower and receiver technicians must be continuous to ensure optimum antenna alignment.

[Continued on page 182]

XL Microwave Inc.
Oakland, CA

It's Time To Hang Up Your Old Technology.

Introducing the millimeter wave Vector Network Analyzer designed to take you into the 21st century: the Lightning™ 65 GHz VNA from Anritsu. Unlike those large, low-performance mmW dinosaurs of the past, the Lightning 65 GHz features a sleek bench-top design. High, fully-leveled, output power and a wide dynamic range. And, of course, the Lightning family's proven track record for speed, accuracy and ease of use.

The new 65 GHz Lightning VNA also brings uncompromising performance to your millimeter wave measurements. With four sampler architecture and a four-channel color LCD display. Built-in hard and floppy drives. Gain compression software suites and an industry standard V-type coaxial connector, specified beyond 65 GHz.

Continuing the Lightning family's heritage for long-term reliability, the 65 GHz VNA also boasts Anritsu's unprecedented technical support. Featuring flexible on-site programs and complete upgrade plans.

To discover our entire line of newer, faster, leaner and meaner VNAs, call 1-800-ANRITSU or check out our website at www.global.anritsu.com.

Linking the World

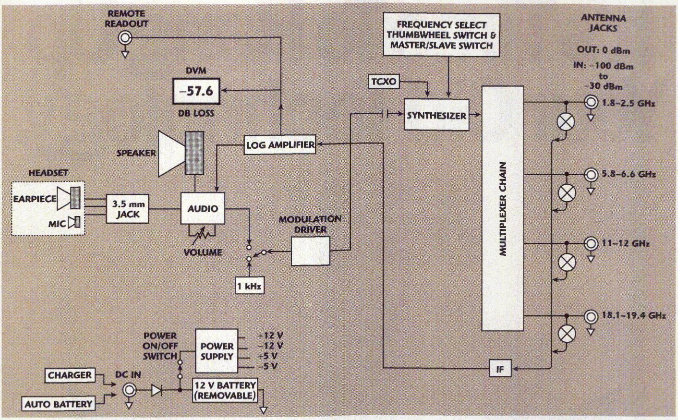
Anritsu

Lightning 65 GHz Vector Network Analyzer

One world. One name. Anritsu.

 Sales Offices: United States and Canada, 1-800-ANRITSU, Europe 44(01582)433200, Japan 81(03)3446-1111, Asia-Pacific 65-2822400, South America 55(21)527-6922, http://www.anritsu.com

CIRCLE 11 ON READER SERVICE CARD



▲ *Fig. 2 The microwave antenna path alignment test set's block diagram.*

TABLE I
KEY SPECIFICATIONS

Transmission	full duplex
Transmitter output power (dBm)	0 nominal
Transmitter stability (%)	0.005
Tunable operating bands (GHz) Band 1 Band 2 Band 3 Band 4	 1.8 to 2.5 5.8 to 6.6 11.0 to 12.0 18.1 to 19.4
Modulation (1 kHz tone or voice)	FM
Transmit/receive offset (MHz)	39
Receiver sensitivity (dBm)	-100 nominal
Receiver bandwidth (kHz)	100 nominal
Receiver readout resolution (dB)	0.1
Operating temperature (°C)	-10 to +40
Input power	self-contained 12 V/2.3 Ah rechargeable lead-acid camcorder battery
Dimensions (H × W × D)	3.5" × 8.375" × 13.1"
Weight (lb)	7 each unit
Connectors	SMA-F

A NEW AND IMPROVED METHOD

A new method utilizing a recently developed high performance test set permits antenna alignment to be accomplished without the use or presence of the system's radio equipment. There are several good reasons for not utilizing the actual system radios to accomplish the antenna alignment process. First, the system radios may not be available at the time the antenna test has been scheduled or their reliability may be questionable. Also, Federal Communications Commission permits for the radios may not have been granted. In addition, if the anticipated path is questionable, a quick, cost-effective method is required to test the link prior to the significant investment of constructing permanent towers and purchasing radios and other equipment.

The Path Align-R™ model 2200 microwave antenna path alignment test set has been specifically designed to quickly and accurately optimize the transmission path between two microwave antenna sites. The process can be completed without the need for the individual site's system radios or other equipment. The battery-powered Path Align-R test set directly drives the site's antenna, providing an indispensable tool for antenna site installation and maintenance personnel. ***Figure 2*** shows a simplified block diagram of the test set. ***Table 1*** lists the model 2200 test set's key specifications.

The Path Align-R test set consists of two identical portable units in weather-resistant, instrument backpack measuring 3.5" × 8.375" × 13.1" and weighing only seven pounds each. Four tunable operating frequency bands are available, thus allowing the test technician to choose the appropriate frequency to match the antenna's required operating frequency. The antenna can be adjusted for minimum path loss by utilizing a test unit at each antenna site. The path loss is displayed on the test set's front-panel meter and/or an external instrument, such as a pocket digital

[Continued on page 184]

voltmeter. The Path Align-R units enable test technicians to talk to each other during alignment over the antenna link in full-duplex FM using the included headset.

The Path Align-R test set provides 100 dB of effective dynamic range, the result of the –100 dBm sensitivity of the individual receivers and the 0 dBm output of the transmitter section. The four frequency bands provided in the standard test set are 1.8 to 2.5 GHz, 5.8 to 6.6 GHz, 11 to 12 GHz and 18.1 to 19.4 GHz. The operator can tune within these bands by means of thumbwheel switches to within 1 MHz of the required frequency. An antenna system with an operating frequency outside of the unit's frequency band edge (for example, 6.8 GHz) may still have its alignment correctly adjusted as long as the antenna system can operate at both the link frequency and a nearby frequency within the test set's operating bands (for example, 6.6 GHz).

A liquid-crystal display indication of direct path loss, within 0.1 dB resolution, is automatically updated every 300 ms and can quickly detect subtle changes to the antenna response, thus permitting small adjustments to the antenna's azimuth or elevation for optimum signal transfer. Communications between sites and from the radio room to the tower top are significantly improved with a full-duplex FM voice channel. One tower technician can speak to the other using the included headset without having to key a radio. Also, voice communication is enabled immediately after setup and activation — the antennas do not need to be fully aligned for the voice channel to function.

The test set's output is from a synthesized internal signal source that provides an accurate and stable test signal. Comparisons to tests run using an HP 8360 synthesized source and a full-featured HP 8594E spectrum analyzer produced path loss agreement to within 1 dB. However, the Path Align-R test set is priced far below that of a separate synthesized signal source and spectrum analyzer combination. In addition, the cost of communicating between sites can become considerably expensive when using cellular phones or other means. Additional savings are achieved because the required test personnel can be reduced to just two tower technicians and the cost of shipping bulky, expensive test equipment to the sites is eliminated.

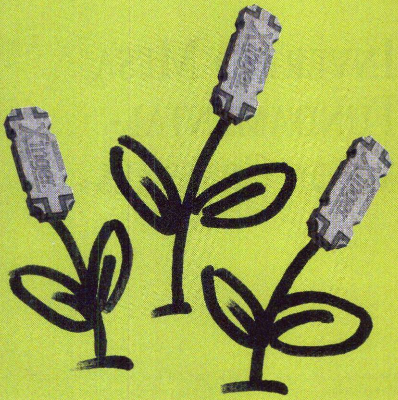
CONCLUSION

The difficulties of scheduling an antenna alignment with the system's radios can cause significant delays. Furthermore, traditional test methods can result in significant test costs. The Path Align-R model 2200 test set offers an accurate and cost-effective method of microwave antenna alignment that is easily performed by two technicians without the use of system radios. Additional information may be obtained from the company's Web site at www.xlmicrowave.com.

XL Microwave Inc.,
Oakland, CA (510) 428-9488.

Circle No. 301

Our smallest Xingers yet just cropped up.



Xinger®

Just as farmers bump up their crop by working their fields — we've strengthened our line-up of Xinger® surface mounts by responding fast to what our Reps are hearing in the wireless field.

The consensus? "Xingers are cool, but can you make them even smaller so we can do more with them?"

You bet. Check out our 1.7 GHz PCS coupler. At only 0.56" x 0.20" x 0.075", it'll fit like a glove into wireless PBX terminals. Base station LNAs. Heck, a dozen of them will now fit on a multi-carrier PA board with room to spare for other components... No home-grown hassles. No performance tradeoffs on smaller, but lesser, solutions.

Or for wireless LAN designers, there's our equally tiny 2.4 GHz ISM band coupler — for use in WLAN access points, cellular boosters for wireless handsets, or any number of wireless devices finding their way into manufacturing, distribution, and healthcare these days.

We even offer 3.5 GHz hybrids for use in LNA, PA, vector modulator, and signal distribution applications.

Not just because innovation's our thing. But because innovation is your thing. Xinger® surface mounts, exclusively from Anaren. **What'll we think of next?**

800-544-2414 • www.anaren.com
In Europe, call 44-1705-232392.
Visa/Mastercard accepted (except in Europe).

Anaren

1.7 - 2.0 GHz couplers, at *half* the size.

Our Xinger® 1.7 – 2.0 GHz surface mount couplers measure up at a mere 0.56" x 0.20" x 0.075" — yet they offer big performance:

> DCS, GSM, and PCS bands, LNA and PA applications
> Low .20 dB max insertion loss; 2 degree phase balance; +/- .2 dB amplitude balance; 23 dB min isolation; and a max VSWR of 1.17:1
> Performance is backed by our exclusive 100% OnSpec® guarantee
> Cost-competitive
> And our B-There® service commitment ensures on-time delivery — plus free samples in 24 hrs. for qualified prototype work

Xinger® surface mounts. **What'll we think of next?**

800-544-2414 • www.anaren.com
In Europe, call 44-1705-232392.
Visa/Mastercard accepted (except in Europe).

Anaren

2.4 GHz ISM-band coupler for wireless LAN lovers.

If you design wireless LANS, you've got to try this 0.56" x 0.20" x 0.075" Xinger® surface mount on for size:

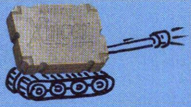
> ISM and WLL bands, LNA and PA applications
> Low .20 dB max insertion loss; 2 degree phase balance; +/- .2 dB amplitude balance; 22 dB min isolation; and a max VSWR of 1.18:1
> Performance is backed by our exclusive 100% OnSpec® guarantee
> A great price
> Plus, our B-There® service commitment ensures on-time delivery — plus free samples in 24 hrs. for qualified prototype work

Xinger® surface mounts. **What'll we think of next?**

800-544-2414 • www.anaren.com
In Europe, call 44-1705-232392.
Visa/Mastercard accepted (except in Europe).

Anaren

High-power handling. In a highly durable package.



Major power handling. Major physical integrity. That's the Xinger® high-power coupler, measuring in at a minuscule 0.65" x 0.48" x 0.14":

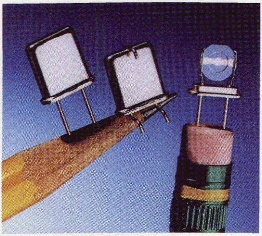
> GSM, D-AMPS, NMT, PCS, UMTS, IMT 2000, and IS95 applications
> Up to 200 watt power handling
> Low .2 dB max insertion loss; +/- .3 dB amplitude balance
> Performance is backed by our exclusive 100% OnSpec® guarantee
> A surprisingly low price, in volume
> Plus, our B-There® service commitment ensures on-time delivery — and free samples in 24 hrs. for qualified prototype work

Xinger® surface mounts. **What'll we think of next?**

800-544-2414 • www.anaren.com
In Europe, call 44-1705-232392.
Visa/Mastercard accepted (except in Europe).

Anaren

CIRCLE 9 ON READER SERVICE CARD



INVERTED MESA FUNDAMENTAL-MODE CRYSTALS

High frequency fundamental-mode crystals are increasingly in demand for applications such as precision high speed clocks, voltage-controlled crystal oscillators (VCXO) and voltage-controlled temperature-compensated crystal oscillators (VCTCXO). However, conventional crystal processing utilizing flat quartz blanks has limited the available frequency range to 55 MHz.

Using higher quality swept quartz, it has long been possible to produce inverted mesa fundamental-mode crystals with frequencies extending beyond 200 MHz. However, the higher cost of materials coupled with slower production throughput has made these resonators undesirable for use in large-volume applications. As telecommunications equipment designers continue to demand oscillators that operate at higher frequencies and still retain the smallest possible size and tightest stability, manufacturers have scrambled to fill this growing market.

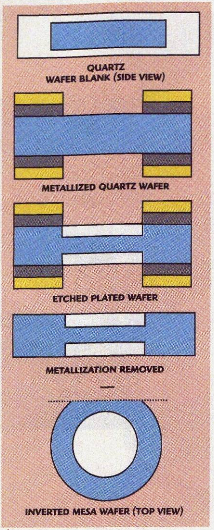
Consequently, a means to produce high frequency inverted mesa fundamental-mode crystals without the need to start with swept quartz has been found. The CIM-32 series high frequency crystals were developed with a proprietary processing technology that produces crystals with low series resistance, high pulling ability and excellent unit-to-unit and lot-to-lot repeatability at an affordable price. The new crystals are available in frequencies ranging from 51 to 155 MHz and are targeted for applications in precision high speed, low jitter clocks as well as VCXOs, VCTCXOs and low jitter hybrid modules for data communications.

THE NEW DESIGN

Several basic process steps are involved in manufacturing an inverted mesa-type quartz. A quartz wafer is metallized on both sides with a chromium gold masking mechanism in the shape of a doughnut. The plated wafer is then etched for the appropriate length of time depending on the desired frequency of operation using a proprietary etching process, and the metallization is removed from the inverted mesa wafer. At this point, the wafer thickness is 0.0030" to 0.0033" and the thickness of the middle active area for a 155.52 MHz fundamental-mode resonator is 0.00042". Finally, the resonator is enclosed in an HC-45 resistance-welded package that can be supplied for through hole or surface-mount applications.

[Continued on page 188]

CHAMPION TECHNOLOGIES INC.
Franklin Park, IL



▲ *Fig. 1 Basic steps for fabricating an inverted mesa-type quartz crystal blank.*

Fig. 2 Frequency stability vs. temperature at 77.76 MHz. ▼

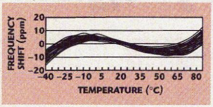
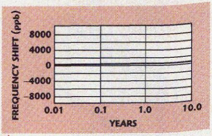
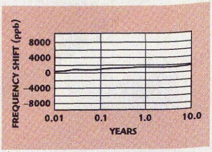


Figure 1 shows the steps involved in this process.

The general specifications for this type of crystal include a maximum series resistance of 25 Ω, a standard load capacitance of 32 pF (other options are available) and a typical frequency tunability of 105 ppm. The device is designed for operation over a –40° to +85°C temperature range. Individual specifications include a nominal operating frequency within the range of 51.84 to 155.52 MHz and a frequency tolerance at 25°C of ±15 ppm. Temperature stability over a 0° to +70°C range is ±10 ppm referenced to 25°C, and aging for the first year at 25°C is typically 4 ppm. ***Figures 2*** and ***3*** show typical temperature stability and aging performance, respectively, for a CIM-32-type crystal at 77.76 MHz. ***Figure 4*** shows aging for a similar crystal at 155.52 MHz.

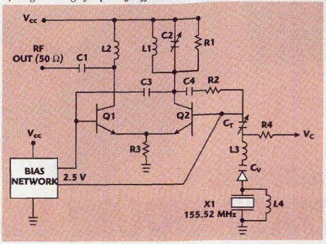


▲ *Fig. 3 The inverted mesa crystal's aging at 77.76 MHz.*



▲ *Fig. 4 The inverted mesa crystal's aging at 155.52 MHz.*

▼ *Fig. 5 A high frequency differential VCXO example.*



A TYPICAL VCXO APPLICATION

One of the more popular applications of this device is in high frequency VCXOs. The example described here illustrates the crystal in a differential pair topology, as shown in ***Figure 5***. This type of circuit offers several advantages: The amplifier can operate at large-signal amplitudes without serious phase degradation due to the saturation and bias shift present in single transistor designs. Also, the differential pair has a broad linear region with smooth and symmetrical limiting.

Using a proper design, the differential pair can be kept out of saturation to improve phase noise. In addition, the limiting function can eliminate the need for automatic level control. The differential pair configuration can be realized at very high frequencies. The circuit is noninverting and the collector of Q1 is AC grounded, thus eliminating the Miller effect at the base of Q1. The output is taken from the collector of Q2. In this example, R2 provides the negative feedback and the design uses a tank circuit at the collector of Q2, which removes undesired capacitance and permits higher frequency operation. It also constrains oscillation to the crystal's fundamental mode.

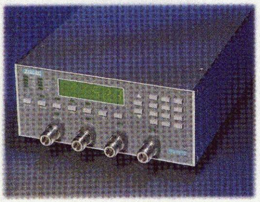
The oscillator's performance is typical of what can be achieved using an inverted mesa-type crystal. This example operates at 155.52 MHz ±20 ppm over a temperature range of 0° to +70°C and produces > –5 dBm from a 5 V DC supply at < 10 mA. The oscillator's phase noise is < –130 dBc/Hz at 10 kHz from the output frequency. The tuning deviation from center frequency is > ±100 ppm with a linearity of < 10 percent for a control voltage of 0.5 to 4.5 V applied to the varactor diode.

CONCLUSION

With the introduction of the CIM-32 series inverted mesa crystals, manufacturers of low cost, high volume electronic equipment can specify their VCXOs with higher frequencies, tighter stabilities and smaller packages without breaking their budgets. A full line of high frequency crystal oscillators using this technology is also available.

Champion Technologies Inc., Franklin Park, IL (800) 888-1499, www.champtech.com.

Circle No. 300



PROGRAMMABLE ATTENUATOR SUBSYSTEMS

Finally there is a low cost, easy-to-use programmable attenuator for use on the test bench or in subsystem applications. The new 8310 series SmartStep™ attenuator units represent a new concept in programmable attenuation that is both flexible and easy to program. The standard 8310 series attenuator houses and controls various programmable attenuator models (for example, models 3200T and 150T and the 4200 series attenuators) via front-panel controls or standard communications interfaces such as the general-purpose interface bus (GPIB) IEEE-488, RS-232, RS-422 and RS485.

The programmable attenuator series provides a flexible, easy-to-program, low cost solution for benchtop test and calibration setups and subsystem applications. Additional features include multichannel attenuation paths (up to four inputs and outputs), relative vs. nominal attenuation step functions and a wide choice of frequency and attenuation ranges (DC to 1, 2, 3, 18 and 26 GHz and up to 127 dB). The units feature internal relay switched, GaAs FET or PIN solid-state attenuators, providing high accuracy and repeatability. The standard units are designed for 50 Ω input and output impedance operation, however, 75 Ω configurations are available.

The 8310 series attenuators are supplied in a 12.00" × 8.38" × 3.47" housing with front-panel control and readout. In addition, the units may be rack mounted either as a single unit using an available rack-mounting kit (part no. 193-8033) or two model 8310 units may be mounted together using a slightly different mounting kit (part no. 193-8033-1). Both kits allow the unit to be easily installed into any rack or cabinet that is designed in accordance with EIA RS-310 or MIL-STD-189. The 8310 units combine the features of the model 8210A device controller with a front-panel user interface to form a flexible, easy-to-use solution.

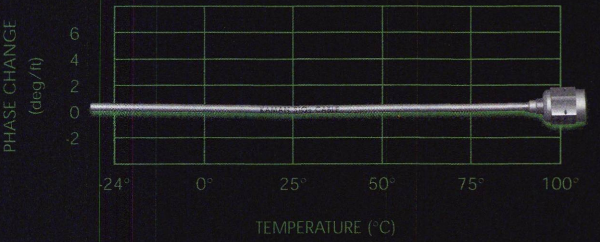
Most 8310 series units are single-channel configurations where the RF signal is routed through either the front- or rear-mounted ports A and B. However, units may be configured for up to four channels of attenuation, RF switching or other functions. Multiple programmable attenuators may be used in conjunction with other coaxial devices such as switches, power combiners, directional couplers and filters, creating single- or multichannel subsystems.

Applications for the 8310 series attenuators range from providing control of a single SmartStep attenuator in a bench test or lab environment using a PC and a terminal emulator to complex multichannel system applications where the 8310 unit is employed to control many devices to create custom subsystems to reduce design cost and increase flexibility. A variety of custom-designed driver interfaces for

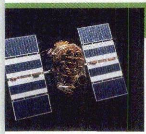
[Continued on page 192]

WEINSCHEL CORP.
Frederick, MD

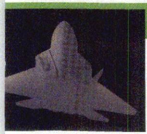
Stable Cable™



PHASE CHANGE VS TEMPERATURE FOR A TYPICAL .141 DIAMETER CABLE

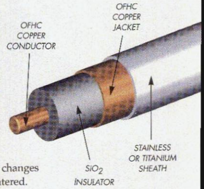


FOR SPACE



FOR EW/AVIONICS

FOR TEST



Not every application needs a cable this stable. But suppose stability is a big issue. Suppose you're designing the antenna farm for a commercial satellite. Or the avionics systems for a high-performance aircraft. Or a phased array radar. Or suppose you're installing a GPS or SATCOM system. Or upgrading your platform to a more advanced EW system. Or maybe you're performing critical thermal vacuum testing on an orbital platform. You simply can't afford phase or insertion loss changes when temperature fluctuations are encountered.

Your application may call for Kaman's SiO_2 insulated cable assemblies. At frequencies as high as 18GHz,the relative phase changes as little as 70 PPM over a 75°C temperature shift. This outstanding stability lowers design costs, because SiO_2 cable reduces the need for environmental conditioning, complex installations, power and space requirements, and the possibility of phase error in a matched system when different cables experience different temperatures.

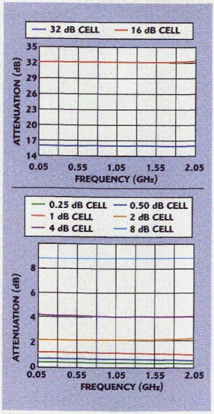
All of Kaman's cables are sold as custom assemblies built to your specs, with connectors laser-welded as hermetic assemblies, making them ideal for hostile environments. And you have your choice of stainless steel or titanium jacketing, depending on your weight budget and how much of a weight problem you have. (SiO_2 stainless cable is significantly lighter than a comparable flexible Teflon assembly; SiO_2 titanium is even lighter that that.) Plus Kaman's cable reliability is outstanding: 1,000,000 hours MTBF.

We'd like to talk to you about the benefits of our stable cable. Please call to discuss your project, because SiO_2 is an alternative you should know about.

Kaman Instrumentation Corporation
1500 Garden of the Gods Rd., Colorado Springs, CO 80907
Voice 719-599-1821 Fax 719-599-1823 info-cos2@kaman.com
www.kamaninstrumentation.com

KAMAN

CIRCLE 74 ON READER SERVICE CARD



▲ *Fig. 1 Typical measured incremental attenuation performance.*

▼ *Fig. 2 Typical zero insertion loss.*

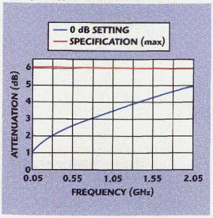
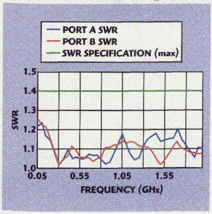


Fig. 3 The SWR at 0.25 dB setting. ▼



various devices, such as RF switches, relays, PIN attenuators, motorized step attenuators and displays, may be supplied.

SPECIFIC MODEL PERFORMANCES

The model 8310-37-2-F attenuator represents a typical example of the 8310 series units. It provides programmable attenuation in 0.25 dB steps to 63.75 dB over the DC to 2 GHz frequency range, as shown in ***Figure 1***. Maximum insertion loss is 6 dB, and input and output SWR is 1.4 (max). ***Figures 2*** and ***3*** show the attenuator's typical insertion loss and input/output SWR performance vs. frequency, respectively. The unit features two channels and utilizes model 3200T-2 attenuators internally. N-type female connectors are mounted on both the front and rear panels.

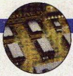
The model 8310-38-3-T unit provides 63 dB of attenuation in 1 dB steps from DC to 2 GHz. This unit has three channels utilizing the model 3206T-1 attenuator and has N-type female connectors at both the front and rear panels. Insertion loss is 5.25 dB (max) and SWR is 1.4 (max).

The model 8310-202-R utilizes two 150T programmable attenuators to provide 121 dB of attenuation in 1 dB steps from DC to 18 GHz. Here, the connectors are SMA female on the rear panel. Insertion loss is 5.25 dB (max) and SWR is 1.95 (max).

Many additional models are available to provide different attenuation levels, resolutions, frequency ranges and configurations to suit the needs of a variety of applications. (A complete listing is provided in the 8310 series data sheet.) All models require 100 to 240 V AC at 50/60 Hz and 50 W and operate over a temperature range of 0° to +50°C. In addition, each unit features an IEEE-488 bus interface utilizing a 24-pin IEEE-488-1 connector and appropriate protocols, an RS-232 bus interface with a nine-pin male D connector, and RS-422 and RS-485 interfaces also utilizing a nine-pin male D connector. Additional information may be obtained from the company's Web site at www.weinschel.com.

Weinschel Corp.,
Frederick, MD (301) 846-9222.

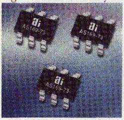
Circle No. 303



COMPONENTS

■ DC - 2.5 GHz Integrated SPDT Switch

The model AS169-73 integrated pseudomorphic high electron mobility transistor (pHEMT) SPDT switch delivers a broadband, low cost, integrated switching solution for transmit and receive chains operating from DC to 2.5 GHz. The AS169-73 features low insertion loss of 0.4 dB at 2.5 GHz and positive voltage operation with low DC power consumption. Manufactured in the miniature SOT-6 plastic package, this general-purpose switch can be used in a variety of telecommunications applications. Price: $2.70 each (100).



Alpha Industries,
Woburn, MA (800) 290-7200, ext. 306
or (508) 894-1904.

Circle No. 215

■ 100 dB High Isolation Switch

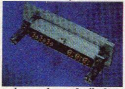
The model SWM-6000-1DTU-ECL-GB ultra-high speed, 20 ns balanced, low video transient, nonreflective, SPST solid-state switch offers 100 dB isolation. Insertion loss is 3 dB and SWR is 2 (max) between 10 MHz and 2 GHz. The switch operates from ±5 V DC at ±100 mA (max) with emitter-coupled logic, but TTL is also available. The unit measures 1.5" × 1.5" × 0.4" with removable SMA connectors. Miniature sizes are also available.

American Microwave Corp.,
Frederick, MD (301) 662-4700.

Circle No. 216

■ Multiport RF Connector System

This flexible multiport RF connector system houses an array of microminiature blindmate RF contacts, each providing a robust RF interface up to 18 GHz, within a chamfered lightweight aluminum shell. The system is designed specifically for applications requiring reliable, high density RF signals where small size and weight characteristics are important, and will accommodate the increased bandwidth required for next-generation broadband communications services, including video conferencing, digital data transfer, audio/video distribution and Internet traffic. A full complement of electromagnetic interference/RF interference shielding features are included to protect signal integrity, and locking jack screws ensure reliability with protection from shock and vibration.



AMP Inc., Harrisburg, PA (717) 393-3831.

Circle No. 217

■ Analog-to-digital Converter

The model AD9288 eight-bit analog-to-digital converter operates at 3 V and contains onboard track-and-hold circuits and separate encode clocks, allowing maximum design flexibility. Its low power requirement (110 mW with an input frequency of 10.3 MHz at 100 Msps per channel), single-supply operation and good dynamic performance make the AD9288 particularly well suited for dual-channel communications applications. The unit's two channels can be operated separately, making it useful for battery-powered applications such as hand-held wireless equipment and low cost digital oscilloscopes. Prices (1000): $15.30 (100 Msps), $9.99 (80 Msps) and $5.40 (40 Msps). Delivery: stock.

Analog Devices Inc.,
Norwood, MA (800) 262-5643
or (781) 937-1428.

Circle No. 218

■ Dual B-band Preselector Shelf

The model 5000440 rack-mount shelf with two eight-pole cellular wireline receive filters protects B-band (wireline) base receivers from interference from most A-band (nonwireline) mobiles and portables. The unit's dual filters offer diversity receiver protection in a single 5.25" package, and combline bandpass filters feature steep skirts below 835 MHz and above 849 MHz. The dual B-band preselector shelf also protects against trunking base transmitter interference and provides extra filtering in the nonwireline receive band (824 to 835 MHz) and trunking transmit band (851 to 866 MHz).

Celwave, a division of Radio Frequency Systems Inc.,
Marlboro, NJ (800) 235-9283.

Circle No. 219

■ Magnetic Coaxial Fail-safe Switch

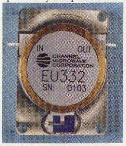
The 601 series low cost, miniature, magnetic coaxial fail-safe switches operate from DC to 18 GHz. Standard with SMA connectors, these 50 Ω impedance switches with actuating voltage of 12 or 28 V DC can handle up to 100 W CW. Insertion loss is 0.50 dB (max), SWR is 1.5 (max) and isolation is 60 dB (min) with a switching time of 20 ms. Intended for test equipment applications, including switch matrices, microwave radios and selection of alternating antennas that are connected to a transmitter or receiver, these switches offer up to five million operations without performance degradation and can be used to alter the path of an incoming signal to one of the two outputs or one of the two inputs for an output.

Dow-Key Microwave Corp.,
Ventura, CA (805) 650-0260.

Circle No. 221

■ 300 W UHF Drop-in Isolator

The model EU332 drop-in isolator is designed specifically to operate in the UHF telecommunication frequency bands and isolate the linear-amplifier output stage from its load. Operating over the 0.8 to 1.0 GHz frequency band, the isolator provides typical insertion loss of 0.08 to 0.10 dB between 836 and 881 MHz, isolation of 23 dB (min) and output power of 300 W. Operating temperature range is 0° to +85°C and SWR is 1.17 (max). The integral termination can absorb 100 W of reverse power continuously. Size: 1.25" × 1.69" × 0.310".

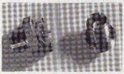


Channel Microwave Corp.,
Camarillo, CA (805) 482-7280.

Circle No. 220

■ DC - 18.2 GHz TNC Connectors

These high power, hermetically sealed TNC connectors cover the DC to 18.2 GHz band with a maximum SWR of 1.1 and can handle 1 kW CW. Designed for use in the company's hybrid couplers and filters as well as other microwave components, these connectors feature very low loss and superior mechanical rigidity as compared to the conventional connector design, protecting the component's internal circuit. This in turn allows for use in extremely harsh environments. These connectors are available in screw-in type (spark plug) or flange-mounted style, and the design can be adapted to a type-N and -SC.

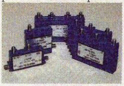


Microwave Engineering Corp. (MEC),
North Andover, MA (978) 685-2776.

Circle No. 230

■ Filters and Diplexers

These millimeter filters and diplexers in a suspended substrate operate from DC to 40 GHz over the passbands of DC to 18, 18 to 26 and 26 to 40 GHz. Crossovers are 18, 23, 26 and 30 GHz, and rejection/isolation is 50 dB (min) at crossovers of ±15 percent. Connectors are K female/male. The filters and diplexers offer insertion loss of 2 dB (max), SWR of 2 and crossover tolerance of ±0.25 percent.



ES Microwave LLC,
Gaithersburg, MD (301) 519-9407.

Circle No. 222

■ Tunable Bandpass and Bandreject Filters

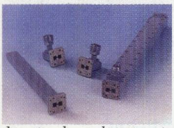
The BT and TNF series tunable filters are designed for cellular, PCS, PCN and WLL applications and include octave range tuning that

replaces the need for several fixed tuned filters. The BT bandpass series filters operate from 500 to 3000 MHz and feature impedance of 50 Ω, nominal 3 dB bandwidth of five percent, SWR of 1.5 and power handling up to 5 W. The TNF bandreject series filters operate from 100 to 2000 MHz and offer passband insertion loss of < 0.5 dB (max) passband, SWR of 1.5 and impedance of 50 Ω. Delivery: stock.
K&L Microwave Inc., Salisbury, MD (410) 749-2424.

Circle No. 225

■ 5.8 - 18.4 GHz Waveguide

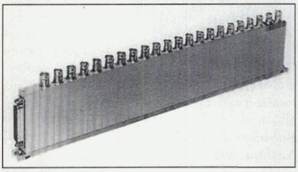
The model WRD 584 waveguide is offered in a new size that allows transmission of C, X and Ku SAT-COM bands as well as the extended DBS band and covers the 5.8 to 18.4 GHz frequency band. WRD 584 directional couplers, terminations, adapters and related components also are available.



Microwave Development Co. Inc., Salem, NH (603) 870-6280.

Circle No. 289

■ Triaxial-to-coaxial Converters

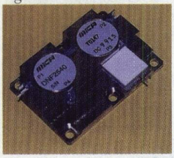


The model 12740 triaxial-to-coaxial converter and/or coaxial-to-triaxial converter and distribution modules feature nine converters in one module, adjustable gain and DC offset, and unity plus gain. Input/output impedance is 50 or 75 Ω over the DC to 200 MHz bandwidth. Typical applications include converter modules and distribution amplifier modules. Special configurations are available.
Matrix Systems, Calabasas, CA (818) 222-2301.

Circle No. 227

■ High Ratio Isolators

This complete line of low cost, high performance high ratio isolators features isolation up to 60 dB, SWR of 1.15, insertion loss of < 0.5 dB through the double pass and a 30 dB ±1 dB flat attenuator port for reverse power monitoring. Designed for cellular, PCS and DCS applications, these isolators can handle up to 300 W CW power in the forward direction and 200 W CW in the reverse direction. Delivery: less than 30 days.



Mica Microwave Corp., San Jose, CA (408) 363-9200.

Circle No. 228

■ GaAs Switches

The model ITT501AJ SPDT high power transmit/receive (T/R) switch operates from +3 to +10 V and features positive control with a 1 dB compression point of 35 dBm at +5 V. Packaged in an MSOP-8 plastic package, the switch is compatible with standard T/R switches. The ITTS159AB –5 V, high isolation, SPST reflective switch operates over the 0 to 5 GHz frequency range. Provided in an SO-8 package, the switches exhibit 49 dB of isolation at 1.0 GHz. These switches, along with six others introduced by the company, are designed for use in wireless handsets, local area networks, data, base stations and other wireless applications.
GaAsTEK, a unit of ITT Industries, Roanoke, VA (888) 563-3949 or (540) 563-3949.

Circle No. 224

■ Bandpass Filters

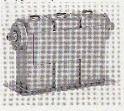
The MMFM-FBGW series bandpass filters feature center frequencies from 500 MHz to 40 GHz, a nominal 10.1 MHz 1 dB operating bandwidth, typical insertion loss of 3.9 dB and nominal input/output impedance of 50 Ω. These narrowband filters offer unique properties that make them well suited for applications in which extremely narrow bandwidths, small size, low insertion loss, moderate power levels and easy integration with other components are critical. The filters are manufactured using the company's Multi-Mix™ multilayer manufacturing process that typically results in a filter that is significantly smaller, lighter and less expensive than conventional counterparts. Operating temperature range is –55° to +125°C. Size: 0.80" × 0.24" × 0.24".
Merrimac Industries Inc., West Caldwell, NJ (888) 434-6636.

Circle No. 233

NEW PRODUCTS

RF Preselector Bandpass Filter

The model 3278RF(3) bandpass filter is a cavity type, fully tunable filter used in UHF applications. The filter offers three high Q cavities, providing less than 2 dB insertion loss over a 6 MHz operating bandwidth and > 15 dB rejection at ±8 MHz from center frequency, > 25 dB rejection at ±13 MHz from center frequency and > 40 dB rejection at ±22 MHz from center frequency. Return loss is 14 dB (min) in the passband, and the filter can be retuned to any 6 MHz channel in the 470 to 890 MHz frequency range. The unit is available in two- or four- cavity configurations to provide more or less selectivity as required, and 50 or 75 Ω configurations as specified.

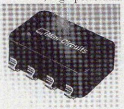


Microwave Filter Co. Inc. (MFC),
East Syracuse, NY (800) 448-1666
or (315) 438-4747.

Circle No. 231

800 - 1000 MHz Frequency Mixer

The model ADM-10DH frequency mixer is a low noise, high performance solution for airphone and cellular applications, and has a typical conversion loss of 6.0 dB and 30 dBm IP3 (typ at midband). Operating over the 800 to 1000 MHz frequency band, these level 17 surface-mount mixers typically provide L-R and L-I isolation of 35 and 37 dB, respectively, and have a maximum 200 mW RF power rating. Operating temperature range is –20° to +85°C. Price: $15.95 (1–9 units).

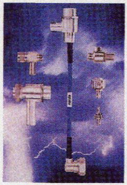


Mini-Circuits,
Brooklyn, NY
(718) 934-4500.

Circle No. 232

Lightning and EMP Protection Products

These coaxial lightning protection products for use in base stations are integrated into an antenna feed line and designed specifically to protect expensive equipment from lightning and electromagnetic pulse (EMP)-induced energy. A variety of interfaces are available, including type-N and 7/16 DIN connectors. All parts are designed to handle the high induced current associated with lightning and EMP as well as deliver superior IM performance.



Narda Microwave-East,
Hauppauge, NY (516) 231-1700.

Circle No. 234

Radiation-resistant RF Coaxial Connectors

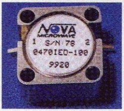
These 50 Ω radiation-resistant RF coaxial connectors are designed with special insulators and constructed for use in nuclear environments. The devices have brass or beryllium-copper bodies with silver or nickel plating (or stainless steel) and aluminum construction. Featuring insulators machined from Rexolite® or other radiation-resistant materials and beryllium-copper center contacts, the connectors are capable of withstanding neutron and gamma irradiation. Available with N, HN, LC, BNC and twin interfaces per MIL-STD-348, the connectors can be supplied as straight plugs, jacks, and tee- or angle adapters, and are ideally suited for use with RG-8A, 9B, 213 and 214/U cable types.

Tru-Connector Corp.,
Peabody, MA (800) 262-9878
or (978) 532-0775.

Circle No. 242

Drop-in Isolator

The model 0470IED drop-in isolator provides 20 dB isolation and has low insertion loss of 0.4 dB over the frequency bandwidth of 4.4 to 5.0 GHz with an SWR of 1.25. The circuit tabs are designed to provide excellent yield during circuit assembly. Operating temperature range is –20° to +85°C. (Storage temperature range is –50° to +125°C.) The package size is: 0.5" × 0.5" × 0.25". Delivery: stock. (Isolators and circulators in other frequency bands are available in a similar package.)



Nova Microwave,
Morgan Hill, CA (408) 778-2746.

Circle No. 235

75 Ω Broadband RF Directional Couplers

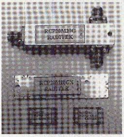
These 75 Ω surface-mount broadband RF directional couplers have an operating bandwidth of 5 to 900 MHz, are rugged enough to withstand IR reflow manufacturing techniques and operate in an environment within a temperature range of –40° to +85°C. Designed specifically for use in high volume cable applications such as set-top boxes, line amplifiers and headend equipment, these directional couplers separate an input signal into two unequal output signals, and the stronger signal appears at the main output port with little degradation. The highly isolated smaller signal allows network designers to sample the main line signal without affecting it. Price: $1.36 (25,000). Delivery: six weeks.

Pulse, a Technitrol company,
San Diego, CA (858) 674-8100.

Circle No. 236

Surface-mount Hybrids and Couplers

These high power, surface-mount quadrature hybrids and surface-mount 3 dB couplers cover the 1.5 to 2.4 GHz and the 20 MHz to 20 GHz bands, respectively. Both series have superior match and repeatability, and cross reference to any size and frequency up to over 20 GHz. While most of the company's products are an octave wide, some can be optimized for 1° phase match and 0.1 dB amplitude match in narrower-band cases, such as cellular and PCS.

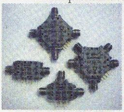


RADITEK, San Jose, CA (408) 266-7404.

Circle No. 237

PIN Diode Switches

These SPST, SP2T, SP3T and SP4T ultraminiature switches operate over the frequency range of 2 to 18 GHz with a 100 ns switching speed. The switches are designed to operate over the –55° to +100°C temperature range and have removable connectors for drop-in applications. Customized variants of these standard switches are also available. Delivery: two weeks.

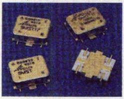


Robinson Laboratories Inc.,
Nashua, NH (603) 880-7880.

Circle No. 238

Wideband, Load-insensitive Mixers

The models SM5T, SM5T17 and SM5TH wideband, load-insensitive mixers are available in hermetic, surface-mount packages for high reliability applications. Frequency coverage is 50 to 5000 MHz, LO and RF (50 to 3000 MHz, IF), with availability in +10, +17 and +23 dBm LO drive levels. Typical performance includes 7.2 dB conversion loss and 35 dB isolation.



Stellex Electronics Inc.,
Palo Alto, CA (800) 321-8075.

Circle No. 239

Miniature, Tight-tolerance Chip Inductors

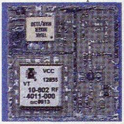
The PTL1005-F series photo-etched chip inductors offer reliability and superior performance to a variety of mobile communication designs and have a 0402 footprint (1.0 mm × 0.5 mm) with a low profile of 0.5 mm. Designed for use in GaAs FET matching circuits such as low noise amplifiers and voltage-controlled oscillators, these highly

[Continued on page 202]

NEW PRODUCTS

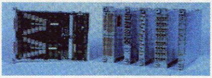
stable chip inductors have a ±0.2 nH or two percent inductance tolerance over the full temperature range and a 100 ppm/°C temperature coefficient. Self-resonant frequency is controlled within ±10 percent and inductance is specified at 800 MHz as well as 100 MHz. The PTL1005 devices are available in 1.0 to 12.0 nH inductance values and are packaged on tape and reel in 10,000-piece quantities.
Toko America Inc.,
Mount Prospect, IL (847) 297-0070.
Circle No. 240

Integrated VCO and Mixer Assembly



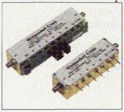
The model VDM/1900-260L combined VCO, mixer, filter and amplifier is integrated and positioned on one circuit board. Primarily designed for wireless applications in PCS base stations, the combination eliminates tuning mismatch errors and reduces tuning and testing time. The integration of these components provides conservation of board space with dimensions of 1.20" × 1.20" × 0.28" and conserves power with a typical current draw of 100 mA.
Trak Communications Inc.,
a Tech-Sym company,
Tampa, FL (813) 884-1411.
Circle No. 241

Power Switches



The model SM2001 16 A power switch and SM7001 terminated microwave switch are designed for high density signal switching systems that require fast switching speeds. The SMIP family of switches provide more than 30 different switch configurations from DC to light, and can be controlled via a general-purpose interface bus, RS-232, Firewire, Ethernet or PCI. Delivery: stock to four weeks (ARO).
VXI Technology Inc. (VTI),
Irvine, CA (949) 955-1894.
Circle No. 243

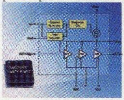
1000 W Coaxial Attenuators & Terminations



The model 82 coaxial attenuators and model 1456 terminations are capable of handling up to 1000 W average (unidirectional) and 10 kW peak power over the frequency range of DC to 3 GHz. The attenuators are available in 20, 30 and 40 dB versions. Others feature of the attenuators and terminations include a maximum SWR of 1.25 and operating temperature range of –55° to +125°C. Type-N or 7/16 connectors are available.
Weinschel Corp.,
Frederick, MD (800) 638-2048
or (301) 831-4701.
Circle No. 244

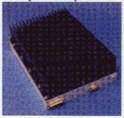
AMPLIFIERS

CDMA Power Amplifier



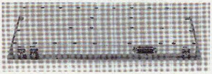
The model AWT6101 MIC CDMA power amplifier operates across the 1850 to 1910 MHz frequency range and has a low leakage of less than 10 µA, allowing extended standby times. Designed to minimize cycle time, save board space and reduce cost, the self-contained amplifier delivers linear operation up to +29 dBm with high efficiency of 32 percent and manages voltage turn-on and turn-off synchronization with a single interface pin. The amplifier is one of the first parts that incorporates the company's integrated DC-to-DC converter technology, which allows all of the benefits of GaAs devices without the need to supply negative voltage and additional supporting components in system designs. Size: 7 mm × 7 mm.
ANADIGICS Inc.,
Warren, NJ (908) 668-5000.
Circle No. 245

2.6 GHz 180 W Broadband Amplifier



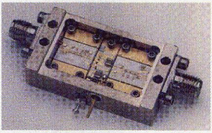
The 180 W class A broadband wireless GaAs FET power amplifier, with a removable heat sink, operates from 2.4 to 2.7 GHz over any 200 MHz bandwidth. All units include over-voltage, reverse polarity and over-temperature protection. The amplifier provides minimum gain of 40 dB, maximum noise figure of 10 dB, input/output SWR of 1.5 (max) and typical IP3 of +66.5 dBm. An output isolator is also integral to all designs to ensure safe operation into open and short circuits, and RF enable/disable and a sample 40 dBc RF output are standard in all designs. Operating temperature range is 0° to +50°C. Size: 9.0" × 13.0" × 1.5", excluding heat sink.
Chesapeake Microwave Technologies Inc.,
Glen Rock, PA (717) 235-1655, ext. 112.
Circle No. 246

13 W CDMA High Power Amplifier



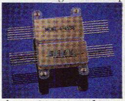
The model HPA1920-13 highly linear 13 W CDMA high power amplifier is fully compliant to J-Std-008 specifications and covers the entire PCS transmit band of 1930 to 1990 MHz with a gain of 30 dB. This solid-state amplifier designed for single-channel towertop or base station applications meets all specifications over a DC input range of 26 to 29 V DC with an operational current of < 5.5 A. Operational baseplate temperature range is –30° to +85°C. Monitor lines are provided for over-temperature, over-current and over/under supply voltage fault status. Size: 12.0" × 5.8" × 1.1".
MPD Technologies Inc.,
Hauppauge, NY (516) 231-1400, ext. 452.
Circle No. 248

Multi-octave Band LNA



The model JCA26-300P low noise amplifier (LNA) has been designed to provide a low noise figure over multi-octave bands. The amplifier covers a frequency of 2 to 6 GHz with a minimum gain of 30 dB and gain flatness of ±1.5 (max). Noise figure is 2.0 dB (typ), input/output SWR is 2.0 and output power is +10 dBm. Amplifiers can be customized to provide optimal performance for the customer's individual specification requirements. Delivery: two to three weeks (ARO).
JCA Technology Inc.,
Camarillo, CA (805) 445-9888.
Circle No. 247

Miniature Dual Log Amplifier



The model MCWL-4-4538 is a pair of matched miniature logarithmic amplifiers featuring log linearity of ±0.75 dB (typ) and a standard center frequency of 200 MHz with an operating bandwidth of at least 20 MHz. The log video slope is 25 ±1.5 mV/dB measured over the input signal range of –67 to +3 dBm (typ). SWR is less than 2.0, limited output power is 0 dBm (nom) and channel-to-channel isolation between pairs is specified at 50 dB (min). The unit requires a power supply of ±5 or ±6 V with total consumption of approximately 2 W and is housed in a dual flatpack with a surface area of approximately 1.3 in^2. Mounting is accomplished via four through-hole threaded flanges. Price: $2950 (5–9).
Signal Technology Corp.,
Olektron Operation,
Beverly, MA (978) 524-7444.
Circle No. 250

Solid-state Power Amplifier

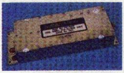
The model SPA-5964-200-26200 solid-state power amplifier covers the frequency band of 5.850 to 6.425 GHz and is designed for satellite communication terminals, travelling-wave-tube amplifier retrofits and very small aperture terminal hub applications. The amplifier features class A linearity, gain and temperature compensation, an integral thermal management system, and control and monitoring func-
[Continued on page 204]

NEW PRODUCTS

tions. Output power is 52 dBm (min) at –1 dB GCP (53 dBm typ), small-signal gain is 70 dB (min) at 25°C and input/output SWR is 1.25. Operating ambient temperature is 0° to +50°C.
Pascall Electronics Ltd.,
Ryde, Isle of Wight, UK +44 0 1983 817425.
Circle No. 249

■ 17 - 19 GHz Microwave Amplifier

The model PAN-19001 microwave amplifier covers the 17 to 19 GHz frequency range and



provides a five percent bandwidth (900 MHz midband) centered between the overall frequency limits. Output power is 30 dBm (min) at a 1 dB compression point over the full band, input SWR is 1.5 (max), output SWR is 1.3 (max), small-signal gain is 40 dB (min) and operating temperature is between 0° and +55°C. In-band spurious is < –60 dBm and noise figure is 10 dB (max). Size (excluding connectors): 172 mm × 72 mm × 31 mm.
Wessex Electronics Ltd.,
Downend, Bristol, UK
+44 117 957-1404.
Circle No. 252

■ W-CDMA Amplifier

The 25 W wideband CDMA (W-CDMA) broadband single-carrier amplifier covers the 2.11 to 2.17 GHz bandwidth and meets the needs of the data-intensive 5 MHz bandwidth third-generation wireless markets. The IMT-2000 amplifier features low cost, small size, high reliability and hot swap field-replaceable modules and is available in a standard rack configuration with up to four 25 W amplifiers per shelf.
Spectrian, Sunnyvale, CA (408) 745-5400.
Circle No. 251

ANTENNAS

■ MMDS Antenna Range

The DataMaster™ antenna range for two-way multichannel, multipoint distribution service (MMDS) systems is available in three versions, including a 90° sector transmit antenna for two-way systems with 18 dBi gain in the 2500 to 2700 MHz frequency band, and receive antennas for two-way systems with a gain of either 18 dBi (90° sector size) or 22 dBi (30° sector size) in the 2150 to 2360 MHz frequency band. Designed for sectorized data transmission and efficient use of the MMDS spectrum for data applications, the antenna pattern performance provides front-to-back ratios of greater than 30 dB and minimizes sector interference. The antennas are available in horizontal and vertical polarization, weigh approximately 20 lb, can survive winds of up to 150 mph and will continue to operate in temperatures between –40° and +70°C.
Andrew Corp.,
Orland Park, IL (800) 255-1479.
Circle No. 253

■ Distributed Antenna System

The RadWire™ distributed antenna system is designed to provide in-building wireless coverage at a low cost and offers an affordable solution to the problem of enhancing wireless coverage inside high-rise buildings, transportation terminals, shopping malls, campuses, warehouses and manufacturing facilities. RadWire replaces radiating coaxial cable, standard coaxial cable and individual antennas with a single-wire transmission line that serves as a high efficiency distributed antenna. Wireless signals are transformed into a surface wave that is simultaneously guided and radiated by the wire. The open system is band specific, entirely passive, rated for plenum environments and available in four versions that cover the cellular/SMR/

[Continued on page 206]

NEW PRODUCTS

paging, DCS, PCS and 2.4 GHz industrial, scientific and medical (ISM) wireless bands.
Rubytron, White Plains, NY (914) 697-7655.
Circle No. 255

Internal Planar Antenna

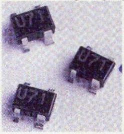
The Splatch internal planar antenna for use in compact applications such as remote controls, pagers and alert devices covers the 902 to 928 MHz frequency band. Designed for direct PCB mounting, the antenna eliminates the mechanical and cosmetic concerns of traditional external antennas. The stable grounded-line design results in excellent pattern and polarization characteristics and minimizes proximity detuning. The antenna exhibits a 50 Ω characteristic impedance and an SWR of < 1.9 and measures 1.100" × 0.500" × .062". Price: less than $1 (production quantities).

Linx Technologies,
Grants Pass, OR (800) 736-6677.
Circle No. 254

DEVICES

GaAs MESFETs

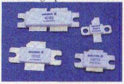
The model NE72218 miniature GaAs MESFET delivers high output power of 15.0 dBm at 12 GHz and low phase noise of –90 dBc/Hz at 10 kHz offset. The MESFETs are best suited for oscillator and amplifier applications and feature a 0.8 µm recessed gate and triple epitaxial technology. Housed in an ultraminiature plastic surface-mount SOT-343 package, the NE72218 is fabricated using ion implantation for improved RF and DC performance, reliability and consistency. Price: $1.57 (3000). Delivery: stock.



California Eastern Laboratories,
Santa Clara, CA (408) 988-3500.
Circle No. 256

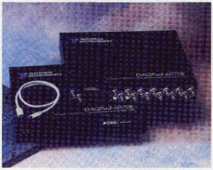
2 GHz RF Transistors

The models PTF 10120, 10043, 10035 and 10112 high power RF transistors are optimized for amplification of PCS signals. These 2 GHz wideband RF transistors are highly linear, gold metallized, silicon LDMOS FETs. Designed for amplifying either CDMA or TDMA signals, these devices support new digital modulations as well as traditional analog applications. The highest power device in the family is the PTF 10120. This GOLDMOS™ device is in a wideband push-pull configuration and displays an intermodulation distortion level of greater than –30 dB for peak envelope power levels up to 120 W. The device has 11 dB of linear gain and a saturated power capability of more than 150 W. The highly reliable, field-proven, full gold metal system used on all of the devices in this family extends the mean time to failure to well over 6000 years.



Ericsson Components,
Morgan Hill, CA (408) 778-9434.
Circle No. 257

Data Acquisition Device



The DAQPad™ -6070E multifunction data acquisition device (DAQ) features eight digital input/output lines, two 24-bit counter timers, 12-bit analog/digital resolution and a 1.25 Msps sampling rate. Available with mass termination or a BNC-equipped option, the device features a 68-pin shielded connector to connect signals and includes an AC-to-DC power adapter and an optional rechargeable battery pack or 9 to 25 V DC supply. The DAQ connects directly to Windows 98 PCs equipped with an IEEE-1394 serial port or PCI-to-1394 adapter and offers engineers and scientists a portable, easily installed and configured solution for computer-based measurement applications. As a FireWire product, the unit is hot pluggable and delivers an easy plug-and-play configuration. Price: starting at $1995.
National Instruments,
Austin, TX (800) 258-7022.
Circle No. 260

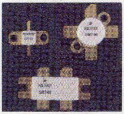
RF LDMOS Devices

The MRF21000 series RF LDMOS devices are fully characterized and individually tuned to operate at frequencies from 2.0 to 2.4 GHz, and are suitable for all linear transmitter formats. The RF LDMOS devices include the model MRF21060, the first ever RF LDMOS single-ended and 60 W device operating at 2170 MHz, which uses the company's fourth-generation RF LDMOS process to support designs for the emerging third-generation (3G) market, including W-CDMA and UMTS base stations. The complete characterization of the devices makes them easier to use in applications where matched device performance is important. The 30 W MRF21030, the 90 W MRF21090 and the flagship MRF21120 internal impedance-matched push-pull transistor that provides 120 W power (peak) and 14 W power while meeting the W-CDMA mask also are included in the family. Price: $140 for the MRF21060 (10,000).

Motorola Semiconductor Products Sector,
Phoenix, AZ (602) 244-7108.
Circle No. 259

RF Power MOSFET Transistors

The models SA741 (35 W), SM746 (175 W) and SR746 (300 W) 50 V RF power MOSFET transistors exhibit low capacitance, which makes them easier to broadband and use at frequencies from less than 1 MHz to 500 MHz. The modular design allows combinations of the same die to produce output power ranging from 35 to 300 W. This modular die concept reduces delivery time and extends the product availability lifetime.



Polyfet RF Devices,
Camarillo, CA (805) 484-4210.
Circle No. 261

SiGe Transistors

The HBT30 series low phase noise silicon-germanium (SiGe) transistors are designed for WLAN, 3G, W-CDMA, LMDS, point-to-point radio satellite, cable modem and fiber-optic systems achieving higher data transfer rates. At 10 GHz, these transistors exhibit typical residual phase noise of –142 dBc/Hz at 100 MHz and –160 dBc/Hz at 10 kHz offsets. Nominally rated at 5, 10 or 20 mA, the transistors provide a maximum output power of +1, +7 or +13 dBm, respectively, and are capable of operating at supply voltages as low as 1 V. Versions are available as die and in SC-70 (SOT-343) and Micro-X packages.
SiGe Microsystems Inc.,
Ottawa, Ontario, Canada
(613) 748-1334.
Circle No. 262

Power MOSFETs

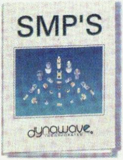
The models Si4880DY, Si4800DY and Si4890DY pulse-width-modulation-optimized Little Foot® power MOSFETs combine lower on resistance and gate charge specifications with record switching speeds, which together ensure maximum efficiency in power conversion circuits across all typical load ranges and are designed specifically for notebook computer and central processing unit point-of-use DC-to-DC conversion applications. The Si4880DY offers on resistance of 8.5 mΩ at a 10 V gate drive with a gate charge of 19.5 nC and turn-off times of 46 ns. The Si4800DY provides turn-off times of 22 ns with on resistance of 18.5 mΩ and a gate charge of 8.7 nC. The Si4890DY features on resistance of 12 mΩ, gate charge of 14 nC and turn-off times of 35 ns. Price: 71¢ (100,000).

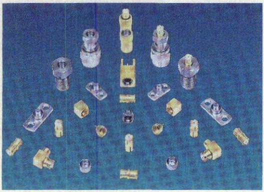
[Continued on page 208]

You know us for the highest quality cable assemblies for RF and Microwave. Now there's a reason to fall in love: a complete line of DSCC SMP connectors that are **fully compatible with all SMP connectors and the Gilbert GPO™**. Our new SMP Series features a broad range of connectors that include cable types, flange types, field replaceable, float types, hermetic, and adaptors.

Another reason to love us is that Dynawave SMP's are designed to minimize space and allow axial (0.010) and radial (0.020) misalignment while sustaining electrical performance (DC to 40 GHZ). They feature **an easy interface** with an insertion force that can vary, depending on your application, and provide the most efficient packaging for both RF and Microwave systems.

Lastly, now **you can order both your cable assemblies and SMP connectors from one trusted company**. Contact us today for more information and our SMP brochure.





dynawave INCORPORATED®

135 Ward Hill Avenue • P.O. Box 8224 • Haverhill, MA 01835 / TEL: 978-469-0555 / FAX: 978-521-4589

Dynawave is an ISO 9001 UL Registered Company

www.dynawave.com

CIRCLE 35 ON READER SERVICE CARD

Delivery: eight to ten weeks.
Vishay Siliconix,
Santa Clara, CA (800) 554-5565, ext. 10 or (408) 567-8220, ext. 10.
Circle No. 263

INTEGRATED CIRCUITS

CDMA Single-chip Modem Solution

The model MSM3100™ sixth-generation single-chip Mobile Station Modem™ baseband processing solution features a 50 percent reduction in chip size and up to 300 hours of standby time. Other features include enhanced voice recognition, such as continuous digit dialing and support for large speaker independent libraries and on-chip acoustic echo cancellation. The MSM3100 chipset and software enable design of a new generation of CDMA handsets and data devices with rich feature sets and industry-leading performance and will be the first baseband modem to offer on-chip hardware support for in-phone GPS-based CDMA position and location services, providing manufacturers with a cost-effective and integrated solution for the upcoming Federal Communications Commission mandate for emergency location tracking.

QUALCOMM Inc.,
San Diego, CA (619) 651-7942.
Circle No. 264

MATERIALS

Irradiated Polyolefin Microwave Substrates

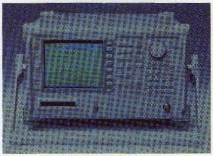
POLYGUIDE™ clad laminates and dielectrics, made from irradiated polyolefin, feature a dielectric constant of 2.32, dissipation factor of .0005 at 10 GHz, peel strength of 8 lb/in and water absorption of < 0.01 percent. Operating temperature range is –55° to +85°C. The substrates are recommended for microwave and UHF applications where optimum low loss operation is a primary requirement, and provide a combination of electrical, physical and chemical characteristics most suitable for microstrip, coplanar waveguide and other demanding uses. Manufactured under the strictest production and quality control conditions, thickness variation for each sheet of the material is held within ± 0.002".
Polyflon Co., Norwalk, CT (203) 840-7555.
Circle No. 265

Urethane Foam

PORON® urethane foam is specifically directed to gasket materials that are used to seal or protect electrical enclosures (UL-50) and industrial control equipment (UL-508). The gasket materials withstand rigorous mechanical testing, including age acceleration and oil immersion, and the urethane foam offers low fogging, low outgassing, high resistance to compression set, resistance to ozone, UV light and other environmental stressors and chemicals. PORON materials are available in a firmness and thickness for nearly any high performance application.
Rogers Corp., Rogers, CT (800) 755-6766.
Circle No. 266

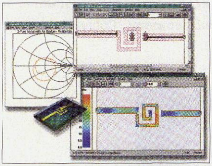
SOFTWARE

Spectrum Analyzer Software



Spectrum Capture custom software dramatically expands the analysis capability of the company's MS2650/MS2660 series spectrum analyzers. The software enables engineers to capture, analyze, store and recall data on a PC with extreme ease, making signal analysis more precise as well as functional, and creates trace markers to display the power level at various frequency points along the signal trace. The software also has the ability to categorize similar data by frequency, create and display upper and lower limit lines and conduct simple pass/fail tests. Multiple sets of limit lines can be saved in the software and recalled later for comparison. Price: $500. Delivery: stock.
Anritsu Co.,
Richardson, TX (800) 267-4878.
Circle No. 269

Electromagnetic Analysis Software



Sonnet® Lite is a free three-dimensional planar electromagnetic (EM) analysis software suite that is suitable for microstrip, stripline and two-layer circuits, including interlayer vias and vias to ground planes. Users can enter circuit layouts in an easy-to-use drawing editor, perform EM analyses, plot and print output results, export output data (S, Y and Z parameters) to other high frequency simulators, and display and animate circuit current density. The software also includes EM analysis combined with lumped elements, as well as the capability to incorporate active devices through external S-parameter data blocks. SPICE model extractions also may be derived for arbitrary circuits and interconnects that are electrically small compared to a wavelength.
Sonnet Software Inc.,
Liverpool, NY (315) 453-3096.
Circle No. 271

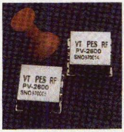
Power Amplifier Design Software

Microwave WinPADS is a design and optimization software tool that uses measure load pull contours as starting data to optimize a wideband, single-stage amplifier stage. The software uses very fast optimizers and a standard netlist file description for the source and load matching networks. In addition, lumped and distributed microstrip circuit elements with accurate models are included.
Focus Microwaves Inc.,
St-Laurent, Quebec, Canada
(514) 335-6227.
Circle No. 270

SOURCES

2600 – 2750 MHz VCO

The model PV-2600 VCO for wireless local area networks and radios operates over the 2600 to 2750 MHz frequency range with a tuning voltage of 0.5 to 5 V. The device has a supply voltage of 5 V and draws 25 mA. Phase noise is –103 dBc/Hz at 100 kHz offset. Operating temperature range is –30° to +85°C. Size: 0.500" × 0.500" × 0.205".



Princeton Electronic Systems Inc. (PES),
Princeton, NJ (609) 275-6500.
Circle No. 272

Synthesized Digital Paging Systems

The PagePro series synthesized digital paging transmitters with built-in POCSAG paging encoder are fully synthesized and can be field programmed in 10 or 12.5 kHz increments via a built-in RS 232 port. The systems can generate numeric, alphanumeric and tone pages and are designed to handle the demands of wide area paging as well as in-house and local area paging. Output power is adjustable with nominal output of 5 W (max) in the 136 to 174 MHz range and 2 W in the 218 to 230 MHz range. Several models are available covering the

[Continued on page 210]

NEW PRODUCTS

134–174, 218–230 and 260–280 MHz frequency ranges.
RF Neulink, a division of RF Industries, San Diego, CA (800) 233-1728 or (858) 549-6340.

Circle No. 273

Low Cost VCO

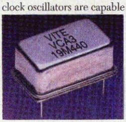
The model V607TEO1 VCO features low noise characteristics, minimal power requirements and a compact size. This VCO generates frequencies between 1279 and 1313 MHz with a tuning voltage between 0.4 and 2.8 DC, making it ideal for quick integration into any PLL where the error voltage can be taken directly from the IC's charge pump circuitry. Developed for the satellite hand-held phone market, the VCO provides output power of –3.5 dBm ±2.5, phase noise of –99 dBc/Hz at 10 kHz offset, supply voltage of 3 V DC and supply current of 6 mA. Size: 0.375" × 0.375" × 0.124". Price: $15.95 (5). Delivery: stock to six weeks.

Z-Communications Inc., San Diego, CA (858) 621-2700.

Circle No. 275

Clock Oscillators

The VCA3-100 and -200 series tight stability clock oscillators are capable of 20 ppm stability, including initial stability, frequency over operating temperature, power variation and aging. Supply voltage is 5.0 V DC at ±10 percent or 3.3 V DC at ±10 percent, and the devices operate over the temperature range of 0° to +70°C or –40° to +85°C. Packaged in an industry-standard 14-pin DIP, the clock oscillators are most suitable for use in telecommunication and networking applications.



VITE, a Vectron International company, Norwalk, CT (888) 835-8483.

Circle No. 274

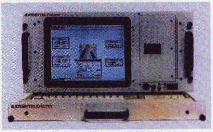
SUBSYSTEMS

VSAT Modem

The STEL-9261 very small aperture terminal (VSAT) modem is programmable for coverage over the full 52 to 88 MHz IF output range. Power level is programmable over the –5 to –25 dBm range. The unit includes integral forward error correction using constraint length K = 7 with rate 1/2, 3/4 or 7/8 Viterbi decoding to reduce overhead and assure the highest signal integrity. A programmable FIR filter allows the modem to match system requirements. The unit includes an AGC value monitor and alarm, C/N (Eb/No) value monitor and alarm, signal quality monitor and bit error rate value and is packaged in a 1RU rack-mounted case. The STEL-9261 transmit and receive functions can be remotely and independently programmed and monitored via a user-selectable EIA 232-E or EIA-485 interface. The data interface is EIA-449.
Stanford Telecom, Sunnyvale, CA (408) 745-2660.

Circle No. 282

20 Mbps PCI Bit Synchronizers

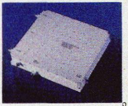


The model 5200 multichannel bit synchronizer subsystems are fully integrated rugged units with installed cards that receive multiple independent baseband data streams and simultaneously process them to provide clean serial output data streams with synchronous clocks. Each unit also includes an optional onboard Viterbi decoder that operates with three-bit soft decision for maximum coding gain, PCI/ISA bus, 300 W power supply and 10-inch diagonal active matrix color liquid crystal display (LCD) VGA display. Designed specifically for preflight system checkout, aircraft flight testing, satellite system checkout, and monitoring and launch vehicle qualification, the unit operates on 110 or 220 V (switch controlled). All storage devices are shock and vibration isolated, and rack-mount slides are included. Operating temperature range is 0° to +45°C.
AYDIN Telemetry, a division of AYDIN Corp., Newtown, PA (215) 497-8000.

Circle No. 279

Dual-input Base Station Receiver Unit

The INTERWAVE 99 dual input base station receiver unit consists of downconverters, baseband amplifiers and an optional control and monitoring interface module. Designed to operate in any 12 MHz segment of the 2100 to 2700 MHz MMDS band, the unit includes a diversity switch to select the stronger of two input signals. The base station receiver unit architecture is implemented to minimize the spectral regrowth, adjacent-channel power and error vector magnitude critical to QPSK, QAM, DQPSK modulations used with CDMA, and other wireless voice and data network architectures. Gain is 40 dB, noise figure is < 4 dB, SWR is 2 and power supply is –48 V at 0.4 A through the input coax. Operating temperature range is –40° to +65°C. Size: 9.0" × 10.0" × 1.6".



ITS Electronics Inc., Concord, Ontario, Canada (905) 660-0405.

Circle No. 281

High Frequency PLL Synthesizer Module

The model PLL800-5800 PLL synthesizer module generates frequencies from 5700 to 5900 MHz in 500 kHz steps with a typical settling time of 12 ms. The unit typically requires 53 mA of current from a 5 V supply voltage. Phase noise at 1 kHz offset is –61 dBc/Hz (typ), phase noise at 100 kHz offset is –105 dBc/Hz (typ) and phase detector spurious suppression is –75 dBc (typ). Output power is 0 dBm (typ) and second- and third-harmonic suppression is –15 and –20 dBc, respectively. The unit is housed in a 15.25 mm × 15.25 mm × 3.50 mm surface-mount, pick-and-place/reflow-compatible package.

Vari-L Co. Inc., Denver, CO (303) 371-1560.

Circle No. 283

SYSTEMS

Multiple Output 350 W Power Supply

The model NT350 compact, multiple output 350 W power supply provides a 3.3 V high current main output and active input power factor correction (PFC). The PFC input stage is followed by a two-transistor forward converter, which provides a proven architecture for high reliability requirements. The NT350's output configurations were developed to support applications in which the circuitry has largely migrated from 5 to 3.3 V. All outputs are fully isolated and regulated and active current sharing is standard to simplify N+1 redundant requirements in fault-tolerant applications. Auxiliary outputs are designed to sustain high surge current demands to support fan and disk drive spin-up requirements. Other features include power fail warning, remote inhibit and remote sense. Price: from $370 (100).

C&D Technologies, Power Electronics Division, Tucson, AZ (800) 547-2537.

Circle No. 276

Redundant Relay Fed LMDS Transmitter

The model TR280120RR local multipoint distribution system (LMDS) transmitter features multichannel block conversion operation, fully redundant throughput and synthesized local oscillators. The transmitter is designed to operate in the 27.5 to 28.5 GHz frequency range and consists of all necessary signal conditioning equipment to upconvert two blocks of video or data channels to the LMDS band and transmit

[Continued on page 212]

NEW PRODUCTS NO.63

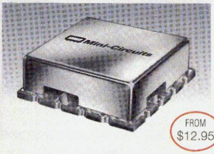
RF/IF MICROWAVE COMPONENTS

DC TO 6GHz TERMINATION HAS N-TYPE MALE CONNECTOR

Mini-Circuits KARN-50 is a 50 ohm DC to 6GHz wideband termination usable to 9GHz. The unit is ruggedly constructed to withstand severe mechanical vibration and shock, and has a 2 watt rating to 70°C ambient. Minimum return loss DC to 500MHz is 36dB, DC to 1GHz is 32dB, DC to 2GHz is 28dB, DC to 4GHz is 20dB, and minimum return loss band wide is 18dB. Applications include cellular and satellite communications and test set-up. Value priced and shipped from stock.

LEVEL 23 (LO) 10 TO 1500MHz MIXER HAS HIGH IP3

Mini-Circuits has started to ship the new SYM-15VH frequency mixer operating in the 10MHz to 1500MHz band. Typically, this unit provides high 31dBm IP3 at center band and a 1dB compression point of +16dBm typical with low 6.5dB midband conversion loss, good 40dB L-R/35dB L-I isolation, and can handle maximum 350mW RF power, 40mA IF current. 5 year Ultra-Rel® guarantee.



12V VCO PROVIDES 75 TO 150MHz OCTAVE BAND TUNING

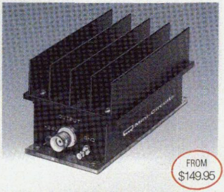
Mini-Circuits has introduced the ROS-150, a compact, low cost voltage controlled oscillator providing 75 to 150MHz octave band tuning, low -103dBc/Hz SSB phase noise typical at 10kHz offset, and excellent -23dBc (typ) harmonic suppression. With 9.5dBm typical power output, this miniature 12V, 20mA (max. current) VCO measures only 0.5"x0.5"x0.18" and is ideal for test instruments such as signal generators. Operating temperature range is -55°C to +85°C (max.).

9 TO 625MHz TRANSFORMER HAS UP TO 1W POWER RATING

Standing only 0.108 inches high,

4WAY SPLITTER/COMBINER FOR CATV APPLICATIONS

Designers requiring a 4way-0° power splitter or combiner for 75 ohm systems operating in the 50 to 860MHz band can specify Mini-Circuits new JS4PS-9-75. Equipped with solder plated J leads for excellent solderability and strain relief, this surface mount unit exhibits typically high 25dB isolation, excellent input matching and very good output matching with VSWR typically 1.20:1 in/1.3:1 out. Amplitude unbalance is excellent at 0.15dB typical. Maximum power input is .50W



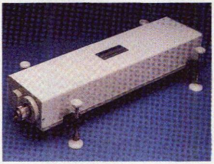
50MHz TO 1000MHz AMPLIFIER HAS HIGH IP2 AND IP3

NEW PRODUCTS

the 1 GHz block at power levels that will provide a range of 5 to 8 km with 0.999 availability, depending upon the rain zone and required carrier-to-noise ratio. Superior performance is achieved by using field-proven RF circuitry and synthesized oscillators phase locked to a rubidium master reference. Optional antennas are available with patterns ranging from 30° to 360° azimuth coverage in either vertical or horizontal polarization.

mm-Tech Inc.,
Eatontown, NJ (732) 935-7150.
Circle No. 278

Automated Harmonic Tuner



The model MT999 precision automated harmonic tuner designed for harmonic load pull or tuning measurements is capable of presenting a high mismatch over a broad frequency range of 0.8 to 7.5 GHz. The tuner also provides a highly accurate and cost-effective method for device characterization where harmonic tuning is required. SWR matching range is 50 (min), carriage step size is 625 microinches and position accuracy is ±1 step. The tuner works with the company's MT986B24/26 harmonic tuner controllers and features power handling of 10 W CW (0.5 kW peak). The high isolation between the fundamental and harmonic frequencies provided by multiplexers assures the accuracy of the harmonic measurements.

Maury Microwave Corp.,
Ontario, CA (909) 987-4715.
Circle No. 277

TEST EQUIPMENT

Precision Current Pulse Generator

The model 507 precision current pulse generator offers digitally controlled current pulses with currents from 0 to 10 A and pulse widths from 0.1 to 100 ms. Precise current control and time-domain resolution allow for complete characterization of electronic systems. Offered in two, four and eight channels, the generator is suitable for automobile airbag squib testing, industrial fuse breakdown testing and precision laser triggering and driving applications. TTL-sync outputs are ideal for video capture or other related test parameters. Price: $3295 (two channels). Delivery: 30 days (ARO).

Berkeley Nucleonics Corp.,
San Rafael, CA (800) 234-7858.
Circle No. 285

[Continued on page 214]

Before you buy an RF personal monitor, monitor their performance.

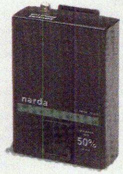
When you look at what our competition *isn't* offering, alarms go off in your head.

Relax.

Just consider everything you *will* get with Narda's personal radiation monitors. Things like guarantees. Ease of use. And performance you can count on.

So no matter what the conditions—even in the most complex, multi-signal environments—you'll get all the protection you need with Narda.

For more information, call today **516-231-1700.**

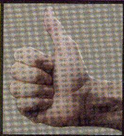


narda
microwave-east

an L3 communications company

ISO9001

© 1999 L-3 Communications, Inc.
www.nardamicrowave.com



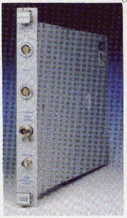
	Narda	Competition
Frequency Range	300 kHz-45 GHz	3MHz-40 GHz
Frequency Response Error	*Guaranteed* Max. ± 2 dB	Not Guaranteed Typical ± 3 dB
Responds equally to all field polarizations	*Guaranteed* Max. ± 0.75 dB	Not Guaranteed Typical ± 2 dB
Accurate at all temperatures	*Guaranteed*	No
Immune to static	*Guaranteed*	No
RMS detection under all conditions	*Guaranteed*	No
Functions near power lines	*Yes*	No
LED Indicator visible when worn on body	*Yes*	No
Unit cost	*$*	$$$
2 Year factory calibration & checkup included*	*Free (No calibration costs for 4 years)*	$
Calibration within 10 business days	*Guaranteed (or calibration is Free)*	No

*Two-year recommended calibration cycle. No additional costs for four years with first two-year checkup and calibration included.

NEW PRODUCTS

VXI RF Power/Volt Meters

The 5730 series RF power/volt meters for measuring power and voltage measurements in VXI configurations have the ability to sample up to 200 readings per second. The units measure power levels from –70 to +44 dBm with a 90 dB dynamic range, measure RF voltage from 10 Hz to 2.5 GHz and cover 10 kHz to 100 GHz when measuring power. The dual-channel meters also allow readings in different units (such as dB and mW) to be displayed simultaneously on different channels. Sensor calibration data, resident in the data adapter, are automatically downloaded to the meter when the sensor is connected, which eliminates the need to re-enter the calibration if a sensor is changed. A zero correction function stores the zero offsets of each range and automatically corrects all subsequent readings.

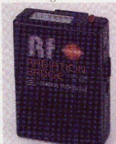


Boonton Electronics Corp., Parsippany, NJ (973) 386-9696.

Circle No. 284

RF/Microwave Radiation Badge

The model H600A RF/microwave radiation badge is intended to be utilized for nonionizing RF and microwave radiation. Designed to monitor the telecommunications frequency range of 50 MHz to 2.5 GHz, the badge provides real-time power density (mW/cm^2) information via its LCD. Measurement modes include a choice of instantaneous or six-minute average. The H600A provides a user-adjustable alarm level setting from 0.2 to 20 mW/cm^2 to satisfy diverse environments. The unit carries a two-year warranty. Standard accessories include a carrying case and earphone for high noise environments. Size: 3.70" × 2.75" × 1.10". Weight: 5 oz.



General Microwave Corp., Amityville, NY (516) 226-8900, ext. 236.

Circle No. 286

RF Spectrum Analyzer

The model P9116 spectrum analyzer is designed for use in production automatic test equipment systems and covers the frequency range of 100 kHz to 1600 MHz. It is packaged in a 2RU industrial PC chassis and can be operated like any other conventional RF spectrum analyzer when used in conjunction with a VGA monitor and supplied graphical user interface. Since the unit's local oscillator is digitally tuned, the precise number of steps and the span between steps are fully controllable with a resolution of 2 Hz across the entire spectrum. This feature, coupled with the synthesizer step of < 150 µs, makes the unit ideal for test applications where increased production throughput is critical. Absolute level accuracy is ±0.5 dB over the –120 to +20 dBm amplitude range and frequency accuracy is 0.5 ppm.

Morrow Technologies Corp. (MTC), Largo, FL (813) 531-4000.

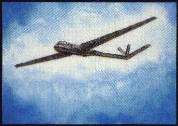
Circle No. 287

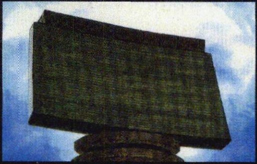
SMP Calibration Kit

This surface-mount package calibration kit from Rosenberger Hochfrequenztechnik GmbH & Co. consists of an open, load and short — all in a male and female interface for use in calibrating various types of test equipment. The calibration kit ensures the reliability of the test results for SMP connectors up to 18 GHz. Also included are two 60 cm precision cables (SMP and SMA) to interface with the test port. The SMP interface is per DESC 94007/94008 and compatible with the GPO™ connector series.

Rosenberger of North America LLC, Lancaster, PA (717) 290-8000.

Circle No. 288





NEW LITERATURE

Flexible Foam Brochure

This new brochure, *Flexible Foams: State-of-the-art Designs...Precision Cut*, describes the company's offerings and capabilities with polyethylene foams, polyurethane foams and extruded profiles. New products, including aircraft accessories, electronic components, pharmaceuticals, gaskets and displays, are also discussed.

Polyfoam Packers Corp., Wheeling, IL (800) 323-7442.

Circle No. 212

Air Filter Engineering Brochure

This six-page application brochure provides prototype information helpful for designing sophisticated equipment that requires electromagnetic interference or RF interference shielding and is a quick reference for design considerations, including Bellcore, CE and UL requirements.

Universal Air Filter Co., Sauget, IL (800) 541-3478.

Circle No. 213

DC Parametric Measurement Application Note

This application note explores the recent advances in DC parametric measurements, including new parametric testers and new parametric wafer probers that reduce system capacitance and noise levels and resolve common measurement problems such as low measurement resolution and high noise. Methods to ensure fast and accurate low level measurements are also discussed.

Cascade Microtech Inc., Beaverton, OR (800) 550-3279 or (503) 601-1000.

Circle No. 201

Logic Analyzer Application Note

This 13-page application note provides hardware engineers, firmware designers and systems integrators with information about acquiring data from a multiplexed address or data bus, using offsets to avoid false triggers, reducing security risks on networked logic analyzers, capturing data before a system crash and analyzing serial data with a logic analyzer.

Hewlett-Packard Co., Palo Alto, CA (800) 452-4844, ext. 6570.

Circle No. 202

Radar Technology Compendium

This comprehensive compendium, *Radar Essentials*, discusses a variety of topics on radar technology, including the history of radar, recent advances in radar technology, new and proposed radar systems, radar simulation and modeling, new radar components and insight into select foreign radar systems.

The Institute of Electrical and Electronics Engineers Inc. (IEEE), Piscataway, NJ (800) 678-4333 or (732) 981-0060.

Circle No. 203

CD-ROM Library

Back issues of the *LabView™ Technical Resource*, a quarterly technical journal, are available via a CD-ROM that features articles about real-world problems and solutions when working with LabView software. The CD-ROM holds the contents of the resource disk published in each issue as well as virtual instrument software examples, utilities, source code and documentation.

LTR Publishing Inc., Dallas, TX (214) 706-0587.

Circle No. 204

Probe Station Navigation Software Brochure

This brochure details pcSetup™ software designed specifically for infrequent users of analytical test stations. The software is also useful to engineers who develop routines that involve testing of samples that are repetitive. Samples of the function icons and toolbars and unique dialog boxes that provide additional information about individual sequence steps are illustrated.

The Micromanipulator Co. Inc., Carson City, NV (800) 967-2426 or (775) 882-2400.

Circle No. 206

Carrier-to-noise Generator Brochure

This four-color brochure provides a thorough overview of the company's carrier-to-noise (C/N) generator designed to evaluate the performance of today's digital communication systems, including PCS, wideband CDMA and satellite systems. A replica of the C/N generator's unique front screen display as well as ordering information are also provided.

Micronetics, Hudson, NH (603) 883-2900, ext. 312.

Circle No. 205

Technical Note

This 18-page technical note, *Advances in Low Noise Receiver Front Ends and Developments in AFC Circuitry for MTI Magnetron-based Radars*, describes special mixer products designed for the radar market. The limitations in dynamic range of Schottky and MESFET mixers are discussed and front end specifications utilizing each mixer are outlined. In addition, several state-of-the-art analog and digital radar phase-lock subsystems are described.

MITEQ, Hauppauge, NY (516) 439-9423.

Circle No. 207

Quartz Frequency Control Product Catalog

This 32-page, full-color catalog contains information about the company's crystal units, monolithic crystal filters and crystal oscillators for computer, telecommunications, wireless data communications, CEM and other OEM markets. Specifications, definitions and application information are also included.

Tekmark Inc., Alpharetta, GA (770) 346-9102.

Circle No. 208

Capability Brochure

This four-page brochure describes the company's full capabilities for designing, developing and manufacturing custom RF and microwave filters for the 1 MHz to 40 GHz frequency range. The supply of dielectric material for filter production from nearby TRAK Communications companies is also described.

Advanced Filter Solutions, Frederick, MD (301) 698-0114.

Circle No. 209

New Component Catalog

This 150-page catalog features thousands of ICs, components, tools, and test equipment and computer products for OEMs, engineers, educators and service/repair technicians. Product photographs and expanded descriptions are included. A user-friendly ordering process is also described.

Jameco Electronic Components, Belmont, CA (800) 831-4242.

Circle No. 210

Thermoelectric Controller Bulletin

This one-page bulletin (No. 9905) introduces the model 5C7-350 temperature controller for use with thermoelectric modules. Key specifications and available options are described.

Oven Industries Inc., Mechanicsburg, PA (717) 766-0721.

Circle No. 211

CLASSIFIEDS

BIPOLAR AMPLIFIERS

STANDARD OPTIONS

- Connector Options: SMA, BNC, Type N
- Integrated Limiters
- Input Bias Tee for Fiberoptic Photodetectors

FREQUENCY (MHz)	MODEL NUMBER	GAIN (dB, Min.)	GAIN FLATNESS (±dB, Max.)	VSWR IN/OUT	NOISE FIGURE F_1 (dB, Max.)	NOISE FIGURE $F_ø$ (dB, Max.)	NOISE FIGURE F_2 (dB, Max.)	OUTPUT POWER (dBm, Min.)	DOMESTIC PRICE (1-9 PCS)
0.01 – 200	AU-1442	35	0.5	2.0:1	1.2	1.2	1.2	5	$300
0.01 – 200	AU-1447	56	0.5	2.0:1	1.2	1.2	1.2	12	$325
0.01 – 500	AU-1310	30	0.5	2.0:1	1.3	1.4	1.5	8	$300
0.01 – 500	AU-1332	45	0.5	2.0:1	1.3	1.4	1.5	10	$325
0.01 – 1000	AM-1300	27	0.75	2.0:1	1.4	1.6	1.8	8	$325
0.01 – 1000	AM-1431	35	0.75	2.0:1	1.4	1.6	1.8	10	$350
0.02 – 1000	AM-1551	38	1.0	2.0:1	1.4	1.6	1.8	15	$350
1 – 100	AU-3A-0110	55	0.5	2.0:1	1.2	1.2	1.2	12	$300
1 – 200	AU-1464	35	0.5	2.0:1	1.2	1.2	1.2	6	$275
1 – 200	AU-1494	56	0.5	2.0:1	1.2	1.2	1.2	11	$300
1 – 500	AU-2A-0150	30	0.5	2.0:1	1.3	1.4	1.5	8	$275
1 – 500	AU-3A-0150	45	0.5	2.0:1	1.3	1.4	1.5	10	$300
1 – 500	AU-4A-0150	60	0.5	2.0:1	1.3	1.4	1.5	10	$325
1 – 1000	AM-2A-000110	26	0.75	2.0:1	1.4	1.6	1.8	8	$300
1 – 1000	AM-3A-000110	35	0.75	2.0:1	1.4	1.6	1.8	8	$325
1 – 1000	AM-4A-000110	51	1.0	2.0:1	1.4	1.6	1.8	9	$350
5 – 300	AU-1021	24	0.5	2.0:1	2.4	2.5	2.7	20	$275
5 – 300	AU-1525	61	0.5	2.0:1	1.2	1.2	1.3	20	$350
100 – 1000	AM-1412	35	0.75	2.0:1	1.4	1.6	1.8	15	$350
100 – 2000	AM-1526	9	1.0	2.0:1	8	5.5	5.5	20	$350
200 – 2000	AMMIC-1427	20	1.5	2.2:1	4.2	4.3	4.6	14	$375
500 – 1000	AM-2A-0510	24	0.5	2.0:1	1.4	1.5	1.6	0	$300
500 – 1000	AM-3A-0510	38	0.5	2.0:1	1.4	1.5	1.6	9	$325
500 – 2000	AM-3A-0520	29	0.75	2.0:1	1.4	1.9	2.4	3	$350
1000 – 2000	AM-3A-1020	29	0.5	2.0:1	1.8	2.1	2.4	10	$325
1000 – 2000	AM-1477	39	1.0	2.0:1	1.8	2.1	2.4	15	$350
1000 – 2000	AM-4A-1020	40	0.75	2.0:1	1.8	2.1	2.4	10	$350

3 YEAR WARRANTY

NQA ISO 9001 REGISTERED COMPANY

Maximum 2 week delivery for small quantities. For additional information, please contact Bill Pope at (516) 439-9115 or e-mail wpope@miteq.com

MITEQ

100 Davids Drive, Hauppauge, NY 11788
TEL: (516) 436-7400 • FAX: (516) 439-9333/436-7430
www.miteq.com

CIRCLE 130 ON READER SERVICE CARD

THE BOOK END

Electrodynamics of Solids and Microwave Superconductivity

Shu-Ang Zhou

John Wiley & Sons Inc.
626 pages; $130
ISBN: 0-471-35440-6

Microwave superconductivity is of great interest now that practical applications are appearing in telecommunications and other areas. This book provides an introductory and comprehensive theoretical foundation for solid electrodynamics and microwave superconductivity to engineers and applied physicists.

"...an introductory and comprehensive theoretical foundation for solid electrodynamics and microwave superconductivity to engineers..."

Chapter 1 contains a review of classical electrodynamics, basic concepts and theoretical principles for the study of electromagnetic phenomena in a material media. Chapter 2 introduces continuum electromagnetic phenomena and its interaction with mechanical phenomena in material solids that may be deformed or in motion under electromagnetic and/or mechanical loading. Particular emphasis is placed on electro-quasistatic and magneto-quasistatic problems.

Chapter 3 introduces the basic concepts of superconductivity and formulates macroscopic electrodynamic theories for superconductors in weak fields. Chapter 4 presents theoretical models for the study of electromagnetic properties and thermomagnetoelectric effects in type II superconductors that maintain their state in very strong magnetic fields. Chapter 5 introduces the Josephson effect, the phenomenon of tunneling of electron pairs across a superconductor-insulator-superconductor junction. Applications of superconducting quantum interference devices are briefly discussed.

Chapter 6 introduces the theory of transmission lines based on a distributed model and Maxwell's equations. A full-wave analysis is performed to investigate properties of anisotropic superconducting transmission lines that may operate at extremely high frequencies. Chapter 7 is devoted to the introduction of theoretical models developed recently for the study of the interaction between electromagnetics and the mechanics of superconductors. This book is highly theoretical and not for the casual reader. However, it ties together both electromagnetic and mechanical phenomena in a way that is understandable.

To order this book, contact: John Wiley & Sons Inc., 605 Third Avenue, New York, NY 10158 (212) 850-6336 or (800) 225-5945.

Feedforward Linear Power Amplifiers

Nick Pothecary

Artech House Inc.
204 pages; $75, £56
ISBN:0-1-58053-022-2

The physical separation of communication channels has become a major problem within wireless transmission. Today's systems must use more complex modulation schemes to increase bandwidth efficiency, and these modulation techniques require highly linear amplifiers. This book describes the challenges and behavior of high power amplifiers linearized using the feedforward technique.

Chapter 1 begins with an overview of feedforward techniques and includes an introduction to a typical radio system for cellular, PCS or IMT2000/universal mobile telecommunications system applications. Specific concepts for RF operations are also discussed. Chapter 2 presents a mathematical-based approach to discussions of amplifier input and output characteristics, signal modulation formats, signal envelopes, peak-to-average ratios and statistical analysis. Power amplifiers and system design are discussed in Chapter 3, including transistors for RF power amplifiers, amplifier efficiency, operating classes, intermodulation performance and system design issues. The concept of a linear amplifier is introduced and practical examples are presented for different system configurations.

"This book describes the challenges and behavior of high power amplifiers linearized using the feedforward technique."

Chapter 4 reviews different linearization techniques, including feedback (RF feedback, envelope feedback, Cartesian loop and polar loop feedback), RF synthesis, envelope elimination and restoration, predistortion and feedforward systems. The principle of operation of feedforward linearization and dual-loop feedforward linearization is presented along with discussions on signal cancellation and loop control. Chapter 5 provides a detailed analysis of feedforward performance, covering such topics as gain, input/output match, noise figure, broadband signal cancellation, error amplifier performance and system efficiency. The book presents the subject in an extremely clear and easy-to-follow manner with an abundance of supporting block diagrams and graphics and a minimum of complex theory.

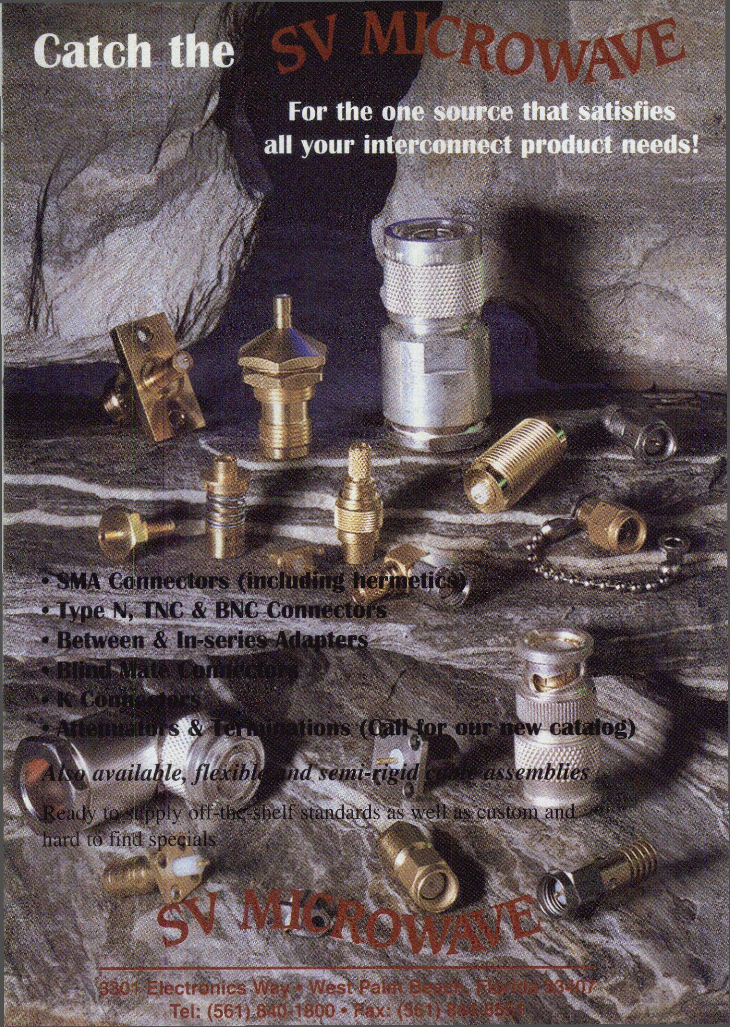
To order this book, contact: Artech House Inc., 685 Canton St., Norwood, MA 02062 (781) 769-9750, ext. 4002; or 46 Gillingham St., London SW1V 1HH, UK +44 (0) 171 973 8077.

Frank Bashore

Frank Bashore is a member of the Microwave Journal *staff.*

ADVERTISING INDEX

Circle No.	Advertiser	Page No.	Phone	Fax	Web/E-Mail Address
1	Advantest Corporation	135	+81-3-3342-7500		http://www.advantest.co.jp/index-e.html
2	Aerocomm Satellite Technology	212	+662-693-8300	+662-693-8304	http://www.aerocommthailand.com
3,4	Alpha Industries	80,184	508-894-1904	617-824-4579	http://www.alphaind.com
5,6	Amcom Communications Inc.	50	301-353-8400	301-353-8401	http://www.amcomusa.com
7	American Technical Ceramics	75	516-622-4700	516-622-4748	http://www.atceramics.com
8	Amplifier Research	117	215-723-8181	215-723-5688	http://www.ar-amps.com
9	Anaren Microwave	185	800-544-2414	315-432-9121	http://www.anaren.com
10,11	Anritsu Company	16,181	800-ANRITSU	972-644-3416	http://www.anritsu.com
12,13,14	Ansoft Corporation	89,91,93	412-261-3200	412-471-9427	http://www.ansoft.com
15	Antenna Research Associates	66	301-937-8888	301-937-2796	http://www.ara-inc.com
16	Aplac	174			http://www.aplac.com
17	Atlantic Microwave	120-I°	+44-1376-550220	+44-1376-552145	e-mail: sales@atlanticmicrowave.co.uk
18	ATN Microwave Inc.	15	978-667-4200	978-667-8548	http://www.atnmicrowave.com
19	Berkeley Varitronics Systems	83	732-548-3737	732-548-3404	http://www.bvsystems.com
191,192	Cascade Microtech	COV 4	503-601-1000	503-601-1002	http://www.cascademicrotech.com
21	Communication Solutions Inc.	137	410-574-4557	410-574-4559	http://www.comsol-inc.com
22	Communication Techniques	119	973-884-2580	973-887-6245	http://www.cti-inc.com
23,24,25,26	Comtech PST	153	516-777-8900	516-777-8877	http://www.comtechpst.com
28	Condor Systems Inc.	120	408-879-2236	408-377-6892	http://www.condorsys.com
29	CTT Inc.	69	408-988-8521	408-986-9097	http://www.cttinc.com
30	Daico Industries	COV 3	310-507-3242	310-507-5701	http://www.daico.com
31	Dielectric Laboratories	68	315-655-8710	315-655-8179	http://www.dilabs.com
32	Dow-Key Microwave Corp.	151	805-650-0260	805-650-1734	http://www.dowkey.com
33	Ducommun Technologies Inc.	209	310-513-7215	310-522-8994	http://www.ductech.com
34,35	Dynawave	77,207	978-469-0555	978-521-4589	http://www.dynawave.com
36	Eagleware Corporation	40-41	770-939-0156	770-939-0157	http://www.eagleware.com
37	EEV Inc.	140	914-592-6050	914-682-8922	http://www.eev.com
38,39,40	EMC Technology	139,141,143	609-429-7800	609-429-6814	http://www.emct.com
41	Emhiser Micro-Tech	28	408-446-3582	775-345-2484	http://www.emhiser.com/vco
42	Filtel Microwave	212	450-455-6082	450-424-5819	
43	Filtran Microcircuits	127	613-737-0706	613-737-0495	http://www.filtranmicro.com
44	Florida RF Labs	43	800-544-5594	888-544-5594	http://www.rflabs.com
45	Focus Microwaves Inc.	195	514-335-6227	514-335-6287	http://www.focus-microwaves.com
46	Frequency Electronics	107	516-794-4500	516-794-4340	http://www.freqelec.com
47	Future Electronics	55	888-680-5892		http://www.future.ca/motorolarf
48	General Microwave Corporation	48	516-226-8900	516-226-8966	http://www.gmcwave.com
49	GGB Industries Inc.	3	941-643-4400	941-643-4403	http://www.picoprobe.com
50	H. Rollet & Co. Ltd.	76	+44-1992-500818	+44-1992-509905	http://www.hrollet.co.uk
51	HD USA	62	301-931-1048	301-931-1049	http://www.hdusa.net
52,53	Herley MDI	84,165	781-729-9450	781-729-9547	http://www.herleympg.com
54,55,	Hewlett Packard	COV 2,	800-452-4844	415-857-5518	http://www.hp.com
56,57,		35,			
58,59,		67,			
60,61		121			
62	Hittite Microwave	71	978-250-3343	978-250-3373	http://www.hittite.com
63	Huber + Suhner AG	42	+41-71-353-41-11	+41-71-353-44-44	http://www.hubersuhner.com
	Hyper	82-I°	+33-1-53-17-11-40	+33-1-53-17-11-45	http://www.birp.com/hyper
	IEEE MTT-S 2000	86			http://www.ims2000.org
64	IFR Americas	138	316-522-4981	316-329-5575	http://www.ifrinternational.com
65	IMI	62	978-373-9190	978-521-1846	http://www.imipcb.com
66	Infineon Technologies	86-I°			http://www.infineon.com/building-blocks
67	Insulated Wire Inc.	25	203-791-1999	203-748-5217	http://www.insulatedwire.com
	IWCE 2000/Intertec Exhibitions	82	800-288-8606	720-489-3165	http://www.iwceconexpo.com
68	JCA Technology	27	805-445-9888	805-987-6990	http://www.jcatech.com
69,70	JFW Industries Inc.	8,54	317-887-1340	317-881-6790	http://www.jfwindustries.com
71	Johanson Manufacturing	103	973-334-2676	973-334-2954	http://www.johansonmfg.com
72	Johanson Technology	96	805-389-1166		http://www.johanson-caps.com
73	K&L Microwave Inc.	6	410-749-2424	410-749-5725	http://www.klmicrowave.com
74	Kaman Instrumentation	191	719-599-1821	719-599-1823	http://www.kamaninstrumentation.com
75,76,77	KMW	29,63,123	562-926-2033	562-926-6133	http://www.kmwinc.com
78	Labtech Ltd.	212	+44-1544-260093	+44-1544-260310	http://www.labtechcircuits.com
79	Lark Engineering	176	949-240-1233	949-240-7910	http://www.larkengineering.com
80	Lorch Microwave	95	410-860-5100	410-860-1949	http://www.lorch.com
81	M-Tron Industries	76	800-762-8800	605-665-1709	http://www.mtron.com
82	Maury Microwave Corporation	9	909-987-4715	909-987-1112	http://www.maurymw.com



Catch the SV MICROWAVE
For the one source that satisfies
all your interconnect product needs!
• SMA Connectors (including hermetics)
• Type N, TNC & BNC Connectors
• Between & In-series Adapters
• Blind Mate Connectors
• K Connectors
• Attenuators & Terminations (Call for our new catalog)
Also available, flexible and semi-rigid cable assemblies
Ready to supply off-the-shelf standards as well as custom and hard to find specials
SV MICROWAVE
3301 Electronics Way • West Palm Beach, Florida 33407
Tel: (561) 840-1800 • Fax: (561) 844-8551

Circle No.	Advertiser	Page No.	Phone	Fax	Web/E-Mail Address
83	MECA Electronics Inc.	189	973-625-0661	973-625-1258	http://www.mecaelectronics.com
84	Mica Microwave Corporation	88	408-363-9200	408-363-9220	http://www.mica-mw.com
	Micro Comm	214	978-685-2272	978-794-5627	http://www.micsearch.com
85	Micro Lambda	201	510-770-9221	510-770-9213	http://www.micro-lambda.com
86,87	Micrometrics Inc.	85,87	603-641-3800	603-641-3500	http://www.micrometrics.com
88	Microwave & Video Systems Inc.	44–45	203-792-7474	203-792-7475	e-mail: mvsmicro@worldnet.att.net
89	Microwave Circuits	212	202-829-3030	202-829-2639	http://www.micckts.com
90	Microwave Comm. Laboratories Inc. (MCLI)	18	800-333-6254	727-381-6166	http://www.mcli.com
91	Microwave Communications & Components	114	+82-2-3424-0800	+82-2-3424-0808	http://www.mcck.com
92	Microwave dB	39	805-499-0410	805-498-0054	http://www.microwavedb.com
93	Microwave Development Company Inc.	17	603-870-6280	603-870-6210	http://www.mdc-inc.net
94	Microwave Development Labs	101	800-383-4189	781-453-8629	http://www.micro-dev.labs.com
95	Microwave Filter Company	204	800-448-1666	315-463-1467	http://www.microwavefiter.com
	Microwave Journal	156,192	800-225-9977	781-769-5037	http://www.mwjournal.com
96	Microwave Power Devices	215	516-231-1400	516-231-8081	http://www.mpd.com
97	Microwave Specialty Corporation	144	760-744-1544	760-744-1565	http://www.microwavespecialty.com
98,99,	Mini-Circuits	4-5,	718-934-4500	718-332-4661	http://www.minicircuits.com
100,101,		7,			
102,103,		11,			
104,105,		47,			
106,107,		52,			
108,109,		56,			
110,111,		81,			
112,113,		131,			
114,115,		157,			
116,117,		161,			
118,119,		183,			
120,121,		187,			
122,123,		193,			
124,125,		211			
126,127,128, 129,130	MITEQ Inc.	49,105,125, 179,217	516-436-7400	516-436-7430	http://www.miteq.com
131	Mitsubishi Electronics America Inc.	148–149	949-660-7080	949-975-1557	http://www.mitsubishichips.com
132	Modco	32	775-331-2442	775-331-6266	http://www.modcoinc.com
133	Modular Components National Inc.	60	410-879-6553	410-838-7629	http://www2.ari.net/modular
	Motorola Semiconductor Products Sector	133	800-441-2447	303-675-2150	e-mail: motorola.com/sps/rf
134	Murata Electronics	79	800-831-9172		http://www.murata.com
135,136,137	Narda Microwave-East, an L3 Communications Co.	109,129,213	516-231-1700		http://www.nardamicrowave.com
138	Noisecom	19	201-261-8797	201-261-8339	http://www.noisecom.com
139	Phoenix Microwave Corp.	59	215-723-6011	215-723-6015	http://www.phnixmw.com
140	Q-Tech Corporation	164	310-836-7900	310-836-2157	http://www.q-tech.com
141,142	QMI	13,203	978-988-9090	978-988-9393	http://www.qmiinc.com
143	Quasar Microwave Technology Ltd.	70	+44-1626-834222	+44-1626-832994	http://www.qmtl.com
144	Radio Research Instrument Co. Inc.	116	203-753-5840	203-754-2567	http://www.techexpo.com/www/radiores
145	Reactel	145	301-519-3660	301-519-2447	http://www.reactel.com
146	Remec Inc.	160	1-877-66-REMEC	408-432-1551	http://www.remec.com
	RF Globalnet	134			
147,148	RF Micro Devices	51,219	336-664-1233	336-664-0454	http://www.rfmd.com
149	Richardson Electronics	97	1-800-RFPOWER	630-208-2550	http://www.rfpowernet.com
150	RLC Electronics Inc.	23	914-241-1334	914-241-1753	http://www.rlcelectronics.com
151	Rogers Corporation	20–21	480-961-1382	480-961-4533	http://www.rogers-corp.com/mwu
152	Rohde & Schwarz GmbH	115	+49-89-41293115	+49-89-41293115	http://www.fsp.rsd.de
153	Sabritec	106	949-250-1244	949-250-1009	http://www.sabritec.com
154	Sage Laboratories	33	508-653-0844	508-653-5671	http://www.sagelabs.com
155	Salisbury Engineering Inc.	212	800-989-2141	302-846-3888	e-mail: sales@salisbury-engineering.com
156,157	Sarnoff Corporation	73,205	609-734-2507	609-734-2443	http://www.sarnoff.com/ad/wireless
	SCVTA	216	408-321-5575		e-mail: personnel.vta.org
158	Seavey Engineering Associates Inc.	124	781-829-4740	781-829-4590	http://www.seaveyantenna.com
159	Sector Microwave Industries Inc.	212	516-242-2300	516-242-8158	e-mail: sales@sectormicrowave.com
160	Special Hermetics Products Inc.	74	603-654-2002	603-654-2533	http://www.shp-seals.com
161	Spectrum	135-I*	+49-89-354-8040	+49-89-354-80490	e-mail: specelek@compuserve.com

ADVERTISING INDEX

ADVERTISING INDEX

Circle No.	Advertiser	Page No.	Phone	Fax	Web/E-Mail Address
162	Stanford Microdevices	36–37	800-764-6642		http://www. stanfordmicro.com/sige
163,164	Stanford Telecom	116,152	978-441-0200	978-453-6299	http://www.stelmsd.com
165	State of the Art	106	800-458-3401	814-355-2714	http://www.resitor.com
166	Stellex Microwave Systems Inc.	147	800-321-8075	650-813-2525	http://www.stellexms.com
167	SV Microwave	221	561-840-1800	561-844-8551	e-mail: sales@svmicro.com
168,169,170	Synergy Microwave Corp.	65,111,223	973-881-8800	973-881-8361	http://www.synergymwave.com
171	T-Tech Inc.	70	770-455-0676	770-455-0970	http://www.t-tech.com
172	Technical Communities	14	650-853-5993		http://www.testmart.com
173	Tekelec Temex	58	+33-1-49-884900	+33-1-48-581046	http://www.tekelec-temex.com
174	Teledyne Electronic Technologies	169	650-962-6944	650-962-6845	http://www. teledynemicrowave.com
175	Tetra Electronic Industries	112	+972-3-5562775	+972-3-5561944	e-mail: gadil@tetra.co.il
176,177	Thomson Microsonics	175,177	+33-0492-9640-00	+33-0492-9630-25	http://www. microsonics.thomson-csf.com
178	Trans-Tech	163	301-695-9400	301-695-7065	http://www. trans-techinc.com
179	Tru-Connector	26	978-532-0775	978-531-6993	http://www.tru-con.com
180	Tusonix	158	520-744-0400	520-744-6155	http://www.tusonix.com
181	Vari-L	113	303-371-1560	303-371-0845	http://www.varil.com
182	Vectron International	171	1-88-VECTRON1	888-FAX-VECTRON	http://www.vectron.com
183	Vertical Net	167			http://www.industrydeals.com
184	Watkins Johnson Co.	31	800-951-4401	650-813-2447	http://www.wj.com
185	Wavesat	34	514-956-6300	514-956-8587	http://www.wavesat.com
186	Weinschel Corporation	150	301-846-9222	301-846-9116	http://www.weinschel.com
187	Werlatone	159	914-279-6187	914-279-7404	http://www.werlatone.com
188	Z-Communications	155	619-621-2700	619-621-2722	http://www.zcomm.com/
189	Zeland Software	142	510-797-8109	510-797-8241	http://www.zeland.com
190	ZETA, a division of Sierra Networks Inc.	173	408-434-3600	408-433-0205	http://www.zeta-sni.com

*Euro-Global only

Visit **Microwave Journal** *on the Web at* **www.mwjournal.com**

SALES REPRESENTATIVES

the microwave journal

Harlan Howe, Jr., Publisher

Eastern and Central Time Zones

Carl Sheffres
National Sales Mgr.
685 Canton Street
Norwood, MA 02062
Tel: (781) 769-9750
FAX: (781) 769-5037
e-mail:
csheffres@mwjournal.com

Tim O'Callaghan
Eastern Reg. Sales Mgr.
685 Canton Street
Norwood, MA 02062
Tel: (781) 769-9750
FAX: (781) 769-5037
e-mail: tocallaghan
@mwjournal.com

Eastern and Central Time Zones

Ed Johnson
Associate Publisher
PO Box 5962
Ocala, FL 34478-5962
Tel: (352) 620-2442
FAX: (352) 620-2443

Pacific and Mountain Time Zones

Wynn Cook
Western Reg. Sales Mgr.
PO Box 23200
San Jose, CA 95153
Tel: (408) 224-9060
FAX: (408) 224-6106
e-mail:
wynncook@ix.netcom.com

Ed Johnson, Associate Publisher

International Sales

Sam Baird
Manager – Europe
Michel Zoghob
Gareth Watson
46 Gillingham Street
London SW1V 1HH,
England
Tel: +44 20 7596 8740
FAX: +44 20 7596 8749

Australia

James Tonkin
Tonkin Media Pty. Ltd.
300 Scenic Highway
Terrigal NSW 2260, Australia
Tel: +61 43 85 1746
FAX: +61 43 85 2017

Germany, Austria, and Switzerland (German-speaking)

Juergen Wissling
Wissling Marketing Services
Riedstrasse 5
72813 St. Johann-
Wuertingen
Germany
Tel: +49 7122 829310
FAX: +49 7122 829330

Michelle Carletti, Traffic Administrator

Japan

Kenichi Takefusa
Appeal Inc.
Arpus Hiroo, 2F, 5-17-11
Hiroo, Shibuya-ku,
Tokyo 150, Japan
Tel: +81 3 3443 0895
FAX: +81 3 3443 0871

Korea

Young-Seoh Chinn
JES Media International
2nd Floor, ANA Bldg.
257-1, Myungil-Dong
Kangdong-Gu
Seoul, 134-070 Korea
Tel: +82 2 481-3411
FAX: +82 2 481-3414

Taiwan

Laura Chen
Arco Publications
4 F, No. 5, Sec. 1,
Pa-Te Road
Taipei, Taiwan ROC
Tel: +886-2 396 5128
FAX: +886-2 396 4511

Israel

Oreet Ben Yaacov
Oreet International Media
15 Kineret Street
51201 Bene-Berak, Israel
Tel: +972 3 570 6527
FAX: +972 3 570 6526

Daico Offers Wireless Solutions With a Switch

Customized Performance

Featuring surface-mount control products with performance that exceeds MMIC technology, Daico offers customized solutions for your specific basestation designs. And with over 30 years of IF/RF and microwave experience, you can switch to Daico to do it right.

Affordable Prices

Imagine getting customized high-performance products that fit your budget. For your Wireless applications, our surface-mount High Dynamic Range Power/VSWR Detector provides 27dB dynamic range with temperature stability of +/– 1db over it's full operating temperature and goes for under $50 in 1K quantities. Best of all, you can get this kind of price and performance from Daico's full line of wireless components.

Production Quantities

Daico now delivers quality components in the quantities you need for all your basestation networks. From switches to detectors to subassemblies, we offer quantities of 1K, 10K, 50K or more. And with our fast development turnarounds, you can't lose.

Lower prices, higher volumes, customized performance. If the application is wireless, the solution is Daico.

DAICO *Industries*

We've Got Your Bases Covered™

1070 East 233rd Street Carson, CA 90745
Tel: 310-507-3242 Fax: 310-507-5701
Web: www.daico.com

CIRCLE 30 ON READER SERVICE CARD

Switches / Attenuators / Phase Shifters / MMICS / Detectors / Couplers / Modulators / Amplifiers / Subassemblies