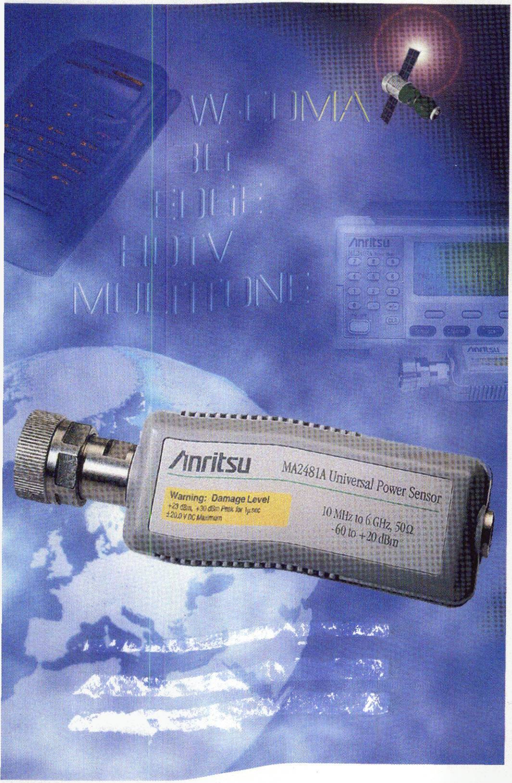
microwave JOURNAL

EURO-GLOBAL EDITION

MARCH 2000

VOL. 43, NO. 3



TEST, MEASUREMENT AND CAD

SWITCHED-COUPLER MEASUREMENTS FOR HIGH POWER RF CALIBRATIONS

SIMPLE WAVEGUIDE CALIBRATION FOR A VNA

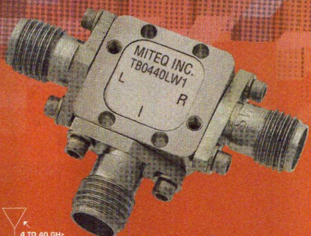
Z-DOMAIN METHOD FOR HIGH ORDER DIGITAL PHASE-LOCKED LOOPS

CONTENTS, P. 10

horizon house

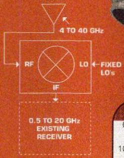
4 - 40 GHz BLOCK DOWNCONVERTER

MITEQ's Model TB0440LW1 allows the use of existing wide bandwidth receivers over millimeter frequency bands!

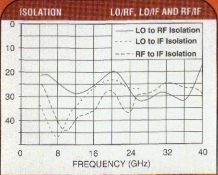


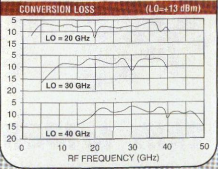
FEATURES:

- RF/LO Coverage....... 4 to 40/4 to 42 GHz
- IF Operation............. 0.5 to 20 GHz
- LO Power Range ...... +10 to +15 dBm (usable at +7 dBm)
- RF to IF Isolation...... 25 dB
- Removable K Connectors
- From Stock



INPUT PARAMETERS	MIN.	TYP.	MAX.
RF frequency range (GHz)	4		40
RF VSWR (RF = -10 dBm, LO = +13 dBm)		2.5:1	
LO frequency range (GHz)	4		42
LO power range (dBm)	+10	+13	+15
LO VSWR (RF = -10 dBm, LO = +13 dBm)		2.0:1	
TRANSFER CHARACTERISTICS	**MIN.**	**TYP.**	**MAX.**
Conversion loss (dB)		10	12
Single sideband noise figure (dB, at +25° C)		10.5	
Isolation - LO to RF (dB)	18	20	
Isolation - LO to IF (dB)	20	25	
Isolation - RF to IF (dB)	20	30	
Input power at 1 dB compression (dBm)		+5	
Input two-tone 3rd order intercept point (dBm)		+15	
OUTPUT PARAMETERS	**MIN.**	**TYP.**	**MAX.**
IF frequency range (GHz)	0.5		20
IF VSWR (RF = -10 dBm, LO = +13 dBm)		2.5:1	





For additional information, please contact Mary Becker at (631) 439-9423 or e-mail mbecker@miteq.com

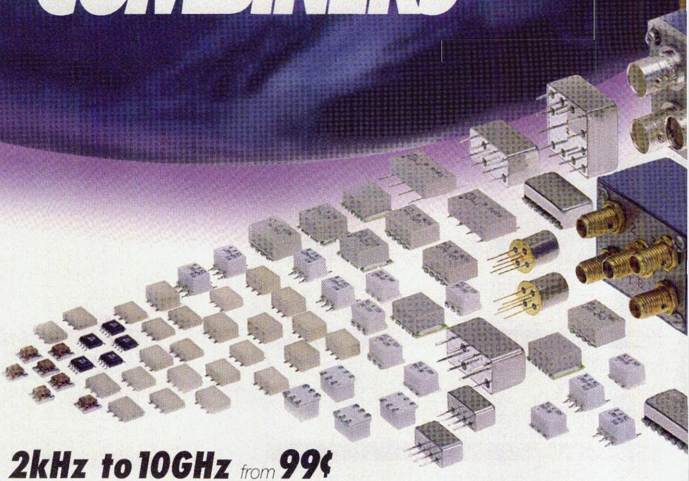
MITEQ

100 Davids Drive, Hauppauge, NY 11788
TEL.: (631) 436-7400 FAX: (631) 436-7430
www.miteq.com

CIRCLE 118 ON READER SERVICE CARD

THE WORLD'S LARGEST SELECTION

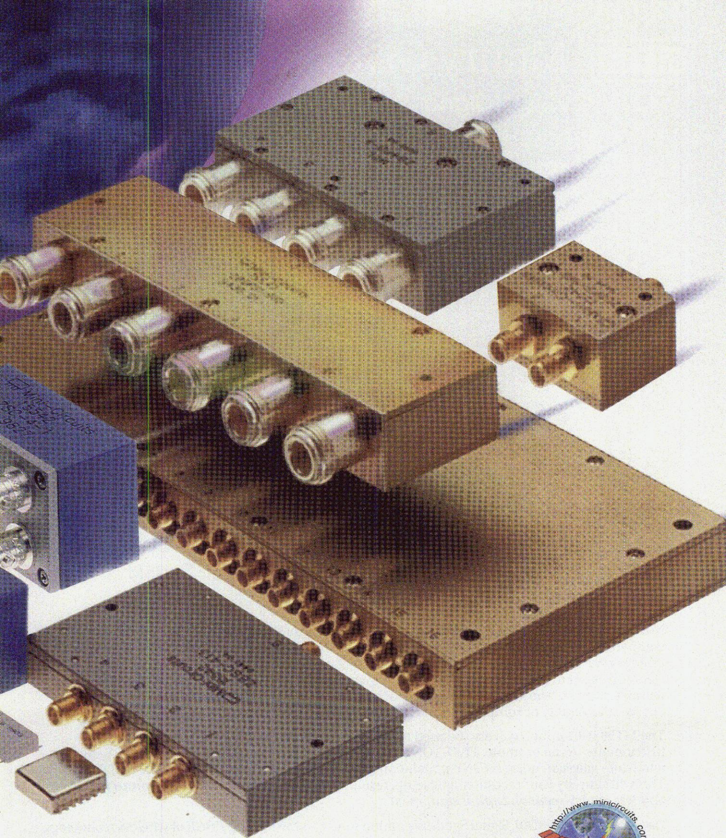
POWER SPLITTERS/ COMBINERS



2kHz to 10GHz *from* 99¢

Choose from over 550 standard off-the-shelf models from 2way and 3way to 48way; 0°, 90°, and 180°; 50 and 75 ohms covering 2kHz to 10GHz. Mini-Circuits will also supply your special needs and custom designs such as wider bandwidths, higher isolation, lower insertion loss and phase matched ports...all at catalog prices with rapid turnaround time. Case styles include surface mount, plug-in, flat pack, and coaxial connectorized... and custom case styles are no problem! Super-miniature and ultra-low profile surface mount units provide excellent solutions in cellular communications, cable systems, and countless wireless applications. And all units come with a 1 year guarantee and skinny 4.5 sigma performance repeatability unit-to-unit and production run to production run. Add fast delivery, unsurpassed applications support and value pricing, and the decision is easy. Call Mini-Circuits today!

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



NEW ERA AMPLIFIERS

WOW! DC to 8GHz (up to +18.5dBm output) From $1.19 (1000 qty.)

Mini-Circuits ushers-in a new era of technology and economy with ERA monolithic GaAs amplifiers. Just check the specs! These surface mount and drop-in amplifiers cover your applications to 8GHz with higher gain, more output, and flatter response. Characterized with S-parameter data, these amplifiers are very easy to use. Simply sketch an interconnect layout, and the design is done. And ERA's are engineered with wider bandwidths to eliminate your need for costly compensation networks and extra gain stages. So, review your present design and replace with Mini-Circuits new ERA technology. Lower overall cost, wide bandwidth, and lots to...*gain!*

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

Model	*Freq. (MHz)	Gain (dB)	Max. Power Out (dBm, @ 1dB Comp)	Dynamic Range NF(dB)	IP3(dBm)	@Device Current(mA)	①Price $ ea. (10 Qty.)
ERA-1	DC-8000	11.8	11.7	5.3	26.0	40	1.80
ERA-1SM	DC-8000	11.8	11.3	5.5	26.0	40	1.85
ERA-2	DC-6000	15.6	12.8	4.7	26.0	40	1.95
ERA-2SM	DC-6000	15.2	12.4	4.6	26.0	40	2.00
ERA-3	DC-3000	20.8	12.1	3.8	23.0	35	2.10
ERA-3SM	DC-3000	20.2	11.5	3.8	23.0	35	2.15
ERA-4	DC-4000	13.5	▲17.0	5.5	▲32.5	65	4.15
ERA-4SM	DC-4000	13.5	▲16.8	5.2	▲33.0	65	4.20
ERA-5	DC-4000	18.8	▲18.4	4.5	▲33.0	65	4.15
ERA-5SM	DC-4000	18.5	▲18.4	4.3	▲32.5	65	4.20
ERA-6	DC-4000	11.3	▲18.5	8.4	▲36.5	70	4.15
ERA-6SM	DC-4000	11.3	▲17.9	8.4	▲36.0	70	4.20

Note: Specs typical at 2GHz, 25°C. Exception: ▲ indicates typ. numbers tested at 1GHz.
* Low frequency cutoff determined by external coupling capacitors.
① Price (ea.) Qty.1000: ERA-1 $1.19, -2 $1.33, -3 $1.48, -4, -5 or -6 $2.95. SM option same price.

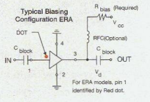
DESIGNER'S AMPLIFIER KITS:

K1-ERA: 10 of each ERA-1,-2,-3 (30 pieces) only $49.95
K1-ERASM: 10 of each ERA-1SM,-2SM,-3SM (30 pieces) only $49.95
K2-ERA: 10 of each ERA-4,-5 (20 pieces) only $69.95
K2-ERASM: 10 each ERA-4SM,-5SM (20 pieces) only $69.95
K3-ERASM: 10 each ERA-4SM,-5SM,-6SM (30 pieces) only $99.95

Chip Coupling Capacitors at 12¢ each (50 min.)

Size (mils)	Value
80x50	10, 22, 47, 68, 100, 220, 470, 680, 1000, 2200, 4700, 6800, 10,000 pf
120x60	.002, .047, .068, .1 µf

ERA-1 ERA-1SM
ACTUAL SIZE



Free User Guide!
Packed with comprehensive technical support. Shipped with order, or call for your free copy today.

Mini-Circuits®

US 92 INT'L 93
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

ISO 9001 CERTIFIED

F 214 Rev E

microwave JOURNAL®

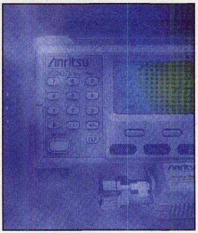
MARCH 2000 • VOL. 43, NO. 3

FEATURES

TECHNICAL FEATURES

APPLICATION NOTE

[Continued on page 12]



ON THE COVER

This month's cover features a universal power sensor that utilizes a patented architecture and allows for highly accurate power measurements on wide bandwidth signals

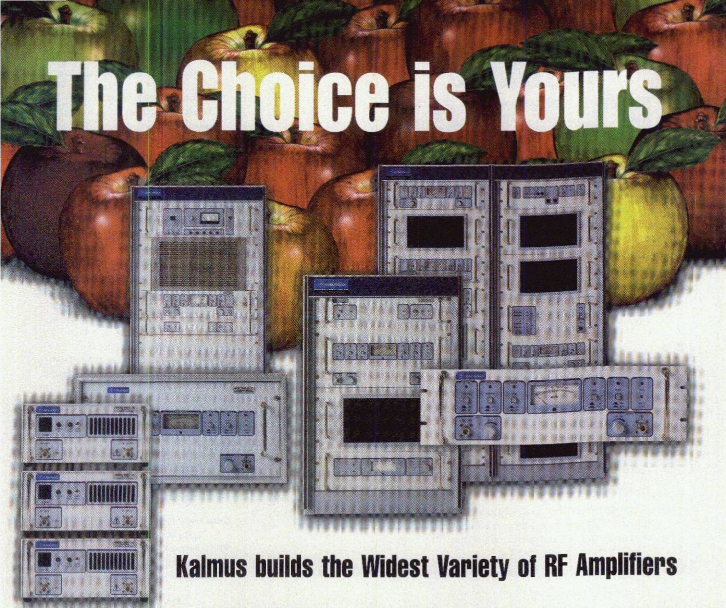
Cover art courtesy of Anritsu Co.

Microwave Journal (USPS 396-250) (ISSN 0192-6225) 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, $110.00 per year, two-year subscriptions, $165.00; foreign, $180.00 per year, two-year subscriptions, $340.00; back issues (if available) and single copies, $10.00 domestic and $20.00 foreign.

Posted under Canadian international publications mail agreement #0738654

The Choice is Yours



Kalmus builds the Widest Variety of RF Amplifiers

We specialize in amplifiers. Kalmus gives you a genuine choice of performance, features and bandwidth for any application that requires RF power amplifiers. From radar, MRI, EMC and high energy physics to EW, communications, broadcast and automotive - Kalmus has the right amplifier.

Choice means savings. Kalmus has worked closely with our customers to develop the industry's widest variety of RF amplifiers. We offer solid-state, cavity and tube amplifiers in broad-band, narrow-band or single frequency configurations. From 10 kHz to 10 GHz and beyond, from a few watts to several kilowatts, there's an amplifier in each frequency and power range with just the features you want. You won't end up buying more than you need.

Built to your specifications. Sometimes there isn't an existing Kalmus RF (or microwave) amplifier that satisfies your particular application. In that case - we'll build it! Kalmus has been meeting all our customer's needs for nearly thirty years.

Contact Kalmus. For more specific details on our complete line of RF and microwave amplifiers, and the name of your nearest Kalmus representative, just visit our web site or call us toll free (US) direct.

KALMUS

A Thermo Voltek Company

The RF Amplifier Company

11807 North Creek Parkway South, Suite 109, Bothell, WA 98011 • **Phone**: (800) 344-3341 • (425) 485-9000 • **Fax**: (425) 486-9657
E-mail: kalmus@kalmus.com • **Web**: www.kalmus.com

CIRCLE 64 ON READER SERVICE CARD

microwave JOURNAL

FEATURES

PRODUCT FEATURES

DEPARTMENTS

Press run for this issue is 58,368 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
DESIGN DIRECTOR: R.A. PIKE
ART DIRECTOR: BILL HAFF
DTP COORDINATOR: JANET A. MACDONALD
GRAPHIC DESIGNER: SACHIKO STIGLITZ
GRAPHIC DESIGN GROUP:
SANDRA DENEAULT • ANDREW ROSS
HILARY SCHMIDT

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

RO4000 circuit board materials fabricate like epoxy glass, but perform like PTFE.

There's no need to sacrifice high frequency performance for the ease of fabrication you get from epoxy glass. RO4000 series laminates are rigid and tough like epoxy glass, with low Z axis expansion and tight control of dielectric constant and thickness. Their low loss tangent yields better performance in high frequency designs, making them a perfect performance upgrade from FR-4 for wireless applications. And they don't cost a bundle, either.

Introducing flame retardant RO4350®.

With all the processability and performance characteristics of RO4000, new RO4350 is for those who require flame retardant high performance without the drawbacks of FR-4 and PTFE.

RO4003 and RO4350 Laminate Properties

Property	Units	RO4003	RO4350
Dielectric Constant, ε_r		3.38	3.48
Dissipation Factor		0.002	0.004
Water Absorption	%	0.06	0.06
Tg	°C	>280	>280
CTE-Z Axis	ppm/°C	46	50
Dimensional Stability	mils/in.	<0.3	<0.5
Flexural Strength	KPSI	28	31
Copper Peel Strength	pli	6.0	5.0
Flammability Rating		NA	94VO

Introducing ROGERS EXPRESS, the new standard in customer service!

We're bringing customer service and support to a new level with Rogers Express. It's the new industry standard for express delivery and quick response to meet your needs.

Call for more information.

For 35 years, Rogers has been developing cutting edge high frequency materials for a wide range of applications, and backing them with great customer support.

E-mail or call us at (602) 961-1382 and ask for test data and free samples.

ROGERS

Rogers Corporation Microwave Materials Division • 100 S. Roosevelt Avenue, Chandler, AZ 85226 • Tel: 480-961-1382 FAX: 480-961-4533
E-mail: iw@rogers-corp.com Web Site: http://www.rogers-corp.com/mwu/info.htm

2000 IEEE Emerging Technologies Symposium on Broadband, Wireless Internet Access
April 10–11, 2000
Dallas, TX

Sponsor: IEEE Dallas section. Topics: Wireless Internet technologies and access systems, including local multipoint distribution systems, low and medium earth orbit satellites and third-generation cellular, and supporting technologies, including mm-wave MMICs, digital signal processing, digital filters, MEMS, smart cellular antenna systems, software radio, wireless ATM, coding and modulation schemes, wireless infrastructure equipment, and Internet standards and protocols. Contact: Dr. Gailon Brehm, TriQuint Semiconductor (972) 994-8571 or e-mail: gbrehm@tqtx.com. Additional information is available at www.ieeedallas-ets.org.

24th Workshop on Compound Semiconductor Devices and Integrated Circuits (WOCSDICE 2000)
May 29 - June 2, 2000
Aegean Sea, Greece

Topics: Compound semiconductor devices and ICs for microwave, millimeter-wave and optoelectronic applications; material growth and characterization; active device technology for MMIC applications (MESFET, HEMT, HBT); novel device technologies and quantum electronics; and reliability and characterization. Contact: Dimitris Pavlidis, University of Michigan, Dept. of Electrical Engineering and Computer Science, 1301 Beal Ave., Ann Arbor, MI 48109 (734) 647-1778 or e-mail: pavlidis@umich.edu. Additional information is available at www.eecs.umich.edu/dp-group/Wocsdice.html.

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

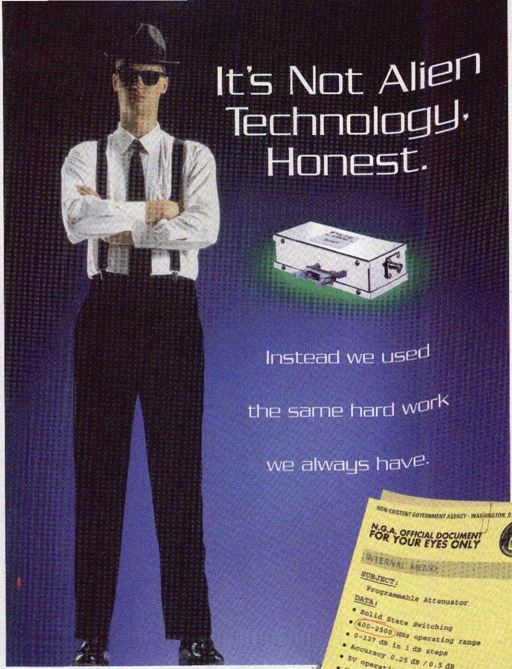
Sponsor: IEEE MTT-S. Topics: Highly integrated ICs and system IC solutions in the RF/microwave frequency range (Si, SiGe, SOI, CMOS, BiCMOS, RFCMOS, GaAs and InP); mixed-signal, cellular/PCS/ISM, receiver, transmitter, and microwave and mm-wave ICs; multifunction ICs and multichip modules; RF/microwave subsystems; integrated filters and antennas; and packaging, testing and reliability. Contact: Christian Kermarrec (781) 937-1217 or e-mail: christian.kermarrec@analog.com. Additional symposium information is available at www.ims2000.org.rfic.htm.

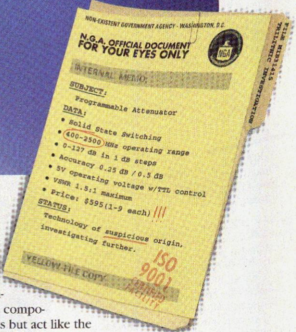
2000 IEEE MTT-S International Microwave Symposium and Exhibition
June 11–16, 2000
Boston, MA

Sponsor: IEEE MTT-S. Topics: Analysis and design; components and assemblies; passive and active microwave technology; frequencies greater than 30 GHz; fabrication, integration and test; phased array design and applications; quasi-optic techniques and systems; broadband terrestrial and satellite communication; and wireless and cellular communications. For symposium information, contact Peter Staecker (781) 861-7643 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.

IEEE International Conference on Third-generation Wireless Communications
June 14–19, 2000
Silicon Valley, CA

Topics: Third-generation (3G) mobile communications, including CDMA and wireless Inter-





When the time came to introduce new technology into Trilithic's component line we took the same hard-working, balanced approach we always have. First we looked at mature technology that would solve our customers' problems, then we developed an ISO 9001 certified production process that would let us deliver on time at a reasonable price. The result is a group of leading edge ATE components that have specifications like experimental units but act like the Trilithic products you've come to depend on. The only problem we're having is convincing certain parties that the only thing out-of-this-world about our new products is their performance. But don't take our word for it, try them yourself–and just among friends, who really cares if something a little other-worldly is in the box?

Call 1-800-TRILITHIC for more information, don't forget to ask for your free catalog.

TRILITHIC
Hard Working Engineers–Like You

9202 East 33rd Street / Indianapolis, IN 46235
(800)874-5484 (317)895-3600 (317)895-3612 Fax
E-Mail: sales@trilithic.com / Internet:www.trilithic.com

net access and protocol, cdmaOne and cdma2000, General Packet Radio Service (GPRS) network planning and wireless mobile asynchronous transfer mode; resource management in Universal Mobile Telecommunications Systems; low cost mobile receivers, bit error rate analysis and joint phase-lock detection; and 3G satellite multiple accesses. For conference information, contact Willie Lu, 1960 Linden Lane, Milpitas, CA 95035 or e-mail: wwlu@ieee.org. Additional information is available at www.3Gwireless.com.

55th ARFTG Conference
June 15–16, 2000
Boston, MA

Sponsors: Automatic RF Techniques Group (ARFTG) and IEEE MTT-S. Topics: Coherent characterization, modeling and simulation techniques quantifying large-signal behavior of RF devices, circuits and systems; calibration of large-signal measurement systems; definition of large-signal network parameters; creation of large-signal models; and simulation and measurement of high frequency, large-signal behavior. For additional information, contact Michael Fennelly, Roos Instruments, 328 Forest St., North Andover, MA 01845 (978) 258-4101 or e-mail: m.fennelly@ieee.org. Additional conference information is available at www.arftg.org.

2000 IEEE International Symposium on Electromagnetic Compatibility
August 21–25, 2000
Washington, DC

Sponsor: IEEE EMC Society. Topics: Electromagnetic compatibility (EMC) management, certification and accreditation, testing, shielding and grounding, electrostatic discharge, spectrum efficiency and monitoring, product and environmental safety, international government standards, new product designs, commercial and military trends, new personnel and laboratory ideas for EMC corporate management. For symposium information, contact William Duff, Computer Sciences Corp. (703) 914-8450 or e-mail: wduff@csc.com.

2000 IEEE Radio and Wireless Conference (RAWCON 2000)
September 10–13, 2000
Denver, CO

Call for Papers. Sponsor: IEEE MTT-S. Topics: Interdisciplinary aspects of radio frequency technology and communications system design, including system architecture and performance, antennas and propagation, active and passive devices, wireless data, smart antennas, ultrawideband systems and software radio architectures. Paper submissions should be submitted electronically via www.rawcon.org. **Deadline: March 31, 2000.** For conference information, contact Michael Heutmaker, Lucent Technologies (609) 639-3116, fax (609) 639-3197 or e-mail: heutmaker@lucent.com. Visit www.rawcon.org for additional conference information and updates.

2000 Asia-Pacific Microwave Conference (APMC 2000)
December 3–6, 2000
Sydney, Australia

Call for papers. Sponsors: CSIRO Telecommunications and Industrial Physics, IEEE New South Wales and South Australia sections and IEEE MTT-S. Topics: Computational electromagnetics, CAD, EMC/EMI, ferrite and solid-state devices, MMIC technology, microwave superconductivity, high speed digital circuits, microstrip and planar antennas, microwave acoustics and measurements, optical devices and systems, phased and active array techniques, mobile communications systems and remote sensing. Paper submission guidelines are available at www.icms.com.au/apmc. **Deadline: April 1, 2000.** For additional information, contact ICMS Pty Ltd. +61 2 9290 3366 or e-mail: apmc@icms.com.au.

WORKSHOPS & COURSES

Electronic Parts and Packaging for Space and Aeronautic Applications

■ **Topics:** Microelectronics and packaging technologies for space and aeronautic applications, and electronic radiation characterization.
■ **Site:** Washington, DC
■ **Date:** April 3–5, 2000
■ **Contact:** Ann Bell, IMAPS, 1850 Centennial Park Drive, Suite 105, Reston, VA 20191 (703) 758-1060, fax (703) 758-1066, e-mail: IMAPS@imaps.org or visit www.imaps.org.

Advanced Electronic Warfare Principles

■ **Topics:** Electronic warfare techniques and development, receiver processor architectures, multiple-channel radar receivers, dual-source techniques and parametric agility. Fee: $995.
■ **Site:** Atlanta, GA
■ **Date:** April 4–7, 2000
■ **Contact:** Continuing Education, Georgia Institute of Technology, Atlanta, GA 30332 (404) 385-3502 or e-mail: conted@gatech.edu. Additional information can be obtained at www.conted.gatech.edu.

How to Design RF Circuits

■ **Topics:** A comprehensive overview of RF circuit design and issues affecting practical implementation of RF circuits as well as transmission line theory and RF printed circuit board design. Fee: £95 (IEE member).
■ **Site:** London, England
■ **Date:** April 5, 2000
■ **Contact:** Liam Devlin +44 (0) 1799 533 261, fax +44 (0) 1799 533 201 or e-mail: lmd@plextek.co.uk.

Phased-array Radar System Design

■ **Topics:** Fundamental concepts for understanding the link between operational requirements and the design of phased-array radar systems. Fee: $1195.
■ **Site:** Smyrna, GA
■ **Date:** April 18–21, 2000
■ **Contact:** Continuing Education, Georgia Institute of Technology, Atlanta, GA 30332 (404) 385-3502, e-mail: conted@gatech.edu or visit www.conted.gatech.edu.

MEMS: Technology, Design and Applications

■ **Topics:** Fundamentals of microelectromechanical systems (MEMS) fabrication technology, sensor and actuator component design and system integration issues. Fee: $1695.
■ **Site:** Los Angeles, CA
■ **Date:** April 24–28, 2000
■ **Contact:** UCLA Extension, Dept. of Engineering, 10995 Le Conte Ave., Suite 542, Los Angeles, CA 90024 (310) 825-1047 or e-mail: mhenness@unex.ucla.edu.

High Efficiency Amplifiers for Wireless Communication Systems

■ **Topics:** Linear power amplifier design and system issues, high efficiency techniques, harmonic terminations and circuit topologies.
■ **Site:** Helsinki, Finland
■ **Date:** May 8–10, 2000
■ **Contact:** CEI-Europe, PO Box 910, S-612 25 Finspong, Sweden +46 122 175 70, fax +46 122 143 47 or e-mail: cei.europe@cei.se.

Antennas: Principles, Design and Measurements

■ **Topics:** Antenna fundamentals, arrays, wire and broadband antennas, horns, reflectors, systems antennas, electromagnetic compatibility topics and measurements.
■ **Site:** Orlando, FL
■ **Date:** May 22–25, 2000
■ **Contact:** Kelly Brown, Northeast Consortium for Engineering Education (NCEE), 1101 Massachusetts Avenue, St. Cloud, FL 34769 (407) 892-6146, fax (407) 892-0406, e-mail: stcloudofl@aol.com or visit www.usit.com/antenna.

RF/Microwave Circuit Design

■ **Topics:** Active device performance limitations, unilateral and bilateral techniques, small-signal linear RF and microwave amplifiers, and CAD applications and layout considerations.
■ **Site:** Cambridge, UK
■ **Date:** May 22–26, 2000
■ **Contact:** CEI-Europe, PO Box 910, S-612 25 Finspong, Sweden +46 122 175 70, fax +46 122 143 47 or e-mail: cei.europe@cei.se.

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.

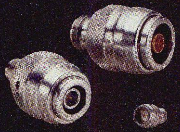
For more information about our products, applications or how we may solve your testing needs, contact us:

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

HIGH PERFORMANCE INTERCONNECTS

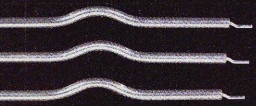
We are • Storm Products–RF/Microwave Group…a leading manufacturer of high performance interconnect products for makers of telecom, wireless, aerospace, military and test equipment systems.



We provide • Engineered interconnect solutions designed to meet demanding applications through 50GHz.

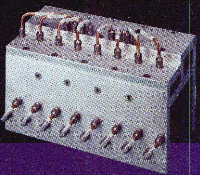
Growth • Storm Products–RF/Microwave Group has been supplying high performance transmission line products to domestic and international markets for more than 20 years. This year we increased our investment, expanding our capacity and adding new capabilities to meet the evolving needs of the rapidly growing wireless and telecom industries.

Capabilities • Design and development of cables, connectors and assemblies are handled in-house to maintain full developmental control. A unique blend of RF/microwave and fiber optics engineering and manufacturing capabilities supports convergence of these technologies at the system level. Partnerships in the UK and Switzerland provide a European engineering and production base.



Facilities • Three facilities support our efforts to best meet our customers' needs. Our original Hinsdale, Illinois, location houses cable manufacturing, assembly production and product development activities. A new Willowbrook, Illinois, facility focuses on specialized cable assembly production and our facility in Mexico supports high volume manufacturing.

Service • Storm Products–RF/Microwave Group is committed to total customer satisfaction based on quality products, backed by the personalized service of our knowledgeable sales team.



STORM®
PRODUCTS CO. ■ DESIGN & MANUFACTURING ■

RF/MICROWAVE GROUP
116 Shore Drive • Hinsdale, IL 60521
TEL 630.323.9121 • FAX 630.323.9398
TOLL FREE 888.347.8676
www.stormproducts.com

SWITCHED-COUPLER MEASUREMENTS FOR HIGH POWER RF CALIBRATIONS

This article describes the design and operational theory behind a new high power measurement system recently developed at the National Institute of Standards and Technology (NIST). This new system utilizes the established low power bolometer calibration service and extends measurement capability up to 1 kW in the 2 to 1000 MHz frequency range.

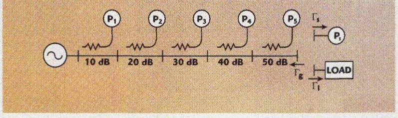
In order to meet the demand for higher power calibrations, a new high power measurement system had to be developed. The cascaded-coupler technique, originally discussed by Kenneth Bramall in 1971,[1] was chosen for its ability to achieve an acceptable uncertainty at minimum cost. Specifically, the technique allows the calibration of a bolometer mount measured on the existing microcalorimeter system to be transferred to 1 kW with measurement uncertainties on the order of two percent.

THEORY OF OPERATION

The Cascaded-coupler Technique (Perfectly Matched Condition)

In the cascaded-coupler technique, the calibration of a low power (10 mW) bolometric power sensor is sequentially transferred to similar sensors on the sidearms of a coupler chain, as shown in ***Figure 1***. The 10 dB coupler increment was chosen so that the bolometric sensors would operate from 1 to 10 mW, the range over which these sensors in combination with the NIST Type IV power meter have the lowest measurement uncertainty.[2]

Fig. 1 A series directional coupler chain.



Calibration of the coupler chain begins by connecting the calibrated sensor to the output port of the coupler chain and adjusting the power until the sensor reads 10 mW. The sensor on the sidearm of the 10 dB coupler should then read approximately 1 mW due to the 10 dB coupling ratio. It is now possible to determine the ratio between the reading on the calibrated sensor and that of the 10 dB sidearm. This method calibrates the coupling ratio for the 10 dB coupler and, to the extent that the system is linear, the ratio will remain constant. For now, perfectly matched and linear conditions are assumed so that the effects of impedance mismatch and nonlinearity can be ignored.

[Continued on page 24]

J. WAYDE ALLEN
National Institute of Standards and Technology (NIST)
Boulder, CO

Replacing the calibrated sensor with a matched load gives

$$\frac{P_s}{P_1} = \frac{P_{l1}}{P_{1x}} \qquad (1)$$

where

P_s = power delivered to the calibrated mount (approximately 10 mW)
P_1 = power read from the 10 dB sidearm (approximately 1 mW)
P_{l1} = power delivered to the load
P_{1x} = 10 dB sidearm power with P_{l1} delivered to the load

Solving Equation 1 for P_{l1} gives

$$P_{l1} = \frac{P_{1x}}{P_1} P_s \qquad (2)$$

If the power is now increased until the 10 dB coupler sidearm power reads approximately 10 mW, the power at the sidearm of the 20 dB coupler will be close to 1 mW. Forming a new set of ratios between the detectors on the 10 and 20 dB coupler sidearms results in

$$\frac{P_{l1}}{P_2} = \frac{P_{l2}}{P_{2x}} \qquad (3)$$

where

P_{l1} = load power referenced to the 10 dB sidearm
P_2 = power reading on the 20 dB sidearm with 10 mW on the 10 dB sidearm
P_{l2} = load power referenced to the 20 dB coupler sidearm
P_{2x} = 20 dB sidearm power with P_{l2} delivered to the load

Substituting Equation 2 for P_{l1} and solving for P_{l2} gives

$$P_{l2} = \frac{P_{2x}}{P_2} \frac{P_{1x}}{P_1} P_s \qquad (4)$$

At this point, the 10 dB coupler is no longer needed and must be physically removed from the coupler chain before the power is further increased. Increasing the power without removing the coupler will overload the power detector on the 10 dB coupler sidearm.

Increasing the power, forming the ratio of powers and physically removing the lowest power coupler stage can be continued to extend the power calibration as far as required. For the diagrammed coupler chain, the power equation for the final 50 dB coupler is expressed as

$$P_l = \frac{P_{5x}}{P_5} \frac{P_{4x}}{P_4} \frac{P_{3x}}{P_3} \frac{P_{2x}}{P_2} \frac{P_{1x}}{P_1} P_s \qquad (5)$$

Effect of Impedance Mismatch on the Cascaded-coupler Equation

In the preceding discussion it was assumed that all of the impedances are matched. In general they are not, and it is necessary to include a mismatch correction in the cascading equation. Because the mismatch correction depends on the equivalent generator reflection coefficient (Γ_g) of the coupler chain, it is important to understand how removing couplers from the chain affects the measurement. To understand the effect of coupler removal on the mismatch correction, the definition of Γ_g must be considered. This definition has been documented in several places by Glenn Engen,[3,4] but can be summarized as follows. Consider the circuit shown in ***Figure 2***. The scattering parameter representation of the emergent wave amplitude b_2 produces[4]

$$b_2 = b_3\left\{\frac{S_{21}}{S_{31}} + \Gamma_d\left(S_{23} - \frac{S_{21}S_{33}}{S_{31}}\right)\right\} + a_2\left(S_{22} - \frac{S_{21}S_{32}}{S_{31}}\right) \qquad (6)$$

where

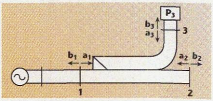
$$\Gamma_d = \frac{a_3}{b_3}$$

Since the coupler or sensor is not changing, both the scattering parameters and Γ_d are constant and the scattering parameter representation can be simplified by writing it in the form

$$b_2 = b_3 S_{coupler} + a_2 \Gamma_g \qquad (7)$$

where

Γ_g = equivalent reflection coefficient[4]

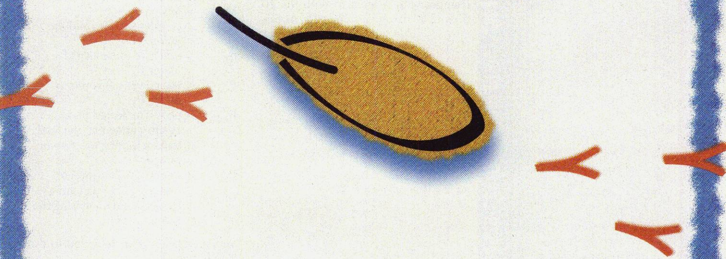


▲ *Fig. 2 A single coupler circuit.*

[Continued on page 26]

An infinitely smarter and safer way to cross the road.

Coming from Anaren, April 2000.



CIRCLE 14 ON READER SERVICE CARD

$$\Gamma_g = S_{22} - \frac{S_{21}S_{32}}{S_{31}} \quad (8)$$

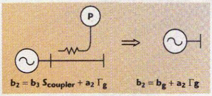
and

$$S_{coupler} = \frac{S_{21}}{S_{31}} + \Gamma_d\left(S_{23} - \frac{S_{21}S_{33}}{S_{31}}\right) \quad (9)$$

In other words, the scattering parameter representation of the coupler can be replaced with the microwave equivalent of Thevenin's theorem,[4] as shown in ***Figure 3***.

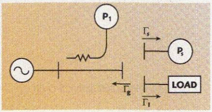
Of particular interest is that Γ_g depends only on the internal characteristics of the directional coupler, not on anything that precedes the coupler. More importantly, the ratio of the power delivered to the coupler's sidearm and the power delivered to its load is not affected by anything preceding the coupler. Now note that during the initial calibration only the 10 dB coupler is used. The other couplers contribute only their insertion loss so the entire chain can be thought of as one large 10 dB directional coupler, as shown in ***Figure 4***. Here, the only Γ_g of interest is the one measured for the entire coupler chain referred to the 10 dB coupler sidearm, and it can be used along with the values of Γ_s and Γ_l to compute the impedance mismatch between both P_s and the test load.

In the next step, transferring the calibration from the 10 dB coupler to the 20 dB coupler sidearm, the power is increased until the power on the 20 dB sidearm can be read. Nothing else is changed, but it is now known how the power delivered to the load changes with respect to both the 10 dB and 20 dB sidearm powers. At this point, since the relationship between the 20 dB coupler sidearm power and the load power has been determined, the 10 dB coupler can be removed without affecting the calibration. The transfer to subsequent couplers continues in the same way; as long as the test load is not changed, only the initial mismatch conditions need to be considered.



▲ *Fig. 3 An equivalent generator representation of a directional coupler.*

Fig. 4 An equivalent circuit for first-stage calibration. ▼



Since a measurement system cannot be constructed using perfect power sensors and perfect impedance matching between the components, Equation 2 must be modified to describe the more general condition. This objective is accomplished by noting that the level indicated by any of the power meters will be only the power delivered to the meter multiplied by the bolometer's effective efficiency η so that

$$P_{s_{meter}} = M_s \eta_s P_s \quad (10)$$

$$P_{l_{meter}} = M_l \eta_l P_l \quad (11)$$

$$P_{lx_{meter}} = M_l \eta_l P_{lx} \quad (12)$$

where

P_{smeter} = DC substituted power reading on the meter connected to bolometer P_s
M_s = mismatch between the coupler chain and the bolometer mount P_s
η_s = effective efficiency of bolometer P_s
P_s = net power delivered to bolometer P_s
P_{lmeter} = power indicated by the sidearm meter P_l with P_s attached
M_l = mismatch between the coupler sidearm and the bolometer P_l
η_l = effective efficiency of meter P_l
P_l = net power delivered to meter P_l
$P_{lxmeter}$ = power indicated on meter P_l after attaching the load and increasing the system power
P_{lx} = net power delivered to meter P_l after attaching the load and increasing the system power

Similarly, the power delivered to the load is given by

$$P_{l_{delivered}} = M_l P_l \quad (13)$$

[Continued on page 28]

where

P_l = net power delivered to the load
M_l = mismatch between the coupler chain and the attached load

Solving Equations 10–13 for the net delivered powers yields

$$P_s = \frac{P_{s_{meter}}}{M_s \eta_s} \quad (14)$$

$$P_l = \frac{P_{l_{meter}}}{M_l \eta_l} \quad (15)$$

$$P_{lx} = \frac{P_{lx_{meter}}}{M_l \eta_l} \quad (16)$$

$$P_l = \frac{P_{l_{delivered}}}{M_l} \quad (17)$$

These equations then can be substituted into Equation 2 to produce

$$P_{l_{delivered}} = \frac{P_{lx_{meter}}}{P_{l_{meter}}} \frac{M_l}{M_s} \frac{P_{s_{meter}}}{\eta_s} \quad (18)$$

M_l and M_s are defined[4] as

$$M_l = \frac{\left(1-|\Gamma_l|^2\right)\left(1-|\Gamma_g|^2\right)}{|1-\Gamma_l\Gamma_g|^2} \quad (19)$$

and

$$M_s = \frac{\left(1-|\Gamma_s|^2\right)\left(1-|\Gamma_g|^2\right)}{|1-\Gamma_s\Gamma_g|^2} \quad (20)$$

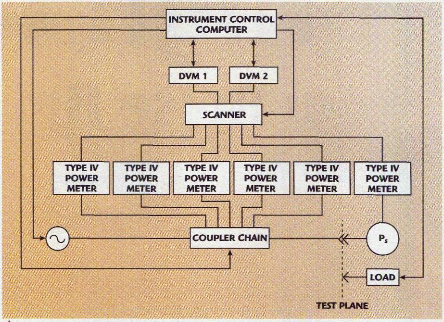
Substituting these values into Equation 18 and generalizing for multiple coupler stages results in the corrected cascaded-coupler equation

$$P_{l_{delivered}} = \frac{P_{nx_{meter}}}{P_{n_{meter}}} \cdots \frac{P_{2x_{meter}}}{P_{2_{meter}}} \frac{P_{1x_{meter}}}{P_{1_{meter}}} \bullet \frac{P_{s_{meter}}}{\eta_s} \frac{1-|\Gamma_l|^2}{1-|\Gamma_s|^2} \left|\frac{1-\Gamma_s\Gamma_g}{1-\Gamma_l\Gamma_g}\right|^2 \quad (21)$$

SYSTEM DESIGN

Hardware

The previous discussion shows that the hardware requirements for the construction of a cascaded-coupler system are relatively modest. Only the couplers required to create the coupler chain, power meters for the coupler sidearms and an RF signal source capable of delivering the required power are required. The coupler chain itself can be manually connected and the couplers removed as the measurement proceeds. This design works well for the occasional measurement but is less attractive when a regular measurement program is anticipated.

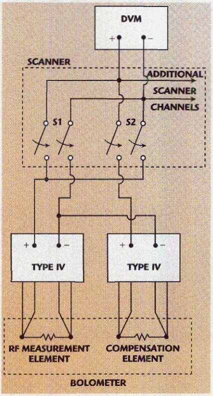


▲ *Fig. 5 The measurement system's block diagram.*

With this limitation in mind, the system developed at NIST is designed to perform these functions under computer control. Automating the measurement of the bolometer power levels is quite straightforward and is achieved through the use of commercial digital voltmeters (DVM), NIST Type IV power meters[2] and a commercial switch control unit or scanner. ***Figure 5*** shows a block diagram of the system.

Two DVMs have been used to minimize the time difference between the power meter readings. Additionally, two Type IV power meters are connected to each bolometer mount. One of the power meters and the compensation element serve as a reference voltage generator. The other meter is connected to the RF measurement thermistors. This configuration helps correct for thermal drift in the bolometer mount and keeps the output voltage from the combined power meters in the DVMs' most accurate operating range.[2,5] ***Figure 6*** shows the wiring diagram for each bolometer. With this arrangement, the voltage can be read directly from the Type IV meter connected to the RF measurement bead by opening switch S2 and closing S1, or the voltage difference resulting from the series connection of both meters is read by opening S1 and closing S2.

▼ *Fig. 6 A power measurement circuit.*

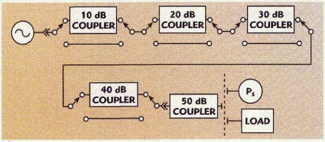


Converting the DVM readings to RF power follows the procedure described by Clague.[5] Initially, switch S1 is closed and the voltage read with no RF power applied to produce the

[Continued on page 32]

DIVERSITY

COMPONENTS



▲ *Fig. 7 The switched-coupler chain.*

initial zero power reading V_{1i} at time t_1. Next, switch S1 is opened and switch S2 is closed, giving a new off-power voltage V_{1xi} with the series combination of the Type IV power meters at time t_2. The RF power is then turned on and, with switch S2 still closed, voltage V_{2x} is measured at time t_3. After the RF power has been turned off, the voltage of the series power meter combination V_{1xf} at time t_4 is measured. Finally, switch S2 is opened and switch S1 is closed. The final off-power voltage V_{1f} is then measured at time t_5. Combining these measurements so that

$$V_1 = V_{1i} + \left(\frac{t_3 - t_1}{t_5 - t_1}\right)\left(V_{1f} - V_{1i}\right) \tag{22}$$

and

$$\Delta V = V_{2x} - \left[V_{1xi} + \left(\frac{t_3 - t_2}{t_4 - t_2}\right)\left(V_{1xf} - V_{1xi}\right)\right] \tag{23}$$

provides the values needed for substitution into the Type IV power equation[5]

$$P = \frac{1}{K_b R_0}\left(2V_1 - \Delta V\right)\Delta V \tag{24}$$

where

R_0 = operating resistance of the mount
K_b = mount calibration factor

Computer control of the cascaded-coupler chain is achieved using a matrix of RF switches connecting the couplers, as shown in ***Figure 7***. This configuration allows the computer to set the switches so that all the couplers are connected at the start of the measurement cycle and to remove the appropriate couplers as the power level increases. However, the added insertion loss and power-handling capacity of the switches put a limit on the power that can be switched.

Typical insertion loss for high power coaxial switches is 0.2 dB. Therefore, the inclusion of the eight switches adds approximately 1.6 dB of loss to the coupler chain. Ignoring the insertion loss of the couplers means that the RF source would be required to supply nearly 1.5 kW in order to overcome the loss in the switching matrix. This power level exceeds the 1.1 kW power rating on the switches used and the maximum power capability of the signal source. Simply excluding the final 50 dB coupler from the switching matrix minimizes this problem. With this arrangement, the operator manually connects the 50 dB coupler and calibrated bolometer P_s to the output of the switched coupler matrix before starting the measurement.

The computer initializes the coupler matrix by connecting all of the couplers in series and measures the power ratio between P_s and P_1 as previously described. The operator then replaces P_s with the RF load, and the computer automatically transfers the power calibration down the chain. This procedure sets up the calibration for the final 50 dB coupler and is sufficient for power measurements up to 100 W.

In this mode, the generator only needs to supply approximately 150 W to overcome the switch losses. To measure powers higher than 100 W, the operator simply disconnects the 50 dB coupler from the switched-coupler matrix and reconnects it directly to the RF generator. The power then can be increased until 1000 W appears at the output of the 50 dB coupler and, assuming that the coupler has approximately 0.2 dB of insertion loss, the generator only needs to supply 1050 W.

Software

The software for the measurement system was designed on the premise that it is easier to test, troubleshoot and maintain several small programs rather than one very large program. This procedure allows the code development to be split among the people working on the project and has the added benefit of the separate programs performing consistency checks on each other's data. For this project, the software was split into three main application groups: instrument control, data analysis and report generation.

The instrument control program is the interface to the actual measurement hardware. It defines the measurement process and collects the data for final analysis. Only a minimal amount of computation, such as the conversion of the Type IV DVM readings to RF power, is accomplished at this level. Data collected by the instrument control program are made available for subsequent processing as a pure ASCII file.

Data are analyzed by several Perl programs. One such program formats these data into a more human-readable form (bramview) and another computes the Type B uncertainty (bramerr). Another program formats the output from the bramerr program into an ASCII grid suitable for importing into almost any spreadsheet program. This procedure allows the results from a series of measurement cycles to be combined into a single spreadsheet, summarized and the Type A uncertainty computed. The spreadsheet also facilitates the creation of a table of results that can be imported into a word processing program that generates the final report.

Ultimately, as more experience with the idiosyncrasies of the system is developed, the final data analysis and report-generation functions may be automated. With the highly modular design of the system's data structure, adding this functionality or changing the analysis does not require a major rewrite of any large pieces of code with the subsequent danger of breaking the existing functionality.

UNCERTAINTY ANALYSIS

Following the conventions described in NIST Technical Note 1297,[6] the system uncertainty analysis is composed of three fundamental parts: Type A (U_a), Type B (U_b) and expanded uncertainty (U). Type A uncertainties are those based on any

[Continued on page 34]

valid statistical method for data analysis. Type B uncertainties are those determined by any other method. The expanded uncertainty is expressed as

$$U = 2\sqrt{U_a^2 + U_b^2} \qquad (25)$$

Type A Uncertainty

The cascaded-coupler system is normally used to compare the power indicated by a high power detector (P_{dut}) to the calibrated power delivered to the detector by the coupler chain (P_l). The ratio of these two powers

$$K = \frac{P_{dut}}{P_{l_{delivered}}} \qquad (26)$$

is the calibration factor for the meter and can be computed at any arbitrary power during the calibration of the coupler chain. Since the calibration factor K is the value reported to the customer, this is the term that ultimately must be assigned an uncertainty. In this case, the Type A uncertainty is determined by computing the standard deviation of the mean values of K determined at each power over at least three full calibrations of the cascaded-coupler chain, or

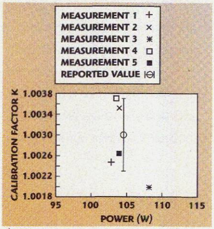
$$U_a = \frac{1}{\sqrt{n}}\sqrt{\frac{\Sigma\left(K_i - K_{avg}\right)^2}{n-1}} \qquad (27)$$

where

U_a = sample standard deviation of the calibration factor K
K_i = calibration factor for any single measurement
K_{avg} = average calibration factor
n = number of measurements made

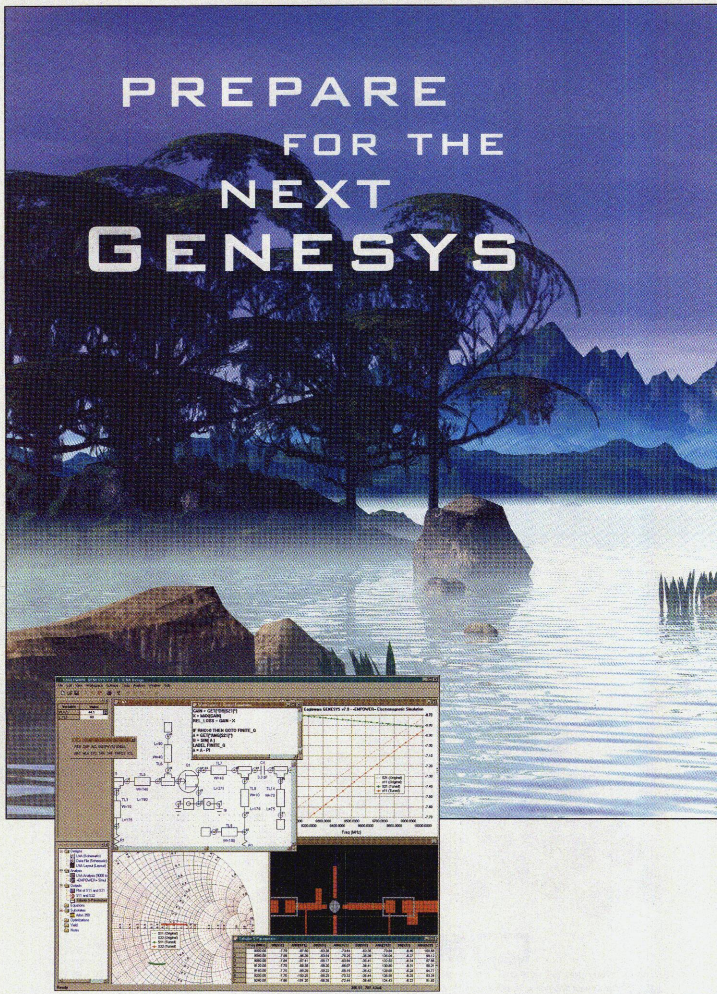
One difficulty with this approach is that it assumes that between any two calibrations the measurement system can be reset to any given power. In practice, the power only can be reset to within several tens of watts. Fortunately, over this range the variation in K does not appear to be highly correlated with this variation in power. This lack of correlation indicates that a more complex multivariate statistical approach is not really warranted.

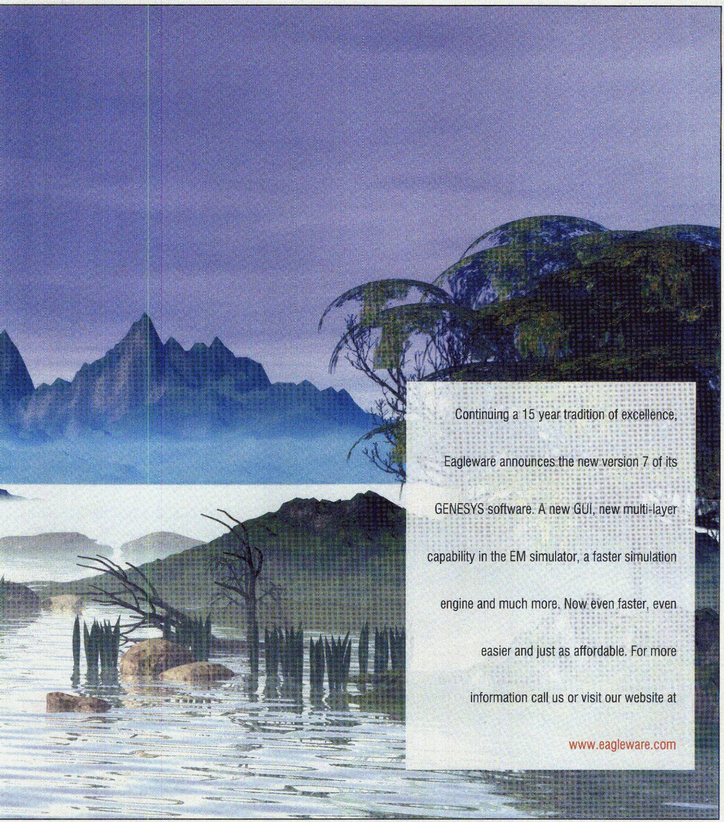
Instead, the fluctuation in power is simply ignored, and the average of the measured powers is reported. The reported value is effectively positioned at the center of the cluster of data and permits computation of the random variation or Type A uncertainty of the calibration factor K as given by Equation 27. ***Figure 8***



▲ *Fig. 8 The reported calibration factor K and its Type A uncertainty for a typical raw data set.*

[Continued on page 38]


PREPARE
FOR THE
NEXT
GENESYS
GAIN = GET("DB[S21]")
X = MAX[GAIN]
REL_LOSS = GAIN - X
IF RHO>0 THEN GOTO FINITE_Q
A = GET("ANG[S21]")
B = SIN[A]
LABEL FINITE_Q
A = A - PI
Eagleware GENESYS v7.0 - -EMPOWER- Electromagnetic Simulation
S21 (Original)
s11 (Original)
S21 (Tuned)
s11 (Tuned)
Freq (MHz)


Continuing a 15 year tradition of excellence,
Eagleware announces the new version 7 of its
GENESYS software. A new GUI, new multi-layer
capability in the EM simulator, a faster simulation
engine and much more. Now even faster, even
easier and just as affordable. For more
information call us or visit our website at
www.eagleware.com

shows how the reported value of K and its Type A uncertainty compare for a typical set of data.

Type B Uncertainty

Several modifications to Equation 21 simplify the Type B uncertainty analysis. First, the reflection coefficient terms can be grouped together to define a general mismatch term

$$M = \frac{1-|\Gamma_l|^2}{1-|\Gamma_s|^2}\left|\frac{1-\Gamma_g\Gamma_s}{1-\Gamma_g\Gamma_t}\right|^2 \qquad (28)$$

and, second,

$$P'_s = \frac{P_{s_{meter}}}{\eta_s} \qquad (29)$$

Thus, the solution for the first coupler stage is written as

$$P_{l1_{delivered}} = \frac{P_{1x_{meter}}}{P_{1_{meter}}} P'_s M \qquad (30)$$

Next, taking the partial derivatives for each of the terms in Equation 30 and computing the fractional change in $P_{l1_{delivered}}$ results in the expression

$$\frac{\Delta P_{l1_{delivered}}}{P_{l1_{delivered}}} = \frac{\Delta P_{1x_{meter}}}{P_{1x_{meter}}} + \frac{\Delta P_{1_{meter}}}{P_{1_{meter}}} + \frac{\Delta P'_s}{P'_s} + \frac{\Delta M}{M} \qquad (31)$$

An additional uncertainty term can be found by noting that Equation 21 assumes the directional couplers used in the system are linear, meaning that the coupling ratio

$$C_1 = \frac{P'_s}{P_{1_{meter}}} \qquad (32)$$

is constant. Equation 32 can be substituted into Equation 30 to produce

$$P_{l1_{delivered}} = P_{1x_{meter}} C_1 M \qquad (33)$$

which indicates that the fractional change in $P_{l1_{delivered}}$ due to a change in the coupling ratio is $\Delta C_1/C_1$. Adding this coupler nonlinearity term to Equation 31 produces an expression for the fractional uncertainty due to the first coupler stage:

$$\frac{\Delta P_{l1_{delivered}}}{P_{l1_{delivered}}} = \frac{\Delta P_{1x_{meter}}}{P_{1x_{meter}}} + \frac{\Delta P_{1_{meter}}}{P_{1_{meter}}} + \frac{\Delta P'_s}{P'_s} + \frac{\Delta M}{M} + \frac{\Delta C_1}{C_1} \qquad (34)$$

The solution for the second-stage equation can be written in terms of Equation 30 as

$$P_{l2_{delivered}} = \frac{P_{2x_{meter}}}{P_{2_{meter}}} P_{l1_{delivered}} \qquad (35)$$

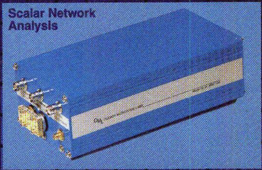
The approach used to derive Equation 31 is then applied to Equation 35 to obtain

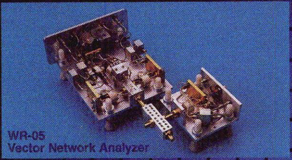
$$\frac{\Delta P_{l2_{delivered}}}{P_{l2_{delivered}}} = \frac{\Delta P_{2x_{meter}}}{P_{2x_{meter}}} + \frac{\Delta P_{2_{meter}}}{P_{2_{meter}}} + \frac{\Delta C_2}{C_2} + \frac{\Delta P_{l1_{delivered}}}{P_{l1_{delivered}}} \qquad (36)$$

[Continued on page 41]

mmW Test Equipment

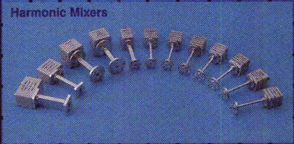
Vector Network Analysis Systems Use with popular microwave VNA equipment to achieve millimeter wave vector/amplitude measurement capability. Can be used in either the forward direction only (S11 & S21) with one T/R module and one T module *or* in the forward and reverse direction (S11, S21, S22, S12) with two T/R modules. Systems are available for all waveguide bands from WR-22 to WR-05.


Scalar Network Analysis


WR-05 Vector Network Analyzer

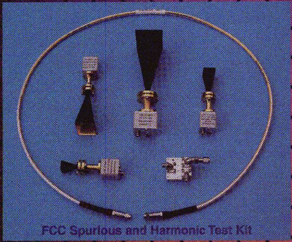
Scalar Network Analysis (SNA) Systems and Multiplier Sources Complete SNA systems containing filtered multipliers with –50 dBc spurs and harmonics. Included are a dual directional coupler and detectors for reference, reflection and transmission. Available for WR-22 through WR-10. Filtered Multiplier Sources are also available without the coupler or detectors. Multiplier Sources are available without filtering for the WR-08 through WR-05 waveguide bands. All of these products are engineered to extend the user's 8 to 20 GHz equipment.

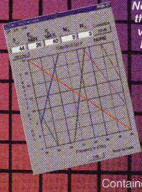
Waveguide VNA Calibration Kits for calibration of the above Vector Network Analysis Systems. Contains all of the components necessary to achieve any of the popular calibration methodologies.


Harmonic Mixers


WR-05 VNA Calibration Kits

Harmonic Mixers Use with popular Spectrum Analyzers to achieve millimeter wave spectrum analysis. Mixers are available for all waveguide bands from 18 to 325 GHz. LO/IF diplexers are available for most modern spectrum analyzers. Measured conversion loss data supplied with emulation of most modern spectrum analyzers for WR-42 through WR-10.


FCC Spurious and Harmonic Test Kit



Now available free at the OML Web Site is the Windows™ compatible, block converter "Spurious Product Prediction Program" illustrated to the left. With this program, engineers can examine their block converter designs for harmful spurious responses.

Also contained on the Web Site are complete specifications for all of the above millimeter wave frequency extension products as well as technical papers addressing many of the more common millimeter wave testing problems. Contained in these papers are many useful millimeter wave charts and graphs not found elsewhere.

FCC Spurious and Harmonic Test Kit for use with popular Spectrum Analyzers. Each kit contains four mixers providing continuous coverage from 40 to 220 GHz. Each mixer is equipped with an appropriate horn antenna for accomplishing the FCC desired radiated spurious level measurement. Shown with optional diplexer and cable.

Visit us at www.oml-mmw.com

OML Oleson Microwave Labs

355 Woodview Drive, Suite 300 • Morgan Hill, CA 95037 • Tel: (408) 779-2698 • Fax: (408) 778-0491

where C_2 is the fractional change in the coupling ratio for the second directional coupler. Equation 36 can be generalized further so that the total uncertainty of any stage following the first one can be written as

$$\frac{\Delta P_{ln_{delivered}}}{P_{ln_{delivered}}} = \frac{\Delta P_{nx_{meter}}}{P_{nx_{meter}}} + \frac{\Delta P_{n_{meter}}}{P_{n_{meter}}} + \frac{\Delta C_n}{C_n} + \frac{\Delta P_{l(n-1)_{delivered}}}{P_{l(n-1)_{delivered}}} \qquad (37)$$

Referring back to Equation 26, note that the calibration factor K only depends on the two values P_{dut} and $P_{l_{delivered}}$. Since for any given measurement P_{dut} is just the power read from the customer's device, the uncertainty U_b depends only on the uncertainty in $P_{l_{delivered}}$ or

$$U_b = \frac{\Delta P_{ln_{delivered}}}{P_{ln_{delivered}}} \qquad (38)$$

A rectangular distribution is assumed for each of the terms in U_b. All that remains is to determine accurate estimates for each of the uncertainty terms: fractional uncertainty in the bolometric power readings ($\Delta P'_s/P'_s$ and $\Delta P_n/P_n$), fractional uncertainty in the mismatch term ($\Delta M/M$) and coupling ratio stability or nonlinearity term ($\Delta C_n/C_n$).

The calibrated power P'_s is determined from the DC substituted power indicated by the Type IV power meter and the calibrated value of the mount's effective efficiency (η_s) as

$$P'_s = \frac{P_{s_{meter}} \pm \Delta P_{s_{meter}}}{\eta_s \pm \Delta\eta_s} \qquad (39)$$

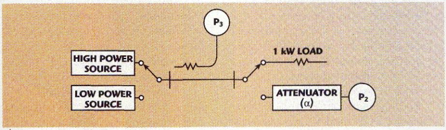
Consequently, the uncertainty in the value of P'_s is expressed as

$$\Delta P'_s = \sqrt{\Delta P^2_{s_{meter}} + \Delta\eta_s^2} \qquad (40)$$

The value $\Delta\eta_s$ comes from the calibration of the mount P_s. The value for $\Delta P_{s_{meter}}$ is computed from the uncertainties in the Type IV power meter and the voltmeter used to read the bias voltages. This computation has been coded directly into the software used to compute the DC substituted power since the raw power meter voltages are most readily accessible at this level. The computation of the DC substituted power uncertainty when using the Type IV power meter has been covered in previous publications.[2,7] For the power measurements made on the coupler sidearms, a correction for effective efficiency is not required since these mounts are calibrated in place against the mount P_s. Only the measured DC substituted power uncertainty needs to be considered.

Measurement of the reflection coefficients Γ_l, Γ_s and Γ_g are made using either a vector network analyzer or six-port network analyzer. The resulting uncertainties are on the order of 0.005 in the real and imaginary components. The uncertainty analysis software (bramerr) computes the mismatch from the measured reflection coefficients Γ_l, Γ_s and Γ_g and the 64 possible variations in the mismatch due to the addition or subtraction of 0.005 from the real and imaginary components. The maximum difference between M and one of the 64 mismatch variants is used as the mismatch uncertainty ΔM.

Equation 21 assumes that the system is linear and the measured power ratios are constant. Unfortunately, the world is not perfect and the possibility that the ratios depend on power must be considered. A direct measurement of the power coupling ratio is not possible because it would exceed the dynamic range of the available power sensors and is the reason for building the cascaded-coupler system in the first place. However, assuming that changes in the coupling ratio are most likely caused by thermal expansion in the coupler, an experiment can be designed to produce a reasonable estimate for the uncertainty due to coupler nonlinearity.



▲ *Fig. 9 Test setup for determining coupler nonlinearity.*

The setup used for determining coupler nonlinearity is shown in ***Figure 9***. The switches can be set so that a low power source can deliver a signal that can be sampled by both power detectors P_3 and P_2. The attenuation factor (α) is chosen so that the detectors P_3 and P_2 are operating within their normal operating range and is assumed to be constant. These powers then can be used to compute the coupling ratio

$$C = \frac{P_3 \alpha}{P_2} \qquad (41)$$

Setting the switches so that the output of the coupler is connected to the 1 kW load and applying a high power signal heats the coupler with the RF in the same manner in which it is used in the coupler chain. The powers P_3 and P_2 can be remeasured on the hot coupler by turning off the heating power and immediately resetting the switches to the low power circuit. The fractional uncertainty due to coupler nonlinearity is then expressed as

$$\frac{\Delta C}{C} = \left| \frac{C_{hot} - C_{cold}}{C_{cold}} \right| \qquad (42)$$

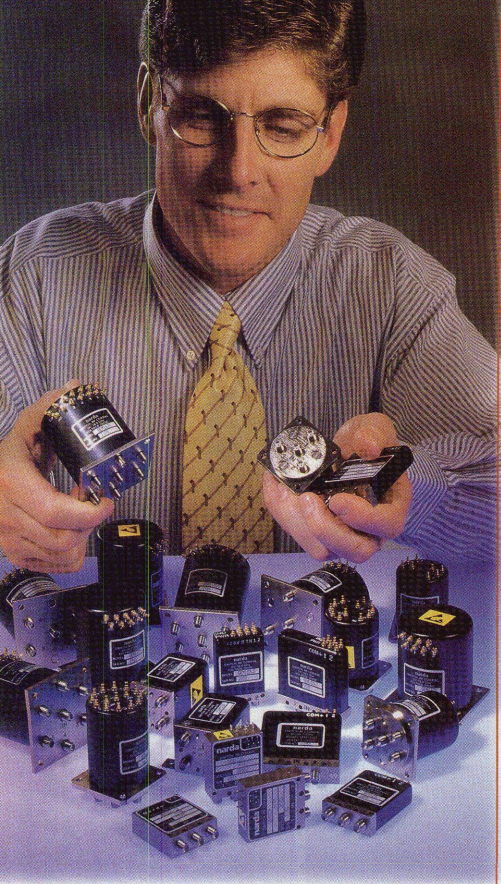
where

C_{cold} = coupling ratio measured before applying the heating power

C_{hot} = resulting measurement afterwards

Tests conducted on water-cooled couplers produced values for the fractional uncertainty ranging from 0.00008 to 0.0005. Since this value is so small, creating a separate uncertainty for each coupler was not worth the extra effort.

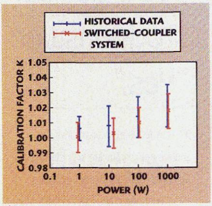
[Continued on page 44]



The maximum value of 0.0005 was chosen to be a reasonable estimate of the fractional uncertainty due to nonlinearity in each coupler stage.

COMPARISON TEST RESULTS

To ensure continuity between the new switched-coupler measurement system and the older, low frequency Bramall system,[8] comparison measurements were performed on a feed-through wattmeter. ***Figure 10*** shows how these two systems compare at 30 MHz. This frequency is the only point where measurement data up to 1000 W exist on the low frequency system. The data show that there is good agreement between both measurement systems.



▲ *Fig. 10 Comparison of historical calibration data with the switched-coupler system data at 30 MHz.*

Table 1 lists representative data taken with the new measurement system. The $\Delta P/P$ uncertainty is the sum of the power ratio uncertainties given in Equation 37. As can be seen, typical uncertainties lie between one and two percent. Some degradation of the system uncertainty at frequencies around 850 MHz and higher caused by a decrease in repeatability between multiple calibrations of the coupler chain is observed. However, this degradation could be due to increased amplifier noise. Work is continuing in an attempt to reduce the random uncertainty in the higher frequency bands.

TABLE I

TYPICAL MEASUREMENT DATA

Frequency (MHz)	Power (W)	$\frac{\Delta P}{P}$ (%)	$\frac{\Delta P}{P}$ (%)	$\frac{\Delta P}{P}$ (%)	K (%)	U_a (%)	U_b (%)	U (%)
550	0.572	0.05	0.24	0.10	0.992	0.71	0.40	1.63
550	13.525	0.08	0.24	0.15	1.003	0.83	0.47	1.91
550	93.424	0.10	0.24	0.20	1.019	0.79	0.54	1.92
550	993.85	0.12	0.24	0.25	1.025	0.82	0.61	2.04

ACKNOWLEDGMENT

The material in this article was reprinted from NIST Technical Note 1510, July 1999. ■

References

1. K.E. Bramall, "Accurate Microwave High Power Measurements Using a Cascaded Coupler Method," *Journal of Research of the National Bureau of Standards*, 75C(3 and 4), July–December 1971, pp. 185–192.
2. N.T. Larsen, "A New Self-balancing DC-substitution RF Power Meter," *IEEE Transactions on Instrumentation and Measurement*, IM-25, 4, December 1976, pp. 28–32.
3. G.F. Engen, "Amplitude Stabilization of a Microwave Signal Source," *IRE Transactions on Microwave Theory and Techniques*, MTT-6, April 1958, pp. 202–206.
4. G.F. Engen, "Microwave Circuit Theory and Foundations of Microwave Metrology," *IEEE Electrical Measurement Series 9*, Peter Peregrinus Ltd., London, UK, 1992.
5. F. Clague, *NIST Model PM2 Power Measurement System for 1 mW at 1 GHz*, NISTIR 5016, National Institute of Standards and Technology, December 1993.
6. B.N. Taylor and C.E. Kuyatt, *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results*, Technical Note 1297, National Institute of Standards and Technology, 1994.
7. N.T. Larsen, *NBS Type IV RF Power Meter Operation and Maintenance*, NBSIR 77-866, US National Bureau of Standards, October 1977.
8. G. Rebuldela and J.A. Jargon, "High Power CW Wattmeter Calibration at NIST," *Journal of Research of the National Institute of Standards and Technology*, 97(6), November–December 1992, 673–687.

Oceanic Surveillance Radar System Successfully Demonstrated

In collaboration with the Canadian Department of National Defence, Raytheon Systems Canada Ltd., a subsidiary of Raytheon Co., has developed and successfully demonstrated the HF SWR-503 long-range, high frequency surface-wave radar. The HF SWR-503 is a shore-based, oceanic surveillance system for monitoring illegal activities such as drug trafficking, smuggling, piracy, illicit fishing and illegal immigration. The surface-wave radar also can be used for tracking icebergs, environmental protection, search and rescue, resource protection, sovereignty monitoring and remote sensing of ocean surface currents and winds. Its long-range capability allows coastal nations to monitor surface and low level airborne targets up to and beyond a 200-nautical-mile exclusive economic zone (EEZ). The Canadian system consists of two land-based, long-range radars and an operational control center. The two unmanned radars will provide coverage of the Grand Banks region of Newfoundland as well as its fisheries and oil fields. Extensive performance testing of the system was conducted using two fully functional radars in conjunction with alternative surveillance sensors such as airborne radar, spotter aircraft and surface patrol craft, which verified targets. The HF SWR-503 successfully detected and tracked all targets observed by the sensors, marking the world's first successful demonstration of surface-wave radar technology that is capable of providing continuous, all-weather, real-time surveillance of EEZ waters.

NASA Awards Satellite Production Contract

The National Aeronautics and Space Administration's (NASA) Goddard Space Flight Center has awarded a five-year contract to Orbital Sciences Corp. for the design, production and testing of small- and medium-class satellites used in space and Earth sciences and advanced technology missions. Under the terms of the Rapid Spacecraft Acquisition contract administered by Goddard's Rapid Spacecraft Development Office, NASA centers and laboratories and other government agencies will be able to procure five types of satellite platforms developed and manufactured by Orbital Sciences, including low earth orbit and geosynchronous orbit spacecraft. Each of the satellite platforms has a successful space flight heritage based on an extensive history of 85 previous satellite missions performed by the company during the last 18 years. The flexible ordering structure is expected to reduce NASA's satellite order-to-delivery cycle to as few as 18 months. The contract has a maximum value of $1.5 B and is expected to cover orders until 2004.

US Army Awards Contract for TUAV Systems

The US Army has awarded a contract to AAI Corp., a subsidiary of United Industrial Corp., for the delivery of its new Tactical Unmanned Air Vehicle (TUAV) systems. The TUAV systems will provide Army commanders with the capability to conduct reconnaissance, surveillance and battlefield damage assessment. Under the terms of the initial contract, which is valued at more than $41 M, AAI will manufacture and provide support for four low rate production TUAV systems for use by the Army in operational test and evaluation. The systems will feature the Shadow 200 air vehicle, which comprises three air vehicles, three ground control stations (including one portable ground control system), a hydraulic launcher and logistics support elements for deployment. Each air vehicle weighs approximately 325 lb fully loaded and measures 13 ft between wing tips and 11 ft nose to tail. The entire system can be transported to the battlefield in two C-130 cargo aircraft. The Army also will have the option to purchase an additional six to 10 full-rate production systems following operational test and evaluation. AAI intends to deliver the first of four systems this year; the Army expects to purchase a total of 44 TUAV systems over the next five years, potentially exceeding the contract's value to more than $300 M. AAI has delivered more than 230 UAVs worldwide.

Lockheed Martin Receives Aegis Production Award

Lockheed Martin Naval Electronics & Surveillance Systems (NE&SS), Moorestown, NJ, has received $175.3 M from the US Navy for the production of three Aegis weapon systems. The award is part of a multiyear funding agreement between Lockheed Martin and the Navy that began in 1998 for the production of 13 Aegis weapon systems and includes an option for an additional system. The NE&SS is responsible for the design and integration of a complete shipboard, multiwarfare combat system that includes all detection, command and control, weapon and support systems for the Aegis class of guided-missile cruisers and destroyers. The Aegis weapon system, which is designed and integrated into the Aegis combat system, includes the AN/SPY-1 phased-array radar, which is capable of simultaneously tracking multiple targets while maintaining aerial surveillance of an area. The multiyear agreement, including options, is valued at more than $926 M. Delivery of the systems is scheduled to begin in October and continue through January 2007. The work will be performed at Lockheed Martin's NE&SS operating site in Moorestown, NJ.

DoD ACTD Strategy for UAV Assessment Examined

The US General Accounting Office (GAO) has released a report, "Unmanned Aerial Vehicles: DoD's Demonstration Approach Has Improved Project Outcomes" (GAO/NSIAD-99-33), which examines the effectiveness of the Department of Defense's (DoD) Advanced Concept Technology Demonstration (ACTD) strategy for assessing Unmanned Aerial Vehicle (UAV) projects. The ACTD strategy focuses on mature technology and proving military utility before committing to a UAV project, thereby enabling the DoD to gain a stronger knowledge base for making well-informed acquisition decisions. To date, ACTD projects for the Predator and Outrider UAV systems have been completed, and an active ACTD project for the Global Hawk UAV system is currently underway.

Following the Vietnam War, the DoD initiated at least nine UAV acquisition programs that were later canceled before reaching completion, spending $4 B in the process. In 1994, as part of its acquisition reform efforts, the DoD adopted the ACTD strategy to more effectively assess UAV programs. Since its inception, the ACTD approach has provided the DoD with a better basis for making UAV acquisition decisions. For example, the report notes that unsatisfactory ACTD results have led the DoD to discontinue acquisitions, such as in the case of the DarkStar UAV, which crashed on its second flight trial and was terminated before its demonstration was completed. The ACTD determined that DarkStar was not aerodynamically stable and correcting the design problems that caused the crash would become expensive and time consuming.

Prior to the ACTD approach, the DoD had allowed programs to proceed with much less knowledge (and thus higher risk) of technologies, design and potential production problems, as in the case of the Aquila UAV. As cited in the report, when the DoD committed to the Aquila UAV system in 1979, the system was not technologically mature. Several of the system's key subsystems, such as a miniaturized jam-resistant data link and a day/night sensor with laser designator, did not exist. By 1982, largely due to the problems of developing subsystem technologies, Aquila's costs quintupled and the schedule slipped 27 months. At the time the DoD opted to continue the program, but terminated Aquila in 1987 after spending more than $1 B in development funds. The report concludes that the DoD's ACTD approach is consistent with the best commercial practices, which require proof of technological maturity and performance before making commitments. ■

INTERNATIONAL REPORT

Martin Streetly, International Correspondent

INTELSAT to Procure Telecommunications Satellite

The International Telecommunications Satellite (INTELSAT) organisation has awarded a contract to Franco-British contractor Matra Marconi Space to build the INTELSAT NI-Alpha telecommunications satellite. Considered the largest and most powerful satellite ever procured by INTELSAT, the NI-Alpha will employ Matra Marconi's high powered version of Eurostar 3000 to provide operators with a high number of transponders. The NI-Alpha will be outfitted with 36 C-band (4 to 8 GHz) transponders to cover North, Central and South America as well as western Europe, and 20 Ku-band (12 to 18 GHz) transponders to provide coverage in Latin America. Compatible with a range of launch vehicles, including the Ariane, Proton and Sea Launch rockets, the satellite will be located in the West Atlantic Ocean region at 310 degrees east longitude with a launch mass of 5000 kg and output on the order of 8 kW. Once in orbit, the spacecraft is expected to have a service life of 13 years. The NI-Alpha currently is scheduled to launch during the summer of 2002. INTELSAT currently owns and operates a global communications satellite system that provides capacity for voice, video, corporate/private networks and the Internet in more than 200 countries and territories.

Racal Introduces Surveillance EW Systems

UK contractor Racal Defence Electronics has unveiled a new range of land-based electronic warfare (EW) systems. Designated under the generic name of Seeker, two models have been identified: Seeker 4 and 5. Seeker 4 is a 20 to 1000 MHz regulatory, direction-finding (DF) surveillance and monitoring system that comprises Racal's RA3726 dual-receiver, a PC and examples of the company's AE3007 (3 to 30 MHz band) and AE3020 (30 to 1000 MHz) Adcock DF antennas. Designed specifically for installation in wheeled vehicles, shelters and fixed sites, the system utilizes digital signal processing techniques with the capability to demodulate amplitude- and frequency modulated, frequency-shift keyed, continuous wave, and upper and lower sideband signals. Seeker 5, which is derived from equipment supplied to the British Army and Royal Marines, covers the 20 to 1000 MHz frequency band and offers search, DF, intercept and signals analysis capabilities. System control of Seeker 5 is by means of a ruggedised computer (running a Windows® NT operating system). Seeker 5 can be deployed in a number of operational configurations; for example, comprising a DF baseline of four sensors under the overall control of a vehicle-mounted command centre.

Rohde & Schwarz Launches EMC Test Antenna

German contractor Rohde & Schwarz has launched the Ultralog HL 562, a universal electromagnetic compatibility (EMC) test antenna for interference field strength and susceptibility measurements. Operating over the 30 to 3000 MHz frequency band, the HL 562 incorporates biconical dipole and directional log-periodic elements. A V configuration of radiators is employed to optimise antenna gain and provide rotationally symmetrical and congruent directional patterns in the E- and H-planes at frequencies above 200 MHz. To minimise measurement ambiguities, the unit has been designed to meet a polarisation isolation value of at least 20 dB. The HL 562, which measures approximately 0.60 m × 1.65 m × 1.68 m, features a single-piece log-periodic array in order to maximise mechanical stability and is calibrated prior to delivery using the three-antenna technique combined with tolerance analysis. Individual calibration records are supplied with each antenna for transfer to the test system. For additional information on Rohde & Schwarz products, visit www.rsd.de.

Next-generation UAV Concept Study Initiated

The UK's Ministry of Defence has issued an invitation to tender to several companies regarding a concept study contract that relates to the British Army's next-generation Sender unmanned aerial vehicle (UAV). The Sender UAV is primarily intended to perform a tactical surveillance role and will be equipped with a range of payloads that are likely to include both electro-optic and synthetic aperture/moving target radar (SAR/MTI) sensors. (Other possibilities include EW and/or communications relay equipment.) Potential companies that may show interest in the UAV include UK contractors BAe Systems and Racal Defence Electronics, Israel's Elta Electronics and US contractor Northrop Grumman. Of these, BAe Systems' contenders may leverage technology from the SAR capability that the company has developed for its Sea Spray 7000 maritime surveillance radar while Elta is likely to offer technology based on its EL/M-2055 UAV and EL/M-2060 podded fast-jet SARs. Racal is expected to offer a system based on its podded fast-jet SAR/MTI demonstrator or the lightweight, low volume modular radar developed by its Wells, Somerset plant. Northrop Grumman's bid is likely to be based on a lightweight variant of its TESAR sensor that was launched in the UK in September 1999. As of press time, the Sender concept study contract is scheduled to be released by this month with a service entry data for the system expected around 2008.

Siemens Awarded Telecommunications Intelligent Network Contracts

German contractor Siemens Information and Communications Networks (SICN) has been awarded two contracts for the supply of telecommunications intelligent network services (INS) in the Middle East and Asia. In the Middle East, Jordanian carrier Fastlink has announced plans to acquire an INS pre-pay add on for its existing mobile telecommunications network based on Siemens INXpress INS platform. The contract builds upon an earlier Siemens contract with Fastlink that covered the supply of switching technology. In Asia, SICN has been awarded a contract by Chinese mobile telecommunications provider Unicom to expand its existing pre-pay INS. Unicom's pre-pay service will be expanded from the original base of Beijing, Guangzhou, Shanghai and Shenzhen to an additional 17 provinces within the People's Republic of China. The Unicom INS expansion also is based on Siemens INXpress INS platform. The contract, which was launched in 1999, is valued at Euro 55 M. Siemens, a provider of complete GSM systems, has already supplied GSM systems to more than 140 network operators in more than 70 countries. Additional information can be obtained at www.siemen.com/ic/networks/ca.

Philips Develops Embedded Flash Memory for CMOS Technology

Netherlands contractor Philips Semiconductors has developed the CMOS18 Flash memory module, a two-transistor cell for use in its 0.18-µm complementary metal oxide semiconductor (CMOS) technology. Forming part of the company's Nexperia™ silicon system platforms strategy for creating complete products on a single chip, the new memory module allows memory size to be tailored to suit a particular application rather than available off-the-shelf capacities. This optimised two-transistor approach has been achieved without major increases in module size. The new cell has an overall size of 0.78 μm^2 compared to a typical single transistor cell's size of 0.50 μm^2. The two-transistor approach requires considerably less peripheral circuitry for programming and erasure. By way of example, the CMOS18 design utilizes Fowler-Nordheim tunneling for memory cell programming and erasure, thereby eliminating the large charge pump needed in a single transistor module hot-channel electron programming technique. Other device features include memory control and testing circuitry design, which help to achieve silicon area parity with single transistor devices together with separated memory and selection functions. ■

THE COMMERCIAL MARKET

Globalstar USA Licensed to Offer Satellite Phone Service

Globalstar USA, the exclusive provider of satellite-based communications services in the US, has received authorization from the Federal Communications Commission (FCC) to market satellite phone service on a limited basis to US customers. The Globalstar system is a state-of-the-art mobile satellite service that extends the coverage of existing analog and digital wireless services, allowing phone calls to be made and received virtually anywhere in the world and offering data capabilities such as e-mail and short messaging. In addition, the company has announced an introductory monthly pricing plan targeted at a broad market. While Globalstar phones are similar in size and weight to earlier hand-held cellular phones, the company intends to offer its services at a more affordable cost. For pricing information, visit www.globalstarusa.com.

Optical Attenuator Market to Reach $1.5 B by 2008

According to a report issued by ElectroniCast Corp., global consumption of optical attenuators reached $178.8 M in 1998 and is expected to increase to $1.5 B by 2008 as a result of rapidly rising quantity growth substantially offset by falling average prices. The consumption value of optical attenuators used for telecommunications networks was $128 M in 1998, representing 71 percent of the total market. Cable television applications consumed $17 M, representing 9.4 percent, while military/aerospace applications spent $16 M, accounting for 8.8 percent. Specialty applications consumed $11 M and premise data networks spent $7 M. By 2008, telecommunications network applications are expected to spend $1.24 B, representing 86 percent of the total market value. Military/aerospace applications are forecast to increase expenditures to $73 M, accounting for five percent, while cable television, specialty applications and premise data network users are expected to account for approximately three percent of the total market.

The report separates the optical attenuator market into three segments: fixed panel-mount, fixed cable assembly, and manual and electronically controlled variable. Electronically controlled variable optical attenuators represented 61 percent of global consumption in 1998 and are expected to dominate the market in 2008 with sales of $1.26 B, accounting for 87 percent. Fixed panel-mount types, which represented 8.1 percent in 1998, are forecast to drop to 2.1 percent by 2008. Manual variable types accounted for 14.5 percent in 1998 and are expected to decrease to 5.9 percent while fixed cable assembly types are expected to decline from 16.8 percent in 1998 to five percent in 2008. For additional information, contact Theresa Hosking, ElectroniCast (650) 343-1398.

Smart Phones to Dominate the Wireless Access Market

A new report from IGI Consulting, "Wireless Web Wonders," predicts that smart phones and personal data assistants (PDA) will dominate the wireless Internet market. The number of smart phones produced is expected to increase to 88 percent (330 million units) in 2003 while PDA sales are expected to increase to 118 percent (35 million units) during the same period. By 2003, the report forecasts that approximately 33 percent of an estimated one billion cellular subscribers will use smart phone-enhanced displays, data entry and storage capabilities to conduct e-commerce, access the Internet via mobile portals, run server-assisted applications and use location-based content and services.

The report also concludes that Palm Computing will dominate the wireless access operating system market while Microsoft's Windows CE will continue to dominate certain vertical market segments. Handspring and Symbian are also forecast to compete for market share. In addition, the report analyzes the business opportunities available to companies that are planning to profit from wireless Internet access. Qualcomm's High Data Rate system, third-generation technologies, location-based technologies and smart phone access to wireless local area networks are described. For additional information, contact Tony Carmona, IGI Consulting (617) 232-3111 or e-mail: tcarmona@igigroup.com.

Wireless Broadband Revenues to Reach $3.4 B in 2003

The Strategis Group's report, "US Wireless Broadband: LMDS, MMDS and Unlicensed Spectrum," projects that wireless broadband revenues will increase from $11.2 M in 1999 to $3.4 B in 2003. Growth in local service and Internet access revenues and broadband wireless deployment are expected to be the driving factors for the significant increase. By 2003, 34 percent of US households and 45 percent of US businesses are expected to be serviced by broadband wireless networks. Wireless broadband technologies, such as local and multipoint distribution systems (LMDS), multichannel multipoint distribution systems (MMDS) and unlicensed spectrum systems, are capable of providing voice, video, data and Internet service. With the exception of cable modems, wireless broadband is the only technology capable of serving all three markets. Wireless broadband technologies

can provide throughputs ranging from 64 kbps up to 15 Mbps. Unlicensed spectrum networks are currently utilized in almost 200 markets nationwide while LMDS and MMDS systems have not yet been widely deployed. However, MMDS spectrum holders Sprint and MCI WorldCom have announced plans to begin MMDS deployment by the middle of this year while LMDS licensees NEXTLINK and HighSpeed.com began installations in late 1999. For additional information, contact The Strategis Group (202) 530-7500.

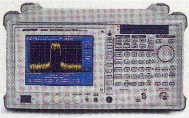
Boeing to Acquire Hughes Satellite Systems Business

The Boeing Co. has announced plans to purchase the satellite systems business of Hughes Electronics Corp. in an all-cash transaction valued at $3.75 B. Under the terms of the acquisition, Boeing will acquire Hughes Space and Communications Co., a communications satellite manufacturer; Hughes Electron Dynamics, a supplier of satellite electronic components; and Spectrolab, a provider of solar cells and panels for satellites. Boeing's large-scale integration capabilities, coupled with Hughes' satellite systems operation, will enable Boeing to offer unparalleled integrated space, air and terrestrial information and communications systems to its customers. As a result of the acquisition, Hughes will become one of Boeing's largest customers with contracts in place for five HS 601 HP satellites for PanAmSat and DIRECTV,® and five HS 702 satellites for PanAmSat and the Hughes Spaceway™ broadband system. The transaction is subject to regulatory and governmental review and is expected to close by the middle of this year.

In related news, Hughes has announced plans to narrow the focus of its wireless business at Hughes Network Systems (HNS), Germantown, MD. The wireless business intends to discontinue its mobile cellular and narrowband local loop product lines after fulfilling outstanding obligations for the discontinued products. As a result of the decision, the wireless business will concentrate on its broadband point-to-multipoint product line. The company expects to record a fourth-quarter pre-tax charge of approximately $275 M. Hughes Electronics is undergoing major changes in its corporate structure and business mix that are designed to sharply focus the company's resources and management attention on its high growth entertainment, information and business communications services. ■

ADVANTEST RACES BEYOND STATE-OF-THE-ART!

Advantest is one of the world's leading suppliers of wireless telecommunications measuring equipment. We make everything from spectrum and network analyzers to a wide range of other measurement instruments — including amplifiers and filters. We are constantly racing beyond state-of-the-art. Our latest spectrum analyzers, for example, can measure your wireless systems in conformance with third generation mobile telecommunications standards like IMT-2000. Which means they can also test leading-edge W-CDMA channels. And everything we make is supported worldwide through our own service network as well as through our partners Rohde & Schwarz in Europe and Tektronix in the U.S. If you supply wireless telecommunications systems, you need the best precision measuring equipment you can get. You'll find it at Advantest!



R3267 Spectrum Analyzer

For IMT-2000 !

The R3267 is a high performance spectrum analyzer designed to meet the needs of the new communication technologies like 3rd generation mobile (IMT-2000), microwave digital broadcast, high-speed multimedia mobile access (MMAC), and satellite-based services. It features a frequency span accuracy within ±1% and a dynamic range of -154dBc/Hz (typ.) in the 2GHz band.

ADVANTEST®

Japan: ADVANTEST CORPORATION +81-3-3342-7500, tmi@advantest.co.jp, http://www.advantest.co.jp/index-e.html
Europe: ROHDE & SCHWARZ Engineering and Sales GmbH +49-89-4129-3711, http://www.rsd.de
North America: Tektronix, Inc. +1-800-426-2200, http://www.tek.com
Asia: Advantest (Singapore) Pte. Ltd. +65-274-3100, tmi@asp.advantest.co.jp

CIRCLE 1 ON READER SERVICE CARD

INDUSTRY NEWS

■ **M/A-COM**, a subsidiary of **Tyco Electronics**, has announced plans to acquire **ITT Industries Inc.'s GaAsTEK** business unit. Under the terms of the agreement, GaAsTEK, which develops and manufactures GaAs MMICs for commercial and defense markets, will operate as part of M/A-COM. Financial details of the agreement were not disclosed.

■ **Alpha Industries**, Woburn, MA, has signed a definitive agreement to acquire privately held **Network Device Inc.**, Sunnyvale, CA, a provider of advanced technology GaAs IC design and fabrication. Under the terms of the acquisition, the number of shares of Alpha common stock to be exchanged for all of the outstanding shares and options of Network Device will be determined by a formula based on an average closing price for a specified period prior to the transaction's closing. The acquisition, which is valued at approximately $141 M, is expected to be completed in 2001.

■ **Kyocera America Inc. (KAI)**, San Diego, CA, has acquired **VisPro Corp.**, a supplier of LTCC multilayer ceramic substrates and structural ceramic components. Under the terms of the acquisition, VisPro will become a new division of KAI and continue operations from its existing facility in Beaverton, OR. Financial terms of the transaction were not disclosed.

■ Electronic test tool provider **Fluke Corp.**, Everett, WA, has acquired **Wavetek Wandel Goltermann's (WWG) Precision Measurement Division**. Under the terms of the acquisition, WWG's division will become part of the Fluke Industrial Group's Calibration Business Unit. The acquisition is expected to accelerate product development and total solutions and improve customer service. In addition, Fluke has purchased WWG's test tools product line, which includes digital multimeters, clampmeters, bench instruments and related accessories.

■ **Connecticut Microwave Corp.**, Cheshire, CT, has acquired the waveguide and coaxial termination line of **Micronetics Wireless Inc.**, Hudson, NH. The acquisition will extend Connecticut Microwave's line of passive components, directional couplers, ferrite circulators, isolators and other components.

■ **Lockheed Martin Federal Systems**, Oswego, NY, has purchased the model 9098 double-density universal grid test system from **Everett Charles Technologies**, Pomona, CA. In related news, **Ibiden Circuits of America Corp.**, Elgin, IL, has purchased the Eclipse Linear Probe Test System from Everett Charles Technologies. The test system offers an optical pattern recognition LCR meter kit for measurement of recognition, inductance and capacitance.

■ **Compaq Computer Corp.** has formed **Compaq Telecommunications** to develop, market and deliver integrated solutions for global communications carriers in the areas of enhanced network services, business and operations support systems, and customer premise equipment. The new organization will be headquartered in the Telecom Corridor near Dallas, TX with operations at sites worldwide.

■ Advanced electronic, mechanical and electro-optical system designer and manufacturer **EDO Corp.**, New York, NY, and privately held **AIL Technologies Inc.**, Deer Park, NY, have signed a definitive merger agreement that is expected to create an integrated defense and aerospace technology company with annualized revenue of approximately $240 M. Under the terms of the agreement, all of AIL's outstanding common and preferred shares will be exchanged or purchased for approximately 6.6 million newly issued shares of EDO common stock as well as a cash payment of $13.1 M. The transaction, which is valued at $86.8 M, is subject to approval by both companies' shareholders and regulatory authorities.

■ **Rayan**, **Starec** and **Chelton France**, members of the **Chelton Group Company**, have merged to form **Chelton Antennas SA**. The merger will enable Chelton Antennas to develop a specialized market approach, provide solutions adapted to specific customer requirements and strengthen its development and manufacture of ground, airborne and space antennas.

■ Radio frequency component and subassembly manufacturer **RF Monolithics Inc. (RFM)**, Dallas, TX, has relocated its European sales office to England. The new location, coupled with recent ISO 9001 certification, expansion of technical manufacturer representatives and additional sales personnel, strengthens the company's presence in the European market. In related news, RFM has expanded its second-generation Virtual Wire® amplifier-sequenced hybrid technology product line to include more than 20 transmitter, receiver and transceiver products.

■ **Philsar Semiconductor Inc.** has opened a sales and marketing office in Tokyo to support its growing number of customers in the Asia/Pacific region, specifically in Taiwan, Korea, China, Singapore and Hong Kong.

■ Wireless and wired infrastructure equipment component manufacturer **Stanford Microdevices Inc. (SMI)**, Sunnyvale, CA, has opened a new design center located in Kanata, Ontario, Canada. The new design center, which focuses on next-generation wireless infrastructure products, houses a state-of-the-art test facility. In related news, LDMOS RF semiconductor manufacturer **UltraRF**, Sunnyvale, CA, has formed a strategic alliance with SMI to supply LDMOS power devices to the expanding base station infrastructure markets. As part of the strategic alliance, UltraRF will provide SMI with LDMOS foundry support and, in turn, SMI will offer drop-in equivalents for several of UltraRF's cellular infrastructure LDMOS devices. The partnership is expected to leverage both companies' intellectual property and technologies and provide an aggressive growth platform.

[Continued on page 60]


Synergy Microwave Corporation introduces a new line of Patent Pending I&Q Modulator/Demodulator with High Dynamic Range in a Miniature Package measuring 0.5 x 0.5 x 0.22 inch.
Being a passive device, it eliminates the need for external supporting circuitry, thus, simplifying the overall application design at reduced cost. These devices are specifically optimized for frequencies in the range of 800 to 2000 MHz.
Miniature
Passive
Excellent Dynamic Range
Low Cost
modulator demodulator
SYNERGY
Microwave Corporation
VMS
Pat. Pend.
VMS
Pat. Pend.
For additional information, contact our Sales and Application Team.
201 McLean Blvd., Paterson, NJ 07504
Tel: (973) 881-8800 Fax: (973) 881-8361
E-mail: sales@synergymwave.com
Web Site: www.synergymwave.com
SYNERGY®
MICROWAVE CORPORATION
CIRCLE 161 ON READER SERVICE CARD

■ RFIC solution designer and manufacturer **ANADIGICS Inc.** has opened its third remote RFIC design center in Thames Valley, UK. The company recently opened RFIC design centers in Dallas, TX and Newbury Park, CA. In related news, ANADIGICS has shipped its first high efficiency, heterojunction bipolar transistor (HBT) power amplifier samples to major wireless handset manufacturers. The HBT power amplifiers operate from a single 3 V sup-

of the growing demand for value-added services within the wireless industry. The new office will provide customers with the design, coordination and licensing of microwave and satellite systems.

■ **Amplifier Research**, Souderton, PA, has announced the opening of its fourth distribution office in Amsterdam. **EMV Benelux** will distribute and service RF and electromagnetic compatibility test equipment in the Netherlands, Belgium and Luxembourg. The European EMV Group is a network of distributors with offices in Germany, France and England.

into a strategic partnership to market US Semiconductor's RHI-NO™ innovative wafer-thinning technology and production thinning processes for radiation hardening commercial microelectronics. Under the terms of the agreement, Space Electronics will provide all back-end IC assembly, screening and qualification for space and military IC radiation hardening products for the RHI-NO line as well as international sales and marketing support.

■ **Andrew Corp.**, Orland Park, IL, and **Channel Master LLC** have entered into an alliance that will enable each company to offer a broader range of earth station antenna products. Andrew offers a full line of fixed and motorized earth station antennas ranging from 1.2 to 9.3 m while Channel Master specializes in the design and production

equipment manufacturer customers. The radio design, which will complement ShareWave's family of high performance network controllers and Whitecap network protocol, incorporates RFMD's 2.4 GHz radio chipset.

■ DC-to-DC converter product supplier **Lambda Electronics**, an **Invensys** company, has been selected by Rockwell Collins and the US Navy Office of Naval Research to participate in a research project to develop three distinct point-of-use power conversion technologies for broad commercial and defense applications. Lambda is expected to market power supply innovations for personal computers and other consumer applications. The $8 M project will span two years and operate under the Joint Services Dual-use Science and Technology Program and the Office of Naval Research Power Electronics Building Blocks Program.

■ **Triton Network Systems Inc.** has selected **Palomar Technologies** to fully automate the assembly of high fre-

power supplies will
E/P aircraft.

, GA, has entered
th Tokyo-based
: its licensed Pan-
, related technical

Electronics Mar-
bution agreement
Anaren Wireless
oducts to Asia, en-
rchase a variety of
e. Avnet currently
it the US. In relat-
, Malvern, PA, has
on agreement with
nic components.

dustries Ltd., San
with **First Source**
onnectors' full line
ement is expected
product offerings
ilities.

cro Devices Inc.
rated with **Share-**
e design of a pro-
reWave's original

telecommunications devices without buying, carrying or connecting cables.

■ **G.T. Microwave Inc.**, Randolph, NJ, has received ISO 9002 certification from the European Quality Assurance authority.

■ Ceramic capacitor and electronic component manufacturer **Murata Electronics North America Inc.**'s State College, PA manufacturing facility has received ISO 14001 certification by Lloyd's Register Quality Assurance for Environmental Management Standard.

■ **Mini-Systems Inc.'s Thin Film Division**, Attleboro, MA, has announced that its MIL-PRF-55342 resistors have qualified for Life Failure Rate R, which indicates a maximum failure rate of 0.01 percent per 1000 unit hours. In order to qualify for this rating, Mini-Systems demonstrated more than 9.16 million hours of successful life testing without a failure.

■ Semiconductor IC manufacturer **STMicroelectronics Inc.'s Region Americas**, Carrollton, TX, has been awarded the 1999 Malcolm Baldrige National Quality Award for performance excellence and quality achievement.

■ **State of the Art Inc. (SOTA)**, State College, PA, has celebrated its 30th anniversary as a manufacturer of high quality, high reliability thick- and thin-film resistive products for the surface-mount and hybrid electronic indus-

[Continued on page 64]

multi-output, low voltage, state-of-the-art
be employed aboard the US Navy F/A-18

■ **Intercept Technology Inc.**, Atlanta
into a distribution agreement wi
Marubeni Solutions Corp. to marke
theon and MoZaiX software programs,
support and maintenance in Japan.

■ **Anaren Microwave Inc.** and **Avnet**
keting have signed an enhanced distri
whereby Avnet will directly distribute
Group's entire line of surface-mount pr
abling customers in the Far East to pu
wireless components from a single sour
distributes Anaren's products throughou
ed news, **Vishay Intertechnology Inc.**
entered into an international distributi
Avnet to distribute its full line of electro

■ **RF Connectors**, a division of **RF In**
Diego, CA, has signed an agreement
Inc., San Jose, CA, to distribute RF C
of coaxial and cable products. The agre
to significantly expand RF Connectors'
and increase its coaxial connector capab

■ Proprietary RFIC provider **RF Mi**
(RFMD), Greensboro, NC, has collabo
Wave Inc., El Dorado Hills, CA, on th
duction radio currently used by Sha

tries. Founded in 1969, SOTA developed the current industry-standard nickel barrier to eliminate solder leaching and inter-metallic formation.

FINANCIAL NEWS

■ **STMicroelectronics Inc.** reports sales of $1.5 B for the fourth quarter, ended December 31, 1999, compared to $1.1 B for the same quarter in 1998. Net income was $184.3 M (62¢/diluted share), compared to $121.8 M (42¢/diluted share) for the same period in 1998.

■ **Andrew Corp.** reports sales of $233.6 M for the first quarter, ended December 31, 1999, compared to $218.6 M for the same period in 1998. Net income was $16.8 M (21¢/diluted share), compared to $23.2 M (28¢/diluted share) for the same quarter in 1998.

■ **Teledyne Technologies Inc.** reports sales of $200.4 M for the fourth quarter, ended January 2, compared to $191.7 M for the fourth quarter of 1998. Net income was $11.7 (44¢/diluted share), compared to $8.7 M (31¢/diluted share) for the same period in 1998.

■ **RF Micro Devices Inc.** reports sales of $73.2 M for the third quarter, ended December 31, 1999, compared to $41.5 M for the same period in 1998. Net income was $12.6 M (15¢/diluted share), compared to $5.6 M (8¢/diluted share) for the same quarter in 1998.

■ **E-TEK Dynamics Inc.** reports sales of $72.5 M for the second quarter, ended January 1, compared to $38.7 M for the same period ending January 1, 1999. Net income was $14.4 M (20¢/share), compared to $6.8 M (11¢/share) for the same quarter last year.

■ **ANADIGICS Inc.** reports sales of $40.1 M for the fourth quarter, ended December 31, 1999, compared to $22.6 M for the same period in 1998. Net income was $4.4 M (22¢/diluted share), compared to a net loss of $3.9 M (26¢/diluted share) for the same quarter in 1998.

■ **Robinson Nugent Inc.** reports sales of $22.8 M for the second quarter, ended December 31, 1999, compared to $17.5 M for the same period in 1998. Net income was $880 K (17¢/share), compared to $39 K (1¢/share) for the same quarter in 1998.

■ **Microwave Power Devices Inc.** reports sales of $18 M for the fourth quarter, ended December 31, 1999, compared to $17.7 M for the same period in 1998. Net loss was $5.4 M (51¢/share), compared to a net income of $1 M (10¢/diluted share) for the same quarter in 1998.

■ **Superconductor Technologies Inc.** has completed a public offering of 2,473,701 shares of registered common stock, thereby providing the company with gross proceeds of $8 M. The majority of shares were purchased by the State of Wisconsin Investment Board, and the remainder of shares were acquired by Wilmington Securities Inc., a wholly owned subsidiary of The Hillman Company.

CONTRACTS

■ **Sanders**, a **Lockheed Martin** company, has been awarded a $7 M foreign military sales contract by the US Army's Communications and Electronics Command to provide missile warning systems for the Greek armed forces. Under the terms of the contract, Sanders will provide 17 AN/ALQ-156(V) missile warning systems for Hellenic Army CH-47 helicopters. The system is currently operating on the CH-47 Chinook and EH-60 Blackhawk helicopters and C-130 Hercules and C-23 Sherpa transport aircraft.

■ **Signal Technology Corp.'s Signal Wireless Group** has received contracts from Spectrian Corp. to supply power distribution devices and systems for CDMA base station applications in North America. The power distribution devices and systems will be manufactured at Signal's Olektron Operation in Beverly, MA. The contracts are valued at $1.7 M.

PERSONNEL

■ Screen actress and frequency-hopping spread spectrum system inventor **Hedy Lamarr** died on January 19, 2000 at the age of 86. Lamarr was only recently recognized for her contribution to present cellular phone technology. (See "A Starlet's Secret Life as Inventor," *Microwave Journal*, February 1999, pp. 70–74.)

▲ *Ted Shoneck*

■ **Ted Shoneck** has been named CEO at Quad Systems Corp. Most recently, Shoneck was COO at Cutting Edge Technologies.

■ **John Harris** has been appointed chairman, president and CEO of RangeStar Wireless. Previously, Harris was senior VP at Uniden America and Mitsubishi Electronics America.

■ Electrocube has announced several new appointments, including **Donald Duquette** as president, **L. Clay Parrill** as VP/general manager and **Gloria Snyder** as national sales manager. Duquette and Parrill each bring to the company more than 20 years of manufacturing and business management expertise and, most recently, Snyder was customer service manager at the company.

■ CTS Corp. has promoted **Donald R. Schroeder** to VP, business development and chief technology officer. Schroeder has been president of sales and marketing at the company since 1995.

■ Signal Technology Corp.'s California Operation has appointed **Joseph Mersereau** acting president. Mersereau has been with the company since 1991 and, most recently, was director of engineering. In addition, Signal Technology's Arizona Operation has named **Robert Levin** VP and chief technologist. Levin, co-founder of Comtech Wireless Inc., a subsidiary of Comtech Telecommunications Corp., brings to the company more than 30 year of technological experience.

■ RELM Wireless Corp. has appointed **Scott Henderson** senior VP and director of its Business and Industrial

[Continued on page 66]

sector and **Thomas Morrow** senior VP and director of its Government/Public Safety sector. Prior to joining the company, Henderson was a sales and marketing executive at the E.F. Johnson, Midland and Uniden radio firms and Morrow was a sales and marketing executive at E.F. Johnson, GE Mobile Communications and Motorola.

■ Unitek Miyachi Corp. has named **Mark Rodighiero** VP of its newly created Laser and Systems division. Rodighiero has been VP of engineering at the company since 1993.


▲ Rocco J. Melchione

■ **Rocco J. Melchione** has been promoted to the newly created position of VP of sales and marketing at Hirose Electronics (USA) Inc. Melchione has been sales and marketing manager at the company since 1998.

■ IFR Systems Inc. has appointed **Mitch Stone** VP of sales, Americas region. Most recently, Stone was VP, sales and marketing at Datum Inc.

■ Stanford Microdevices Inc. has named **Michael Van der Tol** director of its Ottawa design center. Most recently, Van der Tol was senior manager, RF Technology Development for Nortel Networks' Wireless Solutions business unit.

■ Larus Corp. has named **Gary M. Ensign** director of international sales. Most recently, Ensign was director of sales at TransComm Technology Systems.

■ Lawrence Behr Associates Inc. has named **Will Daugherty** director of product marketing. Most recently, Daugherty was director of marketing at Seaward International Inc.


▲ Tally Costa

■ **Tally Costa** has joined Filtronic Solid State as national director of sales and marketing for semiconductor products. Costa has 14 years of sales and marketing experience and, most recently, was regional sales manager at Richardson Electronics.

■ United Monolithic Semiconductors has appointed **Sylvain Dumay** regional sales manager for southern Europe.

■ Philsar Semiconductor Inc. has named **Hiroshi Tsuchiya** sales director for Japan and the Asia/Pacific region. Most recently, Tsuchiya was director of communication products at VLSI Technology KK/Philips Japan.

■ Interconnect Devices Inc. has named **Jay Preister** product specialist. Preister has five years of circuitry testing experience with Lucent Technologies.

■ Champion Technologies Inc. has appointed **Raj Alluri** applications engineer, North America, and **Dick Thompson** sales manager, North America. Most recently, Alluri was prime reliability engineer for the company and Thompson held positions at M-tron Industries and Dale Electronics.

REP APPOINTMENTS

■ **DB Products Inc.**, Pasadena, CA, has appointed five companies to represent its complete line of RF and microwave electromechanical switching products. **Cain-Sweet Co.** will cover Washington, Oregon and Canada; **Jay Stone and Associates** will cover Northern California and northern Nevada; **Thorson Desert States Inc.** will cover Arizona, New Mexico, southern Nevada and El Paso, TX; **The Thorson Co.** will cover Arkansas, Louisiana, Oklahoma and Texas; and **W. Howard Associates** will cover Colorado, Utah, Wyoming, Montana and Idaho.

■ **Commercial Microwave Technology (CMT)**, Diamond Springs, CA, has selected **First Source Inc.** as national representative for its full line of quality microwave filters and assemblies, coaxial and waveguide duplexers, spread spectrum filters and duplexers.

■ **G.T. Microwave**, Randolph, NJ, has appointed foreign representatives in Belgium, Denmark, Finland, Germany, Greece, India, Korea, the Netherlands, Spain and Turkey to represent its PIN diode control components and subassemblies, thereby doubling its existing foreign coverage.

■ **Toko America Inc.**, Mt. Prospect, IL, has selected **Norris and Associates**, Hingham, MA, to represent the company's miniature inductor and filter products throughout New England.

■ **UltraRF**, Sunnyvale, CA, has appointed **Castle Microwave**, Twyford, Berkshire, UK, to represent its complete line of high power, high performance RF power semiconductors in Great Britain, Ireland, France, Italy, Belgium, Holland and Germany.

■ Cable, connector and assembly designer and manufacturer **Storm Products – RF/Microwave Group**, Hinsdale, IL, has selected **MHz Marketing** to represent its line of high performance interconnect products in Maryland, Virginia and the District of Columbia.

WEB SITES

■ Antenna and power product designer and manufacturer **Centurion International Inc.** has introduced a new Web site that enables product designers and manufacturers to quickly and efficiently obtain information on antennas and power products. The new site can be found at www.centurion.com.

■ Specialty material and service provider **SEMX Corp.**, Armonk, NY, has launched a newly designed Web site that provides updated company information and new products. The site is located at www.semx.com.

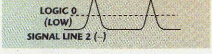
■ **Accumet Engineering Corp.**, Hudson, MA, has introduced a Web site that provides technical specifications for a broad range of substrate materials produced with exact repeatability consistency. The site, which is located at www.accumet.com, also details available precision lapping, polishing, laser machining, diamond sawing and edge grinding capabilities.

Characterization of Differential Interconnects from Time Domain Reflectometry Measurements

Differential signaling schemes are a common approach to achieving higher noise immunity for critical signals in a high speed digital design. However, measurement and modeling of the transmission lines carrying differential signals pose several different challenges, which need to be addressed in order to achieve an accurate picture of differential signal transmission in digital system design and simulations.

A differential pair constitutes a set of coupled transmission lines and, therefore, can be modeled and simulated as such. Short differential lines can be modeled using coupled LC matrices, but a distributed model is required for longer lines. In this article, a technique for extracting such a distributed coupled line model from time domain reflectometry (TDR) measurements is presented. This model can be easily utilized in a SPICE or IBIS simulator, making it extremely usable for high speed differential interconnect modeling and simulation. The resulting accurate models help the designer to achieve a better understanding of the differential interconnects, resulting in higher performance system design.

Fig. 1 Differential signaling.



DIFFERENTIAL LINE SIGNALING AND ANALYSIS

As shown in ***Figure 1***, differential signaling means that two transmission lines and two signals are used to transmit a single data bit from a driver to a receiver. The lines are not completely independent: When the signal on one line is logical low, the signal on the other line is logical high and vice versa. In addition, the two lines are typically laid out quite close to each other and exhibit signal coupling from one line to the other to a varying degree.

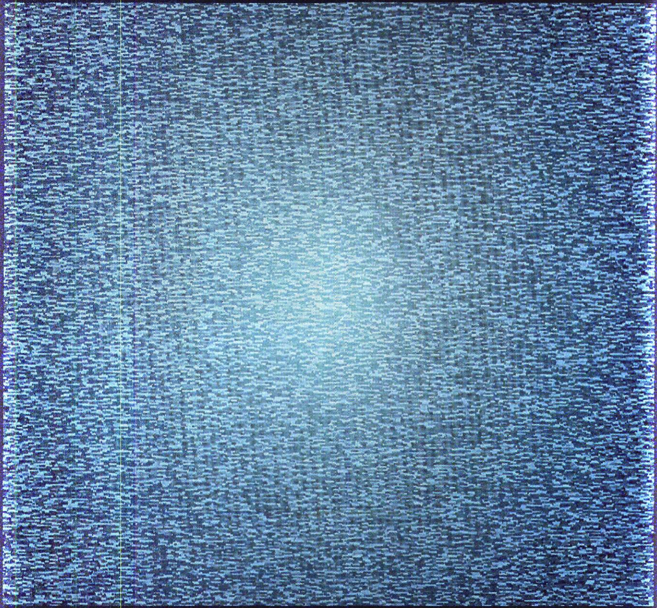
The reason for sacrificing precious space on a circuit board is to allow signal transmission between a driver and a receiver where a clean, reliable common ground between the driver and the receiver cannot be achieved. For example, this may be the case when the spacing between the driver and receiver is large. In such an event, the ground voltage potential of the driver circuit actually may be different from the ground voltage potential of the receiver circuit.

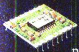
As an additional benefit, differential signaling schemes provide increased immunity to the common-mode noise in the system be-

[Continued on page 70]

Dima A. Smolyansky
and Steven D. Corey
TDA Systems Inc.
Portland, OR

Without our active filter technology, all this talk about HDTV and Broadband would be nothing but noise.





Amidst the buzz surrounding tomorrow's hottest applications is something far less desirable. Noise. That's why design engineers are turning to Murata to keep unwanted signals out. After all, Murata's patented high speed op-amp and thick film innovations have resulted in active filters that are unmatched in functionality. By integrating many filters into a single package, we can actually deliver the specifications you need at about half the usual cost and size. From HDTV and Broadband to xDSL and CDMA, Murata is pioneering solutions that meet the demands of emerging technologies. To find out how we can help you, visit **www.murata.com/tech**. When it comes to technology challenges like noise, there's nothing like a partner who hears you loud and clear.

muRata
Innovator in Electronics

cause the receiver only sees relative (differential) voltage between the two transmission lines in the differential pair. In addition, because the fields radiated by each signal are of opposite polarity, they cancel out to significantly reduce the radiated energy, which is the main cause for electromagnetic interference between devices. Differential signals are also more immune to signal attenuation in the transmission medium because the receiver design typically allows sufficient gain to reproduce the original signal.[1] Typical applications of differential signals are low voltage differential signaling, fiber channels, disk drive flexible interconnects and Rambus™ clock signals.

A DIFFERENTIAL LINE CIRCUIT DESCRIPTION

The characteristic impedance of a transmission line can be described using its series resistance and inductance and shunt capacitance and conductance per unit length:

$$Z=\sqrt{\frac{R+j\omega L}{G+j\omega C}} \qquad (1)$$

This equation reduces for a lossless transmission line to

$$Z=\sqrt{\frac{L}{C}} \qquad (2)$$

The electrical length of such a line can be determined using

$$t=l\sqrt{LC} \qquad (3)$$

where

l = physical length of the line

Typically, differential lines are routed fairly close together. Because of the interaction (coupling) between the lines, propagation of the signal through the differential pair cannot be described by a single capacitance and inductance value per unit length, but instead is described as a set of L and C matrices per unit length:

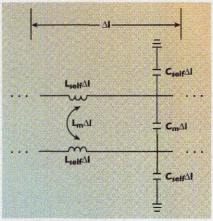
$$L=\begin{bmatrix} L_{self} & L_m \\ L_m & L_{self}\end{bmatrix}$$

$$C=\begin{bmatrix} C_{tot} & -C_m \\ -C_m & C_{tot}\end{bmatrix} \qquad (4)$$

where

$C_{tot} = C_{self} + C_m$

As shown in ***Figure 2***, these quantities are related to a physical circuit by an electrically short section (Δl) of a transmission line in which C_{self} is the



▲ *Fig. 2 An electrically short section Δl of a transmission line.*

[Continued on page 72]

capacitance per unit length of one line to ground and C_m is the mutual capacitance per unit length between lines. The quantities L_{self} and L_m are the self-inductance per unit length of one line and the mutual inductance per unit length between lines, respectively.

But what about the differential and common-mode impedances of the lines, which are often used to describe the differential transmission line behavior? Differential impedance is typically defined as the impedance measured between two conductors driven differentially, that is, with identical, but opposite, polarity signals. Odd-mode impedance is the impedance of a single conductor (transmission line) when the two conductors are driven differentially.[3] Even-mode impedance is the impedance of either conductor when the differential pair is driven with identical, same-polarity (even- or common-mode) signals. Various common-mode impedance definitions are used in the industry; the definition that considers the common-mode and even-mode impedances to be identical will be used in this article.

In some cases, the differential impedance alone is the parameter of interest to a board designer. Based on the differential impedance value, a designer can make a first cut at predicting the propagation of the signal through the differential pair. In addition, the common-mode impedance can help analyze the common-mode noise rejection; if the common-mode impedance is much higher than the differential impedance, the common-mode rejection will be high. If the ratio of the common-mode signal to the differential signal present on the differential transmission line pair and the values for the differential and common-mode impedances are known, the amount of common-mode noise that will propagate through the differential interconnect can be estimated.

Odd- and even-mode impedances for a differential pair can be computed using

$$Z_{odd} = \sqrt{\frac{L_{self} - L_m}{C_{tot} + C_m}}$$

$$Z_{even} = \sqrt{\frac{L_{self} + L_m}{C_{tot} - C_m}} \qquad (5)$$

and

$$t_{odd} = l\sqrt{\left(L_{self} - L_m\right)\left(C_{tot} + C_m\right)}$$

$$t_{even} = l\sqrt{\left(L_{self} + L_m\right)\left(C_{tot} - C_m\right)} \qquad (6)$$

Using these definitions, it is easy to conclude that

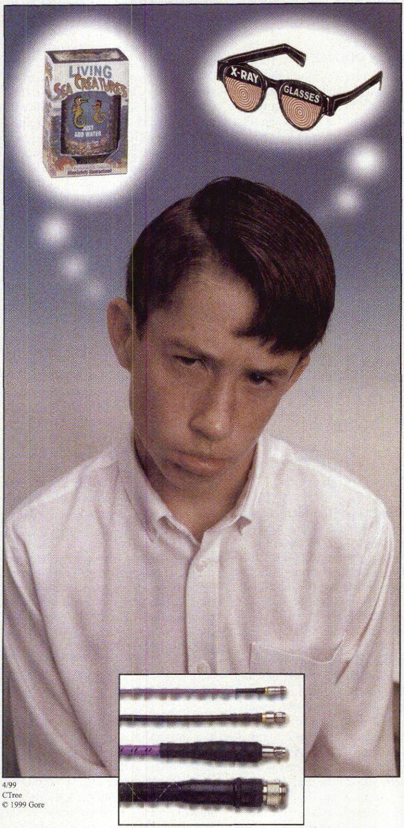
$$Z_{differential} = 2Z_{odd}$$

$$Z_{common} = \frac{Z_{even}}{2} \qquad (7)$$

with the delays for differential and odd mode and common and even mode being equal. Note that in the case where no coupling between the lines in the differential pair is present, both even- and odd-mode impedance values simply collapse to the characteristic impedance of each line. Normally, coupling between the lines would be considered a negative char-

[Continued on page 74]

Some Purchases Are a Big Disappointment...
Don't Make The Same Mistake with Your Microwave Cables



4/99
CTree
© 1999 Gore

Stable, Repeatable, Reliable, Guaranteed

Consult Gore First For All Your Microwave Test Cable Needs

For over 20 years Gore has provided microwave test assemblies with the stability, repeatability, and reliability necessary to produce dependable test results. Our extensive product line, in-depth knowledge, and bulletproof reliability ensures the products we recommend will meet your testing needs today and in the future.

NEXT GENERATION® Assemblies:
Proven performance between network analyzers and device under test. They ensure precise, repeatable measurements, allow greater range of motion, guaranteed long service life, and are refurbishable. Available in a variety of configurations operating to 26.5, 40, 50 and 65 GHz.

PHASEFLEX™ Assemblies:
Provide superior phase and amplitude stability in a crush-proof, high flex, general purpose test assembly, with off-the-shelf availability. Replaceable interface option, plus operating configurations to 12.4, 18, and 26.5 GHz are available.

Wafer Probe/High Frequency Assemblies:
Excellent flexibility and routability as well as superior phase and amplitude stability to ensure longer lasting calibrations. Crush resistance available for long-term durability. Available in configurations operating to 26.5, 40, 50, and 65 GHz.

READYFLEX® Assemblies
High performance alternative to standard RG and semirigid assemblies. Cost effective SMA to SMA assemblies with flexibility for easy installation. Available in both .145" and .195" outer diameter constructions operating to 18 GHz.
Call now for more information.

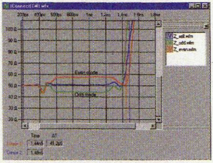
1-800-445-4673

GORE
Creative Technologies Worldwide

www.goremicrowave.com

CIRCLE 174 ON READER SERVICE CARD

W. L. Gore & Associates, Inc., Newark, DE * Fax (302) 738-5993
GORE & DESIGN, NEXT GENERATION, PHASEFLEX, & READYFLEX
are trademarks of W. L. Gore & Associates, Inc.



▲ *Fig. 3 Even- and odd-mode impedance profiles obtained from the differential TDR measurements.*

Fig. 4 Differential pair model based on the even and odd impedance and delay values. ▼

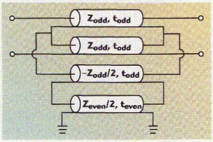
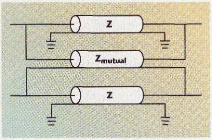


Fig. 5 A simplified differential pair model. ▼



acteristic. However, in the differential signaling case, a higher common-mode rejection actually is obtained due to coupling between the lines. Note that unless there is no coupling between the lines, the even-mode impedance will always be higher than the odd-mode impedance.

It is also interesting to observe that the time delays for the even and odd modes will be different unless the ratio of inductive and capacitive crosstalk in the two lines is the same. The difference in delays and impedances for the even and odd modes for a symmetric differential transmission line pair is shown in ***Figure 3*** using the Z-line algorithm in TDA Systems' IConnect™ software. (Note that in the presence of coupling between the two transmission lines, the even-mode impedance will always be higher.) In most practical cases, the even- and odd-mode delays will be different. Therefore, if a significant amount of common-mode energy is present in the differential signal, the designer will observe signal splitting,[4] resulting in bit errors and intersignal interference.

DIFFERENTIAL LINE SIMULATION IN SPICE

How is the propagation of the differential signal through the interconnect modeled? Since a differential pair is typically just a pair of closely routed symmetric and coupled transmission lines, it would be logical to model them as a symmetric coupled pair. A coupled LC matrix is generally used to describe such a coupled transmission line structure. However, a high number of lumped LC components will be required to simulate transmission lines that are electrically long, which is often the case when a differential transmission scheme must be used.

The electrical length of each LC network must be significantly shorter than the rise time of the signal propagating through the interconnect. A practical rule of a short or lumped interconnect can be described as

$$t_{rise} > \frac{t_{delay}}{6}$$

$$t_{rise} > \sqrt{\frac{L \bullet C}{6}} \qquad (8)$$

where L and C are the total capacitance and inductance values, respectively, for the given interconnect segment. For a rise time of 600 ps, this rule means that the lumped model can be applied to an interconnect segment no longer than 100 ps, or approximately 2/3" in FR4 board material. For a high number of long traces and for complex simulations, using the lumped model approach becomes impractical and cumbersome, slowing down the simulation and making a comprehensive signal integrity analysis more difficult to achieve.

Of course, an alternative is to use a distributed approach. Single-line impedance clearly is not enough to characterize the differential transmission line pair since line coupling must be taken into account. Differential impedance alone is not enough either since common-mode rejection and propagation must be accounted for. The solution comes from a relatively simple mathematical analysis of the differential pair, which also can be viewed as a symmetric coupled transmission line pair. The model shown in ***Figure 4***[5] is an accurate representation of a coupled transmission line pair based on its even- and odd-mode impedances.

It is a simple exercise in circuit analysis to demonstrate that this transmission line configuration will present twice the odd-mode impedance to a differential signal and two separate even-mode impedances to a common-mode signal. Since any signal can be decomposed in its differential- and common-mode components, this model will predict propagation of any combination of differential- and common-mode signals, accurately representing the behavior of the differential transmission line pair. Note that, for practical purposes, it may be preferable to avoid using a transmission line with a negative impedance; however, the line with negative impedance can be easily substituted with a positive impedance line and a dependent voltage source.

One disadvantage of this four-line model is its relative complexity. In addition, this model is difficult to extend to a case of more than two coupled lines. However, if the common-mode impedance is significantly larger than the differential-mode impedance, the common-mode signal will be mostly rejected, and mainly the differential signal will be observed at the receiver end. The high common-mode rejection will make the difference in differential- and common-mode signal delay irrelevant due to the small amplitude of the common-mode signal, and will allow the use of a simplified model, shown in ***Figure 5***. Here,

$$Z_{mutual} = \frac{2 Z_{odd} Z_{even}}{Z_{even} - Z_{off}} \qquad (9)$$

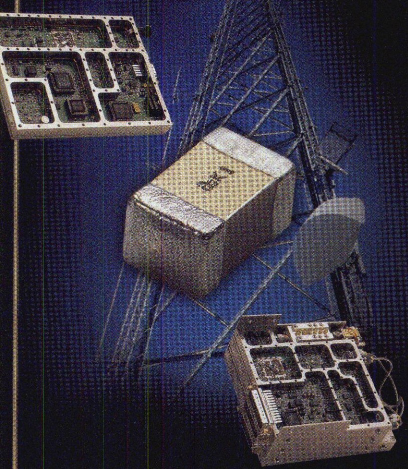
Again, under assumption of $t_{odd} = t_{even}$, it can be easily shown that this model will accurately represent both differential- and common-mode signal propagation through the differential pair. This article focuses on the measurement-based approach to extracting the even and odd imped-

[Continued on page 76]

6OOS **ULTRA-LOW ESR**

EIA Microwave Capacitors

new from ATC



- Lowest ESR in class – typically 80 mΩ @ 1 GHz
- Highest Working Voltage For 0603 NPO
- Broadest Value Range
- Low Cost, with the superior performance and reliability you expect from ATC

Introducing ATC's 600S Ultra-Low ESR Capacitors, designed around RF and Microwave Applications to support requirements where low loss and high performance are paramount. For use in:

- cellular base station equipment
- high Q Frequency sources
- broadband wireless services
- satcom
- Point-to-Point / Point-to-multiPoint Radio

to learn more
Click here
www.atceramics.com

Specifications

ATC Series	600 S
Case Size:	0603
Cap. Range:	Up to 100 pF
WVDC:	250 V
ESR @ 1 GHz:	80 mΩ typ.
Dielectric:	NPO
Marking:	EIA Code
Packaging:	Tape & Reel Plus Options
Options:	Special Testing & Packaging

American Technical Ceramics

FOR ATC'S EUROPEAN SALES OFFICES, SEE OUR WEBSITE

ISO 9002 REGISTERED COMPANY

The Engineer's Choice™

PHONE: 516-622-4700 • FAX: 516-622-4748 • E-MAIL: SALES@ATCERAMICS.COM

CIRCLE 10 ON READER SERVICE CARD

ances for the distributed differential line models presented previously.

OBTAINING A DIFFERENTIAL LINE MODEL FROM MEASUREMENTS

The modeling of a differential line from measurements is shown in ***Figure 6***. The choice of instrumentation for performing this measurement-based modeling work is limited to frequency domain instruments such as vector network analyzers (VNA) or impedance analyzers and time domain instruments such as the TDR.

For designers with significant microwave background, the frequency domain is quite often a more understood and more intuitive domain to work with. However, a problem arises from the fact that differential network analyzer measurements, or four-port measurements, require a multiport network analyzer system. It is only recently that such a system has become available from major measurement equipment manufacturers. A two-port VNA measurement system can be used to obtain four-port network parameters, but this approach requires a large number of measurements[6] and is not easy to complete or simple to analyze.

On the other hand, four and more ports in the TDR instruments have been readily available for quite some time. A TDR may or may not support a comprehensive frequency domain calibration procedure available in most VNA systems, but for purposes of extracting the even and odd impedances and delays the accuracy of the measurement is more than sufficient. Moreover, the propagation delay is more easily obtained in the time domain due to the visual nature of this domain.

TDR MEASUREMENT BASICS

In the simple TDR setup shown in ***Figure 7***, the impedance of the board trace can be determined from the waveform measured by a TDR oscilloscope. The measured waveform is the superposition of the incident waveform at the device under test (DUT) and the reflected waveform, with the reflected waveform offset by two electrical lengths of the cable interconnecting the oscilloscope TDR sampling head to the DUT.[7] The multiple reflection effects must be deconvolved to achieve better accuracy in impedance measurements. A TDR measurement setup for differential line characterization is shown in ***Figure 8***.

Differential TDR measurements can come in handy when it is difficult to achieve a good ground plane reference, or when a differential line analysis must be performed. A virtual ground plane, created by two TDR sources of the same shape and different polarity that arrive simultaneously at a DUT interface, helps achieve the desired measurement results.

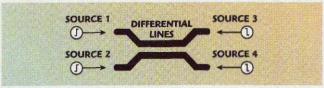
It was mentioned previously that TDR measurement accuracy suffers from multiple reflection effects when multiple discontinuities are involved in the measurement. However, a true impedance profile of the DUT can be obtained through an inverse scattering algorithm reported previously.[8,9] Based on the incident step and TDR response of the system, the multiple reflections can be dynamically deconvolved from the TDR response; because of that process, another name used for this algorithm is dynamic deconvolution.

Even- and odd-mode analysis, based on the even and odd impedance profiles computed from the differential TDR measurements, is an extremely useful tool for characterizing symmetric transmission line systems, such as cables and connectors. The odd impedance profile is obtained from a differential TDR measurement with two TDR sources of opposite polarity; the even impedance profile is obtained through a measurement with two TDR sources of the same polarity. In each case, only a single TDR channel needs to be acquired. A differential reference short is used for computing the impedance profile. The reference short waveform is most easily obtained by disconnecting the DUT and connecting the two signals to ground in close proximity to each other, or connecting them directly to each other and then connecting them to ground. Once the even and odd impedance profiles of the differential pair are obtained, the model can be easily computed.

In addition, the LC matrices can be easily extracted from the even and odd TDR impedance profiles using

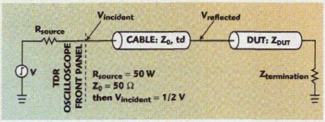
$$
\begin{aligned}
L_{self} &= \frac{1}{2\Delta l}\left(Z_{even}t_{even} + Z_{odd}t_{odd}\right)\\
L_{mutual} &= \frac{1}{2\Delta l}\left(Z_{even}t_{even} - Z_{odd}t_{odd}\right)\\
C_{mutual} &= \frac{1}{2\Delta l}\left(\frac{t_{odd}}{Z_{odd}} - \frac{t_{even}}{Z_{even}}\right)\\
C_{tot} &= \frac{1}{2\Delta l}\left(\frac{t_{odd}}{Z_{odd}} + \frac{t_{even}}{Z_{even}}\right)
\end{aligned}
\tag{10}
$$

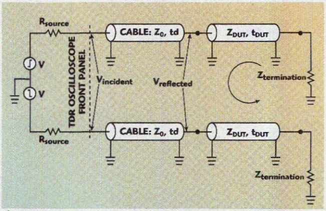
From a practical modeling perspective, the capacitor and inductor values from Equation 10, for example,



▲ *Fig. 6 Differential line modeling from measurements.*

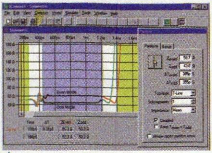
▼ *Fig. 7 A TDR block diagram.*





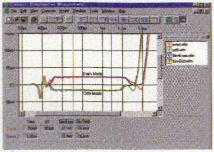
▲ *Fig. 8 TDR measurement setup for differential line characterization.*

[Continued on page 78]



▲ *Fig. 9 Partitioning the impedance profile waveforms in the symmetric coupled line modeling window.*

Fig. 10 Verifying the differential line model. ▼



$L_{self}\Delta l$, may be computed if a lumped model is desired. The above equations also demonstrate that if the mutual capacitance $C_m\Delta l$ is to remain positive, it is necessary that

$$\frac{t_{odd}}{Z_{odd}} - \frac{t_{even}}{Z_{even}} > 0 \qquad (11)$$

A model that does not satisfy this constraint should not be used since it does not represent a physically realizable structure and could produce inaccurate simulations.

A DIFFERENTIAL LINE MODELING EXAMPLE

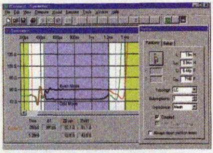
As an example, a differential pair on an FR-4 board was measured and modeled. The lines in this DUT have SMA connectors as an interface to a TDR oscilloscope. The lines are closely coupled. (The spacing to the ground plane on the board was half the gap between the lines.) The impedance profiles for the same differential pair were shown previously.

After the data were acquired from a TDR oscilloscope, they were processed using the Z-line impedance deconvolution algorithm in the IConnect software. As mentioned previously, two waveforms are necessary to compute the impedance profile: the DUT waveform and the reference step waveform. The reference step waveform for a differential measurement can be obtained by connecting the signals on both of the differential TDR channels to each other and then to ground, if possible. When using cables with SMA connectors, the easiest way to achieve this measurement is to connect the cables using an SMA barrel interconnect. Only the waveform on one channel of a TDR instrument needs to be acquired; no additional adding or subtracting of the waveforms in the scope is necessary. The resulting even and odd impedance profiles were shown previously and, based on these impedance profiles, the model for the DUT is easily extracted. Note that without the impedance deconvolution algorithm, the impedance profiles are subject to the multiple reflection effects in TDR oscilloscopes and the impedance readout values may not be correct at each point on the TDR trace.

After the impedance profiles have been computed, the impedance profile waveforms are partitioned in the symmetric coupled line modeling window, as shown in ***Figure 9***. The distributed model is the most appropriate in this case since the electrical length of the lines approaches or exceeds 1 ns. The assumption that the even-mode delay is equal to the odd-mode delay is somewhat difficult to maintain, and the more accurate four-line model is more appropriate. When the model is saved, the equivalent SPICE circuit that describes the model is obtained. A sample listing of such a circuit is given in ***Appendix A***.

To verify the created model, a designer must create a composite model using the IConnect software. The composite model complements the extracted DUT model with the source and termination that emulate the TDR measurement source and termination. Using an integrated interface to a SPICE simulator, the designer can simulate this composite model and, based on the resulting simulation waveforms, verify the accuracy of the DUT model. Both even- and odd-mode stimuli must be used in simulations to ensure that the model accurately predicts both even and odd modes of signal propagation, as shown in ***Figure 10***. (Simulations

[Continued on page 80]



▲ *Fig. 11 The even and odd analysis used to compute LC matrices for the coupled lines.*

with both even- and odd-mode stimuli are performed using an integrated interface to a SPICE simulator and the simulation results are compared to the measured data.) It can be seen that with the exception of the SMA connectors, which are not part of the differential line, the model accurately predicts the signal propagation. In addition, the connectors can be modeled using the IConnect software's lumped circuit modeling capability.

A simplified three-line model also can be used to model the differential transmission lines if the difference between the even- and odd-mode delays can be ignored. In this model, the even-mode delay must be used for the main lines, and the delay for the line responsible for the coupling in the structures must be adjusted to achieve good match between the simulation and the measurement.

Even- and odd-mode analysis also can be utilized for characterization of lumped interconnect structures, even when single-ended signaling schemes are utilized. Structures such as high speed connectors, ball grid array packages and high performance automatic test equipment sockets can be easily modeled using even and odd TDR measurements and Equation 10. Based on the even and odd impedance profiles, the LC matrices for the coupled structure are easily computed, as shown in ***Figure 11***. (Note that for long lines a large number of subsegments must be used to accurately model the line.)

CONCLUSION

A technique for extracting a distributed coupled line model from TDR measurements has been demonstrated. This model can be easily used in any standard time domain simulator (SPICE or IBIS) and can accurately predict the propagation of a digital signal through a differential transmission line pair. As a result, the digital system simulation will predict the system behavior more accurately, resulting in higher performance system designs. ■

References

1. Lee W. Ritchey, "How to Design a Differential Signaling Circuit," *Printed Circuit Design Magazine*, March 1999.
2. F. Romeo and M. Santomauro, "Time Domain Simulation of *n* Coupled Transmission Lines," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 35, No. 2, February 1987.
3. *Differential Ohms Measurement with the 11800-series Oscilloscope*, Tektronix Technical Brief 47W-7520.
4. S. Kaufer and K. Crisafulli, "Terminating Differential Signals on PCBs," *Printed Circuit Design Magazine*, March 1999.
5. A. Tripathi and V.K. Tripathi, "A Configuration-oriented SPICE Model for Multiconductor Transmission Lines in an Inhomogeneous Medium," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 46, No. 12, December 1998.
6. D.E. Bockelman and W.R. Eisenstadt, "Calibration and Verification of the Pure-mode Vector Network Analyzer," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 46, No. 7, July 1998.
7. D.A. Smolyansky and S.D. Corey, "Printed Circuit Board Characterization from TDR Measurements," *Printed Circuit Design Magazine*, May 1999 (also available as an application note (PCBD-0599) from TDA Systems).
8. L.A. Hayden and V.K. Tripathi, "Characterization and Modeling of Multiple Line Interconnections from TDR Measurements," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 42, September 1994, pp. 1737–1743.
9. C.W. Hsue and T.W. Pan, "Reconstruction of Nonuniform Transmission Lines from Time-domain Reflectometry," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 45, No. 1, January 1997, pp. 32–38.

Dima Smolyansky *received an MSEE degree from Oregon State University and an MS degree from Kiev Polytechnic Institute. He has worked as an RF/microwave applications engineer at Cascade Microtech, a characterization engineer at IMS, a signal integrity engineer at Intel and a design engineer at Tektronix' Performance Oscilloscopes Division. Currently, he is a product marketing engineer at TDA Systems. Smolyansky has published a number of papers and taught short courses on interconnect measurements and modeling. He has been an IEEE member since 1992.*

Steven Corey *received his PhD degree from the University of Washington. He has been conducting research on interconnect characterization and modeling since 1993 and has published a number of papers in this area. From 1994 to 1997, Corey worked on applications solutions and performed development work for the Tektronix IPA-510 Interconnect Parametric Analyzer, which used TDR/TDT measurement techniques to extract electrical models of interconnects. Currently, he is responsible for research and development work at TDA Systems. He has been a member of the IEEE since 1996. His research interests include automatic measurement-based model generation.*

APPENDIX A

SAMPLE SPICE CIRCUIT LISTING

```
* Syntax: PSpice
* Name: Automatically Generated
.subckt Symmetric 1 2 3 4 5
****** Partition #1
***** Subsegment #1 *****
   t1   1    5    6    5    Z0=49.7   TD=92.3p
   t2   3    5    7    5    Z0=49.7   TD=92.3p
****** Partition #2
***** Subsegment #1 *****
   t3   6    8    9    10   Z0=43.8   TD=345p
   t4   7    8    11   10   Z0=43.8   TD=345p
   e1   12   8    12   13   2
   e2   14   10   14   15   2
   t5   12   13   14   15   Z0=21.9   TD=345p
   t6   13   5    15   5    Z0=29.9   TD=385p
****** Partition #3
***** Subsegment #1 *****
   t7   9    5    2    5    Z0=44.4   TD=74.7p
   t8   11   5    4    5    Z0=44.4   TD=74.7p
.ends
```

The Correlation between Thermal Resistance and Characteristic Impedance of Microwave Transmission Lines

Power dissipated in the center conductor of a transmission line causes an increase in temperature, which is the determining factor in the power handling capability. Mathematical solutions for the thermal resistance of the center conductor relative to the outer conductor and the electrical solution of the characteristic impedance Z_0 are similar; however dielectric loss is not included and, therefore, makes the similarity invalid. A simple technique is described that includes dielectric loss and preserves similarity, thus achieving an overall correlation between thermal resistance and Z_0. The technique is applied to many important practical transmission line configurations.

The power handling capability of microwave transmission lines is based on the analysis of heat conduction in the cross-sectional region between the inner and outer conductors. The main parameter of interest is the temperature increase T_o of the inner conductor with respect to the outer conductor. Because of the linearity of the heat equation, T_o can be expressed as the superposition of two components:

$$T_o = T_{o(c)} + T_{o(d)}$$

where

$$T_{o(c)} = R_{o(c)}P_c$$
$$T_{o(d)} = R_{o(d)}P_d \qquad (1)$$

$T_{o(c)}$ and $T_{o(d)}$ are the parts of T_o caused by the thermal dissipation in the inner conductor, P_c, and in the dielectric, P_d. $R_{o(c)}$ is the thermal resistance associated with heat flow from the inner conductor through the dielectric region to the external conductor. $R_{o(d)}$ is the thermal resistance associated with heat flow from the dielectric region to the external conductor where the heat is generated in the dielectric region due to dielectric loss tangent.

The distinguishing features of a given microwave transmission line are the cross-sectional shape of the region between the center conductor and the outer conductor and the dielectric material used. The analysis of the electric and thermal fields in the cross-sectional region may be very complex, particularly if the center conductor has a different shape than the outer conductor. Such cases can be more of a scientific investigation into the solution of partial differential equations rather than an attempt at solving the

[Continued on page 85]

Michael Parnes
Ascor
St. Petersburg, Russia

basic problem at hand. There are publications[1] that list standard transmission line configurations along with solutions usually obtained by conformal mapping, but to the author's knowledge there is no apparent general listing in the literature of all types of configurations. The references on heat transfer[2] can supply solutions for additional configurations such as tube in tube, the tube in filled form and the strip in filled form.

Once having obtained a long list of standard solutions, expressions can be developed for Z_0 and $R_{o(c)}$. However, expressions for $R_{o(d)}$ still are not available. As mentioned previously, power dissipated within the dielectric will add to the temperature increase in the transmission line. Accordingly, $R_{o(d)}$ accounts for the temperature increase due to heat generated from within the dielectric and flowing to the external conductor. This component of the power handling capability of transmission lines has only been covered in the literature in one instance — a Russian-language journal.[3] This article uses the results of that reference to relate dielectric loss to Z_0 and applies the results to many transmission line configurations.

For the condition where the external conductor is maintained at constant temperature, it will be shown that the overall correlation between the thermal resistances $R_{o(c)}$ and $R_{o(d)}$ and impedance Z_0 does indeed exist. It is not obvious that $R_{o(d)}$ would be included in this result.

THEORY — BEFORE ADDING DIELECTRIC LOSS

It is known[1] that for the basic TEM mode in the cross-section S of a transmission line filled with dielectric, the electric field is expressed by Laplace's equation:

$$\Delta\phi = 0 \text{ with } \phi\big|_{ib} = \phi_c \text{ and } \phi\big|_{eb} = 0 \tag{2}$$

where

Δ = Laplace's operator

ϕ = instantaneous value of electric potential at any point in the cross-section S and a two-dimensional function over S

The conductors forming the inner and external boundaries of S are assumed to have high conductivity and, therefore, will coincide with the contours of equal potential such as $\phi = \phi_c$ and $\phi = 0$.

Equation 2 assumes charge is located on the inner and outer conductors, and not in the region S. The analogous heat equation is expressed as

$$\Delta T = 0 \text{ with } T\big|_{ib} = T_{o(c)} \text{ and } T\big|_{eb} = 0 \tag{3}$$

Since differential equations (Equations 2 and 3) have the same form, it follows that ϕ and T are similar,

$$\frac{T}{\phi} = \frac{T_{o(c)}}{\phi_c}$$

and congruent,

$$\oint_C \frac{(\operatorname{grad} T, \vec{n})dl}{T_{o(c)}} = \oint_C \frac{(\operatorname{grad} \phi, \vec{n})dl}{\phi_c} \tag{4}$$

where

C = any contour enclosing the inner conductor

$\vec{n}$ = unit vector, normal to the contour, outward from the enclosing surface
dl = elemental length of the contour

Another way to view Equation 4 is that the two types of solutions, ϕ and T, normalized to the boundary condition on the center conductor are equal.

Gauss' Law provides for the last step toward the solution of the transmission line parameters. Keeping in mind such relations as

$$\varepsilon\oint \vec{E}\bullet d\vec{S} = q = C\phi_c,$$

$$\vec{E} = -\nabla\phi,\ Z_0 = \sqrt{\frac{L}{C}}\ \text{and}\ v = \frac{1}{LC},$$

the relationship between the electrical and thermal solutions becomes

$$\oint_C \left(\operatorname{grad}\phi, \vec{n}\right)dl = -\frac{C_1\phi_c}{\varepsilon_0\varepsilon_1} \qquad (5)$$

and the thermal equivalent of Gauss' Law becomes

$$\lambda_d\oint_C \left(\operatorname{grad}T, \vec{n}\right)dl = -r_1\overline{I^2} \qquad (6)$$

where

λ_d = thermal conductivity
r_1 = resistance of the center conductor
I = current carried by the center conductor

$$C_1 = \frac{1}{Z_0 v} = \frac{\sqrt{\varepsilon_0\varepsilon_1\mu_0\mu_1}}{Z_0}$$

is the capacitance per unit length of the transmission line.[1] Because of Equation 4,

$$\oint_C \frac{\left(\operatorname{grad}\phi, \vec{n}\right)dl}{\phi_c} = -\frac{C_1}{\varepsilon_0\varepsilon_1}$$

$$= -\frac{r_1}{\lambda_d T_{o(c)}}\overline{I^2} \qquad (7)$$

and

$$T_{o(c)} = \frac{\varepsilon_0\varepsilon_1 r_1}{C_1\lambda_d}\overline{I^2}$$

$$= \frac{Z_0\sqrt{\varepsilon_1}}{Z\lambda_d}P_c \qquad (8)$$

The result of Equation 8 relates temperature increase $T_{o(c)}$ to the transmission line properties such as Z_0 and $Z = \sqrt{\mu_0/\varepsilon_0}$ according to Equation 1.

THEORY — ADDING DIELECTRIC LOSS

Heat dissipation within S due to the dielectric loss tangent makes Equation 3 nonhomogeneous. The similarity between ϕ and T, which was relied on in the previous section, breaks down unless homogeneity can be restored. With the inclusion of heat generated in the dielectric region, Poisson's equation is

$$\Delta T = -\frac{q(S)}{\lambda_d} \qquad (9)$$

where

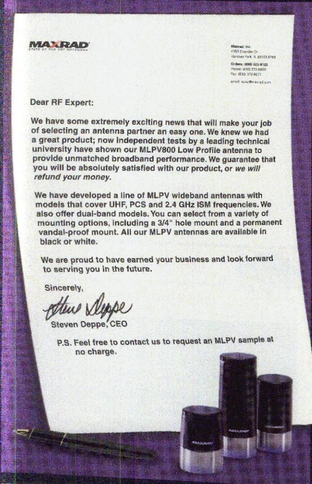
$q(S) = \dfrac{\omega\varepsilon_0\varepsilon_2|E|^2}{2}$ (the energy density of dielectric heat loss for one unit length of transmission line in the area S)
λ_d = thermal conductivity of the dielectric

[Continued on page 88]

YOU CHALLENGED US.

WE DELIVERED. MAXRAD LOW PROFILE.

TESTS SHOW MLPV800 PROVIDES UNMATCHED BANDWIDTH PERFORMANCE.



MAXRAD
STATE OF THE ART ANTENNAS

Maxrad, Inc.

Orders: (800) 323-9122

Dear RF Expert:

We have some extremely exciting news that will make your job of selecting an antenna partner an easy one. We knew we had a great product; now independent tests by a leading technical university have shown our MLPV800 Low Profile antenna to provide unmatched broadband performance. We guarantee that you will be absolutely satisfied with our product, or *we will refund your money.*

We have developed a line of MLPV wideband antennas with models that cover UHF, PCS and 2.4 GHz ISM frequencies. We also offer dual-band models. You can select from a variety of mounting options, including a 3/4" hole mount and a permanent vandal-proof mount. All our MLPV antennas are available in black or white.

We are proud to have earned your business and look forward to serving you in the future.

Sincerely,

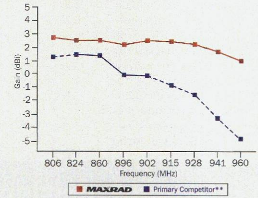
Steve Deppe

Steven Deppe, CEO

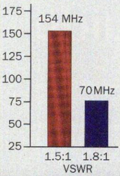
P.S. Feel free to contact us to request an MLPV sample at no charge.

The comparison test results from a leading technical university are clear: MLPV800 provides unmatched industry gain flatness versus frequency over the entire 800 and 900 MHz bands

GAIN COMPARISON OF MLPV800 VS. OUR PRIMARY COMPETITOR†



BANDWIDTH*



MLPV800 ANTENNA SPECS:

- Antenna height: 2.32" H
- Maximum power: 150 watts
- Nominal Impedance: 50 ohms
- VSWR: < 1.5:1

† Measured on a 12-inch square ground plane

* Based on manufacturer's published specs

** MLPV800 is a wideband antenna. The dotted line for our primary competitor's curve shows the performance of their antenna outside its specified frequency range. Our primary competitor requires different antenna models to cover all 800 and 900 MHz frequencies.

OTHER IMPRESSIVE FEATURES:

- Efficient radiator design made of solid brass. No lossy circuit boards utilized.
- 3/4" hole mount for easy installation. Permanent vandal-proof mount also available.
- UHF, PCS and 2.4 GHz ISM wideband models available.
- Dual-band models available.
- All models also available in white.

MAXRAD PERFORMANCE GUARANTEED

MAXRAD®
STATE OF THE ART ANTENNAS

CALL (800)323-9122

www.maxrad.com

ω = angular frequency
ε_0 = dielectric permittivity of free space
ε_2 = imaginary part of the dielectric constant (equivalent of loss tangent)
E = E(S) (the electric field in the area S)

E follows the definition

$$E = -\text{grad}\,\phi \qquad (10)$$

The thickness δ_{ic} and thermal conductivity λ_{ic} of the inner conductor are assumed to be low and high, respectively, so that the temperature across the inner conductor is constant and equal to the temperature increase T_o. It is also assumed that the cooling of the external conductor and δ_{ec} and λ_{ec} are such that the region of the external conductor is at a constant temperature as well. (It is evidently the case that only unusual values of δ_{ec} and λ_{ec} could not warrant the constancy of temperature on the entire area of the external conductor. The microstripline with one-way cooling[4] could be an example.) When the region of the external conductor is at a constant temperature, the boundary conditions can be expressed as

$$T|_{ib} = T_o \text{ and } T|_{eb} = 0 \qquad (11)$$

Following Yurov[3] and starting with what is generally known as Green's first identity,

$$\text{div}(\phi\ \text{grad}\ \phi) = \phi\Delta\phi + |\text{grad}\ \phi|^2 \qquad (12)$$

as well as taking into account Equations 2, 10 and 12, the expression for q(S) becomes

$$\begin{aligned} q(S) &= \frac{\omega\varepsilon_0\varepsilon_2 |\text{grad}\,\phi|^2}{2} \\ &= \frac{\omega\varepsilon_0\varepsilon_2}{2}\text{div}(\phi\,\text{grad}\,\phi) \\ &= \frac{\omega\varepsilon_0\varepsilon_2}{2}\text{div}\left(\frac{\text{grad}\,\phi^2}{2}\right) \\ &= \frac{\omega\varepsilon_0\varepsilon_2}{4}\Delta\phi^2 \\ &= \Delta\left(\frac{1}{4}\omega\varepsilon_0\varepsilon_2\phi^2\right) \qquad (13) \end{aligned}$$

Equation 9 now can be rewritten in homogeneous form as

$$\Delta\Phi = 0 \text{ with } \Phi|_{ic} = T_o \text{ and } \Phi|_{ec} = 0 \qquad (14)$$

where

$$\Phi = T + \frac{\omega\varepsilon_0\varepsilon_2}{4\lambda_d}\phi^2$$

(the electrothermal potential)[3]

The solution Φ is the superposition of the solution for conductor loss only, T, and the solution for dielectric loss only. The two solutions each have an associated boundary condition, the sum of which provides the overall boundary condition $T_o = T_{o(c)} + T_{o(d)}$, which now can be written as

$$T_o = \frac{Z_0\sqrt{\varepsilon_1}}{Z\lambda_d}P_c + \frac{\omega\varepsilon_0\varepsilon_2\phi_{ic}^2}{4\lambda_d} \qquad (15)$$

To solve for the power dissipation in the dielectric (analogous to P_c for the inner conductor), q(S) is integrated in area S. Use is made of the two-dimensional form of the divergence

[Continued on page 90]

Contactless Phase Shifters:

World-First 'Contactless' Brings Better Reliability under All Conditions

Designed by KMW for low insertion loss and good stability under hard environmental conditions, these Contactless Phase Shifter (:CPS) will provide the linear characteristic of phase and low IMD performance

KPH90OSCL000

KPH90OSCL001

Standard Connectorized CPS

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*0.457 B type : 1.225*1.102*0.457		

KPH30OSCL000

KPH35OSCL000

Miniature CPS

Product Code No.	Drop-In type (KPH30OSCL000)			Connectorized type (KPH35OSCL000)		
Frequency Range	~ 1GHz	1 ~ 2GHz	2 ~ 2.5GHz	~ 1GHz	1 ~ 2GHz	2 ~ 3GHz
Insertion Loss (Max.)	0.15dB	0.25dB	0.35dB	0.15dB	0.25dB	0.35dB
VSWR (Max.)	1.3:1	1.3:1	1.3:1	1.25:1	1.25:1	1.25:1
Incremental Phase Shift	30 degree min. @ 2GHz			35 degree min. @ 2GHz		
Electrical Delay	41.7 psec min.			48.6 psec min.		
Nominal Impedance	50 ohm			50 ohm		
I/O Port Connector	Drop-In			SMA(F) / SMA(F)		
Average Power Handling	30W @ 2GHz			30W @ 2GHz		
Temperature Range	-30˚C ~ +60˚C			-30˚C ~ +60˚C		
Dimension (inch)	0.709*0.433*0.244			0.630*0.551*0.244		

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

theorem and, by introducing a cut, the two adjacent sides on which the closed integral cancels. In addition, $\phi_{ec} = 0$.

$$\begin{aligned} P_d &= \int q(S)dS \\ &= \frac{\omega\varepsilon_2\varepsilon_0}{2}\int \operatorname{div}(\phi \operatorname{grad}\phi)dS \\ &= \oint_I (\phi \operatorname{grad}\phi, \vec{n})dl \\ &+ \oint_O (\phi \operatorname{grad}\phi, \vec{n})dl \\ &= \phi_{ic}\oint_I (\operatorname{grad}\phi, \vec{n})dl \\ &+ \phi_{ec}\oint_O (\operatorname{grad}\phi, \vec{n})dl \\ &= \frac{\omega\varepsilon_2\varepsilon_0}{2}\phi_{ic}(\operatorname{grad}\phi, \vec{n})dl \end{aligned}$$

Taking Equation 5 into consideration and noting that the outward normal on C is opposite to that on I,

$$P_d = \frac{\omega\varepsilon_2\varepsilon_0 C_1}{2\varepsilon_1\varepsilon_0}\phi_{ic}^2 \qquad (16)$$

Inserting the expression for C_1, the main result becomes

$$T_o = \frac{Z_0\sqrt{\varepsilon_1}}{Z\lambda_d}P_c + \frac{1}{2}\frac{Z_0\sqrt{\varepsilon_1}}{Z\lambda_d}P_d \qquad (17)$$

For most transmission lines $\mu_1 = 1$, and so

$$\begin{aligned} Z &= \sqrt{\frac{\mu_0}{\varepsilon_0}} \\ &= 120\pi\,\Omega \qquad (18) \end{aligned}$$

Comparing Equations 17 and 1,

$$R_{o(c)} = MZ_0 \qquad (19)$$

$$R_{o(d)} = \frac{1}{2}R_{o(c)} \qquad (20)$$

where

$$M = \frac{\sqrt{\varepsilon_1}}{120\pi\lambda_d}$$

(the scale factor depending on the physical parameters of dielectric, but not on the form and size of the feeder line)

It should be stressed that the simple and exact correlations achieved between Equations 19 and 20 are correct for every transmission line only when the inner and external conductors are the equal potential and isothermal surfaces, and the potential and temperature boundary conditions are alike.

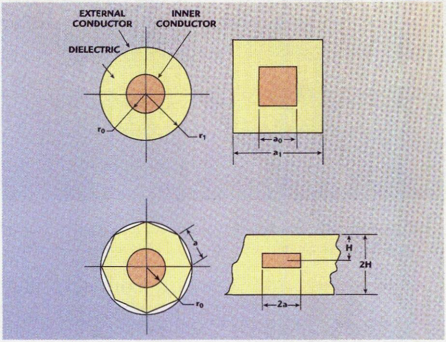


Fig. 1 The crosscut of some transmission lines.

Figure 1 shows some cases of using the correlation found in Equation 19 that will be reviewed. The first case is a coaxial line with conductors of round cross section with radii r_1 and r_0 ($r_1 > r_0$). An exact expression for this case is[1]

$$Z_0\sqrt{\varepsilon_1} = \frac{Z}{2\pi}\ln\frac{r_1}{r_0}$$

Thus, in compliance with Equation 19,

$$\begin{aligned} R_{o(c)} &= \frac{Z_0\sqrt{\varepsilon_1}}{Z\lambda_d} \\ &= \frac{1}{2\pi\lambda_d}\ln\frac{r_1}{r_0} \end{aligned}$$

which is in agreement with the famous expression for the thermal impedance.[2]

The coaxial line with the conductors of square section having the sizes of the arm of the square $a_1 > a_0$ is the next case. The exact expression for $Z_0\sqrt{\varepsilon_1}$ obtained using the conformal transformation is[1]

$$Z_0\sqrt{\varepsilon_1} = \frac{1}{4}\frac{K(k)}{K'(k)}$$

where

$K(k)$ = full elliptic integral of the first type

The value K/K' is identified in the literature.[1] For the situation in question, Wong[2] recommends the expression

$$R_{o(c)} = \frac{0.9252}{2\pi\lambda_d}\left(\ln\frac{a_1}{a_0} - 0.054\right), \quad \frac{a_1}{a_0} > 1.7$$

The departure of the calculation results produced by the formula for $R_{o(c)}$ from the exact result is $\delta = -3.3$ to -6.6%. When $a_1/a_0 \to 1$, this formula becomes meaningless.

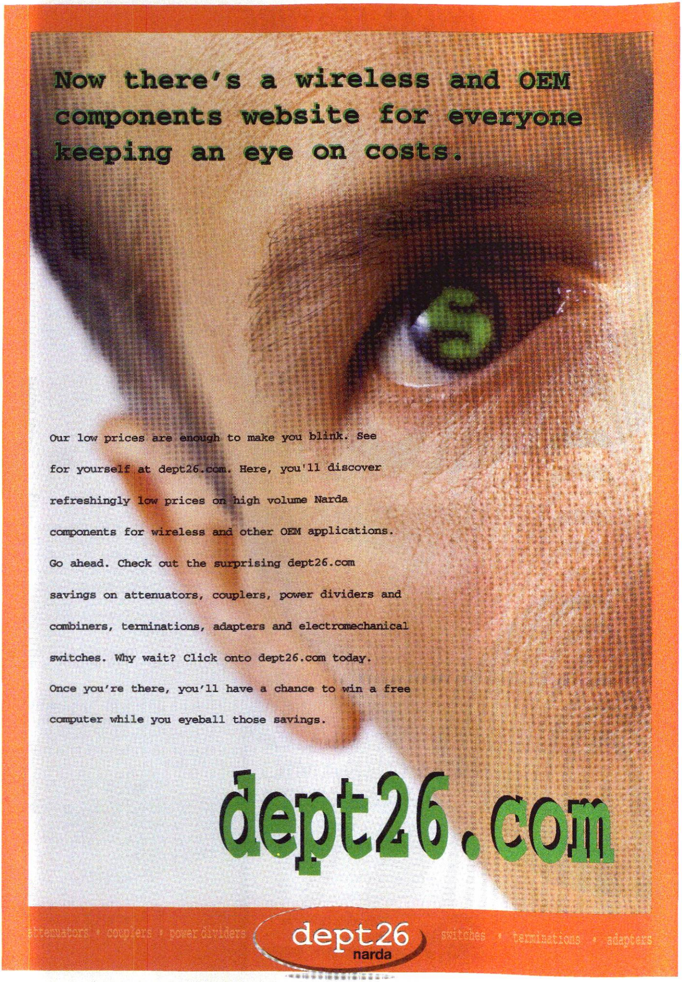
The main round conductor of the r_0 radius coaxial with the external conductor, made as a regular polygon (n-number of arms) with each arm equal to a, is the third case. For this situation an approximate formula that exists in the literature[2] is

$$R_{o(c)} = \frac{1}{2\pi\lambda_d}\ln\left[(0.18n - 0.19)\frac{a}{r_0}\right]$$

(The accuracy is not taken into account.) Multiplying the above equation by $Z\lambda_d$ yields the expression for the $Z_0\sqrt{\varepsilon_1}$.

$$Z_0\left(\frac{a}{r_0}\right)\sqrt{\varepsilon_1}$$

[Continued on page 92]


Now there's a wireless and OEM components website for everyone keeping an eye on costs.
Our low prices are enough to make you blink. See for yourself at dept26.com. Here, you'll discover refreshingly low prices on high volume Narda components for wireless and other OEM applications. Go ahead. Check out the surprising dept26.com savings on attenuators, couplers, power dividers and combiners, terminations, adapters and electromechanical switches. Why wait? Click onto dept26.com today. Once you're there, you'll have a chance to win a free computer while you eyeball those savings.
dept26.com
attenuators • couplers • power dividers
dept26
narda
switches • terminations • adapters

exists in the literature[1] only for n = 3, 4, 5 and 6 and there is no equation for design.

The symmetrical stripline with the strip of zero thickness is the final case. The distance between the ground planes is 2H and the width of the strip is 2a. In the literature[1] there is an exact expression for $Z_0\sqrt{\varepsilon_1}$, which can be transformed using the equation for $Z\lambda_d$ after dividing by $R_{o(c)}$ such that

$$R_{o(c)} = \frac{1}{4\lambda_d}\frac{K(k)}{K'(k)}$$

In addition, approximation formulas exist that deviate from the exact solution by no more than 0.5 percent. For this case and a great number of others that do not fit the examples of the crosscut for which there are exact data,[1] there is no such information available in the literature.[2] Therefore, the way it was shown in the examples (using the correlation of Equation 19 and equations or tabs that are well known in microwave engineering for calculating Z_0) helps to provide at least one of the following results: to determine the unknown correlation for calculating $R_{o(c)}$, to expand the scope of parameters in which the value $R_{o(c)}$ can be calculated, to provide an approximate gauge for estimating the accuracy of the approximation models for calculating $R_{o(c)}$ and to establish the expression for $R_{o(c)}$ in a new form.

On the other hand, the correlation of Equation 19 could be used for establishing a new expression or elaborating on the approximation expression for Z_0 based on the solutions for $R_{o(c)}$ (see example 3). It should be stressed that in case the exact calculations for Z_0 and $R_{o(c)}$ agree precisely with the coefficient $Z\lambda_d/\sqrt{\varepsilon_1}$, the approximate solution for Z_0 and $R_{o(c)}$ in the same systems in microwave engineering and thermophysics traditionally can exist in different forms and methodologies. Thus, for cases 2 and 4 the approximate expressions for Z_0 have been obtained from the exact calculations using the approximation of the elliptic functions in Gunston;[1] however, in Shiffer[4] it was obtained using the exact solution of the equation of the thermal conductivity for the thermal equivalent's approximate model.

The thermal equivalent comprises simple physics principles and the equation for it is easily determined in comparison with virgin systems of bodies, especially when there are multiple systems having a simple form and the error of the solution happens to be acceptable for practice (and can be estimated beforehand). In this way, using the correlation of Equation 19 when deciding the problems connected with microwave engineering and thermophysics can enrich these fields.

Consider one more method of expressing T_o that is comfortable for practical calculations. From Equation 17,

$$T_o = \frac{Z_0\sqrt{\varepsilon_1}}{Z\lambda_d}\left(P_c + \frac{1}{2}P_d\right) = Z_0 M\left(P_c + \frac{1}{2}P_d\right) \qquad (21)$$

or

$$T_o = Z_0 M(2\alpha_{ic} + \alpha_d)P \qquad (22)$$

α_{ic} and α_d are the decrements caused by the losses in the inner conductor and volumetric losses in the dielectric area (Neper/m), and P is the average power in the cut area of the strip in question. Decrements α_{ic} and α_d were used in Equation 22 referring to their definition:

$$\alpha_{ic} = \frac{P_c}{2P},\quad \alpha_d = \frac{P_d}{2P}$$

Using Equation 22, T_o is calculated for the line with unknown factor α_d by taking into account theoretical and experimental data for total loss α_Σ such that

$$\alpha_\Sigma = \alpha_c + \alpha_d \qquad (23)$$

To determine T_o, Equation 22 is transformed keeping in mind that all transmission lines with the basic TEM-mode yield

$$\alpha_d = \frac{\omega\varepsilon_0\varepsilon_2}{2}Z = \frac{\pi\sqrt{\varepsilon_1}\,t_g\delta}{\lambda} \qquad (24)$$

[Continued on page 94]

TABLE I

POWER HANDLING CAPABILITIES OF TRANSMISSION LINES

Cross Section	Type	Cross Section	Type	Cross Section	Type
	High Q Triplate		Unshielded Slab Line		Shielded Slab Line
	Eccentric Coaxial Line		Square Coaxial Line		Coaxial Strip Line
	Coaxial Stripline		Triplate Line with Rounded Off Strip		
	Rectangular Coaxial Line		Triplate Stripline		Hexagon Coaxial Line

λ is the length of the wave and $t_g\delta$ is the dielectric loss tangent of the material, filling the line

$$T_o = Z_0 I\left(2\alpha_\Sigma - \frac{\omega\varepsilon_0\varepsilon_2 Z}{2}\right)P$$

or

$$T_o = Z_0 M\left(2\alpha_\Sigma - \frac{\pi\sqrt{\varepsilon_1}\,t_g\delta}{\lambda}\right)P \tag{25}$$

Two more cases will be examined using the results received.

Case 5 involves the central circular conductor of the r_0 radius coaxial with the external conductor that is made in the configuration of the regular heptagon with the arm a. The approximate formula for $R_{o(c)}$ is written as[2]

$$R_{o(c)} = \frac{Z}{2\pi\lambda_d}\ln\left(1.07\frac{a}{r_0}\right)$$

Making use of the correlations of Equations 19 and 20 yields

$$Z_0 = \frac{Z}{2\pi\sqrt{\varepsilon_1}}\ln\left(1.07\frac{a}{r_0}\right)$$

$$R_{o(d)} = \frac{1}{4\pi\lambda_d}\ln\left(1.07\frac{a}{r_0}\right)$$

Thus, the value of maximum overheat with the help of Equation 21 yields

$$T_o = \frac{1}{2\pi\lambda_d}\left[\ln\left(1.07\frac{a}{r_0}\right)\right]\left(P_c + \frac{1}{2}P_d\right)$$

When the decrement of the α_Σ line (obtained theoretically or experimentally) is known, the total allowable power P_{max} that the strip can hold out is defined if the top allowable overhead is equal to T_o^{max} (for example, from the thermal condition of dielectric):

$$P_{max} = \frac{2\pi\lambda_d T_o^{max}}{2\alpha_\Sigma - \frac{\pi\sqrt{\varepsilon_1}\,t_g\delta}{\lambda}\ln\left(1.07\frac{a}{r_0}\right)}$$

Case 6 involves a symmetrical stripline with the symmetrical cooling of the ground planes. The exact values of Z_0 and α_c are known for this line as

$$Z_0 = \frac{30\pi K(k)}{\sqrt{\varepsilon_1}\,K(k')}$$

$$\alpha_{ic} = \alpha_s\frac{(C_p + 2C_f)}{2(C_p + C_f)}$$

where

$K(k)$ = full elliptic integral of the first type

The connection k, k', C_p and C_f with the sizes of the line and the expression for α_s are provided by Shiffer.[4] Therefore, the exact expression for T_o using Z_0 and α_c is

$$T_o = \frac{K(k)}{4\lambda_d K(k')}\left(2\alpha_{ic} + \frac{\pi\sqrt{\varepsilon_1}\,t_g\delta}{\lambda}\right)P \tag{26}$$

The correlation of Equation 26 allows the exact calculation of the maximum overheat of the symmetrical stripline.

It should be noted that Shiffer[4] provides only approximate estimates of T_o, which are usually decreased by one and a half to two times because of the approximation of the calculation. ***Table 1*** lists examples of the power handling capabilities of various transmission lines.

CONCLUSION

The connection between thermal resistance and impedance has been reviewed. The scale factors depend only on physical qualities of the dielectric material. With the help of the scale factors using known solutions of the electrodynamical task, all impedances that are necessary for calculation of thermal behavior can be determined. Moreover, if the thermal resistance is known, it is possible to calculate the wave impedance of the microwave transmission line. The exact correlation that is obtained allows the calculation of maximum overheat of the inner conductor T_o compared to the field in the known case. In addition, the wave impedance Z_0 and the losses in the inner conductor P_{ic} and dielectric P_d can be determined along with the decrements α_c in the conductor and α_d in the dielectric and the theoretical or experimental value of the full decrement α_Σ. ■

References

1. M.A.R. Gunston, *Microwave Transmission Line Impedance Data*, Van Nostard Reinhold Company Ltd., New York, 1972.
2. H.Y. Wong, *Handbook of Essential Data on Heat Transfer for Engineers*, New York, 1977.
3. Y.Y. Yurov, "Application on the Field Similarity Theory to Strip-line Heating Calculation," *Izvestiya VUZuv*, Vol. 26, No. 8, 1983, p. 34.
4. P. Shiffer, "How Much CW Power Can Stripline Handle?" *Microstrip Microwaves*, No. 6, 1966.

Michael Parnes *graduated from St. Petersburg Electrotechnical University in 1981 and received his PhD degree in microwave techniques from the same university in 1989. From 1981 to 1990, he worked in the antenna laboratory of the Research Institute as an engineer. In 1990, Parnes set up his own small enterprise and has been designing and producing microwave antennas. His research interests include microstrip antennas, phased arrays for communication and radar. Parnes can be reached via e-mail at michael@parnes.spb.ru.*

IMD Products and Spectral Regrowth in CDMA Power Amplifiers

Many articles are devoted to spectral regrowth in wireless communication systems. The most unpleasant consequences are created by nonlinear effects in RF power amplifiers (PA) at high output power levels due to the nonconstant carrier envelope in many digitally modulated communication formats. This article considers the nonlinear effects' influence on the spectral purity of an entire system utilizing the pseudoreal shapes and pseudorandom data streams of input drive voltages and analyzes the resulting effect on the time and frequency domains using a discrete Fourier transform. However, sometimes it is difficult to predict the behavior of a PA by driving its input with a new signal. In this article, an obviously artificial physic-statistical approach is offered based on a two-tone analysis that predicts the correct values of spectral regrowth imposed by the RF PA nonlinearity at frequency offsets specified in CDMA standards. Measurement data for a wideband CDMA (W-CDMA) format are presented as well.

It is known that the output power of each phone channel of a digitally modulated wireless communication system has a statistical nature. Moreover, most of these systems have an approximately log-normal power distribution.[1] Consider an RF PA driven by a statistical signal with an input power probability distribution function $g(P_{in})$. It would be correct to refer to $g(P_{in})$ as the density of the power probability distribution function, but conventional terminology will be used. The average value of the input power is defined as

$$\bar{P}_{in} = \int_{-\infty}^{\infty} P_{in} g(P_{in}) dP_{in} \qquad (1)$$

where

P_{in} = instantaneous value of the input power

The instantaneous power of the PA is

$$P_{out} = GP_{in} \qquad (2)$$

where

G = power gain

The average value of the output power is

$$\bar{P}_{out} = \int_{-\infty}^{\infty} P_{out} g(P_{out}) dP_{out} \qquad (3)$$

where

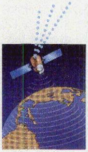
$g(P_{out})$ = probability distribution function for the output power

[Continued on page 98]

Oleksandr Gorbachov
Hexawave Inc.
Hsinchu, Taiwan, ROC

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®

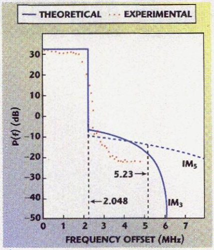
US 102 INT'L 103
CIRCLE READER SERVICE CARD

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

ISO 9001 CERTIFIED

F 232 Rev D



▲ *Fig. 1 The input power spectrum for a power amplifier.*

The input and output powers are connected by functional dependence and thus their probabilities must be equal such that

$$g(P_{in})dP_{in} = g(P_{out})dP_{out} \quad (4)$$

The output power probability distribution function then becomes

$$g(P_{out}) = g(P_{in})\left|\frac{dP_{in}}{dP_{out}}\right| \quad (5)$$

The modulus sign is chosen so that the probability value cannot be negative. Taking into account the log-normal character of the power probability distribution function, it is more convenient for further investigation to consider the power values in milliwatt units (mW). Thus,

$$g(P[dBm])dP[dBm] = g(P[mW])dP[mW] \quad (6)$$

$$g(P[mW]) = g(P[dBm])\left|\frac{dP[dBm]}{dP[mW]}\right| \quad (7)$$

$$P[dBm] = 10\log P[mW] \quad (8)$$

$$\frac{dP[dBm]}{dP[mW]} = 10\frac{1}{\ln 10 \bullet P[mW]} = \frac{4.342945}{P[mW]} \quad (9)$$

$$g(P[mW]) = \frac{4.342945}{P[mW]} g(P[dBm]) \quad (10)$$

For the average input power

$$P_{in}[mW] = \int_0^\infty P_{in}[mW] g(P_{in}[mW]) dP_{in}[mW] = 4.342945\int_0^\infty g(P_{in}[dBm]) dP_{in}[mW] \quad (11)$$

The average output power is

$$P_{out}[mW] = \int_0^\infty P_{out}[mW] g(P_{out}[mW]) dP_{out}[mW] = \int_0^\infty P_{out}[mW] g(P_{in}[mW]) dP_{in}[mW]$$
$$= 4.342945\int_0^\infty \frac{P_{out}[mW]}{P_{in}[mW]} \bullet g(P_{in}[dBm]) dP_{in}[mW]$$
$$= 4.342945\int_0^\infty G(P_{in}[mW]) \bullet g(P_{in}[dBm]) dP_{in}[mW]$$
$$= 4.342945\int_0^\infty G_a(P_{in}) dP_{in}[mW] \quad (12)$$

The function $G_a = G(P_{in})g(P_{in})$ is an auxiliary gain function, meaning that the integral from this function is proportional to the average output power of a PA. The function G_a is convenient for the graphical consideration of Equation 12 and directly represents the contribution of the input signal statistics and gain characteristics of a PA at each drive level to the average output power. The square described by the curve $G_a(P_{in})$ and P_{in}-axis is equal to the average output power with an accuracy coefficient of 4.342945. In a common case the gain function $G_a(P_{in})$ of a PA is the multitone gain for digitally modulated signals. Knowing $g(P_{in}[dBm])$, the average values of the PA input and output powers can be calculated using Equations 11 and 12 for different modulated formats.

Consider the case when the PA is driven by the statistical signal with an ideal rectangular flat shape of the average power spectrum that is a close approximation for CDMA signals. ***Figure 1*** shows one-half of the rec-

[Continued on page 100]

tangular flat spectrum in relative coordinates for a W-CDMA system at a 4.096 MHz chip rate. It is assumed that all of the signal's useful information is restricted to ±2.048 MHz from the carrier frequency and the entire input power is placed inside these margins in the frequency domain. The power spectrum is solid due to the nonperiodic PA drive. Taking into account the physical entity of the statistical signal average power spectrum, the signal can be represented in the frequency domain in a statistical manner with a flat probability distribution function within a margin of $\Delta f = 4.096$ MHz. This representation implies that each average power spectral component inside the flat shape comprises an instantaneous input signal at the same frequency with the additional probability of a signal's appearance at that frequency. Therefore, the probability of the appearance of the input signal spectral component inside the limits df_1 is expressed as

$$g(P_{in})\frac{1}{\Delta f}df_1dP_{in} = g(P_{out})\frac{1}{\Delta f}df_1dP_{out} \quad (13)$$

At the same time the spectral component inside the limits df_2 exists with the probability

$$g(P_{in})\frac{1}{\Delta f}df_2dP_{in} = g(P_{out})\frac{1}{\Delta f}df_2dP_{out} \quad (14)$$

The spectral components at df_1 and df_2 are assumed to be not correlated. This assumption is reasonably correct for the flat spectrum shape and the multichannel signal. These simultaneous spectral components cause instantaneous intermodulation distortions (IMD) of the PA output signal at frequency offsets determined by the difference between df_1 and df_2. In this case the probability of the appearance of the IMD products at different frequency offsets may be represented as

$$g(IMD)\frac{1}{\Delta f}\bullet\frac{1}{\Delta f}df_1df_2dIMD = g(IMD)\left(\frac{1}{\Delta f}\right)^2 df_1df_2dIMD \quad (15)$$

[Continued on page 102]

When you need Clarity and Power

Stanford Microdevices is the clear choice.

When clarity and power matter most, Stanford Microdevices delivers.

Stanford Microdevices, Inc. (SMI) is a leading supplier of RF integrated circuits for the wireless and wired telecommunications markets and a supplier of choice of OEMs worldwide. Stanford Microdevices continues to be on the industry's leading edge because of our superior quality, outstanding value and innovative technological advances. SMI provides the tools to create wireless communications equipment that is smaller, lighter, more powerful at market leading prices.

Our SGA 6000 series of silicon germanium MMIC amplifiers offers the high intercept point, high efficiency and high integration level at high output power desired, while providing the low noise figure and low power consumption needed for all wireless applications.

SGA-6386 has 1dB compressed output power of +20dBm, output third-order intercept point of +36dBm and 15.5dB of gain at 900MHz. Pricing on the SGA-6386 is $1.21 in quantities of 10,000 pieces with availability from stock to eight weeks.

www.stanfordmicro.com

Make us your home page!

SPECIFICATION MATRIX

	SGA-6286 SGA-6289	SGA-6386 SGA-6389	SGA-6486 SGA-6489
Frequency (GHz)	DC-3.5	DC -3.0	DC-1.8
Gain (dB)	13.8	15.4	19.7
TOIP (dBm)	34.0	36.0	34.0
P1dB (dBm)	20.0	20.0	20.0
N.F. (dB)	3.9	3.8	2.9
Supply Voltage (Vdc)	4.2	5.0	5.2
Supply Current (mA)	75	80	75

All data measured at 1GHz and is typical. MTTF @ 150C T_j = 1 million hrs. (R_{TH} = 97C/W typ)

SiGe HBT MMIC features include:

SOT-89 package

- Cascadable 50Ω
- Single voltage supply
- High output intercept
- +20dBm 1dB Compression Point
- Low current draw
- Low noise figure

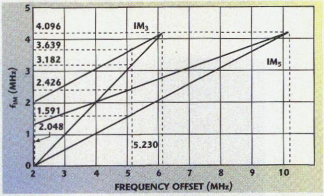
86 package

Stanford Microdevices

We Deliver RF Innovation

1-800-764-6642 *U.S. Toll-Free*

1-408-616-5400 *Outside U.S.*



▲ *Fig. 2 IMD frequency offset vs. power spectrum frequency offset.*

where

g(IMD)= probability distribution function for IMD products imposed by the instantaneous input signal

Assuming that the main contributions to IMD products are produced by frequency components with equal power levels (thus, for the average value of IMD products at different frequency offsets),

$$\mathrm{IMD} = \int_{-\infty}^{\infty} \int_{\Delta f_1}^{\Delta f_2} \int_{\Delta f_1}^{\Delta f_2} \mathrm{IMD}\,g(\mathrm{IMD}) \left(\frac{1}{\Delta f}\right)^2 df_1 df_2 d\mathrm{IMD} \qquad (16)$$

The frequency spacing within which IMD products are defined is calculated using

$$\text{for IM}_3: \quad \Delta f_1 = f_0 - 2.048[\mathrm{MHz}] \qquad (17)$$

$$\Delta f_2 = \frac{\Delta f_1 + 4.096}{2}[\mathrm{MHz}] \qquad (18)$$

$$\text{for IM}_5: \quad \Delta f_1 = \frac{f_0 - 2.048}{2}[\mathrm{MHz}] \qquad (19)$$

$$\Delta f_2 = \frac{f_0 + 2.048}{3}[\mathrm{MHz}] \qquad (20)$$

where

f_0 = offset from the center frequency of the spectrum at which the spectrum regrowth is calculated

These offsets and spacings are shown in ***Figure 2***. It can be observed that for the frequency offset of 5.23 MHz specified for the W-CDMA standard IM_3 is defined at the spacing 3.182 to 3.639 MHz and IM_5 at 1.591 to 2.426 MHz. The difference in spacing is quite small and usually IMD products inside these margins alter less than 0.5 to 1.0 dB for MESFET amplifiers. Thus, for further investigation, the mean values can be used. In this case, Equation 16 can be rewritten as

$$\mathrm{IMD} = \int_{-\infty}^{\infty} \int_{\Delta f_1}^{\Delta f_2} \int_{\Delta f_1}^{\Delta f_2} \mathrm{IMD}\,g(\mathrm{IMD}) \bullet \left(\frac{1}{\Delta f}\right)^2 df_1 df_2 d\mathrm{IMD}$$

$$= \left(\frac{\Delta f_2 - \Delta f_1}{\Delta f}\right)^2 \bullet \int_{-\infty}^{\infty} \mathrm{IMD}\,g(\mathrm{IMD})\,d\mathrm{IMD} \qquad (21)$$

[Continued on page 104]

The function

$$F(\Delta f) = \left(\frac{\Delta f_2 - \Delta f_1}{\Delta f}\right)^2$$

plays the role of a weighting coefficient for the IMD average power value at different offsets and its shape in decibels was shown previously by the solid line for IM_3 and by the dashed line for IM_5. For IM_3 $F(5.23) = -19.05$ dB and for IM_5 $F(5.23) = -13.81$ dB. The spectral components at different offsets f_0 may be represented in the simple additive form including the noise N_0 at the output of the PA such that

$$IMD_\Sigma = IM_3 + IM_5 + \ldots + N_0 \qquad (22)$$

where the individual IM components are calculated by Equation 21. Usually IM_3 is much higher than other IMD components and the value $19.05 - 13.81 = 5.24$ dB is the additional measure of how close IM_3 and IM_5 components are at 5.23 MHz frequency offset measured at the spacing determined by Equations 17 through 20. Excluding the weighting function $F(\Delta f)$,

$$\begin{aligned} IM_3[mW] &= \\ &\int_0^\infty IM_3[mW]\, g(IM_3[mW])\, dIM_3[mW] \\ &= \int_0^\infty IM_3[mW]\, g(P_{in}[mW])\, dP_{in}[mW] \\ &= 4.342945 \int_0^\infty \frac{IM_3[mW]}{P_{in}[mW]} \\ &\quad \bullet g(P_{in}[dBm])\, dP_{in}[mW] \\ &= 4.342945 \int_0^\infty T_3(P_{in}[mW]) \\ &\quad \bullet g(P_{in}[dBm])\, dP_{in}[mW] \\ &= 4.342945 \int_0^\infty T_{a3}\, dP_{in}[mW] \qquad (23) \end{aligned}$$

The function $T_3(P_{in}[mW]) = IM_3/P_{in}$ is the transfer function for IM_3. The function $T_a = T(P_{in})g(P_{in})$ is called an auxiliary transfer function for IMD. The physical meaning of T_a is that the integral from this function is proportional to the IMD product at a given frequency offset f_0. Analogous to the function G_a, T_a is very convenient for the graphical consideration of Equation 23 and directly represents the contribution of the input signal statistics and the IMD transfer characteristics of a PA at each drive level to the spectral regrowth at f_0. Considering curves T_a vs. P_{in}, a circuit may be tuned to decrease IMD products at input power levels that contribute significantly to output power spectrum distortions. A cancellation effect utilization[2] is very attractive for this kind of procedure.

Finally, the power spectral components at different frequency offsets f_0 are calculated as

$$P(f_0) = 10\log\frac{IMD_\Sigma}{P_{out}}[dB] \qquad (24)$$

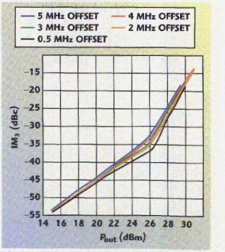
where IMD_Σ is defined by Equation 22 and P_{out} by Equation 12. The phase characteristics consideration is assumed to be eliminated because they are implied in self-evident form by IMD product measurements. No filtering characteristics were considered at the PA output and Equation 24 represents a spectral regrowth inherent only to the PA. The approach considered is valid for the AM-PM conversion inherent only to the nonlinear part of the PA. For this properly designed PA, the contribution of AM-PM conversion to the spectral regrowth is negligible in comparison with AM-AM conversion even for high values of phase variations.[3]

CALCULATION RESULTS

The method proposed has been verified for the model HW3238 three-stage GaAs hybrid PA module[4] destined for W-CDMA system use at 3.4 to 3.5 GHz. The typical dependence of IM_3 products vs. output power at diverse frequency spacing is shown in **Figure 3**. The higher order IMD products are a minimum of 15 dB less than IM_3 up to the saturation region and can be excluded from consideration. From the data it is observed that at the 3.182 to 3.639 MHz spacing IM_3 varies less than 0.5 dB. Even at 5 MHz spacing IM_3 displays an accuracy of less than 1 dB.

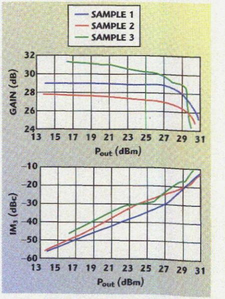
Figure 4 shows two-tone gain and IM_3 characteristics measured at $f_0 = 5$ MHz vs. output power for three sample PA modules. The characteristics differ substantially. Sample 1 has a single-tone $P_{1dB} = 30.9$ dBm and small-signal gain $G_{ss} = 30.8$ dB, sample 2 has $P_{1dB} = 30.9$ dBm and $G_{ss} = 29.7$ dB, and sample 3 has $P_{1dB} = 28.2$ dBm and $G_{ss} = 31.5$ dB. The phase characteristics start to shift at the hard saturating region and are not presented in this article.

For sample 3 an evident cancellation of IM_3 and the sharp slope of the two-tone gain are seen. An analogous effect also is observed for sample 2 but is not as obvious. Characteristics from the data are used for calculations including two-tone gain $G(P_{in})$ in Equation 12. The input power is assumed log-normal and calculations were provided for two normalized rms power values of 2 and 4 dB. The

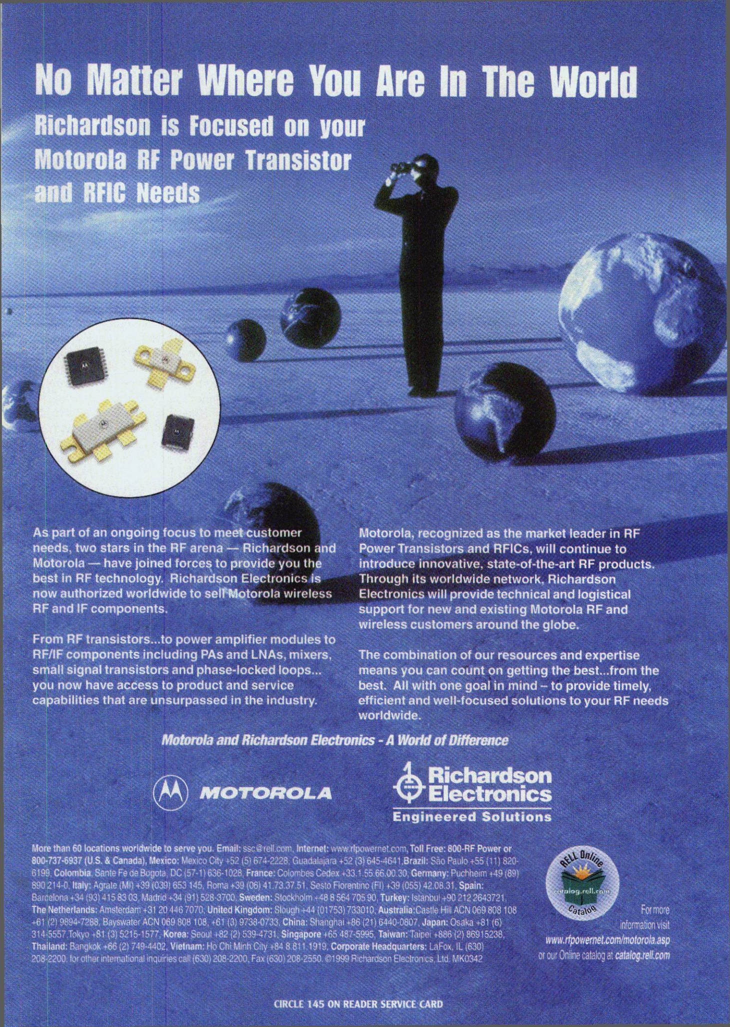


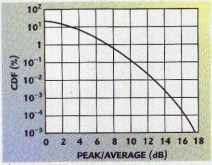
▲ *Fig. 3 Measured IM_3 vs. output power for different frequency offsets.*

Fig. 4 Two-tone gain and IM_3 vs. output power for three different power modules. ▼



[Continued on page 106]


No Matter Where You Are In The World
Richardson is Focused on your Motorola RF Power Transistor and RFIC Needs
As part of an ongoing focus to meet customer needs, two stars in the RF arena — Richardson and Motorola — have joined forces to provide you the best in RF technology. Richardson Electronics is now authorized worldwide to sell Motorola wireless RF and IF components.
From RF transistors...to power amplifier modules to RF/IF components including PAs and LNAs, mixers, small signal transistors and phase-locked loops... you now have access to product and service capabilities that are unsurpassed in the industry.
Motorola, recognized as the market leader in RF Power Transistors and RFICs, will continue to introduce innovative, state-of-the-art RF products. Through its worldwide network, Richardson Electronics will provide technical and logistical support for new and existing Motorola RF and wireless customers around the globe.
The combination of our resources and expertise means you can count on getting the best...from the best. All with one goal in mind – to provide timely, efficient and well-focused solutions to your RF needs worldwide.
Motorola and Richardson Electronics - A World of Difference
MOTOROLA
Richardson Electronics
Engineered Solutions
More than 60 locations worldwide to serve you. Email: ssc@rell.com, Internet: www.rfpowernet.com, Toll Free: 800-RF Power or 800-737-6937 (U.S. & Canada), Mexico: Mexico City +52 (5) 674-2228, Guadalajara +52 (3) 645-4641, Brazil: São Paulo +55 (11) 820-6199, Colombia, Sante Fe de Bogota, DC (57-1) 636-1028, France: Colombes Cedex +33.1.55.66.00.30, Germany: Puchheim +49 (89) 890 214-0, Italy: Agrate (MI) +39 (039) 653 145, Roma +39 (06) 41.73.37.51, Sesto Fiorentino (FI) +39 (055) 42.08.31, Spain: Barcelona +34 (93) 415 83 03, Madrid +34 (91) 528-3700, Sweden: Stockholm +48 8 564 705 90, Turkey: Istanbul +90 212 2643721, The Netherlands: Amsterdam +31 20 446 7070, United Kingdom: Slough +44 (01753) 733010, Australia: Castle Hill ACN 069 808 108 +61 (2) 9894-7288, Bayswater ACN 069 808 108, +61 (3) 9738-0733, China: Shanghai +86 (21) 6440-0807, Japan: Osaka +81 (6) 314-5557, Tokyo +81 (3) 5215-1577, Korea: Seoul +82 (2) 539-4731, Singapore +65 487-5995, Taiwan: Taipei +886 (2) 86915238, Thailand: Bangkok +66 (2) 749-4402, Vietnam: Ho Chi Minh City +84 8.811.1919, Corporate Headquarters: LaFox, IL (630) 208-2200, for other international inquiries call (630) 208-2200, Fax (630) 208-2550. ©1999 Richardson Electronics, Ltd. MK0342
RELL Online
catalog.rell.com
Catalog
For more information visit www.rfpowernet.com/motorola.asp or our Online catalog at catalog.rell.com
CIRCLE 145 ON READER SERVICE CARD



▲ *Fig. 5 Cumulative distribution function (CDF) of the input signal.*

Fig. 6 Calculated output power spectral component values at 5.23 MHz offset. ▼

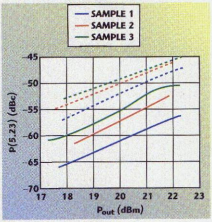
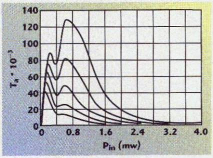
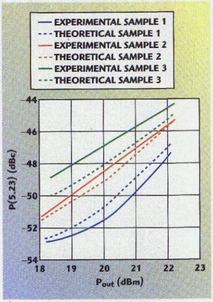


Fig. 7 Auxiliary transfer function T_a for IM_3 of sample 3. ▼

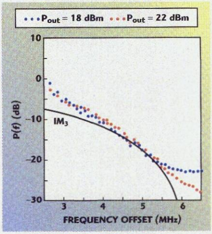


4 dB rms power signal cumulative distribution function is shown in ***Figure 5*** and demonstrates that such a signal is inherent to the multiple-channel CDMA system. The 2 dB rms power signal is less stressful. Calculation results of IM_3 spectral components at a frequency offset of 5.23 MHz are shown in ***Figure 6*** for the three PA samples considered. It can be observed that for the 17 to 23 dBm average output power values P (5.23 MHz) vs. P_{out} can be represented by straight lines with a slope of 2.0 to 2.4 dB per 1 dB output power for an rms power change of 2 dB and a 1.75 to 2.25 dB slope for a 4 dB rms power change. Only for sample 3 and an rms power of 2 dB can a deflection from a straight line be seen due to the perceptible cancellation effect.



▲ *Fig. 8 Spectral component values with real noise level.*

Fig. 9 The normalized experimental output power spectrum of sample 2. ▼



The 5.23 MHz offset spectral components increase by 8 to 9 dB for samples 1 and 2 and by 5 to 7 dB for sample 3 by elevating the rms power value from 2 to 4 dB. Moreover, under those conditions the distance between the three lines becomes shorter. As an example, ***Figure 7*** shows an auxiliary transfer function for IM_3 of sample 3 for different drive levels at an rms power change of 4 dB. The cancellation effect influence can be clearly observed. For the chosen input signals the output signal of the PA achieves hard saturation for a fairly large part of the total power. The presented data do not include the PA output noise. Depending on the noise and power spectral components the output power can differ significantly.

EXPERIMENTAL RESULTS

The three samples considered were driven by the 10-channel 4.096 Mchips signal from the proprietary W-CDMA subscriber unit. Unfortunately, from the characteristics only a crest factor of 9.5 dB is determined by the IF voltage. The results are shown by solid lines in ***Figure 8***. Theoretical results are shown as well for an rms power change of 4 dB taking into account the real measured PA output noise level for each sample and drive level. Good agreement between experimental and theoretical results is observed not only by the figures, but by the shape, including the additive noise. Therefore, the input signal chosen is very close to the real signal.

Figure 9 shows the normalized measured output power spectrum for sample 2 at two different power levels. Normalization is provided at P (5.23 MHz). The theoretical curve of a weighting function F(Δf) is presented as well. It can be clearly observed that good agreement between measurements and theory is achieved at 4.2 to 5.6 MHz frequency offsets. The upper frequency limit is restricted by the noise of the PA and by the IM_5 product influence. At offsets less than 4.2 MHz, slight growth of the spectral components up to 2 to 3 dB is observed over the theoretical value and a small ripple is present on a spectral lobe due to the ripple in the baseband of the input signal and its nonrectangular power spectrum shape. The sharp growth of spectral components at less than 2.8 MHz frequency offset is caused entirely by the input signal shape.

For samples 1 and 3 similar results are observed with even fewer deviations from the theoretical curve. Thus, it can be concluded that by using the proposed method it is possible to calculate an adjacent-channel power ratio (ACPR) with an accuracy up to 2 to 3 dB for the entire bandwidth of the adjacent channel and with an accuracy less than 1 dB for spurious emissions at the most critical frequency offsets specified in CDMA standards. Of course, the method requires more meticulous verification with an initially known signal and for an amplifier driven harder into its saturated region.

[Continued on page 108]

CONCLUSION

A method for calculating power spectral regrowth for a CDMA PA has been proposed based on two-tone measurements and the drive signal statistics. Signal characterization in the frequency domain, the auxiliary gain function, the weighting function and the auxiliary transfer function for IMD products were introduced to facilitate the graphical representation of a PA's physical behavior when amplifying the statistical signals. Theoretical results show good agreement with experimental data even for a hard-driven nonlinear PA. The method proposed is valid not only for CDMA signals, but for different digitally modulated communication standards with a flat power spectrum such as quadrature phase-shift keying (QPSK), $\pi/4$-differential QPSK, quadrature amplitude modulation and orthogonal frequency-division multiplex.[3,5,6] The method works better with an increase in carriers. Implementing the two-tone gain and representing the spectral flat shape by a flat probability distribution function with noncorrelated spectral components for multiple-channel digital signals in the frequency domain, sufficient data are available for calculations and an accuracy is obtained that is comparable with measurements obtained by conventional test equipment.

The frequency offsets at which to measure two-tone IMD products to determine correlation between their values and the spectral components' regrowth as well as ACPR were also discovered. It is senseless to look for a correlation between the fixed values of IMD products and ACPR at a specific output power level. IMD product behavior must be considered through the entire power range where the signal exists due to the appropriate characteristics. Certainly, the method should be verified more extensively for different modulated formats and the first step is to expand frequency limits for the weighting function F(Δf). The AM-PM conversion influence is a topic for further investigation. ■

References

1. J.F. Sevic, "Statistical Characterization of RF Power Amplifier Efficiency for Wireless Communication Systems," *Wireless Communications Conference Proceedings*, 1997.
2. Ahmad Chini, Yiyan Wu, Mohammed El-Tanany and Samy Mahmoud, "Hardware Nonlinearities in Digital TV Broadcasting Using OFDM Modulation," *IEEE Transactions on Broadcasting*, Vol. 44, No. 1, March 1998, pp.12–21.
3. J.A. Higgins and R.L. Kuvas, "Analysis and Improvement of Intermodulation Distortion in GaAs Power FETs," *IEEE Transactions on Microwave Theory and Techniques*, Vol. MTT-28, No. 1, January 1980, pp. 9–17.
4. *1997 Data Book*, Hexawave Inc.
5. F. Amoroso and R.A. Monzingo, "Digital Data Signal Spectral Side Lobe Regrowth in Soft Saturating Amplifiers," *Microwave Journal*, Vol. 41, No. 2, February 1998, pp. 126–132.
6. S. Merchan, A. Garcia Armada and J.L. Garcia, "OFDM Performance in Amplifier Nonlinearity," *IEEE Transactions on Broadcasting*, Vol. 44, No. 1, March 1998, pp.106–113.

Oleksandr Gorbachov *received his PhD degree in electrical engineering. Currently, he is a senior engineer with Hexawave Inc.'s Microelectronics Division. Gorbachov's research interests include the development of power GaAs MESFET, hybrid and MMIC power amplifiers for wireless communication. He can be reached via e-mail at alex_gor40@hotmail.com.*

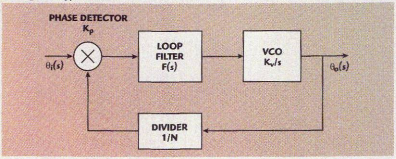
The Z-domain Method for Analysis and Design of High Order Digital Phase-locked Loops

Until now most phase-locked loops (PLL) have been analyzed using S-domain techniques and designed using analog circuitry. The purpose of this article is to provide the system designer with the necessary tools to analyze PLLs using Z-domain methods and design PLLs using digital circuits. Analog PLLs can drift with temperature variations due to changes in the analog component characteristics and are easily disturbed by shock and vibration. An all-digital PLL eliminates these problems and enhances system reliability. With the advent of numerically controlled oscillators (NCO), advances in speed and density of field-programmable gate arrays (FPGA) and other digital application-specific ICs (ASIC) and digital signal processors (DSP), digital PLLs can be easily implemented.

SECOND-ORDER PLLS

This article begins with a basic review of second-order analog PLL theory and design. The Z transformation will be applied to achieve an all-digital PLL. A typical analog PLL is shown in ***Figure 1***. The transfer function of the PLL is expressed as

▼ *Fig. 1 A type 2 PLL.*

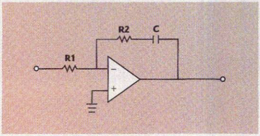


$$\frac{\theta_o(s)}{\theta_i(s)} = \frac{K_p F(s) \frac{K_v}{s}}{1 + \frac{1}{N} K_p F(s) \frac{K_v}{s}} \qquad (1)$$

A type 2 loop filter is shown in ***Figure 2*** and has the following transfer function:

$$F(s) = \frac{-R2}{R1} - \frac{1}{sCR1} \qquad (2)$$

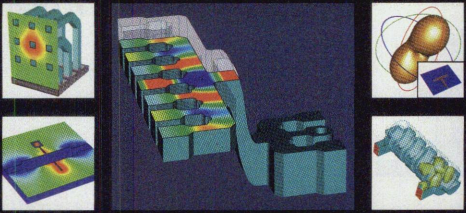
Applying the Z transformation to Equation 2 results in the following Z-domain transfer



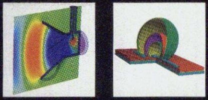
▲ *Fig. 2 An analog type 2 filter.*

[Continued on page 112]

BASEL F. AZZAM
LNR TrexCom
Hauppauge, NY



All kind of S-parameter and antenna problems e.g. waveguides, filters, connectors, couplers, planar structures and *any* antennas.



The Company whose products have been in existence for over ten years and has been providing the U.S. industry leaders with the German engineered MAFIA Simulation Software, announces:

CST MICROWAVE STUDIO

"Changing the standards for 3D EM Simulation"

- A NEW product using a NEW technique *"Perfect Boundary Approximation"* combined with a powerful optimization tool.

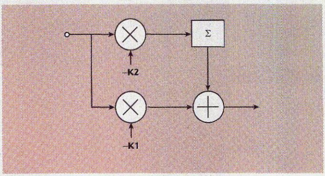
Discover the applications and the new technologies now available and reserve a seat at one of CST's free training seminars being held in the following locations:

Houston
Boston
Seattle
San Francisco
San Diego
Atlanta
Toronto

CST
COMPUTER SIMULATION TECHNOLOGY

CST OF AMERICA
124 Mount Auburn Street
Suite 200 N
Cambridge, MA 02138
Phone: (617) 576 - 5857
Fax: (617) 576 - 5702
CST_America @compuserve.com
Website: www.cst.de

CIRCLE 35 ON READER SERVICE CARD



▲ *Fig. 3 A digital type 2 filter.*

function for the loop filter:

$$F(z) = -K1 - K2\left(\frac{T_s z^{-1}}{1 - z^{-1}}\right) \tag{3}$$

where

$K1 = \dfrac{R2}{R1}$

$K2 = \dfrac{1}{CR2}$

T_s = sampling period of the filter

The digitized form of the type 2 filter is shown in ***Figure 3***. Replacing the VCO in the type 2 PLL with an NCO, the Z-transfer function becomes

$$H(z) = \frac{K_p F(z) K_v \left(\frac{T_s z^{-1}}{1 - z^{-1}}\right)}{1 + \frac{K_p F(z) K_v}{N}\left(\frac{T_s z^{-1}}{1 - z^{-1}}\right)} \tag{4}$$

Finally, substituting Equation 3 into Equation 4 results in the following Z-domain transfer function:

$$H(z) = \frac{K_p K_v T_s (K1 - K2) z^{-2} - (K_p K_v T_s K1) z^{-1}}{\left[1 + \frac{K_p K_v T_s (K1 - K2)}{N}\right] z^{-2} + \left(-2 - \frac{K_p K_v T_s K1}{N}\right) z^{-1} + 1} \tag{5}$$

Equation 5 can be compared to the well-known characterized and Z-transformed control theory second-order closed-loop transfer function

$$H(z) = \frac{\left(-2\omega_n \zeta T_s + \omega_n^2 T_s^2\right) z^{-2} + 2\omega_n \zeta T_s z^{-1}}{\left(1 - 2\omega_n \zeta T_s + \omega_n^2 T_s^2\right) z^{-2} + \left(-2 + 2\omega_n \zeta T_s\right) z^{-1} + 1} \tag{6}$$

where

ω_n = natural frequency

ζ = damping factor of the PLL

[Continued on page 114]

Equation 6 allows K1 and K2 to be defined in terms of ω_n and ζ. Thus,

$$\frac{K_p K_v T_s K1}{N} = 2\omega_n \zeta T_s$$

$$\frac{K_p K_v T_s}{N}\left(K1 - K2\right) = -2\omega_n \zeta T_s + \omega_n^2 T_s^2$$

Solving for K1 and K2 results in

$$K1 = \frac{-2N\omega_n \zeta}{K_p K_v} \tag{7}$$

$$K2 = \frac{-NT_s \omega_n^2}{K_p K_v} \tag{8}$$

Equations 7 and 8 completely characterize the design of a second-order type 2 digital PLL. In practice, a PLL is used to lock onto an incoming reference signal or synthesize a clock or carrier with frequency f_r. The designer also can specify the loop bandwidth (BL) of the PLL, which is a compromise between lock-in range, tracking range and noise suppression. A general compromise is to specify the loop bandwidth to be approximately one percent of the reference signal, that is

$$BL = \frac{f_r}{100} \tag{9}$$

As shown by Gardner,[1] the natural frequency ω_n is related to the loop bandwidth by the following relationship:

$$\omega_n = \frac{2BL}{\zeta + \frac{1}{4\zeta}} \tag{10}$$

The damping factor ζ is typically 0.707. The phase comparator gain K_p depends on the phase comparator type. The NCO gain K_v is defined as

$$K_v = \frac{2\pi F_{nco\_clk}}{2^{nco\_bits}} \tag{11}$$

where

F_{nco_clk} = NCO clock rate
nco_bits = number of bits in the NCO phase comparator

An example and a complete Mathcad set of design and analysis equations for a second-order type 2 digital PLL (DPLL) are shown in ***Appendix A***. The design is for a PLL circuit that locks onto a 1 MHz reference and multiplies it by 10 to generate a 10 MHz phase-locked signal.

THIRD- AND FOURTH-ORDER LOOPS

A typical fourth-order PLL has a loop filter structure as shown in ***Figure 4***. The transfer function of a fourth-order loop filter is expressed as

$$F(s) = \frac{1}{(sT4+1)} \bullet \frac{-(T2s+1)}{sT1} \bullet \frac{1}{(1+T3s)} \tag{12}$$

where

$T1 = R1C2$ ($R1 = 2R_a$)
$T2 = R2C2$
$T3 = R3C3$
$T4 = R_aC1$

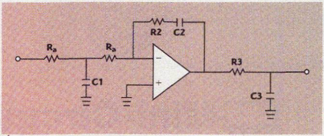
In third-order PLLs, T4 = 0; in fourth-order PLLs,

$$T4 = \frac{T3}{10} \tag{13}$$

Following Przedpelski's[2] optimization of third-order PLLs method, the time constants are derived from the open-loop transfer function

$$H(s) = \frac{K_p K_v}{NT1\omega^2} \bullet \frac{(j\omega T2 - 1)}{(j\omega T3 + 1)} \tag{14}$$

Third-order loop stability is defined by phase margin, which is the difference between 180° and the phase of the open-loop transfer function. In second-order loops, the damping factor ζ is typically 0.707; in third- and fourth-order loops the phase margin ϕ is typically 45°. From Equation 14, the



▲ *Fig. 4 A type 4 loop filter.*

[Continued on page 116]

phase of the open loop is

$$\phi = \tan^{-1}\left[\frac{(T2+T3)\omega}{\left(-1+T2T3\omega^2\right)}\right] \tag{15}$$

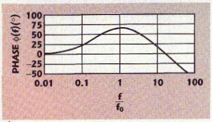


Fig. 5 The open-loop phase response.

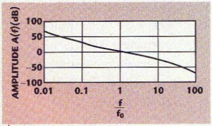


Fig. 6 The open-loop amplitude response.

The open-loop response has an inflection point at the unity gain frequency f_0. A typical open-loop phase response is shown in ***Figure 5***. The slope of the phase at the inflection point is zero. Therefore, by differentiating the phase with respect to ω and setting the result to equal zero, a solution can be found for ω_0.

$$\frac{d\phi}{d\omega} = \frac{-(T2+T3)\left(1+T2T3\omega^2\right)}{1+T2^2T3^2\omega^4+\left(T2^2+T3^2\right)\omega^2} = 0 \tag{16}$$

Solving for ω_0 produces

$$\omega_0 = \frac{\sqrt{(-T2T3)}}{(T2T3)} \tag{17}$$

Solving Equations 16 and 17 simultaneously for T2 and T3 results in

$$T2 = \left|\frac{-\tan(\phi)-\sqrt{\left(\tan(\phi)^2+1\right)}}{\omega_0}\right| \tag{18}$$

$$T3 = \left|\frac{-\tan(\phi)+\sqrt{\left(\tan(\phi)^2+1\right)}}{\omega_0}\right| \tag{19}$$

Figure 6 shows a typical open-loop amplitude response. The gain of f_0 (the phase inflection point) should be 1. Therefore, setting Equation 14 equal to 1 and solving for T1 results in

$$T1 = \left|\frac{K_pK_v}{NT1\omega^2}\bullet\frac{(j\omega T2-1)}{(j\omega T3+1)}\right| \tag{20}$$

As stated earlier, T4 is defined as

$$T4 = \frac{T3}{10} \tag{21}$$

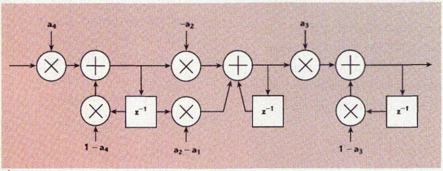


Fig. 7 A fourth-order digital loop filter.

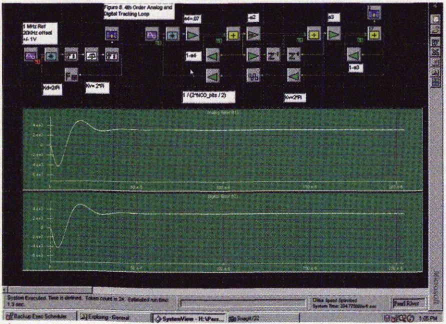


Fig. 8 Simulation of the fourth-order design example.

DIGITIZING HIGH ORDER PLLS

Converting Equation 12 to the Z domain results in

$$H(z) = \frac{a_4z^{-1}}{(a_4-1)z^{-1}+1} \bullet \frac{(-a_2+a_1)z^{-1}+a_2}{-1+z^{-1}} \bullet \frac{a_3z^{-1}}{(a_3-1)z^{-1}+1} \tag{22}$$

where

$$a_1 = \frac{T_s}{T1}$$

$$a_2 = \frac{T2}{T1}$$

$$a_3 = \frac{T_s}{T3}$$

$$a_4 = \frac{T_s}{T4}$$

T_s is the loop filter sampling period. Equation 13 represents a fourth-order digital loop filter. The structure is shown in ***Figure 7***. ***Appendix B*** shows a fourth-order analog and digital design example using Mathcad software. ***Figure 8*** shows a simula-

[Continued on page 119]

tion, using SystemView simulation software by Elanix, of the fourth-order design example. It is no surprise that the loop behavior of both the analog and digital loops is identical as the analog error and digital error signal graphs indicate.

CONCLUSION

The Z-domain design and analysis theory and examples presented in this article demonstrate that it is easy to migrate from the traditional analog design of PLLs to digital PLLs. Besides duplicating loop dynamics and behavior, digital PLLs offer a more stable and reliable solution to the system designer. Unlike analog components, digital circuits generally are not affected by temperature variations, vibrations or shocks, and digital implementation can be easily achieved with DSP algorithms or FPGA/ASIC designs. ■

References

1. F.M. Gardner, *Phaselock Techniques*, Second Edition, John Wiley and Sons Inc., New York, NY, 1979.
2. A. Przedpelski, "Optimizing Phase-lock Loops to Meet Your Needs — or Determine Why You Can't," *Electronic Design*, Sept. 1978.
3. P. Chen and J. Henkelman, "Phase-locked Tracking Loops for Carrier Recovery," *Communication Systems Design*, Aug. 1997.
4. L. Kenney, "Signal Acquisition with a Digital PLL," *Communication Systems Design*, June 1997.

Basel F. Azzam *received his BSEE from the State University of New York at Stony Brook and his MSEE from Polytechnic University of New York. Currently, he is a senior manager with Fujitsu Network Communications Inc., Pearl River, NY. He can be reached via e-mail at basel.azzam@fnc.fujitsu.com.*

APPENDIX A

SECOND-ORDER DPLL DESIGN AND ANALYSIS WITH MATHCAD

Input Parameters

$f_r = 1 \bullet 10^6$

$N = 10$

$\zeta = 0.707$

$K_p = \frac{2}{\pi}$

$NCObits = 16$

$NCOclk = 40 \bullet 10^6$

Calculation of K1 and K2

$BL = \frac{f_r}{100}$ $BL = 1 \bullet 10^4$

$\omega_n = \frac{2BL}{\zeta + \frac{1}{4\zeta}} \bullet 2\pi$ $T_s = \frac{1}{NCOclk}$ $K_v = \frac{2\pi(NCOclk)}{2^{NCObits}}$

$K1 = \frac{-2\omega_n\zeta}{K_pK_v}$ $K1 = -68.622$ $K2 = \frac{-\omega_n^{\,2}T_s}{K_pK_v}$ $K2 = -0.144$

Loop Filter Response

$Z(f) = e^{j\pi f T_s}$ $F(f) = K1 + K2 \bullet \frac{z(f)^{-1}}{1 - z(f)^{-1}}$

Open Loop Response

$G(f) = K_p F(f) K_v \frac{T_s z(f)^{-1}}{1 - z(f)^{-1}}$ $H = \frac{1}{N}$ $GH(f) = G(f)H$

Closed Loop Response

$Hc(f) = \frac{G(f)}{1 + GH(f)}$

Impulse Response

$IR(t) = \frac{1}{2\pi}\int_{-4}^{4} Hc(f) e^{j2\pi f t} df$

Magnitude and Phase Open Loop Response

$M(f) = 20\log(|GH(f)|)$ $PH(f) = \arg(GH(f)) \bullet \frac{180}{\pi}$

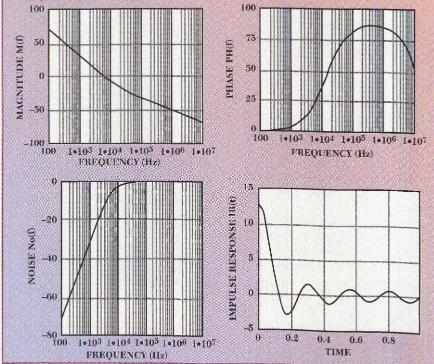
Noise Reduction

$No(f) = 20\log\left(\left|\frac{1}{1 + GH(f)}\right|\right)$

[Continued on page 120]

APPENDIX A (cont.)

$f = 100, 500 \ldots 10^7 \qquad t = 0, 0.01 \ldots 1$



APPENDIX B

FOURTH-ORDER ANALOG AND DIGITAL PLL DESIGN

$f_r = 1 \cdot 10^6 \qquad N = 1 \qquad K_v = 2\pi \qquad K_p = \dfrac{2}{\pi} \qquad F_s = 40 \cdot 10^6$

$f_o = \dfrac{f_r}{100} \qquad f_o = 1 \cdot 10^4 \qquad \phi = 65 \cdot \dfrac{\pi}{180} \qquad \omega_0 = 2\pi f_o \qquad T_s = \dfrac{1}{F_s}$

$$T3 = \left|\frac{\left[-\tan(\phi) + \sqrt{\left(\tan(\phi)^2 + 1\right)}\right]}{\omega_0}\right| \qquad T3 = 3.528 \cdot 10^{-6}$$

$$T2 = \left|\frac{-\left[\tan(\phi) + \sqrt{\left(\tan(\phi)^2 + 1\right)}\right]}{\omega_0}\right| \qquad T2 = 7.179 \cdot 10^{-5}$$

$$T1 = \left|K_p K_v \cdot \frac{\left(iT2\omega_0 - 1\right)}{\left[\omega_0^2 N(1 + i\omega_0 T3)\right]}\right| \qquad T1 = 4.57 \cdot 10^{-9}$$

$T4 = 0.1T3 \qquad T4 = 3.528 \cdot 10^{-7}$

$C2 = 1 \cdot 10^{-10} \qquad C3 = 1 \cdot 10^{-10}$

$R1 = \dfrac{T1}{C2} \qquad R2 = \dfrac{T2}{C2} \qquad R3 = \dfrac{T3}{C3} \qquad R_a = \dfrac{R1}{2} \qquad C1 = \dfrac{T4}{R_a}$

$R1 = 45.703 \qquad R2 = 7.179 \cdot 10^5 \qquad R3 = 3.528 \cdot 10^4 \qquad R_a = 22.852 \qquad C1 = 1.544 \cdot 10^{-8}$

$a1 = \dfrac{T_s}{T1} \qquad a1 = 5.47$

$a2 = \dfrac{T2}{T1} \qquad a2 = 1.571 \cdot 10^4 \qquad a2 - a1 = 1.57 \cdot 10^4$

$a3 = \dfrac{T_s}{T3} \qquad a3 = 7.085 \cdot 10^{-3}$

$a4 = \dfrac{T_s}{T4} \qquad a4 = 0.071$

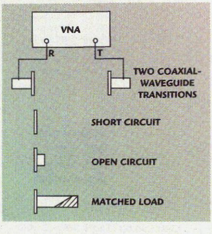
A Simple and Efficient Waveguide Calibration Procedure for a Vector Network Analyzer

Modern vector network analyzers (VNA) can be calibrated for measuring scattering parameters of waveguide circuits without the need for an expensive kit of standard waveguide components. It is possible to specify the quality of a low reflection load by using a sliding matched load of lower quality and, therefore, use it as a standard circuit. Similarly, the VNA can be used as a transmitter/receiver for measuring geometrical parameters of a reference circuit from which a standard open circuit can be specified.

VNAs are generally calibrated before use with a kit of three standard circuits: a short circuit, an open circuit and a matched load. The accessory kit is typically a coaxial kit supplied with the main equipment.

A separate kit, shown in ***Figure 1***, is required when the VNA is used for measuring complex scattering parameters of waveguide circuits. These kits are available from many manufacturers; nevertheless, they are expensive even though they can be constructed by any user who has some technical background in microwave engineering. The aim of this article is to discuss how a VNA user can build a standard waveguide kit at a low cost and specify it over a given range of frequencies. The procedure avoids the use of any complicated methods, such as line-reflect-match or line-reflect-reflect-match, which have been developed for very broadband VNA use.[1–4]

Fig. 1 A traditional VNA calibration procedure using a short circuit, open circuit and matched load calibration kit.



THE PROBLEM

Consider a common user of an HP8714B VNA. This VNA is a low cost instrument that operates from 300 kHz to 3 GHz. It is commonly equipped with a standard type N coaxial kit. It is assumed that the user is concerned with measuring impedances and scattering parameters in WR112/U waveguide between 2.4 and 2.5 GHz. This frequency domain is the industrial, scientific and medical (ISM) band in which most microwave power industrial equipment operates for material processing.[5]

It is easy to construct a pair of transitions that transduce the coaxial line with the waveguide. Many transition designs have been described in the literature.[6] It is also easy to construct a waveguide matched load by progres-

[Continued on page 125]

Georges Roussy, Bernard Dichtel and Haykel Chaabane
Université Henri Poincaré, Laboratoire de Spectroscopie et des Techniques Microondes
Vandoeuvre les Nancy, France

sively introducing an absorbing material in the waveguide.[7] A short circuit can be made with a single metallic plate closing the flange, and an open circuit can be obtained with a $\lambda_g/4$ distance-shifted short circuit.

All of these circuits can be used to calibrate the VNA. It makes sense to assume that the short and open circuits have no loss between 2400 and 2500 MHz if the flanges of the guide are mechanically well dressed and well soldered. However, the open circuit is not perfect between 2.4 and 2.5 GHz because its phase, impedance and complex reflection coefficient are a function of frequency and of the inside dimension a and length D of the waveguide section. The characteristics of the open circuit must be specified for use as a standard circuit in the calibration of the VNA.

THE OPEN CIRCUIT

The reflection coefficient of the open circuit depends on frequency, such that

$$\rho^{\circ} = -\exp - j4\pi \frac{D}{c}\sqrt{\omega^2 - \omega_c^2}$$

where

c = speed of light in vacuum (299,792.5 km/s)

If D and the waveguide cutoff frequency ω_c are known exactly, the value of the coefficients C_0, C_1, C_2 and C_3 that specify the open circuit can be calculated as the Mac Laurin series of the capacitance vs. ω:

$$C_0 + C_1\omega + C_2\omega^2 + C_3\omega^3 = \frac{-0.02}{\omega t_g\left(2\pi \frac{D}{c}\sqrt{\omega^2 - \omega_c^2}\right)}$$

This calibration is recommended and explained in the VNA user's guide.[8] Thus, by assuming that the constructed matched load has a low reflection coefficient, the three waveguide components can be used to calibrate the VNA as is done with the standard coaxial kit. The characteristics of the coaxial-guide transitions need not be known; their defects are included in the calibration.

REFINING THE PROCEDURE

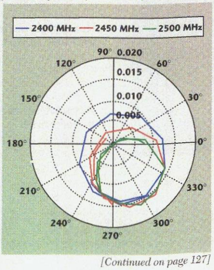
The accuracy of the VNA measurement can be increased by refining the specification of the standard circuits.

Respecifying the Matched Load Circuit

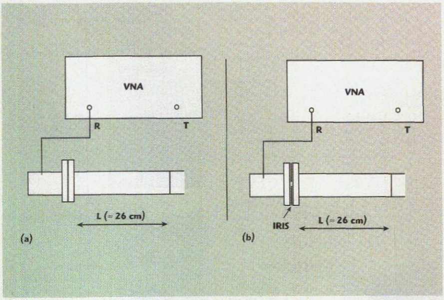
Assume that a matched load is moved in a waveguide. Its complex reflection coefficient will be represented by a circle on the Smith chart. The radius measures the amplitude of the reflection of the movable load; the center of the circle measures the residual reflection coefficient of the matched load, which was used originally for calibrating the VNA. **Figure 2** shows the constructed sliding load, which consists of a plastic carriage that supports a tapered block of rubber, an inexpensive, lossy material. The carriage is guided inside the waveguide with nylon screws. **Figure 3** shows the resulting circle on the

▲ *Fig. 2 The sliding matched load.*

Fig. 3 A plot of the sliding matched load as a function of the displacement. ▼



[Continued on page 127]



▲ *Fig. 4 VNA measurements for respecifying the open circuit with an (a) waveguide length L section and (b) resonant cavity of length L.*

Smith chart. The residual $|\rho^\circ|$ of the matched load is $\rho^\circ_M = 5.10^{-3}$ exp – j42°. The data plot also illustrates the high accuracy with which the low reflection coefficient can be measured because the scale has been magnified around the low values of $|\rho^\circ|$, even if the VNA has not been calibrated. The resulting ρ°_M can be used to specify the matched load as a standard matched load for recalibrating the VNA.

Respecifying the Open Circuit

Refinement of the C_i parameters that specify the open circuit is also possible. The section of RG112/U waveguide in which the matched load carriage was previously sliding is closed with a plunger at L (= 26 cm) from the flange, as shown in ***Figure 4***. The reflection of this circuit can be measured at different frequencies with the VNA.

Inserting a metallic sheet (having an aperture) between the flanges converts the waveguide section to a rectangular cavity. Using the VNA, the resonant frequencies of the cavity can be measured even if the VNA is not fully calibrated. Let ω_{rn} (ω_{r2}, ω_{r3}, ω_{r4}) be the frequencies of the TE_{10n} (TE_{102}, TE_{103}, TE_{104}) resonant modes. The cutoff frequency of the TE_{10} propagation mode (which characterizes the dimension a of the waveguide) and the length L of the circuit can be accurately obtained from two or three measurements. The system of equations is expressed as

$$\omega_{rn}^2 = \omega_c^2 + \left(\frac{c}{2}\right)^2\left(\frac{n}{L}\right)^2$$

From the optimized values ω_c and L, the phase (arg ρ°) can be calculated in the frequency domain in which it was previously measured. Therefore, it is possible to compare the experimental values with the calculated ones. The values of ω_c and L can be obtained with a relative accuracy of $\pm 10^{-4}$, and the agreement in phase between the measured and calculated values is ±0.5°. As a consequence, a refined list of $C_i(\omega)$ can be determined and used for recalibrating the VNA.

Determination of $C_i(\omega)$ of the open circuit does not depend on any geometrical measurement, but only on frequency measurements. The VNA is used as a transmitter/receiver for characterizing a chosen second reference circuit. Of course, this procedure can be repeated with different L values and at different frequencies. The results also can be interpreted as a variable short circuit calibration method. The procedure can work over a broadband domain if the open circuit is broadband, or with other waveguide circuits.

As a final advantage, this self-contained procedure does not require equipment other than the VNA itself. It should be applicable in many circumstances other than the VNA cali-

[Continued on page 128]

bration for providing reference circuits, for directional coupler measurements or for permittivity measurement of industrial materials.[9]

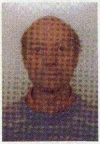
CONCLUSION

This article has presented a VNA waveguide calibration procedure. Although the procedure is not especially new, it is very accurate and requires only some simple and inexpensive waveguide components. ■

References

1. H. Heuermann, "Calibration Procedures with Series Impedances and Unknown Lines Simplify On-wafer Measurements," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 47, 1999, pp. 1–5.
2. H.J. Eul and B. Schuk, "A Generalized Theory and New Calibration Procedures for Network Analyzer Self-calibration," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 47, 1999, pp. 724–731.
3. I. Kasa, "Closed-form Mathematical Solutions to Some Network Analyzer Calibration Equations," *IEEE Transactions on Inst. and Measurement*, Vol. 23, 1974, pp. 399–402.
4. G.F. Engen and C.A. Hoer, "Three Reflected Lines an Improved Technique for Calibrating the Dual Six Port Automatic Network Analyzer," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 27, 1973, pp. 987–993.
5. G. Roussy and J.A. Pearce, *Foundations and Industrial Applications of Microwave and Radio Frequency Fields: Physical and Chemical Processes*, J. Wiley and Sons Inc., 1995.
6. C.G. Montgomery, *Technique of Microwave Measurements*, MIT Radiation Laboratories Series, McGraw Hill, 1947.
7. A.F. Harvey, *Microwave Engineering*, AC Press, NY, 1963.
8. *HP 8714B: RF Network Analyzer User's Guide*.
9. G. Roussy, K. Agbossou and J.M. Thiebaut, "Improved Modeling of Permittivity Measurement Cells," *IEEE Transactions on Inst. and Measurement*, Vol. 41, 1992, p. 336.

Georges Roussy *received his engineering degree from ENSEM in 1962 and his PhD degree in physics from The University of Nancy, France in 1970. He is currently director of research at CNRS where he manages the LSTM. Roussy's main research interests are the interaction of electromagnetic waves with matter, microwave and high frequency circuit properties, and high power techniques for microwave industrial applications.*



Bernard Dichtel *received his doctoral degree in electronics from The University of Nancy, France in 1978. He has been working with CNRS since 1973 as a member of the technical staff at the LSTM.*

Haykel Chaabane *received his post graduate diploma in high frequency electronics and optoelectronics from The University of Limoges, France in 1997 and is currently working toward his PhD degree in electronics.*

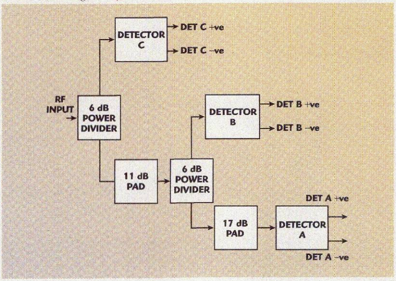
CHECK OUT OUR WEB SITE AT www.mwjournal.com

CIRCLE 7 ON READER SERVICE CARD

A Universal Power Sensor

Power is a fundamental measurement that has been made by RF engineers since the first days of radio transceivers. The basic theory of accurate power measurements has not changed since that time as thermal absorption and diode rectification remain the foundation of all power measurements. These two technologies have satisfied the industry's requirement to perform measurements on CW signals or carriers with relatively narrowband modulation schemes. The introduction of wide bandwidth modulation schemes including CDMA, high definition television, direct audio broadcasting and satellite communications has made such traditional sensor technologies inadequate. As a result, a new universal sensor that integrates a patented architecture has been developed to overcome the limitations of previous-generation sensors and allow for highly accurate power measurements on wide bandwidth signals.

Fig. 1 The universal power sensor's block diagram.



SENSOR PERFORMANCE

Designed for use with the ML2400A and ML2430A power meter series, the model MA2481A universal power sensor has a conventional diode sensor's fast response time and low power sensitivity as well as a wider dynamic range for true RMS detecting. The conventional diode detector has a low level sensitivity of –70 dBm, and a diode sensor operating in true RMS mode has 50 dB of dynamic range. The universal power sensor increases the overall sensor dynamic range to 80 dB by combining three separate diode detection elements into a single sensor. The power at a given input that each element detects in relation to the sensor input power varies, and the element with the maximum detection voltage is selected to be used for a given input power. Simultaneously, the appropriate element is maintained within its square-law region of operation. ***Figure 1*** shows the universal power sensor's block diagram.

[Continued on page 132]

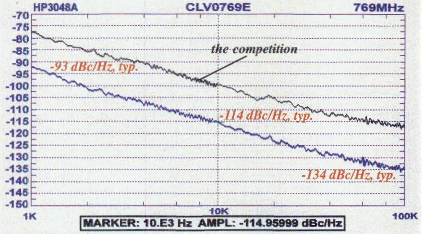
Anritsu Co.
Morgan Hill, CA

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!

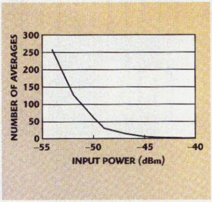
Part No:	Freq. Range:	V_{tune}	Φ_n at 10kHz	V_{supply}
CLV0769E	734-804	1-4	-112	5
CLV0815E	806-824	0.5-4.5	-113	5
CLV0945E	936-953	0.5-4.5	-114	5
CLV1320E	1295-1335	1-5	-113	5
CLV1525E	1500-1550	0.3-4.7	-110	5



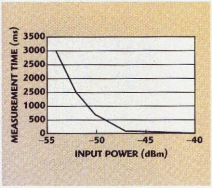
Learn more about Z-COMM's CLV product line by visiting our web site at http://www.zcomm.com/ for datasheets, outline drawings, tape and reel specifications, and application notes, as well as our complete product catalog and custom VCO inquiry form.

Come to the source ... Z-COMM.

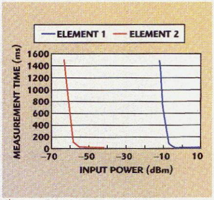
Z-Communications, Inc.
9939 Via Pasar • San Diego, CA 92126
(619) 621-2700 • Fax: (619) 621-2722
WWW: http://www.zcomm.com/



▲ *Fig. 2 Minimum number of diode detector averages to ensure measurement accuracy.*



▲ *Fig. 3 Time per measurement.*



▲ *Fig. 4 Two-element measurement speed.*

The new sensor has been designed to have improved dynamic range overall despite the fact that each of the three elements has a 50 dB individual range. Although a diode element detects very accurately over its 50 dB dynamic range, the detected voltage at the lower 10 dB power levels approaches the noise level. Even at the diode element's lower 30 dB power levels, measurement averaging is required to accurately pick out the detected voltage from random noise voltage. This averaging significantly impacts measurement speed, as shown in ***Figures 2*** and **3**.

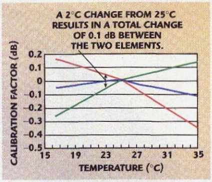
The universal power sensor's first element covers the +20 to −3 dBm power input range, the second element covers −3 to −20 dBm and the third element covers −20 to −60 dBm. While the power meter will slow down when the input power falls below −45 dBm (due to the laws of physics), it excels at −3 to −20 dBm (the power range where most engineers and product personnel conduct the majority of their measurements). At this middle power range, the three-element universal sensor is much faster, easier and more accurate than competitive solutions. ***Figure 4*** shows measurement speed as it relates to the input power of a two-element power sensor. In contrast, the three-element universal sensor requires < 20 ms per measurement with < 0.05 dB of reading fluctuation.

At +13 dBm input to the sensor, element 1 begins to leave square law and enter the transition detection region. The transition region of the diode changes slowly and the deviation from square law is < 0.1 dB over a 10 dB range. This small deviation can be easily corrected without adversely affecting the true RMS accuracy. On the other hand, the crossovers of element 1 to element 2 and element 2 to element 3 were made so that large square law overlaps exist between the crossover elements.

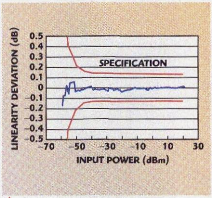
Since wideband CDMA (W-CDMA) can have a 14 dB crest factor, the extended square law overlap in the universal power sensor ensures that the ever-changing power peaks and troughs of W-CDMA are detected accurately in square law and integrated, resulting in an accurate average power measurement. The sensor will accurately measure even wider-bandwidth signals as they become required by the next modulation standard or even dual-tone signals.

The greatest challenge in achieving sensor linearity is to have the three elements operate seamlessly without discontinuity in the linearity curve. Each diode element has its own temperature and frequency characteristics. The universal power sensor/meter has extremely accurate built-in temperature correction. The importance of the temperature cor-

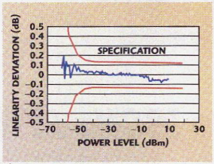
[Continued on page 134]



▲ *Fig. 5 6 GHz calibration factor changes vs. temperature.*



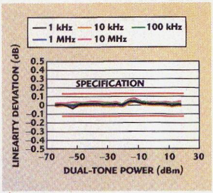
▲ *Fig. 6 CW linearity.*



▲ *Fig. 7 W-CDMA linearity.*

rection error is evidenced by the fact that if the temperature correction error is as little as 2°C, a linearity discontinuity of 0.1 dB can occur. ***Figure 5*** shows the temperature characteristics of three diode elements.

With proper frequency and temperature characterization, the universal power sensor has a CW, W-CDMA and dual-tone linearity of better than three percent, as shown in ***Figures 6***, ***7*** and ***8***. ***Table 1*** lists the specifications for the sensor. Because the universal power sensor already has the same hardware as a regular diode sensor, the least attenuated element of the sensor is fully characterized and data stored in the sensor's electronically erasable programmable read-only memory are



▲ *Fig. 8 Dual-tone linearity for various tone separations.*

TABLE I
UNIVERSAL POWER SENSOR SPECIFICATIONS

Frequency range	10 MHz to 6 GHz
Dynamic range (dBm)	–60 to +20
SWR	
10 to 50 MHz	< 1.90
50 to 150 MHz	< 1.17
0.15 to 2 GHz	< 1.12
2 to 6 GHz	< 1.22
Linearity (%)	< 3

similar to data from a standard diode sensor. When the power meter is switched to a CW measurement mode, CW signal power can be measured with the speed and accuracy of a standard diode sensor.

CONCLUSION

A new power meter sensor is now available that combines the accuracy of a thermal sensor with the speed of a diode sensor while delivering more than 80 dB of dynamic range. The model MA2481A universal power sensor features a patented technology that permits fast and accurate measurement of complex modulated signals over a wide operating region. This new technology may render previous power measurement methods obsolete. Contact the company for price and availability information.

Anritsu Co.,
Morgan Hill, CA (800) 267-4878.

Circle No. 302

RF and Microwave Products

This enhanced Phase IV Web site offers a broad range of categories, including product data sheets, new application notes, employment opportunities and product overviews. The site represents the company's ongoing efforts to keep customers informed regarding its continually improving production processes to meet market demands for world-class performance and short time to market.

Alpha Industries,
20 Sylvan Rd., Woburn, MA 01801

www.alphaind.com

Antenna Systems and EMC Test Equipment

This new and revised Web site describes the company's products and capabilities in RF and antenna systems for SIGINT, direction-finding, high frequency, telecommunications and electronic warfare systems as well as test equipment for full and precompliance EMC testing. Detailed specifications for standard commercial off-the-shelf products also are provided.

Antenna Research Associates (ARA),
11317 Frederick Ave.,
Beltsville, MD 20705

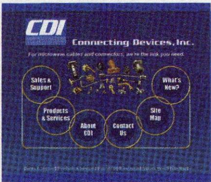
www.ara-inc.com

Microwave Office 2000

This Web site enables visitors to download a fully functioning 30-day evaluation copy of Microwave Office 2000 next-generation RF and microwave design automation software, which features a powerful MMIC layout editor that is seamlessly integrated with linear, nonlinear and EM simulation tools.

Applied Wave Research Inc. (AWR),
1960 East Grand Ave., Suite 530,
El Segundo, CA 90245

www.mwoffice.com

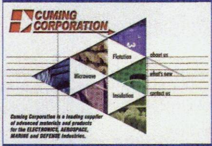


Coaxial Connectors and Cable Assemblies

This Web site offers a source for reliable, high frequency microwave connectors and cable assemblies, off-the-shelf items and fast custom interconnect solutions. The company's SMP, 2.92 mm, SMA, SSMP, TNC, N and coaxial assemblies for commercial, military and space-qualified telecommunication applications also are featured.

Connecting Devices Inc. (CDI),
2400 Grand Ave.,
Long Beach, CA 90815

www.connectingdevices.com



Dielectric and Microwave Materials

This new Web site provides technical information on dielectric and microwave materials and anechoic chambers as well as facility processing and QA equipment. Questionnaires for designing anechoic test facilities and direct links to key personnel also are included.

Cuming Microwave Corp.,
a subsidiary of Cuming Corp.,
225 Bodwell St., Avon, MA 02322

www.cumingcorp.com

Microwave Division

This Web site offers fast access to data sheets and technical information as well as a software engine for constructing valid part numbers from user inputs. The site also highlights the company's products with links to the its three divisions.

DB Products Inc.,
253 N. Vinedo Ave., Pasadena, CA 91107

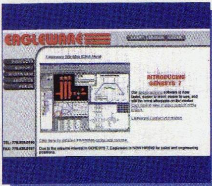
www.dbp4switches.com

CapCad V3

This Web site describes the CapCad V3 capacitor modeling software, which features part number entry, new products and Smith chart plotting. A full-line product catalog is also available. Application notes are included. Two parts can be displayed simultaneously for comparison.

Dielectric Laboratories,
2777 Route 20 East,
Cazenovia, NY 13035

www.dilabs.com



RF and Microwave Design Software

This Web site highlights the new GENESYS 7 RF and microwave design software. Users can download videos that demonstrate fast and easy use of the software. Application notes and manuals, frequently asked questions and answers, and on-line consultants also are available.

Eagleware Corp.,
4772 Stone Dr., Tucker, GA 30084

www.eagleware.com

Base Station Antenna Products

This Web site features a full product catalog, including photographs, drawings and patterns. A product specifier enables users to search products based on criteria most important to the application. Propagation pattern files can be downloaded in 18 different software formats, and an on-line quote request capability has been added to the site.

EMS Wireless,
5060 Avalon Ridge Parkway, Suite 300,
Norcross, GA 30071

www.emswireless.com

RF Power Products

This Web site offers a complete catalog of the company's GOLDMOS, bipolar transistors and high impedance modules. Data sheets, Gerber files and application briefs are available, and sales representatives and distributors are listed.

Ericsson Microelectronics,
RF Power Products
675 Jarvis Dr., Morgan Hill, CA 95037

www.ericsson.com/rfpower

Contact Products

This Web site offers a variety of solutions for high frequency, high volume testing and products such as the K-50 coaxial probe, which supplies superior broadband characteristics and a universal open-tip architecture, thereby eliminating the requirement for a special contact target.

Everett Charles Technologies,
700 E. Harrison Ave.,
Pomona, CA 91767

www.ectinfo.com

High Performance Wire and Cable

This Web site describes high performance, high frequency coaxial cables for the RF and microwave markets, including strip braid and spiral strip shield designs to maximize shielding effectiveness while maintaining flexibility. The company's PTFE dielectrics and foamed polyethylene yield performance expected from more costly alternatives.

Harbour Industries,
4744 Shelburne Rd.,
Shelburne, VT 05482

www.harbourind.com

Microwave Systems

This revised Web site features several design options for frequency generation specialists in the electronic warfare and commercial markets. The company's components and subsystems are optimized for exacting high speed logic, precise wideband microwave performance, low spurious levels and low phase noise.

ITT Industries, Microwave Systems,
59 Technology Dr., Lowell, MA 01851

www.ittmicrowave.com

E-commerce Capabilities

This Web site now offers e-commerce capabilities through the company's Order On-Line system. The site gives customers exclusive Web access to discount pricing for products such as base station duplexers, tunable filters and harmonic rejection filters.

K&L Microwave Inc.,
2250 Northwood Dr.,
Salisbury, MD 21801

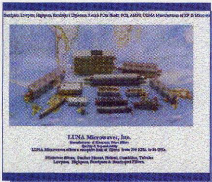
www.klmicrowave.com

High Performance Filters

This Web site provides information on high performance filters, diplexers and subassemblies from 500 kHz to 40 GHz including ISM, MMDS, LDMS and commercial wireless communications frequencies. Ceramic, waveguide, cavity and discrete element topology filters in fixed and tunable designs also are described.

Lorch Microwave,
1725 North Salisbury Blvd.,
Salisbury, MD 21802

www.lorch.com

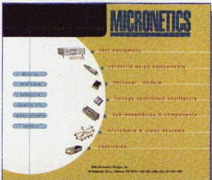


RF and Microwave Filters

This Web site presents miniature, surface-mount, helical, combline, tubular, lowpass, highpass, bandpass and band reject filters. A complete line of filters from 300 kHz to 20 GHz and contact information are included.

Luna Microwaves Inc.,
7610-V Rickenbacker Dr.,
Gaithersburg, MD 20879

www.lunamw.com

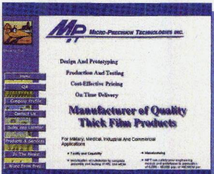


Microwave Components and Test Equipment

This newly designed Web site provides easy access to the company's comprehensive line of microwave and RF products, test equipment, noise components and voltage-controlled oscillators. Product specifications and current news, including press releases, investor information and published articles are included.

Micronetics Wireless Inc.,
26 Hampshire Dr., Hudson, NH 03051

www.micronetics.com



Vector Attenuators

This Web site features vector attenuators and attenuator phase shifters for feedforward amplifiers and RF predistorters used in PCS base stations. The site also describes the company's thick-film capabilities and services such as printed substrates and hybrid microcircuits. Application notes and technical features also are available.

Micro-Precision
Technologies Inc. (MPT),
12-B Manor Parkway, Salem, NH 03079

www.micropt.com


UNMATE
MATE
the ultiMATE
This advanced **coax** design provides new performance for rack and panel, quick release cable, and custom designs for high contact count assemblies, portable computers, test equipment and wireless devices. The Hypertronics' coaxial COAXTAC™ contacts with dual concentric Hypertac® sockets provide a new level of performance.
• Over 25,000 insertion-extraction cycles
• 3 ounce average insertion force
• 50Ω impedance rated at 1.20:1 VSWR at 3GHz and 1.40:1 up to 6 GHz max.
• Exceptional continuity under shock and vibration
25,000
CYCLES
HYPERTRONICS CORPORATION
"New Horizons in Connectors"
16 Brent Drive • Hudson, MA 01749-2978 • 978-568-0451 • Fax 978-568-0680
Call 800-225-9228, 888-HYPERTAC or visit our web site at www.hypertronics.com
Hypertronics is a part of Hypertac Interconnect and Smiths Industries

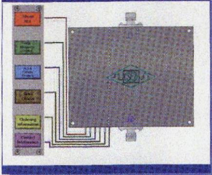
WEB UPDATE

Automated Wire and Die Bonders

This Web site provides information on the company's complete line of automated wire and die bonders and in-line systems for first-level interconnect. Customer service contacts, software options and refurbished equipment as well as current news, articles and trade show information are available.

Palomar Technologies,
2230 Oak Ridge Way, Vista, CA 92083

www.bonders.com



RF and Microwave Components

The Web site offers technical and mechanical information on various RF and microwave products, including high Q base station filters, duplexers, multiplexers, dielectric filters, complete subassemblies, and transmit and receive filters. Low noise amplifiers, power monitors and high power amplifiers for the PCS cellular market also are introduced.

Salisbury Engineering Inc.,
RR # 1 Stage Rd., Delmar, DE 19940

www.salisbury-engineering.com

Antenna Design, Development and Manufacturing

This redesigned Web site features the company's *1999 Standard Product Catalog*, which offers more than 1300 standard antenna designs. The site also includes the company's history and capabilities as well as antenna testing services and engineering information.

Seavey Engineering Associates Inc.,
28 Riverside Dr., Pembroke, MA 02359

www.seaveyantenna.com

Signal Switching

This redesigned Web site offers several new matrices for digital, fiber-optic, RF and microwave applications as well as a new line of notch filters and VXI/VME switch cards. The site also features full fan-out nonblocking designs that allow several inputs to communicate with several outputs with little to no signal degradation.

Signal Technology Corp.,
Systems Operation,
37 Sutton Rd., Webster, MA 01570

www.sigtech.com/systems

Passive and Active Components and Subsystems

This newly designed Web site describes more than a dozen new passive and active components and subsystems for wireless, EW and space requirements up to 18 GHz as well as new lines of switch combiners and multifunction logarithmic amplifiers. A complete listing of data sheets available in PDF format is included.

Signal Technology Corp.,
Olektron Operation,
28 Tozer Rd., Beverly, MA 01915

www.sigtech.com/olektron

Microwave Coaxial Connectors

This Web site provides information on microwave connectors with high performance SMA and extended power SMA as well as 2.92 mm and 2.4 mm connectors for microstrip and stripline circuits. Designed for applications up to 50 GHz, the rugged connectors offer low SWR, low loss and high performance for space, military and commercial applications.

Southwest Microwave Inc.,
900 S. McKemy St., Tempe, AZ 85284

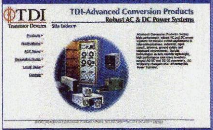
www.southwestmicrowave.com

Wireless, Space and Defense Products

This Web site provides quick, current and accurate information on wireless, space and defense products offered by the company. The site also features new products, company profiles, articles, technical terms and contact information.

Trak Communications Inc., a Tech-Sym company, 4726 Eisenhower Blvd., Tampa, FL 33634

www.trak.com



Power Supply Information

This new, interactive Web site is designed to make product, corporate news and application information more easily accessible for current and potential customers. Product data sheets and an expanded library of custom and application-specific product information also are available.

Advanced Conversion Products (ACP), a division of Transistor Devices Inc. (TDI), 85 Horsehill Rd., Cedar Knolls, NJ 07927

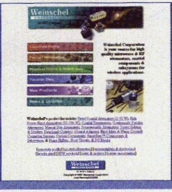
www.tdipower.com/acp

Dielectric Resonators and RF Filters

This updated Web site highlights microwave and RF filters, dielectric resonators and magnetic materials and offers CARD/COAX and CRaFT software for dielectric and coaxial resonator and filter selection. A new user interface enables users to quickly surf the site for information.

Trans-Tech, 5520 Adamstown Rd., Adamstown, MD 21710

www.trans-techinc.com



Microwave and RF Components and Subsystems

This Web site delivers a variety of technical and corporate information, including product data sheets, instruction manuals, technical articles, an on-line sales representative search engine and links to other MCE companies' sites. A Java-applet navigation bar and a keyword site search also are included.

Weinschel Corp., 5305 Spectrum Dr., Frederick, MD 21703

www.weinschel.com

EMI Design Center

This Web site provides an extensive compilation of technical, product and standards information for designers facing electromagnetic interference (EMI) shielding problems. A primer on basic design for EMI control that covers key issues and terminology, electrical and mechanical design modules, and rapid prototyping services also is provided.

W.L. Gore & Associates Inc., 750 Otts Chapel Rd., Newark, DE 19713

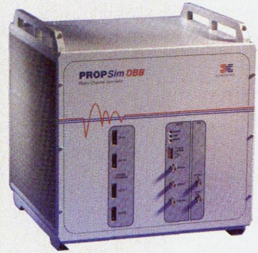
www.gore.com/electronics/emicenter

VCOs

This Web site features the company's line of patented, ultra-low noise, voltage-controlled oscillators (VCO) that deliver performance in a low cost, surface-mount solution. Application engineers also can be contacted via telephone to discuss a customer's particular needs.

Z-Communications Inc., 9939 Via Pasar, San Diego, CA 92126

www.zcomm.com



Digital Baseband Simulation in Design Verification

Time to market and time to volume play an essential role in the competitive environment of today's wireless communication business. One of the most important elements enabling well-managed product launches is systematic design verification in all phases of product development with the quickest possible feedback from testing to design. The cost of design flaws to product development in terms of missed schedule for product launch, reduced profit margins and resources needed for corrective actions depends on the design phase where the flaw is detected — the earlier the flaw is detected, the less expensive it is to fix. In the case of developing key components, such as chipsets, these elements become even more important to emerging high volume, highly competitive markets like the approaching third-generation (3G) mobile system. The most important strategic design decisions are usually made at a very early phase and have a dramatic impact on the rest of the design process. Consequently, the role of baseband signal processing is constantly growing in wireless system design.

One of the most critical parameters for measuring wireless communication system performance is the relationship between bit error rate (BER) and signal-to-noise ratio (S/N). Since BER is highly dependent on radio channel characteristics such as fading, Doppler effects and the number of multipath components, it is important to use a realistic radio channel when evaluating which design option will work best in a real end-user situation. Radio channel simulators, also known as multipath fading simulators, are commonly used to generate this realistic environment in laboratory conditions. Traditionally, these tests have been conducted at RF or sometimes at analog baseband levels.

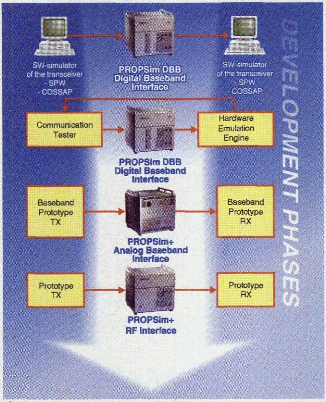
The PROPSim DBB digital baseband radio channel simulator introduces new possibilities for performing such tests already at digital baseband level. Additional benefits include the capability to test algorithms against a realistic channel without any hardware, the ability to reveal design errors in the pre-application-specific IC (ASIC) phase and the option to skip the macromodel design phase.

The simulator can be configured for one or two channels and is capable of generating up to 312 independent fading paths. Both realistic channel models and standardized test cases can be used. The standard product includes two channel-modeling software packages for creating static or dynamic user-defined channel models. The use of real measured channel data also is possible.

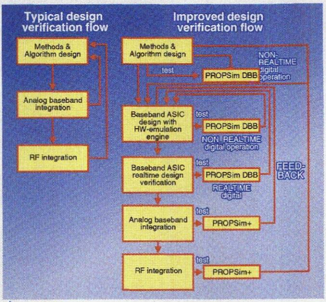
The new simulator generates fully dynamic channels (represented by smoothly sliding delays), which make it particularly useful for testing advanced features in 3G mobile and fourth-generation (4G) experimental systems such as

[Continued on page 148]

ELEKTROBIT LTD.
Oulu, Finland



▲ *Fig. 1 Development phases in digital wireless communication systems.*



▲ *Fig. 2 The use of a channel simulator in different phases of wireless design verification.*

RAKE receiver finger tracking and allocation. 3G Partnership Project channel models are available on CD-ROM.

A MODERN DESIGN CYCLE

A typical product development process of digital wireless communication systems can be broken down into general phases, as shown in ***Figure 1***. These phases include software-based algorithm development and performance tests, hardware emulation engine-based validation and performance tests, and prototype development-based performance tests in the analog baseband and RF domains. The digital baseband radio channel simulator enables performance tests in a realistic environment during the first two steps of the design verification cycle.

As shown in ***Figure 2***, decisions made during the methods and algorithm design phase are usually the most important because they affect the remainder of the product development cycle. Pressure to shorten the product development cycle requires advanced testing to be started at an earlier phase, which means moving more and more testing toward baseband signal processing. Realistic channel simulation at this stage gives the designer a new tool with which to compare different algorithms and methods under various conditions and boost the selection process. Using a digital baseband simulator together with a hardware emulation engine improves the possibilities of revealing design errors in the pre-ASIC phase. Advanced systematic design verification helps to achieve better overall quality and lower the cost of the total design. In all of these cases, testing results can be immediately fed back to the design process for possible corrective actions as opposed to the significant delay often experienced in the traditional design verification process due to limited testing possibilities.

At the system level, the digital baseband radio channel simulator can render unnecessary the building of dedicated hardware test benches to test system-level functions of the design. Instead of trial and error, design verification can be accomplished with the digital baseband simulator and a workstation or PC. The simulator provides the user with realistic information on the design characteristics at the moment when the major design decisions are made. This capability significantly reduces the risk of having to redesign the ASIC at a later stage.

SIMULATION WITH THE DIGITAL BASEBAND SIMULATOR

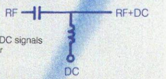
The PROPSim DBB digital baseband channel simulator provides a 10-bit in-phase and quadrature (I&Q) input and 12-bit I&Q output, and uses an external clock for scaling the simulation speed. In a real-time simulation the clock provides the signal sampling frequency; in semi-real-time simulation it can be a slower user-defined clock frequency.

In traditional RF-fading simulators it has been up to the simulator equipment manufacturer to choose the sample rate for the data that are fed into the simulator — assuming that the simulator implementation is digital. However, with the digital baseband simulator the end user is free to choose any sample frequency necessary to perform the simulation. This capability is very challenging to the channel-modeling tools since the modeling software typically maintains a very close relationship to simulator hardware. PROPSim DBB channel-modeling software is capable of handling these signal sample scaling issues in a flexible way.

Semi-real-time simulation is required in software simulation and hardware emulation environments due to the relatively slow speed of the simulation and emulation hardware. The PROPSim DBB simulator can be used to accelerate this process by assuming the load of simulating the radio channel. Although the simulation is slowed down, all of the samples from the original sampling fre-

[Continued on page 151]

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 108 INT'L 109
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

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

ISO 9001 *CERTIFIED*

F 164 Rev B

quency are run through the simulator. This downscaling of signal speed is shown in ***Figure 3***.

CONCLUSION

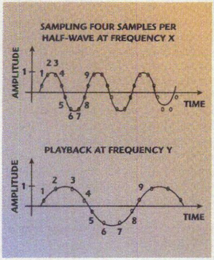
The ever-increasing competition in the wireless communications business and the proliferation of wireless systems and products to new applications have put considerable pressure on wireless system developers to reduce the time to market and time to volume of new products. Companies developing products for new high volume markets, such as the emerging 3G market, are especially faced with these requirements. This need represents challenges to develop new, improved test procedures and to start advanced systematic design verification at the earliest possible phase of product development.

The PROPSim DBB digital baseband radio channel simulator introduces new possibilities for testing wireless system designs in realistic, dynamic multipath fading environments in the digital domain prior to hardware development. It fills the gap between testing in the early design phase and the system integration phase. In addition, the simulator facilitates immediate feedback from testing at the earliest possible phase when fixing design errors is least expensive and design decisions have the most significant effect on subsequent phases.

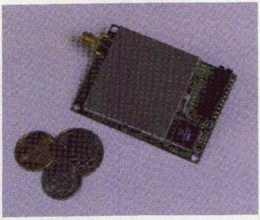
The new PROPSim DBB digital baseband radio channel simulator also enables performance tests of methods and algorithms against a realistic channel environment and reveals design errors in the pre-ASIC phase. Advanced performance tests at an early design phase may also provide the opportunity to skip the macromodel design phase. The new simulator can be integrated into a software simulation environment or operated in conjunction with a hardware emulation engine. It can be configured with one or two channels and is capable of simulating up to 312 independent fading paths. The simulator generates smoothly sliding delays, which make it particularly useful for testing advanced systems including 3G mobile and 4G experimental systems. Additional information can be obtained from the company's Web site at www.elektrobit.fi.

Elektrobit Ltd.,
Oulu, Finland
+358-400-308-396.

Circle No. 301



▲ *Fig. 3 Real-time and semi-real-time signals.*



A Miniature 900 MHz Frequency-hopping Spread Spectrum Radio

Wireless communications is fast becoming recognized as a flexible and reliable method for data telemetry applications. The technology offers numerous benefits over hard-wired solutions, including lower cost, less environmental impact, system protection and greater flexibility. The radios eliminate the need for miles of expensive wiring as well as the high costs of installation in new sites and retrofitting existing sites. In addition, burying cable and stringing wire are environmentally invasive and require a large investment to restore the area to its original state. Radios significantly reduce the footprint in these installations, minimizing the impact and damage to the area. Furthermore, radios allow for isolation of sensitive equipment, thereby reducing the chance of system failure due to a power surge or lightning strike, and eliminate the chance of broken connections due to damaged or severed cables. In addition, sensors and controllers are no longer tied to the location of the hard-wired terminal, offering flexibility when relocating equipment within a building or over large distances outdoors.

The recently introduced 900 SS MicroHopper™ 900 MHz frequency-hopping spread spectrum data radio provides a high performance, low cost solution to many of the described problems. This miniature radio is ideal for applications such as hand-held data collection, facility access and security systems, irrigation systems, heavy equipment and crane controllers, remote cameras and electronic signs. The MicroHopper is a miniature version of the award-winning 900 SS Hopper digital transceiver released earlier and incorporates a proprietary Secure-Sync™ coding technology that dramatically reduces the overhead inherent in other coding methods. The software adds security, increases throughput efficiency and provides faster effective communication speeds at a much lower cost.

The 900 SS MicroHopper transceiver incorporates networking features typically found only in more expensive systems. For example, it supports multiple network configurations, including point-to-point, point-to-multipoint and multipoint-to-multipoint operation with both client-

[Continued on page 154]

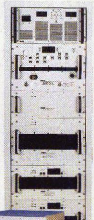
World Wireless Communications Inc. (WWC)
West Valley City, UT

COMTECH PST High Power Amplifiers

Reliability

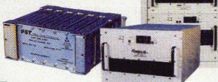
Are Your Key

Depend on PST's proven track record of reliability for your HIGH POWER AMPLIFIERS. Our versatile product line spans the frequency range of 1.5 MHz through 3 GHz with output power levels from 2 watts to multikilowatts.



Amplifier Series	Frequency Range	Power Output
Wireless Band Linears	800 to 3000 MHz	10 to 300 W
General Purpose Linears	1 to 2000 MHz	2 to 200 W
Class "AB" Linears	1.5 to 1450 MHz	100 to 1500 W
Class "C" Amplifiers	1750 to 2120 MHz	50 to 500 W
Pulse Amplifiers	200 to 1600 MHz	50 to 16,000 W

Let PST's experience and reliability in state-of-the-art solid state power amplifiers provide your next system solution.



COMTECH PST

ACCREDITED REGISTRAR ANSI-RAB

105 Baylis Road, Melville, NY 11747
Tel: 516-777-8900 Fax: 516-777-8877
E-mail: info@comtechpst.com
Web: www.comtechpst.com

ISO 9001 Registered KPMG
The Quality Advantage

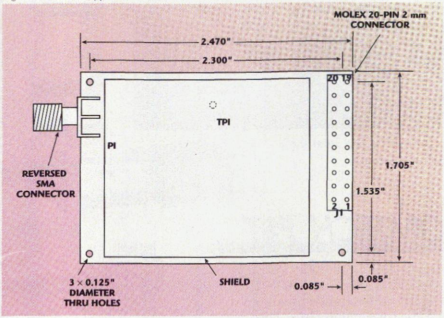
TABLE I

MICROHOPPER SPECIFICATIONS

Operating frequency (MHz)	902 to 928
Radio type	frequency-hopping spread spectrum digital transceiver
Modulation system	direct FM
Frequency control	PLL synthesizer, 100 kHz step size
Transport protocols	transparent or addressable (guaranteed delivery mode)
Mode	full duplex when using guaranteed delivery mode
Interface	asynchronous serial – TTL RS-232C
Channel capacity	25 channels, up to 1600 group codes
Channel spacing (kHz)	400
Repeating capability	user selectable up to seven radios in guaranteed delivery mode
RF data rate (max) (kbps)	20
Range* (m)	500 line of sight
Rx sensitivity (dBm)	–94
RF bandwidth (kHz)	300
System deviation (max) (kHz)	100
Input voltage (V DC)	5
Power consumption (W)	1.5
Current consumption (mA)	300
Output power (mW)	10, 50 and 100 (user selectable)
Connector	included in 20-pin header
Board size (")	1.750 × 2.470 × 0.375
Temperature range (°C)	–40 to +80
Antenna connector	SMA female
Antenna impedance (nom) (Ω)	50

*Range will vary depending upon antenna selection, board integration, physical environment and the OEM's device.

Fig. 1 The MicroHopper transceiver's mechanical outline.



server and peer-to-peer configurations. The MicroHopper transceiver extends its networking capabilities with a fully addressable guaranteed delivery mode. When operating in this mode, the receiver will confirm the successful receipt of each data packet. If the transmitter does not receive delivery confirmation within a specified time frame, it will automatically resend the data until the packet is successfully delivered. In addition, the MicroHopper radio can act as a repeater radio in the fully addressable mode, thus extending the network's range and overcoming difficult transmission environments.

Users also can create multiple independent networks via group codes. Using group codes, only radios within the assigned group may communicate with one another, thus isolating other networks of MicroHoppers as well as other radios. Additional benefits and features of the MicroHopper include Windows®-based software for radio configuration, industry-standard TTL serial or RS-232 interface versions and compliance with FCC Part 15 rules for unlicensed spread spectrum communications. The unit supports interface data rates from 2400 bps to 19.2 kbps with an over-the-air rate of 20 kbps, and effective communication distances of five miles (line of sight) are possible. ***Table 1*** lists the 900 SS MicroHopper transceiver's general specifications.

The 900 SS MicroHopper Developer Kit is available to aid potential users in evaluating the MicroHopper transceiver. The kit includes two 900 SS MicroHopper transceivers, two customer interface modules with RS-232 DB-9 connections, two flexible whip half-wave antennas with SMA connectors, serial cables and power supplies for both radios, a user's guide/quick start guide and an easy-to-use Windows configuration utility.

The MicroHopper circuit assembly measures just 2.50" × 1.75", as shown in ***Figure 1***, and sells for less than $100 each in original equipment manufacturer (OEM) quantities. Additional information may be obtained from the company's Web site at www.worldwireless.com.

World Wireless Communications Inc. (WWC), West Valley City, UT (801) 575-6600.

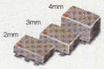
INNOVATIVE MIXERS

WOW!

•smaller size •better performance •lower cost 200kHz to 4200MHz from $1.99 (10-49)

it™ *innovative technology*

Searching high and low for a better frequency mixer? Then take a closer look at the Innovative Technology built into Mini-Circuits ADE mixers. ***Smaller size*** is achieved using an ultra-slim, patent pending package with a profile as low as 0.080 inches (2mm) in height. Electrically, ADE mixers deliver ***better performance*** than previous generation mixers through all welded connections and unique assembly construction which reduces parasitic inductance. The result is dramatically improved high frequency and IP2-IP3 performance. Plus, ADE's innovative package design allows water wash to drain and eliminates the possibility of residue entrapment. Another ADE high point is the ***lower cost***...priced from only $1.99 each (qty.10-49). So, if you've been searching high and low for a mixer to exceed expectations...ADE is *it*™



ACTUAL SIZE

ADE Mixers...Innovations Without Traditional Limitations!

ADE* TYPICAL SPECIFICATIONS:

Model	Height (mm)	Freq. (MHz)	LO (dBm)	Conv. Loss Midband (dB)	L-R Isol. Bandwide (dB)	IP3 (dBm) @ Midband	Price ($ea.) Qty. 10-49
ADE-1L	3	2-500	+3	5.2	55**	16	3.95
ADE-3L	4	0.2-400	+3	5.3	47**	10	4.25
ADE-1	4	0.5-500	+7	5.0	55**	15	1.99
ADE-1ASK	3	2-600	+7	5.3	50**	16	3.95
ADE-2ASK	3	1-1000	+7	5.4	45**	12	4.25
ADE-12	2	50-1000	+7	7.0	35	17	2.95
ADE-4	3	200-1000	+7	6.8	53**	15	4.25
ADE-14	2	800-1000	+7	7.4	32	17	3.25
ADE-901	3	800-1000	+7	5.9	32	13	2.95
ADE-5	3	5-1500	+7	6.6	40**	15	3.45
ADE-13	2	50-1600	+7	8.1	40**	11	3.10
ADE-20	3	1500-2000	+7	5.4	31	14	4.95
ADE-18	3	1700-2500	+7	4.9	27	10	3.45
ADE-3GL	2	2100-2600	+7	6.0	34	17	4.95
ADE-3G	3	2300-2700	+7	5.6	36	13	3.45
ADE-30	3	200-3000	+7	4.5	35	14	6.95
ADE-32	3	2500-3200	+7	5.4	29	15	6.95
ADE-35	3	1600-3500	+7	6.3	25	11	4.95
ADE-18W	3	1750-3500	+7	5.4	33	11	3.95
ADE-30W	3	300-4000	+7	6.8	35	12	8.95
ADE-1LH	4	0.5-500	+10	5.0	55**	15	2.99
ADE-1LHW	3	2-750	+10	5.3	52**	15	4.95
ADE-1MH	3	2-500	+13	5.2	50**	17	5.95
ADE-1MHW	4	0.5-600	+13	5.2	53**	17	6.45
ADE-12MH	3	10-1200	+13	6.3	45**	22	6.45
ADE-25MH	3	5-2500	+13	6.9	34**	18	6.95
ADE-35MH	3	5-3500	+13	6.9	33**	18	9.95
ADE-42MH	3	5-4200	+13	7.5	29**	17	14.95
ADE-1H	4	0.5-500	+17	5.3	52**	23	4.95
ADE-10H	3	400-1000	+17	7.0	39	30	7.95
ADE-12H	3	500-1200	+17	6.7	34	28	8.95
ADE-20H	3	1500-2000	+17	5.2	29	24	8.95

Component mounting area on customer PC board is 0.320"x 0.290".
Specified midband. ****Patent Pending.*

Mini-Circuits®

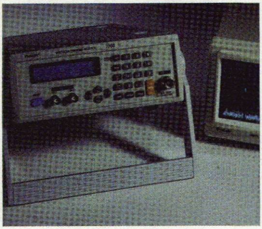
US 110 INT'L 111
CIRCLE READER SERVICE CARD

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

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

ISO 9001 CERTIFIED

F 267 Rev I



A 10 MHz to 1 GHz Spectrum Analyzer Adapter

The explosive growth in wireless instruments has made spectrum analyzers an indispensable tool for testing and troubleshooting wireless equipment and systems. Realizing the need for a moderately priced, fully functional spectrum analyzer, the model 7700 10 MHz to 1 GHz digitally synthesized spectrum analyzer adapter has been developed. This unique device connects to a dual-channel oscilloscope and converts it into a 1 GHz spectrum analyzer with all of the features and functions needed to make precise frequency and power measurements.

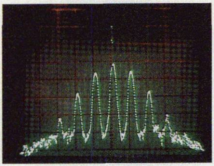
The model 7700 spectrum analyzer adapter is the front end of a spectrum analyzer, which includes the mixers, local oscillators, log amplifiers and synchronizing circuits. The user's oscilloscope provides the display and sweep circuits. This design results in a compact package that is easily transportable from site to site in a toolbox or under the user's arm. It also provides lower power consumption than most spectrum analyzers. The actual power consumption is less than 1 A.

The spectrum analyzer adapter has many applications and uses in the communication and service industries. It is also a valuable tool in technical school laboratories for demonstrating the principles of spectrum analysis by connecting a complex electrical signal to the RF input and displaying on an oscilloscope the resultant harmonic frequency components and their mathematical relationships. The solutions to Fourier transform problems also may be verified in the same manner. The unit can be put to use in a multitude of industrial applications, including checking and troubleshooting IF and RF circuitry in wireless products such as two-way radios, PCS and cellular telephones in addition to cable TV systems, wireless remotes, wireless microphones and video equipment.

All spectrum parameters, such as center frequency, resolution bandwidth and reference level, are accessed via menus displayed on a back-lit liquid crystal display. All menu items are selected from front-panel keys and their values can be entered or changed by numeric or up/down arrow keys, thus making setups fast and easy. In addition, two frequency

[Continued on page 158]

Protek Inc.
Northvale, NJ



▲ *Fig. 1 The display of a 100 MHz carrier modulated with a 20 kHz tone.*

markers can be selected from the menu. These markers may be moved to any position on the waveform via the front-panel keys to display the frequency and amplitude values.

The model 7700 offers features and functions critical to the needs of the wireless industry. These capabilities include zero span for monitoring the amplitude of a carrier signal in the time domain. This mode will display any variations in the carrier amplitude over a period of time. Thus, long-term trends and carrier irregularities may be observed and noted. The instrument also provides frequency spans from 2 kHz/div to 100 MHz/div. These spans are sufficient to cover most wireless applications in the industry today. The 2 kHz/div span is narrow enough for viewing small frequency deviations, closely spaced adjacent carrier signals and sidebands. It is also useful for testing RF output-type sensors where a change in the sensor input value produces a proportional change in RF carrier deviation. ***Figure 1*** shows the instrument's display of a 100 MHz carrier frequency modulated with a 20 kHz tone. The spectrum analyzer adapter's settings for this display are a 100 MHz center frequency with a 20 kHz frequency span and a –30 dBm reference level.

An average noise level of –140 dBm/Hz provides a noise floor as low as –105 dBm. This low noise level with a wide 120 dB input measuring range is critical for detecting and measuring weak fringe area interference signals as well as a receiver's basic sensitivity. ***Table 1*** lists the spectrum analyzer's key performance specifications. The unit operates from a 12 V DC (1.5 A) power adapter. A type N female connector is used for the RF input while the video output is via a BNC connector to the channel 1 oscilloscope input and a trigger output BNC to the channel 2 input. Accessories include an AC/DC adapter. A tracking generator and extended frequency range to 2.6 GHz are available as options.

TABLE I
KEY PERFORMANCE SPECIFICATIONS

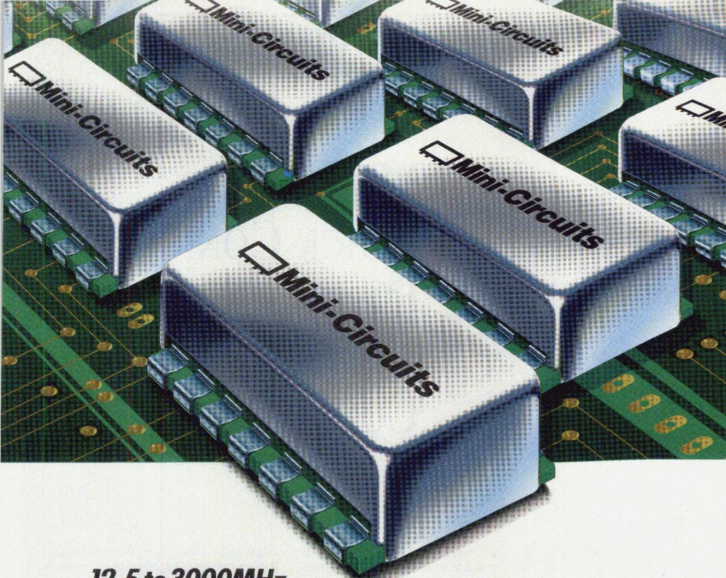
Frequency range	10 MHz to 1 GHz
Frequency resolution (kHz)	1
Frequency stability (ppm)	±10
Frequency spans	0 span, 2 kHz/div to 100 MHz/div
Resolution bandwidth	3 kHz, 30 kHz, 220 kHz and 4 MHz
Input range (dBm)	–100 to +20
Display range (dB)	75
Reference level range (dBm)	–30 to +20
Accuracy (dB)	±1.5 to 80 MHz
Linearity (dB)	±1.5 over 70 dB range
Flatness (dB)	±1.5 (10 MHz/div)
Average noise level (typ) (dBm/Hz)	–140
Phase noise (typ) (dBc/Hz)	–87 at 10 kHz offset
Input attenuation selections (dB)	0, 10, 20, 30, 40 or 50
Maximum input level (dBm)	+20

In addition, the company intends to release software that will allow the user to control the 7700 from a PC via an RS-232 interface or modem. The software also will download the spectrum and its settings (span, center frequency) and display them on the PC monitor.

The model 7700 spectrum analyzer adapter retails for $1600. Complete details and specifications are available upon request. Additional information can be obtained at the company's Web site: www.hcprotek.com or via e-mail: hcprotek@hcprotek.com.

Protek Inc.,
Northvale, NJ (201) 767-7242.

Circle No. 303



12.5 to 3000MHz
SURFACE MOUNT VCO's from $13^{95}

Time after time, you'll find Mini-Circuits surface mount voltage controlled oscillators the tough, reliable, high performance solution for your wireless designs. JTOS broadband models span 12.5 to 3000MHz with linear tuning characteristics, low -120dBc/Hz phase noise (typ. at 100kHz offset), and excellent -25dBc (typ) harmonic suppression. JCOS low noise models typically exhibit -132dBc/Hz phase noise at 100kHz offset, and phase noise for all models is characterized up to 1MHz offset. Miniature J leaded surface mount packages occupy minimum board space, while tape and reel availability for high speed production can rocket your design from manufacturing to market with lightning speed. Soar to new heights...specify Mini-Circuits surface mount VCO's.

ACTUAL SIZE

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

JTOS/JCOS SPECIFICATIONS

Model	Freq. Range (MHz)	Phase Noise (dBc/Hz) SSB@ 10kHzTyp.	Harmonics (dBc) Typ.	V_{tune}** 1V to:	Current (mA) @+12V DC Max.	Price $ea. (5-49)*
JTOS-25	12.5-25	-115	-26	11V	20	18.95
JTOS-50	25-47	-108	-19	15V	20	13.95
JTOS-75	37.5-75	-110	-27	16V	20	13.95
JTOS-100	50-100	-108	-35	16V	18	13.95
JTOS-150	75-150	-106	-23	16V	20	13.95
JTOS-200	100-200	-105	-25	16V	20	13.95
JTOS-300	150-280	-102	-28	16V	20	15.95
JTOS-400	200-380	-102	-25	16V	20	15.95
JTOS-535	300-525	-97	-28	16V	20	15.95
JTOS-765	485-765	-98	-30	16V	20	16.95
JTOS-1000W	500-1000	-94	-26	18V	25	21.95
JTOS-1025	685-1025	-94	-28	16V	22	18.95
JTOS-1300	900-1300	-95	-28	20V	30	18.95
JTOS-1550	1150-1550	-101	-20	***	30	19.95
JTOS-1650	1200-1650	-95	-20	13V	30	19.95
JTOS-1750	1350-1750	-101	-16	***	30	19.95
JTOS-1910	1625-1910	-97	-20	12V	20	19.95
JTOS-1950	1550-1950	-103	-14	***	30	19.95
JTOS-2000	1370-2000	-95	-11	22V	30 (@8V)	19.95
JTOS-3000	2300-3000	-90	-22	***	25 (@5V)	20.95
JCOS-820WLN	780-860	-112	-13	***	25 (@9V)	49.95
JCOS-820BLN	807-832	-112	-24	14V	25 (@10V)	49.95
JCOS-1100LN	1079-1114	-110	-15	***	25 (@8V)	49.95

Notes: *Prices for JCOS models are for 1 to 9 quantity. **Required to cover frequency range. ***Tuning Voltage for JTOS-3000 is 0.5 to 12V, JTOS-1550, JTOS-1750, and JTOS-1950 is 0.5 to 20V, and JCOS-820WLN and JCOS-1100LN is 0 to 20V. For additional spec information and details about 5V tuning models available, consult RF/IF Designer's Guide, our Internet Site, or call Mini-Circuits.

DESIGNER'S KITS AVAILABLE

K-JTOS1 $149.95 (Contains 1ea. all JTOS models except JTOS-25, -1000W, -1300 to -3000).
K-JTOS2 $99.95 (Contains 1ea. JTOS-50, -100, -200, -400, -535, -765, -1025).
K-JTOS3 $114.95 (Contains 2ea. JTOS-1300, -1650, -1910).

Mini-Circuits®

US 112 INT'L 113
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 234 Rev F

MICROWAVE QUICK CONNECT/ DISCONNECT COAXIAL CONNECTORS

When testing microwave devices it is desirable to have an RF connection that can be made quickly while providing low SWR, high isolation and, most importantly, repeatable measurements. In addition, the connection should be stable and not require external fixturing to ensure repeatability. Various patented quick disconnect coaxial connectors exist today; however, all of these designs employ relatively complex and costly methods for achieving a quick connect/disconnect feature.

A newly designed male slotted connector has been developed, which incorporates a compression ring that provides additional support to the slotted and spread fingers of the outer conductor, resulting in electrically repeatable couplings. The QT3.5mm™ Quick Test male connector (patent pending) is capable of being mated to a female connector and connected and disconnected using just a simple push on/pull off motion. The simplicity and ease of use of this new connector, plus its low manufacturing cost, provide the user with a low cost alternative to the more complex and costly methods currently available.

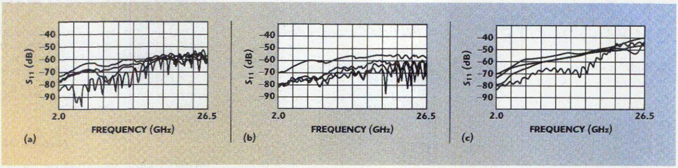
In addition, the connector may be used with an optional integral coupling nut that allows the option of a threaded coupling when performing calibration or measurement verification tasks. When used, the coupling nut offers an engagement of one-half to one-and-one-half threads, providing the ability to quickly thread or unthread the mating connectors or permitting a standard torque wrench to be used to complete the mating. Another variation of the connector employs a solid outer conductor structure with a compression ring.

The QT3.5mm connector can be used to measure devices that utilize various types or sizes of female connectors, such as SMA, 2.92 mm or 3.5 mm. The female connector of these connector series conventionally mates with a male connector that is screwed on and typically requires five or six full revolutions of the coupling nut to securely mate. This approach is also adaptable to other connector types such as N, TNC, 2.4 mm and other sexed connectors with similar construction.

The QT3.5mm Quick Test connectors are supplied in four configurations: the models 8006E1 with no nut, 8006E11 with a 3/8" nut, 8006E21 with a 9/16" nut and 8006Q1 with a guide sleeve. Other models are available that adapt to 7 mm, NMD3.5, N, NMD2.4 and 2.4

[Continued on page 163]

MAURY MICROWAVE CORP.
Ontario, CA



▲ *Fig. 1 QT3.5mm slotted/NMD3.5F connector repeatability; (a) torqued to 8 in/lb, (b) hand-torqued and (c) untorqued.*

TABLE I

QT3.5mm SPECIFICATIONS

Frequency range		DC to 26.5 GHz
SWR		product dependent
Repeatability	DC to 18 GHz	18 to 26.5 GHz
Push-on mode (dB)	> 50	> 35
Torque mode (dB)	> 50	> 50
Hand torqued (dB)	> 50	> 50

mm male and female connectors. ***Figure 1*** shows the repeatability of a QT3.5mm slotted/NMD3.5F connector torqued to 8.5 in/lb, hand-torqued and untorqued. ***Table 1*** lists typical specifications for the QT3.5mm male connector when torqued to 8 in/lb or hand-tightened.

Repeatability and life tests are currently underway. No degradation has been detected thus far after more than 2000 connections. The 2B-060 data sheet (available from the company) describes in detail the connectors and their performance parameters. A simple product demonstration may be arranged by contacting a company representative.

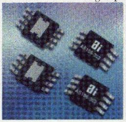
Maury Microwave Corp., Ontario, CA (909) 987-4715.

Circle No. 304

COMPONENTS

High Isolation Nonreflective SPDT Switch

The model AS186-302 positive control, GaAs FET IC single-pole, double-throw



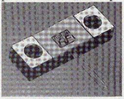
(SPDT) nonreflective switch provides high isolation of 50 dB at 0.9 and 1.9 GHz. Housed in a miniature MSOP-8 exposed pad package, the AS186-302 is an ideal building block for base station applications where synthesizer isolation is critical. The switch also can be used in conjunction with the model AS165-59 single-pole, single-throw switch to meet GSM synthesizer isolation requirements. Price: $3.25 (10,000).

Alpha Industries,
Woburn, MA (800) 290-7200.

Circle No. 215

Aluminum Nitride High Power Terminations

The model 32-7150 aluminum nitride high power terminations operate in the DC to



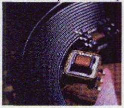
4 GHz frequency range with 60 W of power handling. Designed for applications where toxic beryllia ceramic substrates cannot be used, these nontoxic components are a good alternative solution. The units are available in sizes and configurations identical to standard BeO terminations. A flangeless PowerPak version also is available.

Florida RF Labs Inc.,
Stuart, FL (800) 544-5594
or (561) 286-9300.

Circle No. 219

Versatile Surface-mount Inductor

The model E66 miniature surface-mount inductor occupies 0.078-square-inch of circuit



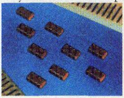
board space and can be wound as a common-mode choke, a high Q inductor or a pulse transformer. (Winding configurations can be either bifilar or separate.) The E66 provides 1.0 to 1000 µH of inductance with corresponding current ratings of 1000 to 150 mA. DCR range (max) is 0.01 to 3.50 Ω and operating temperature range is –20° to +105°C. Price: 65¢ (100,000). (Tape-and-reel is available through special order.) Delivery: stock to six weeks (ARO).

Associated Components Technology Inc.,
Garden Grove, CA (800) 234-2645.

Circle No. 217

Multiple Capacitor Array

The MultiValue Cap Array is a four capacitor array in a standard 0612 package that contains



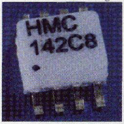
two caps of one value in the second and third positions and two caps of a second value in the first and fourth positions. The resulting symmetry enables greater ease in design and reduces board space by more than 50 percent. The individual values available within the array vary, but specific combinations include 100 pF/0.01µF (101/103) and 0.001 µF/0.1 µF (102/104). Ratios of up to 100 are possible in two capacitance values. Price: 22¢ (100,000). Delivery: stock to eight weeks (ARO).

AVX Corp.,
Myrtle Beach, SC (843) 946-0414.

Circle No. 218

6 - 15 GHz Double-balanced Mixer

The model HMC142C8 miniature, double-balanced mixer offers high dynamic range and

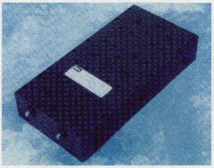


third-order intercept of +20 dBm and is capable of handling larger signal levels than most active mixers. Best suited for point-to-point microwave radio and very small aperture terminal ground equipment applications where small size and surface-mount compatibility are critical, the mixer can also be used as an up- or downconverter. Its MMIC design provides good balance in the circuit, resulting in high LO/RF and LO/IF isolation of > 30 dB and unit-to-unit consistency. Conversion loss is 8.5 dB. Housed in a nonhermetic, ceramic surface-mount package, the mixer also is available in tape-and-reel packaging.

Hittite Microwave Corp.,
Chelmsford, MA (978) 250-3343.

Circle No. 220

WLL Notch Filter



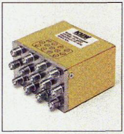
The model WSN-00049 high performance wireless local loop (WLL) notch filter is configured with passbands of DC to 2300 MHz and 2320 to 2500 MHz. Rejection is 40 dB over 10 MHz, passband power handling is 100 W CW and passband return loss is 10 dB (min). Designed for WLL and FCC type acceptance testing applications, the notch filter exhibits passband insertion loss of 2.0 dB (max). Operating temperature range is 0° to +50°C and storage temperature range is –40° to +85°C. SMA female connectors are included at all ports. Size: 10.0" × 4.85" × 2.75", excluding connectors.

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

Circle No. 221

6P7T Electromechanical Switches

The model KSW670E8B000 6P7T electromechanical switch for IMT2000 applications



operates up to 14 GHz with power handling capability of up to 200 W at 1 GHz. This multipole, multithrow switch measures 2.44" × 2.17" × 2.18" and can be used in switch matrix and test equipment applications. For reducing system size, the company also offers the model KSW67058B000 slim-type 6P7T switch which measures 2.40" × 1.42" × 2.13".

KMW Inc., Cerritos, CA (562) 926-2033.

Circle No. 222

Thermal Fusible Resistors

The FTR series cement, wirewound thermal fusible resistors incorporate a thermal fuse

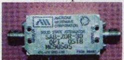
within its cement bases, which are designed to open in 20 to 30 seconds when current overloads and/or high ambient temperatures are reached. The resistors save space on crowded PC boards since the units perform functions usually required by separate over-current and over-temperature fusing devices. Seven models are available ranging from 1.5 to 3.5 W. Price: 40¢ to 69¢ (1000). Delivery: two to four weeks (ARO).

Laube Technology,
Camarillo, CA (888) 355-2823.

Circle No. 223

Switched Bit Step Attenuator

The model SAB-2DR/DT-A is an SP2T switched bit step attenuator that operates from



0.5 to 18 GHz (or from 10 MHz to 18 GHz). Insertion loss is 2.75 dB (typ), SWR is 1.9 and flatness is ±1.5 dB. Switching speed is < 40 ns. Supply voltages are +5 V, –12 V or –5 V at 50 mA. (Other voltages also are available.) The attenuators are available in step sizes of 3, 6, 10, 20, 30 and 40 dB or any combination. Weight: 0.75 oz. Size: 1.30" × 0.70" × 0.40".

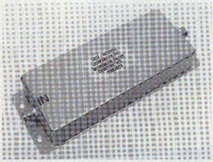
American Microwave Corp.,
Frederick, MD (301) 662-4700.

Circle No. 216

■ Low Drop-out Regulator

The model MIC39100 low drop-out (LDO) regulator for 3.3-to-2.5 V conversion features a low drop-out voltage of 500 mV. Manufactured in the space-saving SOT-223 package, the MIC39100 features fast transient response, reverse battery, and current limit and thermal shutdown. Maximum input voltage is 16 V and drop-out voltage at full load is 410 mV. Operating temperature range is –40° to +85°C.
Micrel Semiconductor Inc.,
San Jose, CA (408) 944-0800.
Circle No. 225

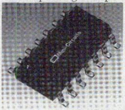
■ Lowpass Filter



The model 3322-W/DD (50) lowpass filter for head-end applications passes all sub-band channels up to channel W (36). Insertion loss is < 3 dB at channel W and rejection is > 50 dB from channel DD (40) to 1000 MHz. The lowpass filter eliminates unwanted channels for reinsertion purposes on upper channels. Intended for indoor use, the unit includes 75 Ω F connectors. (Weatherized housing for outdoor use and other connector options also are available.) Size: 1.00" × 2.25" × 6.00".
Microwave Filter Company Inc. (MFC),
East Syracuse, NY (800) 448-1666
or (315) 438-4747.
Circle No. 226

■ DC - 2.5 GHz High Isolation SPDT Switch

The model RSW-2-25P SPDT switch is capable of operating with positive switching voltage, thereby simplifying control signal generation. Midband isolation is 50 dB (typ), insertion loss is 1.0 dB (typ) and compression point at 1 dB is +27 dBm. Maximum RF input power is 1 W and control voltage is 0 to ±5 V. The switch is best suited for isolating transmitters and receivers. Price: $3.95 (10–49).



Mini-Circuits,
Brooklyn, NY (718) 934-4500.
Circle No. 227

■ Waveguide Flanges

The Pyraflat high vacuum waveguide flange system utilizes stainless-steel knife edges to capture a copper gasket, providing a fully bakeable ultrahigh vacuum joint. Designed specifically for RF imaging, directed energy industrial processing and high energy accelerators for particle physics research, the Pyraflat also provides a zero clearance flange joint configuration that minimizes waveguide wall discontinuities due to the copper gasket. Standard and custom flange sizes also are available for waveguide applications in the 450 MHz to 2.5 GHz frequency range. Custom bonded stainless-steel-to-copper flange transitions also are available.
Thermionics Vacuum Products Inc.,
Port Townsend, WA (800) 962-2310.
Circle No. 232

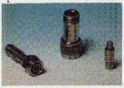
■ Voltage-variable Attenuators

The models AT10-0009, AT10-0017, AT10-0019 and AT65-0008 voltage-variable attenuators (VVA) operate over the 800 to 1000 MHz, 1700 to 2000 MHz, 50 to 1000 MHz and 900 to 2250 MHz frequency bands, respectively. These PIN diode-based VVAs are particularly well suited for multichannel communication and high volume applications. Available in standard Joint Electron Device Engineering Council plastic surface-mount packages, the attenuators offer higher linear operating power and an increase of 15 to 20 dB of third-order input power over traditional GaAs VVAs.
M/A-COM,
a subsidiary of Tyco International Ltd.,
Lowell, MA (800) 366-2266.
Circle No. 224

NEW PRODUCTS

Voltage Passing Attenuators

The model 9093 voltage passing attenuators operate in the 500 MHz to 2 GHz frequency range with attenuation values of 10 dB and 20 dB. The units attenuate RF signals and pass DC voltage and current while offering 2 W of RF power. DC voltage is 100 V (max) and current is 1 A (min). Type N, SMA and TNC connectors are available.



Inmet Corp., Ann Arbor, MI (888) 244-6638.

Circle No. 277

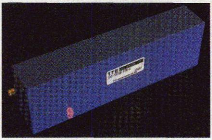
High Power Transmit Filter

The model FF6434-1 high power transmit filter is designed specifically for transmit band filtering in land/mobile radio base stations. Insertion loss is < 0.65 dB, return loss is > 25 dB (max) and rejection is > 20 dB (min) at 823 and 900 MHz. Power handling is rated at 200 W CW and 900 W (pk). Type-N connectors are included, but alternate interfaces also are available. Size: 4.13" × 3.21" × 1.00", including the mounting flange.

Sage Laboratories Inc., Natick, MA (508) 653-0844.

Circle No. 231

Standard Combline Filters



The 315 series combline bandpass filters cover the 700 to 3500 MHz frequency range. The five-pole Chebyshev design features a minimum 1 dBc bandwidth of 1.5 percent at the center frequency. (Any center frequency can be specified from 700 to 3500 MHz.) Price: less than $400 (prototype quantities). Delivery: two weeks (ARO).

TTE Inc., Los Angeles, CA (800) 776-7614 or (310) 478-8224.

Circle No. 233

Wireless Isolator

The model CIC01A1723-01 wireless isolator for amplifier output stage protection operates over the 1700 to 2300 MHz frequency range. Insertion loss is 0.3 dB (max), isolation is 22 dB (min) and SWR is 1.15 (max). Input power is rated at 25 W and operating temperature range is 0° to +55°C. Delivery: stock.

Narda Microwave-West, a division of L-3 Communications, Folsom, CA (916) 351-4500.

Circle No. 228

Drop-in Isolator

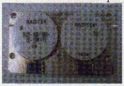
The model 0380IED high temperature, broad bandwidth, drop-in isolator provides 20 dB of isolation with low insertion loss of 0.4 dB over the 3.4 to 4.2 GHz frequency bandwidth. (Isolators and circulators in other frequency bands also are available.) The circuit tabs are designed to offer high reliability during circuit assembly. SWR is 1.25. Operating temperature range is –20° to +85°C and storage temperature range is –50° to +125°C. Size: 0.75" × 0.75" × 0.25". Delivery: stock.

Nova Microwave, Morgan Hill, CA (408) 778-2746.

Circle No. 229

1805 - 1880 MHz Dual Isolator

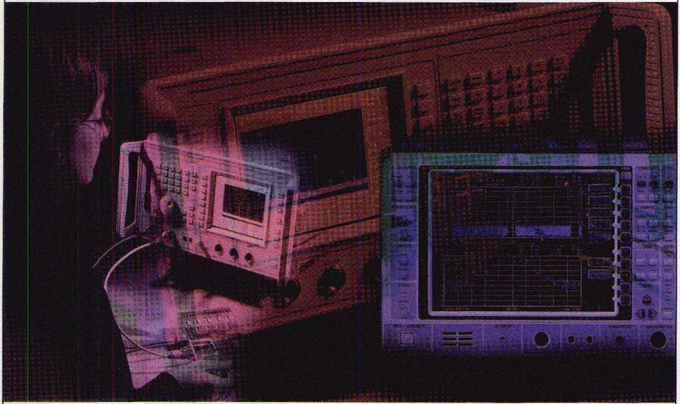
The company's dual isolator operates in the 1805 to 1880 MHz frequency band and is designed to provide low insertion loss at an affordable cost. Reverse power rating is up to 50 W and typical isolation is > 45 dB. (Similar stripline models are available up to 3 GHz.)

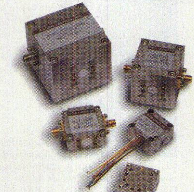


RADITEK, San Jose, CA (408) 266-7404.

Circle No. 230

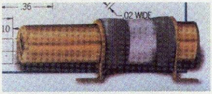
[Continued on page 168]





NEW PRODUCTS

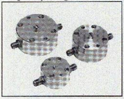
Miniature Trimmer Capacitors



The model A1_12 miniature trimmer capacitors are offered in printed circuit board and surface-mount technology mountings. With 13 turns of adjustment and positive stops, the capacitors are best suited for tuning applications in amplifiers, filters and oscillators. Qs are > 1000 at 200 MHz and self-resonance is 1.2 GHz at 12 pF. High voltage and nonmagnetic versions also are available. Price: $4 (> 1000).
Voltronics Corp.,
Denville, NJ (973) 586-8585.
Circle No. 234

Mechanical Phase Shifters

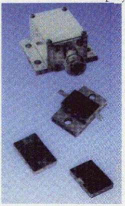
The 980 series mechanical phase shifters offer frequency ranges from DC to 3, 7 and 12 GHz



with different incremental phase shift adjustments. Optimized for wireless original equipment manufacturer applications, the shifters are well suited for phase trimming in densely packaged systems with minimum accessibility. A self-locking mechanism eliminates the need for locking nuts. SWR is 1.45 and input power is rated at 10 W. Operating temperature range is –50° to +85°C and storage temperature range is –50° to +125°C. Ruggedized SMA connectors also are included.
Weinschel Corp.,
Frederick, MD (800) 638-2048
or (301) 846-9222.
Circle No. 235

Attenuators and Terminations

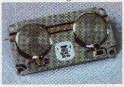
These attenuators and terminations are manufactured with the company's T^2 copper technology,



which reduces material leaching and provides increased connection reliability, thereby offering an affordable solution for requirements demanding increased temperature capabilities and greater tensile strength. Manufactured with a cost-effective direct bond connection, the attenuators and terminations have greater tensile strength, greater connection reliability and increased resistance to lead peeling than conventional soldered connections. The company's proprietary manufacturing process bonds copper thick-film conductors to thick film at 900°C, eliminating the possibility of lead movement during installation.
Bird Component Products (BCP),
Largo, FL (727) 547-8826.
Circle No. 274

Dual-junction Drop-in Isolator

The model 2E4NR dual-junction drop-in isolator features high isolation and lower loss characteristics



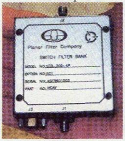
than two single-junction devices in series. Designed specifically for wireless base station applications, the isolator conserves space in circuit design and operates in the 0.80 to 0.96 GHz and 1.80 to 2.70 GHz frequency ranges. Standard loads handle 60 W forward and 60 W reverse. Options for termination type and location, power handling, mounting holes, broader temperature ranges and circulation direction are available upon request.
Renaissance Electronics Corp.,
Boxborough, MA (978) 263-4994.
Circle No. 269

Three-way Power Splitter

The model D3-14FN three-way power splitter operates in the 800 to 2200 MHz frequency range and evenly splits high power signals with minimum reflections, passive intermodulation or insertion loss up to 500 W average power. Its mechanical shape allows simple attachment to a pole or wall using the bracket provided, and the hex-style N connectors allow consistent tightening to a specified torque. Designed specifically for mini, micro and high power base stations, and Leaky-Line applications, the reactive power splitters are more ruggedly constructed than conventional power splitters with no resistors to burn out, fewer solder joints for enhanced reliability and less power back to the transmitter.
Microlab/FXR,
Livingston, NJ (973) 992-7700.
Circle No. 278

Switch Filter Bank

The model SFB-200-4P microminiature switch filter bank operates from 50 MHz to



3 GHz while offering 60 dB of isolation per channel. Insertion loss is –2.5 dB and SWR is 1.5 (typ). The switch operates from a single +5 V DC at 200 mA with TTL control logic. (Other logic is available.) Size: 2.50" × 2.50" × 0.50", including removable SMA connectors. (Other frequencies and options are available.)
Planar Filter Co.,
Frederick, MD (301) 662-7024.
Circle No. 281

High Dynamic Range SWR Detector

The model P-2000 SWR detector has 50 dB of forward power dynamic range and 20 dB of re-

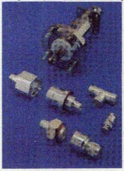
turn loss range. The P-2000, in conjunction with a high directivity directional coupler, is intended for use as an antenna monitor in mobile phone base stations or other transmitters where large variations in output power occur. The unit has a wide bandwidth from 25 MHz to 2 GHz, making the device well suited for spread spectrum applications, and operates on a single +12 V supply. Output voltage is proportional with the measured return loss in decibels. Custom options for digitizing monitor signals are available.
Polar Lab,
Rodovre, Denmark +45 3672 7245.
Circle No. 282

Waveguide Ceramic Block Filters

These high dielectric constant, high power and high Q ceramic block waveguide filters are extremely temperature stable and compact in size. Designed specifically for AMPS and PCS diplexer, trunking/repeater, and GSM applications, the filters are available in surface-mountable form or with SMA interface. The filters can be custom designed to customer's specifications.
Solarr/Polar LLC,
Albuquerque, NM (505) 792-3878.
Circle No. 284

RF Coaxial Connector Adapters

These custom fabricated RF coaxial connector adapters can solve a variety of interface prob-

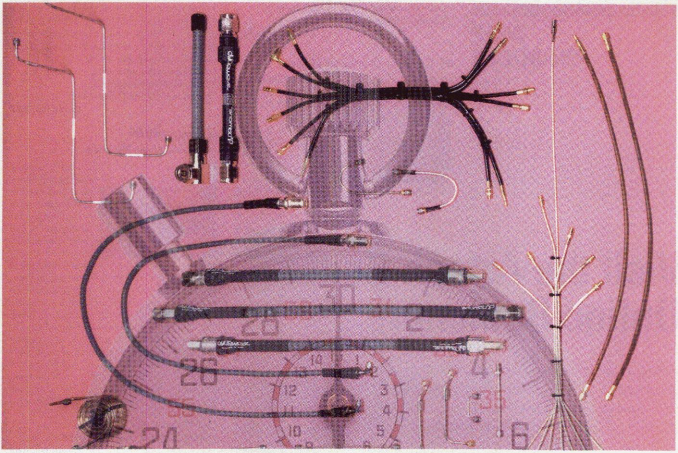


lems, including between series or in-series gender changing, converting standard connectors into quick-disconnect types and compatibility between large to small series connectors and incompatible plugs, jacks and receptacles. Manufactured to customer specifications, these adapters include LC to N, LC to QDS, QDM to N, QDM to BNC and many other combinations. Materials, back-end plating, insulators and gaskets can be specified, and standard tooling exists for more than 100 different types of connectors with interfaces per MIL-C-39012 an MIL-STD-348.
Tru-Connector Corp.,
Peabody, MA (800) 262-9878.
Circle No. 288

Electromagnetic Interference Shield

The BOLDT SHIELD II™ standard off-the-shelf electromagnetic interference (EMI) shield features a unique design that provides easy access to inspect or repair electronic components without having to de-solder the SMT

[Continued on page 170]



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

NEW PRODUCTS

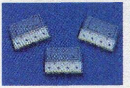
shield. The BOLDT SHIELD II combines high shielding performance, SMT reliability and newly added flexibility for prototype adjustment, allowing fast time to market, and lightweight shields and contacts at a low installation cost. Packaged in standard EIA410 tape-and-reel or automated board level installation, the unit is available in JEDEC sizes, including 52-pin quad flat pack, 256 position ball grid array and 84-pin plastic leadless chip carrier packages.

Boldt Metronics, a unit of BMI Inc., Palatine, IL (847) 934-4700.

Circle No. 272

■ Ceramic Bandpass Filters

The 301-1X series ceramic bandpass filters include the model 301-10010 for receive and the



model 301-10011 for transmit and operate at center frequencies of 836.5 and 881.5 MHz, respectively. Primarily used in CDMA transmitters and receivers for base station applications, the four-pole, surface-mount filters offer low insertion loss of –3.0 with a bandwidth of ±15 MHz and SWR of 1.7 (max). The filters' small size provides a low profile for efficient assembly integration. Tape-and-reel packaging is available.

Trak Communications Inc., Advanced Filter Solutions, Frederick, MD (813) 884-1411.

Circle No. 287

■ Compact RF Transceiver Module

The model TR-XXX-SC transceiver module utilizes an advanced synthesized superhetero-

dyne architecture and features a direct interface for analog and digital information, fully qualified UART compatible data output, received signal strength indication, low power consumption, wide operational voltage, on-board transmit and receive switching, and surface acoustic wave front-end filtering. The transceiver offers fast settling and turnaround times and can accommodate data rates up to 33.6 kbps, making the transceiver well suited for a range of bi-directional communication requirements. Housed in a compact, through-hole package, the transceiver requires no tuning or external RF components, allowing for straightforward integration. Price: \$29.70 (1000).

Linx Technologies, Grants Pass, OR (541) 471-6256.

Circle No. 289

■ Magnetically Shielded Inductors

The DS1608BL series tiny shielded inductors feature high breakdown voltage and good efficiency with 10 to 60 percent lower DC resistance than existing inductors. Designed specifically for demanding backlighting applications, these magnetically shielded inductors are heat resistant to ensure troublefree assembly and reflow soldering. Seven inductance values ranging from 1 to 10 mH are available. Custom inductors also are available. Price: 65¢ (10,000). Delivery: stock.

Coilcraft, Cary, IL (847) 639-6400.

Circle No. 293

AMPLIFIERS

■ Pulsed Amplifier/Transmitter

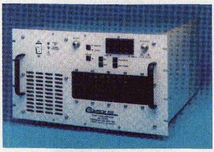
The series 1134 pulsed amplifier/transmitter operates over the 1030 to 1090 MHz frequency range with a frequency stability of ±10 kHz over the operating range. RF power is rated up to 2500 W (pk) and duty cycle is up to 10 percent. Harmonic suppression is 30 dBc, pulse

[Continued on page 172]

NEW PRODUCTS

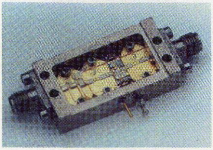
width is 32 µs (max) and operating temperature range is –45° to +75°C.
Technical Services Laboratory Inc. (TSL), Fort Walton Beach, FL (850) 243-3722.
Circle No. 243

50 W GaAs FET Power Amplifier



The model ARD88258-50 power amplifier operates over the 800 to 2500 MHz frequency band with 50 W of output power at 1 dB compression point. Gain is 47 dB (min) with a noise figure of 10 dB (typ). An integral IEEE-488 interface provides full monitoring and control of all amplifier functions.
Comtech PST, Melville, NY (516) 777-8900.
Circle No. 236

PCS and Broadband Amplifiers

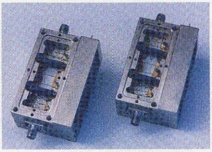


The models JCA12-PC08 and JCA08-B01 amplifiers cover the 1710 to 1910 MHz and 0.1 to 8.0 GHz frequency range, respectively. The JCA12-PC08 exhibits nominal gain of 40 dB, noise figure of 1.3 dB (typ), gain response of ±0.5 dB (typ) and IP3 of +42. Input/output SWR is 2.0. This unit features a compact, drop-in style package. The JCA08-B01 features a minimum gain of 25 dB, gain flatness of ±1.5 dB, power output of +20 dBm and noise figure of 3.0 (typ). Input/output power SWR is 2.0. This unit includes SMA removable connectors for drop-in and microstrip applications. Both units can be customized to provide optimal performance for a customer's individual requirements.
JCA Technology Inc., Camarillo, CA (805) 445-9888.
Circle No. 237

Cellular and PCS Low Noise Amplifiers

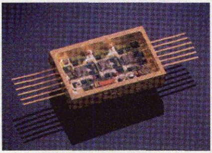
These compact, dual-low noise amplifiers (DLNA) offer good noise figure and intercept performance. The DLNA packages feature high isolation and low current operation and offer typical noise figures of 1 dB. Typical intercept point is greater than +40 dBm. Available in both low and high gain models, the amplifiers are well suited for OEM cellular base stations, and PCS mini- and microcells as well as AMPS, GSM, TDMA and CDMA formats.
Narda Microwave-East, a division of L-3 Communications, Hauppauge, NY (516) 231-1700.
Circle No. 239

8 - 12 GHz Amplifier



The model MSH-6642601 amplifier delivers output power of 1 W at a 1 dB compression point. Operating from 8 to 12 GHz, the amplifier can be used as a traveling-wave tube driver and on testing platforms for military and commercial applications. The amplifier also includes an internal voltage regulator and operates at +15 V DC while providing over-voltage and reverse-polarity protection. Noise figure is 3.0 (max), gain is 40 dB and input/output SWR is 2.0. Designed with GaAs FETs and hybrid technology, the amplifier is unconditionally stable. (Low phase and TTL designs also are available.) Delivery: stock to four weeks (ARO).
Microwave Solutions Inc., National City, CA (619) 474-7500.
Circle No. 238

210 - 710 MHz Log Amplifier



The model MCWL-4-4562 wideband, subminiature logarithmic amplifier instantaneously covers an ultrawide RF input frequency range of 200 to 700 MHz. Log linearity is ±1.0 dB (typ), log video slope is 30 mV/dB ±10 percent as defined by the best fit straight line of video output voltage. SWR is less than 2.0 and limited IF output power is –2 dBm (nom) measured over a typical input signal range of –65 to +5 dBm. The unit requires a power supply of ±5 V with total consumption of less than 1 W and is best suited for next-generation electronic warfare and high performance commercial applications. Price: $1100 (5–9).
Signal Technology, Olektron Operation, Beverly, MA (978) 524-7211.
Circle No. 241

Medium Power RF Amplifiers

The models PA512 and SMPA512 medium power RF amplifiers operate in the 10 to 500

MHz frequency range while generating up to +27.5 dBm at 1 dB compression point. Third-order intercept point is +33 dBm and small-signal gain level is 17 dB. The units are available in hermetic packaging in both TO-8 and surface mount. An SMA connector version is optional.
Stellex Microwave Systems Inc., Palo Alto, CA (800) 321-8075.
Circle No. 242

RF Power Amplifier

The model GRF2035 high power, solid-state RF power amplifier utilizes linear power devices that provide good linearity, high gain and wide dynamic range. Designed for linear applications in the PCS frequency range, the amplifier also features a built-in, voltage-regulated bias supply, and electromagnetic and RF interference filters. High efficiency operation is achieved by employing unique microstrip networks and advanced GaAs FET devices.
Ophir RF, Los Angeles, CA (310) 306-5556.
Circle No. 240

Broadband Solid-state Power Amplifier

The model P/N 30005-201 high power, broadband solid-state power amplifier (SSPA) operates from 15 V DC with quiescent current of 2.0 A. Designed specifically for use in commercial or military systems, the SSPA has a 1 dB compression

point of 39 dBm. Noise figure is less than 4 dB and power-added efficiency is greater than 25 percent. Gain is > 20 dB from 1.0 to 3.2 GHz, gain flatness across any 200 MHz bandwidth is < ±0.5 dB, input SWR is < 2.0 and output SWR is < 1.5. Input and output connectors are SMA female standard. Size: 6.50" × 3.25" × 1.00".
Aethercomm Inc., San Marcos, CA (760) 598-4340.
Circle No. 273

DEVICES

RF Power Transistors

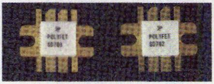
The model PTF 10149 RF power transistors exhibit a linearity of ±0.25 dB over the 920 to 960

[Continued on page 174]

NEW PRODUCTS

MHz band and employ the company's GOLDMOS technology which significantly improves RF performance. Best suited for GSM mobile phone base station transmitters, the transistors offer output power of 70 W and gain of 16 dB. The rugged units operate from a standard 28 V supply and have a minimum drain-source breakdown voltage of 65 V. Load mismatch tolerance is 5 and class AB two-tone third order intermodulation distortion is –39 dBc at 20 W peak envelope power.
Ericsson Microelectronics, Richardson, TX (877) 465-3667.
Circle No. 244

■ MOSFET Transistors



The S series MOSFET transistors operate up to 500 MHz while providing 90 and 120 W of RF power. Designed for both narrow and wideband data and voice communication applications, the transistors exhibit a low C_{rss}. Data sheets, S parameters and SPICE models are available.
Polyfet RF Devices, Camarillo, CA (805) 484-4210.
Circle No. 245

■ 30 GHz SiGe Bipolar Transistors

The model HBT30 series silicon germanium (SiGe) low phase noise, high frequency transistors are designed for oscillator applications up to 16 GHz. The device exhibits low 1/f noise of –142 dBc/Hz at 100 Hz offset and provides +17 dBm output power at the 1 dB gain compression point. Operated from a single supply voltage with appropriate external passive components, the transistors offer > 50 percent power-added efficiency when used as an amplifier and provide high thermal conductivity and low junction temperature.

SiGe Microsystems Inc., Ottawa, Ontario, Canada (613) 748-1334.
Circle No. 315

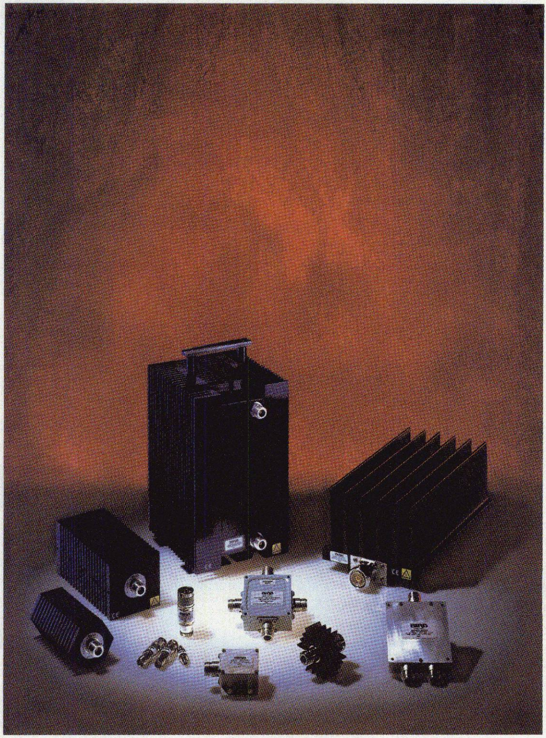
■ High Linearity LDMOS Power Transistors

These high linearity power transistors are based on laterally diffused metal oxide silicon (LDMOS) technology that supports designs for

[Continued on page 176]

B C P

The Component Company



Attenuators

requency Ranges
C - 18 GHz

ower Ratings
- 1,000 Watts

B Rating
1, 02, 03, 06, 10, 20,
0

onnectors
NC, IEC 7/16, N Type,
MA, TNC

Loads

requency Ranges
C - 6 GHz

ower Ratings
- 1,000 Watts

onnectors
NC, IEC 7/16, N Type,
MA, TNC

ivider / Combiners

requency Ranges
60 - 2,000 MHz

ower Ratings
to 150 Watts

onnectors
MA, N Type

Plus application specific designs for your demanding requirements.

B C P
10950 72nd Street N., Suite 107
Largo, FL 33777-1527
Phone: 727-547-8826 Fax: 727-547-0806
www.birdfla.com E-mail: sales@birdfla.com

NEW PRODUCTS

emerging third-generation markets, CDMA and wideband CDMA. Fabricated with gold metallization, gold bond wire interconnects and gold-plated packages, the transistors are tuned for communication frequencies from 800 to 2400 MHz with power levels from 10 to 120 W. Designed specifically to meet the demands of today's linear communication systems, the devices offer high reliability at a reduced system cost.
Stanford Microdevices Inc. (SMI), Sunnyvale, CA (408) 616- 5400, ext. 406.
Circle No. 246

SOFTWARE

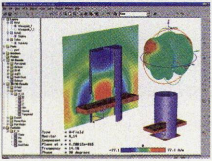
EDA Simulation Software

The Advanced Design System (ADS) electronic design automation (EDA) Release 1.3 software provides real-time interactive tuning of multiple parameters, analysis and synthesis of transmission lines, filter synthesis, matching network synthesis, improved noise analysis and faster large-scale circuit envelope simulations. The software operates on most UNIX system platforms as well as PCs using Windows® 95, 98 and Windows NT 4.0 systems. Price: starts at $21,000.
Agilent Technologies, Palo Alto, CA (800) 452-4844, ext. 6850.
Circle No. 253

Harmonic Load-pull Simulator

The Web-based Harmonic Load-pull Simulator (HeLPS) is a next-generation RF/microwave design tool that dramatically reduces design time and lowers costs to improve circuit performance. HeLPS utilizes the company's proprietary large-signal modeling technology and standard SPICE models to allow designers to perform first-round optimization of circuits without prototyping or testing in hardware. The software solution uses a standard Internet browser and Java Apple-based graphical user interface to determine optimum circuit design parameters.
Gigahertz Design Technology Inc., Los Altos, CA (650) 533-7501.
Circle No. 254

Microwave Studio Software



The CST MicroWave Studio (MWS) (version 2) is a state-of-the-art software tool designed specifically for the calculation of high frequency fields on a Windows-based PC. The software incorporates the Perfect Boundary Approximation™, an extension of the Finite Integration technique, for precision and performance; a modeller that enables the fast definition of complex structures; a three-dimensional Eigenmode solver; and built-in power macro language, which allows thorough integration of MWS into Windows. Typical applications of MWS include the simulation of waveguides, couplers, power splitters, filters, planar structures, connectors and antennas.
CST of America Inc., Cambridge, MA (617) 576-5857.
Circle No. 270

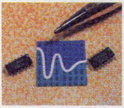
INTEGRATED CIRCUITS

DC/DC Converter

The company's DC/DC converter has been integrated into the Palm VII™, the first handheld organizer equipped with a wireless antenna that allows users to access the Internet, conduct e-commerce transactions, and send and receive instant messages. The company's patented DC/DC converter design provides the Palm VII organizer with a small, highly efficient power management IC. Manufactured using GaAs MESFET technology, the DC/DC converter performs at high frequencies and uses an oscillator that operates outside of the audio band. Housed in an SOT-25 package, the converter measures less than 3 mm × 3 mm.
ANADIGICS Inc., Warren, NJ (908) 668-5000.
Circle No. 247

Fully Integrated Downconverter

The model C2304 fully integrated GaAs MMIC RFIC downconverter is designed for



2.4 GHz industrial, scientific and medical band applications where low cost and high volume manufacturing are primary concerns to original equipment manufacturers in the digital wireless communications markets. The downconverter features gain of 26 dB, noise figure of 4 dB, output IP3 of 27 dBm over a single voltage supply of +5. Housed in an industry-standard SOIC-14 package, the unit comes with separate RF amplifier, mixer/LO amplifier and IF amplifier cells.
Pacific Wireless, Aptos, CA (831) 419-5119.
Circle No. 248

MMIC Chipset Solution

The models CHV2241 VCO, CHV2242 multifunction chip and CHM2179 single-channel mixer comprise a complete MMIC chipset solution for frequency-modulated continuous wave radar. The CHV2241 provides a 38 GHz signal output, a frequency tuning range from 150 MHz to 38 GHz, phase noise better than –75 dBc/Hz at 100 kHz from carrier and output power of 7 dBm. The CHV2242 combines a reference oscillator at 19 GHz and a second-order harmonic mixer at 38 GHz. The CHM2179 offers conversion loss of 7.5 dB and noise figure of 13 dB at 1 MHz IF. The combination of the three parts provides radar manufacturers with optimized chip size, on-chip self-bias circuits, high level performance and a cost-effective solution.
United Monolithic Semiconductors (UMS), Orsay, France +33 (1) 69 33 03 35.
Circle No. 249

Small Footprint Synthesizer

The model PSS-861 small footprint synthesizer for wireless applications operates over the 860 to 925 MHz frequency range with a current of less than 35 mA and a 5 V supply. Phase noise is –102 dBc/Hz at 10 kHz offset and –122 dBc/Hz at 100 kHz offset from the center frequency. Harmonic suppression is better than 10 dBc and spur suppression is better than 65 dBc. Operating temperature is –40° to 85°C. Size: 0.75" × 0.75".
Princeton Electronic Systems Inc. (PES), Princeton, NJ (609) 275-6500.
Circle No. 280

ANTENNAS

10 - 40 GHz Radio Antennas

The FlatFire™ point-to-point radio antennas provide superior sidelobe and gain characteristics while eliminating the conventional bulky shroud, resulting in a smaller, more rugged, attractive antenna. The antennas exceed all FCC, ETSI and BAPT requirements as well as EIA-195-C and EIA-222-F standards. Although well suited for indoor mounting, the antennas are designed to survive severe outdoor environments.
Gabriel Electronics Inc., Scarborough, ME (207) 883-5161.
Circle No. 276

Airborne Helical Array Antenna

The model 9930-800 airborne helical array antenna comprises eight individually sealed helix

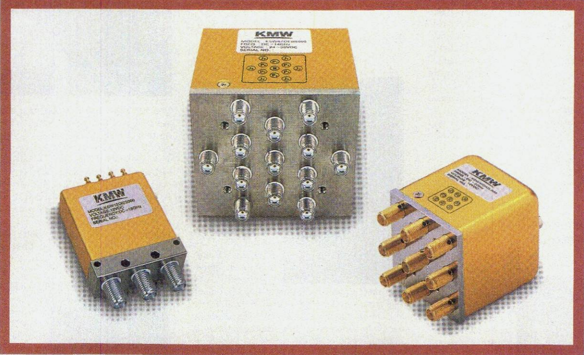
elements arranged in a ring while a microstrip feed network is used to combine the elements electrically. Operating in the 2200 to 2290 MHz frequency range, the antenna offers 100 W CW of power handling, gain of 20 dBi and SWR of 1.5 with right-hand circular polarization. A base plate is provided at the connector end of the array for mounting provisions. Type N female connectors are included.
Seavey Engineering Associates Inc., Pembroke, MA (781) 829-4740.
Circle No. 283

Biconical and Log Periodic Antenna

The model EM-6917B Biconicalog antenna is a hybrid combination of the industry-standard biconical and two log periodic antennas delivering both 26 MHz to 3 GHz frequency cover-

[Continued on page 178]

Designed for Ultimate Quality



Your Complete Switching Solution from KMW

■ 6P7T switch is designed for IMT2000 (6-sector Redundancy)

Product Code No.	KSW12O12S000	KSW67O4AB001	KSW45O48L000
Switch Type	SPDT	6P7T	4P5T
Frequency Range	DC ~ 18GHz	DC ~ 3GHz	DC ~ 3GHz
Insertion Loss (Max.)	0.2 ~ 0.5dB	0.2dB	0.2dB
VSWR (Max.)	1.15:1 ~ 1.5:1	1.15:1	1.15:1
Isolation (Min.)	80 ~ 60dB	80dB	80dB
Operating Mode	TTL Latching with IND.	Latching with IND.	Latching
Actuating Voltage /Current (Max.)	12Vdc ± 10% /240mA (@12Vdc, 25°C)	20 ~ 30Vdc /95mA (@24Vdc, 25°C)	24 ~ 30Vdc /85mA (@26Vdc, 25°C)
I/O Port Connector	SMA(F) / SMA(F)	SMA(F) / SMA(F)	SMA(F) / SMA(F)
RF Power Handling	100W CW (@1GHz)	200W CW (@1GHz)	250W CW (@1GHz)
Dimension (inch)	1.339*1.575*0.528	2.441*2.043*2.177	1.626*1.874*1.626

Higher Frequency available on Multi-Pole Multi-Throw, up to 18GHz
Power Handling capability of 4P5T Switch, up to 250W CW & 4Kw Peak @1GHz
Slim type 6P7T Switch, 2.409*1.417*2.216 (inch), also available.

■ Available Options

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

■ 5 million life cycle SPDT switch is available now.

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

CIRCLE 66 ON READER SERVICE CARD

KMW
RF & Microwave Products

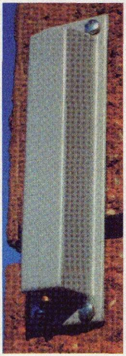
NEW PRODUCTS

age and high power handling capability. The EM-6917B eliminates the need for adjustments or switching antennas in most test applications up to 3 GHz without comprising power handling capability for transmit applications. The antenna is supplied with an integral balun that minimizes the effect of cable placement on measurements and is individually calibrated for field strength measurements from 26 GHz to 3 GHz. Telescopically collapsible biconical elements are available for improved performance at lower frequencies.
Electro-Metrics Inc.,
Johnstown, NY
(518) 762-2600.

Circle No. 298

Wide Beamwidth Panel Antennas

These high performance wide beamwidth panel antennas for 2.4 GHz wireless local area network (LAN) applications are available in seven models with 180° horizontal beamwidth and gains of 3.5, 6.0, 7.5, 8.5, 9.5, 10.5 and 11.5 dBi. SWR is less than 1.5 over 2.4 to 2.483 GHz. The antenna's length varies from 4.5" to 20" and all of the antennas have the same width (2") and thickness (1"). The antennas are bottom-fed with SMA, N, TNC or other connector types.



SuperPass Company Inc.,
Waterloo, Ontario, Canada
(519) 886-5186.

Circle No. 286

Integrated Mast Antenna

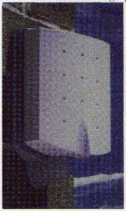
This integrated mast antenna comprises three antennas in the 30 to 420 MHz frequency range based on a 12 m fiberglass mast. The antennas are guyed at 5 and 10 m, supporting the mast against wind loading and the ground screen for the lowest frequency antenna. The fiberglass mast consists of 12 1 m sections, allowing the antenna to be broken down to a convenient size for portability. Total weight is 2 kg, permitting one person to carry the entire antenna system. The base plate is hinged and can be pegged into the ground for fast erection.

Poynting Innovations,
Braamfontein, Johannesburg, South Africa
+27 11 403 0380.

Circle No. 297

Medium Gain Antennas

The DirectLink™ series medium gain antennas offer five mounting options to optimize challenging installation situations, including a ±30° articulating wall mount, standard wall mount, mast mount and universal wall/mast mount, which permits up to ±90° of vertical or horizontal main lobe steering. The model S57212-AMP10SMF antenna is designed specifically for transmission and reception of linearly polarized signals in the 5725 to 5875 MHz industrial, scientific and medical band. The antenna uses a two-element patch array to provide a minimum gain of 12 dBi across the frequency range with a front-to-back ratio of better than 25 dB.

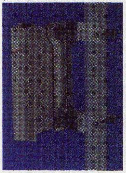


Cushcraft Corp.,
Manchester, NH
(603) 627-7877.

Circle No. 292

Broadband Communications Antennas

The Broadband Communications Antennas (BCA) series has added the BCA series high gain sector antenna and the BCA series Mark II enhanced performance high gain sector antennas. All of the models offer versatile solutions for dealing with the complex and difficult issue of providing optimum, cost-effective coverage for broadband communications. The high gain sector antenna covers the 24.25 to 26.5 GHz frequency band while delivering 20.5 dBi of gain performance at 90° azimuth coverage. (Azimuth sizes of 45° and 90° in either vertical or horizontal polarization are available.) The elevation pattern is contoured to give the required signal strength inside the cover area free of nulls. The Mark II antennas provide enhanced, robust pattern performance and good cross-polarization rejection. The antenna's azimuth patterns ensure minimum response outside of the sector region, which results in reduced sector-to-sector and intercell interference.

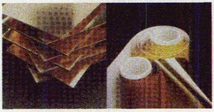


Andrew Corp.,
Orland Park, IL
(800) 255-1479.

Circle No. 296

MATERIALS

High Performance Laminates

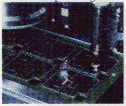


The RO4000® and RO3000® series laminates are designed to support the economical production of high volume circuits for specific applications in wireless communications designs. The laminates feature good electrical characteristics, including stable dielectric constant over temperature and low dielectric loss. The RT/duroid,® DUROID® and TMM® laminates support the highest requirements for very demanding applications.
Rogers Corp., Rogers, CT (860) 774-9605.

Circle No. 250

EMI Gaskets

The Gore-Shield® high performance, surface-mount compatible gasket for electromagnetic interference (EMI) shielding can be installed with standard pick-and-place equipment. The gaskets employ an innovative form factor and the company's GS5200 material, a nickel-filled expanded polytetrafluoroethylene that is well suited for wireless applications. Available in 5.5 mm, 8.0 mm and 12 mm lengths, and 1.25 mm and 1.1 mm widths, the gaskets provide good low pressure EMI shielding and very fast installation times.



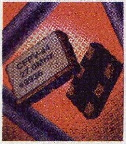
W.L. Gore & Associates Inc.,
Newark, DE (302) 368-2575.

Circle No. 251

SOURCES

Miniature VCXOs

The CFPV-41/42/43/44 series miniature surface-mount voltage-controlled crystal oscillators (VCXO) are designed for SONET/SDH transmission systems in local telephone exchanges and local or wide area networks. The oscillators offer a high degree of frequency pulling (control of the output frequency via an applied voltage), thereby allowing degraded incoming signals to be corrected to nominal frequency via a phase-locked loop. Frequency pulling is up to ±50 ppm (CFPV 41/42) and up to ±100 ppm (CFPV 43/44). The VCXOs operate over a temperature range of –10° to +70°C at any output frequency between 1.0 and 52 MHz, in-



[Continued on page 180]

NEW PRODUCTS

cluding the standard fixed-line telecommunication frequencies at 8.192, 10 and 38.88 MHz. Price: from $3.50 to $11.30.
C-MAC Frequency Products,
Durham, NC (919) 941-0430.
Circle No. 294

Subminiature TCXO

The model 312BE subminiature temperature-compensated crystal oscillator (TCXO) has a frequency range of 12,600 to 19,800 MHz. Frequency tolerance is –0.5 to +0.5 ppm at 25°C and frequency stability is –2.5 to +2.5 ppm over an operating temperature range of –20° to +75°C. Designed for surface-mount applications, the TCXO has low profile packaging with a ceramic base and a metal cover and measures 7 mm × 5 mm × 2 mm. The unit requires a supply voltage of between +2.85 and +3.15 V and input current is 2.0 mA (max). Storage temperature range is –40° to +80°C. Price: $8 (1000). Delivery: eight to 10 weeks (ARO).

Fox Electronics,
Fort Myers, FL (888) 438-2369.
Circle No. 255

Voltage-controlled Ovenized Crystal Oscillators

The K2000 series voltage-controlled ovenized crystal oscillators (VCOCXO) are designed specifically for Stratum 3 timing and synchronization applications. Housed in a compact, hermetically sealed DIL 14 package, the VCOCXOs operate with +5 or +12 V DC power supply voltages. With a +12 V supply, frequency stability is less than ±100 ppb over the temperature range of 0° to 70°C. Overall frequency stability including temperature, voltage, load and aging is less than ±370 ppb/day. Phase noise is less than –95 dBc/Hz at 10 Hz and voltage control (pull-in/hold-in) function is greater than ±10 ppm with deviation linearity less than 10 percent. Standard frequencies are available up to 20 MHz with optional frequencies up to 38.88 MHz. Price: starting at $75 (1000).

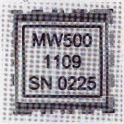
Champion Technologies Inc.,
Franklin Park, IL
(800) 888-1499
Circle No. 275

Commercial Wideband VCO

The model VCO190-1500BT generates frequencies from 1000 to 2000 MHz with control voltages from 0.5 to 20 V. The unit typically requires 23 mA of current from a supply voltage of 8 V. Phase noise is –94 dBc/Hz at 10 kHz offset (typ), output power is +6 dBm (typ), and typical second and third harmonic suppression is –20 and –30 dBc, respectively. Housed in a surface-mount, pick-and-place reflow-compatible package, the unit measures 0.50" × 0.50" × 0.18".
Vari-L Company Inc.,
Denver, CO (303) 371-1560.
Circle No. 257

Low Noise VCO

The model MW500-1109 wideband, low noise voltage-controlled oscillator (VCO) covers an octave from 1250 to 2500 MHz while maintaining a low phase noise of –117 dBc/Hz at 100 kHz offset and –93 dBc/Hz at 10 kHz. Output power is +6 dBm, supply voltage is 5 to 12 V and tuning voltage is 0 to 18 V. Designed for satellite communication, frequency synthesis, test equipment and video transmission applications, the VCO is capable of high FM rates and modulation BW over 40 MHz. Operating temperature range is –40° to +85°C. Size: 0.50" × 0.50" × 0.14".



Micronetics Wireless Inc.,
Hudson, NH (603) 883-2900.
Circle No. 256

805 - 825 MHz VCO

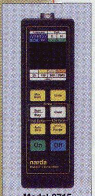
The model V580ME09 high performance VCO covers the 805 to 825 MHz frequency range

[Continued on page 183]

Our precise new spatial averaging meter is so easy to use, practically anybody can do it.

Just touch the ground with the probe. Press the meter's start/stop key. Slowly move the probe from toe to head. Press the key again. That's it.

And for those four baby steps, you instantly get an incredibly precise, spatially-averaged measurement based on about 400 separate readings. Now you know with certainty if you're within threshold limits.



Model 8715

Put this powerful microprocessing ability to work for you. You'll have the precision you need to successfully deal with the increasingly complex signal environments created by the exploding wireless industry.

Our new meter also babys you with other great features. Like a bright seven-segment numeric display. Analog bar graph. An audio alarm that sounds if input exceeds the probe's measurement range. And a variable alarm that can be set to sound at any level.

How close are other meters to offering you all these advantages?

They're still in diapers.

Call Narda today at **631-231-1700.**

NQA ISO 9001

www.nardamicrowave.com

narda
microwave-east
an L3 communications company

It's Narda to be precise.

CIRCLE 127 ON READER SERVICE CARD

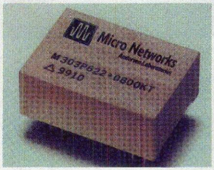
NEW PRODUCTS

with a tuning voltage of 0.5 to 4.5 V DC, allowing quick and easy implementation into phase-locked loop circuits. The unit provides 5.5 ±2 dBm of output power into a 50 Ω load. Phase noise is –110 dBc/Hz at 10 kHz offset, input capacitance is 120 pF (max) and second harmonic suppression is –12 dBc (typ). Operating temperature range is –30° to 85°C. The VCO is well suited for spread spectrum radio, data link and digital cellular applications. Size: 0.50" × 0.50" × 0.13". Price: $15.95. Delivery: stock to six weeks.

Z-Communications Inc., San Diego, CA (858) 621-2700.

Circle No. 258

100 - 800 MHz VCXOs



The M303 series VCXOs have expanded to include frequencies from 100 to 800 MHz. Originally designed for SONET applications, these high performance VCXOs are well suited for high speed computing or telecommunications applications as well as network computing, base stations, high end servers, data communications transmission and automatic test equipment. A standard device provides temperature stability of less than 30 ppm over an operating temperature range of 0° to 70°C. Delivery: stock to 12 weeks (ARO).

Micro Networks/Andersen Laboratories, Worcester, MA (508) 852-5400.

Circle No. 279

PROCESSING EQUIPMENT

Laser Stencil

The LPKF StencilLaser features new concepts for control technology of XY-coordinates-tables

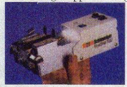
and a laser source with a pulse rate up to 5000 Hz. Optimally adjusted to stencil production, the StencilLaser provides accuracy between 3 and 5 μm. The company also offers its QuickCheck and ScanCheck quality management options which measure selected pads directly after the cutting process and pad geometries and stencil completeness.

LPKF Laser & Electronics AG, Garbsen, Germany +49 (0) 5131 7095 0.

Circle No. 252

Fiber-optic Buffer and Coating Stripper

The FiberStrip 7030 portable fiber-optic buffer and coating stripper is designed specifically for



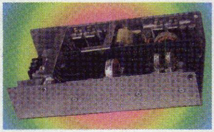
stripping buffers and/or coatings from glass fibers. The lightweight FiberStrip 7030 features a precision die blade and centering system, an adjustable heating and dwell time system and a rate-controlled stripping system. The standard unit includes a carrying case with an AC-to-DC power adapter and other accessories. A rechargeable battery pack also is available for field use.

Schleuniger, Manchester, NH (603) 668-8117, ext. 500.

Circle No. 290

SUBSYSTEMS

300 W Power Supply



The NT301 series compact, multiple output, 300 W power supply has a 3.3 V high current main output and active input power factor correction (PFC). The active PFC circuitry provides compliance with EN61000-3-2 and accommodates a wide-input voltage range of 90 to 264 V DC for global applications. The PFC input stage is followed by a two-transistor forward converter that provides a proven architecture for high reliability requirements. All outputs are fully isolated and regulated. Standard features include power fail warning, remote inhibit and remote sense. Price: from $370 (100).

C&D Technologies Inc., Power Electronics Division, Tucson, AZ (800) 547-2537.

Circle No. 259

SiGe Powered GPS Receiver

The highly integrated Global Positioning System (GPS) receiver features the company's silicon germanium (SiGe) process technology, enabling the direct conversion of RF signals to digital information and eliminating the need for IF support circuitry such as mixers, oscillators and filters. The GPS receiver has 12 parallel processing channels which simultaneously track and process GPS signals from up to 12 satellites, improving the performance and proliferation of satellite navigation technology in

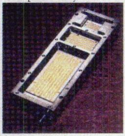
[Continued on page 185]

NEW PRODUCTS

automobile, marine and recreational applications. The system also includes a PowerPC 401 embedded processor and comprehensive support features such as memory, a GPS reference crystal, connectors and a real-time clock. Size: 40 mm × 66 mm.
IBM Microelectronics Division,
Hopewell Junction, NY (914) 499-1900.
Circle No. 260

■ 0.15 - 3.0 GHz Multiplier Subsystem

The model SYSX20-3A integrated three-stage multiplier subsystem is suitable for receiver LO generation using a reference VHF stabilized or voltage-tuned input source. Industry standard size amplifier and multiplier modules are used internally to make the unit easily modified for custom frequencies with 55 dBc spurious levels.



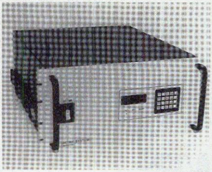
MITEQ, Hauppauge, NY (516) 439-9423.
Circle No. 261

■ Radio Modem Modules

The SLM-C module for the RF9600 series radio modems provides two analog inputs and two analog outputs. The unit can be configured for 0 to 5 V input or 0 to 20 mA input or configured as outputs for the same ranges. The module can be used in remote monitoring operations, sensing machine current changes, control loop circuitry and temperature monitoring.

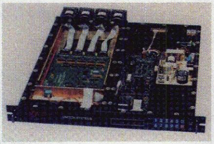
RF Neulink, a division of RF Industries,
San Diego, CA (800) 233-1728
or (858) 549-6340.
Circle No. 262

■ 32 × 32 Coaxial Matrix



The model 10840 coaxial matrix offers a bandwidth of 5 to 20 MHz that covers the HF and VHF bands as well as the IF frequencies of 70 to 160 MHz. The unit provides switching configurations from 32 inputs to 32 outputs in any combination under RS-232 or IEEE-488 control, and features unity gain at full fanout, enabling a high degree of versatility. Speed setup time (up to 40 stored switching configurations) may be recalled. The matrix also features crosspoint verification, front panel keyboard control and liquid crystal display.
Matrix Systems Corp.,
Calabasas, CA (818) 222-2301.
Circle No. 271

■ Coaxial Switch Matrix



The model 2104 coaxial switch matrix is configured with up to four single-pole, 10-throw switch assemblies. Designed specifically for automatic testing equipment, environmental/laboratory test equipment and programmable patch panel/interconnect applications, the switch matrix provides a solid-state controller with a front panel liquid crystal display and keypad for manual override and two remote interfaces (RS-232 and IEEE-488 general-purpose interface bus). Impedance is 50 Ω, switching speed is 20 ms and input power is 85 to 264 V AC (47 to 440 Hz). Operating temperature is 0° to +50°C. The switch matrix measures 1.75" × 19.0" × 20.0" with the four switches mounted externally at the rear.
Dow-Key Microwave Corp.,
Ventura, CA (805) 650-0260.
Circle No. 291

TEST EQUIPMENT

■ Measurement Software for RF Power Meters

The 4530 series RF power meters and the model 4500A RF peak power meter/analyzer now include software that provides highly complex statistical analysis features for added capability in measuring power of next-generation wideband modulation scheme signals such as wideband CDMA, EDGE and third-generation. Designed for production automatic testing equipment, the 4530 series can measure signals from 10 kHz to 40 GHz (depending on the sensor) across a 20 MHz video bandwidth with an effective sampling rate up to 50 Msamples/sec for repetitive signals. The model 4500A operates over the 1 MHz to 40 GHz frequency range and can perform a number of measurements quickly with an effective sample rate up to 5 Gsamples/sec. The software features include statistical modes that provide users with the capability to fully analyze power distribution, including peak power over time, and a unique time gating capability to calculate average power for more accurate measurements of wideband signals. Price: starts at \$3650 (4530 series) and \$15,000 (model 4500A). Delivery: 12 weeks (ARO).
Boonton Electronics Corp.,
Parsippany, NJ (973) 386-9696.
Circle No. 299

[Continued on page 194]

NEW PRODUCTS

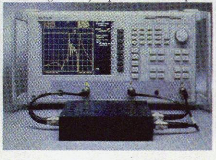
24-channel Noise Generator

The model UFX9736 modular, multichannel noise generator provides uncorrelated, time-varying, random noise signals for each channel, allowing realistic burn-in conditions to operate with every possible input signal level. The channels can be switched from noise to external signal input levels for testing with real data during burn-in channels. Designed for simultaneous burn-in and multichannel system testing, the unit features custom frequency ranges, a local keypad and a remote general purpose interface bus system control, two to 24 channel capacity, and module upgrades and additions to original systems.
NoiseCom, Paramus, NJ (201) 261-8797.

Circle No. 267

Firmware and Calibration Kits

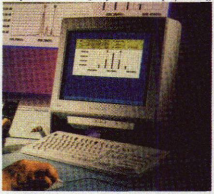
The Version 1.05 firmware and the models 3750LF and 3753LF calibration kits significantly improve the overall performance of the MS462x series vector network analyzers, which can perform error-corrected noise figure measurements on active devices used in wireless communications. The new firmware can display four active on-screen markers per channel and external voltages can be displayed and read via an analog input connector, thereby allowing voltages from ±25 V to be measured with external instruments. The calibration kits contain two precision male and female terminations, and one male and female open and short.
Anritsu Co., Morgan Hill, CA (800) 267-4878.



Circle No. 264

GSM Test Set

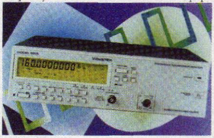
The IFR 2935/PhoneTest GSM test set includes an in-channel spectrum analyzer and an I/Q adjustment display. Designed for applications such as Go/Nogo test, mobile alignment and repair to final QA audit assessment, the unit offers improved level accuracy, SWR and power burst analysis. Optional software that provides maintenance and production facilities for mobile test and repair is available with the PhoneTest test set, giving users the benefits of a complete repair process solution.
IFR Ltd., Stevenage, Hertfordshire, UK +44 (0) 1438 7422 00.



Circle No. 266

Frequency Counters

The models 905 and 905R frequency counters are designed for on-site frequency calibration in automatic test equipment systems and calibration labs. Both models fulfill the requirements for calibrating cellular telephone base station master clocks with a short warm-up period of less than 10 minutes. These user-friendly counters feature a smart automatic input trigger control, plus an



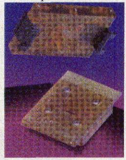
[Continued on page 196]

NEW PRODUCTS

on-screen signal strength indicator to guide the user. Both models offer high resolution of 10 digits at one second measuring time and DC to 300 MHz standard bandwidth (up to 2.7 GHz optional). The 905R features a built-in Rubidium frequency reference and maintains a 50 times margin to base station master clock frequency accuracy specifications for 10 years without adjustment. Prices: $1695 (model 905) and $9995 (model 905R).
Wavetek Corp.,
San Diego, CA (619) 279-2200.
Circle No. 316

■ High Frequency Test Socket

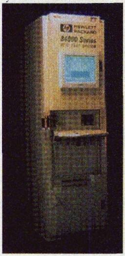
The model 3750 high frequency test socket handler provides the clearance required for the Daymarc 717 plunge mechanism and alignment pins to mate with the handler. The lid assembly contains a compliant leadbacker that ensures contact with the company's patented Microstrip Contacts™ on the board. (Use of the contacts results in a minimal contact self-inductance of 0.01 nH.) This pressure-mounted test interface fits all TSSOP-173 devices from 14 to 28 leads. Price: $2457.00. Delivery: six weeks (ARO).



Aries Electronics Inc.,
Frenchtown, NJ (908) 996-6841.
Circle No. 263

■ RF Integrated Circuit Test System Software

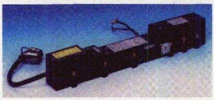
The model 84000 series RFIC and IFIC test systems offer three standard configurations and new software that will improve time-to-market with target deliveries of eight weeks rather than three months and increase throughput up to 15 percent. The A.03.00 software provides incrementally expandable mixed-signal resources and measurement capabilities for meeting emerging production test needs. The test systems are capable of testing error-corrected S parameters and provide noise figure and power measurements on up to 12 RF ports. (Frequency coverage extends from 10 MHz to 3 GHz or 18 GHz.) The software also simplifies copying and pasting of multiple lines within a test plan to enable engineers to leverage entire sections more efficiently. Price (test systems): less than $500,000.



Hewlett-Packard Co.,
Palo Alto, CA (800) 452-4844.
Circle No. 265

TUBES

■ Traveling-wave Tube

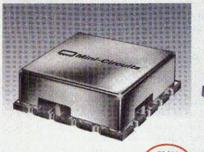


The model TH 3875 traveling-wave tube (TWT) utilizes two technologies: the helix delay line, which ensures large instantaneous bandwidth, and a Wehnelt electrode in the electron gun, which allows modulation of the output signal. (The tubes can operate in CW or pulse mode, depending on the type of scrambling required.) Designed specifically for millimetric-wave electronic countermeasure systems, the TWTs provide the power needed for effective jamming over a very broad frequency range. The TH 3875 delivers 80 W CW power from 18 to 40 GHz, requiring fewer tubes for a given performance level.
Thomson Tubes Electroniques,
Meudon-La-Foret, Cedex, France
+33 (1) 30 70 36 43.
Circle No. 268

NEW PRODUCTS

NO.68

RF/IF MICROWAVE COMPONENTS



FROM $21.95

12V VCO FOR PCS HAS LINEAR TUNING

Mini-Circuits new ROS-2500 voltage controlled oscillator features 1600MHz to 2500MHz broad band linear tuning from a miniature 0.5"x0.5"x0.18" industry standard package. The VCO targets PCS applications delivering low -90dBc/Hz SSB phase noise typical at 10kHz offset, wide 3dB modulation bandwidth of 6000kHz typical, and 0.5 to 14 minimum to maximum tuning voltage. Typical power output is 6.5dBm. Affordably priced and available off-the shelf.

it™

FROM $4.50

0.5 TO 600MHz TRANSFORMERS WITH 4:1 IMPEDANCE RATIO

Mini-Circuits ADT4-6WT surface mount transformers provide 4:1 impedance ratio 0.5 to 600MHz. Typically, in 1dB band-width, these transformers display excellent 0.1dB amplitude and 1 degree phase unbalance plus excellent 20dB return loss. Referenced to midband loss (0.4dB typ), insertion loss is 3dB bandwide. Low profile package stands only 0.155" high (max.) and applications include balanced amplifiers and impedance matching.

FEATURED PRODUCT

FROM $6.95

PATENTED 0.07" MIXER PERFORMS 2800 TO 5900MHz

The MBA-591 level 7 (LO) frequency mixer, part of Mini-Circuits patented family of Blue Cell™ mixers, operates over 2800MHz to 5900MHz with 36dB L-R, 26dB L-I isolation and low 6.5dB midband conversion loss (all typ). The Blue Cell™ mixer series delivers a unique combination of low conversion loss, superb temperature stability, thin profile, and low cost for higher frequency designs. This model is ideal for satellite, ISM, and PCMCIA applications. Available off-the-shelf.

12dB DIRECTIONAL COUPLER IDEAL FOR CATV

Mini-Circuits has started shipment of the broad band RCM-12-4-75, a 75 ohm low cost directional coupler providing accurate power sampling for CATV applications in the 20MHz to 1000MHz band. With 12.6dB±0.5 nominal coupling (±0.9dB max. flatness), this open case surface mount model displays low 0.7dB typical insertion loss, 15dB directivity typical at midband, and good 1.20:1 (typ) VSWR. Power input capability is up to 1 watt.

FROM $3.95

FROM $6.95

2WAY 75 OHM SPLITTER FOR 5 TO 1000MHz

Mini-Circuits has introduced a 2way-0° power splitter/combiner for CATV applications in the 5 to 1000MHz band. The TCP-2-10-75 typically displays low 0.3dB insertion loss (above 3.0dB) with excellent 0.4dB amplitude and very good 1.0 degree phase unbalance. The unit is housed in a miniature 0.16"x0.15"x0.16" surface mount package with solder plated leads for excellent solderability. External resistor and capacitor required.

FROM $11.95

DC TO 20GHz TERMINATION HAS SMA FEMALE CONNECTION

The ANNE-50 is a broad band DC to 20GHz precision termination from Mini-Circuits exhibiting a return loss of 40dB typical up to 4GHz and 20dB typical from 10 to 20GHz. This low cost, off-the-shelf 50 ohm solution is capable of a broad range of applications that might otherwise require a more expensive custom design, including cellular and satellite communications. Power rating is 0.50W to 70°C ambient. Actual test data is available on YONI at the Mini-Circuits web site.

Mini-Circuits®

US 114 INT'L 115
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

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

ISO 9001 CERTIFIED

F 319 Rev. Org.

NEW LITERATURE

■ Microwave Absorber Data Sheets

These data sheets provide information on the LS series low density, high loss flexible absorbers, the MLP series broadband multilayer absorbers and the RT series reticulated foam absorbers. (Other data sheets also are available.) Specifications and graphs are included.
ARC Technologies Inc., Amesbury, MA (978) 388-2993.

Circle No. 200

■ 50th Anniversary New Product Catalog

This 24-page new product catalog features more than 50 of the company's best-selling products, including IC testers, programmable power supplies, and cable and video monitor testers as well as a full line of accessories. Photographs, specifications and pricing information are provided.
B&K Precision Corp., Placentia, CA (714) 237-9220.

Circle No. 201

■ Speed and Proximity Sensor Brochure

This brochure features an expanded line of speed and proximity sensors, including the MP series magnetic proximity sensors, the GS series Geartooth speed sensor assemblies, the SD series Geartooth speed and direction sensors and the VN series vane sensors. Photographs, diagrams and specifications also are provided.
Cherry Electrical Products, Pleasant Prairie, WI (800) 285-0773.

Circle No. 202

■ Antenna Development Guide for Bluetooth Applications

The *Design Guide for Bluetooth Antenna Systems* provides extensive information on antenna selection, orientation and attachment as well as antenna tuning and testing for developers and manufacturers utilizing Bluetooth technology for portable computer device design.
Centurion International Inc., Lincoln, NE (402) 467-4491.

Circle No. 203

■ Militarized Rubidium Atomic Frequency Standard Data Sheet

This data sheet contains information on the FE-5600M series rubidium atomic frequency standard, which meets MIL-E-5400 Class II and can operate from raw aircraft power. Technical characteristics, a functional description and an outline drawing also are included.
FEI Communications Inc., Mitchel Field, NY (516) 794-4500.

Circle No. 204

■ 2000 Computer-based Measurement Catalog

This 672-page catalog provides detailed information on all of the company's hardware and software measurement products, including digital multimeters, electrometers, precision sources, voltmeters, power supplies, switching systems and data acquisition boards with an array of software. A reference guide with application examples also is provided.
Keithley Instruments Inc., Cleveland, OH (888) 534-8453 or (440) 248-0400.

Circle No. 205

■ Coaxial Delay Line Application Note

This application note addresses three major concerns when selecting delay lines for feed-forward amplifiers: cost, configuration and size, and electrical length stability and tolerance. Determining length based upon electrical characteristics, cable types and packaging also is discussed.
MICRO-COAX, Collegeville, PA (800) 223-2629.

Circle No. 206

■ Frequency Control Solution Catalog

This eight-page catalog introduces frequency control solutions for commercial and aerospace applications such as oven-controlled crystal oscillators, temperature-controlled crystal oscillators, resonators and crystal filters. The company's fabrication, processing and testing capabilities also are described.
Piezo Technology Inc. (PTI), Orlando, FL (407) 298-2000.

Circle No. 207

■ DC-to-DC Converter Brochure

This brochure describes the new LPD301 series 50 to 200 W DC-to-DC converters, which employ an innovative topology similar to a standard forward converter and special integrated magnetics to reduce component count over competing converter designs.
Powercube, a Natel company, Chatsworth, CA (800) 866-3590.

Circle No. 208

■ Plenum Cable Catalog

This new 20-page catalog features the company's LMR® LLPL high performance 50 Ω plenum coaxial cables, connectors, accessories and tools for difficult in-building installation where flexibility and ease are critical. Photographs and specifications are provided.
Times Microwave Systems, Wallingford, CT (203) 949-8489.

Circle No. 209

■ 2000 RF Power Semiconductor Catalog

This 300-page data catalog, *UltraRF Power*, contains information on all of the company's cellular infrastructure devices. Detailed specifications and application information for linear and high power design also are provided.
UltraRF, Sunnyvale, CA (877) 206-5657.

Circle No. 210

■ MMIC Design Brochure

This six-page brochure describes state-of-the-art GaAs technologies, MMIC design and foundry services. The company's front-end wafer and back-end processing capabilities also are described.
United Monolithic Semiconductors (UMS), Orsay, France +33 1 69 33 03 08.

Circle No. 211

CLASSIFIED

RF Circuit Design: Theory and Applications

Reinhold Ludwig and Pavel Bretchko
Prentice Hall
641 pages plus CD-ROM; $97
ISBN:0-13-095323-7

This book is intended to bridge the gap between a highly theoretical text based on electromagnetic (EM) theory and a practical circuit design manual based on Kirchoff's laws. The objective of this book is to develop RF circuit design aspects in such a way that the need for transmission line principles is clear without adopting an EM field approach. Lengthy mathematical derivations are either relegated to the appendices or placed in examples. As a result, some of the examples contain considerable detail and have been simulated in MMICAD for the linear circuit models and the Advanced Design System for nonlinear oscillator and mixer models.

> *"...an extraordinarily clear and concise treatment of RF circuit design theory..."*

The book begins with a general explanation of why basic circuit theory breaks down as the operating frequency is increased to a level where the wavelength becomes comparable with the discrete circuit components. Next, transmission line theory is developed to replace low frequency circuit models. The Smith chart is introduced as a generic tool used to describe impedance behavior on the basis of reflection coefficient.

Two-port networks are also covered, along with their flow chart representations and how they are described using scattering parameters. The network models and scattering parameters then are utilized to develop passive RF filter configurations.

A review of key semiconductor fundamentals is presented, followed by their circuit model representations. Impedance matching and biasing of bipolar and field-effect transistors that aim at eliminating potentially dangerous reflections and providing optimum power flow are discussed. A number of key high frequency amplifier configurations are presented along with their design intricacies for low noise and high power applications. Finally, the reader is introduced to nonlinear systems and their use in designing oscillator and mixer circuits.

The book is an extraordinarily clear and concise treatment of RF circuit design theory and will be easily understood and instantly useful to practicing design engineers. Used as a course text, students should gain good practical design knowledge and an ability to use it more effectively.

To order this book, contact: Prentice Hall, PO Box 11073, Des Moines, IA 50336 (800) 947-7700.

M.I.T. Radiation Laboratory Series

Various Radiation Laboratory staff members
Artech House Inc.
CD-ROM (set of two); $325, £223

The M.I.T. Radiation Laboratory was responsible for dramatic advances in microwave and radar technology between 1941 and 1945. The laboratory's work made practical radar technology a reality and produced many advancements in microwave communications and other related technologies. Beginning in 1947, 28 volumes detailing the laboratory's innovations in practical microwave and radar applications were published in an effort to make this valuable information readily available to scientists and engineering professionals. These 28 books are considered the foundation of modern microwave technology and are now available on two fully searchable CD-ROMs, making them useful resources for today's practicing microwave technologists.

The set includes volumes on Radar System Engineering, Radar Aids to Navigation, Radar Beacons, Loran, Pulse Generators, Microwave Magnetrons, Klystrons and Microwave Triodes, Principles of Microwave Circuits, Microwave Transmission Circuits, Waveguide Handbook, Techniques of Microwave Measurement, Microwave Antenna Theory and Design, Propagation of Short Radio Waves and Microwave Duplexers. Also included in the set are Crystal Rectifiers, Microwave Mixers, Components Handbook, Vacuum Tube Amplifiers, Waveforms, Electronic Time Measurements, Electronic Instruments, Cathode Ray Tube Displays, Microwave Receivers, Threshold Signals, Theory of Servomechanisms, Radar Scanners and Radomes, and Computing Mechanisms and Linkages. The final volume is a comprehensive index to the set and its many topics and subjects.

> *"These 28 books are considered the foundation of modern microwave technology..."*

To view and search the 28 volumes contained on the two CD-ROMs requires the use of the Adobe Acrobat Reader. This software is available free from Adobe and is provided on the CDs along with instructions for installation. Once installed the entire set can be easily searched for key words and phrases applicable to specific subjects required by the user.

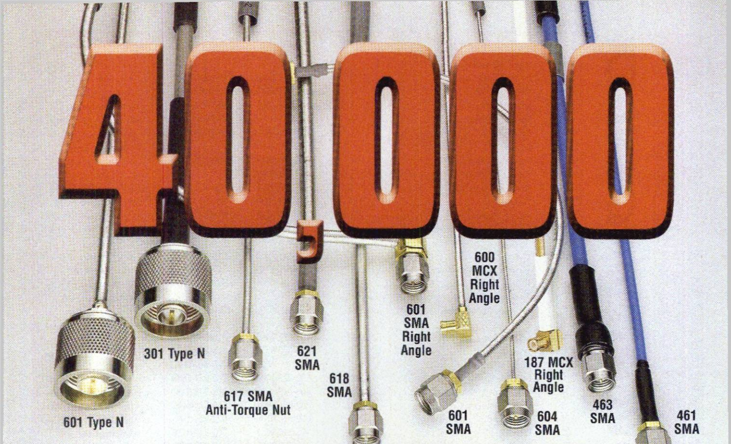
To order this CD-ROM set, contact: Artech House Inc., 685 Canton St., Norwood, MA 02062 (781) 769-9750, ext. 4002; or 46 Gillingham St., London SW1V 1HH, UK +44 (0) 171 973 8077.

Frank Bashore

Frank Bashore is a member of the Microwave Journal *staff.*

ADVERTISING INDEX

Circle No.	Advertiser	Page No.	Phone	Fax	E-Mail Address
76	MECA Electronics Inc.	117	973-625-0661	973-625-1258	www.mecaelectronics.com
77	Megaphase	128	877-MEGAPHASE	877-MEGAFAX	www.megaphase.com
78	Metelics Corporation	119	408-737-8181	408-733-7645	www.metelics.com
	Micro Comm	194	978-685-2272	978-794-5627	www.micsearch.com
79	Micro Lambda	167	510-770-9221	510-770-9213	www.micro-lambda.com
80	Micronetics/Test Equipment	33	603-883-2900	603-882-8987	www.micronetics.com
81	Micro-Precision Technologies	88	603-893-7600	603-893-9110	www.micropt.com
82	Microwave Circuits	56	202-829-3030	202-829-2639	www.micckts.com
83	Microwave Comm. Laboratories Inc. (MCLI)	26	800-333-6254	727-381-6166	www.mcli.com
84	Microwave dB	179	805-499-0410	805-498-0054	www.microwavedb.com
85	Microwave Development Company Inc.	17	603-870-6280	603-870-6210	www.mdc-inc.net
86	Microwave Development Labs	123	800-383-4189	781-453-8629	www.micro-dev-labs.com
87,88	Microwave Filter Company	86,192	800-448-1666	315-463-1467	www.microwavefiter.com
	Microwave Journal	158,174, 180	800-225-9977	781-769-5037	www.mwjournal.com
89	Microwave Specialty Corporation	132	760-744-1544	760-744-1565	www. microwavespecialty.com
90,91,	Mini Circuits Laboratory	4–5,	718-934-4500	718-332-4661	www.minicircuits.com
92,93,		7,			
94,95,		35,			
96,97,		46,			
98,99,		50,			
100,101,		97,			
102,103,		113,			
104,105,		133,			
106,107,		149,			
108,109,		155,			
110,111,		159,			
112,113,		161,			
114,115,		197,			
116,117		COV 4			
118,119,	MITEQ Inc.	3,71,139,	516-436-7400	516-436-7430	www.miteq.com
120,121		199			
122	Modular Components National Inc.	98	410-879-6553	410-838-7629	www.mcn-mmpc.com
123	MTI-Milliren Technologies Inc.	24	978-465-6064	978-465-6637	www.mti-milliren.com
124	Murata Electronics	69	800-831-9172		www.murata.com
125,127	Narda Microwave-East, an L3 Communications Co.	43,181	516-231-1700	516-231-1711	www.nardamicrowave.com
128	Nihon Tsushinki Co. Ltd.	52			www.nitsuki.com
129	Noisecom	19	201-261-8797	201-261-8339	www.noisecom.com
130	Oleson Microwave	40	408-779-2698	408-778-0491	www.oml-mmw.com
131	Optotek Ltd.	45	613-591-0336	613-591-0584	www.optotek.com
132	PCB Engineering	86	800-368-4PCB	408-946-2246	www.pcbengineering.com
133	Polar Waves Consulting	192	306-934-6688	306-931-4694	www.polarwaves.com
134,135,	QMI Tensolite	13,109,	800-362-FLEX	978-988-9393	www.qmiinc.com
136		205			
137	Quasar Microwave Technology Ltd.	52	+44-1626-834222	+44-1626-832994	www.qmtl.com
138	Quinstar Technology Inc.	120	310-320-1111	310-320-9968	www.quinstar.com
139	Radio Research Instrument Co. Inc.	114	203-753-5840	203-754-2567	www. techexpo.com/www/radiores
140	RDL Inc.	147	610-825-3750	610-825-3530	www. rdl-instrumentation.com
141	Reactel	182	301-519-3660	301-519-2447	www.reactel.com
142	RF Globalnet	203			www.rfglobalnet.com
143	RF Industries Ltd.	56	800-233-1728	858-549-6345	www.rfindustries.com
144	RF Micro Devices	30–31	336-664-1233	336-664-0454	www.rfmd.com
145,172	Richardson Electronics	105,173	1-800-RFPOWER	630-208-2550	www.rfpowernet.com
146	RLC Electronics Inc.	23	914-241-1334	914-241-1753	www.rlcelectronics.com
147	Rogers Corporation	14	480-961-1382	480-961-4533	www.rogers-corp.com/ mwu/info.htm
148	Rohde & Schwarz GmbH	193	+49-89-41293115	+49-89-41293115	www.fsp.rsd.de
20	Sabritec	78	949-250-1244	949-250-1009	www.sabritec.com
149	Salisbury Engineering Inc.	42	800-989-2141	302-846-3888	www. salisbury-engineering.com
150	Seavey Engineering Associates Inc.	44	781-829-4740	781-829-4590	www.seaveyantenna.com
151	Sector Microwave Industries Inc.	192	516-242-2300	516-242-8158	e-mail: sales@ sectormicrowave.com



Cable Assemblies now in stock at Richardson Electronics

In stock, fully specified cable assemblies with selected lengths and connector combinations.

Connectors	Flexible Low Loss 301	Semi-Flex 600	Semi-Flex Plus 620	Semi-Flex II 617	Semi-Flex 601	Semi-Flex Plus 621	Semi-Flex II 618	Q-Flex 461	Q-Flex 463	Semi-Flex 604	RG316 187
Cable Code	.195	.086	.115	.086	.141	.180	.141	.110	.170	.047	.102
MCX Straight		✓								✓	✓
MCX Right Angle		✓								✓	✓
SMA	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
SMA Right Angle		✓			✓					✓	
Type N	✓				✓						

Data sheets available at **www.qmiinc.com**

MADE IN THE USA

Tensolite

QMI® Microwave Interconnects

A CARLISLE Company

1-800-362-FLEX

301 Ballardvale St. Wilmington, MA 01887
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

ADVERTISING INDEX

Circle No.	Advertiser	Page No.	Phone	Fax	Web/E-Mail Address
152	Signal Technology Corp. – Systems Operation	135	508-943-7440	508-949-1804	www.sigtech.com
153	Sivers Ima AB	151	+46-8-7036804	+46-8-7519271	www.siversima.se
190	Sonnet Software	COV 3	315-453-3096	315-451-1694	www.sonnetusa.com
	Spectra-Physics	198		650-968-5215	email: jobs@splasers.com
154	Spectrum	118-I*	+49-89-354-8040	+49-89-354-80490	e-mail: specelek@compuserve.com
155	SSI Cable Corporation	18	360-426-5719	360-426-5912	www.ssicable.com
156,157	Stanford Microdevices	101,171	800-764-6642		www.stanfordmicro.com
158	Storm Products Co.	20–21	630-323-9121	630-323-9398	www.stormproducts.com
159	SV Microwave	195	561-840-1800	561-844-8551	www.svmicrowave.com
160	Swift & Associates	150	818-989-1133	818-989-4784	e-mail: sales@cwswift.com
161,162, 163	Synergy Microwave Corp.	59, 137,191	973-881-8800	973-881-8361	www.synergymwave.com
164	Taconic	107	518-658-3202	518-658-3988	www.4taconic.com
165	Techtrol Cyclonetics Inc.	100	717-774-2746	717-774-6799	www.tci-ant.com
166	Tekelec Temex	85	+33-1-49-884900	+33-1-48-581046	www.temex-components.com
167	Testmart	65			www.testmart.com
168	Thomson Microsonics	163	+33-0492-9640-00	+33-0492-9630-25	www.microsonics.thomson-csf.com
169	Trilithic Inc.	16	800-874-5484	317-895-3612	www.trilithic.com
170	Tru-Connector	112	978-532-0775	978-531-6993	www.tru-con.com
171	TSAT AS	192		+47-6677-4401	www.tsat.no
173	UTE Microwave	93	732-922-1009	732-922-1848	www.utemicrowave.com
174	W.L. Gore & Associates	73	800-445-4673	302-738-5993	www.goremicrowave.com
175	Watkins Johnson Co.	39	800-951-4401	650-813-2447	www.wj.com
176	Waveline Inc.	134	973-226-9100	973-226-1565	e-mail: wavelineinc.com
177	Weinschel Corporation	70	301-846-9222	301-846-9116	www.weinschel.com
178	Werlatone	84	914-279-6187	914-279-7404	www.werlatone.com
179,180, 181,182, 183	Z-Communications	125,127, 131,183, 185	619-621-2700	619-621-2722	www.zcomm.com/
184	Zeland Software	124	510-797-8109	510-797-8241	www.zeland.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