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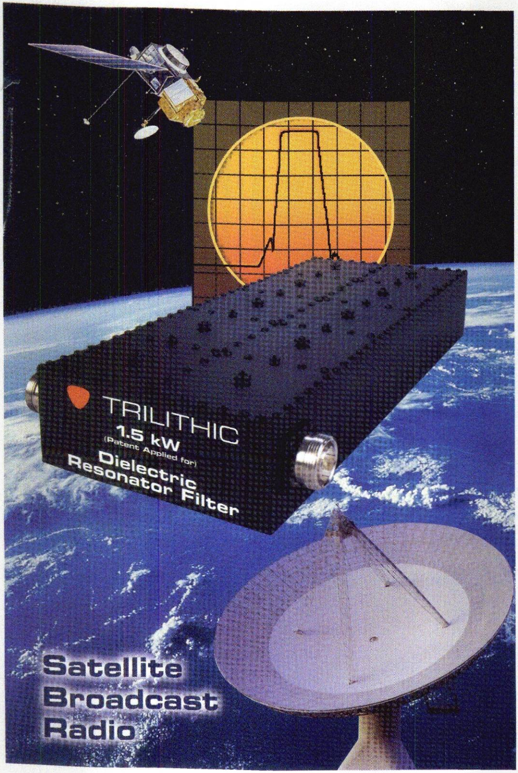


AMPLIFIERS AND OSCILLATORS

A 2.45 GHz Low Cost, High Performance VCO

Increasing Multitone Power Near Saturation

A Digitally Compensated TCXO with Low Phase Noise

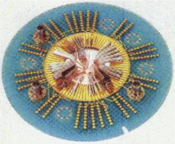
CONTENTS, P. 10

horizon house®

Picoprobe elevates probe cards to a higher level...

(...110 GHz to be exact.)

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



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

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

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

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

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

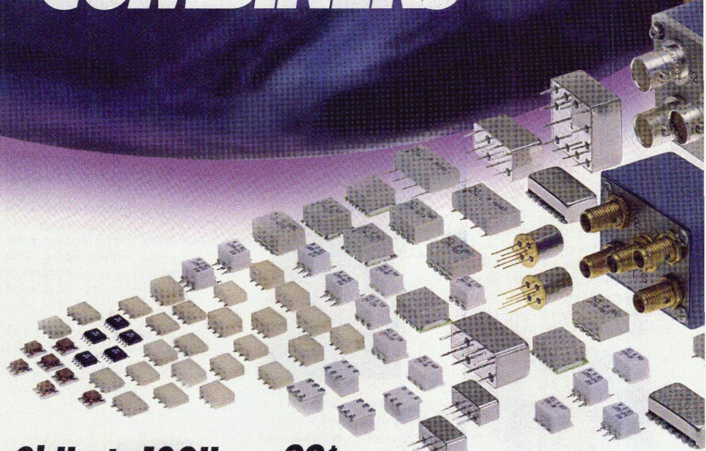
For technical assistance, custom product designs, or off-the-shelf delivery, call GGB Industries, Inc., at (941) 643-4400.

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

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

THE WORLD'S LARGEST SELECTION

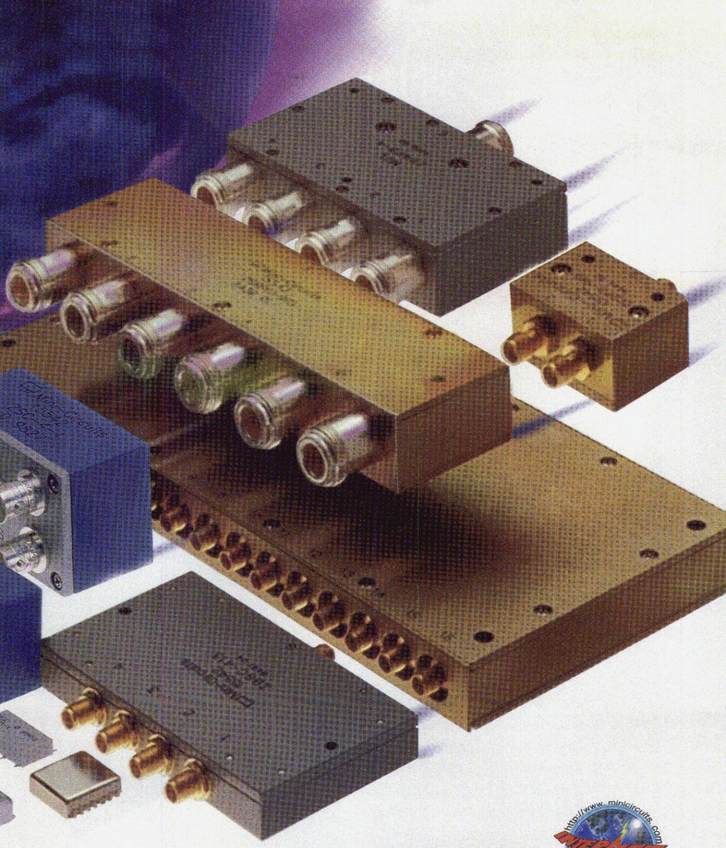
POWER SPLITTERS/ COMBINERS



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 FROM MAURY

QT3.5mm™ Quick Test Connectors & Adapters*

- Excellent Repeatability/ Low VSWR
- Quick & Easy Push-On/ Pull-Off Design
- Guide Sleeve Design For Automated Applications
- Designed for Long Life

ELECTRICAL SPECIFICATIONS

MODEL	FROM	TO	FREQ RANGE (GHz)	VSWR (GHz)
8006E1	QT3.5mm™ (m) with no nut	3.5mm (f)	DC — 26.5**	DC — 16.0, 1.05 16.0 — 26.5, 1.08
8006E11	QT3.5mm™ (m) with 3/8" dia. nut	3.5mm (f)		
8006E21	QT3.5mm™ (m) with 9/16" dia. nut	3.5mm (f)		
8006Q1	QT3.5mm™ (m) with guide sleeve	3.5mm (f)		

**Slightly reduced VSWR specifications to 34 GHz.

REPEATABILITY

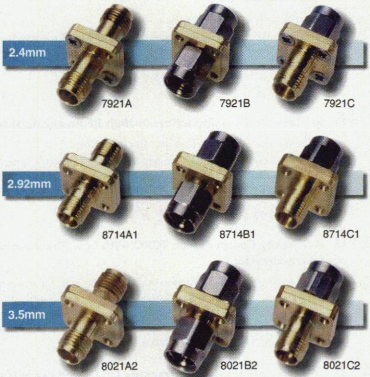
REPEATABILITY	DC — 18.0 GHz	18.0 — 26.5 GHz
Push-On Mode	> 45 dB	> 40 dB
Torque Mode	> 50 dB	> 50 dB
Hand Torque	> 50 dB	> 50 dB

Other available configurations include:
- *7mm*
- *TYPE N (f & m)*
- *NMD3.5mm (f)*
- *NMD2.4mm (f)*

ALSO AVAILABLE FROM MAURY

In-Series Precision Adapters

- Low VSWR / Low Loss
- DC to 50 GHz
- Minimize VNA Test Port Wear
- Phase Matched / Minimum Length
- Bulk Head & Panel Mount Configurations Available
- Between-Series Adapters Are Also Available



ELECTRICAL SPECIFICATIONS

MODEL	FROM	TO	FREQ RANGE & MAX. VSWR
7921A	2.4mm Q (f)	2.4mm Q (f)	DC — 26.5 GHz, 1.06 26.5 — 40.0 GHz, 1.10 26.5 — 34.0 GHz, 1.15
7921B	2.4mm Q (f)	2.4mm Q (m)	
7921C	2.4mm Q (f)	2.4mm Q (m)	
8714A1	2.92mm K (f)	2.92mm K (f)	DC — 4.0 GHz, 1.05 4.0 — 20.0 GHz, 1.08 20.0 — 40.0 GHz, 1.12
8714B1	2.92mm K (m)	2.92mm K (m)	
8714C1	2.92mm K (f)	2.92mm K (m)	
8021A2	3.5mm (f)	3.5mm (f)	DC — 18.0 GHz, 1.05 18.0 — 26.5 GHz, 1.08 26.5 — 34.0 GHz, 1.12
8021B2	3.5mm (m)	3.5mm (m)	
8021C2	3.5mm (f)	3.5mm (m)	

Between-Series configurations include:
- *2.4mm to 2.92mm (K)*
- *2.4mm to 3.5mm*

*U.S. Patent Pending

MAURY MICROWAVE CORPORATION

For more information contact our **SALES DEPARTMENT** at
Tel: (909)987-4715 • Fax: (909) 987-1112
Email: maury@maurymw.com

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http://www.maurymw.com

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FEATURES

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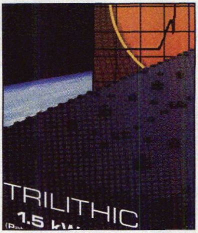

ON THE COVER

A dielectric resonator filter capable of achieving very low passband insertion loss and high near-band rejection is featured on this month's cover

Cover art courtesy of Trilithic

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

Topics: Compound semiconductor manufacturing; 150 mm conversion; cycle time reduction; CIM tools for manufacturing environmental impact and cost management; processing; lithography; gate formation; low capacitance crossovers; high and low dielectric constant materials; failure mechanisms and module integration issues; test and reliability; high speed, high volume and low cost testing; device technologies; yield enhancement and thermal enhancement; optical devices; and materials and packaging. Contact: Wes Mickanin, TriQuint Semiconductor (503) 615-9253, fax (503) 615-8903 or e-mail: wesm@tqs.com. Additional information is available at www.gaasmantech.org/.

Southern California's Regional IMAPS Symposium and Exhibition (SoCal 2000)
San Diego, CA
May 23, 2000

Sponsors: San Diego Chapter of the International Microelectronics and Packaging Society (IMAPS). Topics: Low temperature co-fired ceramics, integrated passive components, flip-chip technology, quality management, telecommunications, chip-scale packaging and copper wire bonding. For registration information, contact Mike Grosse (858) 536-4733. For exhibition information, contact Marty Greenfield (619) 461-1060. Additional information is available at www.imaps.org/chapters/sandiego.htm.

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

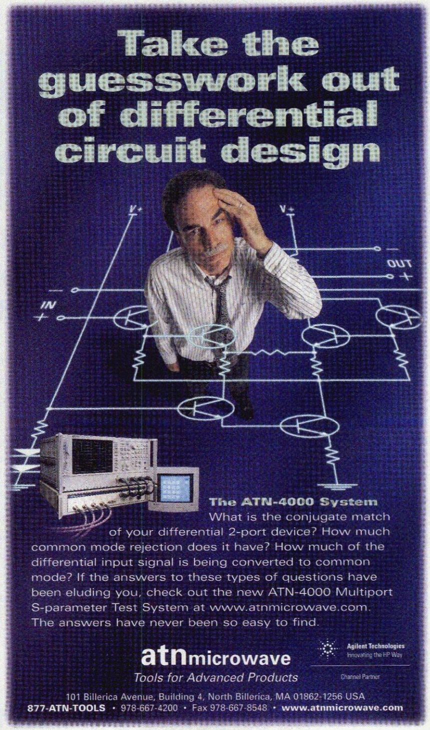
Topics: Compound semiconductor devices and integrated circuits for microwave, millimeter-wave and opto-electronic applications; material growth and characterization; active device technology for MMIC applications (MESFET, HEMT and HBT); power devices; novel device technologies and quantum electronics; and reliability and characterization. Contact: Dimitris Pavlidis, University of Michigan, Department of Electrical Engineering and Computer Science, 1301 Beal Ave., Ann Arbor, MI 48109 (734) 647-1778 or e-mail: pavlidis@umich.edu. Additional information can be obtained 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, Analog Devices (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



CIRCLE 28 ON READER SERVICE CARD

and satellite communication; biological and medical applications; wireless and cellular communications; and sensor and sensor systems. For symposium information, contact Peter Staecker, technical program chair (781) 861-7643, fax (781) 863-5751 or e-mail: p.staecker@ieee.org. For exhibition information, contact Kristen Dednah, Horizon House Publications, 685 Canton St., Norwood, MA 02062 (781) 769-9750 or e-mail: kdednah@mwjournal.com. Additional information is available at www.ims2000.org.

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

Sponsors: Automatic Radio Frequency 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, fax (978) 258-4102 or e-mail: m.fennelly@ieee.org. Additional conference information is available at www.arftg.org.

Topical Meeting on MEMS for High Q Filters
July 17–18, 2000
University of Surrey, UK

Sponsors: IEEE UK and Republic of Ireland MTT/AP/LEO/ED Joint Chapter Administrative Committee, University of Surrey and IEEE MTT-S. Topics: High Q filter design; micromachined electromechanical systems (MEMS); application-specific ICs; MMICS; flip-chip, hybrid and multichip module boards; ultraminiature transmit and receive systems; and commercial simulation tools. Contact: Steve Marsh, Marconi Casswell Ltd. +44 (0) 1327 356 426, fax +44 (0) 1327 356775 or e-mail: steve.marsh@ieee.org. Additional information is available at www.surrey.ac.uk/Where/index.html.

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

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

2000 IEEE-APS Conference on Antennas and Propagation for Wireless Communications (APWC 2000)
November 6–8, 2000
Waltham, MA

Sponsors: IEEE Antenna and Propagation Society and IEEE Boston section. Topics: Military to commercial technology transition, architecture trends, base station and satellite antenna developments, adaptive and active wireless communications arrays, novel antennas and passive array configurations, multiband operation and polarization characteristics, mobile antennas and vehicle modeling, packaging integration and portable devices, antenna CAD, human interaction with antennas, MEMS, and indoor/outdoor propagation and channel models. For additional information, contact the conference office at (781) 890-5290, fax (781) 890-5294 or e-mail: bostonieee@aol.com. Additional information is available at www.eece.unm.edu/apwc2000/.

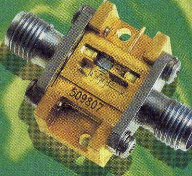
ULTRA-LOW NOISE
AMPLIFIERS
VHF TO V-BAND

MODEL NUMBER	FREQUENCY RANGE (GHz)	GAIN (dB, Min.)	GAIN VARIATION (±dB, Max.)	NOISE FIGURE (dB, Max.)	VSWR IN	VSWR OUT	POWER OUT @ 1 dB COMPR. (dBm, Min.)		DC POWER @ +15 V (mA, Nom.)
OCTAVE BAND AMPLIFIERS									
JS2-00500100-035-5A	0.5 – 1	35	1	0.45*	2:1	2:1	5		250
JS2-00500100-10-5A	0.5 – 1	35	1.2	1	2:1	2:1	5		250
JS2-01000200-035-5A	1 – 2	33	1	0.45*	2:1	2:1	5		250
JS2-01000200-10-5A	**1 – 2**	**33**	**1.2**	**1**	**2:1**	**2:1**	**5**	$395	**250**
JS2-02000400-035-5A	2 – 4	28	1	0.45*	2:1	2:1	5		175
JS2-02000400-10-5A	**2 – 4**	**28**	**1.2**	**1**	**2:1**	**2:1**	**5**	$450	**175**
JS2-04000800-070-0A	4 – 8	22	1	0.7	2:1	2:1	0		150
JS2-04000800-15-0A	**4 – 8**	**22**	**1.2**	**1.5**	**2:1**	**2:1**	**0**	$495	**150**
JS3-04000800-060-5A	4 – 8	30	1	0.6	2:1	2:1	5		175
JS3-04000800-15-5A	4 – 8	30	1	1.5	2:1	2:1	5		175
JS2-08001200-09-5A	8 – 12	15	1	0.9	2:1	2:1	5		150
JS2-08001200-15-5A	**8 – 12**	**15**	**1.2**	**1.5**	**2:1**	**2:1**	**5**	$495	**150**
JS3-08001200-080-5A	8 – 12	25	1	0.8	2:1	2:1	5		175
JS3-08001200-15-5A	8 – 12	25	1	1.5	2:1	2:1	5		175
JS2-12001800-16-5A	12 – 18	15	1	1.6	2:1	2:1	5		100
JS2-12001800-30-5A	**12 – 18**	**15**	**1.5**	**3**	**2:1**	**2:1**	**5**	$495	**100**
JS3-12001800-16-5A	12 – 18	23	1	1.6	2:1	2:1	5		175
JS3-12001800-30-5A	**12 – 18**	**23**	**1**	**3**	**2:1**	**2:1**	**5**	$495	**175**
JS4-12001800-12-5A	12 – 18	30	1	1.2	2:1	2:1	5		200
JS4-12001800-30-5A	12 – 18	30	1	3	2:1	2:1	5		200
JS2-18002600-20-5A	18 – 26	14	1	2	2:1	2:1	5		100
JS2-18002600-30-5A	18 – 26	14	1	3	2:1	2:1	5		100
JS3-18002600-20-5A	18 – 26	22	1	2	2:1	2:1	5		175
JS3-18002600-30-5A	18 – 26	22	1	3	2:1	2:1	5		175
JS4-18002600-16-5A	18 – 26	27	1	1.6	2:1	2:1	5		200
JS4-18002600-26-5A	18 – 26	27	1	2.6	2:1	2:1	5		200
JS2-26004000-35-5A	26 – 40	12	2	3.5	2:1	2:1	5		100
JS2-26004000-45-5A	26 – 40	12	2	4.5	2:1	2:1	5		100
JS3-26004000-35-5A	26 – 40	18	2	3.5	2.5:1	2.5:1	8		175
JS3-26004000-45-5A	26 – 40	18	2	4.5	2.5:1	2.5:1	8		175
JS4-26004000-40-5A	26 – 40	23	2.5	4	2:1	2:1	8		200
JS2-26004000-100-20A	26 – 40	17	1.25	10	2.3:1	2.3:1	20		**
JS4-40006000-65-0A	40 – 60	15	3	6.5	2.75:1	2.75:1	0		175
MULTIOCTAVE BAND AMPLIFIERS									
JS2-00500200-05-5A	0.5 – 2	32	1	0.5	2:1	2:1	5		250
JS2-00500200-20-5A	0.5 – 2	32	1	2	2:1	2:1	5		250
JS2-01000400-07-5A	1 – 4	27	1	0.7	2:1	2:1	5		200
JS2-01000400-20-5A	1 – 4	27	1	2	2:1	2:1	5		200
JS2-02000600-07-5A	2 – 6	24	1	0.7	2:1	2:1	5		125
JS2-02000600-20-5A	2 – 6	20	1	2	2:1	2:1	5		125
JS2-02000800-08-0A	2 – 8	22	1	0.8	2:1	2:1	0		125
JS2-02000800-20-0A	2 – 8	18	1	2	2:1	2:1	0		125
JS3-02001800-25-5A	2 – 18	21	2	2.5	2.5:1	2.5:1	5		150
JS3-02001800-50-5A	2 – 18	21	2	5	2.5:1	2.5:1	5		150
JS4-02001800-22-5A	2 – 18	30	2	2.2	2.5:1	2.5:1	5		200
JS4-02001800-50-5A	2 – 18	30	2	5	2.5:1	2.5:1	5		200
JS3-02002600-30-5A	2 – 26	21	2	3	2:1	2.1	5		150
JS3-02002600-40-5A	2 – 26	21	2	4	2:1	2:1	5		150
JS3-06001800-18-5A	6 – 18	23	1.3	1.8	2:1	2:1	5		125
JS3-06001800-30-5A	6 – 18	23	1.3	3	2:1	2:1	5		125
JS4-06001800-135-5A	6 – 18	31	1	1.35	2:1	2:1	5		200
JS4-06001800-30-5A	6 – 18	31	2	3	2:1	2:1	5		200

* Noise figures to 0.35 dB available on a limited basis.
** This unit requires +8V @ 500 mA and -8V @ 90 mA.

MITEQ's JS SERIES AMPLIFIERS

- High Performance/Price Ratio
- Superior, Rugged Technology
- Low Phase Distortion Design



Actual 18 to 40 GHz Design

MODEL NUMBER	FREQUENCY RANGE (GHz)	GAIN (dB, Min.)	GAIN VARIATION (±dB, Max.)	NOISE FIGURE (dB, Max.)	VSWR IN	VSWR OUT	POWER OUT @ 1 dB COMPR. (dBm, Min.)	DC POWER @ +15 V (mA, Nom.)
MULTIOCTAVE BAND AMPLIFIERS (Continued)								
JS3-08001800-17-5A	8 – 18	24	1.2	1.7	2:1	2:1	5	125
JS3-08001800-30-5A	8 – 18	24	1.2	3	2:1	2:1	5	125
JS4-08001800-13-5A	8 – 18	32	1.5	1.3	2:1	2:1	5	200
JS4-08001800-30-5A	8 – 18	32	1.5	3	2:1	2:1	5	200
JS3-08002600-30-5A	8 – 26	21	2	3	2:1	2:1	5	150
JS3-08002600-40-5A	8 – 26	21	2	4	2:1	2:1	5	150
JS3-12002600-25-5A	12 – 26	22	2	2.5	2:1	2:1	5	150
JS3-12002600-35-5A	12 – 26	22	2	3.5	2:1	2:1	5	150
JS4-12002600-22-5A	12 – 26	30	1.7	2.2	2:1	2:1	5	200
JS4-12002600-35-5A	12 – 26	30	1.7	3.5	2:1	2:1	5	200
JS3-18004000-38-5A	18 – 40	16	2.5	3.8	2.5:1	2.5:1	5	150
JS3-18004000-50-5A	18 – 40	16	2.5	5	2.5:1	2.5:1	5	150
JS4-18004000-30-5A	18 – 40	23	2.5	3	2.5:1	2.5:1	5	200
JS4-18004000-50-5A	18 – 40	23	2.5	5	2.5:1	2.5:1	5	200
ULTRAWIDE BAND AMPLIFIERS								
JS2-00100200-06-5A	0.1 – 2	32	1	0.6	2:1	2:1	5	250
JS2-00100200-15-5A	0.1 – 2	32	1	1.5	2:1	2:1	5	250
JS2-00100400-08-5A	0.1 – 4	27	1	0.8	2:1	2:1	5	200
JS2-00100400-12-5A	0.1 – 4	27	1	1.2	2:1	2:1	5	200
JS2-00100600-10-3A	0.1 – 6	23	1.5	1	2:1	2:1	3	175
JS2-00100600-20-3A	0.1 – 6	23	1.5	2	2:1	2:1	3	175
JS2-00100800-13-0A	0.1 – 8	20	1.5	1.3	2:1	2:1	0	175
JS2-00100800-25-0A	0.1 – 8	20	1.5	2.5	2:1	2:1	0	175
JS3-00101000-18-5A	0.1 – 10	26	1.5	1.8	2:1	2:1	5	150
JS3-00101000-35-5A	0.1 – 10	26	1.5	3.5	2:1	2:1	5	150
JS3-00101200-19-5A	0.1 – 12	25	1.5	1.9	2:1	2:1	5	150
JS3-00101200-35-5A	0.1 – 12	25	1.5	3.5	2:1	2:1	5	150
JS3-00101800-26-5A	0.1 – 18	23	1.5	2.6	2.5:1	2.2:1	5	150
JS3-00101800-40-5A	0.1 – 18	23	1.5	4	2.5:1	2.2:1	5	150
JS4-00101800-23-5A	0.1 – 18	29	1.8	2.3	2.5:1	2.2:1	5	200
JS4-00101800-40-5A	0.1 – 18	29	1.8	4	2.5:1	2.2:1	5	200
JS4-00102000-25-5A	0.1 – 20	28	1.8	2.5	2.5:1	2.5:1	5	200
JS4-00102000-35-5A	0.1 – 20	28	1.8	3.5	2.5:1	2.5:1	5	200
JS3-00102600-32-5A	0.1 – 26	20	1.8	3.2	2.5:1	2.5:1	5	150
JS3-00102600-42-5A	0.1 – 26	20	1.8	4.2	2.5:1	2.5:1	5	150
JS4-00102600-28-5A	0.1 – 26	27	2	2.8	2.5:1	2.5:1	5	200
JS4-00102600-50-5A	0.1 – 26	27	2	5	2.5:1	2.5:1	5	200
JS4-00103000-35-5A	0.1 – 30	20	2.5	3.5	2.5:1	2.5:1	5	200
JS4-00103000-45-5A	0.1 – 30	20	2.5	4.5	2.5:1	2.5:1	5	200
JS4-00104000-65-5A	0.1 – 40	14	3.5	6.5	2.75:1	2.75:1	5	200
JS4-00104000-85-5A	0.1 – 40	14	3.5	8.5	2.75:1	2.75:1	5	200

NOTE: Higher 1 dB compression levels are available on many designs.

For additional information or technical support, please contact either Rosalie DeSousa at (516) 439-9458, e-mail rdesousa@miteq.com or Rizwan Syed at (516) 439-9267, e-mail rsyed@miteq.com.

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A 2.45 GHz Low Cost, High Performance VCO

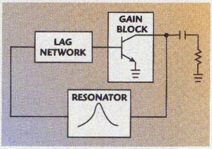
This article addresses performance and cost issues associated with voltage-controlled oscillator design. Although the example design is application specific, the methods demonstrated apply to microwave oscillator design in general. CAE and on-the-bench techniques are used for a comprehensive approach to the designing of microwave oscillators.

Engineers are under constant pressure to reduce the cost of microwave designs without sacrificing their performance. At 100 K volumes, oscillators can be produced at a fraction of the cost when compared to that of small-quantity purchased oscillators. This article presents a design procedure along with a practical example. An attempt is made to clarify some of the concerns associated with low cost, high performance microwave oscillator design. Performance considerations include low phase noise, linear monotonic tuning, low harmonic emissions and adequate output power.

INITIAL TOPOLOGY SELECTION

All oscillator circuits require a gain block and a feedback method. The topology used here is based on the Barkhausen criteria for oscillation. ***Figure 1*** shows that the design requires a network to provide the gain, a frequency selection network (resonator) and enough phase lag so that the overall phase for the loop is equal to 2π radians. A small-signal scattering parameter approach is used to evaluate the design. This method enables the use of a network analyzer for the bench evaluation.

Fig. 1 A basic oscillator configuration.



Before proceeding with the design, Lesson's equation for single-sideband phase noise $\mathcal{L}_{PM}$ is examined.[1] The various factors concerning single-sideband phase noise can be considered using this equation:

$$\mathcal{L}_{PM}(\text{dBc/Hz}) = 10\log\left[\frac{1}{2}\left[\left[\left(\frac{F}{2Qfm}\right)^2+1\right]\bullet\left(\frac{C}{fm}+1\right)\bullet\left(\frac{NkT}{P}\right)\right]+\frac{2kTR_vK_v^2}{fm^2}\right]$$

where

k = Boltzmann's constant
T = temperature in Kelvin
F = frequency of oscillation
fm = offset frequency
Q = loaded Q
P = RF power at amplifier input
N = noise factor
C = flicker noise corner frequency
R_v = tuning diode noise resistance
K_v = tuning gain (MHz/V)

(The equation has been modified to include the effects of varactor tuning.) Practical reduction of the oscillator's noise sidebands is addressed by increasing the loaded Q and signal-to-noise ratio (SNR) and decreasing both the flicker and varactor modulation noise contributions.

[Continued on page 24]

Jim Carlini
Detection Systems
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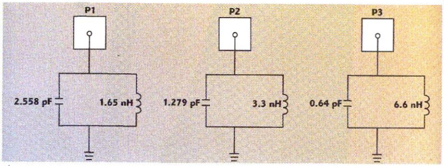
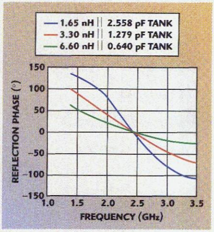


▲ *Fig. 2 Three 2.45 GHz tank circuits used in the simulation.*

RESONATOR DESIGN

The unloaded Q of the resonator ultimately limits the oscillator's loaded Q. The relationship between the loaded Q and noise sidebands can be written as $-10\log(Q_{loaded})^2$. This relationship holds true until the ratio of the loaded Q to unloaded Q exceeds 2/3. To achieve a high unloaded Q the design must maintain the lowest possible series resistance and achieve the lowest possible L/C ratio for the components used in the tank. A fast change in the reflection phase on either side of the resonant frequency indicates a high unloaded Q. ***Figure 2*** shows three 2.45 GHz tanks used in the simulation. The simulation results shown in ***Figure 3*** clearly indicate that the 1.65 nH || 2.558 pF tank circuit produces a rapid change in the reflection phase on either side of the resonant frequency, making it the best L/C combination for the proposed resonator.

A novel design approach was taken that uses a Coilcraft microspring air-core coil. (This coil is available at greatly reduced cost when compared to that of a typical distributed ceramic or Teflon resonator.) It was estimated that the 1.65 nH coil could maintain a Q of at least 180 at 2.5 GHz. This Q value was determined to be high enough for the intended resonator design. The air-core inductor is a primary component in lower frequency RF oscillator designs. The problem at microwave frequencies is that the inductor Q degrades with frequency, particularly as the coil approaches its self-resonant frequency (SRF). The SRF for the 1.65 nH inductor is greater than 10 GHz, thus eliminating this concern.



▲ *Fig. 3 Simulation results for the three tank circuits.*

[Continued on page 26]

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ROS-200	100-200	17	-105	-30	12	20	12.95
ROS-300	150-280	16	-102	-28	12	20	14.95
ROS-400	200-380	17	-100	-24	12	20	14.95
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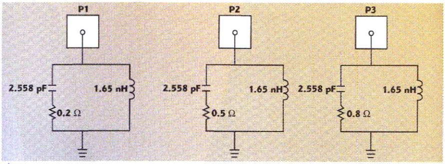
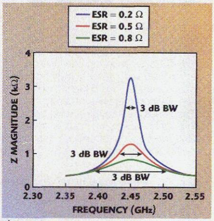


▲ *Fig. 4 Tank circuits used for the Z-magnitude simulation.*

Care must be used in the selection of the tank circuit's capacitive element. As the capacitor's reactance is reduced, its potential to reduce the unloaded Q of the intrinsic tank resonator is increased. A new line of high Q RF capacitors made by American Technical Ceramics was investigated. It was determined that these RF capacitors displayed an equivalent series resistance (ESR) similar to that of most microwave capacitors at 2.5 GHz but with a substantial reduction in cost. ***Figure 4*** shows the circuits used in the simulation. As the ESR of the capacitors used in the tank increases, the overall Q of the tank will decrease. As the tank's unloaded Q is reduced, its 3 dB bandwidth increases. This characteristic is shown in ***Figure 5*** using single-port Z parameters. The 0.707 point of the Z parameter's magnitude response represents the tank circuit's 3 dB bandwidth. Note how the band edges move out in frequency as the capacitor's ESR increases from 0.2 to 0.8 Ω.

RESONATOR DECOUPLING

The resonator is now evaluated as a two-port network. Decoupling elements are used to improve the resonator's loaded Q. This configuration provides valuable insight concerning the design of the intended oscillator. One method used to study the loaded Q for a two-port network is to evaluate the rate of change in the phase slope, which can be expressed as $d\phi/d\omega$ or group delay GD. The group delay differentiation process eliminates the linear portion of the phase response and transforms the deviations from linear phase into deviations from constant group delay. It can be shown that the



▲ *Fig. 5 Effects of the capacitor's ESR on the tank circuit's Q.*

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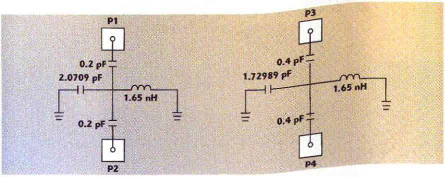
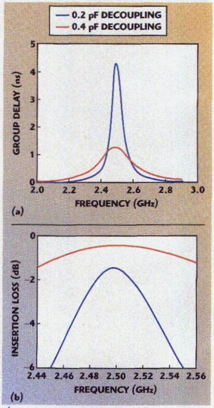


▲ *Fig. 6 The decoupled resonators.*

loaded Q is related to the group delay by $Q_{loaded} = \pi f_0 GD$. Group delay is the rate of change in the phase of the forward transmission coefficient vs. frequency. The nice thing about using group delay as a figure of merit in resonator design is that it can be evaluated with a simulator such as Microwave Harmonica and also measured on the bench with a network analyzer. Note that the end coupling capacitors used increase the capacitive loading on the tank resonator. This effect requires the capacitor(s) in the tank circuit to be tweaked in order to re-center the resonator's center frequency.

To examine the trade-offs concerning insertion loss and loaded Q, a swept display of several decoupled resonators is shown. Different degrees of decoupling were used, as shown in ***Figure 6***. The 1.65 nH inductor is held constant while the tank's capacitor is adjusted to center the frequency at 2.5 GHz. The simulation results shown in ***Figure 7*** clearly display the increase in both group delay and insertion loss as the amount of decoupling is increased. The degree of decoupling used in the final oscillator is a



▲ *Fig. 7 Decoupled resonator performance; (a) group delay and (b) insertion loss.*

[Continued on page 30]

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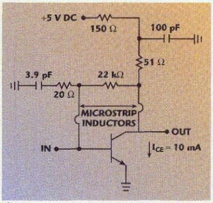
trade-off between the goals of adequate start-up gain and maintaining the resonator's loaded Q.

GAIN BLOCK DESIGN

Often a discrete transistor can provide a much more cost-effective solution than a MMIC. Although a little more work is involved in designing an oscillator using a discrete solution, it is well worth it if low cost is a primary design concern. It is also advisable (although not necessary) to use a device that presents a reasonable degree of match at the intended frequency of oscillation. The device's close match helps to ease the oscillator's gain requirements.

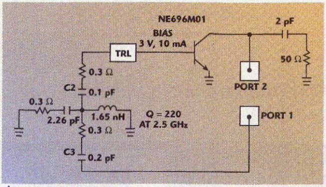
A network that can provide for good spurious suppression should surround the transistor and usually produces unconditional stability at low RF frequencies. At lower frequencies, simple resistor biasing can be used to accomplish this goal. As the frequency increases, it is advisable to use choke biasing networks in order to avoid degrading the gain of the transistor any more than need be. A useful method for preventing moding is to use resistive loading at out-of-band frequencies. This configuration is used so as not to degrade the gain at the desired frequency. A resistor in the DC biasing network also can be used for the prevention of spurious moding. This goal is accomplished using a 51 Ω resistor. ***Figure 8*** shows the intended gain block.



▲ *Fig. 8 The gain block's schematic.*

The required biasing current has a strong effect on the oscillator's close-in noise performance. As the bias current is increased, the close-in phase noise that results from the device transposing low frequency baseband noise is degraded. This low frequency AM and PM noise is converted into frequency fluctuations at the carrier by a nonlinear mixing process. This type of noise is referred to as 1/f noise. In addition, as the bias current is increased the device's noise figure also increases, further degrading the oscillator's noise performance. This result is due to a decrease in the oscillator's SNR. Contrasting the goals of minimizing the transistor's bias current to reduce noise is the fact that the signal portion of the oscillator's SNR is improved with increased bias current. This effect occurs because the absolute value for the noise sidebands does not vary with the signal level produced by the oscillator. It has been noted that both noise figure and low frequency 1/f noise (flicker noise) are not affected significantly by an increase in the bias voltage.

After evaluating cost and performance for various families of transistors, an NE6X6-type device was chosen. These transistors are reasonably priced, and data from the manufacturer show that the NE6X6 devices have both low noise figure and low 1/f noise characteristics. The transistor's V_{CEO} (collector to emitter breakdown voltage with the base held open) is 6 V DC. With V_{CE} set to 3 V, there is ample margin for peak-to-peak variations in the steady-state signal.



▲ *Fig. 9 The initial oscillator schematic.*

It was decided to use the simple biasing network shown previously to reduce circuit complexity and cost. A DC bias current of approximately 10 mA was used to determine a balance for the various noise-related bias concerns. In addition, S-parameter data with 10 mA bias are available from the manufacturer for the entire 6X6 family of transistors.

SUBSTRATE CONSIDERATIONS

Since the design frequency is 2.45 GHz, the PCB material is a significant consideration. In this application it is considered preferable that the utilized material be very inexpensive and provide a well-controlled dielectric constant. This characteristic is required because the printed portion of the circuit is used to control the amount of phase lag between the transistor and resonator. Since the printed portion of the circuit exhibits only a relatively minimal effect on the resonator's loaded Q and loop gain, the attenuation resulting from the substrate's dielectric losses was not considered overly critical. After evaluating several options, including various sources of FR4 material, it was decided to use a low cost material available from GIL Technologies with a dielectric constant of 3.86 ±0.08. In addition, the substrate material is available for approximately the same price as FR4.

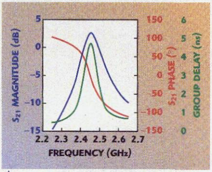
THE FINAL CONFIGURATION

Having chosen the topology, a linear simulation was performed. This procedure allows for precise adjustments in the phase for the intended design. A 2 pF capacitor located at the collector is used to couple the signal to the 50 Ω load. The initial schematic for the oscillator is shown in ***Figure 9***. A break in the circuit is produced in order to enable a two-port analysis technique to be used. It is best to make the break at a point in the circuit where a reasonable degree of match exists. The goal is to adjust the decoupling capacitors C2 and C3 to allow enough gain for the start-up condition while minimizing the degradation to the loaded Q. The desired gain margin for the open loop in this design is between 3 and 4 dB. A minimum of 3 dB is suggested for adequate start-up gain. The 4 dB maximum is recommended to prevent the transistor from hard limiting any more than necessary. As the transistor is driven harder into limiting, it will tend to increase the production of undesired harmonics. Reducing the loop gain also helps reduce the change in the transmission phase during the oscilla-

[Continued on page 32]

tor's transition from small-signal to large-signal conditions.

It is critical for the transmission phase to be 0° at the peak of the resonator magnitude response. It has been shown that degradation in the resulting noise sidebands due to nonoptimal transmission phase is related by 40log(cos θ).[8] The microstrip transmission lines are used to adjust transmission phase. After simulating the intended oscillator design with various transistors from the NE6X6 family it was determined that the model NE696M01 device would produce the required start-up gain. The f_t for the NE696M01 transistor is 14 GHz with a 3 V, 10 mA bias. This f_t is somewhat higher than desired for a 2.45 GHz oscillator and is typical of the type of trade-offs involved in oscillator design. The simulation of the intended oscillation is shown in ***Figure 10***. A 50 Ω, 0.61 λ length of microstrip is used to



▲ *Fig. 10 The open-loop simulation.*

bring the transmission phase to 0° at 2.45 GHz. The gain response is peaked at 2.45 GHz. A gain of 2.63 dB is a bit low but considered enough for start-up concerns. The simulator shows that the group delay is 4.67 ns. The loaded Q for the small-signal simulation is approximately 36. (This Q value shows the potential for low noise performance.) The goals for the initial simulation stage of the oscillator design have been achieved.

TUNING CONSIDERATIONS

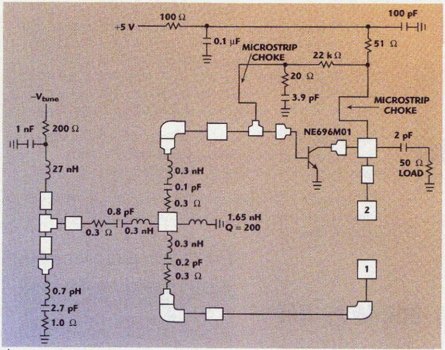
Tuning of the oscillator's center frequency is accomplished by using a varactor tuning diode. Since the cost of the components becomes a critical concern the tolerance used is often not as tight as that of more extensive components. As an example, a 0.2 pF capacitor nearly doubles in price as the component tolerance is increased from ±0.1 to ±0.05 pF. It is advisable to allow for deviation in the center frequency as a result of component variations when evaluating tuning options. This design is intended for use in security sensor applications and is required to tune from 2.435 to 2.465 GHz. The oscillator's tuning bandwidth must extend far enough on either side of these band edges to account for all of the component tolerance variations. This concern must be juggled with the fact that the tuning diode's noise contribution is magnified as its tuning gain is increased. The tuning gain is simply df/dV. The tuning diode is decoupled to reduce its tuning gain by using a capacitive series combination in the resonator tank circuit. One of these capacitors is the tuning diode.

The tuning diode's effect on the oscillator's phase noise performance can vary greatly depending on the type of tuning diode used, its tuning gain and its Q. The modulation noise produced by the tuning diode is summed with the noise sidebands of the oscillator and can degrade the oscillator's phase noise performance. Much of this noise is due to the modulation of the tuning diode junction capacitance by baseband noise. Reducing the baseband biasing resistance helps to reduce varactor modulation noise. In this design the varactor biasing resistor is only 200 Ω. In addition, using a varactor with a less abrupt tuning curve reduces the tuning diode's nonlinearity. However, as the tuning curve becomes less abrupt, tuning linearity may be sacrificed. Furthermore, the tuning diode's series resistance degrades the oscillator's loaded Q. It is suggested that samples of various tuning diodes be evaluated on the test bench prior to final selection.

THE FINAL PROTOTYPE

The final schematic is shown in ***Figure 11***. The rest of the microstrip has been added, and provisions for the tuning diode have been made. The phase has been tweaked to adjust for various distributed discontinuities and parasitic reactances. Low inductance microwave grounding is maintained by using 31-mil-diameter vias to decouple all lumped components.

Having established a promising design with the simulator, the prototype VCO was constructed. An HP 8720B vector network analyzer (VNA) was used to evaluate the open-loop oscillator. The number of test frequency points determines the minimum resolution when recording group delay data on the VNA. This resolution is then increased from minimum by varying the VNA's smoothing aperture. In this way the best possible display of group delay is obtained. A display of the oscillator group delay and insertion loss is



▲ *Fig. 11 The final schematic.*

[Continued on page 36]

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Product Number	Frequency Mhz	POUT Watts	Gain dB	Supply Voltage	Package Number	Internal Matching
To 1.0 GHz – GOLDMOS FET						
PTF 10136	1000	6	18.0	28	20244	N
PTF 10147	1000	10	15.0	26	20244	N
PTF 10137	1000	12	13.0	28	20244	N
PTF 10007	1000	35	12.0	28	20222	N
PTF 10052	1000	35	12.0	28	20235	N
PTF 10015	1000	50	12.0	28	20235	N
PTF 10031	1000	50	12.0	28	20222	N
PTF 10139*	1000	60	12.0	28	20235	N
PTF 10138*	1000	60	12.0	28	20222	N
PTF 10009	1000	85	12.0	28	20230	N
PTF 10049	470–860	85	12.0	32	20240	I
PTF 10159	470–860	120	12.0	32/28	20240	I
PTF 10019	860–900	70	13.0	28	20237	I
PTF 10133	860–900	85	13.0	28	20237	I
PTF 10100	860–900	165	12.0	28	20250	I
PTF 10162	860–960	18	14.0	26	20222	N
PTF 10036	860–960	85	11.0	28	20240	I
PTF 10160*	860–960	85	15.0	26	20248	I/O
PTF 10020	860–960	125	11.0	28	20240	I
PTF 10149	921–960	70	15.0	26	20252	I
1.0–2.2 GHz – GOLDMOS FET						
PTF 10111	1500	6	15.0	28	20222	N
PTF 10107	2000	5	11.0	26	20244	N
PTF 10135	2000	5	11.0	26	20249	N
PTF 10041*	2000	12	10.0	26	20249	N
PTF 10053	2000	12	10.0	26	20244	N
PTF 10021	1400–1600	30	11.0	28	20237	I/O
PTF 10125	1400–1600	135	11.5	28	20250	I/O
PTF 10045	1600–1650	30	10.0	28	20222	N
PTF 10112	1800–2000	60	11.0	28	20248	I/O
PTF 10153*	1800–2000	60	12.5	28	20248	I/O
PTF 10120	1800–2000	120	10.0	28	20250	I/O
PTF 10043	1900–2000	12	11.0	26	20222	I
PTF 10035	1900–2000	30	11.0	28	20237	I/O
PTF 10123*	2100–2200	5	11.0	28	20244	N
PTF 10119	2100–2200	12	10.0	28	20222	I
PTF 10048	2100–2200	30	10.0	28	20237	I/O
PTF 10122	2100–2200	50	10.0	28	20248	I/O
PTF 10134*	2100–2200	100	10.0	28	20250	I/O

Note: An "*" next to the product part number indicates the specifications are preliminary and subject to change without notice. Please contact your sales representative for further product information. Complete product information is available on our Website at: www.ericsson.com/rfpower.

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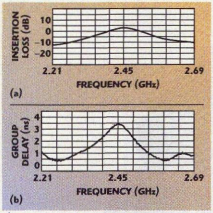


▲ *Fig. 12 The oscillator's (a) insertion loss and (b) group delay.*

Fig. 13 The oscillator's (a) input and (b) output return losses. ▼

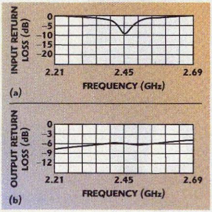
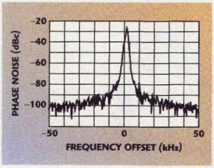
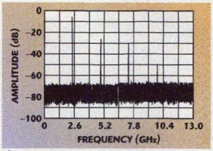


Fig. 14 The oscillator's phase noise at 2.45 GHz in a 1 kHz RBW with 20 dB input attenuation. ▼

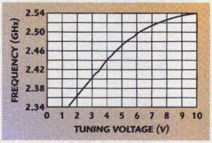


shown in **Figure 12**. The magnitude of both transmission responses is peaked at the intended frequency of oscillation. The input and output return loss of the resonator is shown in **Figure 13**. The low reflections measured at the resonant frequency validate the VNA analysis technique. Having analyzed the group delay, the actual loaded Q is determined to be 26. This value is 25 percent lower than the original simulated value and is attributed to slightly tighter coupling in the actual circuit. However, a loaded Q of 26 is considered respectable for such a low cost design and justifies the resonator selection.



▲ *Fig. 15 The oscillator's harmonics.*

Fig. 16 The oscillator's output frequency vs. tuning voltage. ▼



After evaluation of the oscillator with the network analyzer, the closed-loop analysis is performed and the complete circuit is assembled. The output power and phase noise were measured. **Figure 14** shows the phase noise to be −95 dBc at 10 kHz offset using a 1 kHz resolution bandwidth. This noise level is considered more than adequate for most communication receiver applications. The output power is 5.2 dBm at 2.45 GHz, which is a respectable signal level. The resulting RF-to-DC efficiency is greater than nine percent. The VCO's harmonics are shown in **Figure 15**. It is apparent by the fact that the second harmonic is down by approximately 20 dB that the emission's performance is quite satisfactory. By varying the tuning voltage between 3.3 and 5.9 V the frequency changed linearly from 2.41 to 2.49 GHz. **Figure 16** shows the output frequency vs. applied tuning voltage. Across this tuning span the output power varied by only 1.3 dB and variations in phase noise were measured to be less than 2 dB. Tuning was accomplished using a low cost SMV1234-079 tuning diode from Alpha Industries. A second oscillator was built and tested in order to verify the design. (The test results were nearly identical.) Using typical high volume pricing this circuit was built for less than $1.30.

CONCLUSION

A design technique for using a commercially available simulator (Microwave Harmonica) to evaluate low cost options for a 2.45 GHz oscillator has been demonstrated. The design was later analyzed on the bench using a VNA and spectrum analyzer and was shown to display low phase noise, linear tuning and low harmonic emissions. The output power was verified to be more than adequate for many applications. The only on-the-bench optimization was to the tuning diode used. A practical microwave oscillator design has been demonstrated.

ACKNOWLEDGMENT

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Jim Carlini *has been in the field of RF electronics since 1980 and is currently an RF design engineer at Detection Systems. He spent many years working on microwave receivers for the government and defense electronics industry, and now designs wireless UHF data links as well as S- and X-band microwave sensor products for security applications. One of his main responsibilities is the investigation of low cost design solutions. Carlini's primary interest is in microwave electronics.*

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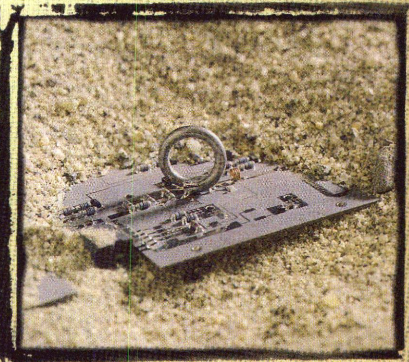

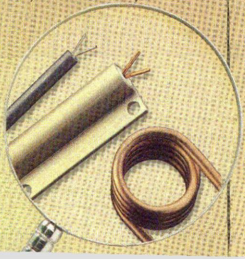

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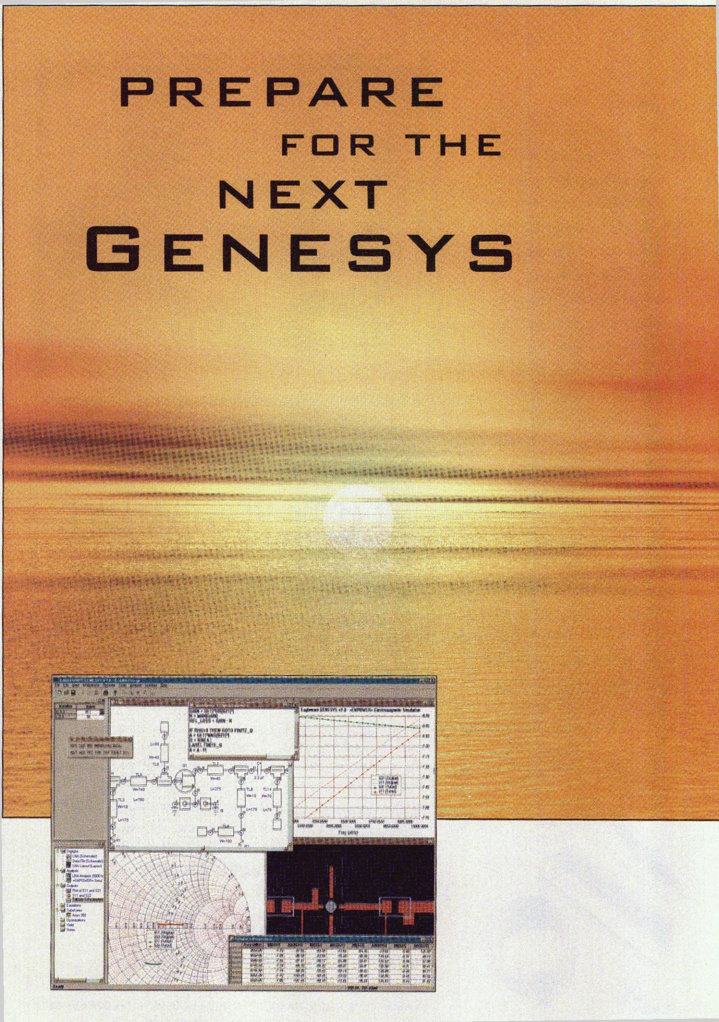
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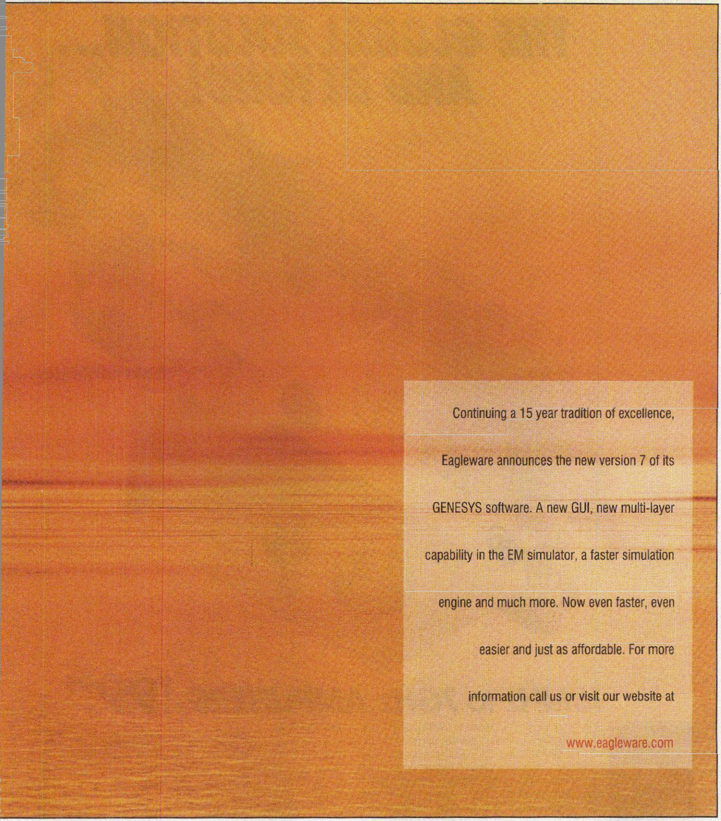
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Pentagon Releases Leading US Military Contractor Rankings for 1999

According to a report issued by the Pentagon, Lockheed Martin Corp., manufacturer of the F-16 and other military aircraft and weapons systems, ranked first among US military contractors in 1999, receiving $12.7 B worth of prime contracts from the Department of Defense (DoD). Boeing Co., manufacturer of the F-15 fighter, placed second in the rankings with prime contracts totaling $10.9 B followed by Raytheon Corp., General Dynamics Corp., Northrop Grumman Corp. and United Technologies Corp. The top six 1999 defense contractors held the same positions in the 1998 rankings. Advanced electronic system provider Litton Industries Inc. jumped from eighth to seventh place with contracts totaling $2.1 B in 1999, compared to $1.6 B in 1998. General Electric Co. finished eighth ($1.7 B) followed by TRW Inc. and Textron Inc. who tied for ninth place with $1.4 B in contracts. Overall, DoD contracts awarded in 1999 to US contractors totaled $125 B, compared to $118.1 B in 1998.

Space Mission to Produce New Topographical Earth Map

According to the Associated Press, the National Aeronautics and Space Administration (NASA) is attempting to produce new topographical maps of the earth by extending a radar antenna boom from the Endeavour space shuttle. The 197-foot radar antenna boom will be the longest rigid structure ever deployed in space, allowing scientists to measure the highs and lows of the earth's terrain with exceptional accuracy for environmental and military purposes. Once fully deployed, NASA expects that scientists will be able to map more than 70 percent of the earth's terrain, collecting enough data to occupy 13,500 compact discs. A 200-foot steel, titanium and plastic mast, with the radar antenna boom anchored to the shuttle's cargo bay, will be deployed to capture more complete global snapshots of the earth. The mast comprises a series of stiff, stacked cubes measuring 1.05 m (3.5 ft) in diameter and can be folded up inside a 2.7 m can. The radar equipment, including the billboard antenna, weighs 13 tons and will scan the earth in 225 km swaths with radar return signals received by the cargo bay and boom antennas. By combining images acquired 59 m apart in space, scientists expect to capture three-dimensional snapshots of the earth's surface, providing nine times more topographic data than currently available to scientists. Topographic measurements are expected to be taken every 29.4 m (98 ft) with elevation readings accurate to approximately 15.6 m (52 ft). A smaller, simpler version of the radar system was launched twice on the Endeavour in 1994.

New Wireless Networking Technologies Demonstrated

Rockwell Science Center, Thousand Oaks, CA, has successfully demonstrated micromachined silicon relays and wireless networking technologies during the space flights of the two smallest satellites ever released into orbit. (The picosatellites weighed less than one-half pound each and measured 4.0" × 3.0" × 1.0".) The micro relays and networking technologies are expected to significantly reduce the size, power and cost of future satellites used for applications such as telecommunications and weather imaging. The picosatellites were launched into space from the Stanford University Orbiting Picosat Automated Launcher, a satellite platform that flew aboard an Air Force rocket launched from Vandenberg AFB on January 26. With funding from the Defense Advanced Research Projects Agency (DARPA), Aerospace Corp. acted as the system integrator for the picosatellite mission; DARPA also sponsored the creation of many of the underlying technologies.

As part of a series of unique experiments, the picosatellites communicated with each other via a low power RF link and a ground station to exchange information obtained from a series of simple onboard circuits. The circuits, which were developed with DARPA funding, tested the reliability of micro-electromechanical systems in space and probed the low earth orbit environment. The satellite networking technologies employed low cost digital cordless telephone technology modified for data communications and networking. Technologies derived from Rockwell's wireless integrated networked sensor (WINS) development programs also were utilized for the first time. WINS systems combine digital cordless telephone technology with data processing capabilities, multihopping networking protocols and actuation devices in order to achieve scalable networks for automation monitoring and control.

US Navy Selects Motorola Digital Modular Radio

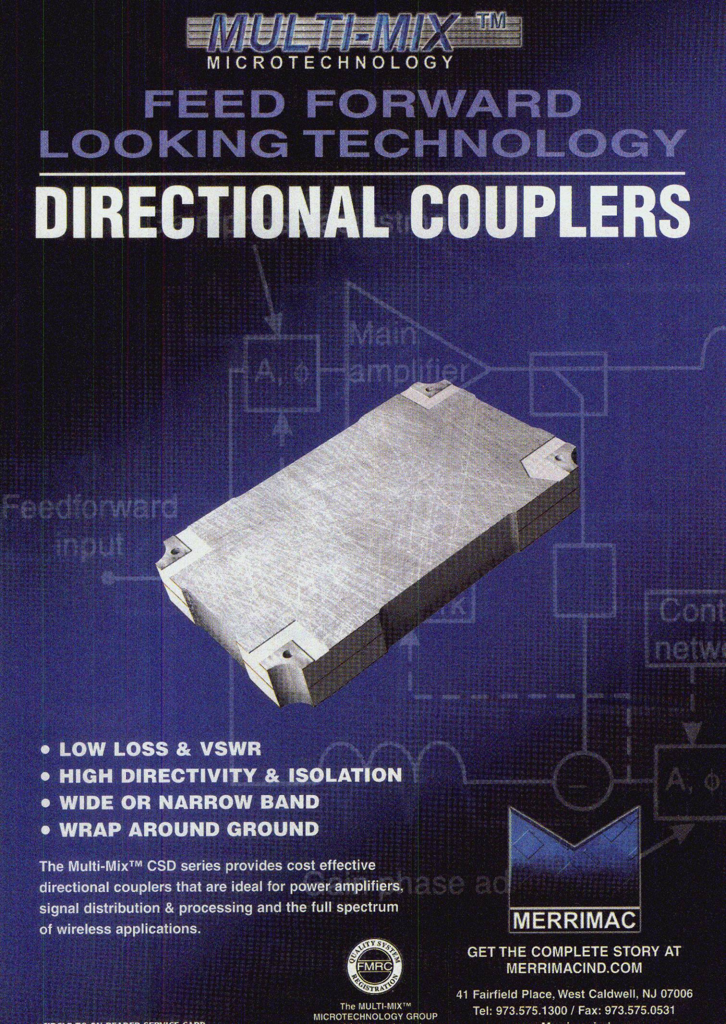
Motorola Inc. has been awarded a $48 M contract by the US Navy Space and Naval Warfare Command (SPAWAR) for the manufacture of an all-digital, software-programmable radio under the Digital Modular Radio (DMR) program. The Navy selected the Motorola DMR for shipboard and shore installations after the successful completion of competitive field trials at the Navy SPAWAR Systems Center in Charleston, SC. The Motorola units demonstrated the key features of reprogrammability, operation with existing radios and mechanical endurance for challenging environments aboard surface ships and sub-

marines. Their fully software-reprogrammable capability enables radio operators to point and click via an interface that is similar to a commercial PC, allowing the setup and alteration of characteristics such as bandwidth, modulation, error control, security and waveforms.

The Motorola DMR will allow the Navy to train operators on one platform, replacing numerous existing systems that are designed specifically to communicate with other armed services, the US Coast Guard and NATO allies. Another key feature of the DMR is the embeddable Advanced INFOSEC Machine, whch recently received Type 1 certification from the National Security Agency. An onboard Secure Operating System allows simultaneous operation on multiple channels using different algorithms, potentially replacing many standard encryption functions with a single device. The Motorola DMR also will offer the Navy the expanded capability of communicating with civilian public safety and law enforcement agencies by simply downloading and installing appropriate frequency and waveform software, and will be compliant with the DoD's Joint Tactical Radio System once the architecture is defined. The DMR is part of the Motorola Wireless Information Transfer System product line and employs commercial standard processors and software to ensure low cost of ownership and extended product life. The agreement is valued at approximately $368 M if the Navy exercises all of its options in the Indefinite Delivery Indefinite Quantity contract.

Naval Solid-state Radar Development to be Examined

Lockheed Martin Corp. and Alenia Marconi Systems SpA of Italy have entered into a teaming agreement to study joint development of an active solid-state S/C-band phased-array radar for applications in the worldwide surface ship marketplace. The agreement is expected to initiate a four-month-long feasibility study in which the two companies will collaboratively identify top-level requirements and architectures for a single-faced active solid-state rotating phased-array radar and project a basic configuration for future development. In addition, the study will evaluate the use of S/C-band active solid-state phased-array radars for other applications. Pending the results of the study and subsequent extensions of the agreement to follow-on phases, the companies intend to explore potential domestic applications of the radar as well as its possible use by foreign navies. In addition, the feasibility of a four-fixed-face active solid-state S/C-band phased-array radar design to support the Anti-Air Warfare and theater ballistic missile defense missions will be examined. The joint study is considered the first step in the development and production of next-generation radars. ■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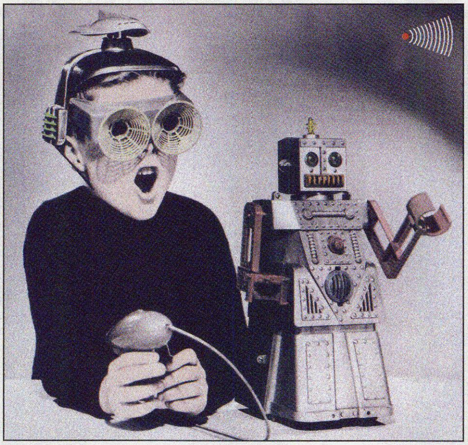

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Earth Observation Efforts Advance

In unrelated moves, Franco-British contractor Matra Marconi Space (MMS) has acquired National Remote Sensing Centre Ltd. (NRSC) and US contractor Ball Aerospace and Technologies is expected to propose a free-flying, space-based synthetic aperture radar (SAR) to the US National Aeronautics and Space Administration (NASA). The NRSC business, with annual turnover of £6.5 M, is based in Farnborough, Hampshire and Barwell, Leicestershire. Considered one the world's largest commercial suppliers of aerial and satellite earth observation data and products, MMS's acquisition of NRSC is expected to complement its core business, improving the overall scope of the company's space services. (In related news, MMS is in the process of joining with DaimlerChrysler Aerospace to create the ASTRIUM organisation.)

The Ball Aerospace campaign kicks off in the wake of February's successful Shuttle Radar Topography Mission (SRTM) and will build upon the company's experience in producing SRTM antennas. Dubbed the LightSAR concept, the new proposal is a revision of a previous space-based radar mapping concept that was denied NASA funding in 1999 in favour of the Franco-American Pathfinder Instruments for Cloud and Aerosol Spaceborne Observations effort. The most recent LightSAR vehicle is expected to fly in a low earth orbit to collect earth science data in the areas of geology, geophysics and agricultural survey. When compared with the SRTM system, the LightSAR concept features a primary antenna that is larger than the outboard unit and electronics with lower volume and power requirements. Prior to SRTM, Ball Aerospace was responsible for the antennas used in the Spaceborne Imaging Radar-C system that was launched in 1994. For the SRTM radar, Ball Aerospace developed an auxiliary reception array that was mounted on a telescopic 60 m mast and used as part of the system's ability to generate necessary data for three-dimensional imagery.

Australia Acquires Danish and Israeli EW Systems

The Royal Australian Air Force (RAAF) has awarded contracts valued at approximately $34 M to Danish contractor TERMA Elektronik and Israeli company Elta Electronics Industries for the installation of electronic warfare (EW) equipment aboard its F-111C strike aircraft. The TERMA contract, which is valued at $4.2 M, will cover the supply of the company's AN/ALQ-213(V) EW Management System (EWMS). Forming part of an interim defensive aids upgrade, the F-111C EWMS application will combine the aircraft's radar warning receiver, countermeasures dispensing system and newly procured Elta EL/L-8222 jamming pod into a single control architecture. The acquisition of the L-8222 pod composes the second segment of the F-111C effort and will be acquired in a $30 M programme that involves Australian company Vision Abell acting as Elta's in-country subcontractor. In addition to the acquisition of the radar jammers, the package includes logistical support, test equipment and software manipulation tools. On a global scale, Australia is the eighth customer to purchase the EWMS since its introduction into service in 1992.

The development of an interim EW fit for the RAAF's F-111C strike aircraft resulted partly from the suspension of the service's Echidna programme, which initially was supposed to develop a modular, integrated EW capability that could be applied across a range of Australian front-line aircraft. A major factor in the failure of the first Echidna iteration was the US State Department's restriction on access to US-sourced EW data, which, in turn, caused Australia to effectively preclude US industry from the bidding process. A resolution to the access problem emerged at an Australian-US Ministerial Acquisition Council meeting in January. Using EW interoperability as the lever, both countries are expected to establish a memorandum of understanding that covers the exchange of EW threat data and the development of an EW co-operation mechanism. Accordingly, US participation is expected when the Australian Department of Defence releases a restructuring plan of the Echidna effort.

Siemens Showcases New Technologies for the Future

German contractor Siemens showcased the SIMpad wireless Web pad, the Internet-controlled C-LAB Pathfinder robot demonstrator, the Voice Butler voice recognition remote control capability, the Bluetooth multi-device automated voice and data exchange interface, and a prototype wireless local area network (WLAN) at the CeBIT 2000 exhibition held in February in Hanover, Germany. The SIMpad wireless Web pad allows users to access the Internet at any time from any location. The prototype weighs slightly more than two pounds and functions as a communications terminal with a graphical interface. The unit can be operated at ranges of up to 150 m from a base station that is connected to a telephone network or a local area network. The SIMpad demonstrator communicates via GMS with the possibility of using General Packet Radio Service or Universal Mobile Telecommunication System links in the future. Developed by Siemens Switzerland, the unit operates from a Windows CE, allowing existing communications capability to be supplemented by third-party software. The C-LAB Pathfinder demonstrator is a small robotic device capable of controlling equipment via commands input into an Internet Web page. Operator feedback takes the form of a

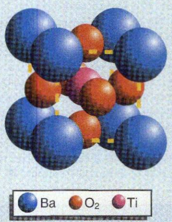
CIRCUIT DESIGNER'S NOTEBOOK

Piezoelectric Effect in Ceramic Capacitors

The Greek root of the word piezo means "to press". In 1880, Jacques and Pierre Curie discovered that pressure applied to a quartz crystal creates an electrical potential on the crystal. Likewise, they also discovered that an electrical potential impressed on the crystal creates a deformation of the crystal. They referred to this phenomenon as the piezoelectric effect.

The piezoelectric effect can be readily defined as the generation of an electrical potential as a result of applying pressure or by mechanically deforming a piezo crystal lattice structure. This deformation causes the molecules in the material to become electrical generating dipoles resulting in a potential difference across the crystal.

The piezoelectric effect occurs in crystals that have no center of symmetry. This lends itself to a net polarization of the crystal. The most widely known piezoelectric material is quartz. Others include various polycrystalline ceramics that are frequently used in capacitor dielectric formulations.

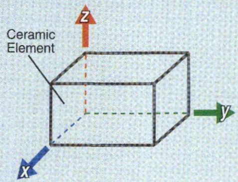


Example of a Perovskite Ceramic - Barium Titanate ($BaTiO3$)

One such group of materials is known as perovskites. Perovskites are one of the most abundant minerals on earth and are used in a large family of crystalline ceramic formulations such as barium titanate, calcium titanite and lead zirconate titanate. These crystals have some inherent piezoelectric properties that require careful processing to minimize the piezoelectric effect when used in capacitor fabrication.

Piezoelectric Ceramics:

Because of the anisotropic nature of many ceramics materials, piezoelectric effects are dependent on direction of mechanical excitation. This concept is illustrated by the ceramic element shown in the following figure. The axes labeled *x*, *y*, and *z* follow the classical right hand orthogonal axial set. The orthogonal coordinate system shown here is commonly used to describe piezoelectric properties. The reference direction is conventionally chosen as the *z* axis. A mechanical or electrical response in any of the three directions will produce a response in its corresponding orthogonal axis. For example, an electric field in the *z* direction causes a mechanical deformation in the *x* direction, and conversely a mechanical deformation in the *x* direction will result in an electric field in the *z* direction. The piezoelectric effect along any axis is dependent on a mechanical excitation of an orthogonal axis.



Circuit Application Considerations:

Stability: Issues regarding the generation of microphonics due to the piezoelectric effect can lead to a myriad of performance issues in many circuit applications.

Some examples are:

- Production of extraneous (unwanted) signal voltages due to structure borne vibration that can de-tune high Q circuits.
- Oscillator instability, especially where tuning is accomplished with passive components.
- Ringing in pulsed circuit applications.
- Generation of erroneous data in digital circuits.

Mechanical Stress:

Mechanical stress on the capacitor due to vibration can disrupt the termination-ceramic interface. The shear forces that exist in piezoelectric ceramics can lead to unreliable ceramic-termination interface. This condition may gradually reduce performance by progressively degrading the loss tangent (DF).

When RF voltage is applied to the capacitor, the microstructure will grow and shrink at the same frequency as that of the applied voltage. This can lead to shear forces that can cause deformations leading to reduced reliability or catastrophic failure.

Phase Sensitive Applications:

Capacitors exhibiting piezoelectric effects should not be used in filter network designs. Phase shifters, filters, oscillators, or any design where phase stability is essential, should avoid the application of piezoelectric dielectric materials, because phase variations in accordance with the mechanical excitation may occur.

Coupling Applications:

Interstage coupling applications are frequently sensitive to capacitors exhibiting piezoelectric effect. The designer should avoid using these capacitors in sensitive applications as they can pass along non-linear distortions to succeeding stages.

Richard Fiore
Sr. RF Applications Engineer
American Technical Ceramics Corp.

video stream generated by an onboard camera. Potential applications include plant automation, home automation and telemedicine. The designation C-LAB is taken from the system's developer, Siemen's Innovation Centre at Paderborn University, and the prototype's interface with the Internet makes use of Apple's Quicktime 4 software. The Voice Butler prototype is a general-purpose, remote control capability that is based on voice recognition and designed to replace current household infrared remote control devices while providing voice activation for domestic lighting, heating and ventilation systems. The Voice Butler is capable of controlling up to 13 discrete devices, handles instructions from up to four different speakers and accepts commands in English, French, German, Italian, Portuguese and Spanish. The WLAN is designed to provide mobile access to personalised network services and information from any device anywhere in the world. Using WLAN technology, users can access personal e-mail accounts, centrally organised schedulers and/or addresses from any mobile terminal compatible with GSM, Bluetooth or similar technology. The Bluetooth interface is a joint effort by Siemens and Fujitsu Siemens Computers, which makes use of a plug-in, cordless communications module that works with a WLAN server. Bluetooth has the capability to seamlessly connect cellular phones, notebooks and desktop personal computers and is expected to be commercially available by this summer.

Philips Introduces FlipChip Variant of DC-to-DC Converter IC

Netherlands contractor Philips Semiconductors has introduced a smaller-sized FlipChip variant of its model TEA1207 DC-to-DC converter IC. The 3.9 mm model TEA1207UK device's chip-scale package can be easily mounted on a PCB using existing surface-mount equipment. If secured to the PCB with solder bumps or balls, the TEA1207UK will eliminate the need for wire bonding and intermediate-level packaging. Other advantages of the FlipChip variant include improved thermal and electrical performance, the use of standard body sizes and pin counts, and the potential lower cost of ownership. The TEA1207UK is capable of downconverting to 1.25 V while maintaining a 90 percent conversion efficiency for output currents between a few milliamps and 0.5 A. In upconvert mode, the IC can generate an output voltage between 2.8 and 5.5 V from an input voltage greater than 1.8 V with a switching frequency from 220 to 330 kHz (275 kHz (typ)). Designed specifically for applications where low voltage, low power CMOS logic is used to minimise battery drain, the device also features a digital control circuit that uses output voltage level as its control input. ■

Global Fiber-optic Coupler Market to Reach $1.75 B by 2008

According to a recent report from ElectroniCast, the global consumption of fiber-optic couplers is projected to increase to $1.75 B by 2008 as a result of rising quantity growth (partially offset by a continuing decline of average prices). The report also predicts that global coupler consumption will be driven by the increasing demand for high capacity transport systems used in a variety of applications, including long-haul submarine networks, local loop networks, cable TV networks, test instruments and sensors. In 1999, North America led global coupler consumption with $149.7 M, followed by Europe with $108.9 M. (Germany, the UK, France and Italy represented the majority of fiber-optic deployment in Europe.) By 2008, global fiber-optic coupler consumption is expected to reach to $664.3 M in North America and $491.9 M in Europe.

Telecommunications fiber-optic coupler applications represented 59.3 percent of the global market consumption in 1999 with $233.5 M. The report predicts, however, that this consumption share is expected to decrease to 56 percent but increase in value to $980.1 M by 2008. Other applications for fiber-optic coupler consumption include cable TV, which represented 14.3 percent of the market share in 1999 with $56.3 M and is expected to increase to $143 M by 2008. The military/aerospace segment, which accounted for 11.6 percent with $45.6 M, is expected to increase to $273.5 M while specialty applications (including test instruments and automotive) are expected to increase to $249.8 M by 2008. Premise data networks, which consumed $19.1 M in 1999, are expected to increase to $103.8 M by 2008. For additional information, contact Theresa Hosking, ElectroniCast (650) 343-1398, fax (650) 343-1698.

Intelligent Mobile Units to be Installed in Service Vehicle Fleets

HighwayMaster Communications Inc., a provider of wireless voice and data communications services to the commercial trucking and service vehicle industries, has been selected by SBC Communications Inc. to supply Ameritech and other SBC member companies with more than 28,000 HighwayMaster series 5005S intelligent mobile units as well as enhanced proprietary software and services. The systems will provide service vehicle fleets with event-based location tracking, mobile voice communications and a location-based panic alarm device using both terrestrial-based wireless communications capabilities and the Global Positioning System (GPS) satellite network, thereby increasing effective utilization of service fleets and providing a safer work environment for service technicians. Installations are expected to occur throughout this year. The enhanced cellular network utilizes more than 70 cellular providers in the US and Canada, offering coverage in essentially all of the available US markets and neighboring Canadian markets. The newest installations are expected to create one of the largest GPS-based fleet service management systems in the US. To date, HighwayMaster has installed more than 43,000 mobile units at various SBC companies.

Ford to Bring Internet Features to the Automotive Industry

Ford Motor Co. has announced plans to equip next year's model vehicles with voice-activated telematics systems that offer advanced security features and information access. The systems will be standard on select Lincoln luxury vehicles and optional on Ford Focus vehicles in Europe. The telematics system will include a voice-activated access option to personalized Internet information including news, stock quotes and weather. Additional features that will enhance passenger safety and security include automatic collision notification, which sends a message identifying the vehicle and its location to an operator whenever the air bags are deployed; an emergency assistance button, which connects a vehicle to an operator when police, fire or medical assistance is needed; and a roadside assistance button, which provides information about nearby roadside assistance.

An optional satellite radio service that offers 100 channels of radio programming throughout the US will be available beginning in 2001. In the near future, optional equipment that enables passengers to surf the Web and download material and remotely monitor the vehicle's operating systems are expected to be made available. Passengers also can expect to control the onboard systems with their own computing equipment. The application of Bluetooth technology is predicted to permit wireless control of car systems from digital devices and, ultimately, provide communication of real-time traffic information between vehicles. The telematics systems are expected to be installed on most Ford vehicles over the next several years.

Cellular Base Station Deployment in Europe Expected to Triple by 2005

The Strategis Group Inc.'s recent analysis, "Strategis dataBank™: European Cellular Network Infrastructure," projects that cellular base station deployment across Europe will nearly triple over the next five years, increasing from approximately 210,000 base stations in mid-1999 to more than 500,000 base stations in 2005. As subscriber growth and wireless phone usage continue to

grow significantly in Europe, wireless operators are scrambling to improve both population and territorial coverage to maintain and improve their competitive position in the European market. In mid-1999, Germany's T Mobil was the leader among European cellular operators with 18,500 base stations deployed. (E-plus, Mannesman, France Telecom and SFR (France) rounded out the list of top-five operators.) While Germany is predicted to maintain a high base station density (in terms of square kilometers), the Netherlands and Belgium are expected to lead the European market with a projected 450 base stations per 1000 square kilometers by 2005. The report projects that five markets will account for approximately 60 percent of Europe's base station deployment by 2005, including Germany (24 percent), Italy (10 percent), the UK and France (eight percent) and Spain (seven percent).

The report, which is a compilation of interviews with 123 cellular operators who represent 160 networks across 39 countries in Eastern and Western Europe, also provides data for base stations by country and technology from 1997 to 2005, population and territorial coverage, network launch dates (including launch dates for dual-band GSM 900/1800 networks), infrastructure vendors, infrastructure vendor market shares and average base station density and population penetration. For additional information, contact Elizabeth Harr Bricksin, The Strategis Group (202) 530-7505 or e-mail: ehbricksin@StrategisGroup.com.

High Speed Internet Service to Reach 16.6 Million Subscribers by 2004

The Yankee Group has released a report, which forecasts that the US market for residential high speed Internet services will reach 3.3 million subscribers by the end of this year and 16.6 million subscribers by 2004. At the end of 1999, the installed base of domestic high speed Internet subscribers totaled 1.4 million with nearly 80 percent of these subscribers using cable modems for access. While the cable industry is expected to continue to lead the market over the next five years, its total share of high speed Internet subscribers is expected to shrink to 42 percent by the end of 2004 as local telephone companies make digital subscriber line (DSL) service more widely available. In addition, approximately 41 percent of US households are expected to have access to cable modem service by the end of this year, while only 24 percent will have DSL access. Nearly two-thirds of PC-equipped homes expressed interest in high speed Internet service and 40 percent of those indicated a willingness to pay up to $40 a month for service. For additional information, contact Kim Vranas, The Yankee Group (617)-880-0214 or e-mail: kvranas@yankeegroup.com. ■

4 Watt PCS Linear Power Amplifiers

Typical performance @ +25° C

Parameter	PA1162	PA1163	PA1151	PA1157	PA1159
Frequency (MHz.)	800-960	1810-1870	1930-1990	2000-2200	2300-2400
Gain (dB.)	35.0	27.0	26.5	24.5	23.5
Gain Flatness (dB.)	±0.4	±0.5	±0.5	±0.5	±0.5
Pout @ 1 dB. comp. (dBm.)	+36.2	+36.5	+36.8	+36.0	+36.2
IP3 (dBm.)	+52.0	+52.0	+54.0	+50.0	+52.0
Noise Figure (dB.)	2.3	2.4	2.4	3.0	3.2
Vcc/Ic (v/mA.)	+10/1350	+10/1350	+10/1350	+10/1350	+10/1350
VSWR	2.1:1	2.0:1	2.0:1	2.0:1	2.0:1

* *CDMA and TDMA test data available upon request*

In today's competitive wireless environment "Time to Market" is a very crucial factor for the success of a new product.

For Cellular, PCS, and WLL cell sites, Phoenix Microwave Corporation *offers the largest selection of linear amplifier modules* to accelerate your multi-carrier power amplifier designs.

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INDUSTRY NEWS

■ **Alcatel** has entered into a definitive agreement to acquire wide area networking solution designer and manufacturer **Newbridge Networks Corp.** The acquisition is subject to Newbridge shareholders' approval of a merger agreement that will allow for the ultimate conversion of each Newbridge share into 0.81 Alcatel ADS. The transaction is valued at $7.1 B. In related news, Alcatel has entered into an agreement with **STMicroelectronics Inc.** whereby Alcatel will adopt the STMicroelectronics ST100 digital signal processor core that is designed specifically for communications applications where a powerful, high end embedded core is required. Under the terms of the agreement, Alcatel intends to embed this core in a variety of system-on-chip solutions for digital subscriber line, voice-over-Internet protocol and other leading-edge technologies.

■ Specialty optical fiber and fiber-optic product designer and manufacturer **SpecTran Corp.** has been acquired by Lucent Technologies. Lucent's **Specialty Fiber Technologies** division will offer customers integrated solutions for industrial, telecommunications, medical, transportation, aerospace and geophysical applications.

■ **Telaxis Communications Corp.**, South Deerfield, MA, has completed the sale of its **Millitech Division** to **Millitech LLC**, an entity formed by private investors. In connection with the sale, Telaxis received $1.75 M in cash payment, a subordinated note and a minority equity interest in Millitech LLC as well as a seat on the Millitech management advisory board for at least three years. The purchase price is subject to post-closing adjustment.

■ **Varian Inc.**, Palo Alto, CA, has acquired the Poway, CA-based electronics manufacturing operation of **Inter-Tel Inc.** Under the terms of the acquisition, Varian is expected to receive inventory and fixed assets for a net book value of $6.6 M and the assumption of the lease for a 112,000-square-foot facility. In addition, Varian is assuming responsibility for the operation's computer telephony products as well as procurement, assembly, test and depot repair.

■ Electron tube manufacturer **Burle Industries** has created **Burle GmbH**, a new European subsidiary to market and support all of the company's power tube and electro-optic products, including high energy power tubes, silicon target imaging devices, scientific detectors and spectroscopy products.

■ **Wyle Electronics**, a member of the **VEBA Electronics Group**, has created **RF Vision**, a new subsidiary business unit that will provide technical distribution solutions to manufacturers in the wireless and electro-optics industries. The new company, which will be located at Wyle's Northern California facility in Silicon Valley, will specialize in advanced RF/microwave and fiber-optic technology.

■ Thermal management solution provider **Aavid Thermal Products Inc.**, a wholly owned subsidiary of **Aavid Thermal Technologies Inc.**, has changed its name to **Aavid Thermalloy LLC** to reflect its recent acquisition of Theramalloy Inc.

■ **Pulse**, a **Technitrol** company, San Diego, CA, has formed a group dedicated to developing and supporting a broad range of off-the-shelf electronic components for the cable market. The **Cable Products Group** will focus development efforts on products that support the accelerating deployment of hybrid fiber-coax networks as well as cable access equipment.

■ **Tektronix Inc.** has formed a new group within its **Measurement Business Division** to focus on meeting the ever-increasing customer desire to access information and conduct business online. The **Internet Business Group** is expected to develop a more interactive and collaborative Web environment with expanded information on products, applications, technologies and other services.

■ **Rockwell Collins**, Cedar Rapids, IA, has created an electronic business unit that will offer expanded e-business solutions to its customers. The company intends to consolidate its information technology, enterprise resource planning and e-commerce departments to form a strategic working group that brings together business unit, customer and supplier requirements.

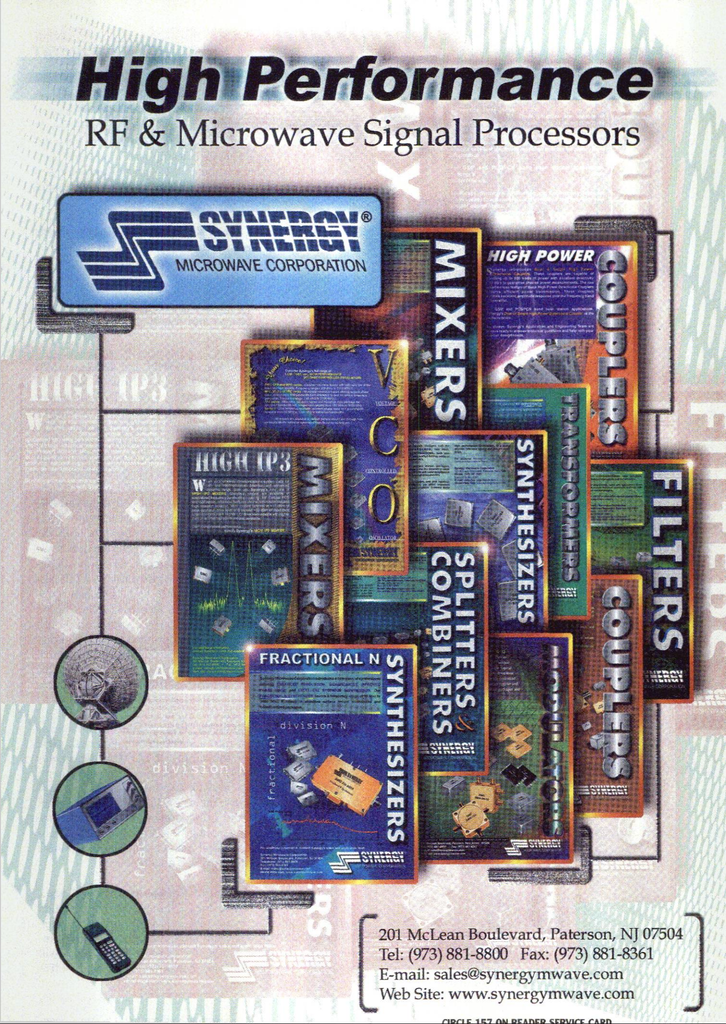
■ **Taiyo Yuden Inc.** of Japan has announced plans to open **Taiyo Yuden (Guangdong) Company Ltd.**, a new 42,650-square-foot manufacturing plant located in the People's Republic of China, in an effort to upgrade existing manufacturing processes and dramatically increase production of high frequency, multilayer chip inductors and multilayer ceramic capacitors. The $8.4 M facility is expected to begin operations in July.

■ **EMP TrexCom** has moved to a new 85,000-square-foot facility located at 900 Enchanted Way, Simi Valley, CA 93065 (805) 581-7868, fax (805) 581-7821 or e-mail: info@emptrexcom.com. The new facility is equipped with state-of-the-art engineering, manufacturing and testing systems including near- and far-field test ranges for accommodating antennas up to 13 m in diameter.

■ **Emerson & Cuming Microwave Products** has opened a new 6000-square-foot, state-of-the-art processing center for carbon-loaded foam microwave absorber products in Randolph, MA. The new facility has the capacity to produce 10,000 to 20,000 square feet per week of both sprayed and dipped carbon foam products.

■ RFIC solution designer and manufacturer **ANADIGICS Inc.** has announced plans to expand its state-of-the-art six-inch InGaP HBT, pHEMT and MESFET manufacturing facility to include additional Class 10 cleanroom space and equipment installation. The $10 M expansion, which is scheduled for completion by the middle of this

[Continued on page 60]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year, is expected to approximately double current production capacity. In related news, ANADIGICS has shipped high volumes of power amplifiers for use in Ericsson T-class, dual-band mobile phones. The amplifiers were designed specifically to meet Ericsson's requirements for a low cost device that combines the high performance and functionality of two power amplifiers in a single, small package.

■ **Brush Wellman Inc.'s Electronic Packaging Products Group**, Newburyport, MA, has formed a strategic partnership with **RJR Polymers**, Oakland, CA, to supply the wireless industry with a complete electronic packaging solution. The partnership is expected to reduce cycle times for the design of new packages and enable customers to have packages and lids that are optimized to work together.

■ **RF Micro Devices Inc. (RFMD)** and **QUALCOMM Inc.** have entered into an alliance to provide advanced power amplifiers for the CDMA market. The companies have agreed to cooperate on the development of CDMA power amplifiers for inclusion in existing and future QUALCOMM CDMA chipsets. Under the terms of the agreement, QUALCOMM will market and sell the jointly developed CDMA power amplifiers using RFMD's wafer foundry manufacturing process. In related news, QUALCOMM has entered into an agreement with **Ericsson Microelectronics** to jointly develop and market the world's first wireless technology solution that supports both the Bluetooth standard and the CDMA digital wireless standard. Under the terms of the agreement, Ericsson will develop a Bluetooth-compatible radio unit and QUALCOMM will develop the Bluetooth digital baseband processing to be integrated into its future Mobile Station Modem (MSM™) chipset and software solutions. Both companies will work together to optimize the RF and digital designs for operation within a CDMA handset environment to create the most complete, high performance solution available for CDMA-based wireless data applications.

■ RF power semiconductor designer and manufacturer **UltraRF** has entered into a strategic alliance with **GHz Technology Inc.** for the supply of LDMOS RF power transistor technology. Under the terms of the agreement, UltraRF will supply UltraGOLD silicon LDMOS wafers to GHz Technology for inclusion in devices that target avionics, broadcast and other nonwireless applications. The alliance is part of a strategy that will allow GHz Technology to reach an expanded market while building on its core design and manufacturing competencies.

■ **Chomerics**, a division of **Parker Hannifin Corp.**, Woburn, MA, and **Nypro Inc.**, Clinton, MA, have formed a strategic alliance to provide telecommunications customers with an efficient and integrated manufacturing resource for obtaining conductive gaskets. The alliance will streamline the production of insert-molded conductive

[Continued on page 62]

products against electromagnetic interference in cellular phones and other electronic devices. As a result, customers can expect simplified ordering, faster deliveries and better-quality parts. In related news, Chomerics' Hudson, NH facility has received QS-9000 certification. The Hudson, NH facility designs, develops and manufactures thermal interface materials, EMI shielding laminates and the SOFT-SHIELD™ 4000 and 5000 lines of EMI shielding gaskets.

■ **Agilent Technologies Inc.** has signed a licensing agreement with **SyntheSys Research Inc.** for its error-analysis technology, which enables engineers to locate the causes behind errors in digital components and system hardware. Under the terms of the licensing agreement, Agilent will develop and market bit error ratio products that incorporate Synthesys' BitAlyzer technology.

■ **Calibre Inc.**, San Jose, CA, has entered into an agreement with **Infineon Technologies Corp.** under which both companies will dual-source selected products in their IrDA-compatible data transceiver product lines. The companies initially are expecting to dual-source a fast infrared IrDA-compatible transceiver with an innovative power architecture that will prolong battery life in IR-enabled personal digital assistants, digital still cameras, portable printers and other battery-powered electronic applications.

■ **Mitel Semiconductor** (a division of **Mitel Corp.**), **Philsar Semiconductor** and **Matsushita Electronic Components Co. Ltd.** have entered into an agreement to co-develop a module for next-generation Bluetooth systems. The companies will combine a silicon chipset designed by Mitel and Philsar with Matsushita's Panasonic high density packaging and RF expertise to provide a high performance and power-efficient route to Bluetooth 1.0-compliant systems. The agreement is expected to accelerate the adoption of Bluetooth technology in personal wireless connectivity solutions.

■ **Microcosm Technologies Inc.**, Cary, NC, and **Cronos Integrated Microsystems Inc.**, Research Triangle Park, NC, have entered into an alliance to offer JumpStart,™ a design kit that provides a low risk, inexpensive, efficient turnkey method for developing and prototyping microelectromechanical systems (MEMS) devices. The unique MEMS design solution will comprise Microcosm's Catapult™ MEMS design tool with integrated layout generators, an engineering design kit for the Cronos certified multi-user MEMS processes (MUMP™) and a reserved slot on a Cronos MUMPs fabrication run.

■ **KCA Electronics**, Anaheim, CA, has purchased a model 9098 universal double-density grid test system from **Everett Charles Technologies**, Pomona, CA. In related news, **Adaptive Circuits**, San Jose, CA, has purchased the A2/16 flying probe test system from Everett Charles Technologies. The A2/16 flying probe test system has the capability to load and test multiple boards at the same time.

[Continued on page 64]

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

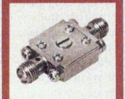
KPH90OSCL000

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		

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■ **EPCOS Inc.** (formerly **Siemens**), Iselin, NJ, has selected **Eastern Components Inc.**, West Conshohocken, PA, as an authorized distributor of the company's ferrites and accessories.

■ **Deltec Telesystems** has entered into a distribution agreement with **Huber + Suhner** of Switzerland. Under the terms of the agreement, Huber + Suhner will distribute Deltec's Teletilt™ and omni range of telecommunications antennas and antenna management systems throughout Europe.

■ Essential process management tool supplier **Electroglas Inc.** has licensed essential measurement technology from **Cascade Microtech Inc.** The licensing agreement is expected to reduce noise and measurement settling times in probers for wafer productions, thereby enabling faster and more accurate testing of advanced semiconductor devices, including high speed telecommunications and computing devices.

■ **Signal Technology Corp.'s Arizona Operation** has received ISO 9001 registration by AOQC Moody International Inc.

■ Digital video compression system provider **Enerdyne Technologies Inc.**, a subsidiary of **Advanced Remote Communication Solutions**, has received ISO 9002 certification.

■ **Times Microwave Systems** has announced that its LMR-900 LLPL series 50 Ω flexible, low loss plenum cables have qualified for in-building applications according to Underwriters Laboratories standards. The LMR-900 LLPL series complies with fire spread and smoke emission requirements, which allow cables to be installed within buildings directly in air-return plenum spaces such as dropped ceilings without the need to be installed in metal electrical conduit.

■ **ARINC Inc.** has received a Supplemental Type Certificate (STC) for its KC-10 aircraft, a DC-10-30 commercial airframe modified to a tanker and passenger-carrying aircraft for the US Air Force. The STC was issued by the Los Angeles Aircraft Certification Office for a series of safety-related modifications, which include an AlliedSignal Traffic Alert and Collision Avoidance System and an Enhanced Ground Proximity and Warning System.

■ RF component and subassembly manufacturer **RF Monolithics Inc. (RFM)**, Dallas, TX, has received the Delphi Automotive Systems Division Delphi-Delco Absolute Zero Defect Award. The award is presented to vendors who delivered units with zero failures or defects during the previous year. RFM is one of eight vendors out of 671 suppliers who received the award.

■ **Superconductor Technologies Inc. (STI)** has received a purchase order for 27 SuperFilter® systems from an unnamed cellular service provider, increasing its backlog to 56 systems. STI has shipped and delivered more than 200 SuperFilter systems during the past two years. The company is expected to announce a new line of SuperFilter products for third-generation high bandwidth networks for wireless communications and wireless Internet access.

■ **JDS Uniphase Corp.** has delivered its first shipment of 10 Gbps transmitter and receiver modules to meet the growing demand for higher functionality modules. The modules provide customers with a low cost solution for error-free data transmission for distances over 2 km.

■ **Crosspan**, a newly named telecommunications division of **Raytheon Commercial Electronics**, has announced that its active antennas, which are integrated into Ericsson's GSM Maxite™ 1900 system, were successfully deployed in Powertel's Jacksonville, FL PCS network. As the first North American PCS operator to use micro base stations with macro coverage capability, Powertel has 18 Maxite cell sites currently in operation.

■ The Center for the Study of Wireless Electromagnetic Compatibility (EMC) at the University of Oklahoma has announced that EMI gasketing solution provider **Instrument Specialties** has become a charter member of the center's Industry Advisory Board. The Oklahoma EMC Center is chartered to work with the wireless and medical device industries as well as government agencies to resolve inter-industry EMC issues.

FINANCIAL NEWS

■ **Signal Technology Corp.** reports sales of $20.3 M for the fourth quarter, ended December 31, 1999, compared to $23.4 M for the same period in 1998. Net income was $1.6 M (20¢/diluted share), compared to $371 K (5¢/diluted share) for the same quarter in 1998.

■ **Ansoft Corp.** reports sales of $8.4 M for the third quarter, ended January 31, compared to $6.1 M for the same quarter last year. Net income was $458 K (4¢/diluted share), compared to a net loss of $356 K (3¢/diluted share) for the same period last year.

■ **Superconductor Technologies Inc.** reports sales of $2.2 M for the fourth quarter, ended December 31, 1999, compared to $1.8 M for the same period in 1998. Net loss was $3.0 M (42¢/share), compared to a net loss of $2.6 M (35¢/share) for the same quarter in 1998.

■ **Cascade Microtech Inc.** has completed a $10 M round of equity financing from the Teachers Insurance and Annuity Association of America. The funds will be used to accelerate the company's marketing and manufacturing capabilities in support of its new Pyramid Probe™ technology, which provides advanced testing capabilities for the development and production environments as well as today's sophisticated semiconductors.

■ **Iridium LLC** has secured interim financing in an effort to expedite the transition of its assets and personnel to a new operating company. The financing, which was approved by the US Bankruptcy Court for the Southern District of New York, is valued at $5 M with investments from Eagle Rivers

[Continued on page 66]

Investments LLC, Craig McCaw's investment company and Motorola. Iridium expected to file a motion to establish procedures for a sale under Section 363 of the Bankruptcy Code and to secure additional debtor-in-possession financing to cover the period extending until the middle of this month, when a sale was expected to be completed.

■ **RangeStar Wireless** has entered the final stages of its mezzanine round of financing. The private placement of funds will allow the company to fully capitalize on immediate marketing opportunities and generate additional embedded antenna technological developments. The investment is expected to accelerate the scheduled initial public offering date to early fall.

■ **REMEC Inc.** has filed a registration statement with the Securities and Exchange Commission for a public offering of 4.31 million shares of common stock. Of the offered shares, 3.5 million will be sold be the company; 250,000 will be held by one shareholder; and 562,000 shares will be held by certain selling shareholders, if the underwriters exercise their over-allotment option. A copy of the prospectus relating to the offering may be obtained from Needham & Company Inc., 445 Park Ave., New York, NY 10022.

CONTRACTS

■ **REMEC Inc.** has entered into an agreement with a major mobile telecommunications network equipment manufacturer for the production of base station products, including integrated assemblies that provide signal conditioning and RF filtering functions. The agreement is valued at approximately $27 M with deliveries forecast over the next 12 months.

■ **Signal Technology Corp.**, Danvers, MA, has been awarded a contract by Raytheon Systems Co. for the supply of microwave oscillators in support of low rate initial production of the Brilliant Anti-armor (BAT) Submunition Program. The BAT Submunition Program employs passive acoustic and infrared sensors to locate, attack and destroy moving tanks and other armored vehicles deep in enemy territory. The contract is valued at $276 K. Future contracts for production hardware could exceed $4 M.

■ **Robinson Nugent Inc.** has received a contract to supply the backplane connector for the newly released MAX TNT multiprotocol wide area network access switch. The switch enables carriers, ISPs, corporations and major network providers to offer a variety of access services, including analog, integrated services digital network, leased T1/E1 and frame relay. Financial details of the contract were not released.

■ **EPI MBE Products Group**, St. Paul, MN, has received an order for a GEN2000 multiwafer production molecular beam epitaxy (MBE) system from RF Micro Devices. The GEN2000 will be utilized for mass production of epitaxial wafers used in the fabrication of high performance GaAs circuits. Financial terms of the contract were not disclosed.

PERSONNEL

■ ANADIGICS Inc. has elected **Dennis F. Strigl** to the company's board of directors. Strigl is currently president and CEO of Bell Atlantic Mobile and Bell Atlantic Global Wireless.

■ American Microwave Technologies (AMT) has appointed **Pete Manno** president and CEO. Manno brings to the company more than 30 years of experience in the RF industry and, most recently, was an independent consultant. Also, **John Carollo** has been named VP and general manager of the company's Wireless Business Unit. Carollo was director of marketing at Hewlett-Packard Co.'s power amplifier division prior to joining AMT.


▲ *Ken Wadors*

■ **Ken Wadors** has been appointed president and CEO at RF Vision, a subsidiary of Wyle Electronics. Most recently, Wadors was senior VP and director of RF/small-signal business at Avnet Inc.

■ **Martin S. McDermut** has been named CFO and VP of finance and administration at Superconductor Technologies Inc. Most recently, McDermut was VP of finance and administration at International Remote Imaging Systems Inc.

■ **Edwin K. Walters** has been named CFO at Larus Corp. Walters brings to the company more than 19 years of management responsibility in financial services.


▲ *Guy Campbell*

■ Andrew Corp. has promoted **Guy Campbell** to president and director. Campbell joined the company one year ago as group president, Wireless and In-Building Products Group. Prior to that, he held numerous executive positions at Ericsson.


▲ *John-Paul Besong*

■ Rockwell Collins has appointed **John-Paul Besong** VP, Electronic Business. Besong has been with the company for 20 years and, most recently, was executive, enterprise resource planning.

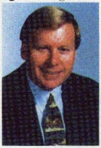
■ STMicroelectronics Inc. has promoted **Enrico Villa** to corporate VP, director of European region and **Carmelo Papa** to corporate VP, region five. Most recently, Villa was corporate VP, region five and Papa was director of product marketing and customer service for transistors and standard ICs.

■ Cascade Microtech Inc. has appointed **Mark Olen** VP and general manager, Pyramid Probe Division and **Ken Smith** VP, corporate technology and Pyramid Probe operations. Most recently, Olen was VP of sales and marketing at Fluence Technology Inc. and Smith was director of operations at Cogent Research.

[Continued on page 68]

▲ Adolph Cheung

■ Trompeter Electronics Inc. has appointed **Adolf Cheung** VP, engineering and **Garry Heverly** regional sales manager for the eastern US. Most recently, Cheung was director of engineering at Dow-Key Microwave Corp. and Heverly was direct sales manager at Robinson Nugent Inc.



▲ Garry Heverly

■ Tektronix Inc. has made several new personnel appointments, including **Bob Agnes** as VP and general manager, Video Business Unit; **Scott Bausback** as VP and general manager, Communications Business Unit; **Karsten Beutnagel** as VP, human resources; **David Churchill** as VP and general manager, Instrumentation Business Unit; **David Coreson** as VP, central operations; **Richard McBee** as VP, global marketing and strategic initiatives; and **Craig Overhage** as VP and general manager, Digital Systems Business Unit.

■ **Otis E. Hayes** has been named director of quality at CTS Corp. Most recently, Hayes was the director of quality assurance at Coto Technology.

■ Robinson Nugent Inc. has appointed **Dennis Frischkorn** district sales manager for the Pacific Northwest. Frischkorn brings to the company more than 20 years of sales experience and, most recently, was area sales manager for the San Francisco Bay area at FCI Berg Electronics.

WEB SITES

■ **iMark.com Inc.**, a business-to-business Internet marketplace for used equipment, has added three new services to speed the buying and selling processes. ActiveSearch,™ ActiveLead™ and ActiveTransfer™ allow customers to access more than 100,000 pieces of used equipment and complement the company's existing services, which include transportation, financing, spare parts, maintenance supplies, inventory, appraisal and data entry.

■ **Micro Networks Corp.**, Worcester, MA, has launched a new Web site that enables design engineers to search for products and information by product family, application, part number or keyword. The site, which is located at www.micronetworks.com, includes current product information, specifications, data sheets and the company's short-form catalog.

■ **SearchMil.com**, a **MaxBot.com** Internet search engine that covers US military Web sites, has reached the one millionth mark in the number of unique publicly accessible Web pages indexed. SearchMil.com specializes in military targeted searches, combining in-depth coverage of the .mil domain with powerful search engine technology that ranks results in order of popularity.

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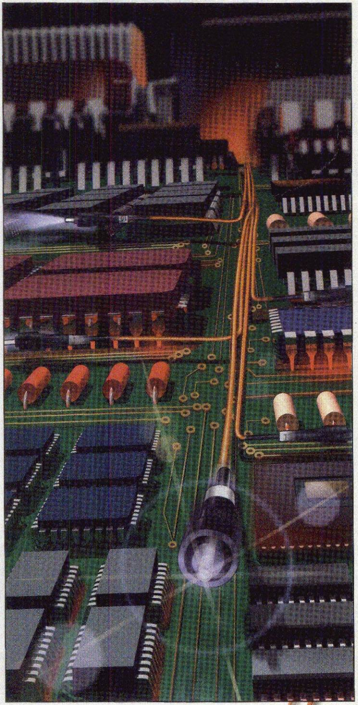

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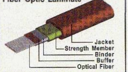

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A GSM EDGE Error Vector Magnitude Estimation Platform for RFIC/ASIC Evaluation

The Enhanced Data Rates for GSM Evolution (EDGE) air interface requires new components in current CAD tools to evaluate the performance of the IF/RF system. Analog integrated circuit designers in particular need to assess the linearity of their designs, expressed by the error vector magnitude (EVM) specifications for EDGE. This article describes an implementation of such a platform using an analog circuit design simulator, and compares the results with a mathematical package.

The evolution of GSM (EDGE) and the linear modulation used (8-PSK) with both amplitude and gain variations come with new specification requirements regarding system linearity. The relatively new standard means that current CAD tools lack libraries and blocks to support this recent specification. Although most major electronic design software players are actively working along with their customers to create those needed libraries, designers, in the meantime, must build their own to evaluate their designs. Such a need arises for integrated circuit designers who want to assess the performance of their circuits against EVM specifications in the European Telecommunication Standard Institute (ETSI) standards in addition to their usual device characterization parameters. The main hurdle for them is to incorporate baseband digital blocks (EDGE modulation, EVM calculation) into an analog circuit simulation environment that works at IF/RF frequencies.

EVM

The calculation of the RMS EVM is described in the ETSI standards.[1] This quantity assesses the modulation accuracy of the transmitted signal, which gives an indication of the linearity of the transmitter. Such information is in addition to the spectrum due to modulation and wideband noise requirements, which do not necessarily provide information on the linearity of the system. Under specified measurement conditions, the EVM calculation determines the error vector between the transmitted waveform and the ideally transmitted waveform at time kT (where T is the symbol

[Continued on page 72]

Ashkan Mashhour
and Assaad Borjak
Nokia Networks
Camberley, Surrey, UK

time $k \in Z$), as shown in ***Figure 1***, through the measuring receiver filter.

The standards specify the measuring receiver filter for EDGE as a 90 kHz single-sideband bandwidth raised-cosine filter with a 0.25 rolloff factor.[1] Its impulse response and transfer function are defined as

$$RC_\alpha(t) = \mathrm{sinc}\left(\frac{t}{T_m}\right)\frac{\cos\left(\frac{\pi\alpha t}{T_m}\right)}{1-4\alpha^2\frac{t^2}{T_m^2}}$$

$$RC_\alpha(f) = \begin{cases} T_m & \text{for } |f| \le \frac{1-\alpha}{2T_m} \\ \frac{T_m}{2}\left[1+\sin\left(\frac{\pi T_m}{\alpha}\left(\frac{1}{2T_m}-|f|\right)\right)\right] & \text{for } \frac{1-\alpha}{2T_m} \le |f| \le \frac{1+\alpha}{2T_m} \\ 0 & \text{elsewhere} \end{cases}$$

where

$\alpha = 0.25$ (the rolloff factor)

$$T_m = \frac{1}{180\ \text{kHz}}$$

Note that the receiver measurement filter is intended solely for measurement purposes and does not allow constellation recovery.

The standards do not define a receiver filter for EDGE; hence, a measurement receiver filter must be selected such that its time and frequency domain characteristics match those of a practical receiver filter. The EVM measurement using such a measurement receiver filter will then reflect actual system performance. The 90 kHz single-sideband raised-cosine filter defined earlier is a good candidate and has presumably been selected for its passband characteristics, which are dictated by EDGE channel spacing (200 kHz). However, the infinite impulse response of such a filter is somewhat impractical and, hence, EVM results may vary from one measurement instrument to another (depending on the implemented length of the measurement filter). In addition, depending on the arbitrarily chosen length, this filter may settle beyond the tail symbols in a GSM burst and therefore artificially degrade the EVM at either end of the useful part of the burst. As a way to overcome these problems, several proposals and change requests have been submitted to the standards body in order to define a universal filter.[3]

Referring to the ETSI standard,[1] the RMS vector error is defined as

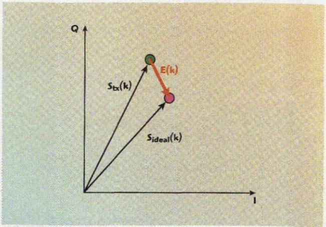
$$EVM = \sqrt{\frac{\sum_k |E(k)|^2}{\sum_k |S_{ideal}(k)|^2}}$$

where

$S_{ideal}(k)$ = ideal transmitted signal at symbol time kT

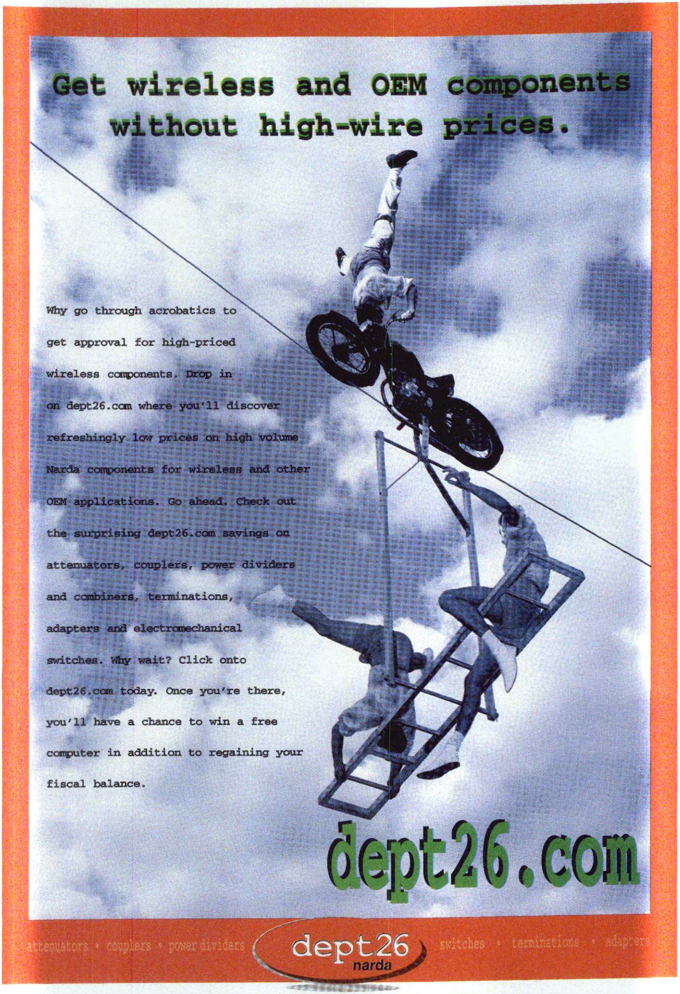
$E(k) = S_{tx}(k) - S_{ideal}(k)$ (the residual error on sample $S_{ideal}(k)$)

The current specifications define EVM measurements at symbol times only ($k \in Z$), that is, the error for other samples (between symbols) is not accounted for. Whether or not all samples should be used in the EVM computation is a controversial issue and remains so far an open question. Likewise, note that poor spectral performance far from the carrier may have little impact on the EVM.



▲ *Fig. 1 The error vector between ideal and transmited signals.*

[Continued on page 75]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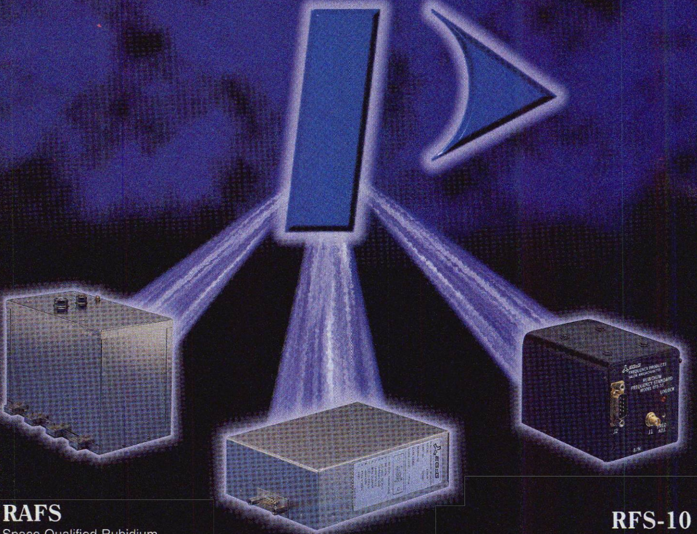

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RFS-10
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EVM is a digital domain characterisation parameter but it is used to evaluate analog circuits. The GSM EDGE standards, listed in ***Table 1***, indicate several EVM specifications for both mobile and base station use.

SYSTEM IMPLEMENTATION

The platform described here is targeted at IC or board-level designs. Hence, widely used simulation packages have been chosen to perform the simulations. The analog circuit simulation environments are Affirma™ Analog Artist® and Spectre RF® Custom blocks are implemented using proprietary programming languages (Verilog-A (AHDL)); postprocessing uses OCEAN. The analog simulator's results are benchmarked with MATLAB®/Simulink® simulations.

The evaluation of EVM is paramount to IC designers who require both EDGE modulation generating blocks and EVM calculation blocks in their simulation environment. It is quite convenient to be able to perform all of the simulations in a single environment rather than simulating the circuits and exporting results data to another package for postprocessing. Integrating all the tools into the analog circuit simulator has been the driving idea behind the presented platform.

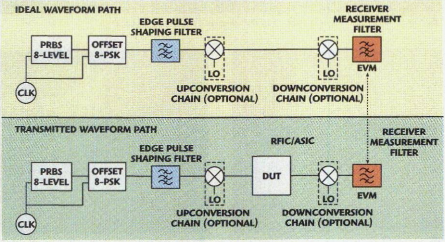
The system setup is shown in ***Figure 2***. The transmitted waveform path consists of a PRBS 8-level first block that generates a pseudorandom sequence of numbers ranging from 0 to 7. This configuration is followed by an offset 8-PSK block that generates the corresponding complex offset 8-PSK signal (rotated by $3\pi/8$). These two blocks are clocked by a reference clock set at the symbol rate for GSM EDGE ($T \approx 3.69$ µs). The resulting complex waveform is then filtered by the Gaussian-like pulse shaping transmitter filter (EDGE pulse shaping filter) specified in the ETSI standard[2]. Next, the device under test (DUT) (here, a RFIC/ASIC) is placed in the path, and the output signal is fed through the receiver measurement filter (raised cosine). Optionally, an upconversion/downconversion stage with adequate filtering can be fitted to bring the baseband signal up to the DUT working frequencies. The ideal waveform path is identical without the DUT. It is essential to incorporate into this ideal transmitted path all the ideal

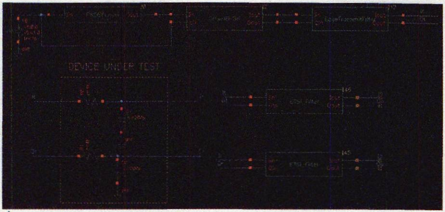
TABLE I

BTS AND MS EVM SPECIFICATIONS

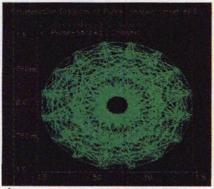
	Base Station		Mobile Station	
	Nominal Conditions	Extreme Conditions	Nominal Conditions	Extreme Conditions
RMS EVM (%)	≤ 7	≤ 8	≤ 9	≤ 10
Peak EVM (%)	≤ 22	≤ 22	≤ 30	≤ 30
95th percentile (%)	≤ 11	≤ 11	≤ 15	≤ 15

Fig. 2 Ideal and transmitted waveform paths for EVM measurement.

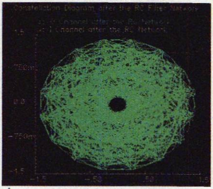




▲ *Fig. 3 Baseband implementation of the ideal and transmitted paths.*



▲ *Fig. 4 Ideal pulse-shaped GSM EDGE constellation diagram.*



▲ *Fig. 5 Transmitted constellation after FC filter DUT.*

characteristics of the DUT (such as gain, phase and delay) so that those characteristics are compensated for when compared to the transmitted path (calibration/normalization). In other words, only the nonidealities of the DUT will affect the EVM (gain compression, phase shift, nonconstant group delay, etc.).

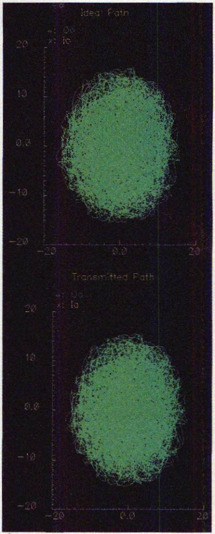
The receiver measurement filter (referred to as the ETSI_Filter) block uses the raised-cosine filter described previously. However, a finite number of taps has been used to represent it (finite-duration impulse-response (FIR)), with $T_m = 1/180$ ms, 10 samples/T_m and FIR length of $[-10T_m; +10T_m]$. The output and input impedances of the blocks, respectively, at the input and output of the custom coded blocks should be carefully matched to the DUT.

ANALOG SIMULATION ENVIRONMENT RESULTS

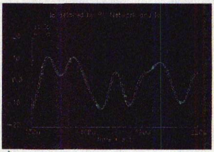
The simulation environment is shown in ***Figure 3***. The DUT is a simple RC network where R = 4 kΩ and C = 200 pF. The delay introduced is accounted for in the EVM calculation (reference signal delayed). However, it should be noted that the EVM calculation was performed on all sampled values as well as on samples spaced at every symbol time T. The source code for these blocks is given partially in ***Appendix A***; some simulation results are provided in ***Figures 4, 5, 6*** and ***7***.

The all_points (all samples) calculated error is EVM ≈ 6.61 percent. It is necessary to estimate the delay introduced by the DUT in order to compare the ideal and transmitted path waveforms. A first-order approximation of this delay is the average group delay over the frequency band of interest. A simple zero crossing method was used here; however, more accurate methods such as correlation can be used.

Mixing baseband and IF/RF signals in a simulation is computationally greedy and time consuming. In time domain simulation mode (transient + steady state), short time steps and long simulation times to represent both IF/RF and baseband signals, respectively, make the simulation inefficient timewise. However, there is no alternative to this approach.



▲ *Fig. 6 Ideal and transmitted constellation diagrams after raised-cosine receiver measurement filter.*



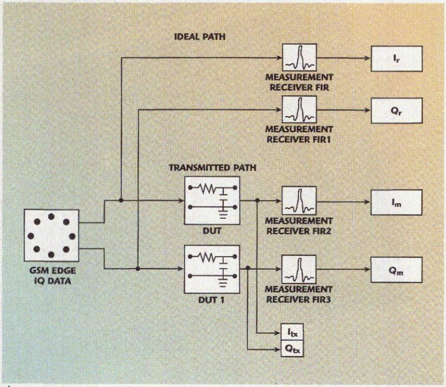
▲ *Fig. 7 Delay introduced by the RD network DUT.*

MATHEMATICAL SIMULATION ENVIRONMENT RESULTS

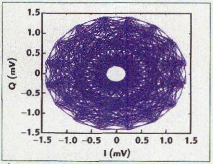
Benchmarking of the results produced by the analog simulator is achieved with MATLAB/Simulink. The simplicity of the DUT used here easily allowed it to be represented in Simulink. For a real IC, this easy representation may not be possible. The

[Continued on page 78]

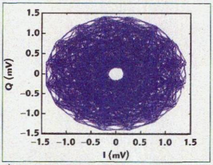
Simulink setup is shown in **Figure 8**. The same results are obtained as with the analog simulator and are shown in **Figures 9, 10** and **11**. The all_points (all samples) calculated error is EVM ≈ 6.73 percent. Note that the variation is a result of variable time steps taken in Simulink being different from those in Analog Artist.



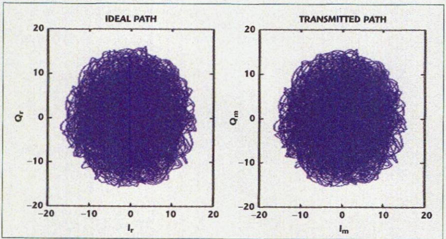
▲ *Fig. 8 The Simulink setup.*



▲ *Fig. 9 An ideal pulse-shaped GSM EDGE constellation.*



▲ *Fig. 10 The transmitted constellation after the DUT.*



▲ *Fig. 11 Ideal and transmitted constellations after the receiver measurement filters.*

CONCLUSION

This article has discussed EVM measurements for GSM EDGE designs and the need to perform such evaluations for analog RFIC/ASIC designers according to the standard specifications. It also described a simulation platform useful for evaluating EVM for analog ICs designed for GSM EDGE. Additional information on the presented material and source code can be obtained from the authors.

ACKNOWLEDGMENT

The authors would like to thank Jason Drew and Eddie Riddington, both of Nokia Networks, for their useful advice and input on RFIC design requirements and GSM standards. Affirma Analog Artist and Spectre RF are registered trademarks of Cadence Design Systems. Simulink and MATLAB are registered trademarks of The Math Works Inc. ■

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Ashkan Mashhour *received his Diplôme d'ingénieur from ENST, Bretagne, France, and his MSc from University College London, UK, both in 1997. He then joined Nokia Networks, Camberley, UK, where he currently works as an RF design engineer. He is involved in the development of new RF technologies and transceiver architectures for future-generation base stations. Mashhour can be reached via e-mail at Ashkan.Mshhour@nokia.com.*

Assaad Borjak *received his PhD from UMIST, UK in 1993. He has held numerous research and senior-level engineering positions at UCL, Nera Telecoms and, currently, Nokia Networks, Camberley, UK, and has several years of experience within the RF and microwave industries. His main interests are circuits and systems for wireless communications. He has published extensively in those fields and is a senior member of the IEEE. Borjak can be reached via e-mail at Assaad.Borjak@nokia.com.*

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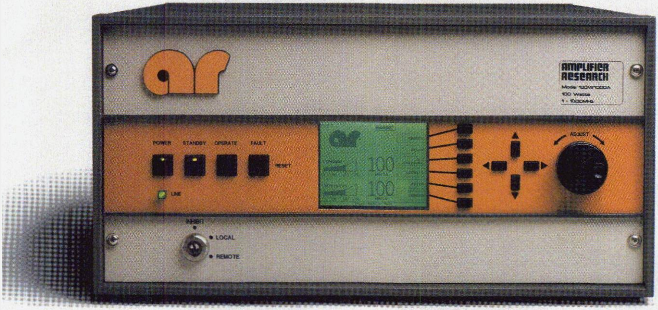

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APPENDIX A

SIMULATION FILES SOURCE CODE (ANALOG ARTIST):

Verilog-A code for the PRBS8Level custom coded block

```
// VerilogA for Aug4, PRBS8Level, veriloga

`include "constants.h"
`include "discipline.h"

module PRBS8Level(Iin,Iout);
input Iin;
electrical Iin;
output Iout;
electrical Iout;

parameter integer start_range = 0;

integer seed, end_range;
real rrandnum;
real rrandnum2;
integer rrandnum1;
integer count;
analog begin
    @(initial_step) begin
    seed = 0;
    end_range = 7;
    count = 0;
    end
    @(cross(V(Iin)-0.5,1,0.1n,1e-6))
    begin
    rrandnum = $dist_uniform(seed,start_range,end_range);
    rrandnum1 = rrandnum;
    rrandnum2 = rrandnum1;
    end
    V(Iout) <+ rrandnum2;
end
endmodule
```

Verilog-A code for the Offset8PSK custom coded block

```
// VerilogA for demo, Offset8PSK, veriloga

`include "constants.h"
`include "discipline.h"

module Offset8PSK(Iin,Iout,Qout,clk);
input Iin;
electrical Iin;
output Iout;
electrical Iout;
output Qout;
electrical Qout;
input clk;
electrical clk;

integer counter;

real DataIn1, DataIn2, edgetime;
parameter real pi = 3.14159265358979;

real iin_int;

analog begin
    @(initial_step)
    begin
        DataIn1 = pi/2;
        DataIn2 = 0;
    end
    @(cross(V(clk)-0.5,1,0.1n,1e-6))
    begin
        counter = counter + 1;
        edgetime = $realtime;
        iin_int = V(Iin);
        DataIn1 = 2*pi/8*iin_int+3*pi/8*counter;
        DataIn2 = 2*pi/8*iin_int+3*pi/8*counter;
    end
    if ($realtime > (edgetime+10e-9)) begin
        DataIn1 = pi/2;
        DataIn2 = 0;
    end
    V(Iout) <+ cos(DataIn1);
    V(Qout) <+ sin(DataIn2);
end
endmodule
```

Verilog-A code for the EdgeTransmitFilter custom coded block

```
// VerilogA for EdgeEVM, EdgeTransmitFilter, veriloga

`include "constants.h"
`include "discipline.h"

module EdgeTransmitFilter(Iin,Qin,Iout,Qout);
input Iin;
electrical Iin;
input Qin;
electrical Qin;
output Iout;
electrical Iout;
output Qout;
electrical Qout;

parameter real T = 1.846153846153846e-06;

real VIin, VQin;

analog begin
    VIin = V(Iin);
    VQin = V(Qin);

    if ($realtime < T) begin
        VIin = 0;
        VQin = 0;
    end

    V(Iout) <+ zi_nd(VIin,
    [0,7.1853e-4,0.03146,0.2604,0.70566,0.9268,0.70574,0.26052,
0.03155,7.50673e-4,3.85144e-6],
    [1],
    T,1e-8,1e-9);
    V(Qout) <+ zi_nd(VQin,
    [0,7.1853e-4,0.03146,0.2604,0.70566,0.9268,0.70574,0.26052,
0.03155,7.50673e-4,3.85144e-6],
    [1],
    T,1e-8,1e-9);
end
endmodule
```

Verilog-A code for the ETSI_Filter custom coded block

```
// VerilogA for Aug4, ETSI_Filter, veriloga
`include "constants.h"
`include "discipline.h"

module ETSI_Filter(Iin,Qin,Iout,Qout);
input Iin;
electrical Iin;
input Qin;
electrical Qin;
output Iout;
electrical Iout;
output Qout;
electrical Qout;

parameter real T = 5.5556e-07;

analog begin
    V(Iout) <+ zi_nd(V(Iin),
// Measurement filter coefficients, not included
    [.......],
    [1],T,1e-8,0);
```

[Continued on page 82]

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Antennas				●				●	●							
Attenuators, Coaxial	●			●			●	●			●					
Cable & Assemblies	●	●	●	●		●		●		●	●				●	
Capacitors, Low Voltage, Varible					●											
Circulators & Isolators							●	●			●					
Connectors, Coax	●	●	●	●		●		●		●	●		●	●	●	
Couplers							●	●			●	●				
Filters, RF								●			●			●		
Filters & Gaskets, EMI/RFI														●		●
Lightning Products (EMPs)	●			●											●	
Resistors, RF Power							●				●	●				
Splitters/Combiners							●	●			●	●				
Terminations	●			●			●	●			●	●				
Transformers, RF								●			●					
Worldwide		●			●	●	●		●	●	●	●	●	●	●	
Europe	●			●				●								
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APPENDIX A (cont.)

```
V(Qout) <+ zi_nd(V(Qin),
// Measurement filter coefficients, not included
    [.......],
    [1],T,1e-8,0);
end

endmodule
```

OCEAN script for EVM post-processing calculation

```
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
; POST-PROCESSING FILE oceanScript.ocn              ;
; This file should be loaded at the                 ;
; end of simulation using load("oceanScript.ocn")   ;
; in the command window "icms"                      ;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

simulator( 'spectreS )
design("/users8/borjaka/simulation/BB_EVM_ETSI/spectreS/
schematic/netlist/BB_EVM_ETSI.C")
resultsDir( "/users8/borjaka/simulation/BB_EVM_ETSI/spectreS/
schematic" )
analysis('tran ?stop "10m" )
save( 'v "/Io" "/Qo" "/Ia" "/Qa")
option ('temp "25")
temp( 25 )

openResults("/users8/borjaka/simulation/BB_EVM_ETSI/spectreS/
schematic/psf")
selectResults( 'tran )

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
; Delay between the reference (ideal) and the measured signals   ;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

D = cross(v("/Ia") 0 1 "rising") - cross(v("/Io") 0 1 "rising")
printf("Delay = %.8e\n" D )

T = 6/1625e3            ; This is the symbol rate
cnt = round(10m / T)    ; Number of Samples taken
cnt = cnt - 10          ; discard samples to account for the delay

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
; This code fragment calculates the EVM                               ;
; I_o and Q_o: the original received signals without the RC filter    ;
; I_a and Q_a: the actual received signals undergoing the RC filter   ;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
evm_n = 0
evm_d = 0
for( k 0 cnt
        I_o = value(v("/Io") k*T)
    Q_o = value(v("/Qo") k*T)
    I_a = value(v("/Ia") k*T+D)
    Q_a = value(v("/Qa") k*T+D)
        evm_n = evm_n + ( pow(I_o-I_a,2)+pow(Q_o-Q_a,2) )
    evm_d = evm_d + ( pow(I_o,2)+ pow(Q_o,2) )
        )
evm = sqrt(evm_n/evm_d)
printf("EVM = %.8e\n" evm )
```

APPENDIX B

SIMULATION FILES SOURCE CODE (MATLAB):

Raised Cosine function

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Raised Cosine function - time-domain impulse response %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

function out = rcos(t,alpha,T)

indices_0 = find((1-4*alpha^2*t.^2/T^2)==0);
indices_not0 = find((1-4*alpha^2*t.^2/T^2)~=0);

t_not0=t(indices_not0);
RCos(indices_not0)=sinc(t_not0/T).*cos(pi*alpha*t_not0/T)./
(1-4*alpha^2*t_not0.^2/T^2);
t_0=t(indices_0);
RCos(indices_0)=pi/2*sinc(t_0/T).*sinc(1/2*(1-2*alpha*t_0/T))./
(1+2*alpha*t_0/T);
out=[RCos(end:-1:1),RCos(2:end)];
```

Loads data for simulation

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Loads simulation data, parameters to workspace %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% measurement receiver filter determination
ns=10;
alpha=0.25;
Tm= 1/180e3;
t=0:Tm/ns:10*Tm;   % FIR for measurement receiver filter
[-10Tm,+10Tm]
                                    % ns=10 samples/Tm
etsi=rcos(t,alpha,Tm)';

% load GSM EDGE data with timing
z1=load('data1.dat');
```

Computes EVM at all points

```
%%%%%%%%%%%%%%%%%%%
% EVM calculation %
%%%%%%%%%%%%%%%%%%%

dt=Tm/ns;
delay=5.60658559e-7;
%delay=0; %delay introduced by DUT (RC network here)
ts=0:dt:(length(Ir)-1)*dt;
td=delay+ts;

xr = Ir+j*Qr;
xm = Im+j*Qm;
xm_interp = interp1(ts',xm,td','*nearest');
xm_interp=xm_interp(1:end-10);

xr_new=xr(1:length(xm_interp));

% EVM calculated with all samples (NOT at kT, differs from
specifications)
EVM_allpoints = sqrt(sum(abs(xm_interp-xr_new).^2))./
sqrt(sum(abs(xr_new).^2))
```

THE EFFECT OF IMPERFECT ANTENNA CROSS-POLAR PERFORMANCE ON THE DIVERSITY GAIN OF A POLARIZATION-DIVERSITY RECEIVING SYSTEM

The achievement of diversity gain relies on the realization of two signal branches with low signal correlation. A statistical technique is used to simulate the coupling between the channels and quantifies the effect of cross-polar coupling as a function of the intrinsic correlation of the received signals and the coupling introduced by the antenna. The definition of polarization orthogonality is examined, and both rigorous and approximate methods of measurement are described.

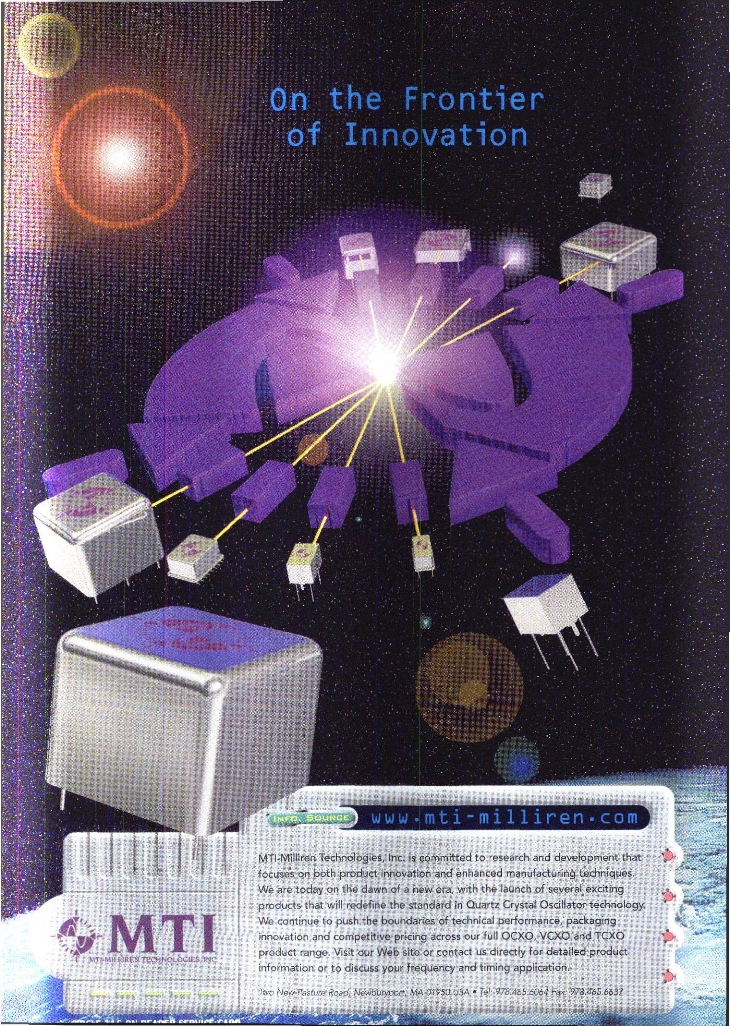
The use of diversity reception in mobile radio systems relies on the realization of two receive signal paths in which the variation of signal level with time is to some extent uncorrelated. The dependence of the achieved diversity gain on the correlation existing between the two paths has been established by a number of investigators.[1] In polarization diversity systems the signal paths are differentiated by the use of two receiving antennas, which respond to orthogonally polarized components of the received signal. It is clear that imperfect cross-polar discrimination at the receiving antennas forms a mechanism that couples the polarization components and increases the correlation between the two branches of the diversity system. This imperfection will reduce the achieved diversity gain compared with that realized when using a perfect antenna. The diversity gain of the system is a function of the correlation between the signals presented to the receivers; their correlation is a function of the transmission path and the finite cross-polar coupling introduced by the receiving antennas.

MODELING THE SIGNAL BRANCHES

The method used in this article utilizes two signal branches carrying uncorrelated pseudorandom signals with equal mean levels. Two mixing processes are then introduced, one

[Continued on page 86]

BRIAN S. COLLINS
CSA Wireless
Elk Grove Village, IL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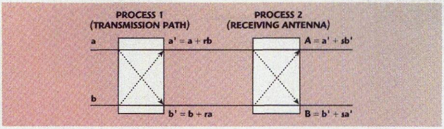
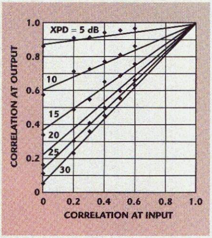
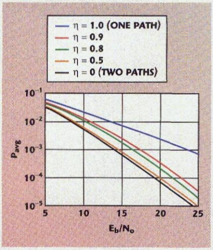


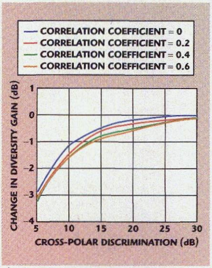
▲ *Fig. 1 The two mixing processes.*



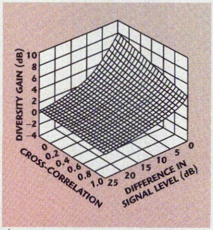
▲ *Fig. 2 Correlation of incoming signals and the resulting output from a dual-polar antenna with finite XPD.*



▲ *Fig. 3 The relationship between diversity gain and signal path correlation.*



▲ *Fig. 4 The reduction in diversity gain as a function of antenna XPD and the correlation of the incoming orthogonal signal components.*



▲ *Fig. 5 The relationship between diversity gain and the relative levels and correlation of the signals in a two-branch diversity system with maximal-ratio combining.*[3]

corresponding to the transmission path and the other to the receiving antenna, as shown in ***Figure 1***. To model the arriving signals a mixing process is used to increase the correlation between channels to the extent required to model a real transmission environment. The objective is to create a pair of signals with a correlation C_p that can be adjusted to accomodate values typical of a transmission path (not to model the actual processes in a real transmission path, which are entirely different).

For the purpose of simulation the two signal paths contain initial uncorrelated signals a and b. At the end of the first mixing process the signals have a correlation coefficient determined by the mixing fraction r, which is chosen to establish the required path correlation C_p. The second process represents the receiving antenna in which some fraction s of the orthogonal signal is coupled into the co-polar output. The parameter s is the cross-polar discrimination (XPD) of the antennas with respect to the orthogonal reference polarization pair and is assumed to have the same value for both channels — a correct assumption for any antenna with symmetrical elements for the two polarizations. (It would be simple to extend the present method to any chosen unsymmetrical pair of coupling factors.)

The simulation was run on a Microsoft Excel spreadsheet using two sets of 1000 pseudorandom numbers to represent the signals on each path and making use of the correlation function provided by the program. The mixing ratio for the first process was adjusted to achieve successive output correlations of 0.1, 0.2, 0.3… 0.7. For each of these values of the signal correlation over the transmission path the second mixing fraction was given values representing antenna XPDs of 5, 10, 15…30 dB. Each trial was run with 10 sets of 1000 random signal values. The values of path correlation, XPD and resulting output signal correlation were plotted, as shown in ***Figure 2***. The slight scatter of the data points results from the statistical nature of the approach used and can be reduced by increasing the number of trials or the number of data points in each trial.

RESULTS

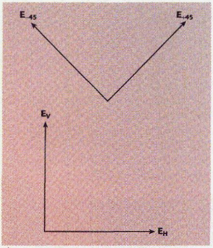
The dependence of output signal correlation on path correlation is essentially linear; the output correlation is always greater by an amount that depends on the XPD of the receiving antenna and the initial path correlation. The form of the result is not surprising since three lines could be drawn by examining extreme situations. If the input correlation is 1 then the resulting correlation will be 1 for any antenna XPD, establishing a point of convergence for all curves at 1,1. If the antenna has 0 XPD then the output correlation is 1 for any input correlation, establishing the line forming the top of the plot as the result for XPD = 0 dB. Finally, if the antenna has perfect XPD, then the resulting correlation of the output signals will be the same as the correlation of the signals in space. Given that all results will be contained within these straight lines, the simple dependence of input and output correlation coefficients is not surprising. When the input signals have low correlation the effect of antenna XPD is large, but as the signal correlation increases the effect of finite antenna XPD diminishes.

The diversity gain of a two-branch system is not a linear function of the correlation of the signals in the two branches. For a signal reliability of 90 percent the diversity gain of a two-branch system begins to fall rapidly only when the branch signal correlation rises above approximately 0.7. To determine the effect of antenna XPD on diversity gain it is necessary to determine the diversity gain associated with each value of input and output correlation coefficient. This analysis has been done using the curves provided by Ling[1] as shown in ***Figure 3***, which displays two correlated paths for a matched filter used for quadrature phase-shift keying and biphase-shift keying applications. The coefficient of correlation $\eta = C_{ov}(x,y)/\sqrt{Var(x)Var(y)}$. The change in diversity gain for a signal reliability of 90 percent produced by the imperfect XPD of the receiving antenna is plotted as a function of the XPD and the incoming signal correlation shown in ***Figure 4***.

For the sake of completeness, the full relationship between signal branch amplitude inequality and correlation is shown in ***Figure 5***. In a situation in which there is a large signal in one channel and a small signal in the other, no effective loss of communication results if some of the large signal is mixed into the low amplitude channel, even if the result is complete cancellation of the lower signal. When the larger signal fades, the existence of channel coupling has little effect on the low level signal. For this reason, the consideration of the effect of finite XPD on diversity gain contained in this article concentrates on the situation in which comparable signal amplitudes are present in both diversity branches.

THE EFFECT OF XPD ON DIVERSITY GAIN

The imperfect XPD of a practical dual-polar receiving antenna will cause a small reduction in the diversity gain, which could potentially be obtained by exploiting the partially uncorrelated nature of the signal components received with orthogonal polarizations. A typical loss of diversity gain of 0.5 dB is produced by an antenna XPD of approximately 17 dB, and a loss of 1 dB is produced by an antenna XPD of 12 dB. On boresight a typical dual-polar antenna will provide an XPD of 20 dB; at the sector edge (60° from boresight) the XPD will have fallen to approximately 12 dB. The consequent 0.5 dB decrease in diversity gain between the center and edge of the sector is comparable with that of a typical space-diversity system where the lateral spacing of the receiving antennas decreases as the received signal moves off the axis of the antennas.[3] The extent of lost diversity gain is only weakly dependent on the correlation of the incoming signal: As the signal correlation increases from 0 to 0.6, the effect of finite XPD typically reduces the available diversity gain by approximately 0.3 dB.



▲ *Fig. 6 The polarization components of an electromagnetic wave.*

DEFINITIONS AND MEASUREMENT METHODS

In the previous analysis the term XPD was used without careful definition of its method of measurement. The polarization performance of a base station receiving antenna varies as a function of the angle of arrival of the received signal; an actual antenna radiates (or optimally receives) an elliptically polarized wave with a particular orientation and eccentricity. The polarization ellipse of the signal changes as a function of frequency and of direction in azimuth and elevation. For most types of slant-polar base station antennas the polarization angle is close to 45° on boresight. However, as the observer moves from boresight, the antenna polarization moves toward the vertical, thus the polarizations received by the two ports converge.

There are several different methods for measuring the polarization performance of a base station antenna. Complete characterization can be accomplished only by measuring the complex components of the field radiated/received by the antenna (E_V and E_H) and computing the polarization ellipse for each spacial direction and frequency. Experiments conducted by others to establish the usefulness of polarization diversity have assumed that the receiving antenna responds to orthogonal linearly polarized signal components with polarization angles of +45° and –45°. For this reason — and because of the simplification of the required measurements — all measurements in this analysis are performed using plane-polar illumination with polarization angles of +45° and –45°. Measurements of radiation patterns in which the antenna under test is illuminated with these two orthogonal polarizations provide a description of polarization behavior that is sufficient to allow the effect of polarization performance on diversity gain to be defined. This method is simple to carry out and requires no complex assumptions or calculations.

The use of XPD in this article differs slightly from its general use. The reference polarizations are considered to be a fixed orthogonal pair of linear polarizations (not the exact co- and cross-polar planes for the two parts of the antenna under test as the two copolar planes may not be mutually at right angles). The result is a simple and self-consistent set of definitions and parameters, which, as is demonstrated, relate easily to the propagation studies carried out by others.

Some antenna specifications include diversity gain as an antenna parameter. This specification is not appropriate since diversity gain is a function of the signal transmission path (and a defined level of signal reliability) as well as antenna performance and the combining method. Separate definitions of orthogonality are not required if the polarization behavior is measured using orthogonal fields as described previously. Measurements of radiation patterns using linear reference polarizations of +45° and –45° generally provide adequate data to characterize the cross-polar performance of base station antennas.

THE PHENOMENON OF POLARIZATION

Most radio engineers are familiar with the concept of polarization as describing the plane of the electric field of an electromagnetic wave. In general, the waves are perceived as essentially linearly polarized (with a few special applications in which the wave is circularly polarized). By contrast, radio astronomers (and many HF radio engineers) deal with received signals with polarizations that are often entirely arbitrary and from which no single real antenna can abstract all of the energy incident on the effective aperture of the antenna.

Any electromagnetic wave can be envisioned as having polarization components, as shown in ***Figure 6***. (In the mobile radio environment the two field components are relatively independent of one another in amplitude and phase. In general, it is not possible to sum the vectors into a single direction containing the entire signal power because the vectors are not mutually in phase. The magnitude and phase relationship of the vectors changes rapidly with time, so the sum vector traces out an ellipse whose eccentricity and orientation depend on the relative magnitudes and phases of the components.) To simplify the notation imagine a wave traveling parallel with the surface of the ground and the electric field characterized by two components E_V and E_H mutually at right angles. These components have a phase difference θ, which can be determined by measurement. Because of this phase difference the two field components cannot be summed simply by drawing the usual simple vector sum.

Special Cases

There are two special cases of polarization state that are familiar to everyone. When describing polarization the standard convention is to look at the signal in the direction of propagation (as if the observer is standing behind the transmitting antenna). When $\theta = 0°$ the two components are in phase and the components can be summed in the usual way. This condition is the special case of linear polarization. The plane of polarization is determined by the relative magnitude of the two components E_V and E_H and a polarization angle is defined as $\phi = \tan^{-1}(E_V/E_H)$.

If $E_V = 0$, then the signal polarization is described only by E_H, thus the signal is horizontally polarized. Similarly, when $E_H = 0$ the signal is vertically polarized. If $E_V = E_H$ (and at the same time $\theta = 0°$), the signal is polarized at 45°; if $E_V = -E_H$ (that is, $\theta = 180°$), the polarization is –45°. If $E_V = E_H$ and the two vectors are in phase quadrature (±90°), the resulting signal is circularly polarized (CP). (The sense of rotation depends on the + or – sign.)

The General Case

Apart from the linear and circularly polarized special cases, all other signals are elliptically polarized, hav-

[Continued on page 90]

ing some relation E_V/E_H and phase θ between them, as shown in ***Figure 7***. As the wave propagates, the electric vector traces an ellipse around the axis of propagation having a maximum value E_{max} and a minimum value E_{min} one-quarter period later. The ellipse is inclined at a polarization angle ψ to the vertical. When the sense of rotation of the electric vector is clockwise (viewed in the direction of propagation), the polarization is referred to as right-hand. It may be noted that the components E_V and E_H reach their maximum values at two points, which are not located on the same diameter of the ellipse; in this example they are approximately one-third of a period apart.

The Polarization Ellipse

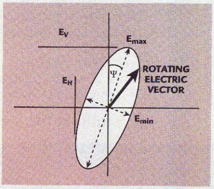
As an alternative to defining a wave by E_V/E_H and θ, an entirely equivalent description is obtained by specifying the polarization ellipse by its ellipticity — the ratio of major to minor axes — and the physical orientation of the major axis in space. The equations relating the two descriptions are set out in the textbooks and the conversion between them can be made graphically using a Carter chart.[4] The two representations of the polarization of a wave described previously are simply alternative descriptions of the same phenomenon. Any polarization can be described in terms of two superposed linear (H/V) components or two superposed circular (RH/LH) components, or by explicit reference to the ellipticity (axial ratio) and polarization angle.

RECEIVING A SIGNAL WITH ARBITRARY POLARIZATION: ORTHOGONALITY

All that must be done to receive a linearly polarized signal is orient the receiving antenna so its polarization is aligned with that of the incoming wave. All of the energy in the wave (as defined by the Poynting vector) then will be received and nothing is wasted.

A CP signal is used in two ways. All the energy can be received using a CP antenna with the correct orientation. Alternatively, a randomly oriented linear antenna can be utilized and half the incident energy will be received. If a vertically polarized receiving antenna is placed in a horizontally polarized incident field nothing will be received. Similarly, a right-handed CP antenna placed in a left-hand CP field receives nothing (assuming in each case that the fields and antennas have pure polarization). The combinations of linear polarizations that are mutually at right angles in space (and left/right CP) are or-

Fig. 7 The general case of elliptical polarization.



[Continued on page 92]

thogonal, a mathematical term implying independence. Clearly, in the linearly polarized case this mathematical orthogonality is related to the spacial orthogonality of the two polarizations. In the CP example a spacial meaning of orthogonality is less obvious.

How is orthogonality defined in the general case of arbitrary elliptically polarized waves and antennas? A polarization-matched antenna can be designed using two crossed linearly polarized antennas such as dipoles feeding the two elements through an adjustable power divider and phase shifter. With the correct settings of the power divider and phase shifter, the polarization of any incoming wave can be matched exactly and all the power carried by it extracted; no power at all may be received by some other setting.[5,6]

When a signal is transmitted by one antenna and received by another, the ratio of the received signal to that which would be received by an antenna that is exactly polarization matched is given by the following equation in which all field components are complex quantities:

$$\frac{P}{P_{max}} = \frac{\left| E1_{+45}E2_{+45} + E1_{-45}E2_{-45} \right|}{\left(\sqrt{E1_{+45}E1^{*}_{+45} + E1_{-45}E1^{*}_{-45}}\right)\left(\sqrt{E2_{+45}E2^{*}_{+45} + E2_{-45}E2^{*}_{-45}}\right)} \quad (1)$$

where

$E1_{+45}$ = +45° field component from port 1
$E2_{+45}$ = +45° field component from port 2
$E1_{-45}$ = –45° field component from port 1
$E2_{-45}$ = –45° field component from port 2
E^{*} = complex conjugate of E

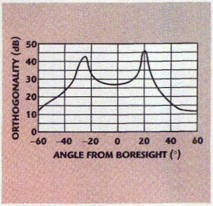
This equation is essentially unchanged for any pair of orthogonal signal components whether H/V linear, ±45° linear or right/left CP. (For H/V, simply substitute E_H for E_{+45} and E_V for E_{-45}; for CP, substitute E_R for E_{+45} and E_L for E_{-45}.) In the special case in which the polarization of the receiving antenna is such that zero power is received, its polarization is said to be orthogonal to that of the incoming wave.

Care must be taken when referring to the polarizations radiated and received from any specific antenna. The sense of the polarization angle is reversed when the radiated wave is viewed from the position of the receiving antennas, so antennas transmit and receive signals with this sign change. Only in the special cases of vertical, horizontal and circular polarizations does this sign change not make a difference, so an antenna transmits and receives with the same polarization.

APPLICATION TO MOBILE RADIO BASE STATION ANTENNAS

In the mobile radio base station environment the received signal is radiated by some (generally randomly oriented) linearly polarized antenna and scattered and reflected in transmission. The received signal has a time-varying polarization. Experiments have shown[7] that if the receiving antenna is arranged to respond to linear components of the field resolved in the ±45° planes, the two resulting signals will have sensibly equal mean amplitudes and a correlation that is low enough to provide useful diversity gain.

A measurement is required to show the quality of the polarization response of the receiving antenna. The antenna port labelled +45° must respond to the +45° field component and not (or at least substantially less) to the –45° field component. This independence must be maintained to a useful extent over the 120° azimuth sector covered by the antenna. The simplest test is to measure the response of the +45° antenna to the +45° component of the incoming wave and compare the result with its response to an incoming wave with –45° polarization. This measurement is effectively an XPD measurement in which the ±45° axes are fixed as the nominal polarization axes. It measures (correctly) the relative response of the antennas to two specific orthogonal field components but, especially off-axis, the ±45° test polarizations may not correspond to the matched polarizations of the antenna, so the result is less than the true orthogonality.



▲ *Fig. 8 A typical orthogonality measurement for a dual-polar base station antenna with a 65° azimuth 3 dB beamwidth.*

A more complex and rigorous measurement establishes the mathematical orthogonality of the responses of the two halves of the antenna using Equation 1. To obtain the data needed to calculate orthogonality at various bearings from the antenna, the relative phases and amplitudes of E_{+45} and E_{-45} must be measured for both ports of the antenna at various directions in space over the sector of coverage. This objective is most conveniently achieved using a near-field measurement system and the results are computed using a suitable spreadsheet. This method allows for the ellipticity of the polarization response of the antenna. In a typical dual-polar base station antenna, the elements for the two polarizations are generally mirror-symmetrical and have opposite orientation in their polarization responses. For this reason the numerical value of rigorously measured orthogonality is usually determined to be larger than the relative response measured by the simpler ±45° test.

Figure 8 shows a typical orthogonality measurement for a 65° sector antenna. The orthogonality exceeds 20 dB over much of the sector, falling to approximately 12 dB at ±60°. The two received polarizations fold slowly toward vertical polarization as the angle from boresight reaches 90° and the orthogonality tends toward zero.

LESS ADEQUATE DEFINITIONS

Other definitions of polarization orthogonality have been encountered with correspondingly different results and methods of measurement. Some groups measure the angle between the major axes of the polarization ellipse characteristics of the two antennas. This technique is related to the simpler method previously described but is less direct and requires additional measurements to correctly

[Continued on page 94]

define the resulting cross-polar coupling effects. Polarization orthogonality is a power ratio, not an angle. Definitions relating to the dot-product of simple time-invariant vectors are not correct because they do not account properly for the phase difference between the polarization components. The only complete expression is that shown in Equation 1 and equivalents derived from it in which the reference axes have been changed.

The discrimination of the receiving antenna to most other pairs of orthogonal polarizations will be less than that for the ±45° test polarizations described previously. For example, discrimination to orthogonal H and V signals is zero. (If the intention had been for the antenna to respond to and discriminate between H and V polarizations, its design would have been different.) The incoming real-world signal can be resolved into any chosen pair of orthogonal components, and it is the relative response of the receiving antenna to the best-resolved pair that is significant to system operation.

CONCLUSION

The effects of imperfect polarization response of a dual-polar base station antenna typically cause a reduction in the diversity gain that could be achieved by a perfect antenna. In a typical environment the available diversity gain is reduced by 1 dB only as the orthogonality of the antennas falls below 10 dB. A full definition and measurement of polarization orthogonality requires measurements of four complex field components radiated/received by a typical ±45° base station antenna. Because of the relatively small effect of orthogonality on diversity gain, a simpler measurement of the relative response of a base station antenna to ±45° linearly polarized signals is usually adequate. ■

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Brian Collins *graduated from University College London in 1962 and has been the technical director of CSA Ltd. since 1978. His early work was on antenna systems for broadcast and military applications. During the last 10 years, he has been active in the mobile radio field where he has led the development of microstrip techniques for base station applications. Collins has been granted 12 UK patents for original contributions to antenna design. He can be reached via e-mail at briancollins@csauk.com.*

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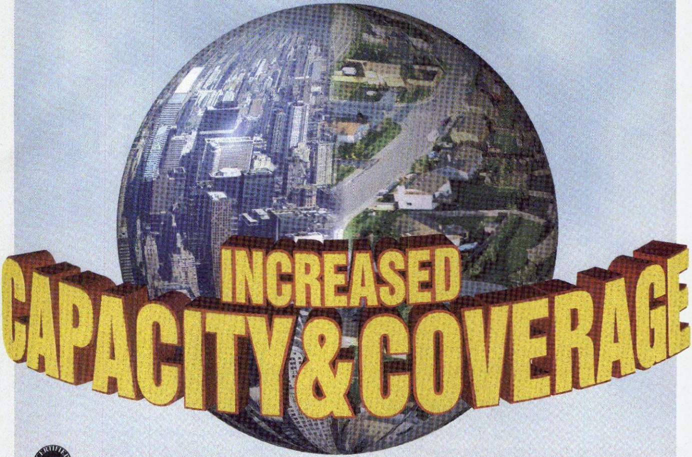

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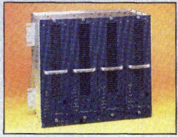

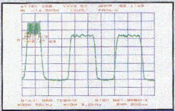
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RF Ceramic Chip Capacitors in High RF Power Applications

In today's world of wireless communications systems there are a myriad of high RF power applications that necessitate the use of high quality specialized ceramic chip capacitors. These demands require the designer to carefully account for factors such as device power dissipation and maximum current and voltage ratings as well as thermal resistance and temperature rise during normal circuit operation. This article highlights some of the most essential elements needed for selecting capacitor products suitable for these applications.

"To ensure the highest level of reliability in high RF power design applications, factors such as maximum device power, maximum voltage and current ratings, thermal characteristics of all circuit devices and various ways that heat is removed should be taken into account before being incorporated into the end product design."

Power Dissipation

In order to determine the device power dissipation of a ceramic capacitor operating in an RF power application the circuit designer must consider several critical factors. Among the most prominent are the equivalent series resistance (ESR) and maximum operating circuit current (I_{max}). The thermal resistance of the capacitor (θ_C) as well as the thermal characteristics of the mounting surface are also key factors that should be taken into account while attempting to establish the power rating for a given capacitor. All of these areas are addressed in this article.

The actual power dissipated by a capacitor (P_{CD}) in an RF power application is readily determined by calculating the product of the rms circuit current squared (I_C^2) and ESR such that

$$P_{CD} = I_C^2 \bullet ESR$$

The ESR takes into account all of the losses incurred by the dielectric material, electrodes, terminations and termination to electrode interfaces. It is interesting to note that capacitors that exhibit ultra-low ESR as well as high voltage breakdown characteristics (such as porcelain types) are especially well suited for high RF power applications.

A Capacitor Power Dissipation Example

Consider the following example consisting of a 51 pF RF porcelain chip coupling capacitor used in the power output stage of a cellu-

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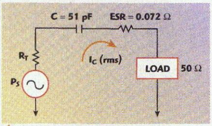
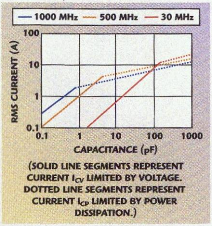
Richard Fiore
American Technical Ceramics Corp. (ATC)
Huntington Station, NY

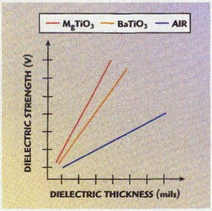


▲ *Fig. 1 Current flow through a capacitor with series loss element.*

Fig. 2 The relationship between current I_C, capacitance and frequency for an ATC series 100 case B capacitor. ▼



▼ *Fig. 3 Voltage vs. dielectric thickness.*



lar base station operating at 900 MHz, as shown in ***Figure 1***. The RF power is 60 W in a 50 Ω system; the coupling capacitor has an ESR of 0.061 Ω at 900 MHz. The total RF current in this application is determined using

$$I_C = \sqrt{\frac{P}{Z}} = \sqrt{\frac{60}{50}} = 1.09\text{A}$$

Therefore, the total power dissipated in the capacitor is

$$P_{CD} = I_C^2 \bullet \text{ESR} = (1.09)^2 \times (0.061) = 0.072 \text{ W (72 mW)}$$

This example illustrates the importance of the relationship between ESR and the total power dissipated by the capacitor. Here, the power dissipated by the capacitor due to its internal losses represents 72 mW or 0.12 percent of the total power applied to the capacitor. This low loss is achieved by utilizing low ESR RF ceramic capacitors in these applications. Recent advances in materials technology have enabled the realization of lower ESR, further reducing the power dissipated by the capacitor.

CURRENT RATING

The maximum current rating assigned to a capacitor by the manufacturer is stated in one of two ways: voltage limited or power dissipation limited. The rating that applies depends on the capacitance value and operating frequency for a given application. If the capacitor's current rating (I_C) in a particular application is limited by voltage it can be calculated using the relationship between the rms voltage rating of the capacitor and the capacitive reactance. Accordingly, the maximum current for the voltage limited operating condition is directly proportional to the capacitor rms voltage rating and inversely proportional to its reactance:

$$I_{CV} = \frac{\text{WVDC} \bullet 0.701}{X_C}$$

where

$X_C = 1/2\pi fC$

Therefore, $I_{CV} = V_{rms} \bullet 2\pi fC$.

As the operating frequency or capacitance is increased, a region on the current curve is entered where the numerical value of the voltage limited current is equal to that of the current limited by power dissipation. This condition occurs at the intersection of the dotted and solid lines as shown in ***Figure 2***. At frequencies above this intersection point the current rating is determined solely by the power dissipation limit. In this region the maximum current is calculated using

$$I_{CP} = \sqrt{\frac{P_{dmax}}{\text{ESR}}}$$

where

P_{dmax} = maximum power dissipation of the device as defined in reference to a given mounting surface with known thermal characteristics

Hence, in this region the maximum current is now limited by the capacitor's power dissipation limit. Regardless of the specified power rating (a somewhat relative term), a capacitor exhibiting low ESR is always desirable for providing an optimum device current rating.

VOLTAGE RATING

Maximum voltage ratings are determined predominantly by the dielectric strength or voltage breakdown characteristics of the dielectric material. As an example, porcelain dielectrics exhibit a breakdown voltage that typically exceeds 1000 V/mil of dielectric thickness and is virtually constant over the specified operating temperature range. Other dielectrics fabricated from barium titaniate ($BaTiO_3$)-based materials for example will exhibit lower breakdown voltage characteristics due to differences in their chemical and microstructural compositions, as shown in ***Figure 3***.

A voltage breakdown also may occur on the outside of the device package. In this instance, the applied voltage is large enough compared to the length of the external path (termination to termination) in air to produce a flashover. Other factors that may promote an external breakdown are surface contamination as well as environmental factors such as humidity and sharp edges, especially in the immediate areas of the terminations. One method of testing for dielectric strength is to submerse the test sample in an insulating oil bath, thereby eliminating the incidence of external flashover failure.

THERMAL RESISTANCE

The thermal resistance of a ceramic capacitor operating in a given application is a key factor that must be known in order to establish the device power rating P_{dmax}. Knowing the length of the heat flow path, the thermal gradient and the perpendicular

[Continued on page 100]

area, as shown in **Figure 4**, makes it possible to determine the thermal resistance θ.

The thermal resistance for a given capacitor structure with length L and cross-sectional area A can be expressed by the relationship

$$\theta = \frac{L}{4.186\lambda A} = \frac{0.2389L}{\lambda A}\left(\frac{°C}{W}\right)$$

Thermal conductance λ is expressed as

$$\lambda = \frac{W}{(°C)(cm)} = \frac{cal}{(°C)(sec)(cm)}$$

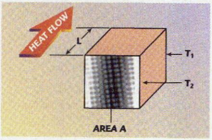
where

λ = coefficient of thermal conductivity for the subject material
L = length of the thermal path (cm)
A = cross-section area perpendicular to the heat path (cm^2)

Note that multiplying [W/(°C)(cm)] by 0.2389 converts the units to cal/(°C)(sec)(cm). In addition, the thermal conductivity λ is essentially constant over the normal temperature range of 25° to 125°C.

From this expression it can be readily seen that the thermal resistance is proportional to the length of the heat flow path and inversely proportional to the thermal conductivity and the cross-sectional area perpendicular to the heat flow path. This relationship suggests that the aspect ratio of the capacitor, that is, the ratio between width and length, plays an important role in the determination of the thermal resistance. The power dissipation of the device can be determined from the thermal resistance

Fig. 4 Heat flow path, thermal gradient and termination area of a ceramic capacitor.



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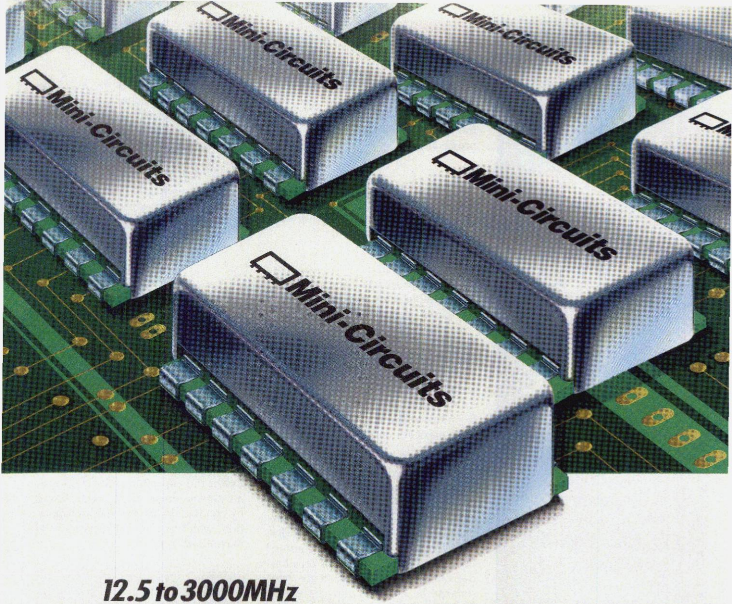

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JTOS-1300	900-1300	-95	-28	20V	30	18.95
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JTOS-1650	1200-1650	-95	-20	13V	30	19.95
JTOS-1750	1350-1750	-101	-16	***	30	19.95
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YONI™ ***The Design Engineers Search Engine*** *Provides ACTUAL Data Instantly From MINI-CIRCUITS At:* ***http://www.minicircuits.com*** expression by establishing the temperature differential across the heat flow path and dividing by θ. Hence, the maximum power dissipation is expressed as

$$P_d = \frac{T2 - T1}{\theta_C} = \frac{\Delta T}{\theta}\ (W)$$

where

P_d = power dissipated at area A (W)
T2 = temperature of cross-section area A (perpendicular to heat flow) (°C)
T1 = temperature at a cross-section area at a distance L from area A (°C)
L = length of path between areas (cm)
θ_C = thermal resistance of path across capacitor length L (°C/W)

The thermal model used for calculating the maximum power dissipation of a ceramic capacitor typically takes into account the thermal resistance of the capacitor and its mounting surface. This model assumes that heat is removed mainly by conduction through the capacitor's terminations and external leads. Since heat removal by radiation and convection is disregarded in this model, a safety factor for maximum power dissipation therefore is established. The model further assumes that the thermal resistance of the capacitor's terminations is insignificant compared to the ceramic body and, hence, is disregarded. The effects of the mounting surface also are disregarded and an infinite heat sink is assumed for the temperature rise calculation shown in ***Figure 5***.

TEMPERATURE RISE

The maximum change in temperature along the heat flow axis is referred to as the temperature rise or thermal gradient. The hypothetical determination of temperature rise as a function of RF current is not always straightforward. To get a reasonable handle on this value the designer must account for the ESR and thermal resistance of the capacitor as well as its mounting surface.

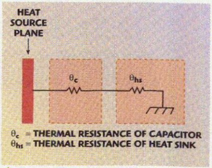
Given the ESR and current in an application, the capacitor's power dissipation P_{CD} as well as the heat generated in the capacitor can be calculated. The thermal resistance of the capacitor and its external connections to a heat sink also can be ascertained and, hence, the temperature rise above the ambient can be established. Assuming an infinite heat sink and a capacitor with zero manufacturing flaws, the temperature rise can be calculated using

$$\Delta T = T1 - T2 = \theta\,(I_C^2 \bullet ESR) = \theta \bullet P_{CD}\ (0°C)$$

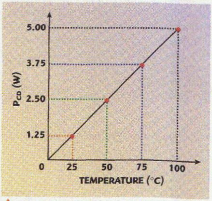
Figure 6 shows the relationship between the capacitor's power dissipation and the change in the capacitor's case temperature.

HEAT TRANSFER METHODS

Heat may transfer either to or from the boundaries of a ceramic capacitor structure in several ways. Heat transfer occurs only when a temperature difference exists between the capacitor and its immediate surroundings. Heat is transferred by conduction, convection and radiation, which may occur separately or in combination.



▲ *Fig. 5 The thermal model of a capacitor mounted on a heat sink.*



▲ *Fig. 6 P_{CD} as a function of temperature.*

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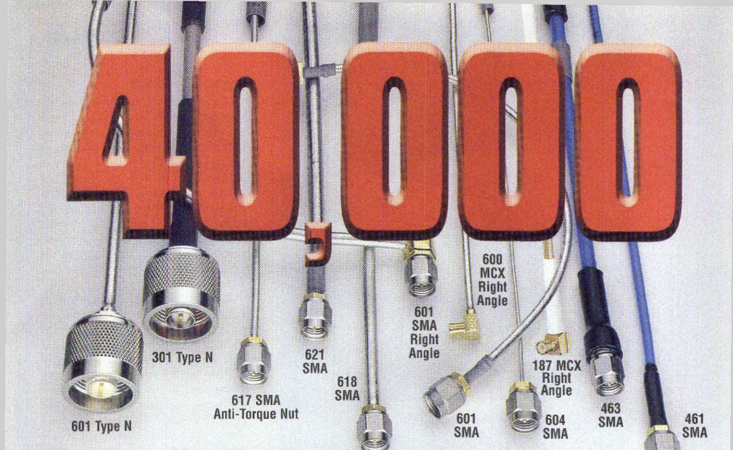

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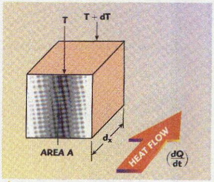
Thermal Conduction

Heat energy transferred by conduction takes place in ceramic capacitor structures essentially at the termination areas. In this case, heat transfer takes place because there is physical contact between the capacitor terminations and the points of connection on the board surface. Energy transfer by conduction occurs in the direction of decreasing temperature and is due to the temperature gradient along the length of the heat flow path.

On the molecular level, conduction can be thought of as the transfer of energy from a more energetic thermal state to a less energetic thermal state. Therefore, as molecules collide with each other energy is transferred in the form of heat from the more energetic to the less energetic molecules. This heat transfer is due to the random movement of molecules and the interactions between them within the two thermal gradients. As the temperature increases, the activity or interaction between the molecules also increases. These molecules collide with each other and, hence, transfer energy in the form of heat.

From Fourier's law of heat conduction the conduction process can be quantified as a heat flux rate equation. The law states that the rate of heat flow through a solid homogeneous structure is directly proportional to the area of a section at right angles to the direction of heat flow path and to temperature differences per unit length along the path of heat flow, as shown in ***Figure 7***. Thus,

$$\frac{dQ}{dt} = -\frac{\lambda A dT}{dx}$$



▲ *Fig. 7 Heat flow through a solid homogeneous structure.*

[Continued on page 106]

where

dQ/dt = rate of heat flow per unit time
A = cross-sectional area at right angle to the direction of heat flow path
dT/dx = temperature gradient per unit length along heat flow path
λ = thermal conductivity of the material

Note that the negative sign associated with λ indicates that the heat flows conductively from high to low temperatures, or against the temperature gradient.

Thermal Convection

Energy transfer between a solid surface and moving air in the immediate surroundings is commonly referred to as convection. The heat transfer due to convection is an interactive combination of diffusion or molecular motion in the dielectric material and the bulk movement of the surrounding air. There are basically two types of convection heat transfers: natural (free) and forced. Natural convection currents are induced by forces due to differences in variations between the device surface temperature and the surrounding ambient temperature; that is, heat is directly picked up by the air and transported away. Natural or free convection is caused by air movement due to thermal gradients between an object (in this case a ceramic capacitor) and its surrounding ambient environment.

Forced convection heat flow is induced by external means, such as a cooling fan. Heat transfer coefficients due to forced flow are generally greater than that of natural convection flow. In most cases the free convection may be neglected when there is forced airflow, hence forced convection provides the greater effect for convection cooling.

Newton's law of cooling is used to model the temperature change of an object that is at some initial elevated temperature placed in an environment of a lower temperature. The law states that the rate at which a warm body cools is approximately proportional to the temperature difference between the temperature of the warm object and the temperature of its immediate surroundings. Thus,

$$\frac{dT}{dt} = k\left(T - T_A\right)$$

where

T = temperature of the object at time t
T_A = temperature of the surrounding environment (ambient temperature)
k = constant of proportionality
t = time variable (s)

Solving the differential equation for T means placing T on one side and t on the other, such that

$$\frac{dT}{T - T_A} = k\,dt$$

Integrating both sides produces

$$\ln(T - T_A) = kt + C$$

and solving for T gives

$$T = e^{kt+C} + T_A$$

From this expression it can be seen that the cooling process is exponential, that is, rapid at first, then levels off. Hence, this characteristic may be thought of as the thermal time constant of an object. The temperature of the object T now can be directly expressed at time t (s). In Newton's law of cooling, t is the variable where T_A, k and C are constants. In order to determine the temperature of the object at a given time, all of the constants must have numerical values.

Thermal Radiation

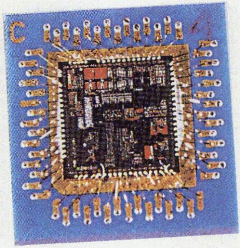
Thermal radiation is energy emitted by matter and transported by electromagnetic waves or photons. While the transfer of energy by convection or conduction requires the presence of a medium, electromagnetic waves do not require a medium to propagate and will transfer heat energy most efficiently in a vacuum. The total energy at which radiation may be emitted from a surface as photons per second by a square centimeter of an ideal black body radiator is equal to the temperature raised to the fourth power. This energy emission results from changes in the electron configurations of the atoms or molecules of the radiating object.

Stefan-Boltzmann's law gives the maximum heat flux at which radiation may be emitted from a surface. The

[Continued on page 108]

Application Profile

How to make Cell Phones Smaller and Lighter? BGA with Integrated Components using DuPont Green Tape™.



National Semiconductor continues to lead the telecommunications industry in applying LTCC advantages to integrated wireless modules. National's latest designs have combined DuPont's line of Fodel® compositions, Green Tape™ and thick film conductor materials with National's LTCC manufacturing expertise to achieve smaller designs with enhanced performance at lower cost. These designs include high-density interconnect capability, integration of passive components, and passive functions with low-loss/high-stability performance.

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Integration of more embedded components in less space at lower cost is the driving model for success in portable wireless applications. Using fine line LTCC technology, National is meeting the need for the precision embedded components (inductors, filters, capacitors and resistors) required to fabricate advanced LTCC modules.

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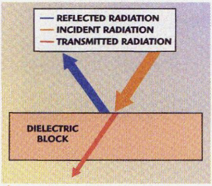


Fig. 8 Thermal radiation dispersion.

law takes the form

$$E = \sigma T^4$$

where

T = temperature
σ = a constant

From this equation it can be seen that a small increase in temperature produces a very large increase in emitted radiation energy. If the temperature is doubled, the energy emitted increases by a factor of 16. The surface emissivity indicates how efficiently the surface of a given object will emit radiation energy relative to an ideal black body radiator. The ideal black body has an emissivity reference equal to 1.0. Just as surfaces emit energy, another surface can absorb a portion of that energy. The surface properties of various materials will affect the amount of heat radiated.

The intensity of radiation is defined as the rate of emitted energy per unit of surface area through a unit solid angle. The radiation from a surface has different intensities in different directions. The intensity of radiation along the normal to the surface is known as the intensity of normal radiation.

When thermal radiation strikes a solid object, portions of the energy can be absorbed, reflected or transmitted through the object. This energy is dispersed in various proportions depending on the surface emissivity and density of the material, as shown in ***Figure 8***. The portion of the incident radiation that is absorbed by the object is its absorptivity α. Another portion of the incident radiation energy will be reflected and is referred to as reflectivity ρ. Lastly, the portion of the radiated energy that is transmitted though the object is referred to as transmissivity τ. The sum of all of these portions of the radiated energy is unity and, therefore,

$$\alpha + \rho + \tau = 1$$

APPLICATION CONSIDERATIONS

This article has highlighted several major factors to consider while designing circuit elements for high RF power applications. Some of the most important considerations relate directly to such things as ESR, thermal resistance of the device(s), mounting surface characteristics and heat removal. These factors are associated with the overall thermal management of the entire design and should necessitate careful assessment of all circuit elements and their contribution to the overall thermal load on the design. Some of the guidelines for these considerations are summarized below.

- It is always prudent to select capacitor products with ultra-low ESR and dissipation factor characteristics, especially concerning thermal management considerations of high RF power designs. This choice will ensure the most efficient operation and minimize the amount of heat generated in the application.

- The thermal resistance of the capacitor's mounting surface and heat sink should be as low as possible. Since the heat is primarily conducted by the capacitor's terminations to the metallic contact points on the board, it is important to evaluate characteristics such as thermal conductivity of all materials involved as well as board trace dimensions and material thickness at the points of contact.
- Since the greater part of the heat transfer is predominantly through the terminations of the capacitor, the thermal path of a ceramic chip capacitor may be further improved by the use of external leads such as silver microstrip ribbon. The ribbon leads will serve to bleed heat away from the capacitor more efficiently. The leads also may serve as a mechanical strain relief, especially in situations where the coefficient of thermal expansion between the capacitor and the board material is significantly mismatched. The silver lead stock is tailored to the width of the capacitor body, making it suitable for this purpose.
- The overall thermal management of the entire design must be judiciously evaluated. Devices such as power FETs and active gain blocks as well as other passives in an application will provide additional sources of heat during operation and thereby add to the overall thermal load of the design module. Care must be taken to account for the impact of all of the heat sources in the final design.
- Using capacitor assemblies that employ several capacitors in parallel will serve to greatly extend the current and power rating over a single capacitor. Assemblies that utilize ruggedized porcelain capacitor building blocks in various combinations will greatly extend the capacitance, voltage and current handling capabilities. For example, two equal value capacitors in parallel will yield approximately one-half the ESR of one capacitor and thereby afford virtually twice the current handling capability, an advantage that is difficult to ignore.

CONCLUSION

To ensure the highest level of reliability in high RF power design applications, factors such as maximum device power, maximum voltage and current ratings, thermal characteristics of all circuit devices and various ways that heat is removed should be taken into account before being incorporated into the end product design. In addition, when selecting ceramic chip capacitors for these applications it is prudent to first evaluate the ESR of the particular capacitor(s) at the application operating frequency. Knowing the ESR along with the network impedance will allow the designer to perform quick calculations of the power dissipated by the capacitor. This consideration is equally important for all other circuit elements in the application. Proper design with emphasis on thermal management will help to ensure efficient and trouble-free operation. ■

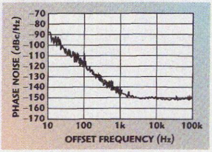
A Digitally Compensated TCXO with Low Phase Noise Characteristics

The phase noise level of a digitally compensated temperature-compensated crystal oscillator (DTCXO) is strongly degraded due to the numerical system of compensation. The requirements of high stability, low power consumption and low phase noise for these oscillators have increased during the last couple of years. This article explains which parameters must be taken into account and the methods required to reduce the noise induced by the quartz crystal design, layout, component choices and electrical configuration. The aim of this analysis is to provide a new high performance oscillator for satellite communications (SATCOM) applications and low phase noise instrumentation equipment and to demonstrate that digitally compensated technology can be utilized to produce potentially cheaper high performance oscillators compared to built-in application-specific ICs.

The growing demand for portable applications and high performance oscillators such as in telecommunications or SATCOM applications leads to the design of DTCXOs with a very low phase noise that can replace oven-controlled crystal oscillators based on cost/consumption criteria. The main parameters are frequency stability and phase noise over the temperature range and aging.

The compensation of a TCXO can be either analog or digital. A DTCXO is an interesting compromise between stability, power consumption and low labor cost. The analog TCXO offers lower performance in terms of frequency stability over temperature range. The main feature of a TCXO is better phase noise when compared to the DTCXO, especially near the carrier and up to 10 kHz offset. The phase noise degradation of a standard DTCXO is mainly due to the digital compensation. **Figures 1** and **2** show the phase noise levels of both types of oscillators.

Fig. 1 Phase noise of an SMD TCXO.



In order to achieve these noise performance goals, the different noise sources must be considered.[1] The various types of phase

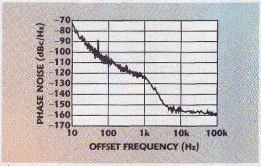


Fig. 2 Phase noise of a standard DTCXO.

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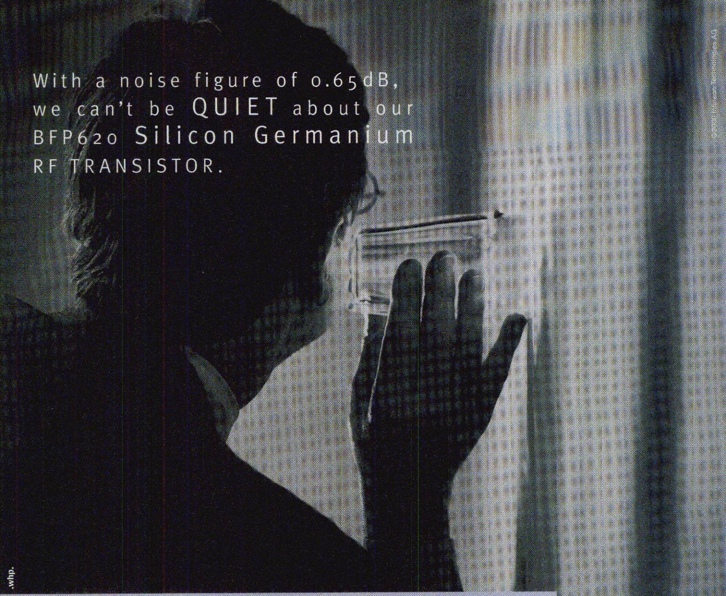

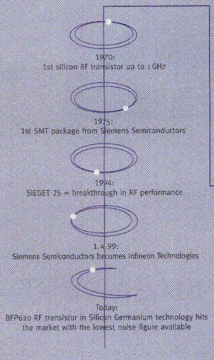

BFP620 electrical characteristics @ 1.8 GHz; 2 V:

Noise Figure	0.65 dB
Power Gain	21 dB
Input IP_3 capability (I_C = 6 mA)	10 dBm
Ic max	80 mA
V_{CEO}	2.8 V

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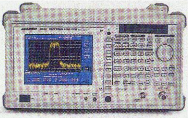

R3267 Spectrum Analyzer

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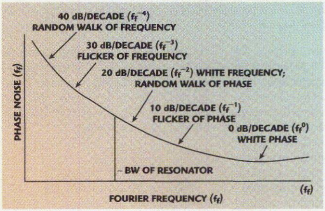
noise associated with a low noise oscillator are shown in ***Figure 3***. The oscillator's resonator is the primary noise source close to the carrier; the oscillator circuitry is the primary source far away from the carrier. Frequency multiplication by N increases the phase noise by N^2 (20logN in decibels). In addition, vibration-induced noise can dominate all other sources of noise in many applications.

The oscillator's loaded Q affects noise when the oscillator circuitry is a significant noise source. The noise floor is limited by Johnson noise, that is, noise power kT = –174 dBm/Hz at 290 K. A higher signal level improves the noise floor but not the close-in noise. Thus, in this article, two ways to improve the performance of DTCXOs will be investigated. The target specifications are a frequency stability of ±0.2 ppm over –30° to +75°C, 1.5 ppm aging over 10 years and a noise floor phase noise of –150 dBc/Hz and –105 dBc/Hz at 10 Hz offset.



▲ *Fig. 3 Types of phase noise.*

CRITICAL ELEMENTS FOR NOISE GENERATION DUE TO THE QUARTZ RESONATOR

The theoretical phase noise parameters are

$$\frac{f_0}{2Q} = f$$

and

$$Q = \frac{f_0}{\Delta f}$$

where

Δf = bandwidth at –3 dB points
Q = quality factor of the resonator

Slopes of –30 dB/decade at –105 dBc/Hz for 10 kHz offset and –20 dB/decade at –145 dBc/Hz for 1 kHz offset are typical. The intersection of the two lines dictates a resonator bandwidth of 200 Hz. In a numerical example,

$$Q = \frac{20}{200} 10^6 = 10^5$$

$$\Rightarrow Q = 100,000$$

The resonator Q is a critical factor and the optimization will be based on a Q >> 100 K.

The various possibilities of a quartz resonator design are listed in ***Table 1***. A third-overtone AT-cut crystal is chosen based on good aging and oscillator stability. The oscillator has been designed

TABLE I

QUARTZ RESONATOR DESIGN COMPARISON

Main Parameters	*AT Fundamental 10 MHz*	*AT Third Overtone 10 MHz*	*AT Fundamental 20 MHz*	*AT Third Overtone 20 MHz*
Q (average value)	150,000 to 200,000	350,000 to 500,000	75,000 to 100,000	175,000 to 250,000
Oscillator stability	medium	good	low	good
Tendancy for external pulling (±8 ppm)	good	too low – no available compensation	good	good
Phase noise improvement	N/A	N/A	–6 dB	–6 dB
Aging	low	high	low	good
Best choice			2	1

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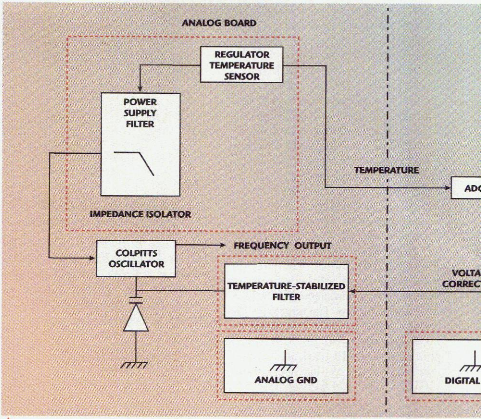


Fig. 4 The DTCXO's block diagram.

to work with a third-overtone AT quartz resonator at 20 MHz, which increases the self-resonant frequency and the quality factor. The quartz resonator is fabricated using a high quality quartz with an optical quality > 2.4 million. The crystal blank then is polished to reduce the quartz resistance and to increase the quality factor. Gold metallization and a primary layout of chromium then are applied and manually finished to a high quality. A burn-in of the metallic layouts completes the crystal fabrication process. All of these procedures improve the electrode stability and, therefore, the long-term aging. Finally, a specific sealing paste is used that contributes to good aging; vacuum sealing reduces the quartz resistance in the final packaged resonator. A fast thermal cycling between –55° and +125°C over five days is utilized on the completed resonator.

THE OSCILLATOR LAYOUT DESIGN

Figure 4 shows the DTCXO's block diagram and the ground separation. The power supply utilizes an integrated low band filter and isolation stages, which separate the impedance and amplify the current. The digital compensation section is isolated from the oscillator and output buffer.

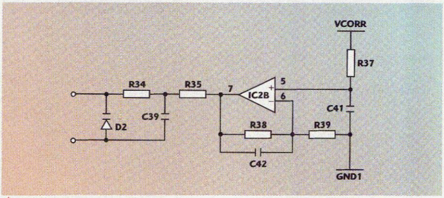


Fig. 5 Filtering of the phase noise due to digital compensation.

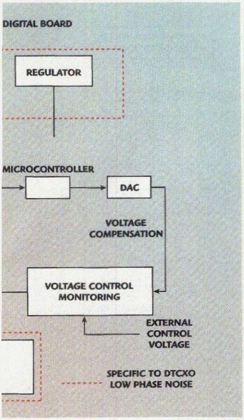


Figure 5 shows the integration of a low band filter prior to the varicap diode of the oscillator using temperature-stabilized components. This configuration strongly decreases the fast frequency variations due to the digital compensation and, therefore, decreases the noise. The low noise output thus is stabilized as a result of the temperature-stabilized components used for the filter. However, this filtering procedure has a strong influence on the start-up time of the DTCXO, which is calculated using

$$\tau = RC$$
$$= 4.7 \text{ s}$$

where

$R = 1\ M\Omega$
$C = 4.7\ \mu F$

PERFORMANCE RESULTS

After manufacturing the 20 MHz AT third-overtone crystals in an HC46 cold weld package, a batch of 20 completed resonators was measured. The measurements indicated a crystal resistance of 15 Ω, an inductance of 28 mH and a capacitance of 2.3 fF with a Q of 206,000 to 252,000. The resonator's phase noise at 25°C is shown in ***Figure 6***. As a result, the actual experimental phase noise (green profile) is improved compared to the first theoretical approach (red profile). This conclusion can be verified using the formula

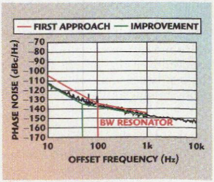
$$Q = \frac{f_0}{\Delta f}$$

where

$f_0 = 20$ MHz
$Q = 200{,}000$

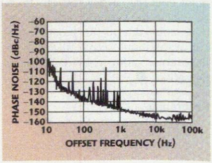
The result is $\Delta f = 100$ Hz. If f represents the crossing point of the two slopes, the graph indicates approximately 45 Hz as the f value (45 Hz × 2 = 90 Hz, which is very close to 100 Hz).

Phase noise vs. temperature range is shown in ***Figures 7***, ***8*** and

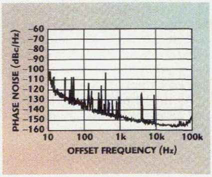


▲ *Fig. 6 The resonator's phase noise vs. bandwidth.*

▼ *Fig. 7 Phase noise at –30°C.*



▼ *Fig. 8 Phase noise at 70°C.*



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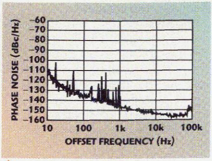
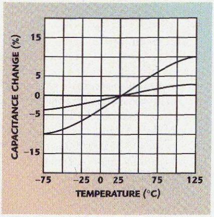
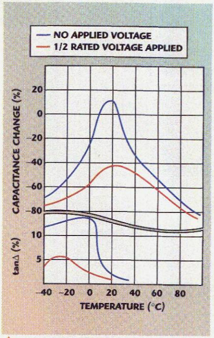


▲ *Fig. 9 Phase noise at 25°C.*

Fig. 10 Typical capacitance change vs. temperature for a tantalum dielectric capacitor. ▼





▲ *Fig. 11 Capacitance change vs. temperature for a multilayer ceramic Y5V capacitor.*

9. The technical problems relating to phase noise vs. temperature range were described at the beginning of this article. Raised noise close to the carrier was observed as shown on the three curves at +25°, +70° and –30°C. The excessive noise was due to the increased cutoff frequency of the filter used to reduce noise on the correction signal coming from the digital system.

The –40 dBc/Hz filter slope was shifted above 10 Hz and influenced the previous –30 dBc/Hz slope from 10 to 100 Hz. The implemented capacitors were responsible for this effect. Initially, Y5V-type capacitors were used; these components were subsequently replaced by tantalum dielectric types. Thus, capacitor stability vs. temperature range is an important criterion to take into account. ***Figures 10*** and ***11*** show the change in capacitor vs. temperature for both capacitor types.

As shown previously, the phase noise specification has been met. In addition, the use of a third-overtone AT-cut crystal has provided an aging of $\pm 2.10^{-7}$/year and the digital compensation has produced good results (±0.10 to ±0.15 ppm over the –30° to +75°C temperature range). The only detrimental effect seen on the oscillator is the start-up time slow down due to filters with high τ (a few seconds). However, for the applications addressed by this DTCXO this parameter is not a major consideration. In addition, a higher level of physical integration of such a device could be difficult considering the 20 MHz AT third-overtone crystal design. Lastly, care must be exercised in the phase noise measurement method. The bandwidth of the analysis filters on the test bench must be set up very tightly to observe the noise near the carrier.

CONCLUSION

This article has described two important points that must be addressed to comply with the required DTCXO specification. The crystal unit's quality factor must be greater than 200,000 as a target to improve phase noise near the carrier and aging, and the electronic circuit design must reduce noise due to the power supply and implement active filters to reduce noise induced by digital compensation. ■

Reference

1. John R. Vig, *Quartz Crystal Resonators and Oscillators for Frequency Control and Timing Applications*, CQE internal document, January 1993.

SELECTING A PEDESTAL FOR TRACKING LEO SATELLITES AT KA BAND

This article discusses the issues involved in selecting a pedestal for tracking low earth orbit (LEO) satellites. LEO satellites offer several advantages over their geostationary earth orbit (GEO) cousins. Compared to a GEO, a LEO satellite has lower launch costs, reduced power requirements and a significantly reduced roundtrip transmission delay. While a constellation of GEOs can only see earth stations with latitudes less than 81°, the use of polar orbits allows a LEO constellation to communicate with all points on the globe.[1] The disadvantages of a LEO satellite are that the earth station must spatially track the satellite across the sky and compensate for Doppler frequencies that are quite large.

The popularity of LEO satellites is increasing rapidly. The advent of constellations such as Iridium (66 satellites), Teledesic (228 satellites), Skybridge (80 satellites) and Globalstar (48 satellites) suggests that LEO constellations could become the basis of future two-way wireless communications systems. This possibility makes the tracking of LEO satellites an important issue for today's earth station designer. Of the systems discussed here both Iridium and Teledesic use Ka-band links in some form.

The tracking of LEO satellites at Ka band provides new challenges in designing and manufacturing earth stations. The high frequencies of the Ka band mean even a medium-sized antenna produces a narrow beamwidth, resulting in stringent antenna pointing requirements. For example, a 1.2 m parabolic antenna has a 3 dB beamwidth of 0.58° at 30 GHz and 0.88° at 20 GHz. The combination of the uplink and downlink beamwidths requires a pointing accuracy on the order of 0.3° to minimize attenuation caused by pointing errors.

Only the fastest and most expensive azimuth-elevation pedestals are able to continuously track LEO satellites on high elevation passes. The problem occurs when the satellite approaches and departs from its highest elevation. At this point the pedestal must make high speed azimuth movements in order to track the satellite. Insufficient azimuth speed results in the earth station being unable to track the satellite continuously for passes that exceed a particular maximum elevation.

Several methods have been suggested to overcome this problem, including trajectory optimization where the antenna trajectory is modified to minimize antenna pointing losses on or near zenith passes.[2] However, a narrow

[Continued on page 120]

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beamwidth precludes the use of this technique. Other solutions include the use of either an azimuth-elevation-tilt pedestal or an X-Y pedestal. Both of these pedestals allow zenith pass tracking.

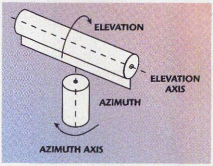
AZIMUTH-ELEVATION PEDESTALS

For azimuth-elevation pedestals, the pedestal's azimuth speed is usually the limiting factor that prevents zenith tracking of a LEO satellite, as shown in ***Figure 1***. For example, a pedestal with a maximum azimuth velocity of 4°/sec would be unable to continuously track a satellite with a 780 km sun-synchronous orbit (UoSAT-3) for passes with a maximum elevation greater than 82°. In the case of a zenith pass there would be a loss of communications with the satellite for a minimum of 45 seconds. This down time is significant when you consider that during an overhead pass a satellite of this type is only at elevations > 20° for approximately 7.4 minutes.

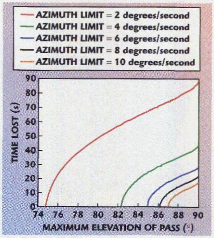
Figure 2 shows the minimum time lost in seconds for passes of a satellite with a 780 km orbit with different maximum elevations for an azimuth-elevation pedestal (which is azimuth limited) with maximum azimuth speeds of 2, 4, 6 and 8°/sec. The situation is even more critical when communication is via a single LEO satellite. In this case, it is not uncommon that during a significant period of time the only usable satellite pass may have a maximum elevation that requires azimuth movements in excess of the earth station's pedestal capability. This condition occurs because all of the other available passes may have low peak elevation angles. ***Figure 3*** shows an example of this scenario involving passes of a UoSAT-3 satellite over an earth station in May 1998. In an urban environment, Ka-band communications for such passes is almost impossible due to multipathing.[3] Even when communication is via a constellation of LEO satellites, these same urban environment restrictions may dictate the use of high elevation satellite passes.

It is important to utilize these high elevation passes as much as possible because they provide the best signal-to-noise ratio and, hence, allow communication at the highest possible data rates to take place. In addition, the maximum elevation of a particular pass is directly related to the amount of time that the satellite is visible to the earth station. The higher the maximum elevation the longer the satellite is visible.

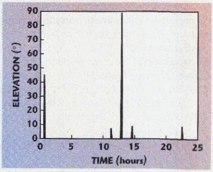
An additional problem occurs if closed-loop tracking is being used to follow the satellite on a near-zenith pass and the pedestal approaches its velocity limits in either azimuth or el-



▲ *Fig. 1 The azimuth-elevation pedestal.*



▲ *Fig. 2 Time the pedestal will be unable to track a 780 km satellite for passes with different maximum elevations and pedestals with various azimuth speeds.*



▲ *Fig. 3 Passes of a UoSAT-3 satellite over an earth station at –33.9° lat/151.8° long on May 10, 1998.*

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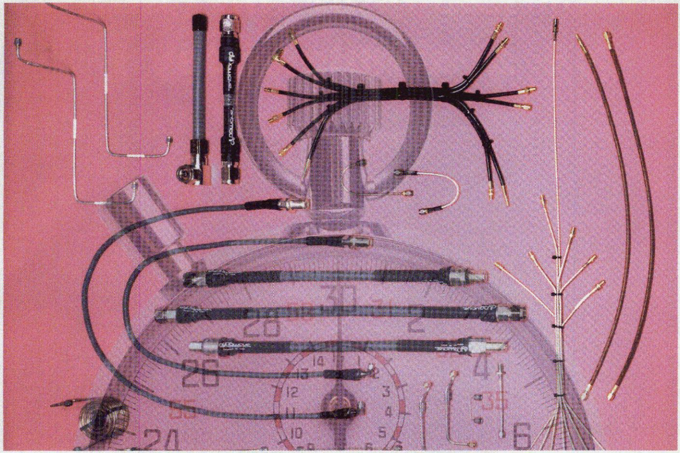

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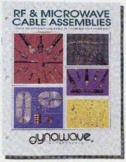

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evation. At such a point there is little or no spare capacity left to make off-boresight movements to track the satellite. Thus, the tracking process, should it be required, would have to be suspended until the satellite reached a lower elevation.

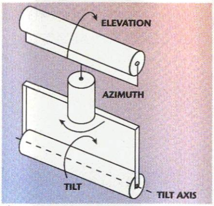
AZIMUTH-ELEVATION-TILT PEDESTALS

An azimuth-elevation-tilt pedestal, shown in ***Figure 4***, is an azimuth-elevation pedestal with the addition of a third axis. The tilt axis is perpendicular to the elevation axis. This type of pedestal is sometimes called a three-axis pedestal. At high elevations the elevation and tilt axes are used together to allow full hemispherical tracking of the satellite (including zenith passes); that is, the required elevation-pointing angle is obtained using a combination of the elevation and tilt axes. This capability reduces the elevation axis component of the required pointing angle and, thus, allows sufficient time for the azimuth axis to rotate without exceeding its maximum azimuth drive velocity.[4]

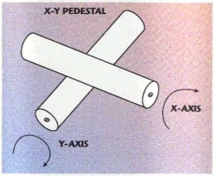
While the azimuth-elevation-tilt pedestal allows full hemispherical tracking it does have some disadvantages. The addition of the third axis increases the unit's weight, complexity and manufacturing cost compared to either an X-Y or azimuth-elevation pedestal. In addition, the interaction of the elevation and tilt axes increases the complexity of the required control electronics. Premission orbit determination is required to predict whether the tilt axis will be needed to allow the satellite to be tracked for the entire pass.[5] In addition, prepositioning the tilt axis prior to a pass increases the setup time.[5] This increase may become significant if an earth station is being used to sequentially track more than one satellite.

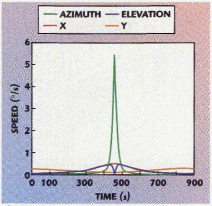
X-Y PEDESTALS

As shown in ***Figure 5***, an X-Y pedestal has two orthogonal axes: the first is a horizontal fixed primary axis; the second is perpendicular to and mounted on top of the first axis.[4] This configuration allows the pedestal to provide zenith pass tracking even



▲ *Fig. 4 The azimuth-elevation-tilt pedestal.*

▼ *Fig. 5 An X-Y pedestal.*




▲ *Fig. 6 Pedestal velocity requirements for an 84° elevation pass of a UoSAT-3 satellite.*

with the use of relatively low speed motors. ***Figure 6*** shows the pedestal velocity requirements for an 84° elevation pass of a satellite with a 780 km sun-synchronous orbit over Sydney for both the X-Y and azimuth-elevation cases. An X-Y pedestal design offers several advantages over its azimuth-elevation-tilt and azimuth-elevation counterparts.

For an X-Y pedestal design the required angular velocities of both axes remain within a small range for all but the lowest elevation satellite passes. This condition is not the case for an azimuth-elevation pedestal where the required angular velocity in azimuth increases rapidly as the maximum elevation of a satellite pass approaches 90°. For an overhead pass of a LEO satellite with an 800 km orbit, the maximum angular velocity required by either axis is only a fraction of a degree per second. This low velocity produces improved pointing accuracy[5] compared to the three-axis system where the angular velocity required is significantly higher. Another advantage is that the X and Y axes are identical, which means that the required spare parts can be kept to a minimum.[6] In addition, the pedestal can be built from high quality, off-the-self components, which allow economical designs to be constructed[6] for a wide range of operating conditions and antenna sizes. Off-the-self components also mean low cost maintenance. The X-Y pedestal uses brushless DC motors, which eliminate the need for expensive rotary joints and slip rings.[6] Finally, the X-Y pedestal is a low cost solution where the simplicity of the design compared to a three-axis pedestal increases the mean time between failures (MTBF).[5]

A standard PC can be used to control the X-Y pedestal, allowing software adjustment of parameters such as tracking speed and tracking range to be set by the user. Two resolvers (one mounted on the shaft of each of the two motors) provide feedback on the antenna pointing angles. Note that an X-Y pedestal is still not capable of full hemispherical tracking but, unlike the azimuth-elevation pedestal that is unable to continuously track high elevation passes, the X-Y pedestal has its limitations at low elevation angles (< 2°) around 90° and 270° in azimuth. At these elevations the satellite moves slowly with respect to the earth station and even small capacity motors (6°/sec) are sufficient to minimize the tracking loss. In any event, it is difficult to imagine a practical application in which such low elevation passes would be required.

CONCLUSION

Azimuth-elevation pedestals, with the exception of the fastest and most expensive, are unable to continuously track LEO satellites on high elevation passes. This drawback results in loss of communications with the satellite at high elevations, which is the time when the signal should have its highest signal-to-noise ratio. It also causes reduced capacity to perform closed-

[Continued on page 126]

PEDESTAL DESIGN OF THE UTS KA-BAND EARTH STATION FOR TRACKING LEO SATELLITES

The Cooperative Research Centre for Satellite Systems in Australia is scheduled to launch the FedSat LEO satellite in November 2001. FedSat will have an 800 km sun-synchronous orbit at an inclination of 98.6°. Its communications payload includes a Ka-band segment that will allow communications at 30 GHz (uplink) and 20 GHz (downlink). UTS has designed an X-Y pedestal for use in its earth station. A standard PC controls the operation of the pedestal.

loop tracking at higher elevation and creates the possibility of having only limited ability to communicate with LEO satellites, especially when the earth station is located in an urban environment.

While an azimuth-elevation-tilt pedestal allows full hemispherical tracking, the addition of the third axis increases its manufacturing cost and the complexity of the required control electronics. The least expensive and most elegant solution to this problem is to use an X-Y pedestal. An X-Y pedestal allows zenith pass tracking even with relatively low speed motors. Additional advantages of an X-Y design include identical X and Y axes, which keep spare part requirements to a minimum,[6] and the ability to use high quality, off-the-self components, which allow significant savings.[6] In addition, the use of brushless DC motors eliminates the need for expensive rotary joints and slip rings.[6] The X-Y pedestal provides improved tracking accuracy for overhead passes compared to three-axis pedestals,[5] and offers an improved MTBF compared to other pedestals.[5]

ACKNOWLEDGMENT

The author would like to thank Michael Eckert, UTS, who edited this article; Ray Clout, UTS, for his input; Ken Bone, Darius Ltd., for his comments regarding the limitations of X-Y pedestals; and Irene Stephens, Australian Broadcasting Corp., and Andrew Thoms, UTS, who created the drawings of the different pedestal types. While the pedestal design and construction are the result of input from several people on the project, Ray Clout performed the majority of the work. The project leader at UTS is Sam Reisenfeld. This work was carried out with financial support from the Commonwealth of Australia through the Cooperative Research Centres program. The UoSAT-3 satellite was built by SURREY Space Centre and launched on January 22, 1990. It has a 780 km sun-synchronous orbit at an inclination of 98°. ■

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Keith Willey *worked for 20 years in the television broadcast industry before receiving his BSEE from the University of Technology, Sydney (UTS) in 1997. As part of his PhD research, he joined the faculty of engineering at UTS' Cooperative Research Centre for Satellite Systems. Willey's research interests include the spatial acquisition and tracking of LEO satellites operating at Ka band. He is involved in the design of the Ka-band earth station being built by UTS.*

Increasing Multitone Power Near Saturation

Microwave high power amplifiers (HPA), particularly traveling-wave-tube amplifiers (TWTA) and klystrons, are increasingly being used for the transmission of multitone signals. Such signals are frequently in the form of complex digitally modulated waveforms as orthogonal frequency division multiplex or CDMA. Some systems require multitone operation at or near saturation. This article investigates the relationship between single-tone and multitone saturated power. It is demonstrated that the two-tone and multitone (≥ 4) saturated power of TWTAs and similar amplifiers can be increased by more than 1 and 2 dB, respectively, through the use of a limiter-linearizer combination.

The need to transmit greater amounts of information has greatly increased the use of microwave HPAs with multitone signals. Many of these systems require only moderate linearity. In some cases the HPA can be operated at or very near saturation and still provide the specified bit error rate and/or intermodulation distortion (IMD) performance. In such system's multitone saturated power becomes a key parameter.

The choice between solid-state and vacuum technology (TWTAs and klystrons) is often made by the required saturated power. At low power levels almost all factors favor a solid-state approach. However, as the required power increases, the trade-offs move to favor a TWTA and, eventually, a klystron solution. For example, at C-band a 400 W TWTA is approximately a quarter of the size, draws half the DC power and costs about 50 percent less than a comparable solid-state power amplifier (SSPA). SSPAs are considered to provide linearity superior to TWTAs, but modern linearized TWTAs (and klystrons) have comparable or better linearity.

One problem not solved by a linearizer is the issue of multitone saturated power. It is generally known that power amplifiers saturate at a lower level with multiple carriers than with a single carrier. TWTAs typically provide a lower multitone saturation level than SSPAs. However, little has been written to quantify these differences. Multitone power levels are frequently measured with a conventional power meter during HPA testing. This approach yields satisfactory results at higher output power backoff (OPBO), but can be in error by 1 dB or more near saturation. This discrepancy occurs because power meters respond to both carrier and IMD power. (A low-pass filter is commonly used to eliminate harmonic, but not IMD, power).

[Continued on page 130]

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MULTITONE SATURATED POWER

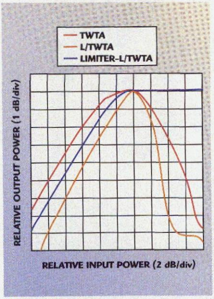
The multitone (or carrier) saturated power (P_{MTSAT}) can be related to three factors

$$P_{MTSAT} = P_{STSAT} - \Delta P_{ENV} - P_{IMD} - \Delta P_{DP} \quad (1)$$

where

P_{STSAT} = single-tone saturated power
ΔP_{ENV} = power loss due to the changing envelope of the multitone signal
P_{IMD} = power converted to IMD
ΔP_{DP} = power loss due to any decrease in power as an amplifier is driven beyond saturation

TWTA output power decreases with input power beyond saturation as shown by the TWTA transfer curve in



▲ *Fig. 1 Input/output power transfer characteristics of a TWTA and L/TWTA showing the elimination of postsaturation power decrease using a limiter-L/TWTA combination.*

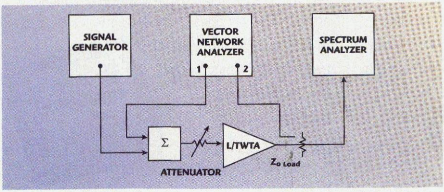
Figure 1. The ΔP_{DP} term is the principal cause for the lower P_{MTSAT} displayed by TWTAs in comparison to SSPAs. Generally, SSPAs maintain a constant output level beyond saturation. (Some SSPAs also drop in power beyond saturation. In the SSPA case, the drop is usually due to thermal effects and not a result of inherent device physics.)

The value of P_{MTSAT} was investigated both experimentally and by simulation. Special care was taken to measure only signal (carrier) power during testing. An HP 8720C vector network analyzer was used both as a signal source to generate one of the test carriers and as a tuned power meter to precisely measure carrier power, as shown in **Figure 2**.

The amount of power loss depends not only on the transfer characteristics of the amplifier, but also on the characteristics of the signal. Generally, the greater the peak-to-average ratio of the signal, the greater the loss in power. **Figure 3** shows the envelope of a two-tone signal (3 dB peak-to-average power ratio), the same signal after passing through an SSPA-like amplifier (no power drop beyond saturation) driven to near saturation and the same signal after passing through a TWTA-like amplifier driven to near saturation. (Note the dimple in the third plot.) Even though the average power has not quite reached saturation, the instantaneous input power is at times well beyond the level for saturation and must cause a power drop at these times. As the peak power increases, the power drop becomes greater and the corresponding dimple becomes deeper.

The difference between P_{MTSAT} and P_{STSAT} in decibels can be expressed as

Fig. 2 A vector network analyzer used as a tuned power meter to measure carrier power independent of IMD. ▼



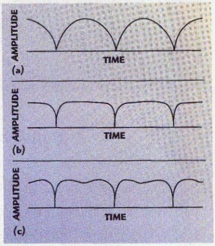
$$\Delta OPBO_{SAT} = 10\log\left(\frac{P_{MTSAT}}{P_{STSAT}}\right) \quad (2)$$

For a typical TWTA with two-tone excitation, $\Delta OPBO_{SAT}$ is approximately 1.6 dB.

THE EFFECT OF LINEARIZATION ON P_{MTSAT}

Linearizers are used to increase amplifier linearity. They allow HPAs to operate closer to saturation for a given level of IMD. Predistortion-type (PD) linearizers have been used almost exclusively with TWTAs.[1,2] PD has been employed because of its excellent performance, relative simplicity and ability to be added to an existing amplifier as a separate, stand-alone module. PD linearizers generate a nonlinear transfer characteristic, which equalizes the amplifier's transfer characteristics in both magnitude and phase.

The gain of the linearizer must increase with input level to cancel the TWTA's corresponding decrease in gain. An increasingly greater change in gain is required for distortion compensation as saturation is approached. This gain increase should cease at the point where the TWTA is driven to saturation. However, such a response is very difficult to achieve in practice. Most linearizers cannot turn off their increasing gain immediately. Consequently, the TWTA is driven further into saturation by the linearizer, as il-



▲ *Fig. 3 Effect of amplification near saturation on the signal envelope; (a) two-tone signal envelope, (b) two-tone signal after passing through an SSPA-like amplifier driven into saturation and (c) two-tone signal after passing through a TWTA-like amplifier driven into saturation.*

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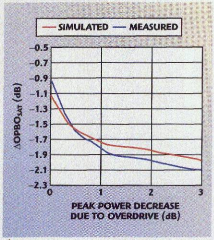
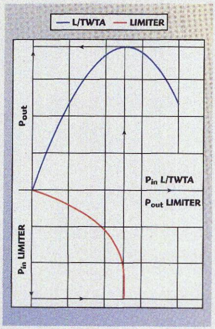


▲ *Fig. 4 The loss in saturated power due to multicarrier excitation.*

Fig. 5 PEP (overdrive) and $\Delta OPBO_{SAT}$ reduction by preceding the TWTA with a limiter. ▼



lustrated by the linearized TWTA (L/TWTA) curve shown previously. This growth in overdrive causes a further decrease in P_{MTSAT}. The resulting $\Delta OPBO_{SAT}$ for a L/TWTA can be greater than 2 dB.

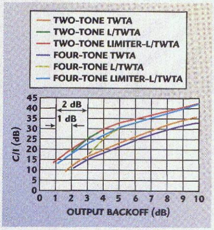
Figure 4 shows how $\Delta OPBO_{SAT}$ varies with the instantaneous peak decrease in power, beyond saturation, due to overdrive for a typical TWTA. (This decrease can be obtained from the input/output power transfer characteristics by entering the peak envelope power (PEP) of the multitone signal.) The displayed curves were calculated and measured for a two-tone signal, but appear to also apply for cases involving a higher number of tones.

TABLE I

$\Delta OPBO_{SAT}$ IMPROVEMENT ACHIEVED BY ADDING A LIMITER TO A TWTA AND L/TWTA

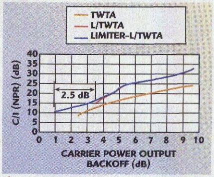
Excitation	*$\Delta OPBO_{SAT}$ Reduction (dB)*	
	TWTA	*L/TWTA*
One-tone	0	0
One-tone QPSK	< 0.1	< 0.1
Two-tone	~ 0.6	~ 1.0
Four-tone	~ 1.0	~ 2.0
N-tone (NPR)	~ 1.2	~ 2.3

Fig. 6 The enhancement in C/I near saturation with the addition of a limiter to a L/TWTA. ▼



THE ADVANTAGE OF LIMITING

Preceding the TWTA with a limiter can reduce the PEP overdrive. If the limiting point is made to coincide with the point of TWTA saturation, as shown in ***Figure 5***, overdrive and the consequent ΔP_{PD} can be prevented. Unfortunately, real limiters tend to have a soft transition into limiting. This gradual change in gain degrades TWTA linearity and increases IMD. Combining a limiter with a linearizer can produce a near-ideal transfer characteristic. The linearizer compensates for the limiter's gain change while the limiter prevents the linearizer from overdriving the TWTA. The input power/output power transfer characteristics of a limiter-L/TWTA combination with the limiter adjusted for different levels of PEP overdrive were displayed previously. The $\Delta OPBO_{SAT}$ of a two-tone signal can be reduced to less than 0.9 dB without any sacrifice in IMD performance at higher backoff levels when the limiter is set for a 0 dB PEP overdrive. Carrier-to-IMD (C/I) performance can actually improve close to



▲ *Fig. 7 The increase in near-saturation carrier power and NPR with the addition of a limiter.*

saturation. The advantage of combining a L/TWTA with a soft limiter was first recognized by G. Satoh and T. Mizuno.[3] Actually, the more rapidly a limiter can switch from a constant gain to a constant power state, the more effective it will be in this application.

The effect of a limiter with a L/TWTA was also examined for single-tone (with and without quadrature phase-shift keying (QPSK) modulation), four-tone and infinite-tone (noise power ratio (NPR)) excitation. As expected, the use of a limiter was determined to not affect single-carrier saturated power. However, it should be noted that limiters can produce harmonics that may in some cases be phased to increase TWTA power and efficiency.[4] A lowpass filter was used to prevent harmonics from affecting carrier power measurements in these tests.

Interestingly, it was found that for a single-carrier QPSK modulated signal, the addition of the limiter had a negligible impact on the saturated power and L/TWTA-induced spectral regrowth (SR). Even very close to saturation, the advantage of adding a limiter to improve SR appears to be negligible. This result is likely an outcome of the relatively small amplitude ripple displayed by single-carrier QPSK in comparison to multicarrier and other higher PEP digitally modulated signals.

In general, the greater the number of carriers, the greater the advantage of adding a limiter. ***Table 1*** lists the improvement in $\Delta OPBO_{SAT}$ achieved by adding a limiter to a TWTA and L/TWTA for different forms of excitation. ***Figure 6*** shows the enhancement in C/I near saturation provided by the addition of a limiter to a L/TWTA for two- and four-tone signals. ***Figure 7*** shows the enhance-

[Continued on page 134]

ment for an infinite-tone signal (NPR). The two- and four-tone C/I values shown are based on the highest individual IMD term.[1] In the case of the NPR data, the equivalent carrier power cannot be measured directly because of the inability to separate the IMD from signal (noise) power. Consequently, the signal power was estimated from the NPR level and total noise power.

CONCLUSION

The use of a limiter in conjunction with a L/TWTA (and some SSPAs) can increase multitone saturated power from 1 to 2 dB, depending on the number of carriers and postsaturation transfer characteristics. It can also provide several decibels of C/I improvement near saturation (at OPBO < 3 dB). However, the addition of a limiter to a L/TWTA appears too be of little or no value for single-carrier QPSK modulated signals, where no significant reduction in SR was observed. ■

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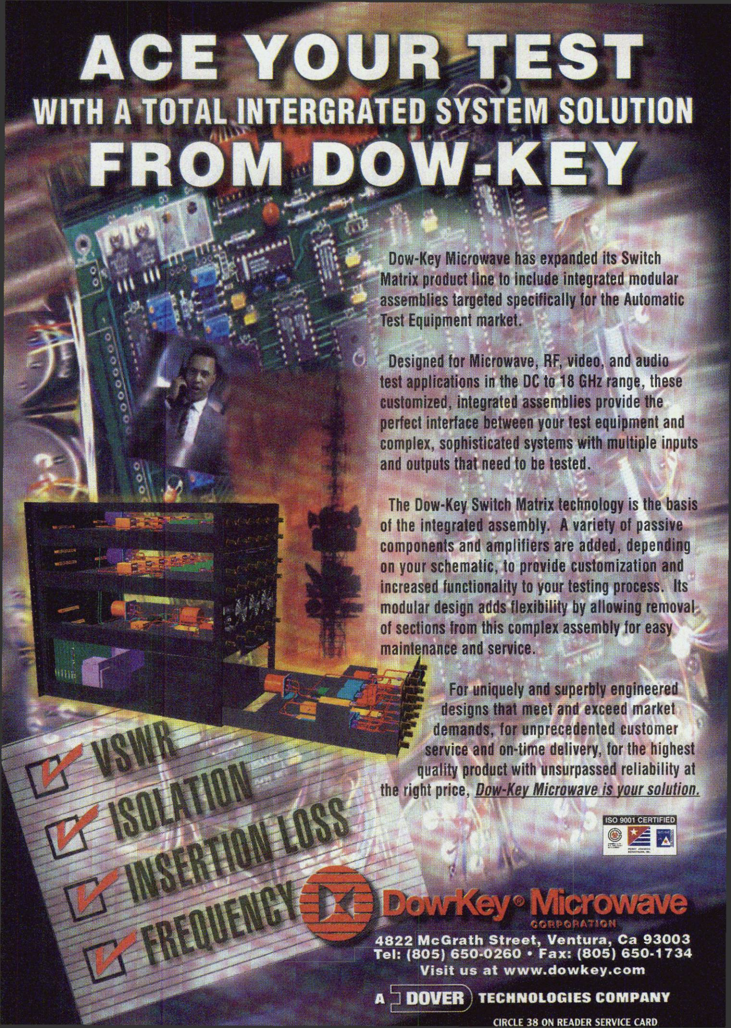
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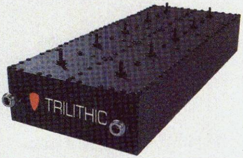

A Low Loss Dielectric Resonator Filter for Cellular and PCS Applications

Because of the growing need for increased capacity in cellular and PCS networks, low insertion loss and high out-of-band rejection are critical parameters for service providers to deliver cost-effective coverage. The use of complex digital modulation schemes to increase capacity also requires that a transmit filter exhibit a wide dynamic range; that is, it must be capable of handling moderate to high power levels while simultaneously maintaining high near-band rejection. Dielectric resonator filters are attractive for their low passband insertion loss. Through careful design and fabrication, a dielectric resonator filter has been designed that is capable of achieving very low passband insertion loss and high near-band rejection.

At present, three types of bandpass filters are typically employed in cellular, PCS and satellite communications base stations: combline cavity/waveguide, high temperature superconducting (HTS) and dielectric resonator. Combline cavity filters are the most widely used in cellular base stations because they are relatively inexpensive and easy to manufacture. At cellular frequencies, these filters are capable of achieving unloaded quality factors (Q) between 2000 and 9000. The high unloaded Qs translate into highly selective frequency responses with low passband insertion loss and high rejection. Combline cavity filters, with fractional bandwidths of 0.5 to five percent (typ), exhibit typical insertion losses of 1 dB or less at cellular frequencies with out-of-band rejection of better than 60 dB and spurious performance of –60 dBc or better. Depending on the filter size and housing, it is not uncommon for a combline cavity filter to handle input power levels of 500 W (avg). Although a waveguide filter can be used for those applications requiring extremely low passband insertion loss, combline cavity filters can be housed in smaller enclosures (as increasingly required for PCS and microcellular applications).

HTS filters have been used for several years at both cellular and PCS frequencies. Fabricated with superconducting films on special substrates rather than with conventional metal conductors on ceramic or polytetrafluoroethylene (PTFE) substrates, these filters are capable of unloaded Qs exceeding 50,000. Originally developed by IBM for possible use in supercomputers, superconductors initially required extremely cold temperatures (typically the 4.2 K temperature of liquid helium) to achieve proper operation. Below a certain critical temperature (T_c) the resistance of a superconductor approaches zero. However, above that temperature, the resistance of the

[Continued on page 138]

TRILITHIC
Indianapolis, IN

superconductor tends to be even higher than that of conventional room-temperature conductors.

In recent years, improvements in HTS materials have made it possible for high performance HTS bandpass filters to operate at temperatures equal to that of liquid nitrogen (77 K) or higher using solid-state cryocoolers to maintain the critical temperature. Because of the limitations of HTS films for handling high current densities, the power-handling capabilities of HTS filters are generally confined to receiver applications. HTS bandpass filters are capable of impressive selectivity performance since their dielectric losses can be reduced to negligible levels by the use of low loss, single-crystal substrates.[1] Packaging losses and spurious coupling must be controlled; nonetheless, HTS bandpass filters have been realized with out-of-band rejection of better than 40 dB at cellular frequencies, spurious performance approaching –100 dBc and passband insertion loss of less than 0.5 dB. For receiver applications, HTS bandpass filters offer the best electrical performance of the three filter types with unloaded Qs approaching 50,000. These filters can be designed with fractional bandwidths ranging from 0.1 to two percent, although the power-handling capability is typically limited to a maximum of 25 W average power.

Dielectric resonator filters are constructed of resonators comprising cylindrical rods or tubes of dielectric material usually mounted on a dielectric substrate in the proximity of supporting microstrip circuitry. The size of the dielectric structure relative to the wavelength of the signal of interest determines the frequency coverage. As the number of resonators (or poles) in the filter increases, the skirts of the filter's frequency response become steeper and the out-of-band rejection increases. However, the passband insertion loss also increases with the number of resonators, especially in narrowband designs.

In a dielectric resonator, the EM field for a resonant mode is largely confined to the ceramic resonator material. The field strength outside the resonator falls off rapidly (approximately exponentially) at distances much shorter than the free-space wavelength of the resonator. The primary loss mechanism in a dielectric resonator is the friction loss of the electronic dipoles at each lattice of the dielectric material and is characterized by the dielectric resonator's loss tangent. Nevertheless, dielectric materials are currently available with unloaded Qs of several thousand for resonator frequencies up to and exceeding 20 GHz.

The new low loss dielectric resonator filter developed for cellular and PCS applications employs careful materials selection and circuit matching to achieve electrical performance approaching that of HTS filters, but without their power-handling limitations. With unloaded Qs between 5000 and 50,000, these dielectric resonator filters can be fabricated with fractional bandwidths between 0.1 and two percent at cellular and PCS frequencies.

[Continued on page 140]

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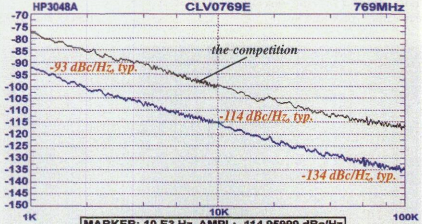
CLV0945E	936-953	0.5-4.5	-114	5
CLV1320E	1295-1335	1-5	-113	5
CLV1525E	1500-1550	0.3-4.7	-110	5



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.

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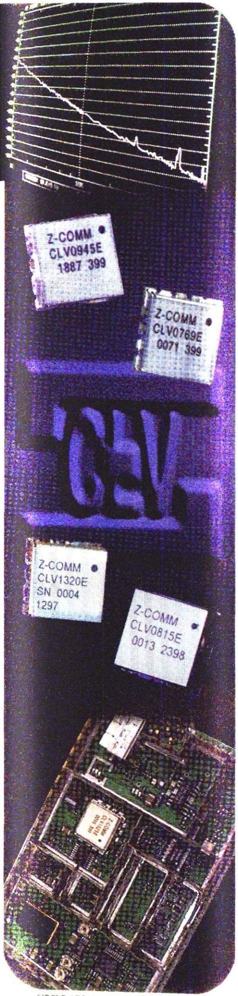

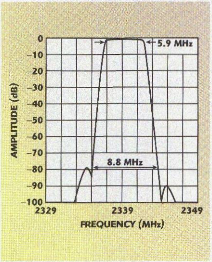

▲ *Fig. 1 The dielectric filter's frequency response.*

The new filters are designed for typical operating temperatures of −55° to +80°C and can handle average power levels exceeding 1 kW at room temperature. The measured insertion loss at 1900 MHz is less than 0.8 dB, as shown in ***Figure 1***, with rejection of better than 60 dB at 40 MHz from the carrier and spurious levels exceeding −100 dBc. A filter fabricated with 1.5 kW average power-handling capability at PCS frequencies exhibits a 3-to-60-dB shape factor of 1.4:1 and a fractional bandwidth of 0.2 percent, making it ideal for both receiver and transmitter applications. ***Table 1*** lists the dielectric resonator filter specifications.

TABLE I

DIELECTRIC RESONATOR FILTER SPECIFICATIONS

Passband frequency (MHz)	2300
Bandwidth (%)	0.2
Passband insertion loss (dB)	0.8
Stopband rejection (dB)	60
Spurious levels (dBc)	−100
Power-handling capability (avg) (kW)	1.5
Operating temperature range (°C)	−55 to +80
Size (")	13 × 7 × 3
Weight (lb)	< 10

These dielectric resonator filters offer the performance of HTS filters with enhanced power-handling capability at a fraction of the cost. They are comparable in size to combline cavity filters and considerably smaller than HTS filters with the low insertion loss and high near-band rejection required by modern communications systems based on complex digital modulation schemes such as wideband code division multiple access. Additional information is available at the company's Web site at www.trilithic.com or via e-mail at sales@trilithic.com.

References

1. Theodore Van Duzer and Charles W. Turner, *Principles of Superconductive Devices and Circuits*, Second Edition, Prentice-Hall, Upper Saddle River, NJ, 1999, pp. 150–151.
2. Charles A. Harper, *Passive Electronic Component Handbook*, Second Edition, McGraw-Hill, New York, 1997, pp. 556–561.

Trilithic,
Indianapolis, IN (800) 344-2412 or (317) 895-3600.

Circle No. 302

CATALOG UPDATE

▲ Precision RF and Microwave Component Catalog

This 40-page catalog details instrumentation-grade adapters, precision attenuators and terminations, and high return loss connectors as well as the K Connector® which offers coverage up to 40 GHz. Measurement components are also featured. Product photographs, specifications and application notes are provided.

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

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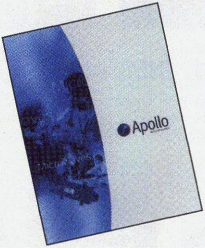

▲ Satellite Communications Component Brochure

This brochure highlights the company's output assemblies, filters, couplers, diplexers and multiplexers, circulators and isolators, terminations, switching and combining networks, and monitor and control systems. Customer service, support and partnership agreements also are discussed.

Apollo Microwaves,
Pointe-Claire, Quebec, Canada
(514) 426-5959.

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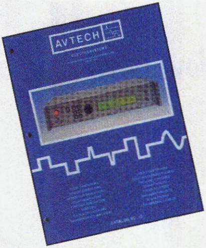

▲ Waveform Generator Catalog

This 113-page catalog provides information on samplers, laser diode drivers, constant current pulsers, frequency dividers, transformers, power splitters, bias insertion units, scope probes and low impedance cables as well as pulse, impulse, monocycle, delay and function generators and pulse, CW and transimpedance amplifiers. Application notes, photographs and key specifications are included.

Avtech Electrosystems Ltd.,
Ottawa, Ontario, Canada (800) 265-6681
or (613) 226-5772.

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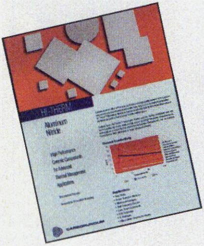

▲ Aluminum Nitride Catalog

This catalog introduces Hi-Therm™ aluminum nitride, a high purity ceramic with superior microstructural and chemical uniformity that results in very consistent properties. Hi-Therm is best suited for heat sink, power transistor module, high frequency device and laser diode submount applications. Key specifications and a thermal conductivity graph are provided.

Carborundum Corp.,
Sanborn, NY (716) 731-9200.

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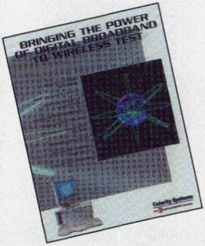

▲ Digital Broadband Catalog

This six-page brochure contains information on the company's mixed-signal test sets, arbitrary waveform generators and digital vector generators, analog and digital recorders, microwave and RF distortion measurement test sets, and broadband signal analyzers. Key specifications also are included.

Celerity Systems,
a division of L-3 Communications,
Cupertino, CA (888) 274-5604.

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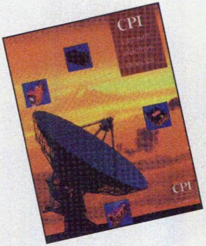

▲ Vacuum Electron Device Catalog

This brochure contains information on the company's standard communication vacuum electron devices and traveling-wave tube products for satellite communication uplink amplifiers. A cross-reference guide is provided. Key specifications and graphs also are included.

Communications
& Power Industries (CPI),
Palo Alto, CA (650) 846-3900.

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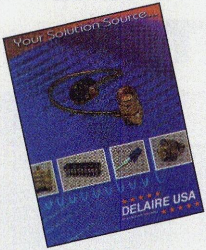
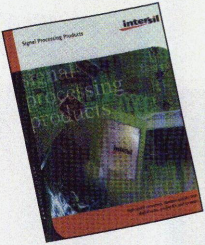


▲ RF and Electronic Specialist Brochure

This brochure provides information on the company's three divisions: RF Products, which manufactures adapters, connectors and cable assemblies; Fiber Optic, which supplies connectors, custom patchcords and accessories; and Distribution, which offers supply management, kitting, purchasing and stocking. A listing of products is included.
Delaire USA,
Manasquan, NJ (732) 528-4520.
Circle No. 316

▲ Product Reference Guide

This eight-page brochure describes RF and microwave silicon power transistors, transponders, cellular base stations and emitters for PCS/cellular, broadcast, SATCOM and radar applications. The company's capabilities in product design, wafer and die fabrication, assembly and test are discussed. A CD-ROM also is included.
GHz Technology Inc.,
Santa Clara, CA (408) 986-8031.
Circle No. 317



▲ Signal Processing Product Catalog

This 18-page catalog describes the company's analog-to-digital converters, function-specific digital signal processing and digital radios, RS-232 interface circuits, analog switches, RF building blocks transistor arrays and linear operation amplifiers. Key specifications and photographs are included.
Intersil Corp.,
Melbourne, FL (888) 468-3774.
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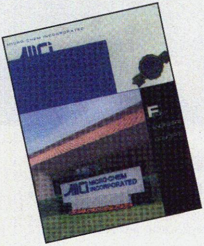

▲ Microwave and RF Circuit Board Brochure

This six-page brochure describes the company's manufacturing capabilities in microwave and RF circuit board design as well as double-sided and multilayer PTFE laminates. Precision etching, chemical milling and drilling also are discussed.
Micro-Chem Inc.,
Santa Clara, CA (408) 970-9777.
Circle No. 319

▲ Telecommunication Solution Catalog

This 20-page catalog describes solutions for next-generation mobile phones; high performance, surface-mount diode technology; electrostatic effects on microchips and mitigation methods; personal digital assistants; and power management concepts for mobile phones. New products, application notes and a CD-ROM catalog are included.
Microsemi Corp.,
Garden Grove, CA (800) 713-4113.
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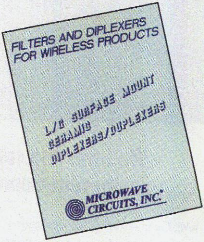

▲ Filter and Diplexer Catalog

This 32-page catalog contains information on filters and diplexers from DC to 40 GHz, including L/C surface-mount and ceramic dielectric filters and cellular/GPS/PCS diplexers and filters. Key specifications, outline drawings and photographs are included.
Microwave Circuits Inc.,
Washington, DC (800) 642-2587
or (202) 829-3030.
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▲ High Volume Interconnect Solution Design Guide

This new design guide outlines an available toolkit for the design of cost-effective, high volume interconnect solutions. Substrate properties, standard metallization, solder mask and insulator parameters, and thick-film cross-under design parameters are provided. Capabilities and specifications are included.
MIC Technology, an Aeroflex company, North Andover, MA (800) 746-4642 or (978) 687-9625.

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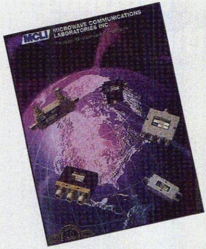

▲ Precision RF/Microwave Component Catalog

This 152-page catalog details power dividers, couplers, detectors, hybrids, adapters, terminations, attenuators, filters, isolators and circulators, oscillators, switches and amplifies. Specifications and mechanical outlines are listed.
Microwave Communications Laboratories Inc. (MCLI), St. Petersburg, FL (727) 344-6254.

Circle No. 338

▲ Planar Scanner Brochure

The six-page brochure describes the company's MI-6900 planar scanners, which are designed to perform repeated measurements at critically accurate standards to match current and future RF and microwave measurement challenges. A custom scan area can be ordered to meet unique scanning requirements.
Microwave Instrumentation Technologies LLC, Duluth, GA (800) 848-7921.

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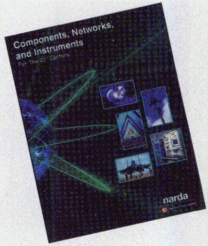

▲ Component, Network and Instrument Catalog

This 648-page catalog contains information on couplers, power combiners and dividers, attenuators and terminations, adapters, stocked and matrix switches, hybrids, phase shifters, waveguide components, custom passive products, GaAs amplifiers, oscillators, and instruments and monitors. Product photographs and outline drawings are provided.
Narda Microwave-East, a division of L-3 Communications, Hauppauge, NY (631) 231-1700.

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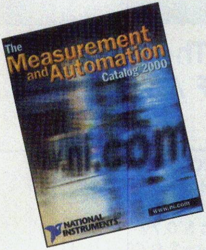
CATALOG UPDATE



▲ 2000 Measurement and Automation Catalog

This 880-page catalog features products for computer-based measurement and automation, including digitizers and oscilloscopes, digital multimeters, switches, waveform generators, dynamic signal analyzers, and temperature and voltage loggers. Tips are provided on how to build a system and select hardware/software as well as measurement and OEM solutions.
National Instruments,
Austin, TX (512) 794-0100.

Circle No. 325

▲ Filter and Crystal Catalog

This 32-page catalog highlights LC, crystal, lumped element and dielectric resonator design products, including crystals, TCXOs and voltage-controlled TCXOs that cover the 450 kHz to 3 GHz frequency range. Products are offered in surface-mount and through-hole packages. Key specifications are included.
Networks International Corp. (NIC),
Overland Park, KS (913) 685-3400.

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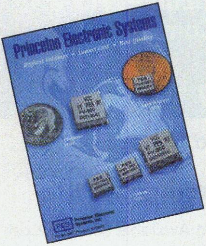

▲ VCO Short-form Catalog

This four-page short-form catalog introduces the company's low noise 5 and 3 V VCOs, which offer –112 dBc/Hz at 10 kHz offset.
Princeton Electronic Systems Inc. (PES),
Princeton, NJ (609) 275-6500.

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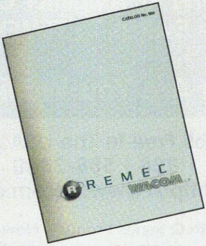

▲ Product Catalog

This catalog provides information on cavity filters, duplexers, isolators and loads, and receive equipment and transmit combiners. Photographs, key specifications and ordering information also are included.
REMEC, WACOM Products Inc.,
Waco, TX (254) 848-4435.

Circle No. 328

CATALOG UPDATE

▲ RF and Microwave Device Catalog

This six-page brochure contains information on RF and microwave devices, power semiconductors and related components, including amplifiers, attenuators, up- and downconverters, interconnect and passive devices, and capacitors. Customer service and support capabilities also are discussed.
Richardson Electronics,
LaFox, IL (800) 348-5580
or (630) 208-2200.

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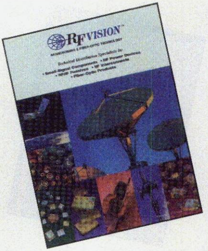

▲ RF/Microwave and Fiber-optic Technology Catalog

This four-page catalog describes the company's manufacturing capabilities in small-signal components, RF power devices, RF/IF passives and interconnects, and fiber-optic components. Value-added services, including parametric testing, tape-and-reeling, solder dipping, screening and special cabling, are described.
RF Vision,
Santa Clara, CA (877) 450-4441.

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▲ Short-form Catalog

The short-form catalog features high performance SMA, extended power SMA and 2.92 mm connectors for microstrip and stripline circuits up to 40 GHz. The low loss connectors are rugged enough to withstand severe environmental conditions such as high temperatures. All of the company's products are available off the shelf.
Southwest Microwave Inc.,
Microwave Products Division,
Tempe, AZ (480) 783-0201.

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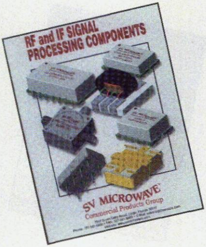

▲ RF and IF Signal Processing Capability Catalog

This eight-page catalog features IQ modulators and demodulators, voltage-variable phase shifters and attenuators, high dynamic range mixers, power splitters and combiners, and directional couplers. A listing of model numbers and key specifications is provided.
SV Microwave,
Commercial Products Group,
Largo, FL (727) 541-5800.

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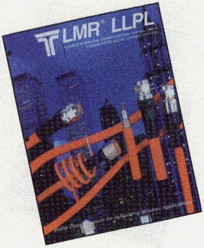

▲ Plenum Cable Catalog

This 20-page catalog covers the LMR® LLPL high performance, 50 Ω, low loss, flexible plenum coaxial cables, connectors, accessories and tools designed for indoor use in wireless systems. Technical information and specifications are provided.

Times Microwave Systems,
Wallingford, CT (203) 949-8489.

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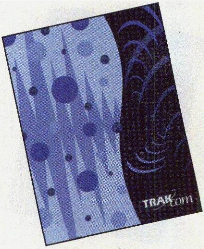

▲ Satellite Component and Integrated Microwave Assembly Brochure

This eight-page catalog highlights space-qualified ferrite circulators, isolators, waveguide switches and sources as well as high frequency synthesizers for the wireless communications and defense industries. An overview of the company's manufacturing capabilities and divisions is included.

TRAK Communications Inc.,
Tampa, FL (888) 283-8444.

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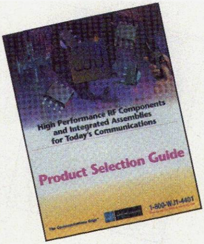

▲ Product Selection Guide

This four-page product selection guide describes high performance RF components and integrated assemblies including amplifiers, mixers and repeaters for today's communications. Specifications and a listing of sales offices and distributors are included.

Watkins-Johnson Co. (WJ),
Palo Alto, CA (800) 951-4401.

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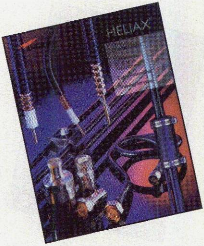

▲ Coaxial Cable, Connector and Accessory Catalog

This 36-page catalog contains information on HELIAX® coaxial cable, assemblies, connectors and accessories. Product photographs and specifications are provided. A company history and description of the Andrew Institute are also included.

Andrew Corp.,
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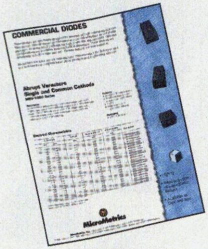

▲ Commercial Diode Catalog

This catalog describes new diodes designed specifically for high volume commercial applications, including abrupt, hyperabrupt and wideband varactors; voltage-controlled crystal oscillator and temperature-compensated crystal oscillator hyperabrupts; SMT PINs; mixers/detectors; and ceramic MELFs. These direct Alpha replacements are available in a variety of surface-mount or standard MELF packages on tape and reel.

Micrometrics Inc.,
Londonderry, NH (603) 641-3800.

Circle No. 347

▲ Automatic Distortion Measurement System Brochure

This eight-page brochure describes the model CTS-1000 automatic distortion measurement system, a turnkey system for making accurate, repeatable measurements of any cable telecommunications frequency plan in minutes without limitation. Features are described. Screen shots illustrating the system's capabilities are provided.

RDL Inc.,
Conshohocken, PA (610) 825-3750.

Circle No. 353

▲ High Frequency Circuit Material Portfolio

This product folder includes product data sheets, physical property guides, electrical design data and fabrication guidelines on the company's complete line of circuit board materials for wireless communications over high frequencies, including microwave and RF.

Rogers Corp.,
Microwave Materials Division,
Chandler, AZ (480) 961-1382.

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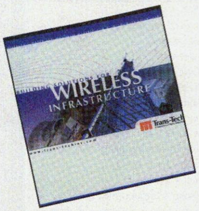
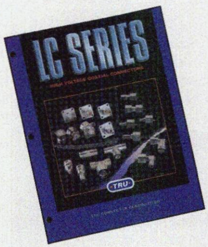


▲ High Quality, Low Cost Ceramic-based Component Brochure

This eight-page brochure decribes dielectric and magnetic materials and RF/microwave components. Company capabilities, including applications engineering assistance and state-of-the-art processing, are detailed.

Trans-Tech Inc.,
a subsidiary of Alpha Industries,
Adamstown, MD (301) 695-9400.

Circle No. 352



▲ High Voltage Coaxial Connector Catalog

This 12-page catalog describes the LC series RF coaxial connectors used in high voltage, high power applications. The connectors are designed to meet the LC interface standard per MIL-STD-348 and MIL-C-3650. Detail drawings of cable plugs, jacks, bulkhead or panel receptacles, and in- and between-series adapters are included.

Tru-Connector Corp.,
Peabody, MA (800) 262-9878
or (978) 532-0775.

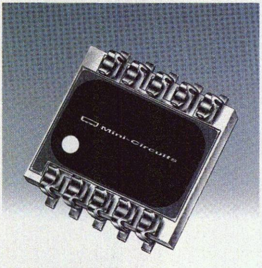
Circle No. 349

▲ Signal Switching and Distribution Subsystem Catalog

This catalog contains information on new notch filters for enhancing a receiver's dynamic range. Switch matrices feature a full fan out, nonblocking architecture and can be designed with more than 100 inputs/outputs in a single chassis.

Signal Technology Corp.,
Systems Operation,
Webster, MA (508) 943-7440.

Circle No. 348



High Performance, Low Cost, Surface-mount Microwave Mixers

As communication bandwidth requirements increase, industry is demanding higher performance in passive devices as well as smaller footprints. Although attempts are being made to utilize semiconductor technologies, they are capital intensive and, hence, the selection is limited. Blue Cell™ technology lends itself to low cost mixer designs for moderate to high volume markets and utilizes standard thick-film technology. A series of high performance passive mixers has been developed that uses patented Blue Cell technology. Each mixer exhibits good conversion loss from 2.5 to 6.7 GHz with excellent LO-to-RF and LO-to-IF isolation. The finished part has an ultra-low height of 0.07" and its footprint measures 0.25" × 0.30".

THE MIXER DESIGN

The design for the mixer series was accomplished using the HP Momentum 2.5D electromagnetic simulator; the nonlinear analysis was performed with HP Microwave Design System software. Because the grounding is through inductive leads, the actual high end performance of the mixer was slightly lower than the computer predicted. However, excellent performance was achieved with just one design iteration.

ASSEMBLY DETAILS

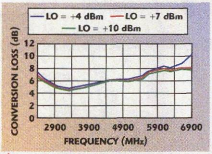
The mixer is fabricated in multilayer thick film using materials and processes chosen to optimize their high electrical performance. Strict controls are placed on both the materials and the processes to ensure repeatable performance from part to part. The diodes are attached using automatic die attach and assembled using automatic wire bonders. The package consists of 10 leads attached to the substrate with high temperature melting point solder. The leads are solder plated, have good solderability and are shaped to provide strain relief to account for variations in the temperature coefficient between the host PCB and the mixer. A proprietary epoxy cure process has been used to protect the diodes and traces, ensuring a part rugged enough to withstand repeated high temperature reflows while maintaining good moisture resistance.

PERFORMANCE

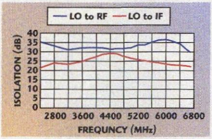
The model MBA-671 mixer operates from 2400 to 6700 MHz. Typical conversion loss is

[Continued on page 158]

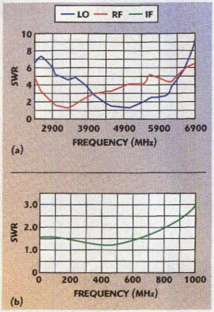
Blue Cell Technology,
a family member of Mini-Circuits
Brooklyn, NY



▲ *Fig. 1 The MBA-671 mixer's conversion loss at 30 MHz IF output.*



▲ *Fig. 2 The MBA-671 mixer's isolation at +7 dBm LO drive.*



▲ *Fig. 3 The MBA-671 mixer's SWR vs. frequency at +7 dBm LO drive; (a) RF and LO and (b) IF.*

TABLE I

MIXER SPECIFICATIONS

	MBA-591	MBA-671
Frequency range (MHz)		
LO/RF	2800 to 5900	2400 to 6700
IF	DC to 1000	DC to 1000
Average conversion loss at center band (dB)	6.5	6.5
LO-to-RF isolation (dB)	36 (typ), 20 (min)	36 (typ), 20 (min)
LO-to-IF isolation (dB)	26 (typ), 17 (min)	26 (typ), 17 (min)
IP3 at center of band (typ) (dBm)	10	10
Price (10 to 49 pieces) ($)	6.95	8.95

less than 6.5 dB from 2600 to 5000 MHz and increases to 8.2 dB at 6700 MHz. LO-to-RF isolation is typically greater than 30 dB across the entire range, while LO-to-IF isolation is typically greater than 22 dB. ***Figure 1*** shows the mixer's conversion loss with a 4, 7 and 10 dBm LO drive. ***Figure 2*** shows the port-to-port isolations at a 7 dBm LO drive. ***Figure 3*** shows the RF, LO and IF port SWRs. Performance is dependent on the quality of the printed ceramic substrate. High performance materials with ground vias placed less than an eighth-wavelength apart are employed. A recommended footprint is provided in the mixer data sheet and can be downloaded from the company's Web site at www.minicircuits.com in the online catalog. ***Table 1*** shows the mixer's specifications.

APPLICATIONS

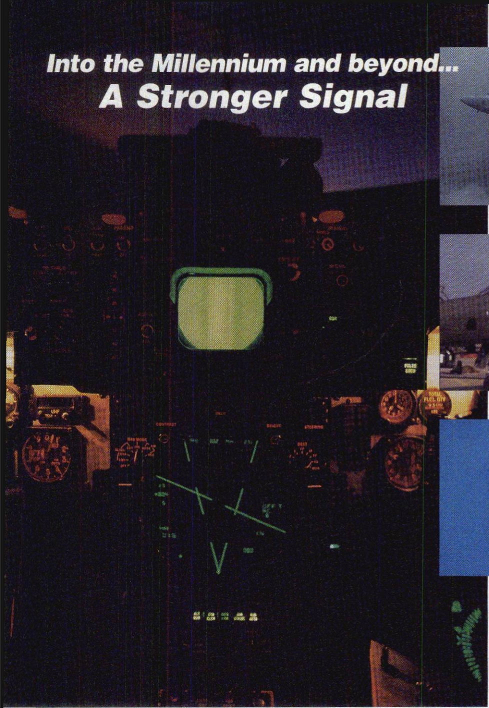
The mixer is a standard double-balanced design and can be used both as an upconvertor and a downconvertor. The IF is DC coupled so the mixer can be utilized for balanced modulator applications. The broad IF range allows the mixer to be used in satellite applications for multichannel communications. The low conversion loss results in lower noise figure. For applications requiring higher dynamic range, higher level mixers that improve IP3 performance are offered.

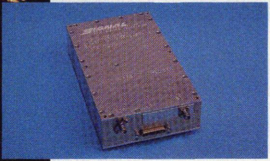
CONCLUSION

A new series of microwave high performance surface-mount mixers has been presented. These mixers are very low height and are suitable for Personal Computer Memory Card International Association computer card applications. The MBA-series products are designed for demanding low cost, high quality, high volume applications.

Blue Cell Technology,
a family member of Mini-Circuits,
Brooklyn, NY (718) 934-4500.

Circle No. 303





MODEL 6458 SYNTHESIZER

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- Fast Switching Speed
- Single Loop Design
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SIGNAL TECHNOLOGY CORPORATION

ARIZONA OPERATION • 340 N. ROOSEVELT AVENUE • CHANDLER, AZ 85226 • TEL. 480.940.1655 • FAX 480.961.6297

Klystron High Power Amplifiers for SATCOM Applications

A new family of C-band, Ku-band and direct broadcast satellite (DBS)-band compact GEN IV klystron power amplifiers (KPA) has been introduced. The new amplifiers incorporate a multistage depressed-collector (MSDC) klystron that allows for a smaller, more efficient and cooler running amplifier than other KPAs on the market. The unique design translates into lower power costs and longer lifetime for the klystron and other electronic components. In addition, a built-in power saver function provides even greater power savings. The new amplifier family comprises the C-band series, Astra series (13.25 GHz), K4U64 series (14.5 GHz) and K4D62/4 series (18.4 GHz).

KPA Description

The GEN IV series KPAs feature 2.4 kW of RF output power at the klystron, which is tunable over the 5.850 to 6.725, 12.75 to 13.25, 13.75 to 14.50 or 17.30 to 18.40 GHz frequency ranges, depending on the klystron used. Options exist for other frequency ranges as well. The amplifier's compact, two-drawer design provides state-of-the-art modularity for ease of use and maintainability.

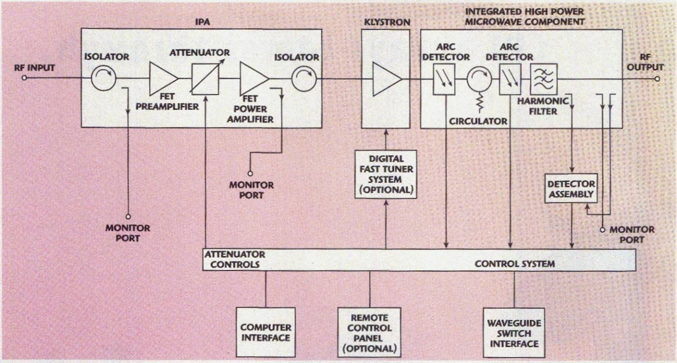
The GEN IV KPA's RF chain is housed in the RF drawer and comprises a solid-state integrated power amplifier (IPA), the MSDC klystron, a high power output isolator, and associated couplers and isolators. The klystron blower, front control panel and embedded controller also are contained in this drawer. A mechanical channel tuner mechanism permits the operator to change any of up to 24 preset frequencies. An optional channel selector (< 1 s per change) with remote controllability is also available.

The power supply drawer houses the AC input filtering, monitoring and high voltage power supply. This supply provides regulated beam, heater and collector voltages for the klystron. The GEN IV amplifier is adaptable to all primary three-phase voltages available worldwide. The KPA is protected from damage caused by AC/DC/RF faults and insufficient cooling, and will automatically recycle after a prime power interruption or transient fault.

The control panel contains a large color thin-film technology liquid crystal display (TFT-LCD) with a wide viewing angle, light-emitting diodes and a long-lasting membrane-style keypad. The controls directly interface with the earth station computer system; a remote control panel with identical functions and configuration is available as an option.

[Continued on page 162]

Communications & Power Industries (CPI),
Satcom Division
Palo Alto, CA



▲ *Fig. 1 The KPA's RF block diagram.*

THE RF CIRCUIT

Figure 1 shows the RF circuit block diagram. The low level input signal is applied through an isolator to the IPA, which includes a voltage-controlled PIN diode attenuator, input and output isolators, and directional couplers. The attenuator permits the operator to

[Continued on page 164]

TABLE I

KPA SPECIFICATIONS

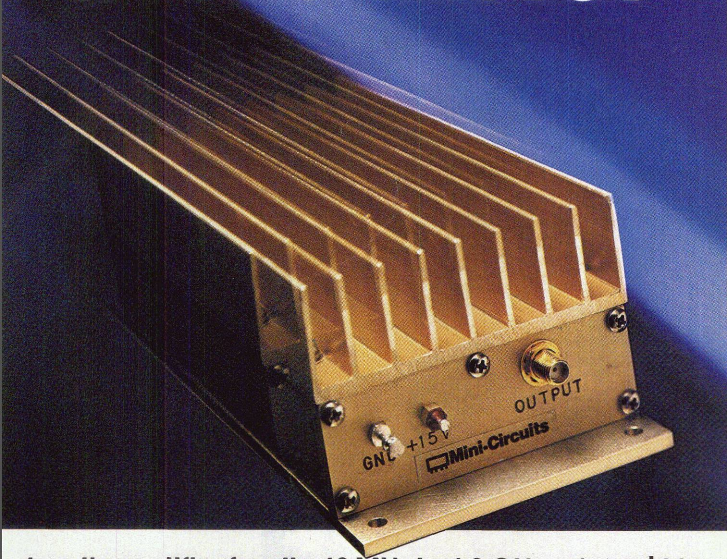
Frequency range (GHz)	5.850 to 6.725 6.700 to 7.025 13.75 to 14.50 12.75 to 13.25 17.30 to 18.10 17.30 to 18.40
Klystron rated power (min) (kW) C band Ku band Astra band DBS band	 3.35 2.4 2.2 2.4 (1.7 for 18.4 GHz)
Preset channels	up to 24
Gain (at rated output) (min) (dB) C, Ku and Astra band DBS band	 80 75
Power adjustability	0 to –23 dB (of output)
Input SWR (max)	1.20 (C, Ku, Astra) 1.25 (DBS)
Output SWR (typ)	1.25 (C, Ku) 1.30 (DBS)
Residual AM* (max) (dBc)	–50 up to 400 Hz –60, 400 Hz to 2 kHz –80, 2 kHz to 500 kHz
AM/PM conversion (max) (°/dB)	4 (at rated output)
Harmonic output (dBc) Ku and Astra band DBS band	 –80 (–35 without harmonic filter) –70 (–30 without harmonic filter)
Phase noise*	exceeds requirements of IESS-308/309 by 10 dB at 10 dB backoff; C band meets INMARSAT requirements
Intermodulation (dBc)	–28 with two equal carriers at total output
Primary power (47 to 63 Hz, three-phase with neutral and ground) (V AC)	208 380 to 415 480 200 w/o neutral (Japan)
Power consumption (max) (kW)	8 8.5 (C band)
Ambient temperature (°C)	–10 to +50 operating –40 to +80 nonoperating
RF input connection	Type N female (C, Ku, Astra) SMA type female (DBS)
RF output connection	CPR 137F flange (C) WR-75 grooved flange (Ku, Astra) WR-62 grooved flange (DBS)
Dimensions (w × h × d) (") RF drawer power supply drawer	 19 × 17.5 × 28, not including fans 19 × 8.75 × 24, not including fans

*Prime power AC line unbalance not to exceed three percent.

quickly adjust the RF drive level within a 25 dB linear range with a resolution of 0.1 dB. An internal memory function returns the amplifier to the previously set level in case of a power outage. The IPA also includes an RF inhibit function to remove the drive signal during faults, channel changes, transfer switch operations or external interlock actions. The IPA is transparent to most final amplifier parameters and is temperature compensated to minimize drift. As a result, the overall KPA gain is stable to within 1 dB over a 20°C temperature change and within 2.5 dB over the 0° to +50°C operating range. ***Table 1*** lists the KPA's specifications.

[Continued on page 166]

incredible!



1 watt amplifier family, 10 MHz to 4.2 GHz…from $895

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Using ultra-linear Class A design, these state-of-the-art amplifiers provide up to 40 dB, flat (±1.0dB), are unconditionally stable, include overvoltage protection, and can be connected to any load impedance without amplifier damage or oscilation.

One week delivery…and, of course, one year guarantee.

SPECIFICATIONS	ZHL-42	ZHL-4240	ZHL-42W	ZHL-W240W
Frequency, GHz	0.7 to 4.2	0.7 to 4.2	0.01 to 4.2	0.01 to 4.2
Gain, dB min.	30	40	30	40
Gain Flatness, dB	±1.0	±1.5	±1.5	±1.5
Power Out @ 1 dB CP, dBm min	+29	+29	+29*	+29*
VSWR in/Out, max.	2.5:1	2.5:1	2.5:1	2.5:1
Noise Figure, dB typ	10.0	4.0	8.0**	8.0**
Power Supply, V/ma	+15/690	+15/700	+15/750	+15/850
Third Order Intercept, dBm min.	38	38	38	38
Second Order Intercept, dBm min.	48	48	48	48
Size, in.	7 x 3¼ x 2⅛ h.	7 x 3¼ x 2⅛ h.	7 x 3¼ x 2⅛ h.	7 x 3¼ x 2⅛ h.
Price	**$895.00**	**$1395.00**	**$1095.00**	**$1495.00**

*+ 28 dBm, 10 MHz to 700 MHz, 3500 MHz to 4200 MHz

**Below 100 MHz increases to 15 dB at 10 MHz

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THE MSDC KLYSTRON

The klystrons used in the C-, Ku- and DBS-band GEN IV amplifiers incorporate an advanced design using MSPCs that deliver up to 2.4 kW (3.35 kW in C band) of output power across the specified frequency band. The instantaneous (–1 dB) bandwidth is 45 MHz (80 MHz optional) for C band, and 85 MHz (80 MHz for Astra) and 50 MHz (85 MHz optional up to 1.7 kW) in the Ku and DBS bands, respectively. A standard integral mechanical channel tuning mechanism provides precise tuning and retrieval of up to 24 channels and allows for manual frequency changing in the field. Preset frequencies are factory tuned in accordance with a standard frequency plan unless otherwise specified.

THE OUTPUT CIRCUIT

The output of the klystron is fed to the integrated output waveguide assembly, which comprises two arc detector ports, a circulator and loads, a harmonic filter and a three-port directional coupler. The optical arc sensor is attached to a waveguide bend that is located near the output of the klystron. If an arc occurs in the waveguide, the light is detected and the protection circuit rapidly turns off the IPA to inhibit the RF drive, thereby quenching the arc.

The high power isolator provides a low SWR source to the external waveguide and antenna feed and protects the klystron from excessive reflected power resulting from external faults. The isolator will continuously dissipate the reflected power from a 2:1 load (11 percent of the rated power), and safely withstands reflected power equal to the full rated KPA output until the protection circuits shut off the RF signal. The optionally removable harmonic filter attenuates the second harmonic to levels at least 80 dB below the fundamental output.

The output directional coupler includes two forward ports and one reflected port. One forward port provides an RF sample at a nominal –50 dBc. The second forward port and the reflected power port are connected through the detector assembly to the controller. The metering signals are also used to activate the high/low RF power alarm and the high reflected power fault-protection circuit. The standard output RF interface is CPR-137F (C band), WR-75 (Ku band) or WR-62 (DBS band) waveguide with a grooved flange.

THE POWER SUPPLY ASSEMBLY

The AC input power is routed through an EMI filter and main circuit breaker and passes through the step start circuit that is used to limit in-rush current to < 180 percent of steady state during high voltage turn on. The AC power is then converted to DC and passed to the power processor, which converts the DC voltage to a 50 kHz AC voltage that is applied to the high voltage transformer and rectifier. The rectified output is filtered and provides the cathode, heater and collector voltages for the klystron. Samples of the cathode and heater voltages are fed to the power processor as part of the regulation scheme. The embedded control system monitors cathode

[Continued on page 168]

The Cable Assembly Standard for Connecting a Wireless World

QMI's proven **LOW LOSS "301"** assembly, ends the 3-way compromise users face when defining insertion loss for higher frequency, with flexible cable assemblies. Historically, low loss meant high price or reduced flexibility. **"301"** cable is a microporous PTFE design in .200" diameter that offers all three advantages: Low Loss, Low Price and Excellent Flexibility.

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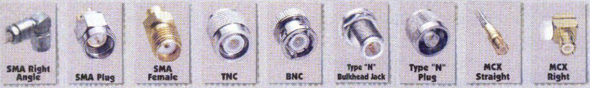
- Transmit/ Receive Systems
- Performance Upgrades
- Cost Reduction
- Replacement for Semi-Rigid

"301" LOW LOSS assemblies help the designer achieve system performance goals while retaining the flexibility of braided cables. Alternatively, **"301"** cables may be used to replace .141" diameter semi-rigid or .250" diameter corrugated copper cables. And for those test applications that require low loss measurement, try our new **Low Loss Workhorse Test Cables.**



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voltage, beam current, body current, heater voltage and heater current.

The cathode and heater voltages are microprocessor controlled and set for the particular klystron. The power saver function uses this flexibility to set the beam voltage when less than rated RF power is required. In addition, the klystron heater voltage is set accordingly to extend the klystron's life. A standby mode is available to allow extended klystron life when the amplifier is not used for long periods of time but is required to be available at a moment's notice.

MONITORS AND CONTROLS

The control and monitor system is designed to assure correct amplifier operation and easy maintenance with minimal operator training and activity. A system of embedded controllers provides automatic sequencing and continuous monitoring of critical parameters. All operational information is clearly displayed on the large color TFT-LCD panel. The membrane keypad provides convenient control from the front panel.

Upon power on, the embedded controller self-tests the internal functions and begins heater warm-up. Once warm-up is complete, the transmit key initiates normal operation. Automatic leveling then can be keyed to maintain a set power output level against RF input variations. The amplifier's fault handling circuit is tolerant of transient faults, returning the amplifier to the state it was in when the fault occurred (if appropriate). In the event of a fault warranting a permanent shutdown, the fault will be clearly displayed with time and date stamps. The fault then must be cleared and the cancel key depressed in order to reset the amplifier. The standard KPA permits computer control and monitoring through an RS-422/485 (four-wire) serial data bus. This capability provides the operator with a convenient and reliable means to monitor and control the power amplifiers at a remote, unattended earth station.

MECHANICAL DESIGN

The GEN IV KPA is packaged in two sturdy aluminum enclosures that offer convenient front access for service and maintenance. Both power supply and RF boxes are designed to be mounted in standard 19-inch racks using chassis slides. Within the RF box the klystron, RF components and RF control parts are mounted on a slide-out drawer.

Measuring 26.25" high (15 RU), the KPA is designed for space-constrained locations. All electrical interface connections and exhaust ducting for the klystron cooling air are located at the rear of the unit. Nearly all maintenance activities can be accomplished from the front of the equipment. Two independent cooling circuits are used in the KPA, one for the klystron collector and one for the power supply.

OPTIONS AND ACCESSORIES

Among the available options and accessories are a digital fast-tuning system that provides an automatic channel selector comprising a motor drive and control unit as an integral part of the klystron. This motorized electronic channel changer achieves a maximum 1 s channel changing time. In addition, a peak power meter is available for use when the KPA is used in a TDMA system. The circuit responds to burst signals of 5 µs (min) pulse width and a maximum repetition of 100 ms. With this option the meter reads either peak or CW power in accordance with the signal being transmitted.

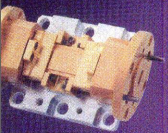
A remote control panel is available that duplicates all of the controls and indicators of the main panel and communicates with the KPA via the serial interface. Also available is a 1:1 switching subsystem that comprises an output waveguide switch and dummy load. The circuit provides 1:1 redundant protection with automatic transfer or manual operation. A power phase combiner consisting of a coaxial input divider network, phase shifter and output waveguide combining system provides four operating modes when two KPAs are used in combination. A linearizer is also available that provides an improvement in AM/PM, third-order intermodulation spectral regrowth and noise power ration performance.

CPI, Satcom Division,
Palo Alto, CA (650) 846-3700.

Circle No. 301

MILLIMETER WAVE COMPONENTS

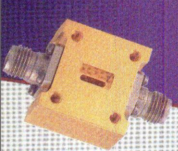
AMPLIFIERS • MIXERS • MULTIPLIERS



AMPLIFIERS

Model Number	Frequency (GHz)	Gain (dB, Min.)	Gain Flatness (±dB, Max.)	Noise Figure (dB, Max.)	I/O VSWR (Max.)	Output Power at 1dB Comp.* (dBm, Typ.)
JSW4-18002600-18-5A	18-26	28	1.0	1.8	2.0:1/2.0:1	5
JSW4-26004000-25-5A	26-40	25	2.5	2.5	2.0:1/2.0:1	5
JSW4-18004000-32-8A	18-40	21	2.0	3.2	2.0:1/2.5:1	8
JSW4-30005000-45-5A	30-50	21	2.5	4.5	2.5:1/2.5:1	5
JSW4-40006000-65-0A	40-60	16	2.5	6.5	2.5:1/2.5:1	0

* Higher output power options available



MIXER/CONVERTER PRODUCTS

Model Number	Frequency (GHz)			Conversion Gain/Loss (dB, Typ.)	Noise Figure (dB, Typ.)	Image Rejection (dB, Typ.)	LO-RF Isolation (dB, Typ.)
	RF	LO	IF				
LNB-1826-30	18-26	Internal	2-10	42	2.5	20	45
LNB-2640-40	26-40	Internal	2-16	42	3.5	20	45
ARE3436LC1	34-36	15.5-16.5	2.7-3.3	25	4	20	60
SBW3337LG2	33-37	33-37	DC-4	-7.5	8	N/A	25
TB0440LW1	4-40	4-42	.5-20	-10	10.5	N/A	20
DB0440LW1	4-40	4-40	DC-2	-9	9.5	N/A	25
SBE0440LW1	4-40	2-20	DC-1.5	-10	10.5	N/A	20

MULTIPLIERS

Model Number	Frequency (GHz)		Input Level (dBm, min.)	Output Power* (dBm, min.)	Fundamental Feed Through Level (dBc, min.)	DC current @+15VDC (mA, nom.)
	Input	Output				
MAX2M260400	13-20	26-40	10	12	18	160
MAX2M200380	10-19	20-38	6	14	18	200
MAX2M300500	15-25	30-50	10	8	18	160
MAX4M400480	10-12	40-48	10	8	18	250
MAX3M300300	10	30	10	10	60	160
MAX2M360500	18-25	36-50	10	8	18	160
MAX2M200400	10-20	20-40	10	10	18	160
TD0040LA2	2-20	4-40	10	-3	30	N/A

* Higher output power options available

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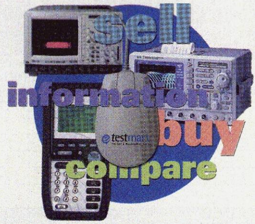
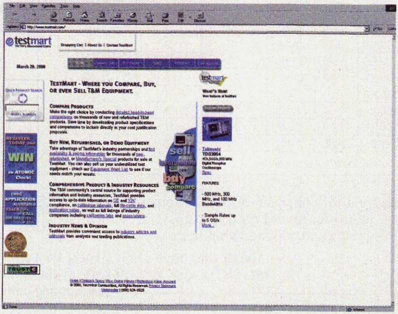
CIRCLE 113 ON READER SERVICE CARD



A WEB-BASED TEST EQUIPMENT LOCATOR

One of the most frustrating jobs an engineer must face is selecting and locating a piece of test equipment to meet a specific demand among the myriad of offerings by hundreds of equipment manufacturers and the many varying performance specifications. It was inevitable that the now ubiquitous World Wide Web would ultimately provide the solution to this time-consuming problem. TestMart™ is a unique new online service that lists more than 13,000 products from 200 manufacturers in more than 90 categories of test equipment and provides a means for side-by-side comparison of their performance specifications, price and availability. The user can now use this information to determine whether to buy, rent or lease new, used or refurbished equipment in an extraordinarily efficient manner.

Fig. 1 The TestMart home page.



The TestMart site, shown in ***Figure 1***, provides answers in seconds to questions that previously required hours or even days to research. In addition, the service offers application assistance from experienced engineers to answer many of the user's questions. When the decision is made to acquire the sought-after equipment, the site provides information on which manufacturers make which equipment in side-by-side views and what price trade-offs are available. It

[Continued on page 172]

TESTMART
San Bruno, CA

BIAS TEES

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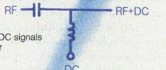

Easily combines RF+DC signals for your modulation or test requirements.

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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

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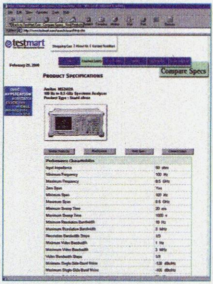


▲ *Fig. 2 Results of a product search.*

▲ *Fig. 3 A product comparison.*

▲ *Fig. 4 A list of calibration laboratories.*

even allows the user to purchase the item online in many cases.

Obviously, this type of universal database is only as good as the data it contains. TestMart maintains an unbiased site for all equipment manufacturers. (TestMart covers the cost of maintaining the site by negotiating agreements with various manufacturers that allow the site to maintain neutrality. These agreements may include commissions, acting as a virtual distributor or warehousing some TestMart-owned stock. However, the cost is never passed on to the buyer.) The buyer is offered free membership and registration is not required until he or she makes the acquisition. Once membership has been established the user has the ability to search the data at will, request additional literature and quotes from listed manufacturers and even purchase online from participating suppliers. In many cases direct links are provided to the manufacturer's own Web site.

Maintaining such a comprehensive database is a daunting task. The database is constantly updated and expanded as new participating companies sign on and new data become available. Information is provided on products from all manufacturers whether or not they have chosen to affiliate. Powerful search engines enable the user to access all sources in the database and locate products that meet his or her specifications quickly. ***Figure 2*** shows the results of a search for a particular type of spectrum analyzer. Detailed specifications are presented in a normalized format, providing for clear and complete side-by-side comparisons. ***Figure 3*** shows a typical product comparison for a series of power meters.

All data are contained within the site, thus eliminating the time-consuming process of gathering and piecing together incomplete information in dissimilar formats from multiple sources. In addition, users can perform parametric searches specific to each product category. The CompareSpecs feature presents side-by-side product comparisons. TestMart's proprietary Similar Products search function, FindLike, retrieves products that are engineering equivalents based on key technical parameters. The BuyOnLine function offers online shopping with secure transaction processing and order confirmation for new, demo and refurbished equipment. TestMart also acts as a distributor and sales representative for many manufacturers of new products and maintains a large inventory of refurbished test equipment. Customers can trade in or sell their unused equipment using TestMart's Sell Online function. The TestMart Equipment Want List guarantees customers a market price online in real time.

One of the added features of the site is the Active Partnership Program, which makes available full-text articles from leading publishers and industry analysts. In addition, exclusive test and measurement market reports from Frost & Sullivan appear on the site. The Web site also features comprehensive reference tools, including calibration interval information and product introduction and out-of-support dates for more than 10,000 test products. The Industry Directory provides information on more than 500 manufacturers while the Calibration Labs Directory, shown in ***Figure 4***, lists more than 1600 calibration laboratories worldwide. A searchable library of hundreds of application notes from major manufacturers is also available online. Finally, the Glossary contains thousands of definitions and acronyms.

In short, the TestMart Web site should be the first stop for anyone trying to select the proper piece of equipment from a long list of available choices or locate information pertaining to a specific piece of test equipment, its specifications, use, price and delivery. For test equipment manufacturers and vendors TestMart provides equal access to an efficient, neutral marketplace for their products that can augment their existing marketing efforts and Web initiatives. Using TestMart, manufacturers can increase their exposure while avoiding the costs traditionally associated with selling their products through direct means and through manufacturers' representatives.

TestMart is located on the Web at www.testmart.com and is offered free of charge for interested users. Locating and selecting test equipment have never been easier.

TestMart,
San Bruno, CA (650) 624-0525.

Circle No. 305

NEW PRODUCTS

COMPONENTS

■ Chip on Board IC Control Switch

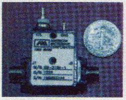
The model ASOO6M2-93 single-pole, double-throw switch is manufactured in small packages for greater freedom in layout and circuit design and features reduced parasitics, enabling the same package to be used for applications from DC to 6 GHz without degradation in performance. The switch offers higher isolation performance than traditional multiple plastic-packaged devices. Typical applications include low frequency, broadband test equipment, 5 to 6 GHz wireless data radios, electronic toll collection and wireless local loop systems operating above 2 GHz. Prices: start at $5.75 (1000). (Prices vary depending on product and quantity.)

Alpha Industries,
Woburn, MA (800) 290-7200, ext. 306
or (508) 894-1904.

Circle No. 215

■ Miniature PIN Diode Switch

The model SW-2184-1 single-pole, single-throw driverless, reflective PIN diode switch operates over the 300 MHz to 20 GHz frequency range. At a bias voltage of –10 V, maximum insertion loss varies between 1.0 dB below 1 GHz and 2.5 dB at 20 GHz. At a bias current of +35 mA, minimum isolation varies between 45 dB below 1 GHz, 85 dB at 10 GHz and 70 dB at 20 GHz. The switch provides fast switching delay of 10 ns and SWR is 2.1 (max). Size: 0.79" × 0.88" × 0.48". Weight: 1.1 oz.

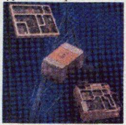


American Microwave Corp.,
Frederick, MD (301) 662-4700.

Circle No. 216

■ Ultra-low ESR Microwave Capacitors

The 6000 series microwave capacitors offer a typical low equivalent series resistance (ESR) of 80 mΩ at 1 GHz with capacitance values ranging from 0.1 to 100 pF. Designed for cellular base station equipment, high Q frequency source and broadband wireless service applications, the NPO capacitor supports requirements where low loss and high performance are critical. Packaged in a 0603 case size, the capacitors are designed to meet and exceed requirements of EIA-198, MIL-C-55681 and MIL-C-123. All units are available laser marked and in tape-and-reel. Delivery: stock.



American Technical Ceramics (ATC),
Huntington Station, NY (613) 622-4700.

Circle No. 217

■ 869 – 894 MHz Circulator

The model BU122 circulator for multicarrier power amplifiers operates over the 869 to 894 MHz frequency range. The circulator provides –75 dBc (min) of intermodulation distortion performance at eight tones at 120 W average power level. Isolation is 23 dB (min), insertion loss is < 0.2 dB and SWR is 1.15 (max). Other power levels and frequency ranges also are available.

Channel Microwave Corp.,
Camarillo, CA (805) 482-7280.

Circle No. 218

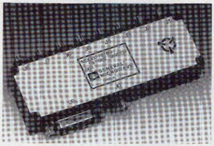
■ Miniature High Power Coaxial Remote Terminations

The model 12-5021 miniature high power coaxial remote terminations are designed specifically for applications where high power terminations are required to be remotely located and connected to an RF system via a coaxial cable. The terminations feature integral cable inputs and are well suited for isolator, coupler and dummy load applications. Average power handling is 150 W CW and operating temperature range is –55° to +100°C (full power). The units decrease the number of interconnections in systems at reduced costs over a discrete cable and termination approach. Coaxial cable lengths from 1" to 100" are available.

Florida RF Labs Inc.,
Stuart, FL (800) 544-5594
or (561) 286-9300.

Circle No. 219

■ SP8T PIN Diode Switch



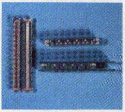
The F9180 series low cost, broadband SP8T PIN diode switches operate over the 1 to 18 GHz frequency range with a ±5 or +5 V DC and –12 to –15 V DC power supply. For the reflective design, insertion loss varies from 60 dB at 1 GHz to 50 dB at 18 GHz and corresponding values for the nonreflective designs are 2.0 and 4.2 dB, respectively. Isolation varies from 60 dB at 1 GHz to 50 dB at 18 GHz and SWR limit ranges from 1.7 to 2.0 depending on frequency. Switching speed is less than 200 ns and operating temperature range is –55° to +110°C withstanding power levels as high as 75 W (pk). Individual port TTL logic control and power supply connections are made by means of a DA15P connector. Size: 4.65" × 1.50" × 0.75". Weight: 8.5 oz.

General Microwave Corp.,
Farmingdale, NY (631) 630-2000.

Circle No. 220

■ Parallel Board-to-board SMT Connectors

The FX10 series parallel board-to-board surface-mounted connectors offer increased transmission speeds at only 4 to 5 mm between boards via ground plenums on both mating assemblies. Ground stability is achieved with direct connection of the ground plenums to the board; signal contacts are 0.5 mm spacing with ground plenum contacts every 10 contact positions. (Additional stability is provided with board solder brackets.) Ground plenums and contacts have effective wipe lengths of 1 mm/min, thereby assuring a reliable interconnection. Designed specifically for portable and miniature electronic applications, the connectors are available in a variety of contact positions (with or without positioning posts) and sizes of 80, 100, 120 and 140. Price: $2.42 (100-position OEM lots). Delivery: six to eight weeks.

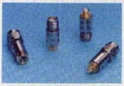


Hirose Electric (USA) Inc.,
Simi Valley, CA (805) 522-7958.

Circle No. 221

■ Between Series Adapters

The GPO™/SMA between series adapters provide a convenient and efficient transition between two popular connector designs. The GPO is a popular push-on connection method where harsh mechanical environments of shock and vibration exist. The models 5190 through 5193 provide a maximum SWR of 1.20 from DC to 18 GHz.



Inmet Corp.,
Ann Arbor, MI (888) 244-6638.

Circle No. 222

■ DCS Fullband Duplexer

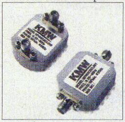
The model WSD-00064 high performance, digital communication system (DCS) fullband duplexer is configured with a receive passband of 1710 to 1785 MHz and a transmit passband of 1805 to 1880 MHz. Insertion loss within the passband is 1.3 dB (max) and passband return loss is 15 dB (min). Antenna to receive rejection is 60 dB (min) from DC to 1620 MHz, 25 dB (min) from 1620 to 1690 MHz, 85 dB (min) from 1805 to 1880 MHz, 45 dB (min) from 1880 to 3800 MHz and 30 dB (min) from 3800 to 12,750 MHz. Transmit to antenna rejection is 85 dB (min) from DC to 1780 MHz, 60 dB (min) from 1970 to 3800 MHz and 30 dB (min) from 3800 to 12,750 MHz. Passband to passband isolation is 8 dB. The unit is well suited for macro or micro DCS base stations, repeaters and systems, or handset DCS test system applications. Operating temperature range is –20° to +70°C. Connectors are DIN 7/16 female at the antenna port and N-F at the receive/transmit ports. Size: 8.36" × 5.75" × 1.77", excluding connectors.

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

Circle No. 223

Contactless Phase Shifter

The models KPH900SCL000 and KPH900-SCL001 contactless phase shifters (CPS) cover



frequency ranges up to 3 GHz and provide 90° of minimum incremental phase shifting at 2 GHz and maximum electrical delay of 125 picoseconds. Insertion loss is 0.15 dB at 1 GHz, 0.25 dB at 2 GHz and 0.35 dB at 3 GHz and SWR is 1.25. The model KPH200SCL000 drop-in type CPS provides 30° of minimum incremental phase shifting at 2 GHz and maximum electrical delay of 41.7 picoseconds. The phase shifters reduce time and complexity in production, making them well suited for applications that require phased signals.

KMW Inc., Cerritos, CA (562) 926-2033.

Circle No. 224

Drop-in Isolators and Circulators

The model DNF1900-T0038A miniaturized isolator operates over the 935 to 960 MHz fre-

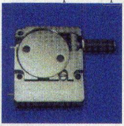
quency band and minimizes printed circuit board space, lowering the overall cost of cellular base stations. (Miniaturized circulators also are available.) Available in either surface-mount (gull wing) or drop-in configurations, the units offer isolation of 23 dB, insertion loss of 0.4 dB and SWR of 1.15. The units are housed in 0.750-inch packages without jeopardizing performance, as compared to the standard one-inch packages. Operating temperature range is –40° to +85° with processing temperatures up to 235°. Delivery: stock to 30 days.

Mica Microwave Corp., San Jose, CA (408) 363-9200.

Circle No. 226

Drop-in Isolator

The model DSW1042-A drop-in isolator for base station power amplifier applications is



available in PCS 1900, DCS 1800, EDSM, AMPS and UMPTS frequencies. The isolator offers good performance specifications and includes integrated termination, reverse power detector with TTL output compatibility and high torque SMA connectors. The DSW1042-A is factory-configurable to meet custom specifications.

TRAK Communications Ltd., a TRAK Communications company, Dundee, Scotland +44 (0) 1382 833 411.

Circle No. 263

High Performance Cable Assemblies

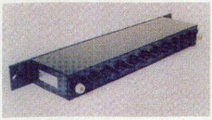
These high performance, semi-rigid, preformed build-to-print cable assemblies maintain electric parameters, including SWR of < 1.25 to 18 GHz. Phase and amplitude matching are available. The company offers competitively priced products as well as a large connector inventory, reducing lead times.

RFCircuits Inc., Hatboro, PA (215) 675-8003.

Circle No. 266

NEW PRODUCTS

AMPS Band Transmit Filter



The model AFB-21A-8689-01 AMPS band transmit filter provides highly selective receive band filtering while delivering more than 75 dB of isolation in the 824 to 849 receive band. Passband insertion loss is 1.0 dB (max) and 0.7 dB (typ). Designed to pass through the full 869 to 892 MHz AMPS transmit band, the filter has power ratings of 500 W CW, 10 kW (pk) with multicarrier power capabilities of 20 carriers at 25 W each. Type-N connectors are standard, and 7/16 DIN connectors are available as an option.

Narda Microwave-West,
a division of L-3 Communications,
Folsom, CA
(916) 351-4500.

Circle No. 231

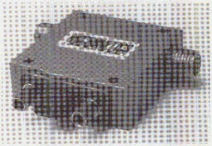
High Power Reactive Signal Sampler

The model HX-10N 500 W sampler-detector consists of a low loss coaxial transmission line to which a reactive probe is loosely coupled. A small portion of the RF energy in the main line is coupled by the probe loop to the auxiliary output via a detector diode. The coupling between the probe and the main line is continuously adjustable and can be locked at any convenient position. A common application is to connect the sampler-detector to the load port of the transmit isolator. When reflected power exceeds a predetermined level, the pre-set detected output will sound the alarm.

Microlab/FXR,
Livingston, NJ (973) 992-7700.

Circle No. 227

1.0 - 18 GHz SPST Nonreflective Switch



This broadband 1.0 to 18 GHz SPST nonreflective switch features –60 dBm in band video transients, a 9-PIN mini D connector and two nonreflective ports with 1 W of hot switching. Switching speed is 30 ns and voltage supply is +5 V at 90 mA and –15 V at 70 mA. Isolation is 60 dB and insertion loss is 3.5 dB. The switch is best suited as a pulse modulator for test equipment, a robust bench-top switch for automatic testing equipment or a high linearity switch for electronic warfare applications. Size: 1.10" × 1.10" × 0.42".

Micronetics Wireless Inc.,
Hudson, NH (603) 883-2900.

Circle No. 228

Channel Filter Assembly

The Merrimac 14 channel filter assembly operates over the 2.53 to 5.26 GHz frequency range and contains 14 seven-pole, stripline Chebyshev hairpin resonator filters. Phase match between odd and even filters is ±45° at ±50 MHz crossover points with a power supply of 1.0 W. Input/output return loss is 10 dB (min) and input/output impedance is 50 Ω (nom). Operating temperature range is –65° to +125°. Size: 1.50" × 2.90 × 0.13".

Merrimac Industries Inc.,
West Caldwell, NJ (888) 434-6636.

Circle No. 225

Single-channel ENG Bandpass Filter

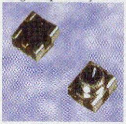
The model 12861 single-channel electronic news gathering (ENG) bandpass filter operates over the 1990 to 2110 MHz frequency range and has an 8 MHz bandwidth, providing less than 3.5 dB of insertion loss at center frequency. The unit offers greater than 25 dB of rejection at ±7 MHz from center frequency, thereby providing selectivity to remove undesired or interfering frequencies. (For greater out-of-band frequencies, the unit offers either 8 or 16 MHz bandwidths and additional sections.) Designed for indoor applications, the unit also can be modified for outdoor use. Connectors are 50 Ω type-N female, but other connectors are available upon request.

Microwave Filter Company Inc. (MFC), East Syracuse, NY (800) 448-1666 or (315) 438-4747.

Circle No. 229

Ultraminiature Switch Connector

This ultraminiature SWD switch connector is designed specifically for use in testing wireless equipment and operates in the licensed or unlicensed DC to 6 GHz frequency bands. The switch connector employs an ultraminiature, surface-mountable receptacle with integrated mechanical switching functions and a choice of test probes, making it well suited for use in troubleshooting RF circuits or performing automated system checks in a high speed process in factories. Insertion loss is 0.1 dB (max) without adapter. Available on tape-and-reel, the unit offers the capability of easy measurement of radio board characteristics from outside of the portable device's case. Price: 45¢ to 55¢ in moderate quantities (10,000 to 25,000).

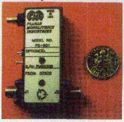


Murata Electronics North America Inc. (MENA), Smyrna, GA (770) 433-5782.

Circle No. 230

Biphase Modulator/Shifter

The model PS-90-0612 miniature, single-balanced biphase modulator/shifter provides ±90° or 180° of phase shifting (±10) over the 6 to 12 GHz frequency range. (Double-balanced options also are available.) Other frequencies from 2 to 18 GHz are available in octave bandwidths. Insertion loss is 2.5 dB and SWR is 2.0 (typ). The biphase modulator/shifter operates from +5 V DC at +75 mA and –5 V DC at –20 mA (max), and offers rise and fall times of 20 ns and 10 ns, respectively, and 60 ns delay on and 45 ns delay off. (High speed 25 ns units also are available.) Output logic is TTL, but ECL also is available. Size: 2.00" × 0.79" × 0.54".



Planar Monolithics Industries Inc. (PMI), Frederick, MD (301) 662-4700.

Circle No. 232

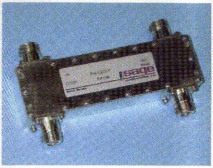
Microwave Assembly

The model MP4269 switch filter bank integrates seven switched bandpass filters that operate over the input frequency range of 0.45 to 20.1 GHz and a passband range of 0.45 to 8.05 GHz. Passband insertion loss is 5.5 dB (max), passband-to-passband variation is 1.5 dB (max) and differential group delay is 10 ns. Channel-to-channel isolation is 60 dB (min), SWR (at all ports) is 1.8 and input third-order intercept is +30 dBm (min). Logic is CMOS compatible. Operating temperature range is 0° to 70°C with power supply voltages of +5 or –15 V. Size: 5.00" × 4.00"× 0.50", excluding SMA field-replaceable connectors.

Robinson Laboratories Inc., Nashua, NH (603) 880-7880.

Circle No. 233

Dual-band Quadrature Hybrid



The model FH6370-1 dual-band quadrature hybrid handles 200 W CW of power while operating over the 800 to 2400 MHz frequency

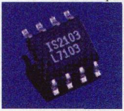
NEW PRODUCTS

range. Insertion loss is 0.2 dB (typ), SWR is 1.22 (max) and isolation is 20 dB (min). Typical applications for the quadrature hybrid include antenna feeds and amplifier combining in telecommunication base stations. Type-N female connectors are standard, but alternate connector requirements are available upon request. Size: 5.60" × 1.50" × 1.00".
Sage Laboratories Inc.,
Natick, MA
(508) 653-0844.

Circle No. 234

DC - 3 GHz GaAs SPDT Switch

The model IS-2103 GaAs SPDT switch covers the DC to 3.0 GHz frequency range with isolation of 50 dB.



Switching speed is 2 ns, insertion loss is 0.7 dB and typical third-order intercept is +49 dBm. The switch is well suited for next-generation applications where package size and performance are critical. Housed in a SOIC-8 plastic surface-mount package, the unit is available on tape-and-reel for automated assembly. Price: $1.48 (1000–2499).
Signal Technology Corp.,
Olektron Operation,
Beverly, MA (978) 524-7444.

Circle No. 235

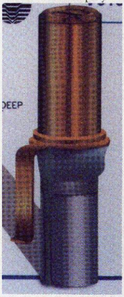
Connector and Ground Kit Attachment

The LMR® flexible coaxial cables now include prep (strip) tools, which simplify preparation of the cable end for connector attachment by easily removing the cable jacket and exposing the center conductor to the exact dimensions required; deburring tools, which remove burrs or sharp edges remaining on the end of the center conductor; heavy duty precision crimp tools and interchangeable dies for years of reliable service; and midspan strip tools, which prepare the cable for attaching the ground kit by carefully removing the outer polyethylene jacket without damaging the underlying shield. The LMR cables are well suited for use as antenna feeders, system jumpers and interconnects.
Times Microwave Systems,
Wallingford, CT (203) 949-8489.

Circle No. 236

Precision Trimmer Capacitors

The model V6152 sapphire dielectric has been added to the company's line of dual-tracking



precision trimmer capacitors to work in the gigahertz range. The tuning screw of the split-stator style adjusts two capacitors at the same rate, and the capacitors have one common terminal. The V6152 measures 0.48" long, tunes from 0.5 to 3.5 pF and can be used over 2 GHz. At 250 MHz, Q is over 1500. The unit also can be used fine-tuned with more than 10 full turns. Price: $16 (1000). Delivery: four weeks.
Voltronics Corp.,
Denville, NJ (973) 586-8585.

Circle No. 238

Miniature 75 Ω SMB Edge-mount PCB Connectors

These 75 Ω SMB matched-impedance connectors feature an air-dielectric interface that allows the envelope dimensions to conform to the miniature size of MIL-PRF-39012 SMB series connectors. The convenient snap-on mating and small size make them ideal for use

in applications requiring dense packaging. The connectors fit on the edge of a PCB up to 0.062"" thick and are soldered directly to the board circuitry without drilling. The connectors also can replace more expensive conventional right-angle types, and are constructed with brass bodies and contacts and Teflon insulators. All metal parts are gold plated to meet MIL-PRF-39012 requirements.
Applied Engineering Products (AEP), New Haven, CT (203) 776-2813.
Circle No. 270

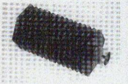
RF Coaxial Panel Jack

The model 7-16 EL RF coaxial panel jack features a connector body that measures 1.25-inches from the flange to easily attach cables and a large center conductor access hole to simplify soldering. Available for 0.141-inch and 0.250-inch semi-rigid cable, the panel jack has a direct solder inner and outer center conductor with a solid outer ring. The panel jack is manufactured with silver-plated or Tru-Lustre™ tri-metal brass bodies, silver-plated beryllium copper female contacts, and silver- or gold-plated brass male contacts. Designed specifically for cellular base station antenna, telecommunication and related equipment applications, the 7-16 EL offers –155 dBc typical intermodulation and is rated up to 2700 V rms with 50 Ω impedance. Price: $12.95 (1000).

Tru-Connector Corp., Peabody, MA (978) 532-0775.
Circle No. 237

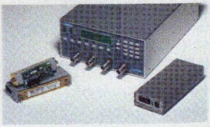
Low Intermodulation 50 W Load

The model 50-T-FN 50 W load offers low intermodulation for cellular and PCS applications. Typical intermodulation for the cellular band is –116 dBc when tested at +43 dBm; typical intermodulation for the PCS band is –121 dBc when tested at +43 dBm. The load has a frequency range of DC to 4 GHz with SWRs of 1.10 (DC to 1 GHz) and 1.25 (DC to 4 GHz). Connector options are BNC, IEC 7/16, N type and TNC.



BCP, Largo, FL (727) 547-8826.
Circle No. 271

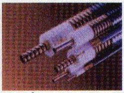
Programmable Attenuators and Interfaces



The model 8210A SmartStep™ interface provides a flexible, low cost solution for the control and operation of electromechanical switches and programmable step attenuators using standard communications interfaces. The 8210A is designed specifically to interface with SmartStep programmable attenuators, providing a high level interface from various industry standard communications interfaces, including IEEE-488 and RS232/RS422/RS485. The SmartStep technology streamlines system design and device integration by providing a flexible bus interface as well as components that are simple to configure and control.
Weinschel Corp., Frederick, MD (800) 638-2048 or (301) 846-9222.
Circle No. 239

Improved Cables

HELIAX® cables now provide enhanced electrical performance due to improvements in the closed cell foam dielectric design and refinements and advances in the company's cable manufacturing process. For example, at 894 MHz, HELIAX LDF7-50A (1-5/8") cable now has 0.71 dB/100 feet attenuation, a 0.6 dB improvement. At 2 GHz, the cable offers 1.17 dB/100 feet attenuation, a 0.08 dB improvement.

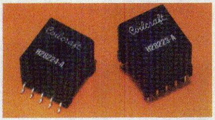


Andrew Corp., Orland Park, IL (800) 255-1479.
Circle No. 269

[Continued on page 181]

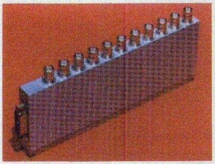
NEW PRODUCTS

High Performance Transformers



These HDSL2 transformers are optimized for level one SK70740/-41/-42 and other HDSL2 transceiver chip sets. The model H27650-A and surface-mount model H27695-A transformers are among the smallest available with a footprint of 0.650" × 0.675" × 0.350" (16.5 × 17.2 × 8.0 mm). The company's HDSL2 magnetics are engineered for minimum DC resistance (1.5 to 5 Ω) and very low leakage inductance (15 μH, typ). Primary inductance with and without bias is stable from –40° to +85°C. Return loss is 13 to 15 dB at 320 kHz and typical longitudinal balance at 40 kHz is rated at 65 dB. All parts are designed to meet UL 1459 and UL1950 requirements. Price: $1.80 (10,000). Delivery: stock.
Coilcraft, Cary, IL (847) 639-6400.
Circle No. 272

Coaxial Relay



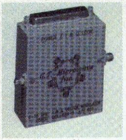
The model 76A00 coaxial relay incorporates a built-in RF or video amplifier that is convenient when assembling nonblocking matrices or when a gain block is needed in conjunction with a coaxial relay. The module is self-terminating, allowing it to mate with power splitters (which always need to be terminated). In addition, the unit can be used independently or incorporated in the company's model 11600 controller chassis, which provides RS-232, RS-422, IEEE-488 and keypad control. The relay's frequency response of DC up to 800 MHz makes it ideal for switching wideband RF/IF or fast rise video/pulse signals.
Matrix Systems,
Calabassas, CA (818) 222-2301.
Circle No. 275

Low Loss, High Linearity MOSFET Quad Mixer

The model PE4120 high linearity MOSFET quad mixer is a passive broadband device that performs functions ranging from frequency conversion to phase detection at up to 2.5 GHz. A conversion loss of only 6 dB across its entire operating frequency range of 500 MHz to 2.5 GHz makes the unit ideal for such applications as cellular/PCS telephone network base stations and cable modems. The device mixes a received RF signal without the output of a LO to produce an IF. Similarly, it mixes IF and LO signals to produce an RF output. Power loss during the conversion process is only 6 dB at any frequency, with a 20 dBm LO drive. Linearity is 36 dB and LO-RF isolation is 34 dB over the temperature range of –40° to +85°C. Price: $1.00 (10,000).
Peregrine Semiconductor Corp.,
San Diego, CA (858) 455-0660.
Circle No. 278

6 - 18 GHz I & Q Vector Modulator

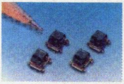
The model M2L-68N-5 360°/20 dB PIN diode I & Q vector modulator operates from 6 to 18 GHz and offers simultaneous phase and amplitude control. Total phase error access across the entire band is < ±10° and amplitude error is < ±1.5 dB. SWR is better than 2 and insertion loss is < 12 dB. The device demonstrates a linear control input slope with output voltage and is packaged to form, fit and function as an industry-recognized standard. With monotonic performance, the device is digitally controlled via two sets (I & Q) of 12-bit, TTL-compatible, binary logic inputs and



NEW PRODUCTS

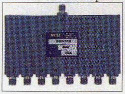
the switching speed is < 500 ns. A device with a frequency range of 2 to 18 GHz is also available.
G.T. Microwave Inc., Randolph, NJ (973) 361-5700.
Circle No. 273

■ Low Cost SMT Directional Couplers



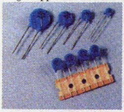
The GLSN series surface-mount directional couplers provide a selection of coupling values from 6 to 16 dB and the compact design (5.7 × 5.7 × 4.0 mm) uses a dual-aperture ferrite core on a ceramic base. The model GLSN16D152 16 dB coupler offers a maximum loss at 20 MHz of 0.6 dB and 3 dB band limits of 0.5 to 1500 MHz. All models have an operating temperature range of –40° to +125°C. The couplers are suitable for automatic insertion into circuits assembled using reflow or vapor phase soldering. Terminals are formed from the ends of the coil windings, eliminating solder joints between the coil and the terminals that could open from the heat of circuit assembly. Price: 99¢ (production quantities). Delivery: eight to 10 weeks.
Sprague-Goodman Electronics Inc., Westbury, NY (516) 334-8700.
Circle No. 280

■ 18 - 26.5 GHz Eight-way Power Divider/Combiner



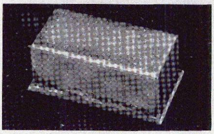
The model PS8-116 eight-way power divider/combiner operates from 18 to 26.5 GHz and offers a high isolation of 17 dB (min) and low insertion loss of 2.8 dB (max) (over nominal loss). SWR is 1.6. The unit exhibits a ±0.5 dB amplitude and ±12° phase balance. It is housed in a rugged aluminum material with type SMA female connectors. Delivery: stock.
Microwave Communications Laboratories Inc. (MCLI), St. Petersburg, FL (727) 344-6254.
Circle No. 276

■ Metal Oxide Varistors



These metal oxide varistor transient voltage surge suppressors are offered in seven model sizes from 5 to 20 mm (dia) and have a V_M (AC/RMS) voltage range from 10 to 1000 V. Energy absorption capabilities are up to 560 joules. These radial leaded devices are ideally suited for operating continuously across the line (AC) for protecting expensive, sensitive electronic components. Prices (1000): 5¢, 5 mm size; 30¢, 20 mm size. Delivery: stock to eight weeks.
Laube Technology, Camarillo, CA (888) 355-2823.
Circle No. 274

■ Surface-mount LC Filter



The model 8623 fully hermetic sealed surface-mount LC filter for wireless applications is capable of surviving high temperature reflow and aqueous cleaning requirements. The unit is centered at 6 MHz with a 1 dB passband of 300 kHz and a 40 dB stopband of ±1 MHz. The filter also features outstanding group delay performance and 50 Ω input/output resistance.
Piezo Technology Inc. (PTI), Orlando, FL (407) 298-2000.
Circle No. 279

■ Lumped Element VHF Circulators

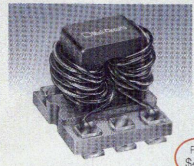
The models 3C100, 3C101 and 3C102 drop-in circulators are designed for 200 W CW input

[Continued on page 185]

NEW PRODUCTS

NO.69

RF/IF MICROWAVE COMPONENTS

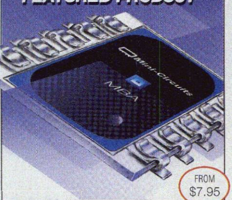


FROM $4.45

RF TRANSFORMERS HAVE 4:1 IMPEDANCE 200 TO 1400MHz

Broad band TCM4-14 surface mount RF transformers from Mini-Circuits operate in the 200 to 1400MHz band with 4:1 impedance ratio. Referenced to midband loss (0.8dB typ), insertion loss is 1dB from 800MHz to 1000MHz, 2dB in the 300 to 1300MHz range, and 3dB band wide when operated within -20°C to +85°C (max.). Open case design has plastic base with solder plated leads, and applications include impedance matching and baluns. RF power is 250mW (max.).

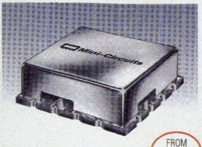
FEATURED PRODUCT



FROM $7.95

3000 TO 4000MHz MIXER IS TEMPERATURE STABLE

Higher frequency designs will benefit from Mini-Circuits patented family of MBA model Blue Cell™ mixers, which deliver a unique combination of low conversion loss, superb temperature stability, thin 0.07" profile, and low cost. This level 13 (LO) MBA-35MH model spans 3000MHz to 4000MHz with 22dB L-R, 14dB L-I isolation and low 5.1dB midband conversion loss (all typ). Operating temperature is -40°C to +85°C (max.) and applications include satellite and PCMCIA.



FROM $19.95

1550 TO 1720MHz VCO HAS LINEAR TUNING

The ROS-1720 voltage controlled oscillator from Mini-Circuits operates within the 1550MHz to 1720MHz band targeting PCS and DCS applications with low -141dBc/Hz SSB phase noise typical at 1MHz offset, wide 3dB modulation bandwidth typical at 18000kHz, and 28-34MHz/V (typ) linear tuning sensitivity. Housed in a miniature 0.5"x0.5"x0.18" industry standard package, typical power output is 7dBm.

it™

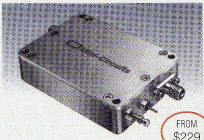
FROM $12.95

50 TO 200MHz MAGIC-TEE OPERATES WITH LOW LOSS

Mini-Circuits has introduced a versatile 2way-0°/180° power splitter and combiner for the 50 to 200MHz band. Model AMT-2 typically has low insertion loss (0.25dB S-1 and S-2, 0.8dB J-1 and J-2), very good 1.10:1 input/1.12:1 output VSWR, plus excellent 0.1dB amplitude and 1 degree phase unbalance. Designed for 50 ohm systems, this 4 port hybrid covers IF receiver and satellite applications. Maximum power input as a splitter is 0.5W.

824 TO 849MHz COAXIAL AMPLIFIER FEATURES LOW NOISE

This 824 to 849MHz cellular band ZQL-900LN low noise amplifier from Mini-Circuits typically provides high 16.5dB gain (±0.2db flatness), ultra-low 1.0dB noise figure, and 22.5dBm maximum power output at 1dB compression. High +35dBm IP3 helps suppress noisy intermodulation products, and operating temperatures range from -40°C to +70°C maximum. Equipped with 50 ohm SMA-Female connectors.



FROM $229

6 pc. KIT $150

2W SMA ATTENUATORS AVAILABLE IN DESIGNER'S KIT

Six different DC to 18GHz fixed attenuators from Mini-Circuits "BW" series are now available at a special evaluation price in designer's kit form. Kit number K-BW2 contains units that display nominal attenuation values of 3dB, 6dB, 10dB, 20dB, 30dB, and 40dB. Built tough to handle 2W average, 125W peak power, these miniature stainless steel precision attenuators are ideal for matching, test set-ups, and instrumentation applications. Available from stock.

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

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

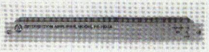
power and operate over the 132 to 174 MHz, 132 to 154 MHz and 150 to 174 MHz frequency ranges, respectively. All models offer 18 dB (min) isolation, 0.6 dB (max) insertion loss and 1.3 (max) SWR. Return loss is 18 dB (min). Size: 1.99" × 2.54" × 0.75" (50 × 65 × 19 mm). Delivery: two weeks.

Alcatel, Ferrocom Ferrite Products, San Jose, CA (408) 229-8171.

Circle No. 268

AMPLIFIERS

High Isolation Distribution Amplifiers

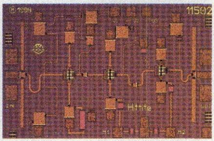


The model FE-7923A low cost,10-channel sinewave distribution amplifier operates from 1 through 10 MHz. Designed to meet stringent satellite ground station requirements, the amplifier offers low phase and amplitude noise bursts with isolation greater than 100 dB. The unit operates from a 115 V AC line or +15 V DC power supply. SWR of the input does not exceed 1.5 (referenced to 50 Ω). Various mechanical configurations and connector types are available, including 19-inch rack-mounting.

FEI Communications Inc., a subsidiary of Frequency Electronics Inc., Mitchel Field, NY (516) 794-4500.

Circle No. 241

GaAs MMIC Low Noise Amplifier



The models HMC262, HMC263, HMC281 and HMC282 low noise amplifiers (LNA) are well suited for microwave and millimeter-wave point-to-point radios, LMDS, VSAT and other SATCOM applications. The HMC262 features gain of 25 dB from 15 to 24 GHz, a single bias supply of +3 V at 36 mA with noise figure of 2 dB. The HMC263 provides gain of 23 dB from 24 to 36 GHz, a single bias supply of +3 V at 46 mA with noise figure of 2.3 dB. The HMC281 offers gain of 22 dB from an output P1dB of +9 dBm and noise figure of 2.5 dB. The HMC282 provides gain of 26 dB from 36 to 40 GHz and an output P1dB of +9 dBm with noise figure of 3.5 dB. Operating temperature range is –55° to +85°C.

Hittite Microwave Corp., Chelmsford, MA (978) 250-3343.

Circle No. 242

40 W RF Power Amplifier

The model GRF2030DC 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.

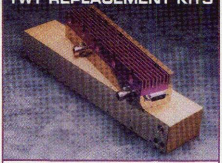
Ophir RF, Los Angeles, CA (310) 306-5556.

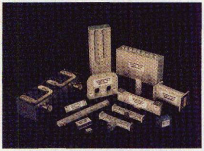
Circle No. 243

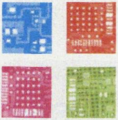
CDMA Amplifier

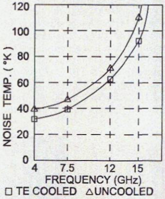
The model AMT-1930-016 class A/B amplifier is designed as a single carrier amplifier for use in base stations. The fully integrated amplifier features alarms and cooling while delivering 16 W of average power and 31 dB of gain. Size: 10.2" × 10.3" × 8.80".

[Continued on page 187]

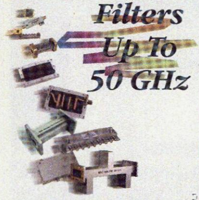


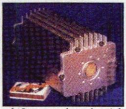






NOISE TEMP. (°K)
0
20
40
60
80
100
120
4
7.5
12
15
FREQUENCY (GHz)
□ TE COOLED △UNCOOLED





NEW PRODUCTS

American Microwave Technologies (AMT), Anaheim, CA (714) 456-0777.
Circle No. 240

■ Medium Power GaAs FET Amplifiers

The models PA2010/SMP2010 low cost, medium power GaAs FET amplifiers operate in the 200 to 2000 MHz frequency range while generating up to +25.5 dBm for 1 dB compression point. Third-order intercept is +33 dB and small-signal gain is 10 dB. Hermetic packaging is available in both TO-8 and surface mount. An SMA connector version is available as an option.

Stellex Microwave Systems Inc., Palo Alto, CA (800) 321-8075.
Circle No. 244

■ 36 - 40 GHz High Power Amplifier

The model CHA5094 high gain, three-stage monolithic high power amplifier is designed for a range of applications, including military and commercial communication systems. Available in chip form, the circuit is manufactured with a pHEMT process, 0.15 µm gate-length via holes through the substrate, air bridges and electron beam gate lithography. The backside of the chip is both RF and DC grounds, thereby simplifying the assembly process. Output power is 28 dBm with 11 dB ±1 gain. DC power consumption is 1.3 A at 3.5 V. Chip size: 4.51 mm × 2.60 mm × 0.05 mm.
United Monolithic Semiconductors (UMS), Orsay, Cedex, France +33 (0) 1 69 33 03 35.
Circle No. 265

■ C-band and Ku-band Power Boosters

These C-band and Ku-band power boosters include control and protection functions and consist of three major subsystems: the RF amplifier, a power supply unit and a cooling system. The amplifier section contains all of the necessary DC power conditioning circuitry for bias and sequencing of the RF amplifier devices as well as over-temperature protection, RF power detection, mute control and gain drop detection. Gain flatness is ±1 dB (max) and SWR is 1.5 (max). Designed specifically for use in very small aperture terminal applications, the unit's innovative mechanical design features high thermal dissipation efficiency with 12° to 15°C rising temperature, resulting in a higher MTBF number.

Wavesat Telecom Inc., Ville St-Laurent, Quebec, Canada (514) 956-6300.
Circle No. 245

ANTENNAS

■ Millimeter-wave Sector Antennas

The WavShapr™ antennas are available for 24, 26, 28, 31 and 38 GHz operation with ultra-low cross-polarization. Designed using internally developed genetic optimization techniques that result in good antenna performance, the antennas offer extremely flat amplitude within the azimuth coverage region and extensive sidelobe suppression outside the sector. The WavShapr antennas are low profile, rugged and significantly outperform traditional sector antennas. Uniform power density is provided by a highly controlled cosecant elevation pattern throughout a 45° downtilt. Available in horizontal or vertical polarizations, the antennas offer SWR of 1.5 and maximum RF input power of 10 W.
Endgate Corp., Sunnyvale, CA (408) 737-7300.
Circle No. 261

■ 300 MHz - 3 GHz Log Periodic Dipole Array Antenna

The model EM-6946 log periodic dipole array antenna offers an exceptional combination of frequency coverage and high power handling capability without compromising the consistent performance vs. frequency that makes the log periodic antenna so desirable for test applications. The rugged antenna is powder coated,

[Continued on page 188]

not raw or painted aluminum, ensuring that the unit will not corrode or otherwise change its electrical characteristics over time. The wideband technology used in the unit allows the convenience of a single antenna for tests that previously would have required two or more antennas.
Electro-Metrics, Johnstown, NY (518) 762-2600.

Circle No. 282

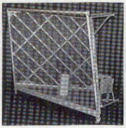
GPS Antennas

The GPS series antennas feature a low profile microstrip patch design and provide higher gain and versatility than previous GPS antennas supplied by the company. Two basic model are available according to the user's mounting requirements and can be ordered in 26 or 31 dBi versions. The models AGPS26 and AGPS31 antennas are available with magnetic, screw or adhesive tape mount options and feature a built-in ground plane. The M mount-compatible units provide 360° azimuth and 0° to 90° elevation coverage with right-hand circular polarization. A low profile housing and electrically shielded LNA PCB with burnout protection is provided. In addition, the antennas are supplied with 15 feet of RG174/U cable and various connector choices.
MAXRAD Inc., Hanover Park, IL (800) 323-9122.

Circle No. 283

High Power Trihedral Corner Reflector

The model 9887-800 high power trihedral corner reflector consists of a high power radome-enclosed monopole element placed into a trihedral



corner reflector. The unit operates over the frequency range from 150 to 300 MHz and power handling is 325 kW at a 0.01 duty factor. Polarization is linear (rotatable for horizontal or vertical). Gain is 8 dBi (min); SWR is 2 (max); sidelobes are 13 dB (min), E and H planes; and cross polarization is 10 dB (min). The RF port os 3-1/8" 50 Ω coaxial line.
Seavey Engineering Associates Inc., Pembroke, MA (781) 829-4740.

Circle No. 284

INTEGRATED CIRCUITS

■ Integrated Data Tuner Solution

This low power, high performance integrated data tuner solution consists of an integrated upconverter with a surface-acoustic wave filter and an integrated downconverter with a dual-synthesizer. The tuner conserves printed circuit board real estate while enabling high speed data, video and voice-over-cable and features the lowest power consumption for cable set-top, cable modem and cable telephony applications. Designed specifically to support the latest 256 quadrature amplitude modulation digital formats, the tuner solution reduces component count, minimizes power consumption and offers DOCSIS-compliant performance essential for next-generation cable devices. Price: $7.50 (10,000).
ANADIGICS Inc., Warren, NJ (908) 668-5000.

Circle No. 246

■ LNA/Mixer 900 MHz Downconverter

The model RF2461 low noise amplifier (LNA)/mixer 900 MHz downconverter is a complete receiver front-end that provides good noise figure and linearity performance for dual-mode CDMA/FM cellular applications. In addition to its digitally controlled LNA gain, mixer gain and power-down mode, the RF2461 also features adjustable IIP3 of the LNA and mixer bias current using an off-chip current-setting resistor. The unit can be digitally controlled between two levels, reducing current draw in CDMA standby and other situations that do not require high IIP3 while offering a 30 dB stepped gain control range as it amplifies and downconverts RF signals. Typical noise figure is 1.8 dB (RF2461), 1.8 dB (LNA) and 5.7 (mixer). Designed specifically for CDMA/FM cellular systems and general-purpose downconversion for various battery-powered equipment applications, the unit is housed in an LPCC-20 package that measures 4 mm × 4 mm. Price: $1.87 (in quantities exceeding 10,000).
RF Micro Devices Inc. (RFMD), Greensboro, NC (336) 664-1233.

Circle No. 247

■ Single-chip, Zero-IF, ISM-band Transceiver

The model NT2903 Chip-Ceiver™ is reportedly the world's first fully integrated, single-chip, FM/FSK transceiver utilizing a unique, direct-conversion, zero-IF architecture. This approach allows a 30 to 40 percent reduction in total component count compared to a superheterodyne receiver. The Chip-Ceiver offers full duplex operation in any 26 MHz band from 400 to 1000 MHz on a 2.7 to 3.3 V supply and integrates on-chip, dual VCOs, dual phase-locked loops, a reference oscillator, a quadrature mixer, baseband filters, AGC and a patented tankless discriminator. In addition, the device utilizes a direct modulation scheme, which can accept either analog or digital signals. Tuning is accomplished via a three-wire serial interface. Power output is 1.5 dBm. The device is fabricated as a monolithic BiCMOS IC and is available in a TQFP-48 (7 mm) package. Price: $4.63 (10,000). A fully functional evaluation board is also available for $199.
NUMA Technologies Inc., Naples, FL (941) 591-8008.

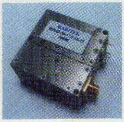
Circle No. 285

SOURCES

■ Dielectric Resonator Sources

The company's dielectric resonator sources are designed with the lowest phase noise at the

[Continued on page 191]



lowest cost. Internal reference models are available up to ±5 ppm stability. (Phase-locked sources over 27 GHz also are available.) Special options include two outputs and a separate reference module to minimize size. The company also offers special units and surface-mount synthesizers as well as voltage-controlled oscillators.

RADITEK, San Jose, CA (408) 266-7404.

Circle No. 249

■ Crystal-controlled Oscillators

The XO2000 series crystal-controlled oscillators cover the output frequency range from 80 to 120 MHz with frequency stability of ±5 ppm. RF output power is 13 dBm (typ) with a power supply of +12 V DC at 35 mA. Phase noise at 10 Hz is –85 dBc/Hz and at 100 Hz is –122 dBc/Hz. Supply ripple sensitivity is 50 mV, –76 dBc at 400 MHz and vibration sensitivity is < 5 × 10⁹/G. Operating temperature range is 0° to +50°C. Size: 1.00" × 1.00" × 0.50".

Techtrol Cyclonetics Inc. (TCI), Cumberland, PA (717) 774-2746.

Circle No. 250

■ OCXOs

The OX-2000 series oven-controlled crystal oscillators (OCXO) are available in frequencies

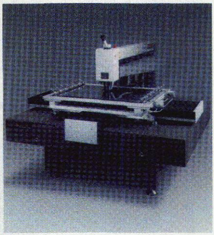
from 1 to 160 MHz with a center frequency of ±0.1 ppm (from 0° to 50°C). The oscillators meet ANSI Stratum-3 requirements, including ±4.6 ppm total stability over a lifetime and ±0.37 ppm over a holdover period as well as variations in temperature, supply voltage, load variations and 24 hours of aging. The oscillators utilize a contemporary semiconductor heating design, ensuring that the units reach thermal stability and specifications within 1.5 minutes (typ) and three minutes (max). The OCXOs consume less than 2.5 W during warm-up and less than 1 W steady-state at 25°C. The OX-2000 series are available in small 14-pin DIPs with package height of less than 10 mm from 1 to 60 MHz and less than 12.7 mm for frequencies up to 160 MHz, which include SONET and asynchronous transfer mode applications. Prices: start at $50 (10,000). Delivery: 12 weeks (ARO).

Raltron Electronics Corp., Miami, FL (305) 593-6033.

Circle No. 264

PROCESSING EQUIPMENT

■ Laser Stencil



The LPKF StencilLaser/Polymer enables the production of polymer SMD stencils while drastically reducing print rejects due to better paste release, especially in fine pitch technology. The SMD stencils offer superior board contact during printing process as well as print speeds up to three times faster than metal stencils. The stencils also offer a longer lifespan and better memory effect of polymer stencils than metal stencils. In combination with the company's TurboCut, the StencilLaser is well suited

SUBSYSTEMS

■ High Power Pulse Modulator

The PowerMod™ HVPM solid-state, high power pulse modulator features fast rise and fall times of 5 µs for use in ion implantation, high energy physics, semiconductor

A) at up to 30 kHz and insertion loss of less than 0.2 dB. Nominal pulse width is 1 to 100 µs and nominal pulse frequency is 0 to 30 kHz. Offering full internal self-protection against over-voltage and over-current conditions, the PowerMod is well suited for upgrading switch tubes or thyratron/PFN systems. The 19-inch rack-mountable unit is fully air-cooled and insulated and measures 19.0" × 30.0" × 24.0". Price: $50,000.

Diversified Technologies Inc.,
Bedford, MA (781) 275-9444.

SYSTEMS

Programmable Digital Downconverter

The CommLink™ HSP50216 programmable digital downconverter (PDC) for cellular base stations delivers multiple channel processing of high dynamic range cellular protocols. The PDC contains four channels that can support up to four different protocols simultaneously, including IS-136 TDMA, GSM, EDGE, IS-95 CDMA, 3G and legacy protocols such as AMPS, enabling cellular operators to efficiently support multiple transmission protocols within the confines of one base station. The unit features on-board digital automatic gain circuitry, which, when used in conjunction with on-board digital filtering, provides gain to a low level signal while simultaneously attenuating out-of-band interfering signals. A small outline BGA package that reduces required board space is included. Price: $60 (1000).

Intersil Corp.,
Melbourne, FL (888) 468-3774, ext. 7976.

Circle No. 262

Spread Spectrum Data Transceiver

The model SS9600 spread spectrum data transceiver for use in point-to-point and point-to-multipoint systems features a built-in modem. Operating in the 2.4 GHz band and capable of 9600 bps over the air rate, the transceiver is a true frequency-hopper and can configure large systems with as many as 238 units. The transceiver is a true plug-and-play radio modem with built-in self-adjusting power control to ensure good communications.

RF Neulink, a division of RF Industries,
San Diego, CA (800) 233-1728
or (858) 549-6340.

Circle No. 253

2 W Ku-band Transceiver

This 2 W transceiver comprises a solid-state power amplifier, a low noise amplifier, Ku-band to L-band converters and an orthogonal-mode transducer with waveguide filters. (An external reference oscillator is available.) Nominal input power is ±1 dB in the transmit section. The self-contained unit also features a micro controller and fault monitoring. Operating temperature range is –20° to +55°C.

TSAT, +47 23 037360, fax +47 23 037361
or e-mail: info@tsat.com.

Circle No. 286

TEST EQUIPMENT

Multiport Test System

The Agilent 87050E multiport test sets can dramatically improve throughput and accuracy when evaluating the performance of 50 Ω RF components on high volume production lines. The multiport test sets are designed to work with the Agilent 8712E series network analyzers to offer a complete solution up to 3 GHz for measuring devices with up to 12 ports. The Agilent 87050E allows all transmission paths and port reflection characteristics of a multiport device to be completely characterized with a single set of connections to a device's ports, substantially reducing typical test times by eliminating the need to constantly connect and re-connect components. An integrated local area network interface allows the measurement system to become part of a factory-wide Ethernet network using standard protocols. Prices: $8250 to $14,250 (87050E) and $9750 to $22,250 (8712E). Delivery: eight weeks (ARO).

Agilent Technologies,
Palo Alto, CA
(800) 452-4844, ext. 6849.

Circle No. 254

[Continued on page 199]

NEW PRODUCTS

Manual Harmonic Tuner

The model MMT-4006-2H manual microwave tuner covers the 0.4 to 50 GHz frequency range in several medium and large bandwidth model types. Best suited for use in critical RF impedance matching operations, such as load-pull and noise measurements, the manual microwave tuner provides independent tuning of the harmonic impedance at 2 f_0. The tuner also allows for fundamental tuning at frequencies between 6 and 40 GHz and second harmonic tuning at any user-defined frequency between 12 and 44 GHz.

Focus Microwaves Inc.,
St-Laurent, Quebec, Canada
(514) 335-6227.

Circle No. 256

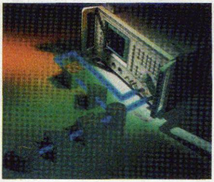
Distortion Measurement Test Set

The model CS29010 fully integrated distortion measurement test set offers high performance arbitrary waveform generation, radio frequency up- and down-conversion and wideband recording capability with the deep memory via a 600 MHz Pentium II process with a Windows NT™ operating system. Designed specifically for test and measurement requirements of cellular, PCS, satellite, LMDS, wireless data and data link systems operating in complex multichannel and multisignal environments, the test set can determine key performance characteristics such as noise power ratio, third-order intermodulation distortion and adjacent-channel power ratio. The test set, which includes the company's unique and easy-to-use LabVIEW™ configured measurement and control software that provides initiation and scroll of test routines, is well suited for a variety of wideband, complex mixed-signal design and development for components, subsystems and systems.

Celerity Systems,
a division of L-3 Communications,
Thousand Oaks, CA
(805) 523-7464.

Circle No. 255

Microwave Analyzer



The 6800 series microwave system analyzers now have expanded capabilities that include the addition of a high output power source option. The option provides a minimum +10 dBm of leveled power up to 24 GHz, allowing for local oscillator substitution in mixer and converter measurements. The increased output power also increases the dynamic range in scalar and tuned input modes by 5 dB, yielding up to 90 dB for filter and passive component testing. Other features of the 6800 series include frequency versions of 3, 8.4, 20 and 24 GHz, precision scalar network measurements, real-time transmission line fault location with 0.1 percent accuracy and modular design for rapid service. Price: \$1620 to \$4050, depending on series model. Delivery: four weeks (ARO).

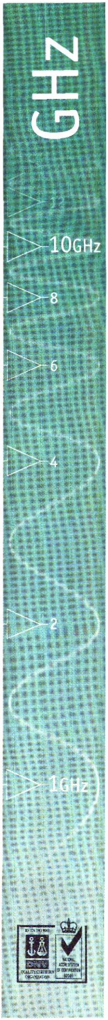
IFR Systems Inc.,
Wichita, KS (800) 835-2352
or (316) 522-4981.

Circle No. 257

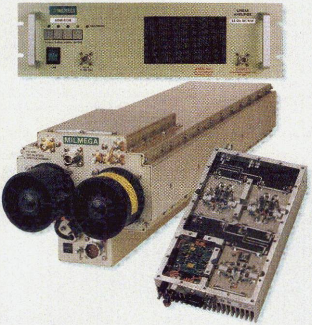
[Continued on page 201]

HIGH POWER

Microwave Amplifiers



Milmega's strength is the flexibility to design and build standard and custom products and systems for high quality solid state microwave amplifiers. This has created the Company's global reputation as being the experts in the field of high power microwave engineering.



Milmega's capability to custom build for a comprehensive range of leading edge market applications include:

Physics research, where amplifiers provide high levels of energy to pump electrons up into required energy orbits.

For Electromagnetic Compatibility (EMC) testing, where wide frequency ranges are essential, Milmega amplifiers can be found generating field strengths over 200V/m.

For defence applications, the ability to operate over wide temperature ranges with high reliability, allows Milmega amplifiers to be built into sophisticated jamming systems, operated from external pods suspended below aircraft wings.

In hospitals, microwave energy is used in many processes to eliminate unwanted tissue and many other specialised applications.

MILMEGA

A **Thermo Voltek** Company

Designers and Manufacturers of High Power Microwave Amplifiers and Systems

Milmega Ltd, Ryde Business Park, Nicholson Road, Ryde, Isle of Wight, PO33 1BQ, UK
Tel: +44(0) 1983 616863 Fax: +44(0) 1983 616864
E-mail: sales@milmega.co.uk Web: www.milmega.co.uk

A division of Thermo Voltek, a Thermo Electron Company

CIRCLE 81 ON READER SERVICE CARD

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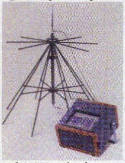
NEW PRODUCTS

Interference Analyzer



The BaseStAR™ interference analyzer is designed to protect specific licensed uplink/reverse telecommunications channels (for example, 805 to 821 MHz, 824 to 849 MHz and 1850 to 1910 MHz) by simultaneously monitoring the protected band and potential interference sources located between 50 MHz and 2 GHz. The device can identify interference generated by a single emitter or the interaction of two independent emitters. The analyzer provides information about the source of emission, including the offending company's name and location, transmitter characteristics and the interference mechanism.
Summitek Instruments,
Englewood, CO (303) 768-8080.
Circle No. 287

Automated Noise Power Ratio Test Set

The model UFX-NPR-22 automated noise power ratio (NPR) test set is a single, self-contained unit that provides accurate NPR measurements and return path laser testing characterization, eliminating the need for a spectrum analyzer or other external hardware. At the push of a button or remote command via a general-purpose interface bus, the unit can perform up to 25 NPR measurements at different input levels, and store on-going measurement results in memory. Noise power output is –60 to 0 dBm and impedance is 50 or 75 Ω while operating over the 5 to 42 MHz frequency range. (The unit uses industry recommended test procedures for characterizing NPR over dynamic range.)
Noise Com, Paramus, NJ (201) 261-8797.
Circle No. 258

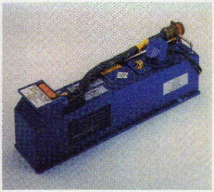
DEVICE

4 W Plastic-packaged GaAs Power FET

The model AM144MX-TF plastic-packaged GaAs power FET has a total gate width of 14.4 mm and is designed for high power microwave applications up to 8 GHz. The plastic package is provided with straight leads in a drop-in mounting style. The bottom of the package serves simultaneously as DC ground, RF ground and thermal path. The unit features high gain and saturated power of 36.5 dBm at 2 GHz. Three heat sink paths are provided for effective heat removal.
AMCOM Communications Inc.,
Clarksburg, MD (301) 353-8400.
Circle No. 281

TUBES

EHF-band Traveling-wave Tubes



The models TH 3760 and TH 3971 traveling-wave tubes (TWT) are designed specifically for the military SATCOM market as well as emerging multimedia requirements in the 42.5 and 47.5 GHz band. The TH 3760 uses a helix delay line and conduction cooling while the TH 3971 utilizes a coupled cavity delay line and forced-air cooling. Designed for integration in ground transmitters handling satellite uplinks for military transmissions, the TH 3760 and TH 3971 generates 250 W of power, respectively, over the 43.5 to 45.5 GHz band.
Thomson Tubes Electroniques,
Meudon-La-Foret, France
+33 (1) 30 70 36 43.
Circle No. 259

microwave JOURNAL

CALL FOR PAPERS

To see one's work in print is the rightful reward of every creative engineer and scientist. The editors of *Microwave Journal* invite you to submit your technical manuscripts for consideration to be published in one of our upcoming issues. Technical articles, application notes and tutorial articles based on the monthly editorial themes are encouraged. Editorial themes include wireless, radar and antennas; RF components and systems; test and measurement; amplifiers and oscillators; semiconductors and MMICs; commercial applications; IVHS and ITS; dual technologies; communications and PCN; passive components; and control devices, modulation and DSP.

Design features should contain new and innovative technical ideas of practical use and interest to our predominantly engineering readers. Papers should be 14 to 16 double-spaced pages and contain 8 to 12 visual aids in the form of sketches, graphs, photographs or tables.

Papers should be submitted to the attention of the Technical Editor and will be reviewed promptly by our Editorial Review Board prior to acceptance. Articles outside of the monthy themes also will be considered.

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NEW LITERATURE

Advanced Filter Solution Brochure

This four-page brochure contains information on the company's 300 to 3500 MHz ceramic or dielectric resonator filters, DC to 5 GHz LC filters and 500 MHz to 40 GHz cavity filters. An overview of the company's manufacturing capabilities and a facility description are included.
Advanced Filter Solutions (AFS), Frederick, MD (301) 698-0114.

Circle No. 200

Crystal Product Data Book 2000

This 284-page data book provides specifications for hundreds of standard and custom frequency control devices, including the CFPT-9100 Stratum III surface-mount TCXO and the CFPV-2365 low voltage VCXO. Customers can order components using the specifications and controlled issue numbers provided. A CD-ROM version also is available.
C-MAC Frequency Products, Durham, NC (919) 941-0430.

Circle No. 201

Frequency Distribution System Data Sheet

This two-page data sheet describes the company's frequency distribution system designed specifically for satellite ground station and shipboard, mobile and laboratory applications. Full technical specifications for primary and secondary models FE-798A and FE-799A are included.
Frequency Electronics Inc., Mitchel Field, NY (516) 794-4500.

Circle No. 202

Ultrawideband Personal Monitor Data Sheet

This data sheet introduces the company's 8846 and 8848 series Nardalert® RF personal monitors, which offer 300 kHz to 45 GHz of detection. Product descriptions, photographs and key specifications are provided.
Narda Microwave-East, a division of L-3 Communications, Hauppauge, NY (631) 231-1700.

Circle No. 204

High Power Microwave Amplifier Catalog

This 12-page catalog provides information on high power amplifiers that cover the 80 MHz to 10 GHz frequency ranges and an overview of the company's capabilities in communications testing, medical products, electronic warfare, EMC and high energy physics.
Milmega Ltd., Ryde, Isle of Wight, UK +44 (0) 1983 616 863.

Circle No. 204

DAQ Designer™ 2000 CD

This CD helps engineers and scientists interactively configure custom measurement systems by recommending real-time data acquisition and motion control hardware and software in addition to signal conditioning, computer-based instruments and instrument controllers, and image acquisition hardware and software.
National Instruments, Austin, TX (800) 258-7022.

Circle No. 206

Enclosure and Packaging Capability Brochure

This 20-page brochure highlights the company's range of standard, modified and custom enclosure solutions and packaging system capabilities for telecommunications, data communications, test and measurement, computer, broadband, military and aerospace applications. The company's Prototype to Production process also is described.
Pentair Electronic Packaging, Plymouth, MN (888) 550-9543.

Circle No. 207

Surface-mount Frequency Synthesizer Data Sheet

This four-page data sheet describes the company's surface-mount synthesizers, which consist of a miniature VCO integrated with a high performance PLL chip, resulting in a low phase noise programmable or fixed-frequency synthesizer for RF operation up to 2.5 GHz. Key specifications and outline drawings are included.
Princeton Electronic Systems Inc. (PES), Princeton, NJ (609) 275-6500.

Circle No. 208

2000 Designer's Handbook

The 2000 Designer's Handbook features more than 150 products from the company's power amplifier, digital cellular, silicon system and broadband product lines. Technical information, performance test data, specifications, schematics and application notes also are provided.
RF Micro Devices Inc. (RFMD), Greensboro, NC (336) 664-1233.

Circle No. 209

RF and Microwave Solution Brochure

This four-page brochure describes the company's integrated microwave products, including oscillators, multipliers, comb generators, frequency synthesizers and microwave assemblies as well as ferrite isolators and frequency and timing systems. Product photographs are included. A company overview and a facility description also are provided.
TRAK Microwave Corp., Tampa, FL (813) 901-7200.

Circle No. 211

EMF Report

This 28-page report provides information on electromagnetic exposure and its potential negative effects as well as H-field measurements based on personal specialists' knowledge, organization background and national environment. Price: $20.
Wandel & Goltermann GmbH & Co., Eningen, Germany +49 71 21 86 1616.

Circle No. 212

Capability Brochure

This eight-page brochure describes the capabilities and product offerings of 10 specialized divisions of Vertex Communications Corp., a designer and manufacturer of satellite earth station subsystems. Photographs are included and a listing of sales offices is provided.
Vertex Communications Corp., Kilgore, TX (903) 984-0555.

Circle No. 213

THE BOOK END

Feedback Control Systems

Charles L. Phillips and Royce D. Harbor
Prentice Hall
658 pages; $100
ISBN: 0-13-949090-6

This fourth edition has been updated to include the SIMULINK™ simulation program, a block diagram program used with MATLAB™ for the simulation of both continuous (analog) and discrete systems and nonlinear continuous systems. Most of the examples in the book now contain short MATLAB programs. The material has been organized into three principle areas: analog control systems, digital control systems and nonlinear analog control systems.

"...practicing engineers will find this book very useful for reference and instruction."

After a brief introduction, a short history of feedback control systems is presented and mathematical models of some common control system components are developed. The section on the analysis and design of linear analog systems (control systems with no sampling) begins by developing the transfer function and state-variable models of linear analog systems. Typical responses of linear analog systems, including the concept of frequency response, are presented. Important control system characteristics are developed and some applications of closed-loop systems derived from these characteristics are noted. The concept of system stability is presented along with the Routh-Hurwitz stability criterion. An analysis and design using root locus (time-response) procedures are presented next, and the equally important frequency response analysis and design procedures are described. Modern control system design is covered in the final chapter of this section. Pole-placement design is developed and the design of state estimators is introduced.

Digital control systems are covered in the next section. All of the previously presented techniques are developed again for digital systems. The final section deals with nonlinear system analysis. These methods include the describing-function analysis, linearization and state-plane analysis. Three appendices include reviews on matrices and Laplace transforms as well as a table of Laplace and z transforms.

Many examples are offered, primarily limited to illustrating one concept at a time for the benefit of the beginning students who use this text in course work. A solutions manual is available for teachers for classroom work using this text. Although written as a classroom textbook, practicing engineers will find this book very useful for reference and instruction.

To order this book, contact: Prentice Hall, PO Box 11073, Des Moines, IA 50336 (800) 947-7700.

Wireless Technician's Handbook

Andrew Miceli
Artech House Inc.
256 pages; $59, £41
ISBN: 1-58053-005-2

A text aimed at technicians is somewhat unique. However, a book with information more detailed than needed for business professionals, but less complex than engineering texts without the baffling formulas and graphs can be quite refreshing. The primary purpose of this book is to train technicians in wireless system fundamentals. However, it is also a great reference text for those engineers who are not directly in the field and desire a cursory look at the subject.

As expected, the book begins with an introductory chapter on basic RF and digital principles, including RF propagation and modulation formats. Cellular radio concepts are covered next, with a review of the history of cellular radio communications and a discussion of cellular networks and multiple access techniques. The technical aspects of the AMPS system are also presented along with an explanation of the many terms and abbreviations associated with the service and its formats and standards. In addition, North American-TDMA (NA-TDMA) and CDMA-ONE dual-mode standards are explained. Separate chapters cover the details of NA-TDMA (strong in the Americas), GSM (primarily in Europe) and CDMA system architecture and operation.

"...this book is useful for anyone seeking a simple understanding of today's wireless cellular and PCS communications systems."

The basics of field testing are introduced next. This section is designed to give a technician and technical manager a basic understanding of many of the tools available as well as an overview of the primary tests that are performed in the field for each of the discussed technologies. The building blocks of a common cellular transceiver are presented and typical system measurements are discussed. The final three chapters are devoted to testing procedures for AMPS, TDMA and CDMA systems.

Much of the information in this book is useful for anyone seeking a simple understanding of today's wireless cellular and PCS communications systems. Technicians will find the sections on testing of particular interest.

To order this book, contact: Artech House Inc., 685 Canton St., Norwood, MA 02062 (781) 0769-9750, ext. 4002; or 46 Gillingham St., London SW1V 1HH, UK +44 (0) 20 7596 8750.

Frank Bashore

Frank Bashore is a member of the Microwave Journal *staff.*

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2	Aerocomm Satellite Technology	192	+662-693-8300	+662-693-8304	www.aerocommthailand.com
3,4,5,6	Agilent Technologies	COV 2, 77	800-452-4844	415-857-5518	www.agilent.com
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28	ATN Microwave Inc.	15	978-667-4200	978-667-8548	www.atnmicrowave.com
33,34	Cascade Microtech	COV 4	503-601-1000	503-601-1002	www.cascademicrotech.com
29	Coilcraft	53	800-322-2645	847-639-1469	www.coilcraft.com
142	Connecting Devices Inc. (CDI)	190	562-498-0901	562-494-0955	www.connectingdevices.com
30	Cougar Components	166	408-522-3838	408-522-3839	www.cougarcorp.com
31	CPI Canada	161	905-877-0161	905-873-7416	www.cpii.com/cmp
32	CST of America	133	617-576-5857	617-576-5702	www.cstamerica.com
35	CTT Inc.	120	408-988-8521	408-986-9097	www.cttinc.com
10	DB Products Inc.	187	626-449-3790	626-449-7169	www.dbprod.com
119	Dept26.com	108–109			
37	Dielectric Laboratories	62	315-655-8710	315-655-8179	www.dilabs.com
38	Dow-Key Microwave Corp.	135	805-650-0260	805-650-1734	www.dowkey.com
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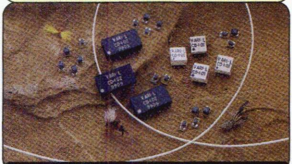

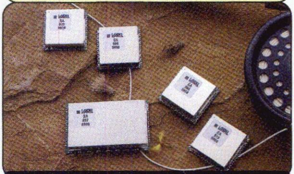

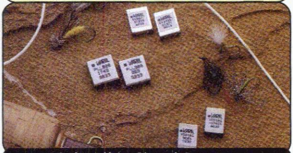

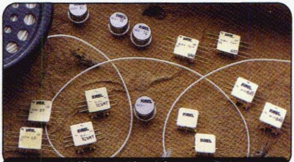

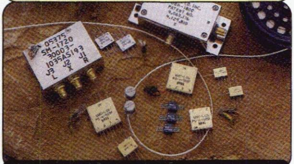

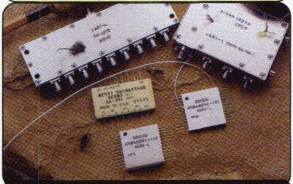

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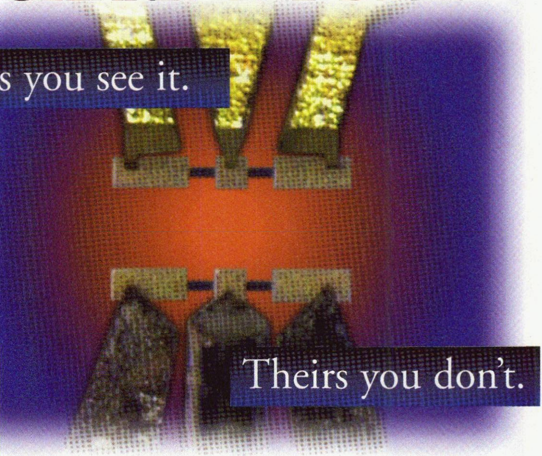

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