An INTERTEC®/K-III Publication

RF design®

engineering principles and practices

December 1996

Featured technology—3-Volt Circuits

The Complete Article Index: 1996

This is pure bull...

*

...this isn't:

When you're looking for a way to beef up your signal output, look for the newest power amp from RF Micro Devices.

Our 700mW RF2104 shows more muscle than you'd expect in a 16-pin SOIC package, delivering a solid gain of 26dB. At 3.6V, it kicks out 800mW of CW power at 46% efficiency (1.0W at 4.8V). Combine that kind of performance with a 43dB power control range, a precise 50Ω input match and a price lower than a pound of ground round, and you've got a new breed of power amp that'll put the competition out to pasture.

We're RFMD – we're outstanding in the field... and that's no bull.

RF2104 POWER AMPLIFIER
Frequency Range: 400 MHz - 1GHz
Price: $1.95 ea. *(In quantities exceeding 10,000)*

RF MICRO·DEVICES®

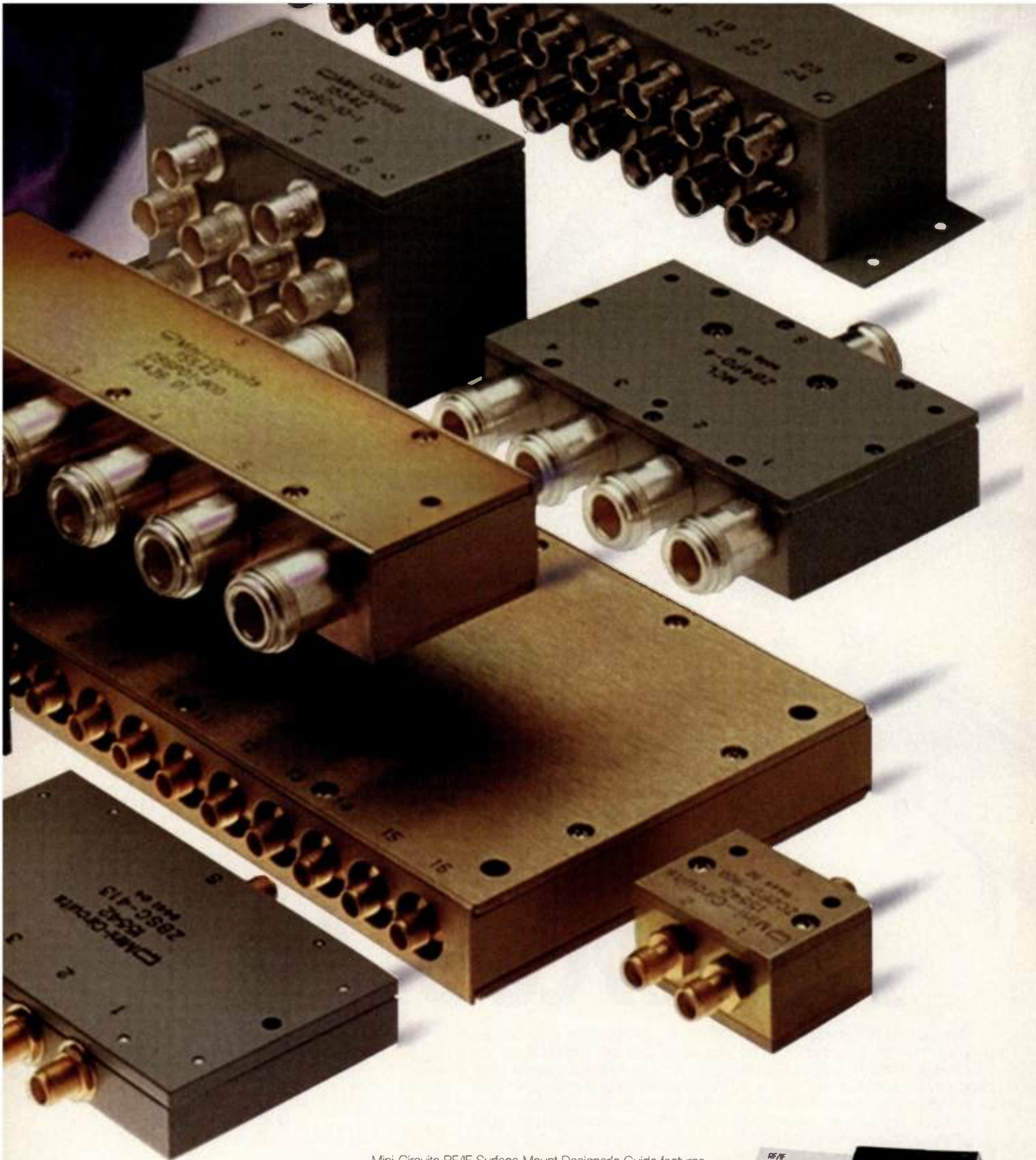
Powerful, Efficient, Affordable Performance

Proprietary, State-Of-The-Art RF Integrated Circuits

7625 Thorndike Road – Greensboro, NC 27409-9421 – Phone 910.664.1233 – FAX 910.664.0454 – Online: http://www.rfmd.com

** This is Samson – strong as an ox, but twice as smart. Don't let the curls fool you – a champion Charolais weighs in at 2,700 pounds, and half of that's attitude.*

INFO/CARD 27



Mini-Circuits RF/IF Surface Mount Designer's Guide features 48 pages of the most up-to-date and complete product and specification information about Mini-Circuits surface mount components. The RF/IF Microwave Handbook is packed with 740 pages of articles, selection guides and detailed specifications for Mini-Circuits components.

Call, write or fax for your free Surface Mount Designer's Guide and Handbook today!

Mini-Circuits®

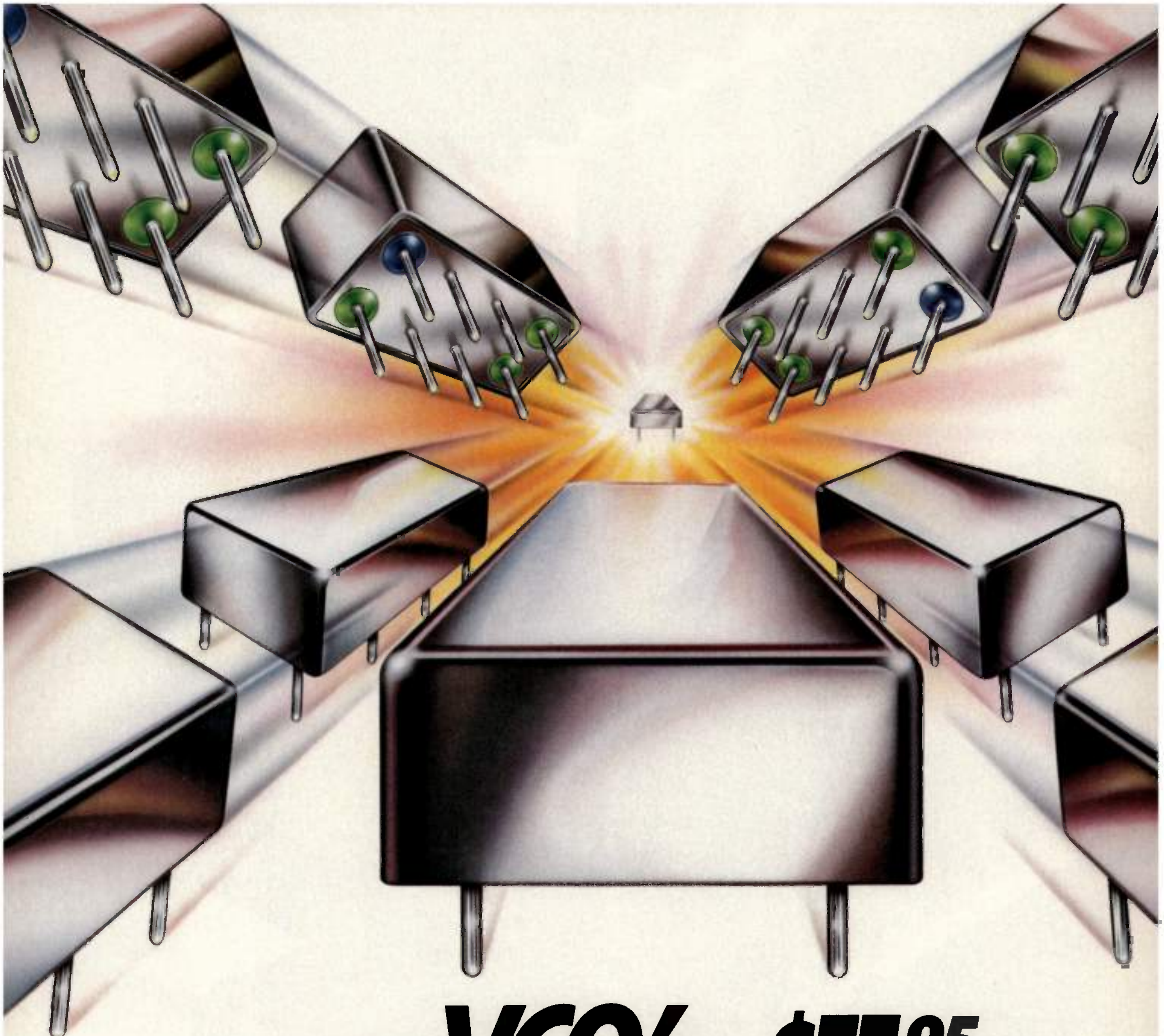
US 3 INT'L 66
CIRCLE READER SERVICE CARD

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

For detailed specs on all Mini-Circuits products refer to • 740- pg. HANDBOOK • INTERNET • THOMAS REGISTER • MICROWAVE PRODUCT DATA DIRECTORY • EEM

CUSTOM PRODUCT NEEDS...Let Our Experience Work For You.

F 194 Rev Orig

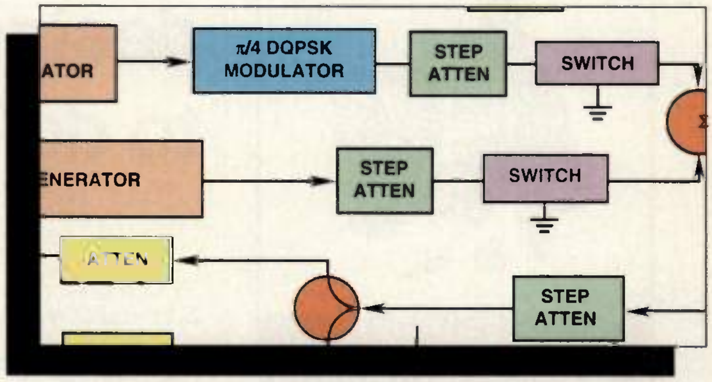


RF design
engineering principles and practices

contents

December 1996

featured technology — 3-volt circuits



cover story — p. 30

cover story

tutorial

Coming in January

- Oscillators
- Coil tutorial
- New cover story format: PCS
- The return of the product forum: Transistors

departments

RF editorial

What's a designer to do?

By Don Bishop
Editorial Director

Designing electronic products to fit regulatory requirements, to meet cost restrictions and to appeal to consumers or industrial users isn't easy. We like to think that RF engineers play a key role in the process—which they do—but consider a manufacturer's perspective.

"We have seen a shift in what makes customers decide to buy our products instead of another manufacturer's," a company president told me. We were talking in the aisle at a trade show. There was plenty of room ... in the aisle ... in his booth ... in everyone's booth. Where were all the engineers? Actually, the sessions were well-attended!

But back to the story.

"Used to be, if you were *nicer* to customers than the next guy, you would win the business," he explained.

What makes the difference now?

"These days, it's 40% price, 40% looks, 15% delivery and 5% technology." *Only 5% technology?* I'll come back to that.

First, let's consider this matter of *looks*. The company president said that, when he competes for contracts to provide new original equipment manufacturer (OEM) subsystems, it isn't good enough to provide a version that looks as though it were created in a laboratory. Not even if it works perfectly and looks OK. He said he can lose the business if the *prototype* doesn't look like a *finished, manufactured product*.

Form over function. Style over substance. Who can deny that appearance is important? Apparently, it isn't enough to leave the matter of appearance to those who design plastic cases and packaging materials. Sometimes the way subassemblies and components look when they reach the customer evaluation stage can make the difference in a sale.

Second, let's think about *delivery*. To the company executive, that means everything from actually presenting the finished product to the customer when and where scheduled, to meeting commitments about the product. Commitments might include adherence to specifications, ease of use, ease of installation, durability, suitability and other elements of customer satisfaction.

Third, let's take price into account. Some manufacturers report customer expectations of *declining prices* every year. It isn't sufficient to have the lowest price going in—although that may be critical. Price negotiations may include a sliding *downward* scale with commitments for price reductions over the life of the contract.

Fourth, the characteristic with the lowest-percentage effect on the sale (for this particular manufacturer), *technology*. For all of the pride that may be taken in engineering new products, systems or services (read that: solutions), apparently it accounts for only a small part of the customer decision.

Or does it?

Although the pure technology, the "gee whiz, that works great, glad you thought of that" reaction that we might like our customers to have is one kind of a direct expression of technological success, don't all of the other aspects of the product depend on the engineering, too?

Engineers have to meet the timetables and specifications that allow *delivery*. Selections of components, electronic and mechanical designs, and manufacturing techniques have an enormous effect on *price*. Skill and talent in crafting prototypes (and a willingness to use advice from the right sources) can tip the scale in favor of *looks*.

The 5% that the company president assigns to the technology factor actually calls engineers into play for the other factors as well. RF

THE ONLY SOURCE FOR RF AMPLIFIERS FOR...

EMC Test - *Amplifiers from 1 to 3000 Watts*
- EMC frequency spectrum from 10kHz to 1GHz and RF power levels to 3000 Watt CW
- Manual/remote control as well as GPIB interfacing of all front panel functions
- Output power may be set at user defined levels and saved without readjusting signal source
- VSWR protection guards against load mismatches and maintains a safe output level

Communications - *Amplifiers from 200 to 1000 Watts*
- Communication bands from 1 - 1000 MHz
- Model M200U-BPA covers UHF Satcom band
- Communication systems also cover HF
- Multi-band with built-in harmonic filters and T/R

Dual Band - *Amplifiers from 10 to 100 Watts*
- Coaxial relay switching permits use of two individual RF amplifiers in a single enclosure
- Common power supply, control circuits and I/O connections to yield a GPIB controllable ultra wideband amplifier greater than 16 octaves
- User-friendly, cost-effective

Distributed Tube - *Amplifiers from 200 to 2000 Watts*
- Power delivery into severe impedance mismatch without shutdown or foldback
- Solid state drivers
- 200, 250, 500, 1000 and 2000 Watts available

OEM Amplifier Modules - *1 to 250 Watts*
- Frequency ranges from 50 kHz to 1 GHz at power output levels to 250 Watts
- Available direct from stock or customized to meet specific application
- Proven reliable performance worldwide

For over 25 years, Kalmus has been providing RF Amplifiers to meet the needs of EMC test, medical device, communications and laboratory applications. Kalmus RF amplifiers are the choice of many manufacturers in their OEM applications. With a range of over 125 models, Kalmus has an amplifier to meet your specific requirements.

Kalmus
11807 N. Creek Parkway South
Suite #109
Bothell, WA 98011 USA
(800) 344-3341 • Tel: (206) 485-9000 • Fax: (206) 486-9657
http://www.thermovoltek.com • E-Mail: kalmus@kalmus.com

KALMUS
Thermo Voltek

In Europe, contact Onno de Meyer, European Regional Manager, EMC Products, Thermo Voltek
Tel: +31 71 541 3910 • Facsimile: +31 71 5 416 310

COMTEST • KALMUS • KEYTEK • PACIFIC POWER SOURCE • VERIFIER • UVC

INFO/CARD 6

RF design
engineering principles and practices

Established 1978

Editorial offices
5660 Greenwood Plaza Blvd., Suite 350
Englewood, CO 80111
303-793-0448; Fax 303-793-0454

Don Bishop, *Editorial Director*, 913-967-1741
Gregg V. Miller, *Technical Editor*
Patricia Werner, *Associate Editor*
Valerie J. Hermanson, *Art Director*
Ernest Worthman, *Contributing Editor*

Editorial Review Board
Andy Przedpelski, The Shedd Group, *Chairman*
Madjid A. Belkerdid, Univ. of Central Florida
Alex Burwasser, RF Products
Dave Krautheimer, MITEQ
Joe Gorin, Hewlett-Packard
Raymond Sicotte, American Microwave
Robert J. Zavrel, Jr., IBM

Intertec Publishing offices
9800 Metcalf Ave.
Overland Park, KS 66212-2215
913-341-1300; Fax 913-967-1898

Raymond E. Maloney, *President and CEO*
Cameron Bishop, *Senior Vice President*
Mercy Contreras, *Group Publisher*
Darren Sextro, *Publisher*
Tom Cook, *Senior Managing Editor*
Carl Bentz, *Directories Manager*
Nick Cavnar, *Vice President – Circulation*
Michele Bartlett, *Senior Circulation Manager*

Advertising Representatives
Midwest and West
AR, IA, IL, IN, KY, MI, MN, MO, ND, SD, NE, WI, AL, LA, MS, TN, AK, CO, ID, KS, MT, NM, NV, OK, OR, TX, UT, WA, WY, CA, AZ, HI, Ontario and Western Canada
Janell Count, 303-220-4291; Fax 303-793-0454
East
CT, DE, MA, ME, NH, NJ, NY, PA, RI, VT, OH, VA, WV, DC, MD, FL, GA, NC, SC, Quebec and Eastern Canada
Mike Henry, 703-257-1202; Fax 703-257-3215
Classified
Terri Stenson, 303-220-4288; Fax 303-793-0454

Barbara B. VanSickle, *Print Services Manager*
Sarah Barnes, *Advertising Production Coordinator*, 303-220-4275
Jennifer Vogt, *Senior Advertising Coordinator* for classified, 913-967-1820
Dee Unger, *Director Advertising Services*
Ed Laborwit, *Reprints Manager*, 770-618-0481
Lori Christie, *List Rental Manager*, 913-967-1875

Back issues printed since April 1996 are available for $10 postpaid from Intertec Publishing customer service. Call 800-441-0294 or 913-341-1300; Fax 913-967-1899. Photocopies are unavailable from the publisher.

Photocopies of individual articles and of entire issues can be ordered from UMI Information Store, 800-248-0360 or 415-433-5500 ext. 282; Fax 415-433-0100.

This publication is available on microfilm and microfiche from UMI, 300 N. Zeeb Road, Ann Arbor, MI 48106-1346. 800-521-0600 or 313-761-4700; Fax 313-677-0108.

Customer Service
800-441-0294

Subscription inquiries
847-647-0756; Fax 847-647-7543
P.O. Box 1147, Skokie, IL 60076

BPA INTERNATIONAL

INTERTEC PUBLISHING
A K-III MEDIA COMPANY

RF calendar

— 1997 —

February 10–14 Wireless Symposium and Exhibition—*Santa Clara, CA*. Information: Penton Publishing. Tel. 201-393-6256.

23–27 Nepcon West—*Anaheim, CA*. Information: Reed Exhibition Company, 383 Main Ave., Norwalk, CT 06852-6059. Tel. 800-467-5656; Web site: http://www.nepcon.reedexpo.com.

March 3–5 CTIA Wireless—*San Francisco*. Information: Dobson & Associates. Tel. 202-463-7905.

13–19 CeBIT '97 World Business Center: Office, Information and Telecommunications—*Hannover, Germany*. Information: Mette Fisker Peterson, Hannover Fairs USA, 103 Carnegie Center, Princeton, NJ 08540. Tel. 609-987-1202; Fax 609-987-0092.

17–20 European Design and Test Conference—*Paris*. Information: Conference Secretariat, CEP Consultants, 43 Manor Place, Edinburgh, EH3 7EB, United Kingdom. Tel. +44-131-300-3300; Fax +44-131-300-3400; E-mail edtc@cep.u-net.com.

April 14–17 International Conference on Antennas and Propagation—*Edinburgh*. Information: ICAP Secretariat, IEE Conference Services, Savoy Place, London WC2R 0BL, United Kingdom. Tel. +44 (0) 71-344-5467/5473; Fax +44 (0) 71-240-8830; E-mail lhudson@iee.org.uk or mswift@iee.orguk.

21–23 *RF Design* Seminar Series—*Las Vegas*. Information: Intertec Presentations, 6300 S. Syracuse Way, Suite 650, Englewood, CO 80111. Tel. 303-220-0600; Fax 303-770-0253.

22–24 International Wireless Communications Expo—*Las Vegas*. Information: Intertec Presentations, 6300 S. Syracuse Way, Denver, CO 80111. Tel. 800-288-8606 or 303-220-0600.
RF Pavillion—Manufacturers exhibits within IWCE. Components, test equipment, software and services for RF equipment manufacturing.

22–24 Convergence Tech and IC Expo for microelectronics, communications and computer professionals—*Dallas*. Information: Electronic Conventions Management, 8110 Airport Blvd., Los Angeles, CA 90045. Tel. 800-877-2668, ext. 243; Fax 310-641-5117.

23–26 Broadcast Technology—*Jakarta, Indonesia*. Information: Eileen Lavine, Information Services, 4733 Bethesda Ave., Suite 700, Bethesda MD 20814. Tel. 301-656-2942; Fax 301-656-3179.

May 5–7 Vehicular Technology Conference for cellular and mobile wireless communications—*Phoenix*. Information: Wendy Rochelle, Registrar, IEEE Conference Service, 455 Hoes Lane, P.O. Box 1331 Piscataway, NJ 08855-1331. E-mail w.rochelle@ieee.org.

6–8 Electronics Industries Forum of New England—*Boston*. Information: Linda Hanson. Tel. 914-779-0696.

13–16 Computer and Communication Electronics Design Exposition—*Dallas*. Information: Reed Exhibition, 383 Main Avenue, Norwalk, CT 06851. Tel. 800-840-5614.

28–30 IEEE International Frequency Control Symposium—*Orlando, FL*. Information: Wendy Ortega Henderson, National Institute of Standards and Technology, Time and Frequency Division, 325 Broadway, Boulder, CO 80303. Tel. 303-497-3593; Fax 303-497-6461; E-mail ortegaw@boulder.nist.gov.

June 1–5 Supercomm—*New Orleans*. Information: Telecommunications Industry Association. Tel. 202-326-7300.

9–14 Asia Telecom—*Singapore*. Information: Tom Dahl-Hansen, senior vice-president, Telecom. Tel. +41-22-730-5298; Fax +41-22-730-6444; E-mail. dahl-hansen@itu.ch.

10–12 International Microwave Symposium and Exhibition—*Denver*. Information: Horizon House. Tel. 617-769-9750.

11–13 Virginia Tech Symposium on Wireless Personal Communications—*Blacksburg, VA*. Information: Business Administrator, Jenny Frank, Mobile and Portable Radio Research Group, Virginia Polytechnic Institute, 840 University City Blvd., Pointe West Commons, Suite 1, Blacksburg, VA 24061-0350. Tel. 540-231-2958; Fax 540-231-2968; E-mail hilda@vt.edu; Web site: http://www.ee.vt.edu/mprg/home.html.

July 14–17 Image Processing and Applications—*Dublin*. Information: Sheila Griffiths, Conference Organizer, Institution of Electrical Engineers, Savoy Place, London WC2R 0BL, United Kingdom. Tel. +44 (0) 171-344-5475/72; Fax +44 (0) 171-240-8830; E-mail kmoorley@iee.org.uk.

September 9–11 *RF Design* Seminar Series—*Santa Clara, CA*. Information: Intertec Presentations, 6300 S. Syracuse Way, Suite 650, Englewood, CO 80111. Tel. 303-220-0600; Fax 303-770-0253.

10–12 RF Design '97—*Santa Clara, CA*. Information: Renie Mayfield, Intertec Presentations, 6300 S. Syracuse Way, Denver, CO 80111. Tel. 800-288-8606 or 303-741-0215.

22–24 Connector and Interconnection Technology Symposium—*Anaheim, CA*. Information: Chairman, IICIT, P.O. Box 880, Westfield, NJ 07090. Tel. 800-854-4248; Fax 908-233-5116; E-mail IICITDIR@msn.com.

RF courses

Arizona State University—*Global System for Mobile Communication*—Jan. 14–17, 1997. Information: Professional Development, ASU, P.O. Box 877506, Tempe, AZ 85287-7506. Tel. 602-965-1740; Fax 602-965-8653.

Besser Associates—*RF and Wireless Made Simple*—Jan. 13–14, 1997; *Applied RF Techniques I*–Jan. 13–17; *Modern Computer Communications*–Jan. 13–18; *RF Impedance Matching and Component Models*–Jan. 14; *RF Productivity Improvement*–Jan. 15–17; *RF Small-signal Amplifiers*–Jan. 17; *RF Receivers*–Jan. 20; *EM Field Simulator Made Practical*–Jan. 20–21; *Antennas for Wireless Applications*–Jan. 20–21; *EMC and EMI Engineering and Design*–Jan. 20–23; *Applied RF Techniques II*–Jan. 20–24; *Wireless RF System Design*–Jan. 20–24; *RF Oscillators*–Jan. 21; *RF Mixers and Applications*–Jan. 22; *Error Correction Coding and Multiple Access Techniques*–Jan. 22; *RF Power and High-efficiency Amplifiers*–Jan. 23–24; *RF Measurement Techniques*–Jan. 27–30. Information: Besser Associates, 4600 El Camino Real, Suite 210, Los Altos, CA 94022. Tel. 415-949-3300; Fax 415-949-4400; E-mail BesserCourse@delphi.com.

Celwave University—Marlboro, NJ. Modules offered include: *Antenna Basics, Advanced Theory, Towertop Amplifiers, Bidirectional Amplifiers, Filters and Combiners.* Information: Gail Magid, Sales Engineering Department, Celwave, 2 Ryan Road, Marlboro, NJ 07746-1899. Tel. 800-235-9283.

CKC Laboratories—*Immunity to ESD*—Feb. 3, 1997, Seattle; May 12, Orange County, CA; *CE Mark Design and Compliance Routes*—Feb. 4–5, Seattle; May 13–14, Orange County, CA; *Core EMC Design*—Jan. 14–15, Orange County, CA; March 11–12, Fremont, CA; June 17–18, Hillsboro, OR; *EMC for Medical Electronics*—April 22–23. Information: Linda Grunow or Todd Robinson, CKC Laboratories, 5473-A Clouds Rest, Mariposa, CA 95338. Tel. 800-500-4362 or 209-966-5240; Fax 209-742-6133; E-mail lgrunow@ckc.com.

Georgia Tech Continuing Education—*Radar Signal Processing: Theory and Application*–Jan. 28–31, 1997; *Coherent Radar Performance Estimation*–Feb. 3–6; *Antenna Engineering*–Feb. 3–7; *Principles of Pulse Doppler Radar: High, Medium and Low PRF*–Feb. 11–13; *Introduction to Radar Target Identification*–Feb. 25–28. Information: Department of Continuing Education, Georgia Institute of Technology, Atlanta, GA 30332-0385. Tel. 404-894-2547; E-mail conted@gatech.edu; Web site http://www.conted.gatech.edu.

Learning Tree International—*Wireless Networks and Mobile Communications*—Dec. 17–20, Jan. 14–17, 1997, Feb. 18–21 Washington. Information: Learning Tree International, 1805 Library St., Reston, VA. Tel. 800-850-9197 or 703-709-9119; E-mail uscourses@learningtree.com; Web site http://learningtree.com.

Mead Microelectronics—*Architectural and Circuit Design for Portable Electronics Systems* (3-days digital, plus 3-days analog)—March 31–April 5, 1997; *RF IC Design for Wireless Communication Systems*–May 12–16; *Data Communication ICs*–May 14–16. Information: Mead Microelectronics, 7100 Grandview Dr., Corvallis, OR 97330. Tel. 541-758-0828; Fax 541-752-1405. In Europe, contact Mead Microelectronics, Venoge 7, 1025 St. Sulpice, Switzerland. Tel. +41-21-691-0244; Fax +41-21-691-0245; E-mail mead@netgate.net; Web site http://www.netgate.net/~mead.

***RF Design* Seminar Series**—April 21–23, Las Vegas; Sept. 9–11, Santa Clara, CA. Information: Intertec Presentations, 6300 S. Syracuse Way, Suite 650, Englewood, CO 80111. Tel. 303-220-0600; Fax 303-770-0253.

Technology International—*Achieving and Maintaining Compliance with the Medical Devices Directive*—Jan. 14–15, 1997, Denver; Feb. 11–12, Dallas. Information: Kristin Eckhardt, Technology International, 609 Twin Ridge Lane, Richmond, VA 23235, Tel. 804-560-5334; Fax 804-560-5342; E-mail Eckhardt@TechIntl.com.; Web site www.TechIntl.com.

Tektronix—*CDMA Modulation Technologies and Measurements; Deploying Digital Transmission in Cabled Networks; TDMA (IS-136 and PCS 1900) Technologies and Measurements*—Two-day seminars; Jan. 20–21, Los Angeles; Jan 23–24, Santa Clara, CA; Jan. 27–28, Seattle; Jan. 30–31, Vancouver. Information: Tel. 800-763-3133; Fax 800-835-0025; E-mail TEKFORM2@TEK.COM; Web site http://www.tek.com.

University of Oxford—*RF and Microwave Design*—Jan. 6–10, 1997. Information: Helen Starkey, CPD Centre, University of Oxford, Department for Continuing Education, 67 St. Giles, Oxford, OX1 3LU, United Kingdom. Tel.+44-(0) 1865-288170/3; Fax +44 (0) 1865-288163; E-mail helen.staskey@conted.oxac.uk.

Z Domain Technologies—*DSP Without Tears*—Jan. 15–17, 1997. Information: Z Domain Technologies, 555 Sun Valley Drive, Suite A4, Roswell, GA 30076. Tel. 800-967-5034 or 770-587-4812. Fax 770-518-8368; E-mail dsp@zdt.com; Web site http://www.zdt.com/~dsp.

IBOC system withdrawn from field testing

AT&T, Lucent Technologies and Amati Communications informed the Consumer Electronics Manufacturers Association (CEMA) that they are removing their in-band and on-channel (IBOC) digital audio radio (DAR) system from field-testing consideration because no acceptable testing facility is available. The National Association of Broadcasters (NAB) had agreed to find a San Francisco radio station willing to host the experiments, but was unable to find a volunteer station. The AT&T, Lucent Technologies and Amati Communications IBOC system joins those systems proposed by U.S.A. Digital Radio, which last May also elected to remove its systems from further testing and evaluations.

The events follow the release of laboratory test data last year that revealed poor performance of IBOC DAR systems' audio quality, degradation of the host analog signal, limited digital coverage, and interference caused to existing broadcast stations. Some believe that these results show fundamental design problems with IBOC systems. Proponents say redesigns may be needed, but it is unclear as to whether system changes can cure these critical deficiencies.

Contracts:

Comsat to supply antennas for Sprint PCS project—Comsat RSI Mark Antennas has agreed with Black & Veatch and MFS Network Technologies to supply antennas for the Sprint Spectrum digital wireless personal communications services (PCS) project.

Richardson to distribute Siemens' products—Richardson Electronics has formed a relationship with Siemens Components to distribute Siemens' line of RF and wireless products in North America. Richardson will distribute four key families of Siemens RF products. These include RF integrated circuits, such as phase-locked loops (PLLs), mixers, low-noise amplifiers (LNAs) and modulators; the Siemens grounded emitter transistor (SIEGET) high-speed bipolar RF transistor family; the RF diode family of products such as PIN, varactor and Schottky diodes; and Siemens' gallium arsenide (GaAs) discrete and monolithic microwave integrated circuits (MMIC) components. These products are aimed at such markets as PCS and industrial, scientific and medical bands (ISM)-based technology, as well as cellular and cordless telephony.

Contract for precision compact range reflectors—Electronic Space Systems, Concord, MA, has been awarded a $1.3 million contract to fabricate and install a precision compact range reflector that will operate at frequencies as low as 300 MHz. Jointly designed by National Aeronautics and Space Administration (NASA) Langley and the Electroscience Laboratory at Ohio State University, the 26' × 26' compact range reflector is intended to demonstrate new technologies in compact range design. It will be used for indoor radar cross-sectional measurements of electrically small reflectors. The new compact range reflector will be smaller in size and will operate at lower frequencies than traditional compact range reflectors.

Business Briefs

FTC facility will increase flip chip capacity—Flip Chip Technologies (FCT), a joint venture between Delco Electronics and Kulicke & Soffa Industries, will open its new production facility in Phoenix, which will quadruple its wafer bumping facility. FCT will use Delco's proprietary Flex On Cap (FOC) solder-bumping process, a technology that has produced more than 300,000 flip chips a day. The new facility will have 36,000 square feet of production and office space and 55 employees.

Anadigics gets clean room—Anadigics is constructing a 10,000-square-foot clean room for the production of gallium arsenide (GaAs) integrated circuits. The clean room will occupy part of the company's new manufacturing space next to its headquarters in Warren, NJ. The expansion will revive a 131,000 square foot building and create more than 250 high-skilled, high-technology jobs. Wafer production capacity will double. The company intends to run 4" GaAs wafers, but the new equipment will be upgradable to 6" wafer production.

Dielectric expands facility—Dielectric Laboratories broke ground for a 23,000-square-foot expansion to its current facility. The addition will allow the company to double its current output of single and multilayer ceramic capacitors, substrates and other passive components for the high-frequency electronics and communications market.

Analog Devices and Sawtek join forces—Analog Devices and Sawtek will collaborate on the development of next-generation infrastructure components for cellular base stations used in global system for mobile communications (GSM) and its variants, PCS1900 and DCS1800. The joint development effort will focus on advanced receiver technology and will result in a new generation of GSM standards-compliant chips and reference designs incorporating surface acoustic wave (SAW) technology.

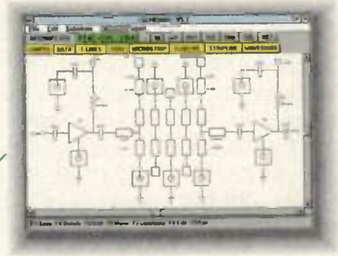
Xtalonix expands capacity—Previously serving military applications, Xtalonix, Columbus, OH, has expanded its manufacturing capacity to meet the growing private sector demand for high-volume, ceramic-based dielectric resonator materials, ferrites and garnets, typically used in microwave and wireless communication devices.

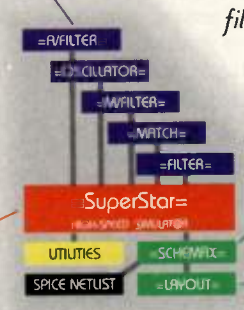
Ansoft acquires MSC's business unit—Ansoft has acquired the electronics business unit from MacNeal Schwendler for $5.6 million in cash.

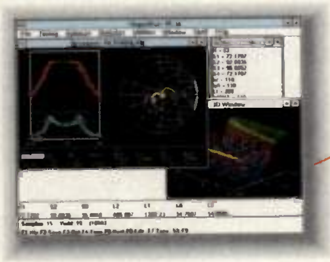
DESIGN FROM START-TO-ART

1 GENESYS synthesis modules make it easy to create initial designs for L-C filters, matching networks, active filters, oscillators, printed and machined filters, amplifiers and group delay equalizers. The many design alternatives and quick evaluation of each help you save time and achieve higher performance.

2 Schematics make it easy to enter your own designs, modify synthesis created designs and merge subcircuits. Schematics and simulation are integrated for back annotation. The GENESYS schematic module also writes Touchstone and Spice files.







3 =SuperStar= Professional redefines the circuit simulator standard. Step up to real-time tuning, statistical analysis, unrestricted global noise analysis, adaptive optimization, accurate models, unparalleled execution speed and the industry's easiest to use interface. Non-linear and time domain analysis is supported through the Spice interface.

NEW!

4 The new layout module creates artwork on your plotter or printer and in DXF (AutoCad) and optimized Gerber file formats. Discontinuity and transmission line dimensioning, coplanar ground pours, multilayers, arbitrary polygons and user footprint libraries make RF and microwave layout easier than ever before.

EAGLEWARE

11th Anniversary

Our first program shipped in 1985. Today, with thousands of users worldwide, Eagleware is a recognized leader in RF and microwave design software for IBM and compatible PCs. Here are a few reasons why we feel GENESYS provides unequaled value:

- Start-to-art solution including synthesis
- One easy to learn interface for all programs
- Industry's fastest execution means less waiting
- Accuracy verified with in-house lab
- Reads industry standard S-parameter files
- Free technical support with no annual fees
- Low cost
- 30 day money back satisfaction guarantee

Eagleware products run on standard IBM and compatible PCs under DOS, Windows 3.1, Windows NT and Windows 95. Windows versions are 32-bit for even faster execution.

GENESYS

VERSION 5.4

=SuperStar= Professional simulator	$999
Simulator with schematic entry and layout	$1990
Complete GENESYS package with synthesis	$5990
Layout upgrade for current customers	$699

(Upgrade discounts available for a limited time)

日本のお問い合わせ先
テクダイヤ株式会社
170 東京都豊島区東池袋3-1-1
TEL 03-3988-1731 FAX 03-3988-1706

SAME PRICES INTERNATIONALLY
DIRECT SALES & USER SUPPORT
BY FAX, PHONE OR LETTER

EAGLEWARE

Eagleware Corporation ★ 1750 Mountain Glen ★ Stone Mtn, GA 30087 ★ USA

http://www.eagleware.com ★ eagleware@eagleware.com

TEL (770) 939-0156 ★ FAX (770) 939-0157

RF in industry

By Ernest Worthman

Earlier this year, Congress, in what may have been one of the most sweeping pieces of legislation of the decade, enacted the Telecommunications Act of 1996. The deregulatory aspects of this act will intimately affect every part of the telecommunications industry. Although it is likely to be several years before the effect of the legislation becomes noticeable, there are already a number of promising opportunities for RF technologies.

For example, it is likely that new technologies such as voice over the Internet, and digital satellite systems (DSSs) will compete for direct access to the home or office, a domain long coveted by the local service providers. Additionally, cable companies will offer both wirelines and wireless telephone services, and telephone companies will offer cable service. It is also likely that the developing technologies such as personal communications services (PCS) and low-earth orbit (LEO) communications will jockey for position in non-traditional markets such as wireless networking.

Depending on who you talk to, there is much speculation that this legislation will be either the second coming or the antichrist. One school of thought is that the big players will gobble up every promising technology, be it RF, data, fiber or whatever and merge into one ubiquitous service provider. On the other side of the fence is the thought that this legislation will force everyone to come to the table and try to work out complementary partnerships where everyone can coexist peacefully.

Either way, the RF industry is likely to benefit for the following reasons.

First of all, this is the '90s, an intense worldwide business atmosphere. Any technology that can support efficiency and cost containment is likely to succeed. Take, for example, radio frequency identification (RFID) and radio frequency data communications (RFDC). One application for RFID and RFDC is to provide real-time, online inventory and process control in manufacturing. This increases inventory accuracy and throughput in warehousing and distribution operations, and it increases productivity on the shop floor. When RFDC systems are integrated with a warehouse management software control system, the results can be linked, worldwide, to other locations or even to other suppliers. And what will the link be? Traditional wireline? Satellite? LEO? PCS? Internet? It is an interesting point to ponder.

Second, the integration of computers and communications (a technology that, a few years ago, I dubbed "computeradio") is a given. Untethered data transmission is the next wave. Just look at the GTE wireless PageCard, for example. In a typical point-to-point transmission, data may flow over any number of wireline or wireless technologies. The future belongs to those who can move information quickly and accurately, whatever the medium. Given the fact that current wireline infrastructure is aging, and bandwidth is limited, it seems logical for business to look to RF for solutions.

And third, unrelated to the telecommunications industy, RF is showing up in unlikely places. RF technology is being used to heat, dry and seal products such as textiles, leather, plastics and ceramics. In these applications it saves money and time over conventional oven-drying methods.

Whichever way it goes, RF's presence in industry is almost assured. Developing digital technologies, a driving thirst for information exchange, the compelling need for a lean, mean manufacturing machine and innovative implementation will see to it. **RF**

As a closing note, this will be the last Industry Insight column as you have come to know it. Beginning with the next issue, the industry insight concept will be integrated into the cover story, bringing you timely and pertinent coverage of RF technologies in the brave new world. Having been given the assignment to write many of the 1997 cover stories, I look forward to the challenge of providing RF Design *readers with informative, interesting and relevant articles.*

With our new PC software, high-frequency design is almost this easy.

HEWLETT® PACKARD

Introducing HP EEsof Series IV/PC: Total integration from a single software package.

Okay, so you can't get your high-frequency designs all the way to production just by pointing and clicking. But thanks to HP EEsof Series IV/PC, designing for manufacturability is almost that simple.

You see, HP EEsof Series IV/PC is a truly integrated high-frequency circuit design solution, bringing schematic capture, simulation, analysis and layout together in a single software package. That means you can now simulate and tune your designs directly from layout. And you only have to learn one tool.

HP EEsof also features the world's largest parts libraries — over 90,000 models in all. So you not only get the highest performance simulators money can buy, you get the accurate models you need.

In fact, the Discrete Value Optimizer lets you fully analyze your designs with actual, not theoretical, parts. Making product development time shorter than ever.

For more information on Series IV/PC, or the other innovative solutions HP EEsof is bringing to high-frequency design, call **1-800-452-4844, Ext. 1396*** or your local sales representative today for a free brochure.

Taking your designs from concept to production has never been easier.

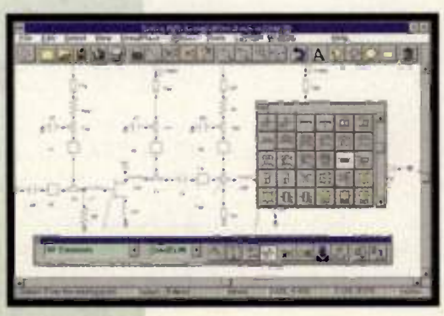
There is a better way.

*In Canada, call 1-800-276-8661, Dept. 255.

http://www.hp.com/go/info/sivpc

INFO/CARD 52

HP EEsof Series IV/PC lets you solve real world problems using real world parts.



Bias-circuit methods to reduce process and temperature variations in GaAs MESFET ICs are compared

By Joe Staudinger

In volume production of RF and microwave integrated circuits, such as low-noise amplifiers, implementing an integrated-bias method on the circuit to provide a constant quiescent current in response to process and temperature variations is critical for achieving uniform (part-to-part) RF performance characteristics. RF characteristics including gain, noise-figure and efficiency strongly are correlated to the device's quiescent current. Process variances in field effect transistor (FET) threshold voltage, and to a lesser extent in β, usually are the most significant parameters affecting the bias point. The following information examines three methods of biasing gallium arsenide metal semiconductor field effect transistor (GaAs MESFET) circuits to reduce the effect of processing and possibly temperature variations on quiescent current. These include: fixed bias, source-resistance feedback, and gate- and source-resistance feedback. Both simulation and measured data demonstrate that the latter technique can provide superior performance.

The RF performance characteristics of GaAs MESFET devices are highly sensitive to the quiescent operating condition (primarily the quiescent drain current). For example, noise figure, gain and the device's reflection coefficients vary considerably with quiescent drain current. Thus, in high-volume manufacturing of GaAs MESFET-based circuits, such as low-noise amplifiers (LNAs), achieving uniform part-to-part RF performance requires provisions to account for biasing differences that arise from processing tolerances. Similarly, these characteristics tend to be temperature sensitive as well, and it is desirable to minimize any temperature dependence.

Stabilizing the bias point with GaAs processing and temperature is usually achieved with some type of bias circuit, located either on or off chip. Numerous high-performance, off-chip methods are possible, but cost and size limit their usefulness in commercial applications. Although physically smaller and less expensive, on-chip solutions tend to be based on simpler techniques and thus often exhibit limited performance.

The intent of this work is to benchmark three GaAs MESFET bias-circuit methods suitable for integration on a GaAs monolithic microwave integrated circuit (MMIC) chip. These methods include: *fixed bias*, *source-resistance feedback*, and *a combination gate and source-resistance feedback* technique. All three methods are used in conjunction with a small (400 µm gate width) enhancement mode (positive-threshold voltage) GaAs MESFET. A number of wafers from several lots containing all three circuits were fabricated with significantly varying MESFET parameters, including threshold voltage, gate length and current I_{DSS}. Bias-circuit performance was measured and the results contrasted for each of the three circuit methods.

Process and temperature effects

Some insight into the bias circuit's response to both temperature and process variations can be observed by using a large signal model description of a GaAs MESFET. Based on the selected model, drain current variances can be determined by considering the dependence of the constituent model parameters with processing and temperature. This assumes that model parametric dependence with temperature and process is known, which is a rather extensive characterization task. Even if these dependencies are not known precisely, general bias-circuit performance trends still can be observed.

Certainly a number of large signal MESFET models are available, ranging from physically-based models (those using physical and geometrical properties) to simpler, empirical models, defined by a particular functional form [1]. For simplicity, a traditional empirical model (Curtice) is chosen for this

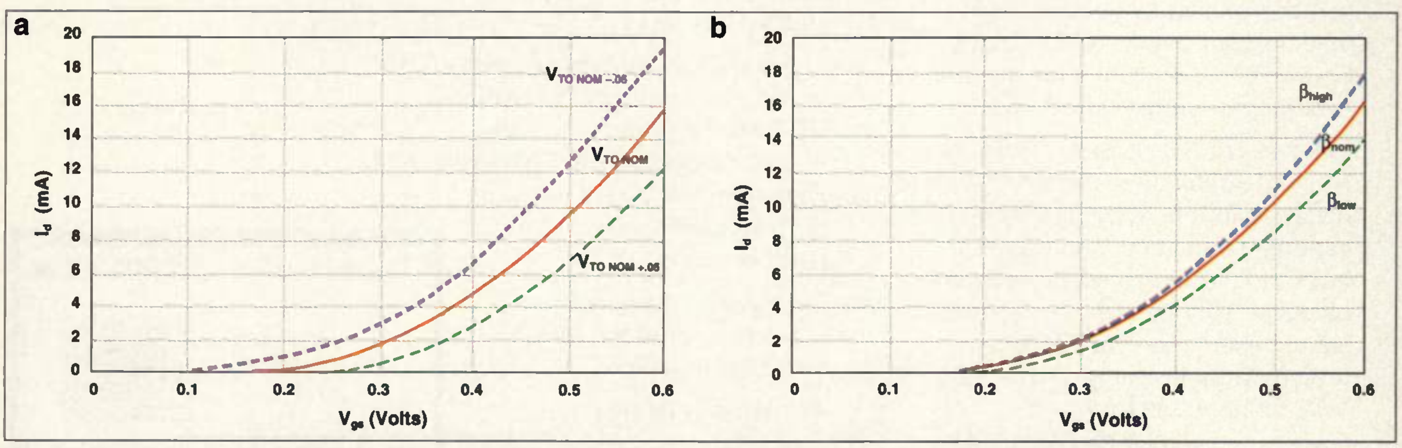


Figure 1. Effect of β and V_{TO} on the DC I-V characteristics of an enhancement mode GaAs MESFET a) β dependence, and b) V_{TO} dependence.

FILTERS

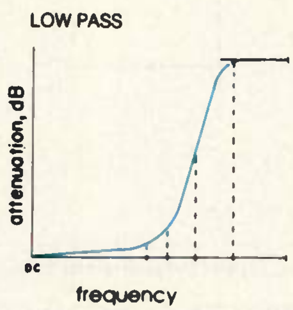
low pass, high pass, bandpass

• less than 1dB insertion loss • greater than 40dB stopband rejection • surface mount • BNC, Type N, SMA available • 5-section, 30dB/octave rolloff • VSWR less than 1.7(typ.) • rugged hermetically sealed pin models • constant phase • meets MIL-STD-202 tests • over 100 off-the-shelf models • immediate delivery

Mini-Circuits RF/IF Surface Mount Designer's Guide features 48 pages of the most up-to-date and complete product and specification information about Mini-Circuits surface mount components. The RF/IF Microwave Handbook is packed with 740 pages of articles, selection guides and detailed specifications for Mini-Circuits components.

Call, write or fax for your free Surface Mount Designer's Guide and Handbook today!

dc to 3GHz from $11⁴⁵



low pass, Plug-in, dc to 155MHz

Model No.	Passband MHz loss < 1dB	Stopband, MHz loss > 20dB	Stopband, MHz loss > 40dB
•★LP-1.9	DC-1.9	3.4-4.7	4.7-200
•★LP-2.5	DC-2.5	3.8-5.0	5.0-200
★LP-5	DC-5	8-10	10-200
★LP-10.7	DC-11	19-24	24-200
★LP-21.4	DC-22	32-41	41-200
★LP-30	DC-32	47-61	61-200
★LP-50	DC-48	70-90	90-200
★LP-70	DC-60	90-117	117-300
★LP-90	DC-81	121-157	157-400
★LP-100	DC-98	146-189	189-400
★LP-150	DC-140	210-300	300-600

dc to 1200MHz

Model No.	Passband MHz loss < 1dB	Stopband, MHz loss > 20dB	Stopband, MHz loss > 40dB
★LP-200	DC-190	290-390	390-800
★LP-250	DC-225	320-400	400-1200
★LP-300	DC-270	410-550	550-1200
★LP-450	DC-400	580-750	750-1800
★LP-550	DC-520	750-920	920-2000
★LP-600	DC-680	840-1120	1120-2000
★LP-750	DC-700	1000-1300	1300-2000
★LP-800	DC-720	1080-1400	1400-2000
★LP-850	DC-780	1100-1400	1400-2000
★LP-1000	DC-900	1340-1750	1750-2000
★LP-1200	DC-1000	1620-2100	2100-2500

All models priced qty. 1-9 ($ea.), Conn. Type P = 11.45, B = 32.95, S = 34.95, N = 35.95
• Exceptions: ★LP-1.9 P = 13.95, B = 34.95, ★LP-2.5 P = 14.95, B = 35.95
On both models, add following to B price: $3.00 for N, $2.00 for S
75 ohm versions available

Surface-mount

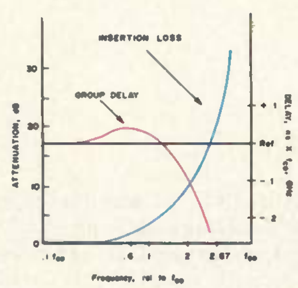
dc to 108MHz

Model No.	Passband MHz loss < 1dB	Stopband, MHz loss > 20dB	Stopband, MHz loss > 40dB
SCLF-5	DC-5.0	8-10	10-200
SCLF-8	DC-8.0	12.5-16.5	16.5-200
SCLF-10.7	DC-11	19-24	24-200
SCLF-21.4	DC-22	32-41	41-200
SCLF-25	DC-25	36-47	47-200
SCLF-30	DC-30	47-61	61-200
SCLF-45	DC-45	70-90	90-200
SCLF-95	DC-95	146-189	189-400

dc to 1200MHz

Model No.	Passband MHz loss < 1dB	Stopband, MHz loss > 20dB	Stopband, MHz loss > 40dB
SCLF-135	DC-135	210-300	300-600
SCLF-190	DC-190	290-390	390-800
SCLF-225	DC-225	340-440	440-1200
SCLF-380	DC-380	580-750	750-1800
SCLF-420	DC-420	750-920	920-2000
SCLF-550	DC-550	800-1050	1050-2000
SCLF-700	DC-700	1000-1300	1300-2000
SCLF-1000	DC-1000	1620-2100	2100-2500

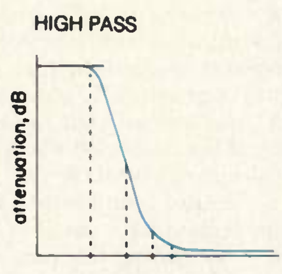
Price: SCLF 21.4–SCLF 420 $11.45 ea. SCLF-8, 10.7, 550, 700, 1000 $12.95 ea. SCLF-5 $14.95 Qty. (1-9)



Flat Time Delay, dc to 1870MHz

Model No.	Passband MHz loss < 1.2dB	Stopband MHz loss >10dB	Stopband MHz loss >20dB	VSWR Freq. Range, DC thru 0.2fco X	VSWR Freq. Range, DC thru 0.6fco X	Group Delay Variations, ns Freq. Range, DC thru fco X	Group Delay Variations, ns Freq. Range, DC thru 2fco X	Group Delay Variations, ns Freq. Range, DC thru 2.67fco X
★BLP-39	DC-23	78-117	117	1.3:1	2.3:1	0.70	4.0	5.00
★BLP-117	DC-65	234-312	312	1.3:1	2.4:1	0.35	1.4	1.90
★BLP-156	DC-94	312-416	416	1.3:1	1.1:1	0.30	1.1	1.50
★BLP-200	DC-120	400-534	534	1.6:1	1.9:1	0.40	1.3	1.60
★BLP-300	DC-180	600-801	801	1.25:1	2.2:1	0.20	0.6	0.80
★BLP-467	DC-280	934-1246	1246	1.25:1	2.2:1	0.15	0.4	0.55
▲BLP-933	DC-560	1866-2490	2490	1.3:1	2.2:1	0.09	0.2	0.28
▲BLP-1870	DC-850	3740-5000	5000	1.45:1	2.9:1	0.05	0.1	0.15

Price, (1-9 qty), all models: plug-in $19.95, BNC $36.95, SMA $38.95, Type N $39.95
NOTE: ▲ -933 and -1870 only with N and SMA connectors.



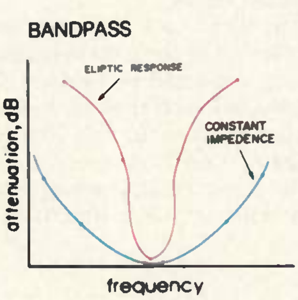
high pass, Plug-in, 13 to 1200MHz

Model No.	Stopband MHz loss > 40dB	Stopband MHz loss > 20dB	Passband, MHz loss < 1dB	VSWR Passband Typ.
★HP-25	DC-13	13-19	27.5-200	1.7:1
★HP-50	DC-20	20-26	41-200	1.5:1
★HP-100	DC-40	40-55	90-400	1.5:1
★HP-150	DC-70	70-95	133-600	1.8:1
★HP-175	DC-70	70-105	160-800	1.5:1
★HP-200	DC-90	90-116	185-800	1.6:1
★HP-250	DC-100	100-150	225-1200	1.3:1
★HP-300	DC-145	145-190	†290-1200	1.7:1

210 to 2200MHz

Model No.	Stopband MHz loss >40dB	Stopband MHz loss > 20dB	Passband, MHz loss < 1dB	VSWR Passband Typ.
★HP-400	DC-210	210-290	395-1600	1.7:1
★HP-500	DC-280	280-365	500-1600	1.9:1
★HP-600	DC-350	350-440	600-1600	2.0:1
★HP-700	DC-400	400-520	700-1800	1.6:1
★HP-800	DC-445	445-570	780-2000	2.1:1
★HP-900	DC-520	520-660	910-2100	1.8:1
★HP-1000	DC-550	550-720	1000-2200	1.9:1

Price, (1-9 qty), all models: plug-in $14.95, BNC $36.95, SMA $38.95, Type N $39.95. For ★HP-25, Add $2 ea. †Loss 1.5 dB max.



bandpass, Elliptic Response, 10.7 to 70MHz

Model No.	Center Freq. (MHz)	Passband I.L. 1.5 dB Max. (MHz)	3 dB Bandwidth Typ. (MHz)	Stopbands I.L. > 20dB at MHz	Stopbands I.L. > 35dB at MHz
★BP-10.7	10.7	9.5-11.5	8.9-12.7	7.5 & 15	0.6 & 50-1000
★BP-21.4	21.4	19.2-23.6	17.9-25.3	15.5 & 29	3.0 & 80-1000
★BP-30	30.0	27.0-33.0	25-35	22 & 40	3.2 & 99-1000
★BP-60	60.0	55.0-67.0	49.8-70.5	44 & 79	4.6 & 190-1000
★BP-70	70.0	63.0-77.0	58.0-82.0	51 & 94	6.0 & 193-1000

Price, (1-9 qty), all models: plug-in $18.95,
BNC $40.95, SMA $42.95, Type N $43.95

Constant Impedance, 21.4 to 70MHz

Model No.	Center Freq. MHz	Passband MHz loss < 1dB	Stopband loss > 20dB at MHz	VSWR 1:3:1 Total Band MHz
★IF-21.4	21.4	18-25	1.3 & 150	DC-220
★IF-30	30.0	25-35	1.9 & 210	DC-330
★IF-40	42.0	35-49	2.6 & 300	DC-400
★IF-50	50.0	41-58	3.1 & 350	DC-440
★IF-60	60.0	50-70	3.8 & 400	DC-500
★IF-70	70.0	58-82	4.4 & 490	DC-550

Price, (1-9 qty), all models: plug-in $14.95,
BNC $36.95, SMA $38.95, Type N $39.95

NOTE: **★Add Prefix P, B, N, or S for Pin, BNC, N, or SMA connector requirement.**

Mini-Circuits®

US ● INT'L 74
CIRCLE READER SERVICE CARD

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

For detailed specs on all Mini-Circuits products refer to • 740- pg. HANDBOOK • INTERNET • THOMAS REGISTER • MICROWAVE PRODUCT DATA DIRECTORY • EEM

CUSTOM PRODUCT NEEDS...Let Our Experience Work For You.

F 200 Rev Orig

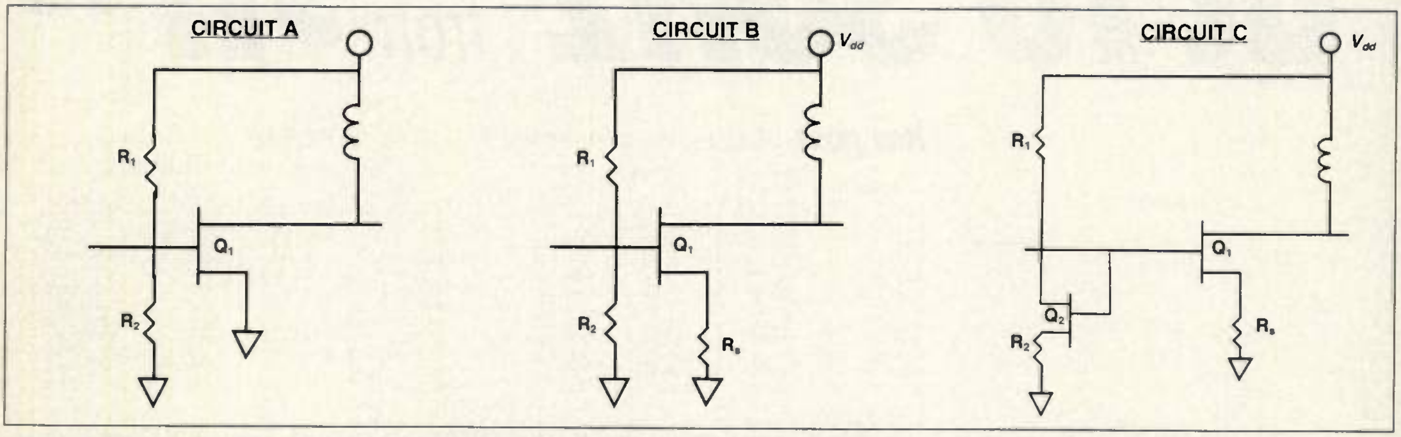


Figure 2. Circuit diagram of the three bias methods considered. a) voltage-divider, b) source-feedback resistance, c) gate- and source-resistance feedback.

work. Per the Curtice model, drain current is described as a function of intrinsic gate-source and drain-source voltages and four parameters (α, β, λ, and V_{TO}). Thus, we have:

$$I_{ds} = \beta\left(V_{gs} - V_{TO}\right)^2\left(1 + \lambda V_{ds}\right)\tanh\left(\alpha V_{ds}\right) \tag{1}$$

Parameter λ describes the device's output conductance. The α term primarily describes the knee region (I_{ds} - V_{ds}). The term V_{TO} defines the threshold voltage. β relates to current gain. If we assume that the device is biased above the knee region (i.e., at V_{ds} of several volts), the two most significant parameters affecting drain current are β and V_{TO}. Figure 1 illustrates the effects that both V_{TO} and β have on the I_{ds} - V_{gs} characteristics of the device. In this case, the device is an enhancement mode MESFET with a nominal threshold voltage of 0.15 V. Changes in either V_{TO} or β can result in significantly different drain currents for a given gate-source voltage.

Bias circuits

We will consider the three circuits shown in Figure 2. The first circuit (Circuit A) is based on a simple voltage-divider method where R_1 and R_2 establish a voltage on the device's gate terminal. The dependence of I_{ds} with β and V_{TO} can be observed by calculating the derivative of Equation 1 with respect to β and V_{TO}. For simplicity, we can assume that the device operates with a drain-source voltage of several volts. If secondary effects from λ and α are neglected, the derivatives are given as:

$$\frac{\partial I_{ds}}{\partial \beta} \cong \left(V_{gs} - V_{TO}\right)^2 \tag{2}$$

$$\frac{\partial I_{ds}}{\partial V_{TO}} \cong 2\beta\left(V_{gs} - V_{TO}\right) \tag{3}$$

The second circuit (Circuit B) is based on using the traditional source feedback resistance R_s connected between the device's source terminal and ground. In addition, because we are considering devices with positive-threshold voltages, a resistive divider network is used to raise the gate voltage above zero. Although the dependence of I_{ds} with β and V_{TO} can be determined in a manner similar to the above, a graphical approach illustrates the performance sensitivity in a simple manner. Figure 3 graphically shows this dependence by plotting the DC load line with the device's I-V characteristics. The intercept of the load with the I_{ds} - V_{gs} curves determines the quiescent current level. Better performance is obtained with this technique compared to the previous method. Additional improvements are possible either by increasing the value of R_S or by raising the gate-voltage offset or both. Be aware that in doing so, the device's drain-source voltage either is reduced or V_{dd} also must be increased (or both) to maintain the same value.

The third circuit (Circuit C) uses a source resistor along with a second FET Q_2 located in the gate-resistor divider network. Device Q_2 is scaled to a small percentage of Q_1, and resistors R_1 and R_2 are selected such that Q_2 operates at a low drain-source voltage (few tenths). In this manner, Q_2 functions as a variable resistor that is dependent on β and V_{TO}. This can be observed by considering the output conductance of device Q_2, which by differentiating Equation 1 results in the following:

$$gds = \frac{\partial Ids}{\partial Ids} = \beta(Vgs - VTO)^2(1 + \lambda Vds)\left(\frac{\alpha}{\cosh^2(\alpha Vds)}\right) + \beta(Vgs - VTO)^2\lambda\tanh(\alpha Vds) \tag{4}$$

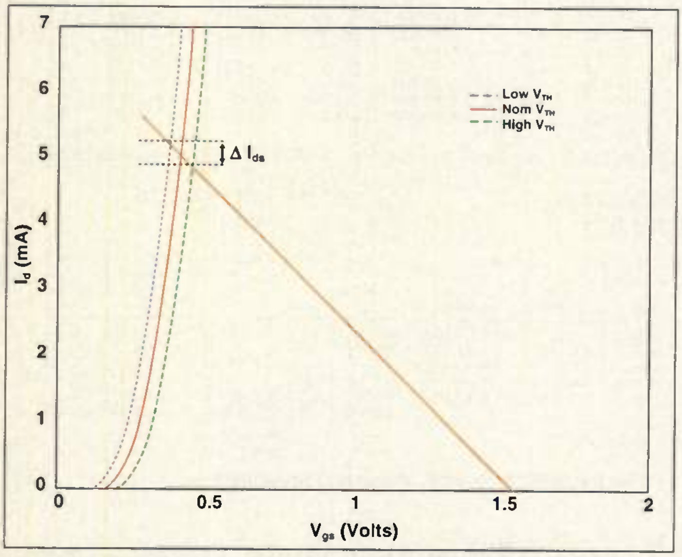


Figure 3. Performance of bias method (Circuit B) due to change in β and V_{TO}.

If both Q_1 and Q_2 are fabricated monolithically (i.e., are on

NEW ERA AMPLIFIERS

WOW! DC to 8GHz
(up to +19dBm output)

From $1.19 (1000 qty.)

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

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

Model	*Freq. (MHz)	Gain (dB)	Max. Power Out (dBm, @ 1dB Comp)	Dynamic Range NF(dB)	Dynamic Range IP3(dBm)	①Price $ ea. (10 Qty.)
ERA-1	DC-8000	11.6	13.0	7.0	26	1.80
ERA-1SM	DC-8000	11.0	13.0	7.0	26	1.85
ERA-2	DC-6000	14.9	14.0	6.0	27	1.95
ERA-2SM	DC-6000	13.1	13.0	6.0	27	2.00
ERA-3	DC-3000	20.2	11.0	4.5	23	2.10
ERA-3SM	DC-3000	19.4	11.0	4.5	23	2.15
ERA-4	DC-4000	13.9	▲19.1	5.2	▲36	4.15
ERA-4SM	DC-4000	13.9	▲19.1	5.2	▲36	4.20
ERA-5	DC-4000	19.0	▲19.6	4.0	▲36	4.15
ERA-5SM	DC-4000	19.0	▲19.4	4.0	▲36	4.20

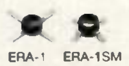
Note: Specs typical at 2GHz, 25°C.
▲ Typ. numbers tested at 1GHz. At 2GHz, Max. Pwr. Out may decrease by 0.4dB & IP3 by 3 to 4dB.
* Low frequency cutoff determined by external coupling capacitors
① Price (ea.) Qty.1000: ERA-1 $1.19, -2 $1.33, -3 $1.48, -4 or -5 $2.95. SM option same price.

DESIGNER'S AMPLIFIER KITS:

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

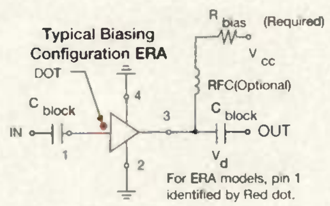
Chip Coupling Capacitors at 12¢ each (50 min.)

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



ACTUAL SIZE

Typical Biasing Configuration ERA



For ERA models, pin 1 identified by Red dot.

Mini-Circuits®

US 53 INT'L 69
CIRCLE READER SERVICE CARD

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

For detailed specs on all Mini-Circuits products refer to • 740- pg. HANDBOOK • INTERNET • THOMAS REGISTER • MICROWAVE PRODUCT DATA DIRECTORY • EEM

CUSTOM PRODUCT NEEDS...*Let Our Experience Work For You.*

F 214 Rev A

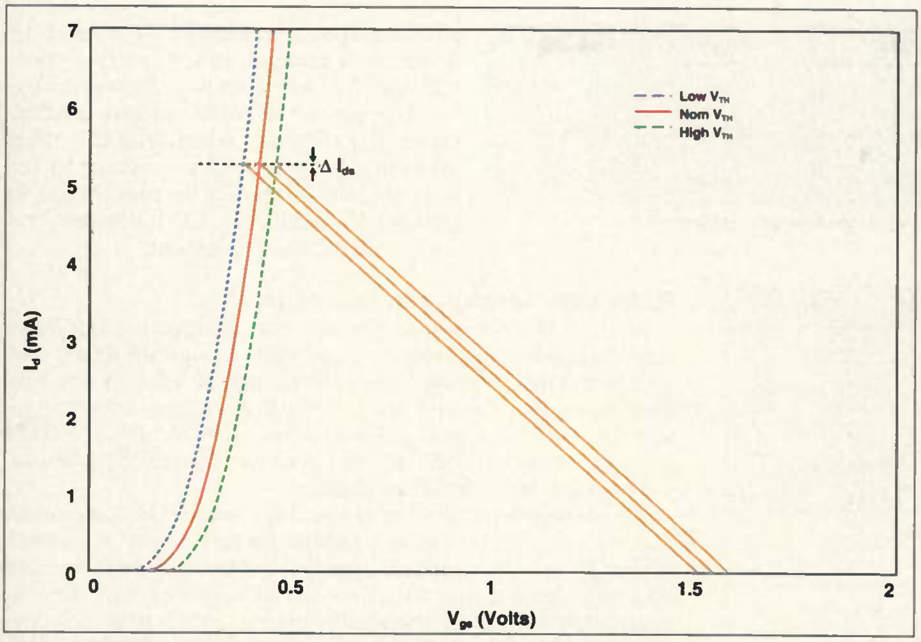


Figure 4. Performance of bias method C (Circuit CB) due to changes in β and V_{TO}.

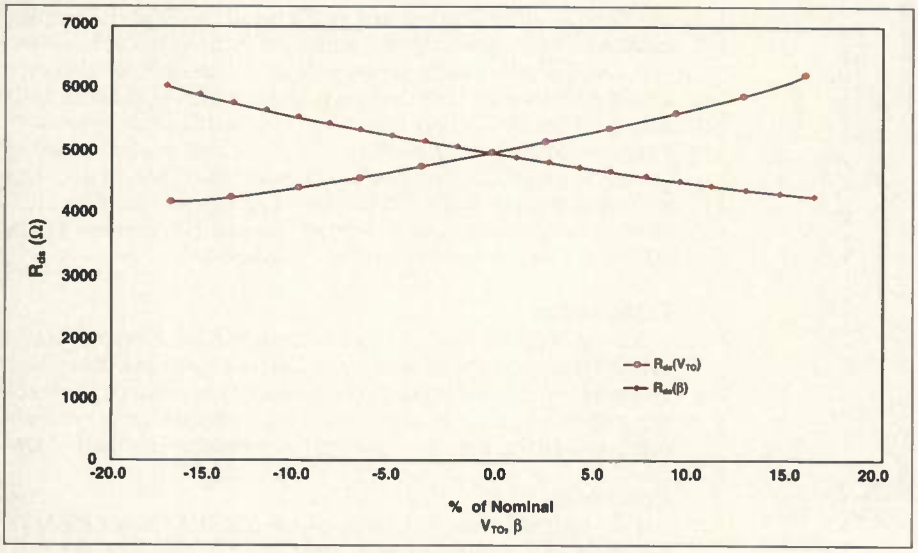


Figure 5. Output resistance is plotted as a function of model parameters V_{TO} and β.

the same die and are located in close proximity to one another), then they both are expected to exhibit similar values of β and V_{TO} in response to process tolerances and temperature. The performance of this circuit is illustrated graphically in Figure 4. Again, the DC load line is plotted along with the device's I_{ds} -V_{gs} response. The intercept of the load with the I_{ds} - V_{gs} curves again determines the quiescent current level. On the other hand, although the slope of the DC load line is established by R_S, the gate-offset voltage is determined by R_1, R_2 and Q_2. The output conductance of Q_2 is dependent on parameters β and V_{TO} as described in Equation 4. As is illustrated in Figure 4, if the values of R_1, R_2 and Q_2 are chosen properly, then:

$$\frac{\partial I_{ds}}{\partial \beta} \cong 0 \quad \text{and} \quad \frac{\partial I_{ds}}{\partial V_{TO}} \cong 0$$

The operation of transistor Q_2 in this bias circuit further can be observed by considering the output conductance g_{ds} given in Equation 4. Figure 5 shows a

PARAMETER (MEAN)	WAFER A	WAFER B	WAFER C	WAFER D
V_{TO}	0.24 V	0.20 V	0.15 V	0.23 V
I_{ds}@V_{gs} = 0.7	47.68 mA	45.51 mA	49.95 mA	56.99 mA
GATE LENGTH	0.49 μm	0.55 μm	0.61 μm	0.62μm

Table1. Measured mean parametric values for all three circuits on four different wafers.

PARAMETER	CIRCUIT A	CIRCUIT B	CIRCUIT C
IDQ (MEAN, mA)	5.48	5.19	5.21
IDQ (STD mA)	0.90062	0.21181	0.12821
IDQ (MIN)	1.40	4.65	4.94
IDQ(MAX)	4.53	5.63	5.48

Table 2. Circuit comparisons for the wafers used in Table I.

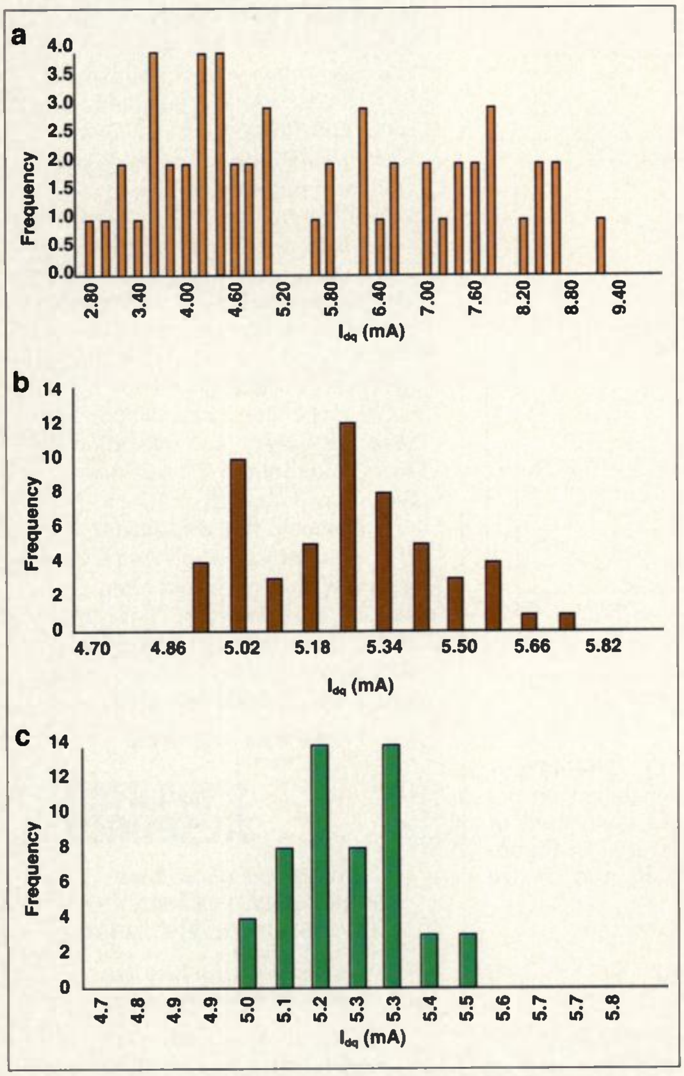


Figure 6. Measured response of each bias circuit to significantly varying FET parametric differences. a) Circuit A, b) Circuit B, c) Circuit C.

plot of output conductance for a given Q_2 device as a function of the relative value of β and V_{TO}. As either β increases or V_{GS} - V_{TO} increases (or both), output conductance g_{ds} decreases, which has the effect of reducing the gate-offset voltage in the bias circuit. It should be noted that in general, V_{TO} and β are not indepdent, but are correlated to some extent.

GaAs MMIC design and fabrication

Each of the three bias circuits was designed using large signal-modeling techniques to exhibit a nominal drain current of 5.0 mA based on a supply voltage of 3.0 V (V_{dd} = 3.0). The latter two circuits used a resistor-divider network selected to provide a nominal gate offset of 1.5 V. For the third circuit (Circuit C), FET Q_2 and resistors R_1 and R_2 were selected using large signal methods.

All of these circuits were placed together on the same mask and were fabricated using a MMIC GaAs process. A number of wafers and lots containing all three circuits were fabricated and processed with the intention of significantly varying parametric values for threshold voltage, gate length and current I_{DSS}. Measured mean parametric values for four such wafers are tabulated in Table 1.

Circuits from these wafers were measured, and the results are illustrated in Table 2 and in Figure 6. Each of the circuits exhibited approximately the same nominal quiescent current of 5.3 mA. Performance sensitivity to process can be observed by examining standard deviation in I_{ds}, which is substantially less for Circuit C than the other two. Additional measured parameters are tabulated in Table 2. The performance of Circuit C clearly is superior to the other two. The histograms shown in Figure 6 also illustrate that I_{ds} data for Circuit C tend to be grouped closely around the mean compared to the other two, which are more widely scattered.

Conclusion

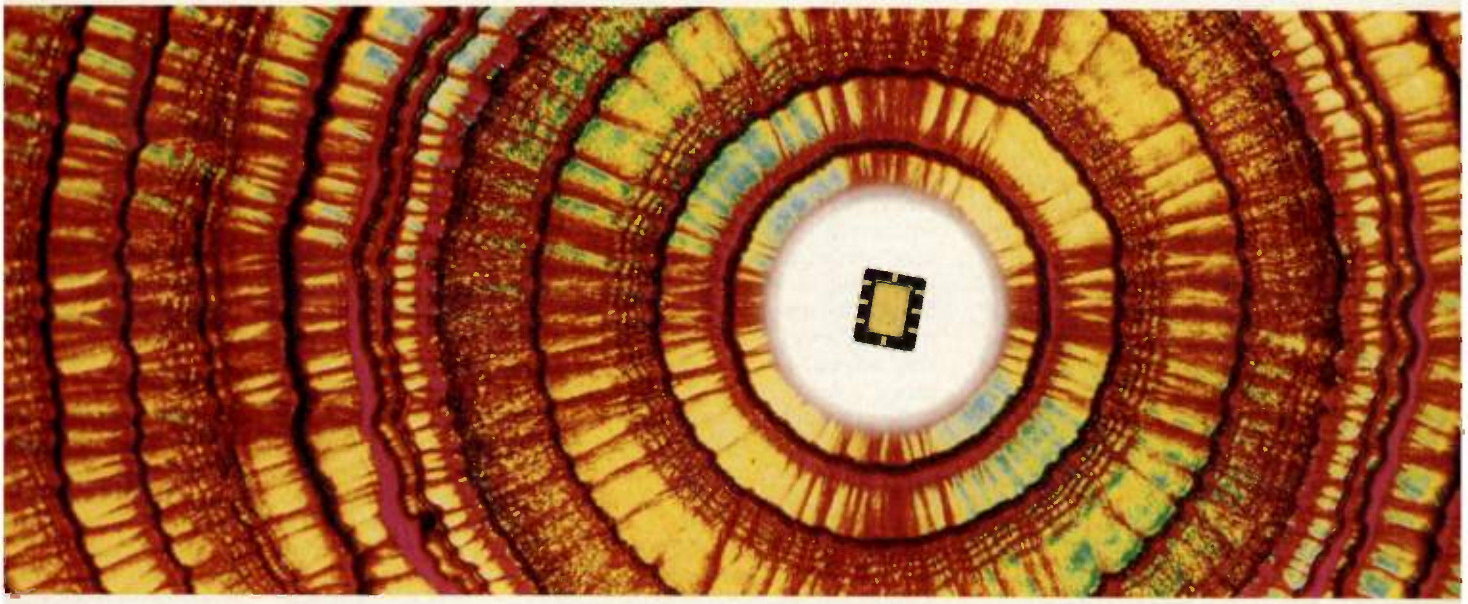
The performance of three methods of biasing GaAs MESFET circuits to process variation has been benchmarked. The use of a combination gate and source-resistance feedback method resulted in a significant performance improvement compared to the use of only a source-resistance method. RF

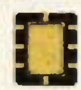
Reference

1. J. Michael Golio, ed., *Microwave MESFETs and HEMTs*, Artech House, Norwood, MA, 1991.

About the author

Joe Staudinger received a B.S.E.E. from Kansas State University and an M.S.E.E. from Arizona State University. He has been with Motorola since 1980 working in the areas of large-signal modeling, simulation and circuit design supporting wireless product development. He can be reached at Motorola Semiconductor products sector, MS EL-712, 2100 E. Elliot Road, Tempe, AZ 85284; Tel. 602-413-4456; E-mail ryym71@email.sps.mot.com.





Integrated test solution emulates real-world environment

By Alex Kim

In wireless communication systems, engineers must take into account various communication channel impairments to adequately compensate with equalization, diversity and error correction. Interference, multipath fading and noise are three impairments that help characterize the wireless channel. These should be used to verify the receiver performance under as realistic a condition as possible. An integrated test solution has been developed that provides the channel impairments called for by cellular, personal communications services (PCS) and satellite communications test specifications. In this article, these impairments are described in detail, as well as their usage and specifications in different wireless standards.

In actual field conditions, interference probably is the most troublesome impairment that degrades the transmitted signal. To emulate interfering signals from either analog phones or from nearby cell sites, continuous-wave (CW) tone generators often are used. It is essential that the phase noise of the interfering signal be low to ensure that the equipment under test is properly evaluated without the uncertainty of the phase-noise effect of the interferer. Especially when testing mobile phones, a CW interfering signal from a base station should be high-quality with low phase noise.

For example, code-division multiple-access (CDMA) specifications for cellular and PCS require about –105 dBm/1.23 MHz of integrated phase noise at 900 kHz offset and –104 dBm/1.23 MHz at 1,200 kHz offset, respectively [1]. CDMA specifications test single-tone desensitization and two-tone intermodulation spurious for the receivers in the presence of CW interference. For dual-mode phones, i.e., advanced mobile phone system (AMPS) and CDMA, the phase-noise specifications become even tighter.

Time-division multiple-access (TDMA) specifications call for adjacent and alternate channel selectivity testing. Because the TDMA channel is π/4-digital quadrature phase-shift keying (DQPSK) modulated, the integrated test solution for TDMA applications includes a π/4-DQPSK modulator at the output of the CW tone generator. (See Figure 1.) Low error vector magnitude (EVM) is required for this modulated signal.

Multipath fading

In a wireless channel, the transmitted signal often is obstructed by natural and man-made structures causing the signal to reach the receiver by more than one path. At the receiver, the direct and indirect path components combine to produce a distorted version of the original transmitted signal. This is called multipath fading, and it can cause significant power losses on the signal when the phase differences among the path components interfere destructively. For example, assuming that there exist two paths of equal amplitude that are delayed so that they produce exactly a 180° (or odd multiples thereof) phase offset, then the paths combine destructively to create deep nulls in the fre-

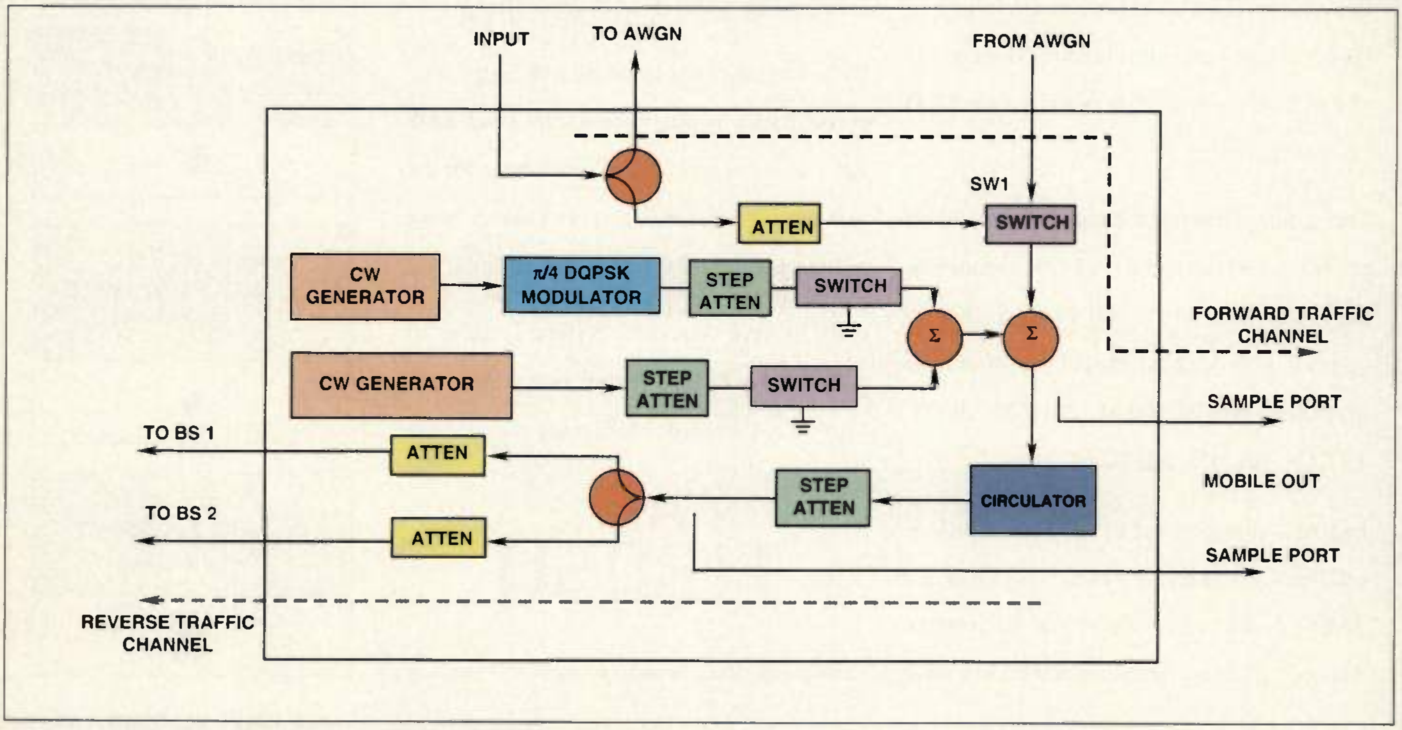


Figure 1. Adjacent channel interference for TDMA mobile station.

quency response of the signal. In the real-world environment, indirect path components exhibit random relative phases. The power envelope can be described by several different statistical distributions, depending on the characteristics of the channel.

Types of fading statistics

1. *Rayleigh distribution* — This is the most widely used model to characterize the multipath fading channel. Industry test standards for global system for mobile communications (GSM), TDMA (IS-54 and IS-136), CDMA (IS-95 and J STD-008), personal digital cellular (PDC), trans-european trunked radio access (TETRA), APCO-25 and cellular digital packet data (CDPD) among others, specify Rayleigh as the default fading statistic. It is derived mathematically, under the assumption that the amplitude of each path component is the same, and that the phase is random but uniformly distributed. Because the envelope of the sum of two quadrature Gaussian noise signals follows a Rayleigh distribution, implementing a multipath fading emulator based on this model is less complex than with others. This makes it popular and widely used.

2. *Nakagami distribution* — This is a more general form of Rayleigh fading, where the path component amplitude is assumed to be random, instead of uniform. Intuitively, this may resemble more realistic multipath environments because reflecting objects may consist of a combination of materials such as wood, glass, metal and concrete, each with a different reflection coefficient. Future standards such as universal mobile telephone system (UMTS) and future public land mobile telephone system (FPLMTS) may employ this particular distribution in their standard test plan.

3. *Log-normal distribution* — Also known as "shadowing," log normal distribution refers to slow, but large-scale, variations of the signal amplitudes over time. This is caused by multipath components that go through a multiplicative process. It is important to realize that not only the variance, but also the maximum step size in output power level must be specified and controlled for this fading model.

4. *Suzuki* — This is a combination of log-normal and Rayleigh distributions. Suzuki distribution may be used to describe areas ranging from indoors to outdoors that would encounter deep attenuation as well as many indirect paths.

5. *Rician* — This is similar to Rayleigh, except it assumes that a line-of-sight (LOS) or strong path exists between the transmitter and the receiver, in addition to the small amplitude scattered paths. Depending on how strong the deterministic path is, compared with the indirect paths, the shape of the distribution changes considerably. The Rician factor, also known as the parameter K, is defined as the ratio between the deterministic signal power and the variance of the scattered paths [3]. As K approaches $-\infty$, the strong path component is eliminated, and the Rician distribution becomes Rayleigh. Conversely, if K is large (i.e., amplitude of the

Your Wireless Design Freedom Begins with PSElect

When Your Specifications Need To Be Guaranteed Let PSElect RF and Microwave Semiconductor Performance Fill Your Needs

Designing 6 Sigma performance just got easier with **PSElect Semiconductor Guarantee**.
Working with leading-edge products from major RF & Microwave Semiconductor suppliers, PSElect will test and sort to your exacting specifications. To ensure your successful design through increased manufacturing yields,
call PSElect Now.

PSElect
An AVNET Company

OUR PARTS ARE IN WIRELESS SYSTEMS AROUND THE WORLD

1-888-PSE RF 4U

For Immediate Assistance (1-888-773-7348)

INFO/CARD 42

strong path is large), then the Rician distribution approaches Gaussian [2].

To emulate the multipath environments described above in a laboratory setting, the integrated test solution includes a multipath fading channel emulator. The transmitted signal is shaped by any one of the chosen random fading statistic. Then it is pre-shaped by a finite impulse response (FIR) Doppler spread filter in the frequency domain. By using this spectral filter, accurate time-domain waveforms of Doppler fading can be produced. Depending on the type of the antenna system (e.g., omnidirectional or sectored), the power spectral density of the signal can change. For this reason, Rician provides four types of filters as standard, but the 256-tap FIR filter also is user-programmable, making it a powerful function.

On the other hand, for some engineers, reproducing the field measurement data in the laboratory setting may be more appealing than depending on statistical distributions. First, by using a channel sounder, impulse response parameters such as path loss, delay and Doppler frequency are measured and recorded. The recorded live data can be "played back" via the multipath fading emulator, enabling full reproduction of the multipath channel response.

Another unique and time-saving function of the multipath fading emulator is its built-in average output power-level setting capability. Power levels of fading signals are difficult to measure because of their fluctuations; therefore, without the power-level setting feature, it may be necessary to average the measurement data over a long period of time. The multipath fading emulator's power-level setting accuracy vs. Doppler frequency is 0.1 dB. That accuracy is maintained even if the fading statistic changes. For wideband and spread-spectrum applications, RF bandwidths up to 24 MHz are available.

Additive white Gaussian noise

Another common problem in wireless communication systems is noise, such as white Gaussian noise. All materials produce noise at a power level proportional to the physical temperature of the material. The noise is generated by random vibrations of conducting electrons and by holes in the material. This noise often is referred to as thermal noise. Thermal noise is white and has a Gaussian amplitude distribution.

"White" implies that the power is uniformly distributed over all frequencies, just as white light includes power at all colors. Therefore, the power spectral density of white noise is constant over frequency. This implies that noise power is proportional to bandwidth. "Gaussian" denotes that the voltage amplitude follows a Gaussian probability distribution. According to the central-limit theorem, if the stochastic variables are independent and equal in significance, then the density of their sum ($x = x1 + x2 + ... + xn$) tends to a normal (Gaussian) curve as n approaches infinity [4]. Because this type of noise is close in form to the noise found in communication systems, it can be used to

Global solutions... for all your communications testing needs.

Noise Com noise products and test instruments are being used throughout the world to evaluate the performance of cellular, satellite, and radar communications and data transmission systems.

Whether you require noise sources, modules, or generators, or are interested in our state-of-the-art test instruments such as our multipath fading emulator or Interference Test Set™, we have the products to suit your application.

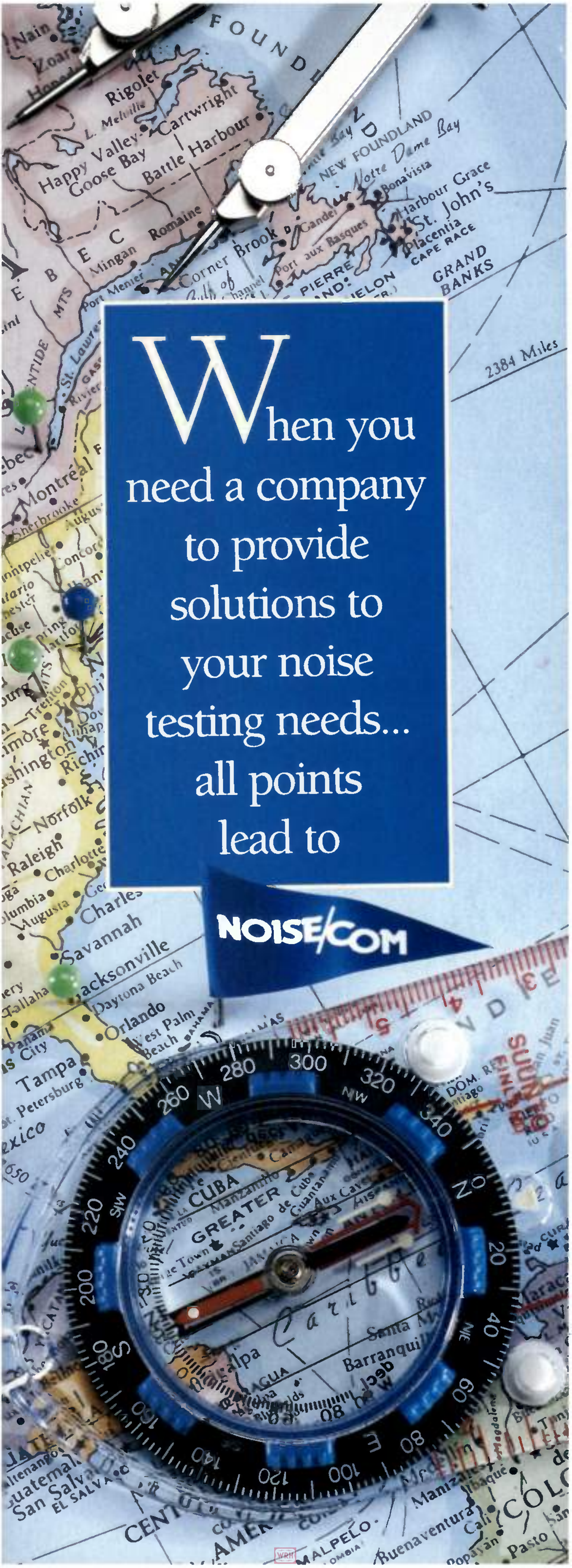
Every Noise Com product is backed by years of research and testing where it counts...*in the field.* That translates to products that deliver outstanding stability and quality...in the toughest applications.

At Noise Com, the only thing better than our products is our dedication to providing the best technical service and support in the business. We also realize that time is money, so you can count on receiving your custom component, test equipment, or an entire turnkey system on time...every time.

Pictured here are some of our standard products. For more details, ask for our *Complete Line of Broadband Noise Products* catalog. If you're interested in our critically-acclaimed test equipment, make sure you request a copy of our *Test Equipment For Wireless & Telecommunications* catalog. Whatever you decide...we'd love to hear from you.

Noise Com. Your global partner for noise, wireless, and telecommunications testing solutions.

For more information and a quick response, call NOISE COM, the experts in testing, at 201-261-8797.


When you
need a company
to provide
solutions to
your noise
testing needs...
all points
lead to
NOISE/COM

Chips and Diodes

All Noise Com diodes deliver symmetrical white Gaussian noise and flat output power versus frequency. Noise Com diodes are available in a wide variety of package styles, and in special configurations on request.

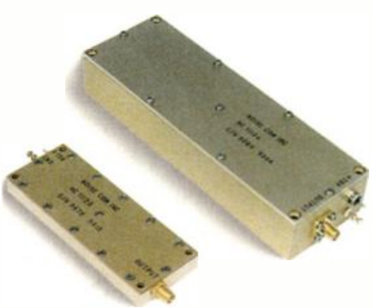
TYPICAL STANDARD MODELS	
MODEL	**FREQUENCY RANGE**
NC 302	10 Hz – 3 GHz
NC 305	10 MHz - 11 GHz
NC 401	100 MHz – 18 GHz
NC 406	18 GHz – 110 GHz

BITE Modules

The NC 500 series drop-in noise modules in TO-8 cans and flat packs for surface mounting are an economical solution for built-in test requirements. These devices contain complete biasing networks and need no external components. Also available are TO-39 packages.

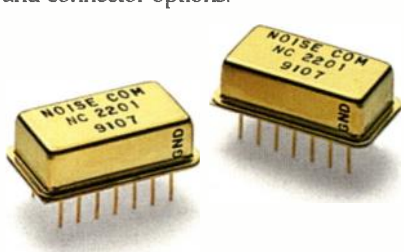
TYPICAL STANDARD MODELS		
MODEL	**FREQUENCY RANGE**	**OUTPUT ENR**
NC 501/15	0.2 MHz – 500 MHz	31 dB
NC 502/15	0.2 MHz – 1000 MHz	31 dB
NC 503/15	0.2 MHz – 2000 MHz	31 dB
NC 506/15	0.2 MHz – 5 GHz	31 dB
NC 511/15	0.2 MHz – 500 MHz	51 dB
NC 513/15	0.2 MHz – 2 GHz	51 dB

Broadband Amplified Modules



The NC 1000 series amplified noise modules produce white Gaussian noise from -14 dBm to +13 dBm at frequencies up to 6 GHz. They are designed for coaxial test systems, and are available with several bias voltages and connector options.

TYPICAL STANDARD MODELS		
MODEL	**FREQUENCY RANGE**	**OUTPUT**
NC 1101A	10 Hz – 20 kHz	+13 dBm
NC 1107A	100 Hz– 100 MHz	+13 dBm
NC 1112B	20 MHz – 2 GHz	0 dBm
NC 1126A	2 GHz – 6 GHz	-14 dBm



The NC 2000 series amplified noise modules are an excellent choice when a high level noise output is desired and the noise source is to be mounted on a circuit board. 24 pin packages are standard; 14 pins are also available.

TYPICAL STANDARD MODELS		
MODEL	**FREQUENCY RANGE**	**OUTPUT**
NC 2101	100 Hz – 20 kHz	0.15 Vrms
NC 2105	500 Hz – 10 MHz	0.15 Vrms
NC 2201	1 MHz – 100 MHz	+5 dBm
NC 2601	1 MHz – 2 GHz	-5 dBm

NOISE/COM

A Wireless Telecom Group Company

Broadband Precision, Calibrated Coaxial

Noise Com's NC 346 series is designed for precision noise figure measurement applications. These products are available with coaxial or waveguide outputs. For OEM applications, the NC 3200 series provides high performance in a small ruggedized package.

TYPICAL STANDARD MODELS		
MODEL	**FREQUENCY RANGE**	**OUTPUT ENR**
NC 346A	0.01 GHz – 18 GHz	6 dB
NC 346B	0.01 GHz – 18 GHz	15 dB
NC 346C	0.01 GHz – 26.5 GHz	15 dB
NC 346D	0.01 GHz – 18 GHz	25 dB
NC 346Ka	0.1 GHz – 40 GHz	15 dB

Broadband Calibrated Millimeter-wave

The NC 5000 series noise sources feature outstanding stability and convenience in waveguide bands up to 110 GHz.

TYPICAL STANDARD MODELS		
MODEL	**FREQUENCY RANGE**	**WAVEGUIDE**
NC 5142	18 GHz – 26.5 GHz	WR-42
NC 5128	26 GHz – 40 GHz	WR-28
NC 5122	33 GHz – 50 GHz	WR-22
NC 5115	50 GHz – 75 GHz	WR-15
NC 5110	75 GHz – 110 GHz	WR-10

Broadband Noise Generators

The NC 6000 and NC 8000 series noise-generating instruments are designed for applications on the test bench or incorporated with other equipment to provide a wide variety of functions. Each instrument contains a precision noise source, amplification, and step attenuators to provide repeatable symmetrical white Gaussian noise with variable output power.

TYPICAL STANDARD MODELS		
MODEL	**FREQUENCY RANGE**	**OUTPUT POWER**
NC 6107	100 Hz – 100 MHz	+13 dBm
NC 6108	100 Hz - 500 MHz	+10 dBm
NC 6110	100 Hz – 1500 MHz	+10 dBm
NC 6124	2 GHz – 4 GHz	-10 dBm
NC 8107	250 kHz – 100 MHz	+30 dBm
NC 8111	5 MHz - 1 GHz	+30 dBm

The new UFX-7000 series noise-generating instruments are extremely easy to use, combining dedicated keys for control of operations and programming, with a large 4 x 20-character LCD display. Control of output power, filter settings, and attenuator step size for both the noise and the signal (for units with internal combiners) is performed from the front panel or by remotely using the IEEE-488 interface.

TYPICAL STANDARD MODELS		
MODEL	**FREQUENCY RANGE**	**OUTPUT POWER**
UFX-7107	100 Hz–100 MHz	+13 dBm
UFX-7108	100 Hz – 500 MHz	+10 dBm
UFX-7110	100 Hz – 1500 MHz	+10 dBm
UFX-7218	2 GHz – 18 GHz	-20 dBm
UFX-7909	1 MHz – 300 MHz	+30 dBm

NOISE/COM

Your global partner for noise, wireless, and telecommunications testing solutions.

NOISE/COM
A Wireless Telecom Group Company
E. 49 Midland Ave., Paramus, NJ 07652
Tel: 201-261-8797 • Fax: 201-261-8339

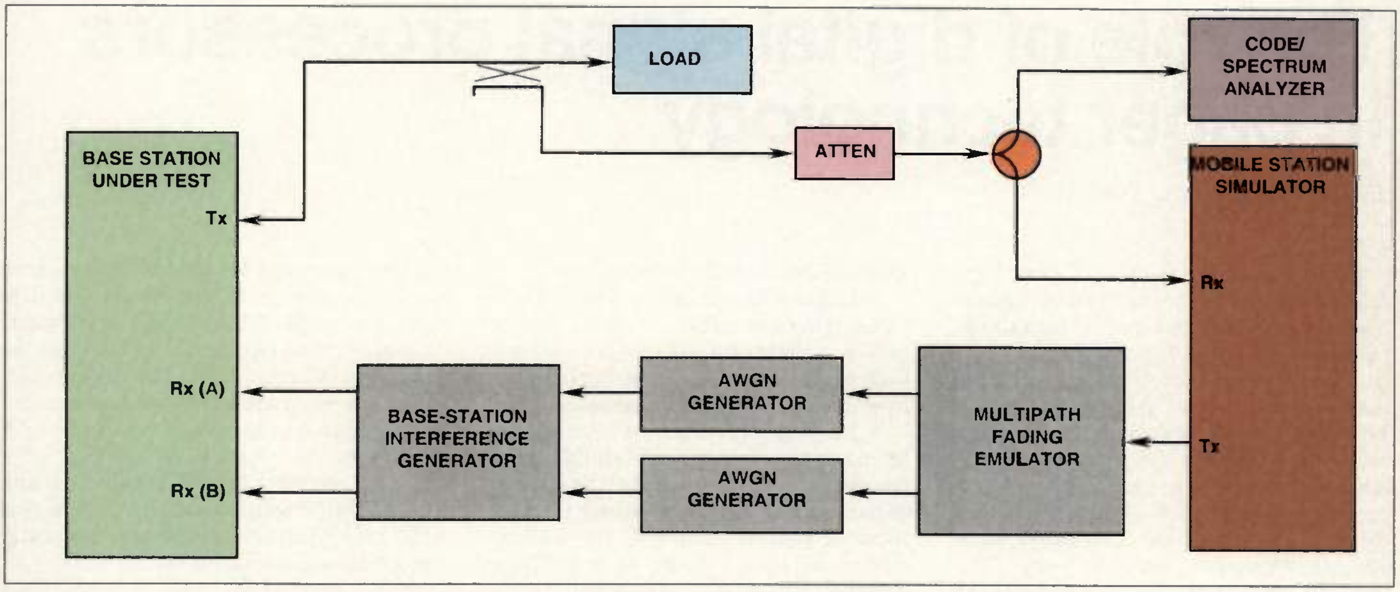


Figure 2. A typical base-station setup. The instruments from the integrated test solution described in this article are in gray.

emulate the real-world environment. In general, the random noise is injected into the system, and this type of noise is referred to as additive white Gaussian noise (AWGN).

Because digital communication systems often are characterized by their performance under various signal-to-noise ratios, bit error rate (BER) as a function of bit energy per noise density (Eb/No) is the predominant quality factor for evaluating receiver performance. The BER increases as the Eb/No (or C/N) decreases. The accuracy of BER strongly depends on that of Eb/No. That is, a small change in the Eb/No will cause a large change in the BER. It is critical, therefore, to set the Eb/No accurately with excellent repeatability and stability. Traditionally, though, it has been a manual and cumbersome process to set the desired Eb/No, especially with any meaningful accuracy. For example, CDMA specifications require at least ±0.2 dB of accuracy, and this can be a daunting task with a manual method.

The integrated test solution automatically provides accurate Eb/No settings (with up to ±0.1 dB accuracy) to simplify BER measurements. If a user provides the carrier input and enters the bit rate, the desired output power level and the Eb/No ratio, then the instrument automatically provides the combined noise and carrier signal on the output with proper Eb/No setting. Internal broadband noise sources generate high-quality AWGN to emulate the real world as closely as possible.

Conclusion

To properly design and test wireless communications equipment, the channel must be characterized accurately and must be emulated to reflect the conditions in the field. The integrated test solution is tailored to meet general-purpose and standards-specific applications. For TDMA and CDMA applications, the system is ideal for testing fully to the specifications. (See Figure 2.) Other applications such as paging, satellite communications, cable television and digital television also are requiring performance tests under impaired channel conditions. More robust engineering can be performed to alleviate the effects of channel impairments on the wireless communication systems by using proper test solutions. *RF*

About the author

Alex Kim is a marketing manager for Noise Com, Paramus, NJ. He has a B.S.E.E. from MIT and an M.S.E.E. from USC. The integrated test solution described is the Wireless Impairment System (WIS) from Noise Com.

References

1. TIA/EIA/IS-98, "Recommended Minimum Performance Standards for Dual Mode Wideband Spread Spectrum Cellular Mobile Stations," Global Engineering Documents.

2. H. Hashemi, "The Indoor Radio Propagation Channel," *Proceedings of the I.E.E.E.*, Vol. 8, No. 7, July 1993, pp. 943–968.

3. T. Rappaport, *Wireless Communications Principles & Practices*, Prentice-Hall, NJ, 1996, p. 176.

4. A. Papoulis, *Probability, Random Variables, and Stochastic Processes*, 2nd Ed., McGraw-Hill, NY, 1984, p. 194.

Figure 3. A typical base-station test system.

The role of digital signal processors in pager technology

By Xiao-an Wang and Dwane Bell

Pagers and the paging technology have become a large part of the rapidly evolving wireless and mobile communications industry. Advanced paging protocols, including those that support two-way communication, give pager service providers greater capacity to meet the increasing demands for pager coverage and features. These demands present considerable technical challenges to produce products that are competitive both in performance and in cost. Today's integrated circuit (IC) and digital signal processor (DSP) technologies, provide effective means to deal with such challenges. As a result, the market will see more sophisticated, cost-effective pagers with more user-friendly features.

Technology advances are shrinking the differences between pagers and cellular phones, especially among pagers that support two-way protocols. Advanced paging protocols significantly increase channel capacity and add a vast array of functionalities, including two-way communications.

While cellular communications requires high bandwidths and data rates, pagers operate on narrow bandwidths with relatively low data rates. Here are some of the other differences:

- Pagers are primarily receive devices, whereas cellular phones support two-way communications. In two-way paging, however, the user can send a brief response to a received message.
- Paging messages are brief compared to the duration of cellular phone connections. Consequently, the channel capacity of a paging channel (i.e., the number of users allowed) can be hundreds of times that of a cellular channel.
- Because of the short duration of paging messages, a single paging channel usually is adequate for the local coverage area of a service provider. A single pager can be locked to one fixed radio channel, yet the cellular phone has to have the ability to scan all possible channels within the coverage area. The lack of scanning capacity greatly simplifies the receiver because its frequency-synthesizer circuit can be reduced to a minimum.
- Pagers consume less power because one-way pagers do not have a transmitter, and transmission is brief for two-way pagers. In a cellular phone, the transmitter consumes a large amount of power. Moreover, because a pager need not be as responsive as a cellular phone, it can be designed to have a longer "sleep" time. The longer sleep time results in even greater power savings, as well as longer battery life. Current pagers can operate for more than five months on a single AAA battery.
- In contrast to cellular phones and the cellular infrastructure, pagers and the pager infrastructure are less costly to build and maintain.

Paging bands

Paging protocols specify only the modulation methods and the bandwidth of the paging signals. (See Table 1.) Where exactly the paging bands are located is left to service providers and government regulations. Popular paging bands include 138–174 MHz (VHF), 420–470 MHz (UHF), and three bands in the 900 MHz range. Each band is divided into channels. Different bands have different advantages and disadvantages for wireless applications. For example, lower-frequency signals tend to have less path loss and, thus, a wider coverage area. Higher-frequency signals, on the other hand, have a smaller coverage area but better frequency reuse. Frequency reuse involves the implementation of the same paging band in areas that are far enough apart that the signals in one area will not interfere with the signals in another area.

Paging systems that use the Post Office Code Standardization Advisory Group (POCSAG) of the United Kingdom standard have been ubiquitous in all paging bands, including the relatively new 900 MHz bands. In Europe, the 448 MHz band is widely used for POCSAG systems. Systems based on the European Radio Messaging Systems (ERMES) standard will operate with all 16 of their channels in the 169.4–169.8 MHz band, which has been allocated by all participating countries. Motorola's Flex-based products primarily target the 900 MHz band in the

PROTOCOL	DATA RATE	MODULATION	NUMBER OF CHANNELS
POCSAG	512, 1200 and 2400 bps	Binary FSK	
ERMES	6250 bps	Four-level FSK	16
FLEX	1600, 3200 and 6400 bps	Binary FSK for 1600 and 3200 bps, four-level FSK for 3200 and 6400 bps	
ReFLEX	6400 bps FC; 9600 bps RC	Binary or four-level FSK on both channels	
InFLEXion	800, 1600, 6400 and 9600 bps RC; single-sideband (SSB) FC	SSB modulation (for voice) FC, four-level FSK RC	

KEY: FC - FORWARD CHANNEL
RC - REVERSE CHANNEL
FSK - FREQUENCY SHIFT KEYING

Table 1. Specifications for the different paging protocols.

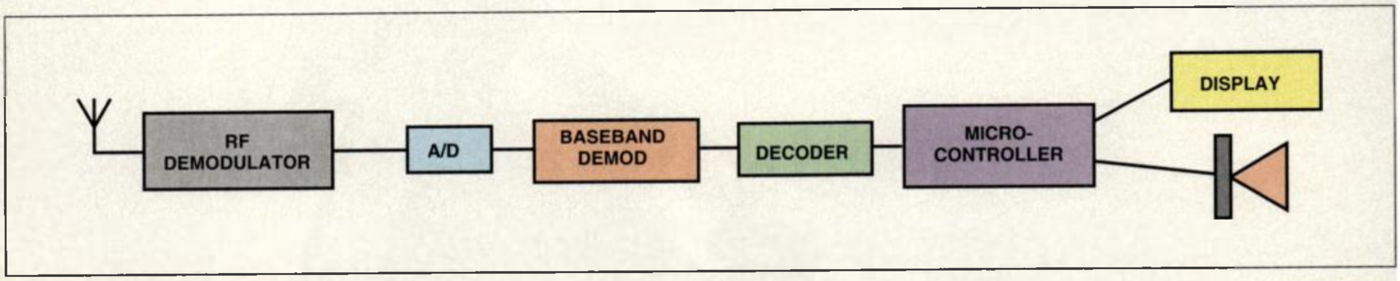


Figure 1. Pager functional block diagram.

United States. Theoretically, any protocol can work on any frequency band.

Data transfer rates are determined largely by channel width and by modulation method. Protocols that use four-level frequency shift keying (FSK) modulation, such as Flex and ERMES, achieve relatively high data rates (6,250 bps and 6,400 kbps, respectively). The pager must contain a relatively sophisticated demodulation section for the signal to be decoded.

POCSAG

The POCSAG standard has been the most successful standard, possibly because it is nonproprietary and has an extremely simple protocol. In fact, the entire POCSAG document is only five pages long. To date, the POCSAG protocol remains dominant.

POCSAG came about as a de facto standard (being exercised as if legally constituted) by the British Post Office in the late 1970s. It was accepted as an international standard by the Consultative Committee for International Radio (CCIR) in 1981. POCSAG was renamed CCIR Radio Paging Code No. 1 (RPC1), but the old name seems to have prevailed.

A shortcoming of POCSAG is that its data rate is relatively low and, thus, its capacity is low. Its limitations have become more conspicuous as the number of users has grown. Competing protocols, including ERMES and Flex, have been developed to achieve higher capacity.

ERMES

ERMES was developed in the late 1980s and was established as a standard by the European Telecommunications Standards Institute (ETSI). It was recommended by the International Telecommunications Union (ITU) for paging systems intended for international use. Operational ERMES systems have been deployed in France, Germany and Switzerland.

Unlike other paging systems, ERMES specifies 16 paging channels. An individual pager is able to receive messages sent on any of the 16 channels, and this requires the pager to have the capacity of scanning and selecting. Such a feature allows the user to roam internationally. As long as there is a roaming agreement between the home and visited networks, subscribers with an ERMES pager can receive messages anywhere they travel.

Flex

In 1994, the Federal Communications Commission (FCC) allocated 3 MHz of the electromagnetic spectrum in the 900 MHz band to narrowband personal communication services (N-PCS): 901–902, 930–931 and 940–941 MHz. The message channels (those on which data and voice are sent to pagers) are allocated in 50 kHz bands, but some of those bands may be subdivided into 25, 12.5 or 6.25 kHz subchannels. The Flex family of protocols—Flex, Reflex, and Inflexion—were designed with the N-PCS bands in mind [1]. Like POCSAG and ERMES, the Flex protocol supports only one-way transmission. Additionally, within the N-PCS bands, the FCC designated eight 12.5 kHz response channels, which allow pagers to transmit messages. Reflex and Inflexion support the use of message and response-channel pairs to enable two-way paging. Reflex supports the sending and receiving of alphanumeric messages and data. Inflexion-based pagers receive voice messages and transmit acknowledgement responses. Both InFLEXion and Reflex use the concept of location-specific transmission, which provides the frequency reuse feature so the paging capacity can be increased further across the infrastructure.

Because a majority of paging service providers have a license for only a single 50 kHz channel, increased capacity has to be achieved by more efficient channel use. Within a 50 kHz band, only two Flex channels can be accommodated. However, the relatively large bandwidth has spurred the development of Reflex50, a Reflex-based protocol that enables a data rate of 25,600 bps on a 50 kHz channel.

Transmission modes

A significant advantage of ERMES and Flex is battery saving caused by their synchronous transmission characteristics. A synchronous protocol allows the pager to switch on periodically (e.g., every couple of minutes) and check to see whether a message is being sent. The pager's controller circuitry can place unused peripherals into various levels of "sleep," depending on whether the unit is checking for messages, processing received data, interacting with the user, sending responses or being inactive. A POCSAG pager uses an asynchronous protocol, so it must spend more time with its circuitry in active mode.

Pager receiver design

Figure 1 is a functional block diagram of a pager receiver. The RF modulator downconverts the RF input signal to baseband. Flex and ERMES pagers typically require multistage downconversion, whereas POCSAG pagers can use direct conversion. After the baseband signal is converted to a digital signal, it is processed by the baseband demodulation function to produce a bit stream of the received data.

The data bits from the demodulator are considered to be the raw data, possibly corrupted by noise during transmission. It is the decoder's task to recover the message from the raw bits. This is accomplished through the following steps.

- *Frame synchronization* — The decoder aligns its receive buffer to the frames in the received bit stream. Generally, the bit stream is divided into 32-bit frames by protocols. For

OUR STANDARD MONOLITHIC CRYSTAL FILTERS

All 2 pole and 4 pole monolithics ship from stock on hand.

10.7 MHz

NO. POLES	TEMEX P/N	PASSBAND dB	PASSBAND ±KHz	STOPBAND dB	STOPBAND ±KHz	STOPBAND dB	STOPBAND ±KHz	LOSS dB	RIPPLE dB-MAX	ULT. REJ. dB-MIN.	TERM. Ω/PF
2	TE5000	3	3.75	20	18.0	-	-	2	1.0	50	1800//+4
4	TE5010	3	3.75	30	14.0	-	-	3	2.0	60	1500//+3
6	TE5020	6	3.75	60	12.5	-	-	4	2.0	70	1500//+3
8	TE5030	6	3.75	60	10.0	90	12.5	5	2.0	80	1500//+3
2	TE5040	3	6.50	20	30.0	-	-	1	1.0	50	2700//0
4	TE5050	3	6.50	30	15.0	-	-	2	2.0	75	3100//0
6	TE5060	6	6.50	60	19.5	-	-	3	2.0	90	3100//0
8	TE5070	6	6.50	60	13.0	80	17.5	4	2.0	100	3100//0
2	TE5080	3	7.50	20	35.0	-	-	1	1.0	50	3000//0
4	TE5090	3	7.50	30	17.5	-	-	2	2.0	75	3300//0
6	TE5100	6	7.50	60	22.5	-	-	3	2.0	90	3300//0
8	TE5110	6	7.50	60	15.0	80	20.0	3	2.0	100	3300//0
2	TE5120	3	15.0	20	70.0	-	-	1	1.0	35	5000//-1
4	TE5130	3	15.0	30	35.0	-	-	2	2.0	60	5000//-1
6	TE5140	6	15.0	60	45.0	-	-	2	2.0	90	5000//-1
8	TE5150	6	15.0	60	30.0	80	40.0	3	2.0	100	5000//-1

21.4 MHz

NO. POLES	TEMEX P/N	PASSBAND dB	PASSBAND ±KHz	STOPBAND dB	STOPBAND ±KHz	STOPBAND dB	STOPBAND ±KHz	LOSS dB	RIPPLE dB-MAX	ULT. REJ. dB-MIN.	TERM. Ω/PF
2	TE5180	3	3.75	15	12.5	-	-	2	1.0	50	850//+6
4	TE5190	3	3.75	30	12.5	-	-	3	2.0	70	850//+5
6	TE5200	6	3.75	60	12.5	-	-	4	2.0	90	850//+5
8	TE5210	6	3.75	60	10.0	80	12.5	5	2.0	100	850//+5
2	TE5220	3	6.50	15	20.0	-	-	2	1.0	50	1300//+2
4	TE5230	3	6.50	30	22.5	-	-	3	2.0	70	1400//0
6	TE5240	6	6.50	60	22.5	-	-	4	2.0	90	1400//0
8	TE5250	6	6.50	60	17.5	80	22.5	4	2.0	100	1400//0
2	TE5260	3	7.50	15	25.0	-	-	2	1.0	50	1500//0
4	TE5270	3	7.50	30	25.0	-	-	3	2.0	70	1600//0
6	TE5280	6	7.50	60	25.0	-	-	4	2.0	90	1600//0
8	TE5290	6	7.50	60	20.0	80	25.0	4	2.0	100	1600//0
2	TE5300	3	15.0	15	50.0	-	-	2	1.0	45	3000//0
4	TE5310	3	15.0	30	45.0	-	-	3	2.0	60	3000//-1
6	TE5320	6	15.0	60	45.0	-	-	3	2.0	90	3000//-1
8	TE5330	6	15.0	60	33.0	80	45.0	4	2.0	100	3000//-1

45.0 MHz

NO. POLES	TEMEX P/N	MODE	PASSBAND dB	PASSBAND ±KHz	STOPBAND dB	STOPBAND ±KHz	LOSS dB	RIPPLE dB-MAX	ULT. REJ. dB-MIN.	TERM. Ω/PF
2	TE9420	3-OT	3	3.75	18	16.0	3	1	40	2000//-1.0
4	TE9310	3-OT	3	3.75	30	12.5	3	1	70	2000//-1.0
2	TE7420	3-OT	3	7.50	18	28.0	2	1	40	3000//-1.0
4	TE7430	3-OT	3	7.50	40	30.0	3	1	70	3000//-1.0
2	TE7440	3-OT	3	15.0	15	47.0	2	1	40	8000//-1.5
4	TE7450	3-OT	3	15.0	30	50.0	3	1	70	8000//-1.5
2	TE7730	FUND	3	15.0	15	50.0	2	1	40	1100//+1.5
4	TE7740	FUND	3	15.0	40	60.0	3	1	70	800//+1.0

70.0 MHz

NO. POLES	TEMEX P/N	MODE	PASSBAND dB	PASSBAND ±KHz	STOPBAND dB	STOPBAND ±KHz	STOPBAND dB	STOPBAND KHz	LOSS dB	RIPPLE dB-MAX	TERM. Ω/PF
2	TE10400	3-OT	3	7.5	18	30	35	-910	2	1	2000//-1
4	TE10410	3-OT	3	7.5	35	25	80	-910	3	1	2000//-1
2	TE10420	3-OT	3	10	15	30	35	-910	2	1	2500//-1
4	TE10430	3-OT	3	10	35	40	80	-910	3	1	2500//-1

90.0 MHz

NO. POLES	TEMEX P/N	MODE	PASSBAND dB	PASSBAND ±KHz	STOPBAND dB	STOPBAND ±KHz	STOPBAND dB	STOPBAND KHz	LOSS dB	RIPPLE dB-MAX	TERM. Ω/PF
2	TE10440	3-OT	3	7.5	18	30	35	-910	2	1	2000//-1
4	TE10450	3-OT	3	7.5	35	25	80	-910	3	1	2000//-1
2	TE10460	3-OT	3	10	15	30	35	-910	2	1	2500//-1
4	TE10470	3-OT	3	10	35	40	80	-910	3	1	2500//-1
4	TE10480	3-OT	3	15	30	50	80	-910	3	1	4000//-1

European contacts:

France or Benelux
(Tel)
(33)25.76.45.00
(Fax)
(33)25.80.34.57

United Kingdom
(Tel)
(44)1.734.258.040
(Fax)
(44)1.734.258.050

Germany
(Tel)
(49)89.51.640
(Fax)
(49)89.51.64.194

Nordic
(Tel)
46)8.756.70.40
(Fax)
(46)8.756.70.44

Italy
(Tel)
(39)2.761.101.68
(Fax)
(39)2.738.54.62

All Others:
(Tel)
(33)25.76.45.00
(Fax)
(33)25.80.34.57

TEMEX

VISA AND MASTERCARD ACCEPTED

MONOLITHIC CRYSTAL FILTER PROTOTYPING KITS ARE STILL AVAILABLE

CONSULT TEMEX FOR ALL YOUR FREQUENCY CONTROL PRODUCTS

IN THE UNITED STATES CONTACT: **TEMEX ELECTRONICS, INC.**

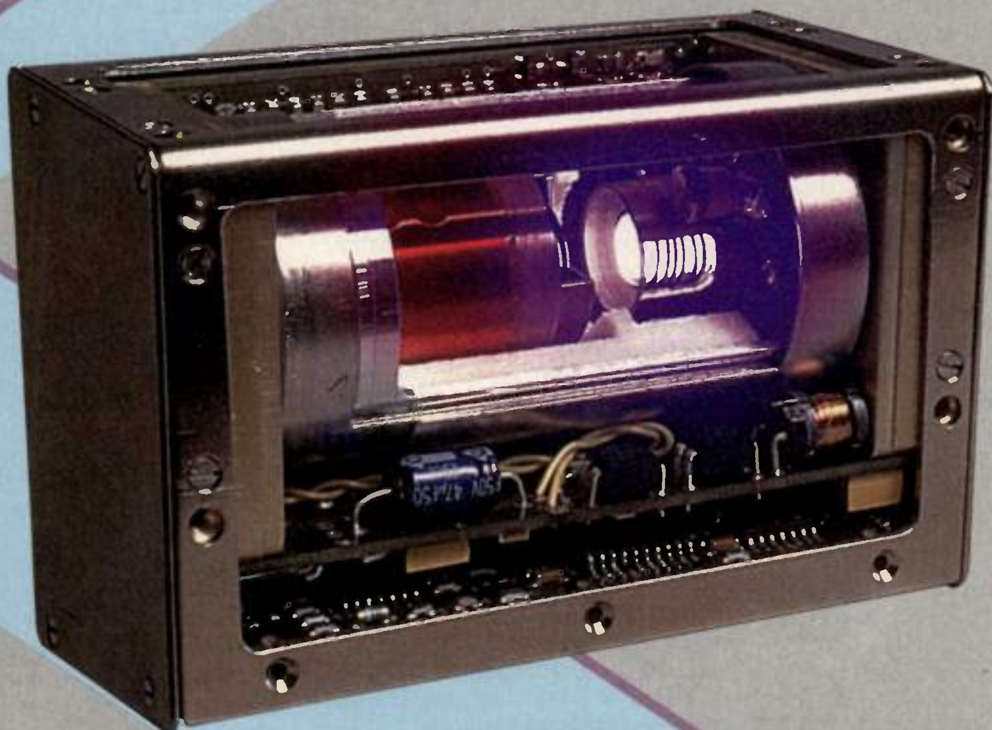
3030 W. DEER VALLEY RD. PHOENIX, AZ USA 85027

(602) 780-1995 FAX (602) 780-2431

NEW FROM OUR FACILITY IN
NEUCHATEL, SWITZERLAND.

TEMEX

RUBIDIUM ATOMIC CLOCKS



FEATURING:

- LOW TEMPERATURE SENSITIVITY
- LOW PHASE NOISE
- EXCELLENT SHORT & LONG TERM STABILITY
- LOW POWER CONSUMPTION
- FAST WARM-UP
- SMALL VOLUME
- 15 YEAR Rb LAMP LIFE EXPECTANCY
- PLUG-COMPATIBLE WITH AN INDUSTRY STANDARD
- RS 232 INTERFACE FOR CENTER FREQUENCY ADJUSTMENT AND MONITORING OF THE WORKING PARAMETERS

INFO/CARD 22

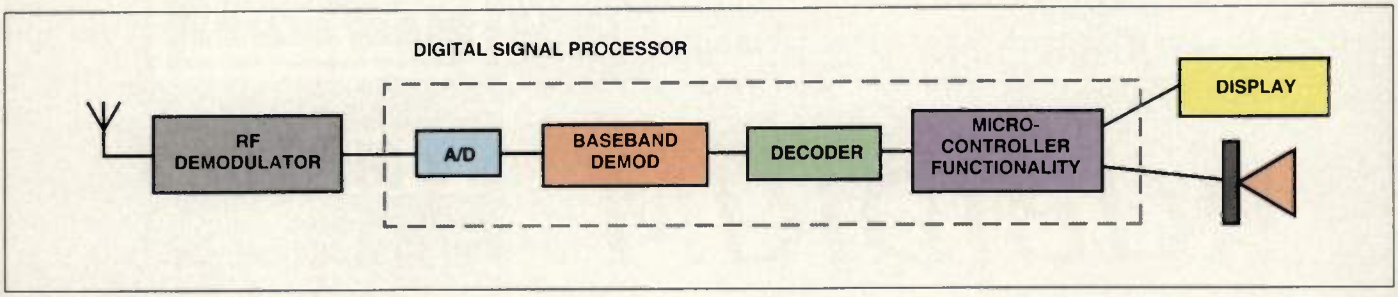


Figure 2. Scope of DSP use in pager receivers.

ERMES and Flex, deinterleaving also is performed.

• *Information retrieval* — The framed raw data are sent to the error control decoder to extract the address data, ID data and message data. In the process, errors in the raw data bits get corrected by the decoder so that the decoded data will have an extremely low bit error rate (BER).

• *Address match* — The decoder examines the address field in the decoded frame to determine whether the message is for the particular pager. If not, the decoder informs the controller, and the controller shuts off major receiver parts to conserve power.

The controller interprets the corrected message from the decoder in its intended form (numeric, alphanumeric or voice) and delivers it to the user by either liquid crystal display (LCD) or by speaker. It also handles the unit's power management by switching the pager's circuitry on and off as needed.

The DSP in low- and high-tier pagers

The pager market can be divided into two tiers: low-tier and high-tier. To a large extent, the tier will determine how a DSP configuration will work. Low-tier pagers include POCSAG pagers and some Flex numeric pagers. This tier can be characterized by mature, simple technology.

POCSAG receivers have simple but robust structures. POCSAG-based numeric pagers can be made as compact as a pen or as thin as a wristwatch or a credit card.

The low-tier pager has rendered DSP advantages irrelevant. For example, the simple POCSAG receiver structure minimizes the advantage of a higher degree of integration. Proven and well-established POCSAG decoder chips make the new round of DSP development unnecessary. The modulation scheme is handled adequately by analog circuits without the need for digital filtering. The core operations of the POCSAG pagers are binary and bit-oriented. For a DSP product, most of the special modules of a DSP chip, such as the hardware multiplier and the filtering structure, would remain inactive during those operations.

For high-tier pagers, including those based on ERMES and on most of the Flex family, a DSP-based pager shows great potential and is indispensable for some applications. For example, Inflexion- and Reflex-based pagers operate on densely packed channels. There are seven 6.25 kHz voice channels in a 50 kHz channel for Inflexion. In such cases, digital filtering appears to be the only feasible choice for suppressing adjacent interchannel interference because the transition band and out-of-band attenuation of a digital filter can be designed to meet the stringent specifications.

The complexity of the high-tier pagers requires more components in receiver design. This makes the cost and power consumption of DSP chips a less serious problem. For alphanumeric pagers, the display takes up a considerable size, which makes the size of a DSP chip a lesser concern. High-tier pagers also require the implementation of more processing functions. Thus, the advantage of a high degree of integration of the DSP product can be significant. For two-way pagers, a DSP can perform most of the transmission functions, including the sophisticated Reed-Solomon encoding.

Higher integration within the DSP also helps to reduce the power consumption. Although an application-specific integrated circuit (ASIC) decoder chip set consumes less power, the power consumption of the DSP chip can be made comparable to the set of components it replaces.

There are other advantages to having a DSP in high-tier pagers. For example, a DSP is a natural candidate for voice signal-processing in voice pagers. To further increase the channel capacity, 16-quadrature amplitude modulation (QAM) or even 64-QAM is expected to be used in the future. Again, a DSP is most suitable to demodulate, and possibly, to equalize such signals.

Use of the DSP in pager designs

Figure 2 shows that a DSP can implement most of the pager's receiver operations, whereas an alternative would require several devices to cover the same functions. For two-way pagers, most transmission functions, including data generation, encoding, and pulse shaping, also can be implemented on the DSP. In contrast to an ASIC-based chip set, a DSP is easy to program, debug and test. This significantly shortens the development period and delivers a design that pager manufacturers can bring to market quickly.

Other DSP characteristics include:

• *Easy upgradeability* — Paging protocols keep changing and keep being updated to meet the ever-increasing demand for capacity and new features. Because a DSP is programmable, protocol changes can be accommodated by modifying DSP programs.

• *Plug-and-play nature* — A DSP chip with built-in analog-to-digital (A/D) and digital-to-analog (D/A) converters and controller functions easily can be interfaced with the analog signal from the RF unit output and with the control inputs of the display. As a comparison, current ASIC-based solutions require preprocessing to convert the analog signal to digital form. In addition, they require postprocessing by a microcontroller. Because pager IC manufacturers typically do not provide the microcontroller, pager manufacturers are left responsible for choosing and programming it.

In some applications, an ASIC proves superior to a DSP. In particular,

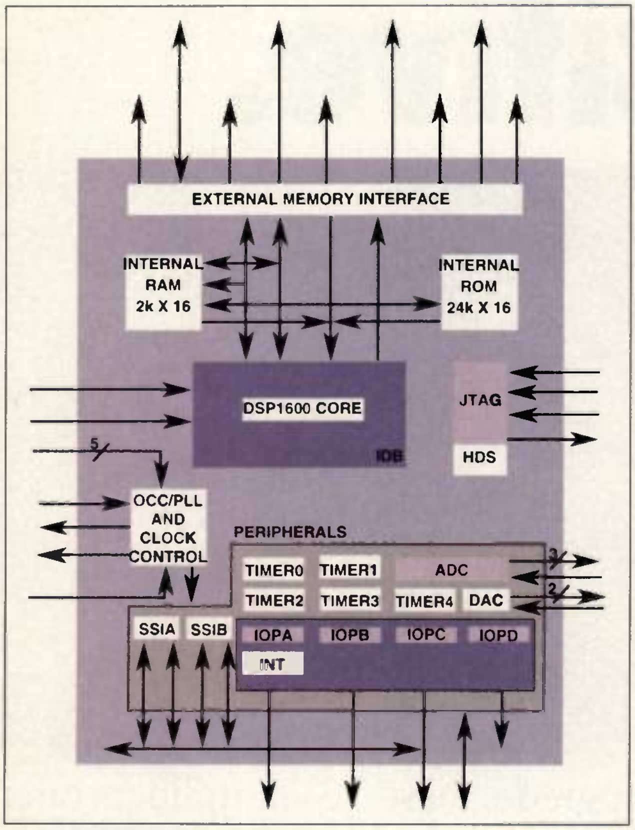


Figure 3. Block diagram of the DSP.

when ASIC chip sets are tailored specifically to a pager application, they can be both more cost-effective and more power-efficient. The better choice between an ASIC-based solution and a DSP-based solution usually will depend on which pager protocol is being followed.

DSP-based solution

A DSP specifically has been designed to provide versatile paging. Both the DSP and its paging software library are designed to meet current paging protocols and to support evolving paging protocols. A 20 millions of instructions per second (MIPS) mixed-signal device core, the DSP contains 24K 16-bit words of read-only memory (ROM), 2K 16-bit words of dual-port, random-access memory (RAM) and several peripheral blocks. The core contains a data arithmetic unit, memory addressing units and cache. The device is illustrated in Figure 3.

To achieve power savings and cost-effectiveness, the DSP integrates the digital circuitry with A/D and D/A converters, a clock synthesizer, a memory controller, an interrupt controller and serial input-output (I/O) controllers. The integration results in the functionality usually found only across an entire chip set. Microcontroller-type functions are implemented through the five timers and the four 8-bit ports. The serial peripheral interface is designed to drive an alphanumeric display.

To further reduce device cost and power dissipation, the clock synthesizer was designed to be driven by a low-speed (32 kHz or 38.4 kHz) external crystal. The crystal drives an on-chip phase-locked loop (PLL) that generates clocks required for the internal functions. Through on-chip power management, peripherals can be switched off when they are not in use. Under a 2.7 V supply, the device runs at 0.9 mA/MIPS in active mode. In full sleep mode, only 18 µA is consumed.

For current paging solutions, the DSP runs at less than 10 MIPS—less than half of its capacity. This leaves plenty of room for designers to add new features and functions. Alternatively, the clock frequency can be lowered to achieve further power savings.

Protocol independence also makes the DSP a platform that nicely enables pager designs. Programmability in the system architecture is an important factor in pager technology because the signal-processing requirements are dependent upon the protocol, and it is not yet clear what protocols will be dominant in many developed and undeveloped markets. This DSP was created for wireless messaging that can support protocols as the markets evolve.

Market conditions demand that signal-processing supports rapid application development and easy upgrades to existing designs. Programmability allows designs to be changed and new protocols to be implemented through software updates.

Through placing on-chip flash memory where the ROM normally is found, a "flash version" allows developers to load and to debug application software on the spot, instead of waiting several weeks for the DSP to be ROM-coded with the software.

In addition to costs reduced through programmability as well as a high degree of integration, further cost reductions are achieved through design innovations that enable the DSP, which is a mixed-signal device, to be manufactured entirely in digital complementary metal oxide semiconductor (CMOS) technology. No additional masks are required for the inclusion of analog circuitry.

Conclusion

The role of a DSP in paging designs is largely based upon the protocol followed. For pagers designed to support a relatively simple protocol such as POCSAG, an ASIC-based implementation generally is more cost-effective. But for designs based on ERMES and on the Flex family of protocols, a DSP-based solution may be the only viable option because of the signal processing required to detect the information in the received signal. A DSP-based pager also gives the designer the ability to tailor a pager design to meet evolving protocols simply through updating the DSP software. A DSP that contains such on-chip functionality as controller tasks and clock synthesis can prove to be even more effective. RF

About the authors

Xiao-an Wang is a systems engineer for Lucent Technologies Microelectronics Group, Allentown, PA. He can be reached at 610-712-2814 or E-mail xwang@micro.lucent.com.

Dwane Bell is an applications engineer for Lucent Technologies Microelectronics Group, Allentown, PA. He can be reached at 610-712-3438 or E-mail dbell@micro.lucent.com.

The DSPs described in this article are the DSP1615 and the FlashDSP 1615, both available from Lucent Technologies Microelectronics Group, Allentown, PA.

Reducing IM distortion in CDMA cellular telephones

By Dick Bain

Code-division multiple-access (CDMA) spread-spectrum technology enables more cellular users to coexist in a given segment of the allocated cellular frequency band. This will be a boon to those carriers struggling with overburdened analog cellular systems in high-density markets such as the Los Angeles area. Unfortunately, a problem has appeared in high-density markets where the CDMA systems have been tested. The gremlin is interference caused by intermodulation distortion (IMD) products generated in a CDMA receiver from multiple off-channel analog signals. What are these products, and how are they generated?

IMD products are generated when two or more signals pass through an active or inactive device in a receiver or transmitter. The most troublesome products are of two types: two-tone (two signal), third-order products and three-tone (three-signal) IMD products. Figure 1 shows the third-order, two-tone IMD products and the two signals from which they derive. The following formula describes how the third-order products are generated:

$$f_{IM} = 2f_1 - f_2 \text{ and } 2f_2 - f_1.$$

The three-signal IMD products are generated as follows:

$$f_{IM} = f_1 + f_2 - f_3$$

$$= f_1 + f_3 - f_2$$

$$= f_2 + f_3 - f_1$$

Three tones and their products are shown in Figure 2. The third product is not visible because it is the same frequency as f_2. There are other, higher-order products, such as 5th order and 7th order, but these generally are at a much lower level than the third-order products and therefore often can be ignored. A helpful tutorial on IM distortion appeared in the February 1996 *RF Design* [1], and a paper discussing the IMD problem in CDMA systems was presented at the 1996 IEEE Vehicular Technology Conference [2].

Which devices in a receiver generate IMD products? When multiple signals pass through any device, mixing action occurs because of the non-linearities of the device. No device has perfect linearity; even a passive device such as a type N connector will generate IMD products, though passive devices generate only small levels of IMD products compared to most active devices. The level of IMD products a device will generate can be characterized by the device's intercept point. Figure 3 is a graphical representation of the third-order intercept point (IP_3) of a device. The higher the intercept point, the lower the level of IMD products generated for a given level of input tones. So why not simply use high intercept point devices to solve IMD problems in CDMA phones? The drawback is that a higher IP_3 generally means higher supply current. To raise the IP_3 of an amplifier by 3 dB, for instance, the collector current generally would have to be doubled. It is possible

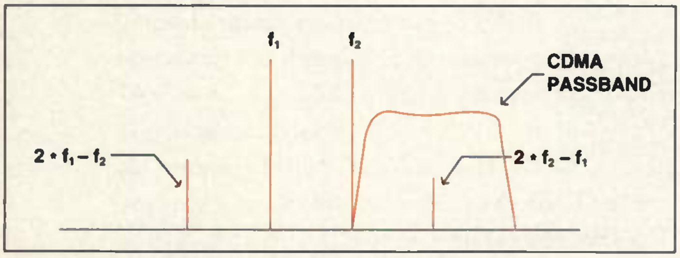


Figure 1. Third-order, two-tone IM tones and products.

Figure 2. Third-order, three-tone IM tones and products.

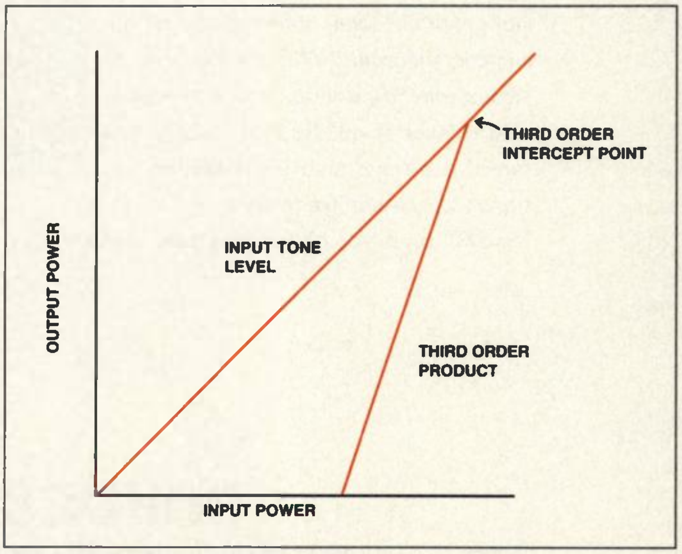


Figure 3. Third-order IM intercept point.

SystemView®

BY ELANIX

Experience the new generation of PC-based design and simulation tools.

Join the professionals. Experience SystemView by ELANIX.

AT&T Bell Labs
Bell Northern Research
Dolby Labs • E-Systems
GEC Plessey
General Dynamics
GTE
Harris RF Communications
Hewlett-Packard
Honeywell
Hughes • Intel
ITT • JPL • Lockheed
Loral • MIT Lincoln Labs
Motorola
Northern Telecom
Polaroid • Rockwell
Sandia National Labs
Scientific Atlanta
Stanford Telecomm
Watkins-Johnson

NOW AVAILABLE:
Extensive Communications, DSP, Logic, RF/Analog, and User Code design libraries.

Design, develop and test:

- **DSP systems**
- **Communications**
- **Signal processing**
- **Control systems**

Why have so many successful companies adopted SystemView by ELANIX for DSP, communications and signal processing system development? Simple. SystemView by ELANIX, running under Windows™, helps designers develop products faster while dramatically reducing software, platform, and maintenance costs.

SystemView by ELANIX is a key element of the design cycle, from system definition through hardware prototype testing. SystemView by ELANIX enables you to design, develop and test not only subsystems, but fully integrated end-to-end systems.

Intuitive and powerful, SystemView by ELANIX offers tools for analog, digital, and mixed-mode system development, linear and non-linear system design, and Laplace and z-domain linear system specification. These features are made accessible through our breakthrough user interface, which makes you truly productive within minutes of installation. And our new selection of feature-rich libraries for DSP, Communications, Logic, and RF/Analog design gives you the flexibility to customize the tool to your specific applications.

In short, SystemView by ELANIX will dramatically increase the efficiency of your entire design team. And all at a remarkably low cost.

But don't just take our word for it, judge for yourself. Try SystemView by ELANIX now!

SystemView

BY ELANIX

For your free evaluation kit call:
1-800-535-2649
http://www.elanix.com

5655 Lindero Canyon Rd., Suite 721 • Westlake Village, CA 91362 • **818-597-1414** • Fax: **818-597-1427** • e-mail: SystemView@elanix.com ©ELANIX, Inc. 1995. SystemView by ELANIX is a registered trademark of ELANIX, Inc.
European Distributor: EnTegra, Ltd. • 2 Waltham Rd. • Maidenhead, Berkshire SL6 3NH, England • (44) 01628 829061 • FAX: (44) 01628 824790 • Windows is a trademark of Microsoft Corporation.

INFO/CARD 32

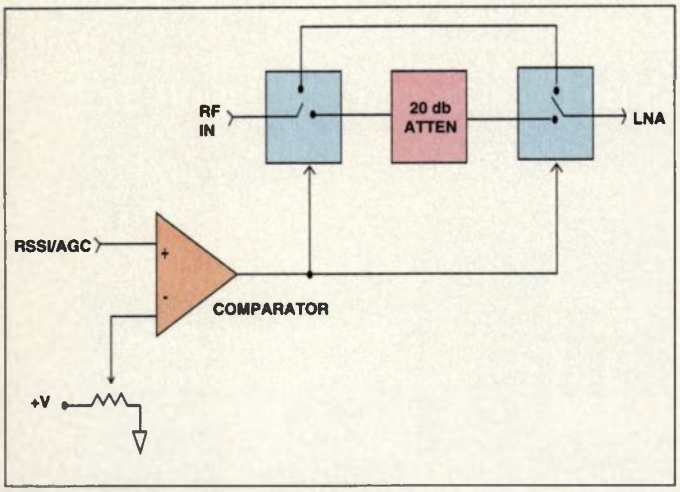


Figure 4. A 20 dB, switched front-end attenuator.

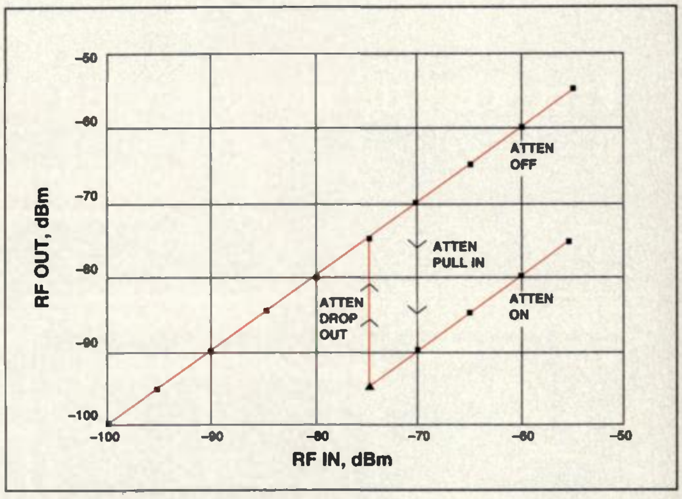


Figure 5. Fixed attenuator operation.

to use some type of distortion-canceling scheme using feedback or feed-forward techniques to achieve higher IP_3 without increasing device current but, unfortunately, distortion-canceling techniques involve significant amounts of additional circuitry, added cost and additional board space. Because the phone operates on battery power, increasing device current shortens the operating time of the phone before the battery needs to be recharged. What else can we do to treat this problem?

Raising the CDMA base station power seems like another logical solution. Unfortunately, CDMA and analog are often collocated at a base station and share the same power amplifier. Because the total power from the amplifier is constant, raising the CDMA power means lowering the power in the analog signals and reducing the reliability of communications for the analog cellular phone customers. Fortunately, there is an answer that avoids the problems of the previously referenced solutions. *Sacrifice some surplus signal-to-noise ratio to reduce IM levels.*

The following formula indicates how much IM will be generated by a given device with a particular level of input signals:

$$IMD = 3S - 2IP$$

where:
S = the level of each tone applied to the device in dBm
IP = the device's IP_3 in dBm

Note that if the tone level is dropped by 1 dB, the level of each IMD product drops by 3 dB. Because this is so, if the input signals are attenuated by 1 dB, the signal to IMD ratio will improve by 2 dB. When the receiver is operating above the level of its minimum sensitivity, it is possible to sacrifice some signal-to-noise ratio to increase the third-order intercept point and thereby reduce the level of IMD products generated. This can be done by switching an attenuator in series with the front end of the receiver, preferably before the first active device, to achieve maximum reduction of IM distortion products.

Fixed attenuator solution

A fixed attenuator can be switched in or out at a selected RF input level to reduce IM distortion at signal levels above threshold. This can be accomplished with a comparator that compares the level of the receiver's automatic gain control (AGC) voltage with a settable reference voltage as shown in Figure 4. Figure 5 shows how the signal level would change if a 20 dB attenuator were switched in series with the front end of a receiver. Notice that the attenuator must be switched in at an input signal level that is higher than the level at which it is switched out. This signal level increment, known as hysterisis, needs to be incorporated to avoid chattering, which otherwise would occur at the threshold point of the attenuator. Without the hysterisis, a signal at threshold level could cause the attenuator to switch in and out rapidly and repeatedly because of small fluctuations of the AGC or received signal strength indication (RSSI) input to the comparator. (Although RSSI originally was intended to drive a signal strength indicator in an FM receiver, in a dual-mode CDMA receiver, it can be used as an AGC voltage in the CDMA mode to control the gain of an amplifier.) In the case shown in Figure 5, the attenuator operates at an input level of –70 dBm and drops out at –75 dBm input. The pull in point of the attenuator is set by the amount of hysterisis needed and the drop out point required. The drop out point is determined by the threshold sensitivity of the receiver. For the CDMA cellular receiver, it is necessary to have the attenuator drop out at –75 dBm, so the signal will not drop below –95 dBm, and so a signal-to-noise ratio of at least 9 dB above minimum sensitivity will be maintained. The present CDMA receiver sensitivity recommended by the Telecommunica-tions Industry Association (TIA) document IS-98A is –104 dBm.

When the fixed attenuator is in the circuit, the third-order IMD products will drop by 60 dB, and the signal-to-IMD ratio will improve by 40 dB. Unfortunately, because the attenuator is disengaged for signal levels below –75 dBm, no IMD relief is available, and call drop outs may be a problem. Fortunately, there is another attenuator solution that offers IMD product reduction at significantly lower receiver RF input levels.

Variable attenuator solution

Positive intrinsic negative (PIN) diodes are devices that can be characterized as resistors with an RF resistance that decreases as the current through them increases. Although these devices make excellent switches,

BIPOLAR AMPLIFIERS FROM .01 TO 2 GHz

FROM* STOCK

STANDARD OPTIONS

- Connector Options: SMA, BNC, Type N
- Integrated Limiters
- Input Bias Tee for Fiber Optic Photodetectors

OPERATING FREQUENCY (MHz)	MODEL NUMBER	GAIN (dB, Min.)	GAIN FLATNESS (±dB, Max.)	VSWR IN/OUT	NOISE FIGURE (dB, Max.) F_L	F_M	F_H	OUTPUT POWER (dBm, Min.)	1-9 PIECE PRICE
0.01–200	AU-1442	35	0.5	2.0:1	1.2	1.2	1.2	5	$315
0.01–200	AU-1447	56	0.5	2.0:1	1.2	1.2	1.2	12	$325
0.01–500	AU-1310	30	0.5	2.0:1	1.3	1.4	1.5	8	$325
0.01–500	AU-1332	45	0.5	2.0:1	1.3	1.4	1.5	10	$350
0.01–1000	AM-1300	27	0.75	2.0:1	1.4	1.6	1.8	8	$350
0.01–1000	AM-1431	35	0.75	2.0:1	1.4	1.6	1.8	10	$375
0.02–1000	AM-1551	38	1.0	2.0:1	1.4	1.6	1.8	16	$375
1–100	AU-3A-0110	53	0.5	2.0:1	1.2	1.2	1.2	12	$300
1–200	AU-1464	35	0.5	2.0:1	1.2	1.2	1.2	6	$275
1–200	AU-1494	56	0.5	2.0:1	1.2	1.2	1.2	12	$300
1–500	AU-2A-0150	30	0.5	2.0:1	1.3	1.4	1.5	8	$275
1–500	AU-3A-0150	45	0.5	2.0:1	1.3	1.4	1.5	10	$300
1–500	AU-4A-0150	60	0.5	2.0:1	1.3	1.4	1.5	10	$325
1–1000	AM-2A-000110	27	0.75	2.0:1	1.4	1.6	1.8	8	$300
1–1000	AM-3A-000110	35	0.75	2.0:1	1.4	1.6	1.8	9	$325
1–1000	AM-4A-000110	52	1.0	2.0:1	1.4	1.6	1.8	9	$350
5–300	AU-1021	24	0.5	2.0:1	2.4	2.5	2.7	20	$275
5–300	AU-1525	61	0.5	2.0:1	1.2	1.2	1.3	20	$350
100–1000	AM-1412	35	0.75	2.0:1	1.4	1.6	1.8	15	$350
100–2000	AM-1526	9	1.0	2.0:1	4.5	4.0	4.2	20	$350
200–2000	AMMIC-1427	20	1.5	2.0:1	4.2	4.3	4.6	14	$450
500–1000	AM-2A-0510	24	0.5	2.0:1	1.4	1.5	1.6	0	$300
500–1000	AM-3A-0510	36	0.5	2.0:1	1.4	1.5	1.6	9	$325
500–2000	AM-3A-0520	30	0.75	2.0:1	1.4	1.9	2.4	3	$395
1000–2000	AM-3A-1020	30	0.5	2.0:1	1.8	2.1	2.4	10	$350
1000–2000	AM-1477	39	1.0	2.0:1	1.8	2.1	2.4	15	$350
1000–2000	AM-4A-1020	40	0.75	2.0:1	1.8	2.1	2.4	10	$375

NQA ISO 9001 REGISTERED COMPANY

3 YEAR WARRANTY

* Maximum 2 weeks delivery.

For additional information, please contact Bill Pope at extension 282.

MITEQ

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

INFO/CARD 60

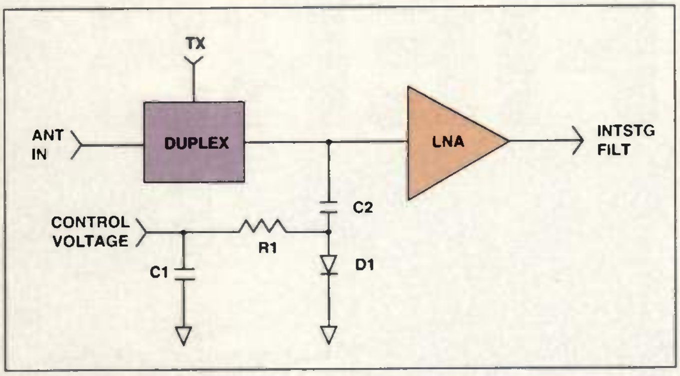


Figure 6. Shunt PIN diode attenuator.

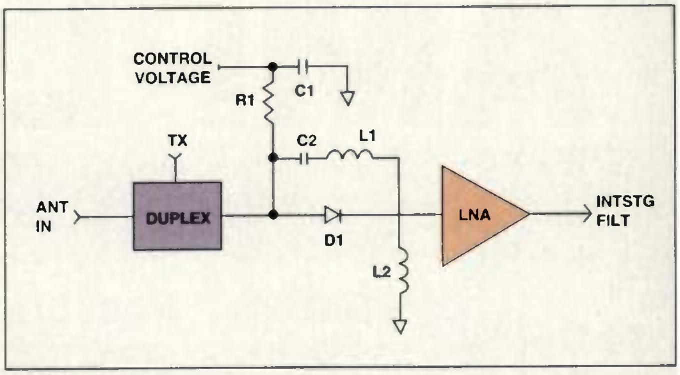


Figure 7. Series PIN diode attenuator.

they also can be used as current controlled RF attenuators. This capability has been harnessed to reduce IMD products in a CDMA cellular telephone and thereby increase communications reliability by significantly reducing dropped calls. Figures 6 and 7 show two ways to incorporate a PIN diode attenuator in a cellular phone receiver. We chose the shunt configuration for three reasons:

1. The shunt configuration requires fewer parts.

2. The stray inductance of the device is easily resonated out with a series capacitor. With the parasitic inductance resonated out, the measured attenuation of the shunt attenuator was a nominal 20 dB. A series attenuator requires a parallel inductor (L1 in Figure 7) to resonate the parasitic capacity of the diode to provide a high resistance when the diode current is minimum. A 1% tolerance part that is parallel-resonant with the stray capacitance of the diode is needed to achieve the full attenuation of the series PIN diode attenuator. In the case of the shunt attenuator, a 1% tolerance series capacitor is needed to resonate with the stray inductance of the PIN diode. Unfortunately, an inductor with a 1% tolerance is much more expensive than a capacitor with a 1% tolerance, and the procurement process of such inductors would have to include a long lead time—if they could be obtained at all.

3. The shunt PIN diode attenuation increases rapidly at the beginning of its attenuation curve. In the case of the series attenuator, the greatest attenuation change occurs at the end of its attenuation range because the diode current is maximum at minimum attenuation, and attenuation increases as the current through the diode is decreased. The rapid change of attenuation vs. diode current at small diode currents of the shunt attenuator has important consequences.

Figure 8 shows the measured attenuation vs. control voltage for a shunt attenuator. This is the voltage applied to a resistor in series with the diode. Notice the rapid increase in attenuation at levels between 0.5 and 1.0 VDC, which corresponds to about –95 dBm to –75 dBm. This means that there will be significant reduction of IM products even at –90 dBm input to the receiver, as opposed to the fixed attenuator case, where the attenuator offers no IM reduction until it is switched in the circuit at –70 dBm. Figure 9 shows the maximum tolerable tone levels during a two-tone IM test with the shunt attenuator active and inactive. The criteria for the CDMA IM test is a frame error rate (analogous to bit error rate) not exceeding 1% at the specified tone level. The area between the curve measured with the attenuator deactivated and the curve measured with the attenuator activated represents the improvement in receiver IM performance. Field tests show this improvement eliminates almost all dropped calls in a busy cellular market such as the Los Angeles area during times of peak use.

To take advantage of the full benefit of the PIN diode attenuator, it was necessary to temperature-compensate the RSSI voltage of the receiver with a temperature sensor integrated circuit (IC) and several sections of an IC as amplifiers and summers. This reduced the variation in the turn-on point of the

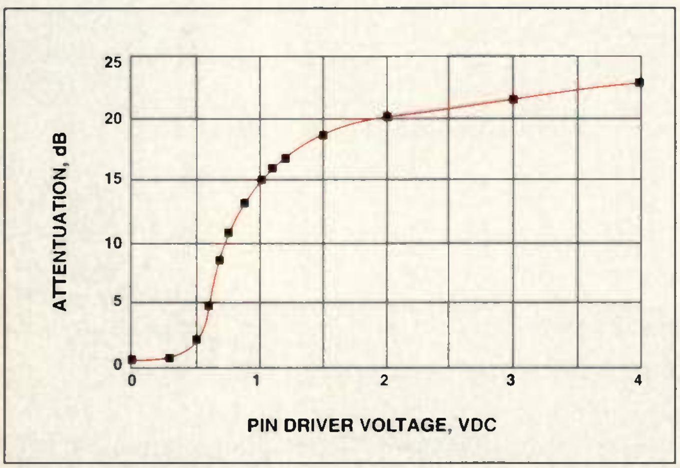


Figure 8. Attenuation vs. voltage.

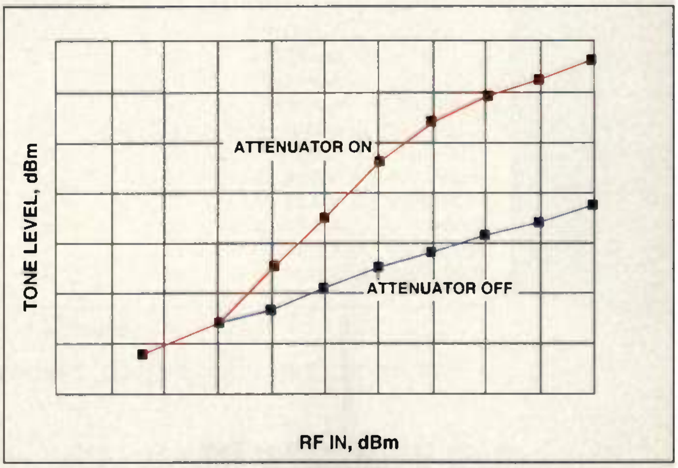


Figure 9. IM improvement with a PIN attenuator.

YOU MAKE THE CHOICE . . . WE MAKE THE SYNTHESIZER

- WIDE BAND?
- NARROW BAND?
- WIRELESS BAND?
- SINGLE CHANNEL?
- DUAL CHANNEL?
- FINE RESOLUTION?
- COARSE RESOLUTION?
- PHASE CONTROL?
- MANUAL CONTROL?
- BCD CONTROL?
- GPIB CONTROL?
- INT. FREQUENCY STANDARD?
- EXT. FREQUENCY STANDARD?

The PTS line of frequency synthesizers covers 100 KHz to 3.2 GHz. With a dozen different models, and hundreds of options and configurations, you can specify a unit that's just right for you. For special OEM requirements, call and talk to an applications engineer.

For a complete catalog, call or fax us today.

Tel: 508-486-3400

FAX: 508-486-4495

SERVING THE INDUSTRY SINCE 1975

PTS

PROGRAMMED TEST SOURCES, inc.

INFO/CARD 30

9 BEAVER BROOK ROAD
P.O. BOX 517
LITTLETON, MA 01460, U.S.A.

attenuator from 10 dB to less than 2 dB. This permits the turn-on point for the attenuator to be as low as –95 or even –100 dBm. The exact point is dependent on the minimum audio signal-to-noise ratio that is acceptable in the active range of the attenuator.

This PIN diode attenuator remedy for the IMD problems encountered in high-density markets, along with the other advantages of CDMA cellular systems, brings the CDMA system one step closer to providing badly needed additional capacity to supplement existing analog cellular systems. *RF*

Acknowledgements

I acknowledge Bob Lyall's contributions to the design and testing of the PIN diode attenuator and Pat Maresca's design and testing of the temperature compensation circuit. A patent has been applied for that covers the use of a variable PIN diode attenuator to reduce IM distortion as described in this article.

References

1. Jeffrey Pawlan, "A Tutorial on Intermodulation Distortion and Non-Linearity in RF Systems," *RF Design*, February 1996, pp. 71–74.

2. Khalid Hamied and Gerald Labedz, "Amps Cell Transmitter Interference to CDMA Mobile Receiver," *Proceedings of 1996 IEEE Vehicular Technology Conference*, Vol. 3, pp. 1467–1471.

About the author

Dick Bain, an RF staff engineer, conducts CDMA and PCS receiver design and support work at OKI Telecom. He has previously worked as an RF engineer at Aritech Moose, the ECI division of E-Systems, and at Magnavox. He received a B.S.E.E. from Indiana Institute of Technology. He holds an amateur Extra class license, N4RB. Several of his articles have appeared previously in *RF Design*. He can be reached at OKI Telecom, 437 Old Peachtree Road, Suwanee, GA. Tel. 770-995-9800, ext. 1402.

The complete article index: 1996

This index lists all articles published by RF Design *in the past year. They are organized into major topic categories, and listed in chronological order within those categories. Past years are available on microfilm and microfiche from UMI at 800-521-0600 or 313-761-4741 (from outside the United States). Photocopies of back issues and of specific articles are available from UMI Information Store at 800-248-0360 or 415-433-5500 Ext. 282 (from outside the United States). Information Store will need the following information when ordering: ISSN number 0163-321x; Issue date; Article title; Article; author; Page number. Questions and comments concerning the articles listed should be addressed to: Technical editor,* RF Design, *5660 Greenwood Plaza Blvd., Suite 350, Englewood, CO 80111.*

Amplifier design

Harmonic Performance," Chris Trask, August 1996, p. 81.

Antennas and propagation

"Notes on Electrically Small Antennas," Gary A. Breed, March 1996, p. 64.

"A Novel GPS Avionics Slot Antenna," Chien H. Ho, Paul K. Shumaker, Keith B. Smith, Juhn W. Wang and Hua Y. Wang, August 1996, p. 26.

"Selecting Vertical Radiation Patterns for Directional Base-Station Antennas," Charles M. DiFronzo," August 1996, p. 34.

"Log-Periodic Antenna as a Standard-Gain Antenna," John R. Tighe, Sharon Bradley and Joe Granados, August 1996, p. 44.

Circuit analysis

"Capacitor Behavior at Radio Frequencies," Gary A. Breed, January 1996, p. 58.

"RF Circuits for Communications Applications," Steve Andrezyk and Raphael Matarazzo, January 1996, p. 74.

"Noise Figure Modeling of Bipolar Transistors Using SPICE," Keelan Jennings and J. Alvin Connelly, February 1996, p. 33.

"A Tutorial on Intermodulation Distortion and Non-Linearity in RF Systems," Jeffrey Pawlan, February 1996, p. 71.

"A Tutorial on Intermodulation Distortion: Part 2–Practical Steps for Accurate Computer Simulation," Jeffrey Pawlan, March 1996, p. 74.

"Sideband Suppression Considerations for Complex Baseband Processing of FDM Waveforms," Rock Roberts, April 1996, p. 32.

"Noise Sources and Noise Calculations for Op Amps," Stephan Baier, May 1996, p. 66.

"Pull-out Range and Noise Bandwidth of Third Order PLL," Fu-Nian Ku, June 1996, p. 79.

"Cost-effective Evaluation of Digital Communication ICs," Marc Brendan Judson, October 1996, p. 56.

"Bias-circuit Methods to Reduce Process and Temperature Variations in GaAs MESFET ICs Are Compared," Joe Staudinger, December 1996, p. 20.

"Reducing IM Distortion in CDMA Cellular Telephones," Dick Bain, December 1996, p. 46.

Components

"RF Transformers Part 2: The Core, Nic Hamilton," January 1996, p. 64.

"Inductor Behavior at Radio Frequencies," Gary A. Breed, February 1996, p. 67.

"Structured Design of Third-Order, Type-2 and Type-3 PLLs," Fu Nian Ku, April 1996, p. 95.

"A Low Voltage FMIF System for DECT and Other High Speed GFSK," Yangpeng Guo, Randall Yogi and Alvin Wong, May 1996, p. 36.

"SAW-based Frequency Control Products for Modern Telecommunications Systems," C. S. Lam, D. S. Stevens and D. J. Lane, June 1996, p. 76.

"The Role of Digital Signal Processors in Pager Technology," Xiao-an Wang and Dwane Bell, December 1996, p. 36.

Filter design

"Computing Image Filter Requirements for Digital Cellular Radios," Alex

Gletfelter, February 1996, p. 76.

"Reducing Active Filter Cost Using Symbolic Three-Pole Synthesis," Glenn A. Parker, March 1996, p. 70.

"Active Filter and Other Op Amp Circuits for RF Applications," Gary A. Breed, April 1996, p. 74.

"Microstrip Bandstop Filter Cuts Spurious Carrier Frequencies," Denis Jaisson, September 1996, p. 30.

"A Simple Chebychev Bandpass Impedance-matching Program," Yves Borlez, October 1996, p. 80.

"RF Lumped-notch Filter Design for FCC Compliance Testing of Wireless Radio Modems," Lizhong Zhu, Bryan Taylor, Perry Jarmuszewski, November 1996, p. 36.

Frequency synthesis

"Isolator for DECT Open-loop Modulation," Rishi Mohindra, January 1996, p. 30.

"High Level Integration and Performance Comes to DDS," Dave Crook and Jim Surber, April 1996, p. 56.

"Dual DDS Offers High Performance for Critical Applications," Jonathan King, May 1996, p. 44.

"Designing a Frequency Synthesizer Using Low-temperature Co-fired Ceramic, Michael O'Hearn," November 1996, p. 46.

General purpose software

"Software System Adds New RF Layout Capability," Eagleware Corporation Staff, February 1996, p. 51.

"Program Accelerates Receiver and Transmitter Design," Mark Atkinson, July 1996, p. 36.

"A Circuit Simulator for Microwave and Wireless Applications," Ulrich L. Rohde, August 1996, p. 56.

High-speed analog and digital circuits

"Microwave Integrated Circuits Meet HF Project Demands for High-dynamic Range," Adrian I. Cogan, Donald Apte, Frank Sulak, Thomas Wei, Jim Spear and Lee B. Max, September 1996, p. 64.

Industry insight

"No More Talk About Talk—Broadband PCS Hitting the Airwaves," Andy Kellett, January 1996, p. 26.

"Wireless Telemetry Plays a Major Role in Market Growth," Gary A. Breed, February 1996, p. 30.

"Packaging Drives RF Power Device Development," Gary A. Breed, March 1996, p. 30.

"DSP Grows in Importance for New Communications Technologies," Gary A. Breed, April 1996 p. 28.

"Digital Cellular Technology Drives Component and Instrument Makers," Gary A. Breed, May 1996, p. 26.

"Broadcast Industry Eyes New Transmission Technologies," Gary A. Breed, June 1996, p. 22.

"Production Testing Grows as an RF Product's Design Requirement," Gary A. Breed, July, 1996, p. 61.

"RF Research Rising on Tide of Commercial Activity," Andy Kellett, August 1996, p. 24.

Miniaturization—The Shrinking Circuit, Ernest Worthman, September 1996, p. 28.

"RF Technology on the Cutting Edge of Science," Ernest Worthman, October 1996, p. 22.

William G. Newhall, Theodore S. Rappaport, Dennis G. Sweeney, April 1996, p. 40.

"Measuring Range and Reliability for Part 15 Systems," Bernard Kasmir, May 1996, p. 28.

"Anritsu Wiltron's Site Master Drops Cell Site Maintenance Costs," Ken Harvey, June 1996, p. 62.

"CDMA Signals: A Challenge for Power Amplifiers," Klaus D. Tiepermann, September 1996, p. 72.

"Test Set Measures Phase Noise Within 5 Hz of the RF Carrier," Charles Luke, October 1996, p. 66.

"Fine Phase-Error Measurements for a Quadrature Demodulator," John T. Clark and Edward A. Viveiros Jr., November 1996, p. 28.

"Integrated Test Solution Emulates Real-World Environment," Alex Kim, December 1996, p. 30.

Transmission lines and couplers

"Coaxial Cables," Jim Weir, August 1996, p. 70.

"Linear Simulators Offer Successful Microstrip Modeling for Wilkinson Power Splitters," Sean Mercer, September 1996, p. 38.

"Intermodulation in Coaxial Connectors," John King, September 1996, p. 68.

Transmitters and receivers

"Build a One-Tube Regenerative Receiver," Mark Starin, January 1996, p. 62.

"One-transistor Transmitter Circuits," William Rynone and S. Kan, February 1996, p. 82.

"Simple Direct-Conversion Receiver Checks Frequency Counters," Michael A. Covington, April 1996, p. 102.

An Inexpensive Receiver Preselector," Eric Kushnick, June 1996, p. 56.

Miscellaneous articles

Previews of the Dallas RF Design Seminars," January 1996, p. 44.

"A New Statistical Method for Designing Circuits and Systems," Peter Vizmuller, February 1996, p. 41.

"What You Should Know Before Returning to School for That Advanced Degree," Jeff Reed, Ted Rappaport and Brian Woerner, March 1996, p.67.

"Measured Effects of Seasonal Foliage Growth on a Short UHF Telemetry Link," Noel E. Evans, May 1996, p. 74.

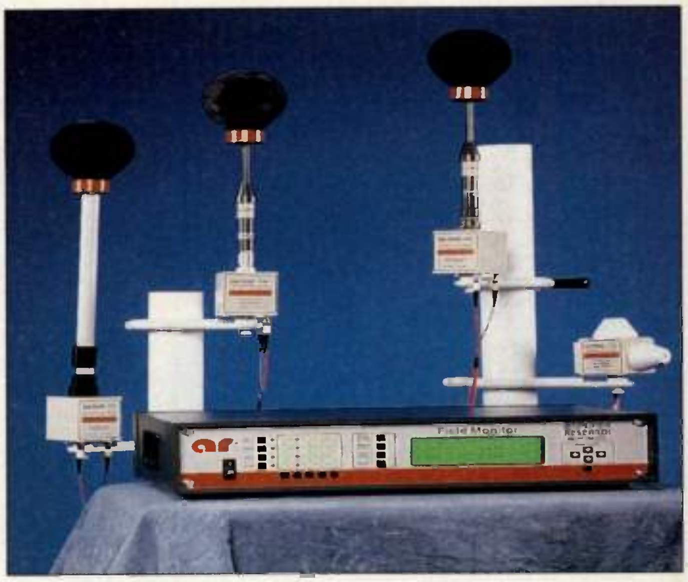
"Coping With Cost Constraints in a Market-Driven Economy," Ernest Worthman, July 1996, p. 54.

"The Complete Article Index: 1996," December 1996, p. 54. RF

EMC-test control center monitors four filed probes simultaneously

The FM5004, an EMC-test field monitor with the capability to read and display E or H field data from four field probes simultaneously acts as a computer control center in EMC-test environemnts. The FM5004 features microchips on boards inside the unit that allow it to recognize, control and view data from as many as four probes at once. Readings from the four probes, or from each of three axes of an isotropic probe plus an average reading of the three axes, can be called up at the touch of a soft key. Other features include capability to measure field strength at as many as four locations simultaneously or to extend operating bandwidth without test interruption. The FM5004 recognizes each probe, and readout is in actual engineering units with no correction factor required. Available probes include a two-unit combination for measuring E fields from 10 kHz to 40 GHz, 1–300 V/m. The FM5004 is priced at $7,900.

Amplifier Research
Info/card 168



RF power MLCs offer low ESR

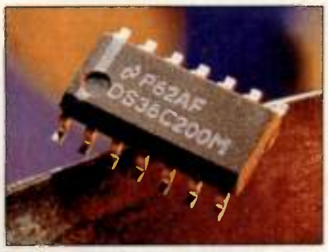
The 180 R, a standard 10 pF RF and microwave multilayer capacitor (MLC), exhibits an electrostatic resistance (ESR) of less than 0.075 Ω at 1 GHz. The 180 R has a capacitance range of 0.5–100 pF with a rated working voltage of 500 WVDC. Comparable to conventional RF capacitors, a

47 pF capacitor in this series can operate at currents greater than 10 A at 500 MHz. However, the 180 R measures 0.07″ × 0.105″. Typical pricing for the 180 R is less than $1 in quantities greater than 10,000.

American Technical Ceramics
Info/card 169

Dual transceiver for IEEE 1394 standard

A low-swing dual transceiver optimized for applica-

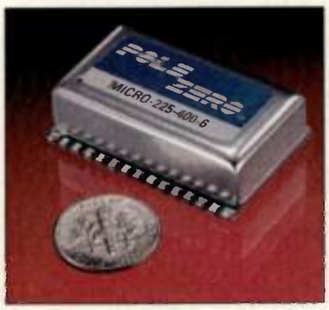


tions that require high data rates and low power, the DS36C200 is compatible with the Institute of Electrical and Electronics Engineers (IEEE) 1394 interface standard. The DS36C200 is designed using low voltage differential signaling (LVDS) technology, allowing data rates of more than 100 Mbps while using lower signal levels and signal swings. The DS36C200 is designed for digital satellite service (DSS) set top box to digital VHS (DVHS) interfaces, digital television (DTV) and multipoint high-speed applications. The DS36C200 is priced at $2.90 in 1,000 piece quantities.

National Semiconductor
Info/card 170

Digitally tuned filters feature low power

The Micro-pole digitally tunable bandpass filter line covers the frequency range of 30–1,000 MHz. The five filter units covering from 30–90, 90–200, 200–400, 400–700 and 700–1,000 MHz, each have 251 selectable center frequencies that provide continuous coverage over the entire bands. The Micro-pole filters feature a two-pole Butterworth response and operate at low power (2.7–5 VDC at 750 μA). The frequency is selected using either a parallel or



serial digital format and quickly (about 200 μs) tunes to any discrete frequency within the range of the filter's band.

Pole/Zero
Info/card 171

UHF transceiver gives reliable wireless links

The BiM-418-F and BiM-433-F bidirectional UHF

data transceivers combines a low-power, UHF FM transmitter and matching superhetrodyne receiver with data recovery and antenna transmitting or receiving change-over circuitry. The BiM devices feature half-duplex data transmission rates as high as 40 kilobits per second, operate from a 5 V power supply and will draw less than 15 mA when transmitting or receiving. Suitable for high-integrity, one-to-one wireless links or multinode, time-division multiple access (TDMA) communication networks, the modules are designed for cable-free PC-printer links and remote telemetry links.

Radiometrix
Info/card 172

Product focus: surface acoustic wave (SAW)

315 MHz SAW resonator

High-frequency SAW resonators allow designers to reduce the number of components required in wireless transmitter

designs. The KAR-CK series of resonators feature 315–450 MHz operating frequencies and have a standard stability of ±250 kHz (±100 kHz stability optional). The resonators are designed to eliminate spurious responses in RF applications such as keyless remote entry systems.
AVX
Info/card 173

SAW filters designed for WLAN applications

Two intermediate frequency (IF) SAW filters designed to support the IEEE 802.11 standard for wireless local area network (WLAN) applications feature center frequencies of 240 and 325 MHz. They also feature low insertion loss (13–14 dB maximum), low group delay (< 100 nsec peak-to-peak) and high ultimate rejection (40–55 dB minimum).
Sawtek
Info/card 174

SEMI-CONDUCTORS

Wideband HF receiver

A dual-channel wideband high-frequency (HF) receiver, model 9640, features an output frequency range of 1–11 MHz, a 4 MHz bandwidth, 53 dB nominal gain and 2:1 maximum voltage standing wave ratio (VSWR).
Interad
Info/card 175

Chip makes speech more intelligible

A smart preamplifier system-on-a-chip features variable compression and automatic noise gating to give microphone-level signals as high as 20 kHz a higher degree of intelligibility. With a single, user-selectable, external resistor, the SSM2166's compression ratio can be customized to produce a steady, undistorted audio output level even though signal inputs vary. The SSM2166 also limits high levels, amplifies low levels, and features signal compression, adjustable noise gating, automatic signal limiting and 5 V single-supply operation. It is priced at $1.50 in quantities of 10,000.
Analog Devices
Info/card 176

High-speed 2.4 GHz wireless bridge

The BR2040-EE high-speed wireless bridge is the next addition in a series of 2.4 GHz direct-sequence spread-spectrum (DSSS) bridges. The bridge can connect Ethernet networks at a data speed of 4 Mbps as far as six miles apart using a parabolic grid antenna in line-of-sight applications. The bridge operates in the 2.4 GHz industrial, scientific and medical (ISM) frequency band at an output level of as much as 100 mW so as to limit the effective isotropic radiated power (EIRP) to the 4 W Federal Communications Commission (FCC) maximum.
Aironet Wireless Communications
Info/card 177

SIGNAL SOURCES

Crystal offers high-frequency stability

The ECCM5 microprocessor crystal is a compact (6 × 3.5 × 1 millimeters) ceramic surface-mount device offering the high degree of frequency stability required by advanced communication applications. The ECCM5 series is available at a frequency range of 10–150 MHz and can sustain ±10 ppm tolerance and ±5 ppm

stability. It is designed for use in wireless, RF, microwave, telecom and satellite applications.
Ecliptek
Info/card 178

OCXOs at 10 and 26 MHz

Oven-controlled crystal oscillators (OCXO) models XO5026-003 at 10 MHz and XO5026-004 at 26 MHz both feature –155 dBc/Hz phase-noise performance at 10 kHz offset. They also feature less than $\pm 4 \times 10^{-10}$ per day aging, complementary metal oxide semiconductor (CMOS) output and a unit price of $220 at quantities greater than 1,000.
Piezo Technology
Info/card 179

Miniature surface-mount clocks

Models 042 and 342 are surface-mount quartz crystal clock oscillators designed for use in a variety of commercial applications, including personal communications services (PCS) base stations, cellular base stations, synthesizers, digital switching, test equipment and avionics. Both clocks cover a wide frequency range of 1–85 MHz. Model 042 has a 5 V supply. Model 342 has a 3.3 V supply. Both clocks are transistor-transistor logic (TTL) and analog complementary metal oxide semiconductor (ACMOS) compatible.
Oak Frequency Control Group
Info/card 180

VCOs tune from 1,930–1,990 MHz

The VCO190-1960T and VCO191-1960U both are voltage-controlled oscillators (VCOs) that tune from 1,930–1,990 MHz. The 190 has a tuning voltage of 2.0–3.7 V typically, draws 10.5 mA (typical) from a 5 V supply and has a typical phase noise at 50 kHz offset of –116 dBc/Hz. The 191 has a tuning voltage of 0.9–2.3 V typically, draws 6.5 mA (typical) from a 3 V supply and has a typical phase noise at 50 kHz offset of –114 dBc/Hz.
Vari-L
Info/card 181

TEST & MEASUREMENT EQUIPMENT

Synthesizers deliver –100 to 10 dBm amplitude

The series 50000A VXIbus microwave synthesizers give users the ability to generate, modulate, level and attenuate RF output signals from 10 MHz to 20 GHz. The synthesizers use a two-loop indirect synthesis design with a fundamental YIG-tuned output oscillator phase-locked through a reference loop to a crystal-controlled time base to produce frequency accuracy and stability, frequency resolution and spectral purity. The result is frequency stability better than 3 Hz per GHz per day, frequency resolution of 1 Hz, harmonics

<=–50 dBc from 2–20 GHz and single sideband (SSB) phase noise from 2–20 GHz of –97 or less at a 100 kHz offset. The Series 50000A microwave synthesizers are available in 11 models with prices starting at $20,750.
Giga-tronics
Info/card 182

Sweep system has multiuser capability

The 3HRV headend reverse sweep receiver simultaneously can perform 10 reverse sweeps and helps to eliminate the effect of ingress on the measurement. The 3HRV can stand alone for reverse alignment only or can be used in conjunction with the 3ST transmitter to provide full forward and reverse sweep alignment. The system also features an in-service signal analyzer for measuring carrier-to-noise and hum, a reverse noise and ingress spectrum display and a digital QAM carrier-level measurement option.
Wavetek
Info/card 183

CDMA AWGN generator achieves ±0.1 dB accuracy

The UFX-BER series of code-division multiple-access (CDMA) mobile- and base-station testers generates additive white Gaussian noise (AWGN) and automatically sets accurate C/N (Eb/No) ratios. This greatly reduces frame error rate (FER) test time in laboratory and production environments. The UFX-BER series features ±0.2 dB C/N accuracy with an optional ±0.1 dB and a typical crest factor of 18 dB.
Noise-Com
Info/card 184

Accelerometer calibration at ultra-low frequencies

The MB WIN475 vibration transducer calibration system with the low-frequency option makes it possible to have less than 1.25% system accuracy from 1–10,000 Hz. The MB WIN475 allows users to maintain a 4:1 ratio when calibrating 5% devices to 1 Hz.
MB Dynamics
Info/card 185

One-box system simplifies testing battery life

The 66312A and 66332A one-box, DC power supply functions both as a power

source and as a dynamic-measurement subsystem to assess battery-operating times quickly and accurately. Designed to simplify the testing of battery-operating time for cellular phones, mobile radios and other digital wireless communication products, the 66312A half-rack 40 W DC source and the 66332A full-rack 100 W source are priced at $1,695 and $2,095 respectively.
Hewlett Packard
Info/card 186

Signal generator guarantees output power of 10 dBm

A compact, programmable microwave signal generator, model 8003, covers 2–20 GHz in 1 MHz increments with a guaranteed output power of 10 dBm. It features a –90 dBc typical phase noise at a 20 kHz offset from the carrier and spurious output typically less than –60 dBc. The 8003 requires less than 30 WAC power and is priced at $8,995.
April Instrument
Info/card 187

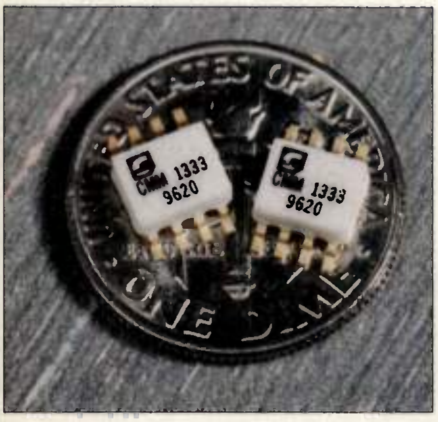
Signal source provides atomic clock accuracy

Model 2955AR rubidium standard with synthesized output has a direct-digital synthesizer output that is 32 bit programmable from 10 Hz to 4 MHz. It also has fixed outputs at 1 and 10 MHz. The synthesized output has spectral purity with typically less than –135 dBc phase noise at 1 kHz offset and long-term stability equal to the rubidium atomic clock. The 2955AR can be set to standard frequencies and also can be used as a master oscillator in laboratories and in ground stations as well as for test and calibration. The system is priced at $4,295.
Novatech Instruments
Info/card 188

AMPLIFIERS

Power amplifier meets PCS and PHS requirements

Model CMM1333 is a surface-mount SO-8 packaged digital power amplifier designed for personal communications services (PCS) and personal handy-phone systems (PHS) operating in the 1.85–1.91 GHz frequency band. The amplifier features 30 dBm time-



division multiple-access (TDMA) digital output power from a standard 5 V supply with 40% efficiency and 32 dB gain. The amplifier's high gain and efficiency eliminate the need to require a driver amplifier within the handset circuitry. The CMM1333 is priced at $20 in quantities of 1,000.
Celeritek
Info/card 189

Power amplifier meets high-linearity requirements

The ADCA-896-40 10 W linear cellular power amplifier is designed to meet the high-linearity requirements imposed by most multicarrier and digital transmission systems. It includes an internal isolator to protect against high voltage standing wave ratio (VSWR) and to ensure stable performance under any load condition. The ADCA-896-40 operates over the 869–894 MHz frequency range.
AdComm
Info/card 190

Power amplifier operates from 30–100 MHz

Model 100-30-120-35-E3 class AB power amplifier is a compact amplifier (6" × 2" × 1") featuring high-efficiency and low-harmonic output. It also features a gain of 40 dB typical, 50 Ω input and output impedance, a 30–100 MHz operating range and a saturated output power of 120 W. The unit is priced at $5,950.
LCF Enterprises
Info/card 191

RF amplifier provides high output power

The MHW2821-1 and MHW2821-2 RF power amplifiers operate in the 806–950 MHz frequency range and are designed for 12.5 V UHF applications. The MHW2821-1 requires an RF input power of ≤ 250 mW and an RF output power of 20 W. MHW2821-2 requires an RF input power of ≤ 300 mW and an RF output power of 18 W. Manufactured using laterally diffused metal oxide silicon (LDMOS), the amplifiers feature 50 Ω input and output impedances, stability, ruggedness and low harmonics. Both models are priced at $42.90 in low volumes.
Motorola Semiconductor
Info/card 192

Technology blocks offer increased integration

Silicon Systems, a Texas Instruments company, has a custom IC program that offers design teams access to technology blocks for implementing advanced, high-performance, digital, application-specific integrated circuits (ASICs) for mass storage applications. The technology blocks include disk formatters, headerless disk formatters, error detection and correction, buffer management, host interfaces and microprocessor interfaces, that ensure proper operation between blocks. The technology blocks speed development and integration and facilitate final device testing.
Silicon Systems
Info/Card 153

Modem algorithms available for DSP cores

VoCal's library of data modulation, fax modulation, speech coders and other telephony standards, including V.34 Annex 12 (33,600 bps) and full-duplex speakerphone, are available for the Analog Devices ADSP-2100 digital signal processor (DSP) core. Original equipment manufacturers (OEMs) can license the core from Analog Devices or from Mentor Graphics. The software library will allow users to embed the DSP architecture, supported by algorithm libraries and hardware and software development tools to produce communication and multimedia products.
Analog Devices
Info/Card 154

Antenna analysis software enables viewing capabilities

NEC-Win Basic provides an interface to the standard NEC-2 core as well as the capability to view antenna structures and to produce radiation and surface-pattern plots. NEC-Win Pro extends those capabilities. Features include: NEC-2 support with graphical entry for all commands, including surface patches; an antenna geometry viewer under Windows, with capability to view currents, sources, loads and transmission lines in addition to the viewing features found in NEC-Win Basic; wire identification within the NEC-Win Pro viewer that allows the user to click on a wire and have the input file highlight the wire; a 3D antenna pattern viewer under Windows that enables the user to view the pattern and the antenna simultaneously with independent zoom control; expanded polar plotting that includes - electric fields in addition to save features; rectangular plotting capability for viewing voltage standing wave ratio (VSWR), currents and radiation patterns; Smith charts for examining VSWR vs. frequency; and integrated NEC-Win Basic capability with spreadsheet operations.

NEC-Win Pro comes on four disks with a three-volume user manual.
Paragon
Info/Card 155

Design process simplified

MicroSim Schematics version 6.3 software for electronic design automation (EDA) includes enhancements that apply to the company's range of products from schematic entry through printed-circuit-board layout. Software capabilities include a graphical part browser, error traceback, a symbol creation wizard for improved schematic entry, a goal functions wizard and expanded libraries for enhanced simulation.

The graphical part browser lets the designer select a part from the 40,000 plus symbol library by name, number or description. Error traceback helps the user to find the source of design entry errors. A pop-up window alerts designers to any errors during netlisting, packaging and other operations. The symbol creation wizard provides a step-by-step process to define symbol shapes and adjust them as pins are added. Multiple pins may be added, named and numbered sequentially.

MicroSim's simulation products, MicroSim PSpice and MicroSim PSpice A/D contain goal functions, such as rise-time and bandwidth, that extract performance data from waveforms. The release of both simulation programs provides a model for a power semiconductor device, the insulated gate bipolar transistor (IGBT), which provides more than 150 IGBT models from which to create custom circuits.
MicroSim
Info/Card 156

Software addresses spectrum management

Phasor Design's Splash predicts the detailed spectral occupancy of transmission by a detailed mathematical modeling of the modulation process. The software simulates the key transmitter characteristics that determine spectrum use. Baseband signals are generated, shaped and processed to accurately model reality. For FM systems, the non-linear modulation process is simulated mathematically, allowing spectrum expansion to be examined. Splash is a Microsoft Windows application and runs on an IBM or compatible 486 or above.
Phasor Design
Info/Card 157

VXI instruments provide scaleable test systems

The VXI plug and play-compliant line of multifunction VXI-based multifunction data acquisition (DAQ) instrument modules, from National Instruments, delivers scaleable test to users who have developed applications using the company's DAQ products for PC and XT, AT, EISA, PCI, NuBus or PCMCIA. Because the modules use NI-DAQ driver software, users can run their applications on the VXI-based modules with no software rewrite.

The R&D engineer can test initial designs using a PC-based system; the test engineer can reuse this software with a VXI system for production; the service technician can again reuse the same software with a lap-top computer and the company's PCMCIA-based DAQ interfaces.
National Instruments
Info/Card 158

Software and hardware aid Lode DSP core

A software and hardware development platform for the Lode digital signal processor (DSP) core is available from TCSI. Lode is a 16-bit DSP designed for high performance in digital cellular, speech and voice communications applications.

The suite of tools includes an assembler, linker, simulator and hardware development platform. The software components allow the DSP programmer to develop and verify application software. The hardware platform enables a DSP programmer to analyze the efficiency of an application before implementation.
TCSI
Info/Card 159

Handbook combines resistor theory, application

The Resistor Handbook by Cletus J. Kaiser combines resistor theory with practical circuit application information. This book complements the author's *The Capacitor Handbook* and *The Inductor Handbook*. The first chapter covers the fundamentals of all resistors followed by chapters on composition, film, wirewound and nonwirewound types of resistors. Later chapters cover thermistors, shunts, current shunts and current sensors. A glossry, symbols and equations, resistor selection guidelines and index also are included. The 100-page book costs \$15.95 plus \$4 shipping and handling.
CJ Publishing
Info/Card 160

Designer's guide available

Mini-Circuits' 180-page *RF/IF Designer's Guide* contains practical articles, a glossary of terms, environmental and reliability test procedures, answers to frequently asked questions about surface-mount technology and specifications and prices for the company's signal-processing components. The guide is free and may be obtained by mail, fax, phone or E-mail.
Mini-Circuits
Info/Card 161

Catalog includes test instruments and tools

The fall catalog from Contact East includes test instruments and tools for those involved in design, R&D, testing, quality control and management. Product highlights include oscilloscopes and accessories, graphical multimeters (wavemeters), programmable power supplies, spectrum analyzers, frequency counters, breadboards, milliohmmeters, infrared temperature probes, SMT products, instrument carts, soldering and desoldering systems, magnifiers and inspection equipment, power analyzers, measuring tools, hand tools and reference books. Brand name manufacturers include Tektronix, Fluke, 3M, Alphametals, Hakko, Weller, Microcare, Charleswater and Chemtronics. The catalog is free.
Contact East
Info/Card 162

On line:

Free resource for electronic engineers—As part of Eg^3's virtual publishing project, *The EE Virtual Trade Conference* (EE VTC) is available at http://www.eg3.com/vtc.htm. The EE VTC features more than 225 technical papers on topics such as object oriented programming, virtual distribution, digital signal processing (DSP), microcontrollers and microprocessors, the set top (Internet) box, world-wide web for embedded systems, embedded java, networking and embedded networking and real-time operating systems. The free software can be downloaded after registration. It can be accessed at three different web sites: www.eg3.com, www.eetoolbox.com and www.cera2.com. More information is available at info@eg3. com.
Eg^3
Info/Card 163

Web site for security products—Torfino Enterprises manufactures and distributes law-enforcement and corporate security products including near-field transmission detectors, explosive detectors, X-ray machines for package screening and hand-held and walk-through metal detectors. The company is active in R&D and can custom-design equipment to the user's specifications. The web site address is http://www.torfino.com.
Torfino Enterprises
Info/Card 164

Signal conditioning and data communications web site—Dataforth designs and manufactures signal conditioning and data communications products. These include the SCT line of two-wire transmitters; isolated analog and digital input and output (I/O) modules and accessories, including industry standard 5B and 7B modules; and industrial modems and modem systems. The web site includes product data sheets for the company's limited distance modems and modem systems; application notes covering technical issues; the industrial signal conditioning design guide; product announcements; a listing of the company's sales representatives and distributors; and links to other technical sites for those working in industrial data acquisition, measurement and control. The interactive site facilitates technical questions and literature orders. The site can be visited at www.dataforth.com.
Dataforth
Info/Card 165

Bumping service design guide for IC package designers—Flip Chip Technologies, the joint wafer-bumping venture between Delco Electronics and Kulicke and Soffa, has a bumping service design guide for integrated circuit (IC) package designers. The guide is available for free on diskette or by downloading it from the website at http://www.flipchip.com.

The electronic document is useful for designers incorporating flip chip technology into their designs. The guide covers wafer requirements and minimum pitch capablities. It addresses Flip Chip design standards and includes the subjects of metallurgy, available solder alloys, IC design considerations and mask data requirements. One section deals with such development directions as fine pitch, redistributions, interconnect capability and 200 millimeter wafer capability.

Also included are directions on how to obtain quotations and information on available test die. The Bumping Service Design Guide also may be obtained by calling the company. E-mail may be addressed to info@ flipchip.com.
Flip Chip Technologies
Info/Card 166

PTI product line on web site—Piezo Technology (PTI)'s web site provides information on its line of resonators, diplexers, crystal filters, GPS filters and crystal oscillators. Also featured are detailed specifications, design aids, application notes, a listing of representatives and company information. The site can be accessed at http://www.piezotech.com.
Piezo Technology
Info/Card 167

RF LITERATURE/PRODUCT SHOWCASE

TESLA 2.0
Block Diagram Simulation
Nonlinear RF and digital simulation with fast spectrum analysis. Call now for a free 30-day trial.
800-631-1113 http://www.tesoft.com
TESOFT Inc. 770-751-9785 Fax770-664-5817
PO Box 305 Roswell GA 30077

INFO/CARD 100

Congratulations Jake!
You found the perfect Signal Generator!

$795
Quantity 1
Made in USA

Features:
- DC-20 MHz, .1Hz steps
- Fully synthesized
- 10 Setup save/recall
- DC offset
- RS232 remote ctrl
- Field upgradable

Modes:
- Sinewave
- Int/Ext AM
- Int/Ext FM
- Int/Ext PM
- Int/Ext SSB
- Int/Ext BPSK
- Linear/Log Sweep
- Int/Ext FSK
- Burst
- DTMF Generation
- DTMF Detection
- Power Level Meas

Telulex Inc. 2455 Old Middlefield Way S
Mountain View, Ca. 94043
Tel: (415) 938-0240 Fax: (415) 938-0241
http://www.telulex.com

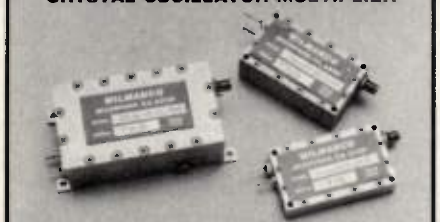
INFO/CARD 101

USA • Tel: 619 674 8100 • FAX: 619 674 8262
Europe • Tel: 353 93 24107 • FAX: 353 93 24459
Asia • Tel: 65 741 5277 • FAX: 65 741 3013
World Wide Web • http://www.pulseeng.com

INFO/CARD 102

LOW COST HIGH PERFORMANCE FREQUENCY SOURCES

CRYSTAL OSCILLATOR MULTIPLIER



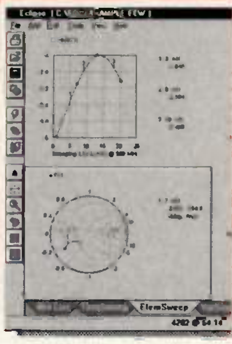
- ✓ *MODEL VSA – $195.00 .01 GHz TO 1.0 GHz*
- ✓ *MODEL USA – $245.00 1.0 GHz TO 1.8 GHz*
- ✓ *MODEL SSA – $295.00 1.8 GHz TO 4.2 GHz*

RF OUTPUT: +8dBm min., at any spot frequency in above ranges
FREQ. STABILITY: ±30ppm, -20°c to +60°c
B+: +12 to +16 VDC

Wilmanco 5350 Kazuko Court, Moorpark, CA 93021
(805) 523-2390 FAX (805) 523-0065

INFO/CARD 103

Eclipse 4.0 *for Windows*



- Comprehensive Element Library
- User-defined Equations
- Flexible Sweep Capability
- Multiple Graph Sheets
- Manual Element/ Variable Tuning
- Optimization
- Customizable Graphs
- Network Analyzer style Markers

An Unparalleled RF/Microwave Linear Simulator

only $495.00 http://www.ardentech.com for a fully functional demo

Arden Technologies, Inc.
PO Box 286 • Forest, VA 24551
Voice 804-525-6837 Fax 804-525-5376
e-mail: arden@ardentech.com

INFO/CARD 104

RF POWER AMPLIFIERS

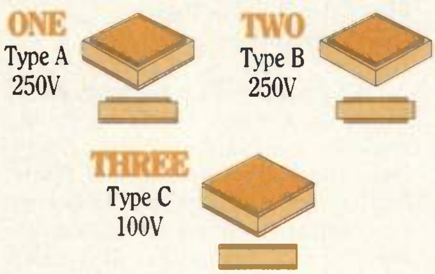
1 MHz 2GHz 1W 1KW

- Small Size • High Efficiency • Durable
- Module and Rack Mount Systems
- Customization Available

LCF ENTERPRISES RF POWER AMPLIFIERS
651 Via Alondra, #712
Camarillo, CA 90312 USA
TEL: (805) 388-8454
FAX: (805) 389-5393

INFO/CARD 105

Only TECDIA has THREE!
SINGLE LAYER CHIP CAPACITORS



FOR CAPACITORS WITH:
- Extremely smooth and uniform metalized surfaces
- Pt metalization to withstand 400°C die attach temperature up to 20 min max
- TiW adhesion layer to prevent diffusion and provide stability at very high temperatures

TECDIA
2672 Bayshore Parkway, Suite 702, Mountain View, CA 94043
Tel: (415) 967-2828 Fax: (415) 967-8428

INFO/CARD 106

READY WHEN YOU ARE

As soon as you're ready, you can reach over 40,000* technical professionals with the subscriber list from *RF Design*.

Professionals from all segments of the marketplace rely on *RF Design* for the latest industry developments and for your message.

Don't keep them waiting.
Call Lori Christie
913-967-1875 • Fax 913-967-1897

*Based on the June 1996 BPA International Statement

An INTERTEC®/K-III Publication
RF design®

RF marketplace

Classified display ads are available at $125 per column inch. Frequency rates available for multiple insertions. Please call for further information, 303-220-4288. Or fax your ad copy for a rate quote to: (303) 793-0454.

Business Opportunity

STRATEGIC ALLIANCE WANTED

Newly developed RF receiver architecture dubbed the "Universal Digital Receiver," promises both a high level of integration and an outstanding cost performance ratio for wireless applications.

The new architecture, developed over a five-year period, is targeted to wireless markets including, but not limited to, **AMPS, GSM, DECT**, and **PCS**.

NUMA Technologies, Inc. is currently seeking a limited number of strategic partners, who are currently engaged in, or interested in, the design, production, and distribution of RF integrated circuits. For further information, please contact Mr. Mark Hedstrom at (941) 591-8008.

Career Opportunities

ENGINEERING PERSONNEL SERVICES

- RF / Analog & Digital Circuit Design
- Hardware / Software Design
- Cellular / PCS System Design

Send resume to address below

ALL LEVELS OF POSITIONS FILLED GLOBALLY

Employer inquiries welcome.

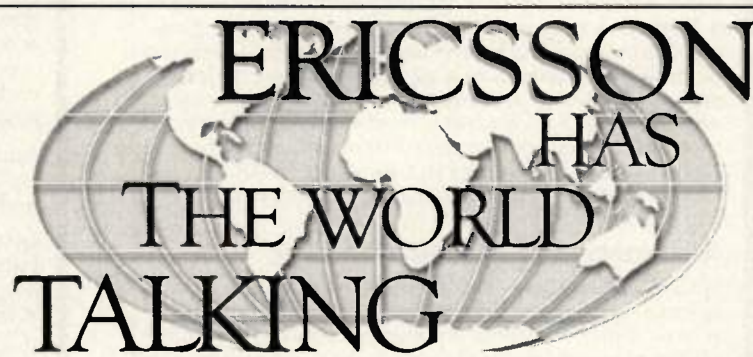
Communication Resources, Inc.
The Communication Personnel Specialists
P.O. Box 141397, Cincinnati, OH 45250
606-491-5410 FAX 606-491-4340
E-Mail, Careercom@AOL.com

ENGINEERING OPPORTUNITIES

PCS/PCN/CELLULAR/CDPD
RF/HW/SW/FW/DSP
Terminals/Systems

FITZPATRICK & ASSOCIATES
6540 East Ashbrook Dr. • Fountain Hills, AZ 85268-2832
E-Mail: FITZPAT@ix.netcom.com
FAX: (602) 956-7644

Career Opportunities



Ericsson is an undisputed world leader in telecommunications, renowned for its advanced systems and products for wired and wireless communications. Lynchburg is the headquarters for Private Radio Systems, R&D, design and manufacturing, and Cellular Telephone and Radio Systems manufacturing. As a member of the Ericsson-Lynchburg team, you'll be at the forefront of a fast-paced industry. As a Lynchburg resident, you'll enjoy the scenic, historical city, nestled in the mountains with easy access to the ocean.

TEST ENGINEER

Will be responsible for developing advanced hardware and software test systems for state of the art manual and automated cellular phone manufacturing assembly lines. Serve as a technical interface with design engineering, product management to provide for new product testability. Requires 5 or more years test engineering experience with emphasis in RF testing and FM communications systems. Recent experience in automated manufacturing systems a plus. Good background in C programming. Job Code: TE/NM

RF VERIFICATION ENGINEER

Responsible for the verification of new product processes and changes to insure highest quality and productibility with the Cellular Phones manufacturing products. Be a technical liaison between design and manufacturing functions (component, factory process). Identify, evaluate and approve short-term and long-term solutions for radio/process problems. BSEE with 3 years RF design experience preferably with cellular and/or other portable phones. General radio knowledge in audio and software a plus. Experience with Spectrum/network analyzers, signal generators, RF component fixtures, communication test sets, modulation analyzers, etc. a plus. Job Code: RVE/NM

SOFTWARE - LOGIC HARDWARE VERIFICATION ENGINEER

Responsible for verification of software for new products and changes to insure the highest quality and productivity consistent with Cellular Phones manufacturing products. BSEE with 3 years software and some logic hardware design experience with cellular and/or other portable phones. 6303 up and C, C++ knowledge strongly desirable as well as some general analog experience. Job Code: SLH/NM

Please forward resumes, referencing correct Job Code, attn: Natalie Martin, to FAX: 804-948-6543, or EMAIL: <Natalie_Martin@ena-east.ericsson.se>. Additionally, we request resumes be EMAILED to <ericsson@adaptservices.com> or FAXED to 800-611-7414 for inclusion in our company-wide database. Visit our site on the World Wide Web at: http://www.ericsson.com Equal Opportunity Employer.

ERICSSON

ENGINEERING

• RF Engineer
• Microcontroller Senior Engineer
• Mechanical Engineer
• DSP Engineer

RACAL COMMUNICATIONS, INC. a world leader in the design and manufacture of high quality secure tactical communications products, has several positions available in our Engineering department.

RF ENGINEER

The candidate will have a BSEE degree and 5+ years experience in hands-on RF hardware design and analysis of VHF and/or UHF frequency hopping and/or fixed frequency batter powered transceivers. A strong background designing synthesizers, IF amplifiers, mixers, low-noise small signal amplifiers, RF filters and power amplifiers of up to 10 watts is required. Experience in designing transceivers that operate in a digital environment, to include advanced modulation techniques, would be a significant plus. Candidates must have a working knowledge of computer aided analysis tools, good administrative skills with PC and proficiency in using standard RF test equipment. Familiarity with MILSTD test methods and the SINCGARS frequency hopping wave form is desired. US citizenship required.

(Microcontroller) SENIOR ENGINEER

The ideal candidate will have a BSEE and at least 5 years of experience in hands-on digital hardware and software design for the development of wireless communication systems. A strong background in digital design and software/firmware development of real-time, embedded microcontroller applications for portable radio products is required. Experience in developing microcontroller firmware in C and/or Assembly is a must. Hardware and firmware design experience using the Hitachi H8 and/or Intel 805x microcontroller families is preferred. The position also requires proficiency using the PC for engineering design and administrative tasks. US citizenship required.

MECHANICAL ENGINEER

The Mechanical Engineer will have at least a BSME (MSME preferred) and at least 5+ years experience in electronic packaging design for our hand held radio equipment. Experience in designing cast aluminum housing using AutoCad (3D preferred) is necessary. Experience with other electronics packaging techniques such as plastics, magnesium castings and precision sheet metal would be a significant plus. The chosen applicant will design rugged packages for our hand-held radio equipment. US citizenship is required.

DSP ENGINEER

The ideal candidate will have a BSEE/BSCS degree and at least 5 years of experience in DSP algorithm and software development for portable radio applications including baseband (audio) filtering and processing. IMBE and/or CVSD encrypted voice processing, digital data processing and modulation/demodulation. Experience developing DSP applications for the Analog Devices ADSP21xx or Motorola 563xx processor family is a plus. The position also requires proficiency using the PC for engineering design and administrative tasks. US citizenship is required.

RCI offers our engineering staff the technical rewards, challenges, opportunities and professional environment necessary to produce existing results. For immediate consideration, please fax your resume with salary requirements to:

RACAL COMMUNICATIONS, INC.
5 Research Place • Rockville, MD 20850
Fax: 301-948-6015

EOE
Principals Only

M/F/D/V

RACAL

Place A Classified Ad Today!
Terri Stenson: 303-220-4288 • FAX 303-793-0454

PRODUCT MANAGER

Thin Film Substrates

Join our growing team!

American Technical Ceramics has an excellent career opportunity in our expanding Thin Film Custom Products Group in Jacksonville, Florida. Position requires an experienced, dynamic individual with a technical sales background in thin metalized film substrates or related products.

American Technical Ceramics Corp. (ATC) is a manufacturer of thin film custom circuits and is the world's leading manufacturer of Microwave Capacitors.

Qualified candidates may mail or fax resume to: **Attn: Human Resources, ATC, 2201 Corporate Square Blvd., Jacksonville, FL 32216. Fax: (904) 724-9722.** EOE

american technical ceramics

ENGINEER, SYSTEMS DESIGN

LOCUS is a growing, leading edge OEM product developer/supplier specializing in wireless communications and embedded systems products. Our exciting, fast paced environment offers an opportunity to work on a variety of challenging projects for a number of diverse industries.

Ideal candidates will have a minimum five years experience in complete product development including: RF circuit simulation, digital radio, RF propagation, FCC regulations, and production test. Analog experience a plus.

Locus offers an excellent salary and benefits package as well as continuing opportunity for professional growth. EOE/Smokefree Office. Forward resume and salary history (principals only) to: Attn: Ms. Rounds

LOCUS

LOCUS, Inc., 1842 Hoffman St., Madison, WI 53704
Phone: 608-244-0500 FAX: 608-244-052
http://www.locusinc.com

Unlock The Secret To Successful Advertising...

CONTINUITY is the KEY!

Inquire About Frequency Discounts:
303-220-4288

Paging PCS Cellular SMR

CNI
Career Networks
Recruiters for the Wireless & Telecom Industries
800-JOB LINK™
Specializing in Sales, Marketing, Technical, Engineering, Software Development & Executive Placements

Gables One Tower, Suite 801
1320 S. Dixie Highway
Coral Gables, FL 33146
joblink@aol.com
www.cnijoblink.com

Fax Resume to (800) JOB-FAXX

Apply Yourself

IN A WIRELESS WORLD

With the innovative technologies of BellSouth Cellular Corp., opportunity knows no boundaries. If you're looking for the ultimate challenge in wireless telecommunications, we have the perfect landscape.

Our engineers utilize the latest technologies and design solutions to provide the most powerful, reliable forms of telecommunications in the U.S.A. In fact, during the Olympics, we delivered one of the most sophisticated technical projects in communications history. One hundred forty-four square miles of land in Atlanta was fortified to carry a level of wireless technology previously never attempted anywhere. And we are making an impact in other major markets in the U.S. like **Atlanta, Los Angeles, Houston, Indianapolis, Birmingham** and **South Florida**.

It's all part of an expansive network of wireless communication services that began in 1984 and now serves more than four million customers.

BellSouth Cellular Corp. is better known locally as BellSouth Mobility Inc. and American Cellular Communications Corporation. Together, we provide service in more than 200 markets and we continue to expand as one of the fastest growing cellular service providers. We utilize TDMA and IS-136 to support a host of new digital features, while still providing our analog customers with the best call quality around.

We're working to become one of the best places to work in America.

At BellSouth Cellular Corp., we're working to become one of the best places to work in America. You'll share ideas, suggestions, concerns... and be recognized for your accomplishments.

What's more, your potential to learn and grow will unfold as groundbreaking technologies present unique opportunities. Positions are currently available for engineers with two or more years of experience in the following areas:

- **RF Engineering**
- **Network Engineering**
- **Field Engineering**

So apply yourself in our wireless world. Working for an industry leader, you'll find an excellent compensation package including stock investment options and a 401(k) plan with immediate vesting. Please forward your resume, indicating position of interest and location to:

BSCC Wireless Recruiting
Suite 1401, Dept. RF
1100 Peachtree Street N.E.
Atlanta, GA 30309-4599
E/O/E

American Cellular Communications
A BELLSOUTH Company

BELLSOUTH
CELLULAR CORP.

BELLSOUTH Mobility

Alabama • California • Florida • Georgia • Hawaii • Illinois • Indiana • Kentucky • Louisiana • Mississippi • Tennessee • Texas • Virginia • Wisconsin

• PCS • CELLULAR •

Employer Inquires Welcome

Engineering • Operations • Technical

FIRST SEARCH

6584 N.W. Hwy., Suite RF
Chicago, IL 60631
Phone (312) 774-0001
FAX (312) 774-5571
e-mail: fsihunter@aol.com
http://www.firstsearch.com

- RF Engineers
- Cellular System Engineers
- System Optimizers
- Cell Site/Switch Maintenance
- Performance Engineers

DIRECT & CONTRACT POSITIONS

Senior Wireless Communications Systems Engineering

Globalstar, a growing, satellite-based telecommunications company, currently has openings for Senior Systems Engineers in the following capacities:

- Design and analysis of system architecture for satellite wireless systems (requires at least 3 years' experience with satellite link budgets)
- Analysis of satellite/gateway/ground operations interface and requirements issues, including trade studies in the areas of satellite OBP and terrestrial network architecture for broadband services and PCS for next generation systems

These positions require an MS/PhD in EE, with emphasis on communications systems design and analysis; 8-12+ years' experience with telecommunications networks and/or wireless systems (especially PCS, VSAT, and satellite on-board processing). All positions will be staffed at Globalstar's headquarters and development center in San Jose, California.

Globalstar offers competitive compensation, benefits and relocation packages, as well as a chance to work on some of the most exciting technical challenges in Silicon Valley.

For immediate consideration, please forward your resume to: Globalstar Professional Staffing, 3200 Zanker Road, P.O. Box 640670, San Jose, CA 95164-0670. Fax (408) 473-5910. Principals only, please. Globalstar is an equal opportunity employer.

Globalstar

EMC Test Systems, a world leader in the manufacturing of Electro-Magnetic Compatibility products, is seeking candidates for the following current opening:

R.F. Engineer

Candidate needed to support proposals by reviewing design requirement and suggesting absorber treatment. Will dedicate time to perform field tests, prepare test plans and reports. Candidate will prepare technical write ups for proposals, generate anticipated performance data of new chamber designs and develop absorber layouts for proposed chambers. Will also perform EMC and VSWR tests. Arrange test plans/reports and support R&D.

Requirements for this position will include undergraduate certification and (at least imminent) graduate certification in electrical engineering with concentration in the field of electro-magnetics.

EMC Test Systems offers competitive salaries and an excellent benefit package including a smoke and drug-free environment. For immediate consideration, please send you resume including salary history to:

EMC Test Systems
Human Resources Department
P.O. Box 80589
Austin, TX 78708-0589

ELECTRONICS ENGINEERS

CRS is a high tech R&D organization involved with innovative system design and development using cutting edge technology. We are in immediate need of several experienced electronics engineers with interest in diverse areas of electronics. The experiences should include either of the following areas: low noise analog and instrumentation, H.F. and Radio frequency, microwave and also digital electronics involving PC and DSP. Digital engineer should have software experiences related to real time graphics and DSP. We also need a communication engineer with specialization in modulation, coding and waveform design. We provide excellent salary and benefits.

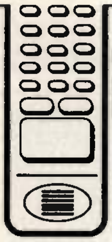
Please send your resume to:

Center For Remote Sensing, Inc.
P.O. Box 9244
McLean, VA 22102
Fax: 703-848-9773

MANAGEMENT RECRUITERS® OF BOULDER, INC.
The search and recruiting specialists

WINDY BRADFIELD
RF / MICROWAVE SPECIALIST

CONTINENTAL BLDG., SUITE 301
1401 WALNUT STREET, P.O. BOX 4657
BOULDER, COLORADO 80306
(303) 447-9900
FAX(303) 447-9536



...YOUR CAREER

Wireless Start-Up/RF Design Engineers: Design of Si RF ic's for Wireless Communication applications (AMPS, DAMPS, GSM, DECT, POS). Si RF ixc design experience in the 400-2400 MHz; fast RF PLL synthesizer design experience; RF receiver/transmitter/design experience using Si Bipolar and MOS technologies.

Product Marketing Director: Incumbent would be required to work closely with product management and sales to design and develop product line strategy and tactical marketing programs in support of an enterprise wide strategy for success in the digital wireless terminal industry. Knowledge of cellular/PCS markets and/or wireless telephony is required. A proven ability to work with customers and product realization teams on marketing strategy development.

CATV Design: Rf Design experience should include LC filter, microstrip, amplifier, circuit modeling and system analysis in the 5-1000Mhz range. BS/MSEE fiber optics a plus.

Project Leader Base Station: Design, fabricate, test and develop rf/mw components, circuits and subsystems for cellular basestation front-ends. BSEE/MSEE.

Regional Field Sales: Aggressive individuals to create and serve new accounts. Positions are located throughout the U.S.A. An engineer who wants to enter sales world is acceptable. Base salary, commission and car. BSEE.

RF Microwave Test Engineers: Develop and refine automated RF/Microwave test methodologies for product characterization, production test, system test and FCC Certification. BSEE.

RF Engineer: RF circuit design and development for wireless phones. Develop radio architectures and RF circuit design for systems operating in the 800-900MHz and the 1800-2000MHz regions.

Sr. Project Antenna Design: Lead the conception, design and development of a wide variety of antennas and antenna systems, including both reflector and array systems using microstrip, stripline and waveguide technologies. BS/MS with 5 years experience.

RF Design Manager: Lead a team of RF engineers from initial design and implementation through product integration and testing into high volume production. 8+ years of RF design with emphasis on low cost radio design. BS/MS.

Sr. MMIC Design: Design highly integrated GaAs MMICs for advanced cellular products. Circuits to be designed include: power amplifiers, LNAs, mixers, IF amplifiers, buffer amplifiers. RF frequencies are 900 and 1800 MHz.

Product Line Manager Wireless: Specific responsibilities include product line strategic planning, establishing revenue and price objectives, setting internal cost targets and oversight of internal product realization schedules.

RF PA Engineers: Requires 3+ years experience in design, test and manufacturing of high efficiency GaAS MESET and HBT class A and C power Amplifiers (c2watts) in the frequency range (-2GHz). Experience in both discrete and MMIC design a plus.

Sr. Analog IC Designers: Responsible for conceptual circuit design and developing new analog/mixed signal ic's. BS/MS experience in A/D D/A, ASIC's bipolar and BiMOS.

Filter Design Engineer: Development of microwave high "Q" coaxial cavity and machine filter designs for PCS base stations. BS/MS familiar with simulation and modeling tools, three plus years filter design experience with direct "Q" designs (6-8000 Q's).

Applications Engineer: 5 years of directly relevant RF/MW engineering applications and measurement techniques. Strong presentation and instructor skills; must be able to communicate effectively with individuals and groups of all levels of technical expertise and experience.

Systems Engineer: Design system architecture for wireless phones. Lead the effort in new system architecture design which includes RF, baseband processing, software, standards, user and other communication features. Experience and knowledge with CDMA, TDMA, GSM and AMPS standards and operation for cellular and PCS applications is desired.

MICRO COMMUNICATIONS EXECUTIVE SEARCH

We specialize in the placement of wireless, RF, microwave communications nationally.

FOR THESE AND OTHER OPENINGS
CALL COLLECT: TEL: 508-685-2272

800 Turnpike St. • North Andover, MA 08145
E-mail: micsearch@aol.com FAX: 508-794-5627

SR. OSCILLATOR DESIGN ENGINEER

This highly visible senior position reports directly to V.P. of Engineering and will assume complete project/program responsibility for bids, schedule, performance and cost. Responsibilities include ensuring that product development strategies reflect marketing and customer needs, and assist in the formulation of company goals, specifically as it relates to anticipated technology trends. BSEE (MS preferred) with 5-10 years experience and a track record in the development of crystal oscillators and complex frequency management subassemblies.

RF DESIGN ENGINEER

BSEE with 2-5 years experience and a track record in the development of analog/digital RF signal processing components or subsystems. Knowledge in high speed analog to digital and digital to analog conversion techniques. A strong digital background, project management, laboratory testing, computer aided design (Touchstone, Spice and Autocad) and technical writing for proposals and test procedures are needed.

We offer an attractive salary and benefits package. Please forward your resume in confidence to:

SIGNAL TECHNOLOGY CORPORATION
OLEKTRON OPERATION

Gail Noye,
28 Tozer Road,
Beverly, MA 01915
Fax (508)927-9328

An equal opportunity employer, M/F/V/A.

A RANGE OF CHALLENGES, A SEQUENCE OF DYNAMIC SOLUTIONS

Government Electronic Systems

As an International high tech leader, we have a reputation to uphold and that's why we hire the best. Lockheed Martin Government Electronic Systems, a United States Navy partner with a proven track record of success, is expanding its staff in the Engineering area. These challenging opportunities exist in Moorestown, N. J., just outside of Philadelphia.

ANTENNA DESIGN ENGINEERS
Will conceive, design, and analyze advanced microwave solid state phased array antennas and radiating elements. A background in electromagnetics, field theory, and analysis of antenna aperture radiation properties is preferred. A minimum of a Master's degree in Engineering, five years of experience and familiarity with MMIC-based microwave T/R module or radar subsystems also desired.

T/R MODULE DESIGN ENGINEERS
BSEE with minimum of three years experience in microwave subsystem and component design is required. Responsibilities include the design and application of solid state and T/R modules in phased array radars. Experience in the development of GaAS MMIC's or T/R modules as well as the use of microwave simulation and modeling software tools is preferred.

RF/ANALOG DESIGN ENGINEER
BSEE or Physics and 5-7 years experience in design and development of RF/Analog circuits and assemblies is required. You will design and test RF/Analog assemblies, including low noise oscillators and agile synthesizers for incorporation into current and future product requirements; implement design modifications to RF/Analog equipment to enhance manufacturing producibility and improve design margins; and assess fielded systems and recommend reliability and maintainability enhancements.

Discover the challenge, opportunity, and rewards of a career with us. For immediate consideration, please forward your resume, indicating position of interest, to: Dept. OA9612c, Fax # 609-273-5377 or mail it to: Lockheed Martin Government Electronic Systems, Staffing Dept. OA9612c, 199 Borton Landing Road, Moorestown, NJ 08057-0927. Ability to obtain a security clearance is required. An equal opportunity employer. See us on the internet: http://www.lmco.com/ges/donoho3.html

LOCKHEED MARTIN
Mission Success

CAREER OPPORTUNITIES

WIRELESS RF DESIGN

BethelTronix, Inc. (BTI) is a fast growing leader of ASIC and standard product designs. BTI specializes in the world's highest levels of integration of RFIC and MMIC using low cost silicon technology to achieve single chip solutions, like: the BT1071 "The BeSST Chip" for Spread Spectrum applications and the "TRFIC Family" of BT107X series transceivers for wireless applications, like cellular, CT-2 and GSM. BTI's leading edge solutions focus on Wireless/Optical communications and Telecommunications.

We are seeking highly motivated, promising, and team-oriented associates, like YOU, to be a part of BTI's talented team. Stock options for all associates.

RFIC/MMIC Design Managers & Engineers
With minimum 3 years experience in the design of RFIC, MMIC, or RF circuits.

RF/MMIC Module Design Managers & Eng.
With minimum 3 years experience in the design of modules for the RF/MMIC front end.

Digital CMOS IC Design Managers & Eng.
With minimum 3 years experience in VHDL coding and logic synthesis using COMPASS tools. JTAG/BIST experience a plus.

Analog IC Design Managers & Engineers
With minimum 3 years experience in the development of analog IC products.

BSEE required; MSEE preferred.

Send, fax, or email resume to:
BethelTronix, Inc.
Attn: Human Resources
13825 Cerritos Corp. Dr.
Cerritos, CA 90703
F: 310-407-0510
email: bti@betheltronix.com

BTI

DSP

Without Tears®

Learn DSP and put your knowledge to work
IMMEDIATELY!

To receive an informative brochure on this popular seminar, call Z Domain Technologies, Inc. at 1-800-967-5034 or 770-587-4812. Hours: 9-5 EST. Or E-mail: dsp@zdt.com

Also, a 3-day ADVANCED class in DSP is available on alimited basis — call for more details.

By taking this 3-day course, you will really learn DSP. *Guaranteed!*

Coming to a city near you:
Richardson, TX • Long Beach, CA
Rosemont, IL • San Jose, CA

Now Available on CD-ROM!

http://www.zdt.com/~dsp

RECRUITMENT

COMMUNICATIONS ENGINEERS

Our clients are hiring RF engineers with the following skills:

Wireless Telecomm, Cellular, Mobile, Telephony, NPCS, spread spectrum, DSP, AMPS, SMR, GSM, CDPD, TDMA, CDMA, WLAN, WPBX, Transmitters, Recievers, modulators, demodulators, low noise amps, mixers, oscillators, filters, DDS, synthesizers, 900/1900 MHz.

- Never a fee to applicants
- Positions available nationwide
- Send email, fax or call Randy Brei today!

Brei & Associates, Inc.
P.O. Box 445 Marion, IA 52302-0445
(319) 377-9196 Fax (319) 377-9219
RBREI@NETINS.NET
http://www.NETINS.NET/showcase/RDBREI/

PRODUCTS & SERVICES

PRODUCT DEVELOPMENT

For successful, proven OEM product development, depend on LOCUS – your strategic partner for:

- Product Definition, Design & Production
- RF Systems / RFID / Spread Spectrum
- DSP / Digital Radio / RF ASICs
- Innovative, Cost Effective Solutions
- Rapid Time to Market
- Ongoing Product Support
- Communications / Medical / Consumer

For quality products the 1st time, contact:

LOCUS

LOCUS Incorporated
1842 Hoffman Street
Madison, WI 53704
Phone: 608/244-0500
Fax: 608/244-0528
Email: sales@locusinc.com
http://www.locusinc.com

A-COMM ELECTRONICS

Refurbished Test Equipment
DC-2 ghz HP GR Wavetek Tektronix
Send for Catalog Listing:
7198 S. Quince Street
Englewood, CO 80112
303-290-8012 • FAX 303-290-8133

PART 15 WIRELESS DESIGNS

Use one of our proven RF designs for your next wireless project. Apex offers over 70 years of combined wireless design experience and extensive test and simulation capabilities

- Spread Spectrum Systems
- Portable, Low Power, Small Size Devices
- RF Identification Devices
- Pagers
- GPS
- Keyless Entry

APEX WIRELESS, INC.
A subsidiary of Apex Systems, Inc.
2400 Central Ave., Suite A, Boulder, CO 80301
(303) 443-6699 FAX (303) 443-4974
E Mail: 75017.3120@Compuserve.com

STRETCH

Your Advertising Dollars! Contact Terri Stenson Today!
303-220-4288 • Fax: 303-793-0454

RF design Buyers' Guide

The Buyers' Guide is a convenient guide to suppliers of products and services available for design and development engineers. Buyers' Guide listings are sold on an annual basis at the rates shown

	Per Issue	Total/Year
Regular Listing	$22.00	$264.00
Additional Line	$19.00	$228.00
Bold Listing	$25.00	$300.00
Additional Line	$21.00	$252.00
1" Ad	$200.00	$2,400.00
Drop Out In White	$25.00	$300.00

All orders must be prepaid. You can forward your check or charge your ad to:

For information on closing dates and details on a special Introductory Offer, call **1-303-220-4288**. Ask for Terri Stenson.

DISCRETE COMPONENTS

CAPACITORS

Vacuum

COMET North America, 11 Belden Ave., Norwalk, CT 06850 .... (203) 852-1231
Surcom Associates, Inc., 2215 Faraday Ave., Suite A, Carlsbad, CA 92008 ..... (619) 438-4420

Variable

COMET North America, 11 Belden Ave., Norwalk, CT 06850 .... (203) 852-1231

CRYSTALS/RESONATORS

NEL
Nortech Electronics Ltd

SC-cut Crystal Resonators

For your SC-cut crystals requirement frequency 4-20 Mhz 3rd overtone, High Q, low aging $5x10^{-11}$ - $1x10^{-10}$ per day, calibration ±0.5 ppm, G-sensitivity up to $<3x10^{-10}$/g Holders HC37, HC40.

11 Beith Hadfus St., Jerusalem 95483 Israel Tel. +972-2-6510082 Fax.+972-2-6510292

Quartz

Oak Frequency Control Group
100 Watts St., PO Box B, Mt. Holly Springs, PA 17065 .... (717) 468-3411
email: sales@ofc.com web site: http://www.ofc.com

***FUNDAMENTALLY* Better!**

VALPEY-FISHER
A SUBSIDIARY OF MATEC

'AT' Crystals for all of your FILTER and OSCILLATOR requirements • Ideal for SONET SDH ATM

- Wide spur-free areas • Superior spurious suppression
- Pullability up to 1000 ppm
- *Fundamental* Crystals to 350 MHz

Call: 717-258-5425
Fax: 717-258-5840

489 East North Street • Carlisle, PA 17013

DIODES

Loral Semiconductor Division, 75 Technology Dr., Lowell, MA 01851...(508) 256-4113 ext.3311

Varactor

Knox Semiconductor, Inc.
13 Quarry Rd., P.O. Box 609, Rockport, ME 04856 ... (207) 236-6076 Fax (207) 236-9558

HIGH POWER DIODE SWITCHES

Hill Engineering, 461 Boston Rd., Topsfield, MA 01983 .. (508) 887-5754 Fax 887-7244

RF, Analog & Mixed-Signal ASICs

Full-Custom Designed ICs: Bipolar, CMOS, BiCMOS
Frequency Synthesis, Mixers, Amplifiers, A/Ds, D/As, Switch Cap Circuits

RTG, Inc. TEL: **(310) 534-3016** • FAX: (310) 534-3728
P.O. Box 3986, Torrance, CA 90510 • E-MAIL: sales@rtg.com

MODULAR COMPONENTS

AMPLIFIERS

Broadband

Dressler HF Technik Gmbit,
Werther Str. 14-16, D-52224, Stolberg, Germany+49-2402-71091 Fax: (-71095)FILTERS
Delta Microwave Inc., 840 Vira Alondra, Camarillo, CA 93012 .... (805) 987-6892

OSCILLATORS

CRYSTAL OSCILLATORS

VALPEY-FISHER
A SUBSIDIARY OF MATEC

- ACMOS TTL to 200 MHz
- HCMOS TTL to 80 MHz
- ECL to 630 MHz
- VCXOs to 200 MHz
- SMD to 300 MHz

***FUNDAMENTAL* Crystals to 350 MHz**

800-982-5737(ext. 244)

Valpey-Fisher Corporation • 75 South Street • Hopkinton, MA 01748 Fax: **508-497-6377**

Crystal

Oak Frequency Control Group,
100 Watts St., PO Box B, Mt. Holly Springs, PA 17065 .... (717) 468-3411
email: sales@ofc.com web site: http://www.ofc.com

MODULAR COMPONENTS

Wenzel Associates, Inc., 1005 La Posada Dr., Austin, TX 78752 .... (512) 450-140

Phase Locked

Universal programmer for phase-locked loop ICs
MYcom Instruments, 142 N. Milpitas Blvd., Ste. 277, Milpitas, CA 95035 .... (408) 946-197
Fax: (408) 262-4763

VCOs & Synthesizers

www.wireless-radio.com

WIRELESS RADIO OSCILLATORS

PH 313-669-2901 FAX 313-669-2902

SYSTEM SUBASSEMBLIES

PRINTED CIRCUIT BOARDS

CALL SOUTHWEST CIRCUITS NOW! (800) 279-5572

- PROTOTYPES AND SHORT RUNS FOR ALL MICROWAVE AND WIRELESS APPLICATIONS
- ALL POPULAR MICROWAVE LAMINATES: PTFE - TEFLON - DUROID - GX
- MULTI-LAYERS - QUICK TURN - EXOTICS

Southwest Circuits, 3760 E. 43rd Place, Tucson, AZ 85713
TEL (602) 745-8515 FAX (602) 747-8334 MODEM (602) 747-5108

RF TRANSMISSION COMPONENTS

Custom & Specialty

Myers Engineering International, Inc.
P.O. Box 15908, Ft. Lauderdale, FL 33318 .... (954) 345-5000 Fax: (954) 345-500

FILTER ASSEMBLIES

Low Pass

Coil Specialty Co.
2730 Carolean Ind. Dr., PO Box 978, State College, PA 16801 .... (814) 234-704

INDUCTORS & CHOKES

Kintronic Labs,
144 Pleasant Grove Rd., Bluff City, TN 37618 .... (423) 878-3141 FAX: (423) 878-422

ISOLATORS/CIRCULATORS

AEROTEK COMPANY LIMITED
Manufacturers of Circulators and Isolators
Coaxial and Drop-in types, 400 MHz–18 GHz
"TOP QUALITY, REASONABLE PRICE"
1756 Sukhumvit 52, Sukhumvit Rd., Bangkok, Thailand.
AEROTEK **Tel: (662) 311-4448, 332-5035 Fax: (662) 332-5034**

Coaxial Connectors, Inc.
1500 N.W. 62nd St., Ste. 501, Ft. Lauderdale, FL 33309 .... (305) 772-266

PRECISION RF CONNECTORS

Berg Electronics,2100 Earlywood, Franklin, IN 46131(317) 738-2800 Fax: (317) 738-285

SURGE & TRANSIENT PROTECTORS

FCC
Lightning Suppressors · D.C. - 26 GHz
Coaxial · Powerline · Digital
FISCHER CUSTOM COMMUNICATIONS, INC. ▫ (310) 891-0635

SWITCHES

Electromechanical

Dow-Key Microwave Corp., 1667 Walter St., Ventura, CA 93003 .... (805) 650-026
MBF Microwave, Inc., Rt. 2, Box 252A, Hardy, AR 72542 .... (501) 856-268

VACUUM CAPACITORS

COMET North America, 11 Belden Ave., Norwalk, CT 06850 .... (203) 852-123

RF guide to editorial coverage

RF advertising index

RF DESIGN (ISSN:0163-321X USPS: 453-490) is published monthly. December 1996. Vol. 19, No. 12 *RF Design* is a registered trademark of Intertec Publishing Corp. Copyright 1996 by Intertec Publishing Corp., 9800 Metcalf Ave., Overland Park, KS 66212-2215. Editorial and advertising offices at 5660 Greenwood Plaza Blvd., Suite 350, Englewood, CO 80111, 303-793-0448. Printed in USA. Periodicals postage paid at Overland Park, KS, and at additional mailing offices. Subscription office: *RF Design*, P.O. Box 1147, Skokie, IL 60076. Subscriptions are $48 per year ($82 for two years) in the United States; $68 (surface mail) or $108 (air mail) per year for countries outside the U.S. Payment must be made in U.S. funds and accompany request. If available, single copies and back issues are $10.00 each in the U.S. This publication is available on microfilm/fiche from UMI, 300 Zeeb Road, Ann Arbor, MI 48106 USA. Tel.: 313-761-4700. Authorization to photocopy items for internal, personal or educational classroom use is granted by *RF Design*, provided the appropriate fee is paid directly to Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923 and provided the number of copies is fewer than 100. For authorization, contact the Copyright Clearance Center at 508-750-8400. The Transactional Reporting Service fee code is: 0163-321X. For those seeking 100 or more copies, please contact Ed Laborwit at 770-618-0481. SUBSCRIPTION INQUIRIES: 847-647-0756. POSTMASTER & SUBSCRIBERS: Please send address changes to RF Design, P.O. Box 1147, Skokie, IL 60076.