FEBRUARY 2000

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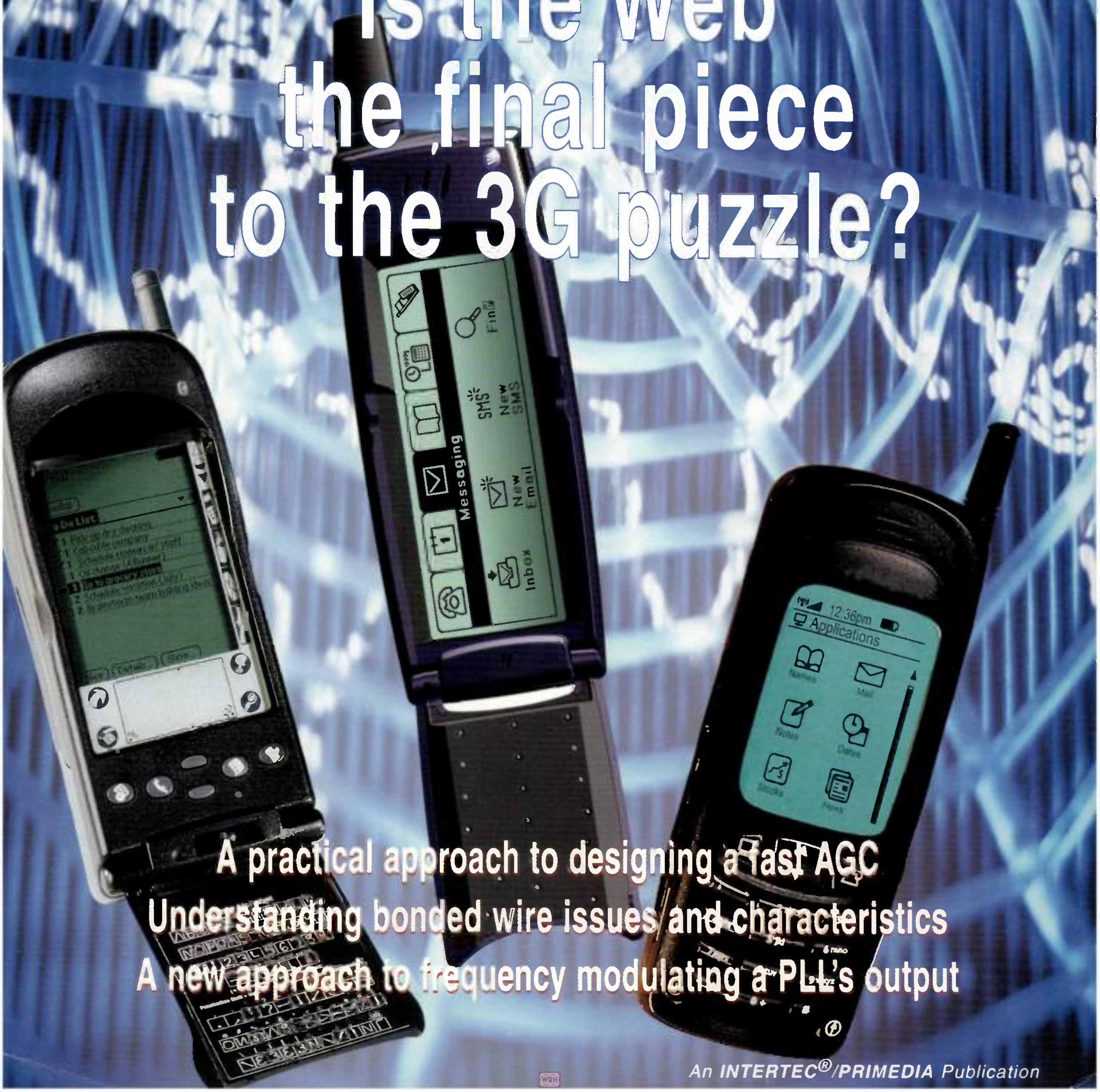
Is the Web the final piece to the 3G puzzle?



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A new approach to frequency modulating a PLL's output

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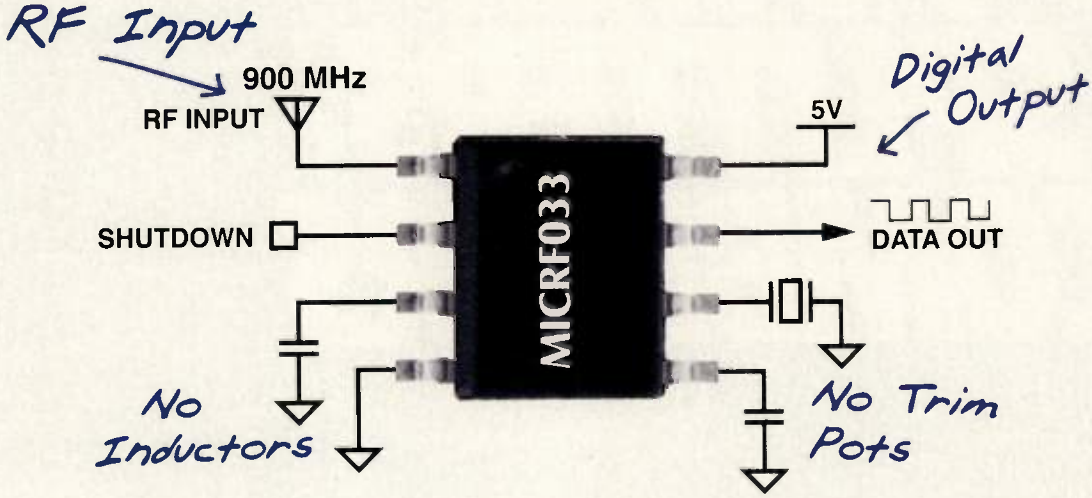
INFO/CARD 97

900MHz Single-Chip RF Receiver



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- Incredibly easy to design
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- Lower cost
- 20 kbps data rate

The Specs

Part No.	Data Rate	Spectrum
MICRF001	4.8kbps	300 - 440MHz
MICRF011	2.5kbps (SWP), 10kbps (Fixed)	300 - 440MHz
MICRF002	2.5kbps (SWP), 10kbps (Fixed)	300 - 440MHz
MICRF022	2.5kbps (SWP), 10kbps (Fixed)	300 - 440MHz
MICRF003	5kbps (SWP), 20kbps (Fixed)	800 - 1,000MHz
MICRF033	5kbps (SWP), 20kbps (Fixed)	800 - 1,000MHz

Developed with AIT, Orlando, FL
*See data sheet for actual pinout
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The MICRF003/033 are the latest additions to Micrel's revolutionary QwikRadio™ single-chip RF receiver family.

QwikRadio ICs have already set a new standard for ease of use and low cost in the 300MHz to 400MHz frequency band. The MICRF003/033 brings the same benefits to the less-used and less-restrictive 900MHz band.

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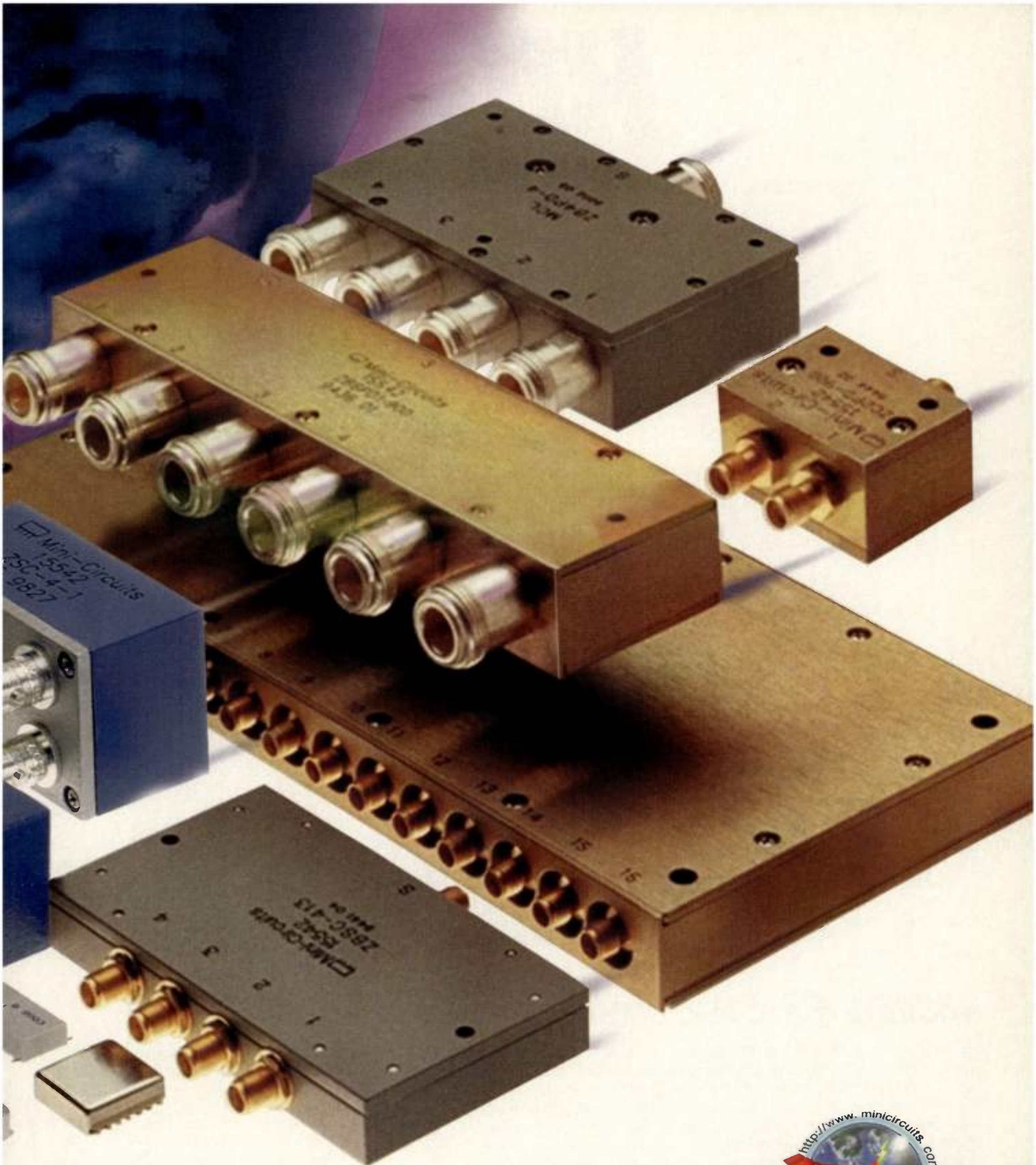
INFO/CARD 5



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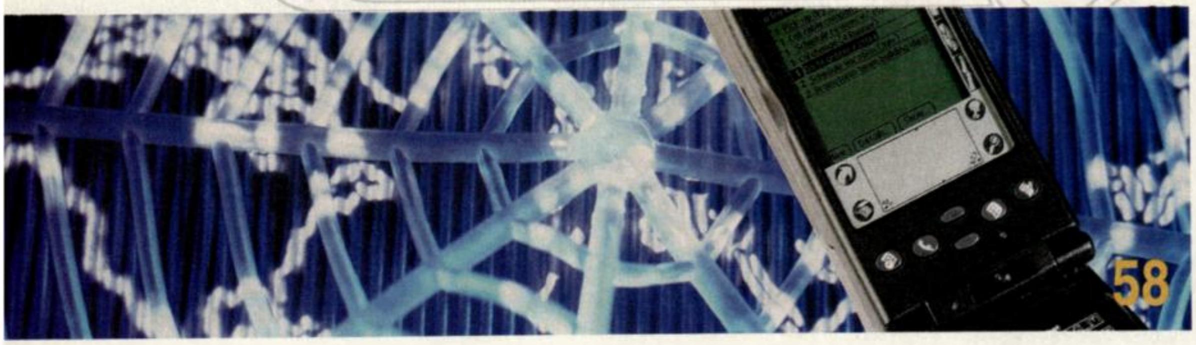

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RF editorial

Build the future, but remember the past

By Roger Lesser
Editor
roger_lesser@intertec.com

Build the future,...

While I was going to college I had the opportunity to work in the Speech Department. It was there that I met one of those rare people who make a lasting impression or cause you to make a life-changing decision. His name was Tom Cook.

Tom introduced me to the world of communications, broadcasting to be specific. From that point, I wanted to be a communicator. I ended up changing my major to communications with the intent of making the spoken and written word my life's work. It was the Vietnam era, so I joined the U.S. Air Force, becoming an avionics officer ("It's communications," the recruiter said).

One of the side benefits of meeting Tom was his interest in old-time radio programs. It was through Tom that I discovered the future.

You see, the future was in those old shows. I learned of videoconferencing and car phones, thinking computers and information on demand, wrist radios and miniature communications.

So, here we are in the 21st Century. And all those radio shows have even more meaning to me today. Why? The accurate prophecy of those radio visionaries is being realized. And how did we get from someone's science fiction-based ideas to today's science-based realities? Why, you the designer, made it happen. I realize that often it is a team of individuals who create concepts and even develop the technical requirements to make a device. So, when I say designer, I have to include anyone who makes a contribution to the final product development

Did you ever stop to think of the impact you are having on the present and the future? One needs only to look at the recent Consumer Electronics Show. From the latest in wireless capable handheld computers to the introduction of a wrist phone, the dreams of yesteryear are being realized. And they all started with you, the designer.

...but remember the past.

If it sounds like I'm preaching to the choir, so be it. But, remember this, while you are building the future, don't forget those who laid the groundwork for your successes today. If you are lucky enough to have access to an individual who, in the 40s, 50s and 60s, was a future thinker, a design engineer, take a moment and thank them for what they did. And take a moment to listen, too. Because, due to retirement and other life events, they may not be there for you to talk to in the future.

I was fortunate enough to meet Fred Link at a Radio Club of America breakfast at the International Wireless Communications Expo a couple of years ago. It was truly moving to meet a man that meant so much to communications. And now he is gone.

During my career in the Air Force, I met and talked with another technology future thinker, Jimmy Dolittle. Famous for the raid on Tokyo at the beginning of WWII, he also proved instrumentation flying was possible. He was the first one to do it. The half hour I spent one-on-one with him was truly memorable. And now he, too, is gone.

Since being with *RF Design,* I've had the opportunity to meet a number of yesteryear's future thinkers as well as today's visionaries. I'm proud to be associated with such an elite group. That's why I enjoy talking with you and exchanging e-mail.

Thanks to you who made our past and brought us to the present, and good luck to you who are developing the future.

Oh, and thanks Tom. *RF*

Editorial Forum

By Ramona Isbell, Executive Editor

The future is now

The New Year has come and gone, proving that the Y2K hype was just that ... hype. Now that we no longer need to fret about prophecies of doom and gloom, we can savor the real fun of the year 2000—exploring the mind-boggling mix of technologies that make their way past the prototype stage.

Your challenge is to incorporate tomorrow's converging technologies into today's products. So, as we head into the new century, the timing is perfect to offer a few predictions.

It's a safe bet to count on Internet developments dominating technology news. But, according to a "Brain Snacks: Future Forecasts" report prepared by Young & Rubicam's Brand Futures Group, industry pundits expect significant advancements in other niche markets. One such area is "information appliances," products designed for households without computers that will offer a simpler, less expensive option over PCs. The report adds that cable modems and DSL high-speed phone service will replace dial-up lines. And, for the wireless telecom industry, specialists look for Web-enabled phones to add new value-added services, while Bluetooth wireless technology makes its appearance by year's end.

Expect opportunities in the wireless telecommunications market to inspire the automobile industry. As satellite and vehicle-location technologies are further developed, we'll see new applications via mobile phones and in-car computers.

There's no doubt about it, technology-hungry consumers can expect a well-rounded product menu in the coming months. This fact was evidenced at January's Consumer Electronics Show, which showcased every techno-gadget from the newest mobile Internet access devices to the latest in wireless phones—a wristwatch phone James Bond would be proud of.

The distant future has arrived, at least in the design stage. Now, guess who gets to incorporate these futuristic ideas into today's technology, all while providing seamless integration, of course!

RF design

Engineering RF & Wireless Products ...... DC to Light

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RF calendar

February 22–24 **Wireless Symposium**—*San Jose, CA*—Information: Wireless/Portable 2000, 611 Route 46 West, Hasbrouck Heights, NJ 07604. Fax: 201.393.6297; Web site **www.wirelessportable.com**.

Feb 28–Mar 1 **CTIA 2000**—*New Orleans*—Information: Michael Cerami, CTIA, 1250 Connecticut Ave., NW, Suite 800, Washington, DC 20036. Tel. 202.736.3895; e-mail BKnight@ctia.org; Web site **www.wow-com**.

Feb 28–Mar 2 **Embedded Systems Conference Spring**—*Chicago*—Information: Miller Freeeman Tel. 415-538-3848; e-mail *esc@mfi.com*.

March 21–23 **IEEE Semi-Therm XVI**—*San Jose, CA*—Information: Bonnie L. Crystall, C/S Communications, P.O. Box 23899, Tempe, AZ 85285. Tel. 520.323.2870; Fax 520.323.2803; e-mail *cscom@indirect.com*.

April 10–12 **DSP World Spring Design Conference**—*San Jose*—Information: Miller Freeman. Tel. 415.538.3848 or 888.239.5563; e-mail *dspworld@mfi.com*.

10–14 **IEEE IFIP 200 Network Operations and Management Symposium**—*Honolulu*—Information: Cayle Weisman, IEEE Communications Society. Tel. 212.705.8941; Fax 212.705.8999; e-mail *noms2000@comsoc.org*.

April 26–28 **Global Wireless Convergence—4th Annual Summit 2000**—*Cancun*—Information: Universal Wireless Communications Consortium, 1800 - 112th Ave NE #260E, Bellevue, WA 98004-2937. Tel. 425.372.8922; Web site **www.uwcc.org**.

May 21–24 **50th Electronic Components and Technology Conference**—*Las Vegas, NV*—Information: Jim Bruorton. Tel. 864.963.6621. Web site **www.ectc.net**.

June 11–16 **2000 IEEE MTT-S International Microwave Symposium** —*Boston*—Information: Web site **www.ims2000.org**.

14–19 **IEEE International Conference on Third Generation Wireless Communications**—*Silicon Valley, CA*—Information: Willie W. LU, 1960 Linden Lane, Milpitas, CA 95035. e-mail *wwlu@ieee.org*; Web site **www.3Gwireless.com**.

18–22 **IEEE International Conference on Communications**—*New Orleans*—Information: Richard W. Miller, Tel. 504.528.2553; e-mail *r.w.miller@ieee.org*; Web site **www.icc00.org**.

RF courses

- **UCLA Extension**—*The Engineer in Transition to Management*—Feb 14–16; *Technical Proposal Marketing and Management*—Feb 17–18; *Project Management Principles and Practice*—Feb 22–25. Information: UCLA Extension, Department of Engineering, Information Systems and Technical Management, Short Courses, 10995 Le Conte Ave., Suite 542, Los Angeles, CA 90024-2883. Tel. 310.825.3858; Fax 310.206.2815; e-mail *tlawrenc@unex.ucle.edu*.
- **Georgia Institute of Technology**—*RF and Wireless Principles and Practice*—Apr 10–14, Atlanta. Information: Continuing Education, Georgia Institute of Technology, Atlanta, GA 30332-0385. Tel 404.385.3502; e-mail *conted@gatech.edu;* Web site **www.conted.gatech.edu**.
- **Virginia Tech**—*Antennas: Principles, Design and Measurements*—Mar 13–16, San Diego; May 22+25, Orlando. Information: Dr. Warren Stutzman, Virginia Tech, Electrical Engineering Dept., Blacksburg, VA 2401-0111. Tel. 540.231.8401; Web site **www.usit.com/antenna**.

RF Design Seminar Series and Base Station Workshops—

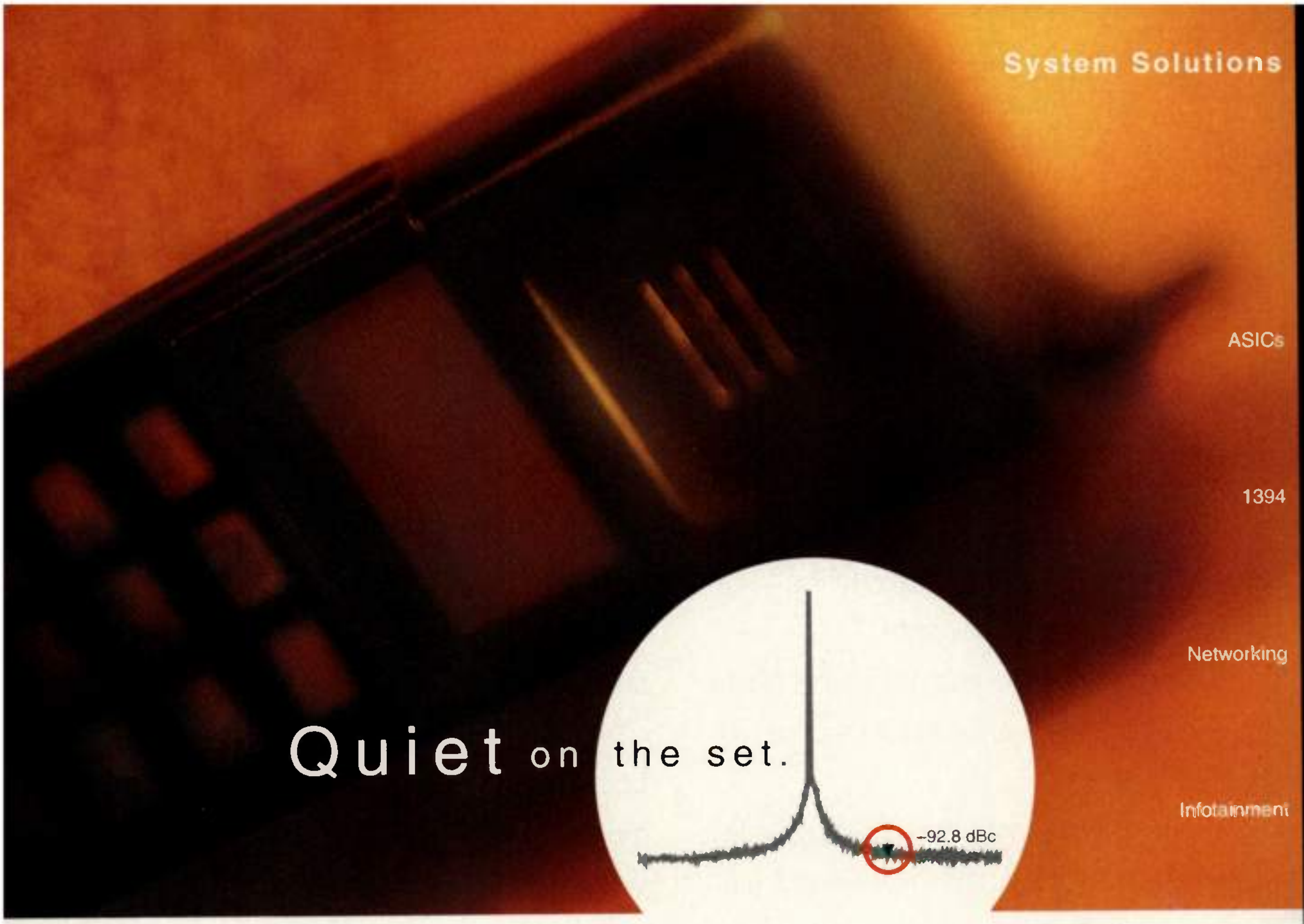
Held in conjuction with the International Wireless Communications Expo—Mar 22–24—Las Vegas, NV. Information:, Anne Vogal, Intertec Presentations, 5680 Greenwood Plaza Blvd, Suite 100, Englewood, CO 80111. Tel.303.741.2901 or 1.800.288.8606; e-mail: trade_shows@intertec.com.

Tentative RF Design Seminar Series Schedule

RF Design Series: The Big Picture
Monday, March 20, 9:00 a.m. – 5:00 p.m.
RF and Wireless Made Simple (T1)
Tuesday, March 21, 9:00 a.m. – 5:00 p.m.
Antennas and Propagation for Wireless Communications (T2)
Wednesday, March 22, 9:00 a.m. – 5:00 p.m.
Measuring the Wireless Transmission Spectrum (T3)

Frequency Synthesis and DSP
Tuesday, March 21, 9:00 a.m. – 5:00 p.m.
Digital Signal Processing, Part 1 (D2)
Wednesday, March 22, 9:00 a.m. – 5:00 p.m.
Digital Signal Processing, Part 2 (D3)

Wireless Engineering Track
Monday, March 20, 9:00 a.m. – 5:00 p.m.
Part 1: Foundations of RF Hardware Design (E1)
Tuesday, March 21, 9:00 a.m. – 5:00 p.m.
Part 2: Techniques for RF Hardware Design (E2)
Wednesday, March 22, 9:00 a.m. – 5:00 p.m.
Part 3: RF Amplifier Design (E3)



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SL Series PLL Frequency Synthesizers

Single PLLs

Part Number	fIN Max	Icc (mA)	Vcc (V)
MB15E03SL	1.2 GHz	2	2.7
MB15E05SL	2.0 GHz	3	2.7
MB15E07SL	2.5 GHz	3.5	2.7

Dual PLLs

Part Number	fIN Max	Icc (mA)	Vcc (V)
MB15F02SL	1.2 GHz 0.5 GHz	1.8 1.2	2.7 2.7
MB15F03SL	1.75 GHz 0.6 GHz	2.3 1.2	2.7 2.7
MB15F07SL	1.1 GHz 1.1 GHz	2.5 2.5	2.7 2.7
MB15F08SL	2.5 GHz 1.1 GHz	4.4 2.6	2.7 2.7

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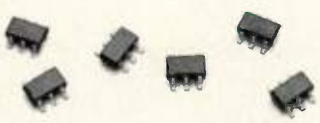
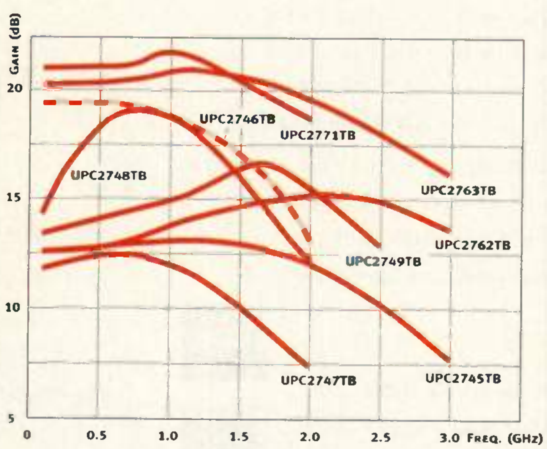




GAIN VS. FREQUENCY

NEC

5V WIDEBAND RFIC AMPS—FROM 25¢

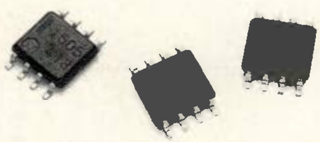
PART	FREQ. RANGE	GAIN (dB)	NF (dB)	P_{1dB} (dBm)	ICC (mA)	fTEST
UPC1678GV	50MHz–2.0GHz	23	6	+15.9	49	500MHz
UPC2708TB	50MHz–2.9GHz	15	6.5	+9.2	26	1.0GHz
UPC2709TB	50MHz–2.3GHz	23	5	+8.7	25	1.0GHz
UPC2710TB	50MHz–1.0GHz	33	3.5	+10.8	22	500MHz
UPC2711TB	50MHz–2.9GHz	13	5	-2.6	12	1.0GHz
UPC2712TB	50MHz–2.6GHz	20	4.5	-0.4	12	1.0GHz
UPC2713T	50MHz–1.2GHz	29	3.2	+0.3	12	500MHz
UPC2776TB	50MHz–2.7GHz	23	6.0	+6	25	1.0GHz
UPC2791TB	50MHz–1.9GHz	12	5.5	+1	17	500MHz
UPC2792TB	50MHz–1.2GHz	20	3.5	0	19	500MHz

3V WIDEBAND RFIC AMPS—FROM 35¢

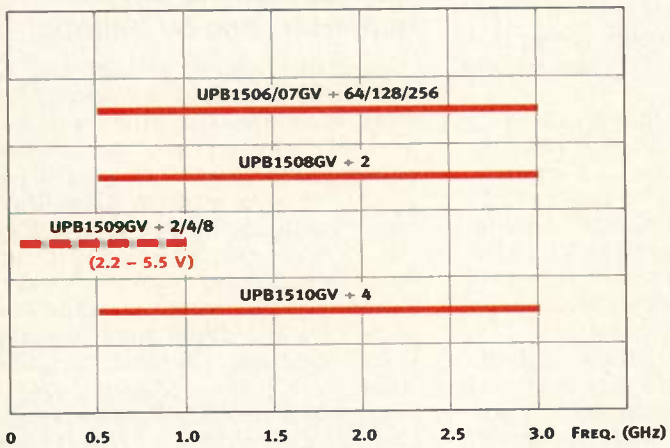
PART	FREQ. RANGE	GAIN (dB)	NF (dB)	P_{1dB} (dBm)	ICC (mA)	fTEST
UPC2745TB	50MHz–2.7GHz	12	6	-3.0	7.5	500MHz
UPC2746TB	50MHz–1.5GHz	19	4	-3.7	7.5	500MHz
UPC2747TB	100MHz–1.8GHz	12	3.3	-11	5	900MHz
UPC2748TB	200MHz–1.5GHz	19	2.8	-8.5	6	900MHz
UPC2749TB	100MHz–2.9GHz	16	4	-12.5	6	1.9GHz
UPC2762TB	100MHz–2.9GHz	14.5	7	7	27	1.9GHz
UPC2763TB	100MHz–2.4GHz	20	5.5	6.5	27	1.9GHz
UPC2771TB	100MHz–2.1GHz	21	6	11.5	36	900MHz

Prices at 100K quantity

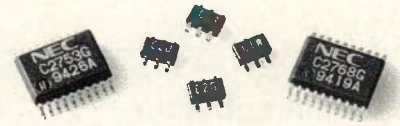
Selection guides, data sheets, application notes, S Parameters and non-linear model data can all be found at **www.cel.com**



5V Prescalers—from 70¢



Frequency Range



3V Frequency Converters—from 60¢

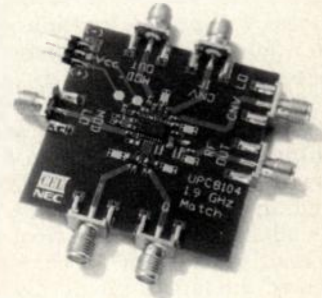
Part	RF Frequency (MHz)	Icc (mA)	Conversion Gain (dB)	Output IP_3 (dBm)
UPC2756TB[1]	100 - 2000	5.9	14	0
UPC2757TB[1]	100 - 2000	5.6	13	0
UPC2758TB[1]	100 - 2000	11	17	+6
UPC2768GR[1]	10 - 450	7	80	-17
UPC8106TB[2]	100 - 2000	9	9	+1
UPC8112TB[1]	800 - 2000	8.5	13	-10
UPC8116GR[3]	100 - 500	4.1	6.5	—

1. Downconverter 2. Upconverter 3. AM/ASK Receiver IC

UPC8104GR

IQ Modulator

Evaluation boards for most NEC RFICs are available free from CEL



Plus Discretes...!

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25GHz f_T Series

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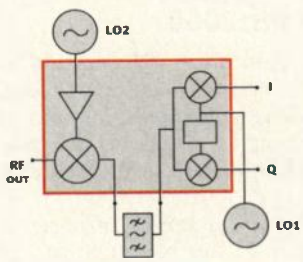

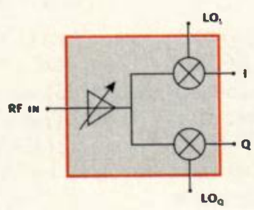

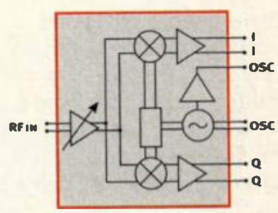

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INFO/CARD 6

Cellular RF semiconductor market to reach $7.7 billion

According to Strategies Unlimited, Mountain View, CA, the worldwide market for RF semiconductor devices in cellular telephones will reach $7.7 billion by 2004, up from $3.9 billion in 1999. The study, *RF Semiconductors for Cellular/PCS Handsets, Market Review and Forecast 2000*, believes the driver behind the increase will be the strong global demand for mobile communications. According to Strategies Unlimited, the number of cellular and PCS subscribers is forecast to reach 1.3 billion in 2004.

According to the report annual handset demand is projected to grow from 240 million units in 1999 to 600 million in 2004. New services such as instant messaging, wireless data and Internet access will provide continued momentum for strong growth over the next five-years.

GSM handsets are the largest market for RF semiconductors with device shipments of $2 billion in 1999, followed by CDMA, IS_136 TDMA, PDC and analog chipsets with $1.9 billion. Small signal amplifiers, frequency conversion devices and IF chipsets represented the largest part of the the total chip market by type. Power amplifiers control chips also showed strong growth over 1998 levels.

Silicon bipolar technology companies such as Infineon, Motorola, NEC and Phillips provide the majority of the silicon RF chips used in the handset market. GaAs chips comprised 33% of the market in 1999, with strong growth in heterojunction bipolar transistor sales, by Conexant and RF Micro Devices.

Over the next five-years increased integration of RF and IF circuits will reduce the number of chips per handset with CMOS, BiCMOS and SiGe IC leading the way. GaAs ICs will continue to lead in power amplifier and switch sockets. Bluetooth data links and GPS receivers for location-based services will appear in 2000, leading to an estimated $500 million chip market in 2004.

Bluetooth sales may exceed $2 billion in 2005

Bluetooth products, an open standard for wireless connectivity, may exceed $2 billion in sales by 2005. According to a new report released by Allied Business Intelligence (ABI), Oyster Bay, NY, one of the key factors will be the reduced cost of Bluetooth modules from $30 initially to $5 within the next few years. The report, *Wireless Data Communications 2005: From WANS to Bluetooth*, notes that module shipments will exceed 400 million in 2005

Bluetooth is designed to enable wireless connection between electronic devices over a distance of up to 10 meters. Broadcasting at the 2.4 GHZ ISM band, Bluetooth microtransceivers take advantage of IEEE 802.11 specifications of wireless LANs. Future devices are expected to have a range up to 30 meters

User devices can include virtually any digital communications or control device found in-home, factory or workplace. Examples include notebook, desktop and handheld computers, PDAs, cellular/PCS handsets, pagers, printers, fax machines, modems, wireless LAN and LAN access devices, handsets and thermostats.

Currently, Bluetooth is supported by a number of manufacturers including Ericsson, Nokia, IBM, Toshiba, Intel and a number of other electronic manufacturers.

R&D spending predicted to increase for 2000

Battelle, Columbus, OH, has forecasted research and development (R&D) spending will increase by up to 8%. The National Science Foundation estimates R&D spending in 1999 was $247 billion.

Jules J. Durga, a senior researcher and co-author of the report says, "A combination of situations has created what could very well be the continuation of a major resurgence in R&D support and activity in the United States."

Battelle forecasts that federal spending will see little change, while industrial R&D will increase by 10% for the $169 billion spent in 1999. Industrial R&D, according to Battelle, is rebounding from a combination of cost-cutting and organizational structure modifications, and is benefiting from the strong expansion of the national and international economy.

"The shape of the R&D enterprise will continue to evolve and the successful organization will seek both positions and procedures that will permit flexibility," Duga says. "No fixed recipe will suffice over the next decade."

Wireless power device market to rise by billions

It should come as no surprise, but due to the growth of wireless broadband networks and other wireless markets, the market for wireless power products will see significant growth. In a report from Allied Business Intelligence (ABI), Oyster Bay, NY, *Wireless Power Devices–Transistors, ICs and Power Modules*, wireless power products, including GaAs ICs, transistors and silicon power modules and transistors, will grow from $1.7 billion in 1999 to $5 billion in 2004.

According to Andy Fuertes, senior analyst and author of the report, "Early growth will be driven by the use of GaAs IC power amplifiers in the fast-paced cellular/PCS handset market," Fuertes says. "Wireless broadband strategies such as local multipoint distribution systems and third-generation cellular systems will spur significant growth in the latter part of the study period."

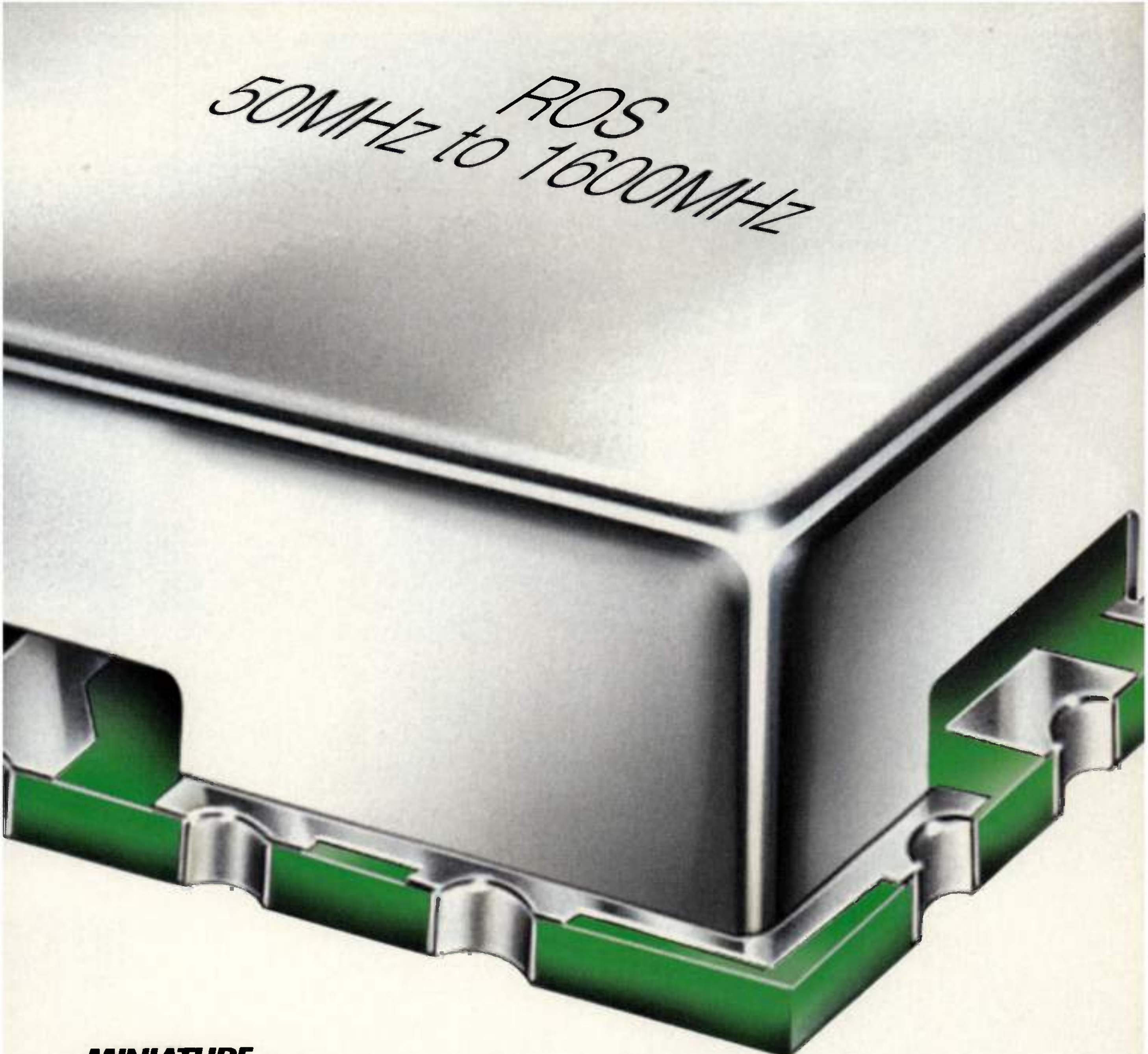
Currently, GaAs ICs represent 53% of the total market for RF power products. According to ABI, the segment is experiencing the highest annual growth of any of the considered devices. ABI expects GaAs IC power amplifier market to grow 32% annually over the next five-years.

The report finds the MESFET ICs, once the leading product in the market, are expected to fall from approximately 40% of the market in 1999 to just over 10% in the year 2004

The leading process of the GaAs IC power amplifier market in 1999 is HBT, with up to 50% of the market share. The rise of LDMOS in the silicon power transistor sector continues. LDMOS accounted for 29% of the silicon power transistor market in 1999 and is expected to achieve a 50% share by 2004.

ABI finds that much of the original growth of the LDMOS share was at the cost of silicon bipolar and GaAs transistors. Although LDMOS may limit the use of both processes in certain new applications in the future, it is unlikely, ABI notes, to cause any more erosion.

For more information concerning these reports, contact Strategies Unlimited, Allied Business Intell-



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ROS SPECIFICATIONS:

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ROS-285PV	245-285	5	-100	-20	5	20	17.95
ROS-900PV	810-900	5	-102	-25	4.5	12	19.95
ROS-960PV	890-960	5	-102	-27	5	12	19.95
ROS-1000PV	900-1000	5	-104	-33	5	22	19.95
ROS-1600PV	1520-1600	5	-100	-26	5	25	18.95
ROS-100	50-100	17	-105	-30	12	20	12.95
ROS-150	75-150	18	-103	-23	12	20	12.95
ROS-200	100-200	17	-105	-30	12	20	12.95
ROS-300	150-280	16	-102	-28	12	20	14.95
ROS-400	200-380	17	-100	-24	12	20	14.95
ROS-535	300-525	17	-98	-20	12	20	14.95
ROS-765	485-765	16	-95	-27	12	22	15.95
ROS-1410	850-1410	11	-99	-8	12	25	19.95

*Phase Noise: SSB at 10kHz offset, dBc/Hz. **Specified to fourth.

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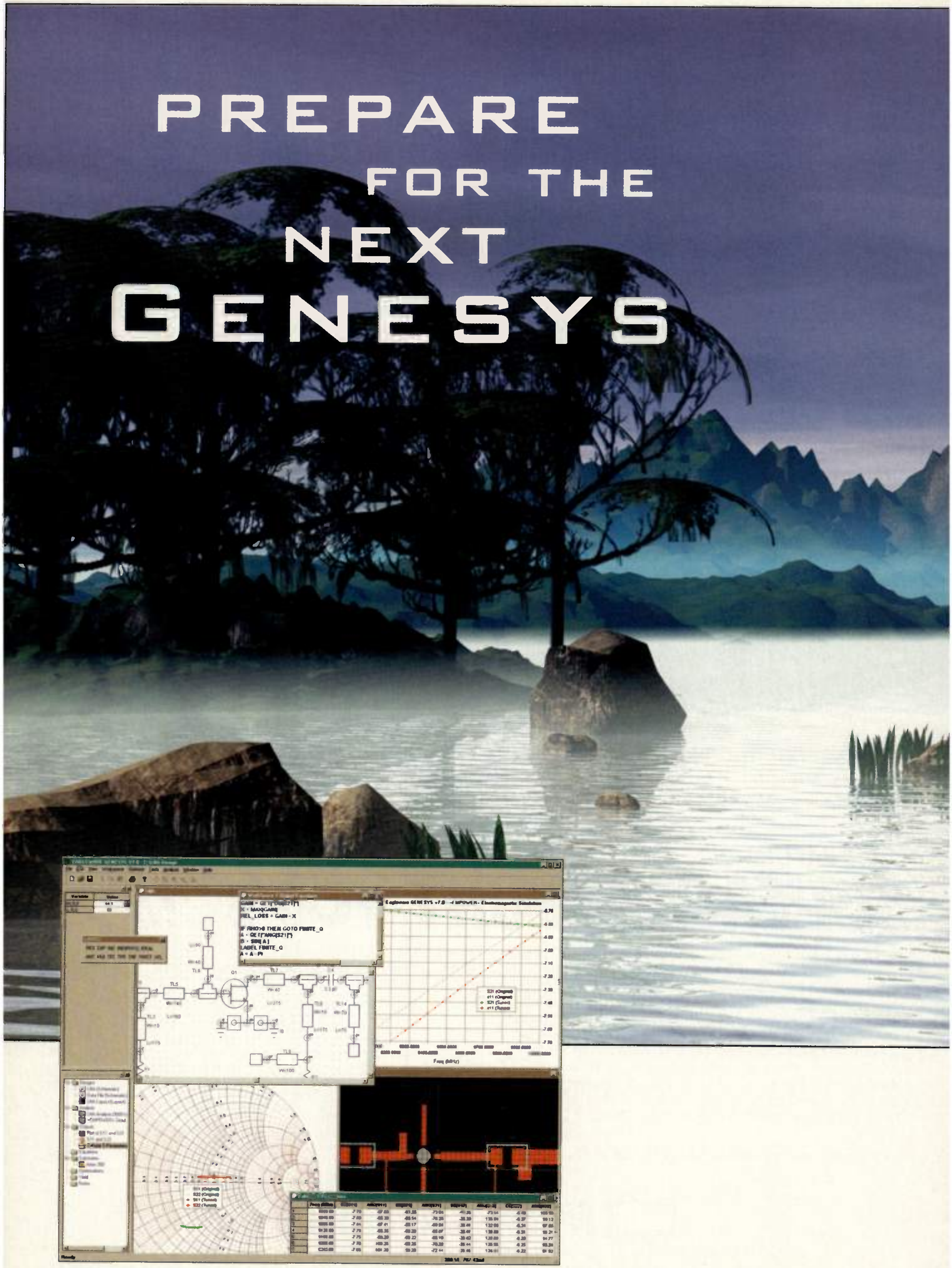
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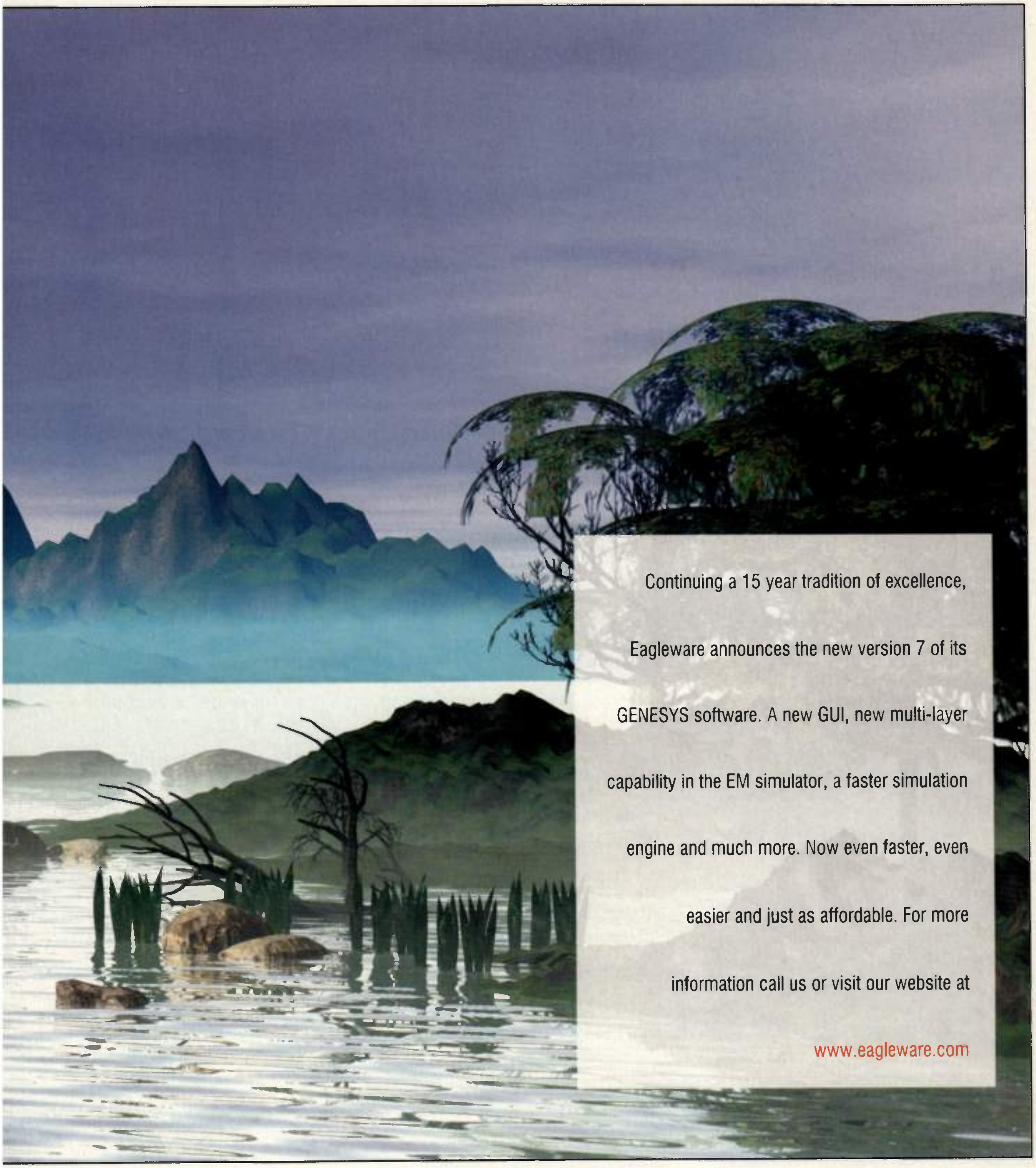
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gence and Battelle through the **RF Design Online** editorial links.

RF Micro Devices ships 50 millionth CDMA product

RF Micro Devices (RFMD), Greensboro, NC, has shipped its 50 millionth CDMA product. William Pratt, RFMD's chairman and chief technical officer, notes "CDMA technology has been a part of RF Micro Devices from the beginning, and we are proud of the accomplishment this production figure represents. CDMA chips were some of the very first RFICs that we developed for our original customers."

Contracts

Giga-tronics wins $3.3 Million contract—Giga-tronics, San Ramon, CA, has received a follow-on production order for VXI synthesizers and down converters totaling $3,300,000 from ManTech Test Systems, Chantilly, VA.

Boonton Electronics receives VXI Order from ManTech Test Systems—Boonton Electronics, Parsippany, NJ, has received a $1.2 million order for its Model 8701 VXI Modulation Meter from ManTech Test Systems, Chantilly, VA. The model 8701 meters will be used in the U.S. Marine Corps Third Echelon Test System (TETS).

BUSINESS BRIEFS

Qualcomm CDMA unit acquired by Koycera—Qualcomm, San Diego, has sold its terrestrial-based wireless CDMA consumer phone business to Koycera, Japan.

Fluke acquires Wavetek Wandel Goltermann assets—Fluke, Everett, WA, has acquired the precision measurement division of Wavetek Wandel Goltermann, Research Triangle Park, NC. Fluke will maintain the Precision Measurement division in the UK.

Vishay and Nichicon form cooperative technical agreement—Vishay, Malvery PA, and Nichicon, Japan, have entered into a cooperative technical agreement to jointly develop tantalum capacitor technology.

Harris to outsource PCB manufacturing—Harris, Melbourne, FL, will outsource its printed circuit board (PCB) assembly manufacturing to Sanmina, San Jose. Sanmina will buy Harris' PCB assembly assets and inventory and will lease a portion of Harris' manufacturing facility in San Antonio, TX.

Andrew acquires Conifer—Andrew, Orland Park, IL, has acquired Conifer, Burlington, IA. Conifer designs and manufactures multichannel multipoint distribution services product, wireless LAN and direct broadcast satellite accessories.

Anadigics opens UK design center—Anadigics, Warren, NJ, has opened its third design center at Thames Valley, UK, near London's Heathrow Airport.

Watkins-Johnson teams with Cisco Systems—Watkins-Johnson, Palo Alto, CA, has been selected by Cisco Systems, San Jose, CA, as a technology partner for the RF outdoor unit in support of the Broadband Fixed Wireless alliance.

Lambda signs new distributor—Lambda, Melville, NY, has signed RS Electronics, Livonia, MI, as a distributor of its industrial and telecom products.

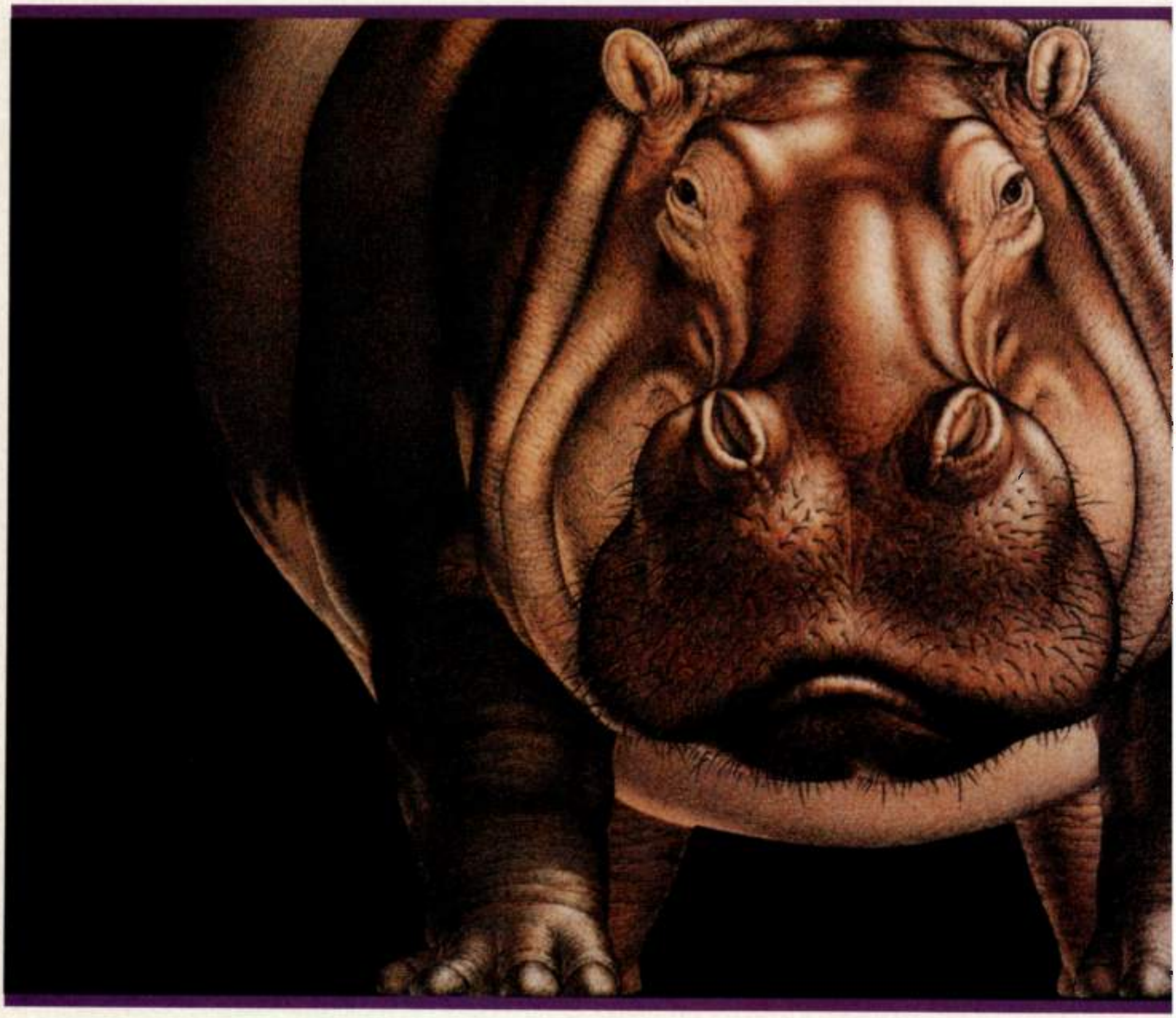
Agilent Technologies and Adaptec enter co-development agreement— Agilent Technologies' Semiconductor group, Palo Alto, CA, and Adaptec, Milpitas, CA, will co-develop, market, and sell Fibre Channel host bus adapters for Windows NT-based servers. This alliance is targeted at providing interoperability and support to drive customer confidence and accelerate the adoption of Fibre Channel in Windows NT markets.

National Semiconductor and Qubit to develop wireless Web Tablet—Qubit Technology, Lakewood, CO, has selected the National Semiconductor's, Santa Clara, CA, Geode WebPAD reference platform as the enabling hardware for Qubit's new Wireless Web Tablet.

National Instruments and Dell Computer announce strategic alliance—National Instruments Austin TX, and Dell Computer, Austin, TX, will join forces to produce integrated measurement and automation workstations for computer-based measurement and automation tools.

CTS establishes RF integrated modules unit—CTS, Elkhart, IN, will expand its product line to include RF integrated modules. The new CTS business will be named RF Integrated Modules and will become part of the Wireless Group

AT AML, SIZE REALLY



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Wide bandwidth frequency modulation of phase lock loops

A new approach to the traditional weakness of frequency modulating a PLL's output.

By David Rosemarin

The phase lock loop is the popular method of frequency synthesis, however one of its main weaknesses is the difficulty in frequency modulating its output. This article will review some of the techniques found in literature, will suggest a new approach and present a practical solution.

The basic PLL

Figure 1 shows a common phase lock loop (PLL) circuit. The loop includes a phase detector, loop filter, voltage controlled oscillator (VCO) and a divider. The sensitivity of the (VCO) is given by:

K_0 (rad/sec/V) = $\Delta\omega/\Delta V = 2\pi\Delta f/\Delta V$

The sensitivity of the phase detector is:

K_p (V/rad) = $\Delta V/\Delta\theta$

F(s) is the lowpass filter transfer function.

The PLL can be analyzed by taking the input and output phase as variables.

Since phase is the integral of frequency or $\omega = s\theta$, then K_0/s should be placed as the block for the VCO (see Figure 2.).

The PLL can be, alternatively, be analyzed by taking the input and output angular frequencies as variables (see Figure 3.). A block of 1/s should be placed in front of both inputs of the phase detector or the phase detector can be replaced with K_p/s. The transfer function for both block diagrams is actually the same. It is defined by:

$$\theta_0/\theta i = \omega_0/\omega_i = f_0/f_i = K_pK_0F(s)/s/D \qquad (1)$$

where:

$$D = [1 + K_pK_0F(s)/s/N] \qquad (2)$$

Using a phase modulator

One of the ways often described in literature, to get wideband frequency modulation, is shown in Fig. 4.

Our interest is in understanding the small signal AC behavior of the loop in response to outside stimuli such as modulation. Since the reference frequency is fixed in the FM PLL system, the small signal component of the reference signal is zero. In Figure. 4, two modulating signals are used, V_{m1} and V_{m2}. Using superposition, and knowing that $\omega_0 = s\theta_o$, we get for modulating at V_{m1}:

$$\omega_0/V_{m1} = K_0/D \qquad (3)$$

This transfer function has a high pass response and allows frequency modulation of the output frequency at rates greater than the loop bandwidth when a modulation voltage is applied at the V_{m1} input. For modulating at V_{m2} we get:

$$\omega_0/V_{m2} = K_iK_pK_0F(s)/s/D \qquad (3')$$

The transfer function has a nature of a lowpass response and allows for modulating at rates inside the loop bandwidth. If we apply the modulation signal to both the V_{m1} and V_{m2} or $V_{m1} = V_{m2} = V_m$,

then:

$K_m = \omega_0/V_m = K_0[1 + K_iK_pF(s)/s]/D$. And scaling the in-band FM path by setting $K_i = K_0/N$, will obtain a flat frequency response of K_0. The mathematical result is flat response dependent only on K_0 for modulation rates both inside and outside the loop bandwidth. F(s) block and loop bandwidth do not

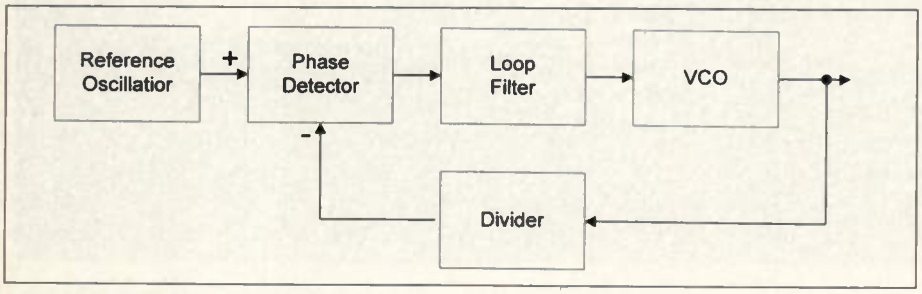


Figure 1. The basic PLL block diagram.

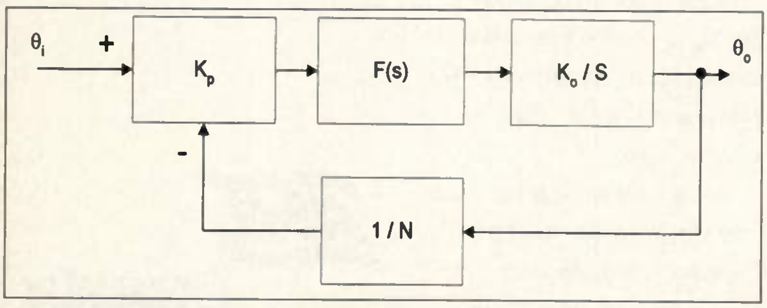


Figure 2. The block diagram using phase variables.

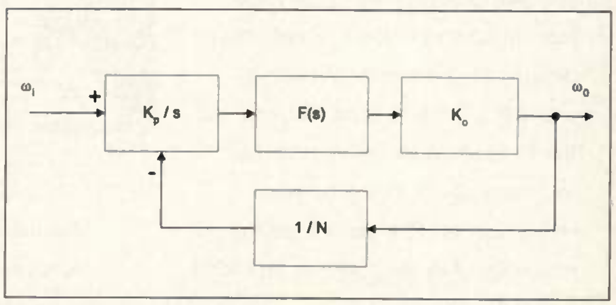
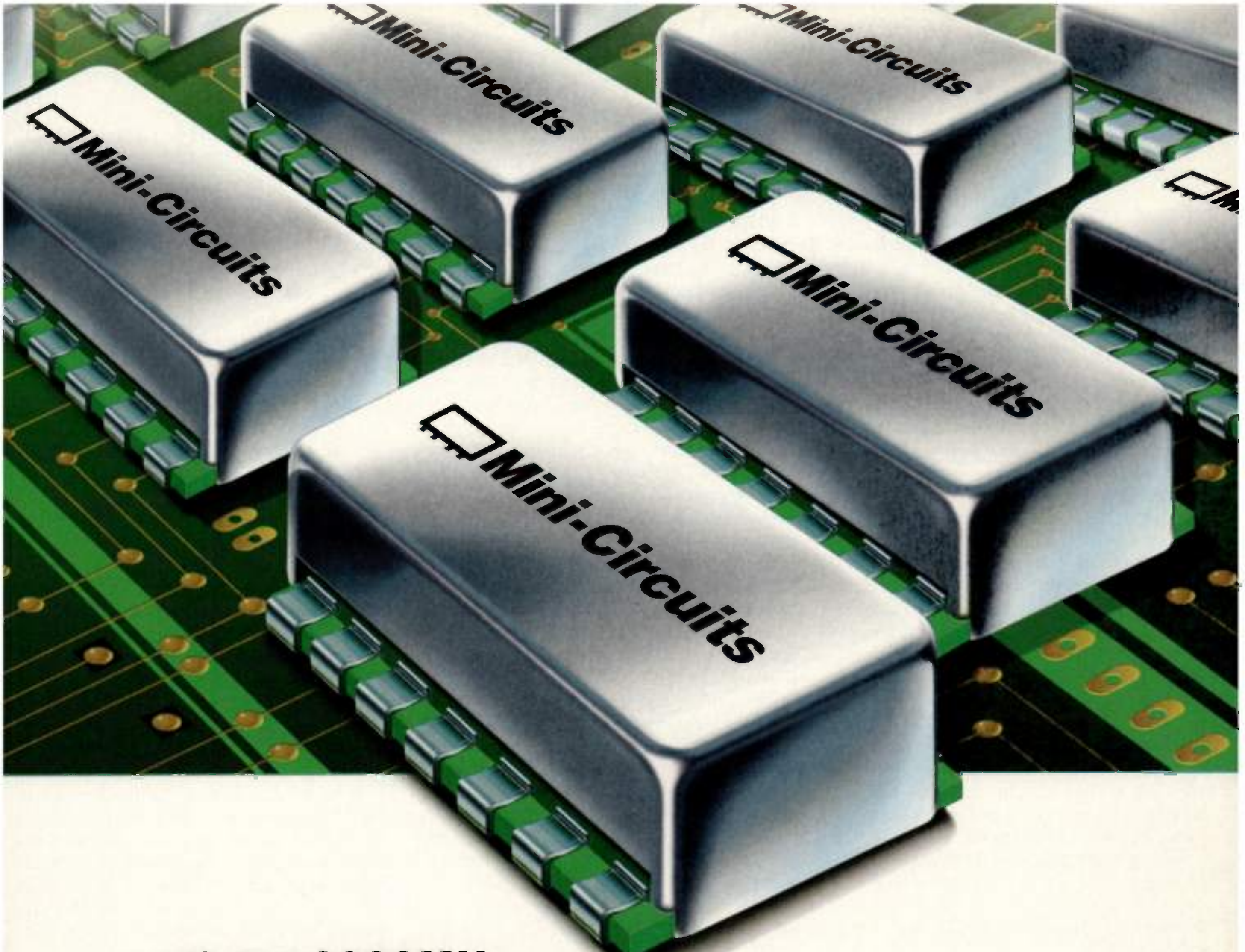


Figure 3. The block diagram using angular frequency variables.



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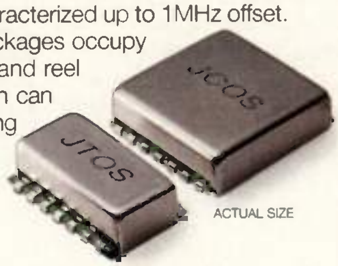

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JTOS/JCOS SPECIFICATIONS

Model	Freq. Range (MHz)	Phase Noise (dBc/Hz) SSB@ 10kHzTyp.	Harmonics (dBc) Typ.	V_{tune}** 1V to:	Current (mA) @+12V DC Max.	Price Sea. (5-49)*
JTOS-25	12.5-25	-115	-26	11V	20	18.95
JTOS-50	25-47	-108	-19	15V	20	13.95
JTOS-75	37.5-75	-110	-27	16V	20	13.95
JTOS-100	50-100	-108	-35	16V	18	13.95
JTOS-150	75-150	-106	-23	16V	20	13.95
JTOS-200	100-200	-105	-25	16V	20	13.95
JTOS-300	150-280	-102	-28	16V	20	15.95
JTOS-400	200-380	-102	-25	16V	20	15.95
JTOS-535	300-525	-97	-28	16V	20	15.95
JTOS-765	485-765	-98	-30	16V	20	16.95
JTOS-1000W	500-1000	-94	-26	18V	25	21.95
JTOS-1025	685-1025	-94	-28	16V	22	18.95
JTOS-1300	900-1300	-95	-28	20V	30	18.95
JTOS-1550	1150-1550	-101	-20	***	30	19.95
JTOS-1650	1200-1650	-95	-20	13V	30	19.95
JTOS-1750	1350-1750	-101	-16	***	30	19.95
JTOS-1910	1625-1910	-92	-13	12V	20	19.95
JTOS-1950	1550-1950	-103	-14	***	30	19.95
JTOS-2000	1370-2000	-95	-11	22V	30 (@8V)	19.95
JTOS-3000	2300-3000	-90	-22	***	25 (@5V)	20.95
JCOS-820WLN	780-860	-112	-13	***	25 (@9V)	49.95
JCOS-820BLN	807-832	-112	-24	14V	25 (@10V)	49.95
JCOS-1100LN	1079-1114	-110	-15	***	25 (@8V)	49.95

Notes: *Prices for JCOS models are for 1 to 9 quantity. **Required to cover frequency range. ***Tuning Voltage for JTOS-3000 is 0.5 to 12V, JTOS-1550, JTOS-1750, and JTOS-1950 is 0.5 to 20V, and JCOS-820WLN and JCOS-1100LN is 0 to 20V. For additional spec information and details about 5V tuning models available, consult RF/IF Designer's Guide, our Internet Site, or call Mini-Circuits.

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K-JTOS2 $99.95 (Contains 1ea. JTOS-50, -100, -200, -400, -535, -765, -1025).
K-JTOS3 $114.95 (Contains 2ea. JTOS-1300, -1650, -1910).

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affect the frequency modulation.

There are, however, some limitations to that solution.

(a) Wideband voltage-controlled oscillators have a non-constant K_0 and the PLL has a non-constant divider ratio, N. And, K_i has to vary with output frequency in order to hold a fixed frequency deviation.

(b) A second problem is the integrator. The output of an ideal integrator would slew up and down without bounds when a DC voltage is applied to the input. Any DC offsets at the integrator input will cause a center frequency offset proportional to it. This may be desirable for DC coupled FM, however, for many applications it is necessary to have the output frequency locked at the correct center frequency. In this case, AC coupled FM is needed instead [1].

Modulating the Reference

Figure 5. is a block diagram representing a second approach to modulating. For convenience angular frequency analysis is applied.

Using superposition, and modulating at V_{m1}:

$$\omega_0 = (V_{m1} - \omega_0 K_p F(s)/s/N)K_0, \text{ and } \omega_0/V_{m1} = K_0/D \quad (4)$$

As before, the transfer function has a high pass response and allows frequency modulation of the output frequency at rates greater than the loop bandwidth.

Next, modulating the reference at V_{m2} yields:

$$\omega_0 = (V_{m2}K_R - \omega_0/N)K_pK_0F(s)/s, \text{ and } \omega_0/V_{m2} = K_RK_pK_0F(s)/s/D \quad (5)$$

Again, the transfer function has a nature of a low pass response and allows for modulating at rates inside the loop bandwidth. If we apply the modulation signal to both the V_{m1} and V_{m2} and scaling the in-band FM path by setting $K_R = K_0/N$, we get a flat frequency response of K_0.

The advantage in this configuration is the elimination of an integrator, but it has, still, some limitations. For example, if a voltage-controlled crystal oscillator (VCXO) has to be used instead of a reference oscillator, there is a limit to its maximum deviation. Also, the maximum modulating frequency into the VCXO has to be much smaller than the parasitic modes of the crystal since there is an overshoot of the audio response at those frequencies.

If the loop frequency is smaller than the frequency of the parasitic modes, a low pass filter can be added at the modulation input of the reference. Its 3 dB frequency should be between those two frequencies so it will not affect at the loop bandwidth but will help in suppressing the incoming signal at frequencies close to the parasitic modes of the crystal.

Modulating in the loop filter

Figure 6 is a diagram of modulation in the loop. Again using superposition and modulating at V_{m1}:

$$\omega_0 = (V_{m1} - \omega_0 K_p F(s)/s/N)K_0 \text{ and } \omega_0/V_{m1} = K_0/D \quad (6)$$

Modulating at V_{m2} yields:

$$\omega_0 = (V_{m2}K_i/s - \omega_0 K_p/s/N)F(s)K_0 \text{ and } \omega_0/V_{m2} = K_iK_0F(s)/s/D \quad 7)$$

If we apply the modulation signal to both the V_{m1} and V_{m2} and scaling the in-band FM path by setting $K_i = K_pK_0/N$, we get a flat frequency response of K_0.

As usual there are several limitations of the error corrected FM PLL and reference 2 addresses the particulars.

Because the circuit of Figure 6 blocks part of the loop, it is desirable that a further analysis of the dashed section of the circuit be analyzed and further simplified. The dashed circuit in Fig. 6 can be re-written as:

$(V_{m2}K_i/s + V_e)F(s) + V_{m1} = V_{0,}$ and for

$V_{m1} = V_{m2} = V_m$ then:

$$V_m(1 + K_iF(s)/s) + V_eF_{(s)} = V_o \quad (8)$$

Substituting $K_i = K_pK_0/N$ and using (2) gives us:

$$V_mD + V_eF(s) = V_o \quad (8')$$

The modified circuit is shown in Fig. 7.

Voltage type Phase Detectors

It would seem that taking an example would be prudent at this time.

A typical lag-lead filter is shown in Figure 8. For reference:

$$F(s) = \frac{1 + sR_2C_2}{1 + s(R_1 + R_2)C_2} \quad (9)$$

If we try to make a realization of the modulation block "$1 + K_i F(s)/s$" shown in Figure 7, the process will be performed in the two steps shown in Figures 9a and b. Looking at 9a and using the virtual ground at the inverted input of the operational amplifier and Thevenin's theorem:

$$V_x/V_m = F(s)/2, \ I = V_x/(2R_1)$$
$$V_o = -I/(sC_a) = -F(s)V_m/(s\,C_a4R_1)$$

In Figure 9b we added another capacitor and changed the op-amp to a summing amplifier. Therefore:

$V_o/V_m = -(1 + F(s)/s/(4\ R1Ca))$, which is equivalent to the first term of (8) or (8'). That assumes that $C_a = 1/(4R_1K_i) = N/(4R_1K_pK_0)$ (10)

If a different sensitivity, K_m, is required, Fig. 9b can be modified to 9c and the following relationship can be developed:

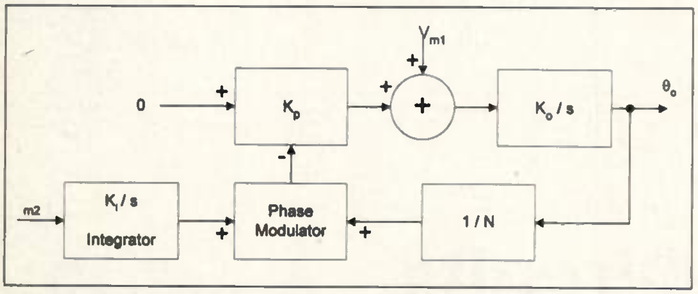

Figure 4. FM using a phase modulator.

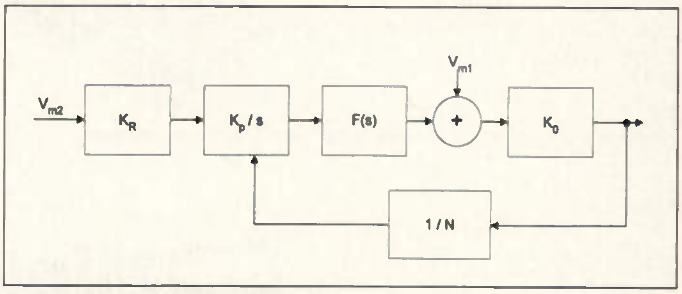

Figure 5. Modulating the reference.

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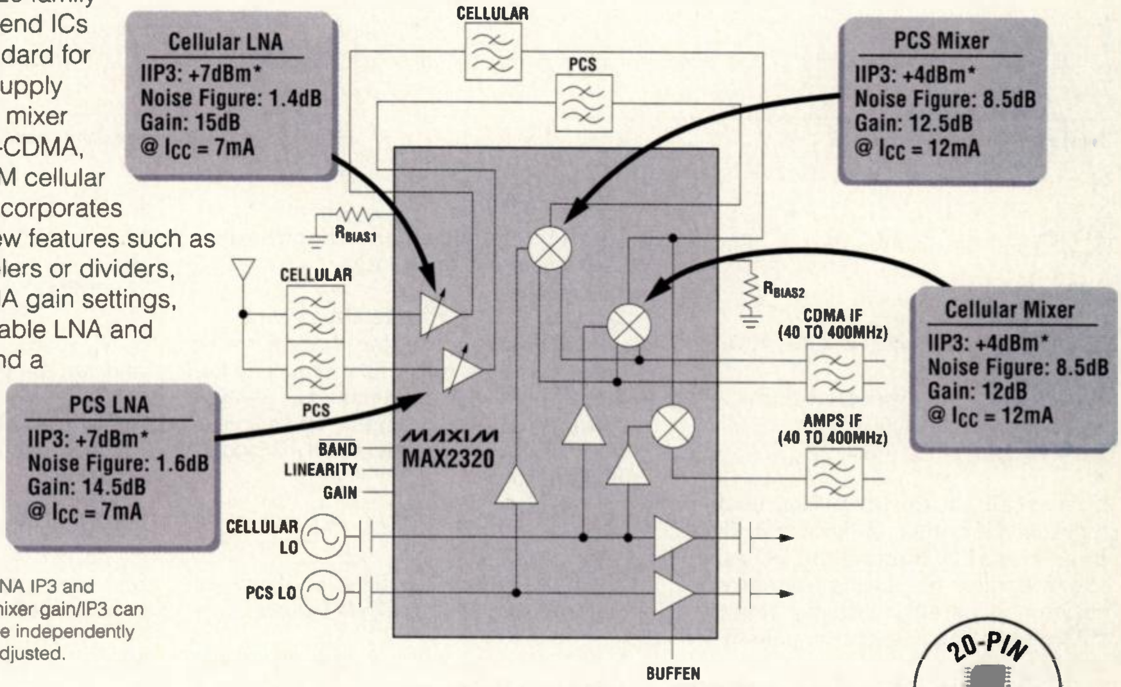

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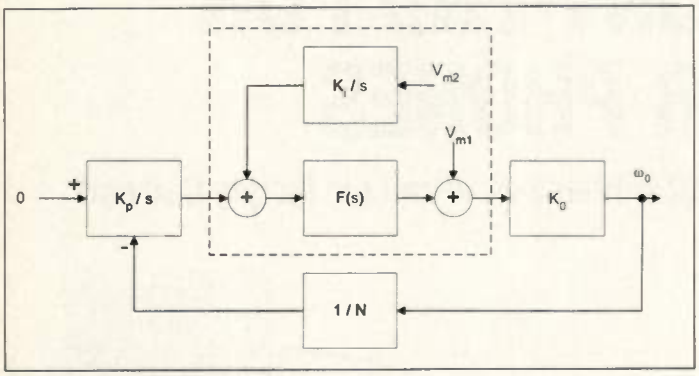

Figure 6. Modulation in the loop.

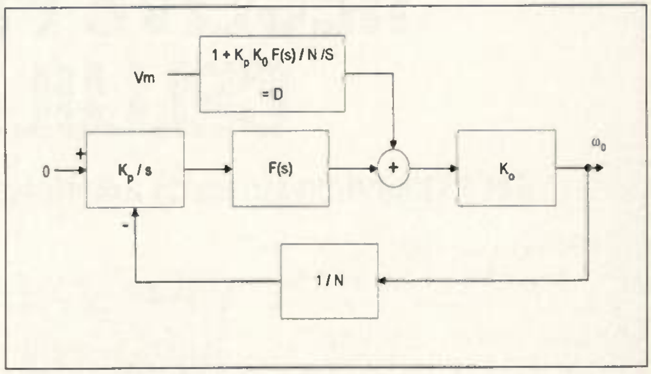

Figure 7. Figure 6 with equivalent circuit.

$V_o/V_m = -[F(s)/s/(4R_1C_b) + C_a/C_b] = -(C_a/C_b)[1 + F(s)/s/(4R_1C_a)]$,

and:

$K = -K_0(C_a/C_b)[1 + F_{(s)}/s/(4R_1C_a)]/D$.

By using Eq. (10), we determine:

$K_m = K_0C_a/C_b$ or $C_b = K_0C_a/K_m$ (11)

This circuit has the limitations of an integrator. Of course, integrator drift can be decreased by limiting the DC gain of the integrator by placing a large value resistor in parallel with C_b. However, this moves the integrator pole of f of zero .

Furthermore, if desired, and with some degradation, the circuit in Figure 9c can be changed into a passive network shown in Figure 10, using the following analysis.

Using Equation (9) and (10) it can be shown that:

$V_o/V_m = [1 + K_iF(s)/s]/[(C_a + C_b)/C_a + K_i(2 - F(s))/s]$
and:

$K_m = K_0C_a/[C_a+C_b + (2 - F(s))/(4sR_1)$ (12)
From (9), the limits of F(s) are:

$R_2/(R_1 + R_2) < F(s) < 1$, or $1 < [2 - F(s)] < 1 + R_1/(R_1 + R_2)$.

The third term in the denominator of (12) can be ignored for all frequencies much greater than f_{min} where:

$f_{min} = 1/(8\pi R_1C_b)$ (13)

then:

$K_m = K_0C_a/(C_a + C_b)$ (14)

Obviously, when the ratio K_m/K_0 gets smaller, C_b has to be larger and f_{min} is smaller, which means that the frequency bandwidth is larger.

Charge-Pump Phase Detectors

Another technique for phase detector design is using a charge-pump. The following section will derive the design concept for such a circuit. In this case the phase detector sensitivity, K_p, is given by:

$I/2/\pi$ (15)

A charge-pump loop filter is shown in Figure 11 and the analysis follows.

$V_0 = I_pZ(s)$, and $F(s) = V_0/I_p = Z(s)$. From literature, defining:

$T_1 = R_2C_1C_2/(C_1 + C_2)$, and $T_2 = R_2C_2$ (16)

The impedance of Figure 11 was solved by:

$Z(s) = (1 + sT_2)/(1 + sT_1)/[s(C_1 + C_2)]$ (17)

It has been shown also that:

$T_1 = (\sec\phi_n - \tan\phi_n)/\omega_n$ (18)
$T_2 = 1/(\omega_n^2T_1)$ (19)
$C_1 = T_1K_pK_0\ SQRT\ \{[1 + (\omega_nT_2)^2]/[1 + (\omega_nT_1)^2]\}/(T_2\omega_n^2N)$ (20)
$C_2 = C_1(T_2/T_1 - 1)$ (21)
$R_2 = T_2/C_2$ (22)

A realization of the modulation block, $D = 1 + K_iF(s)/s$, shown in Figure 7, can be executed by the passive circuit shown in Figure 12. In that circuit, the assumption is made that the resistors, R, are large enough to act as current sources.

Next, determining the following:

$V_0/V_m = [sC_a + 1/(R^2N)]/[s(C_a + C_b) + 1/R(1 - 1/(RN))]$, where $N = 2/R + 1/Z(s)$,

and assuming that $Z(s) << R/2$,

then:
$N = 1/Z(s)$ (23)

$V_0/V_m = [sC_a + Z_{(s)}/R^2]/[s(C_a + C_b) + 1/R]$, and assuming that $s(C_a + C_b) >> 1/R$ (24)

$V_0/V_m = C_a/(C_a + C_b) \times [1 + Z(s)/(sC_aR^2)]$, and because F(s) = Z(s), equation (2) becomes: $D=[1+KpK_0Z(s)/s/N]$ (25)

$K_m=K_0C_a/(C_a+C_b)\times[1+Z(s)/(sR^2C_a)]/D$ (26)

and the requirement for K_m to be independent of frequency, is:

$K_pK_0/N = 1/(R^2C_a)$ (27)

then:

$K_m = K_0C_a/(C_a + C_b)$ (28)

Additionally, in the above derivation we assumed that $R >> Z(s)$.

Next, $Z_{(s0)} = 1/[s(C_1 + C_2)]$, and the requirement for R is:

$R >> 1/[2\pi f_{min}(C_1 + C_2)]$ (29)

Now calculate:

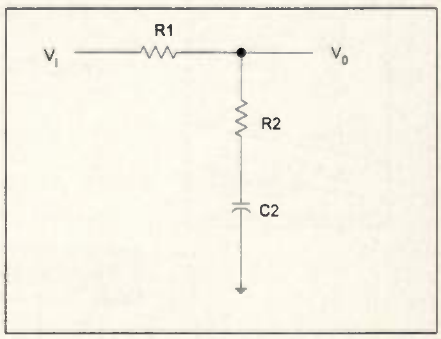

Figure 8. Lead-lag loop filter.

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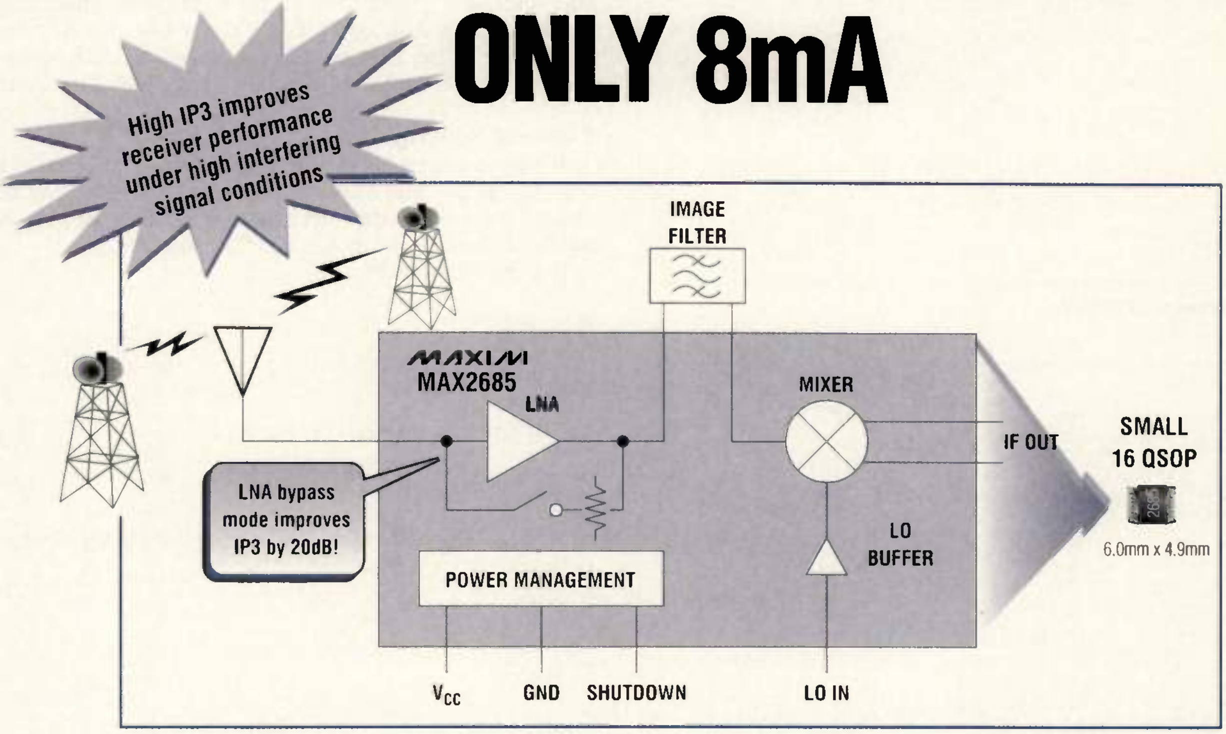

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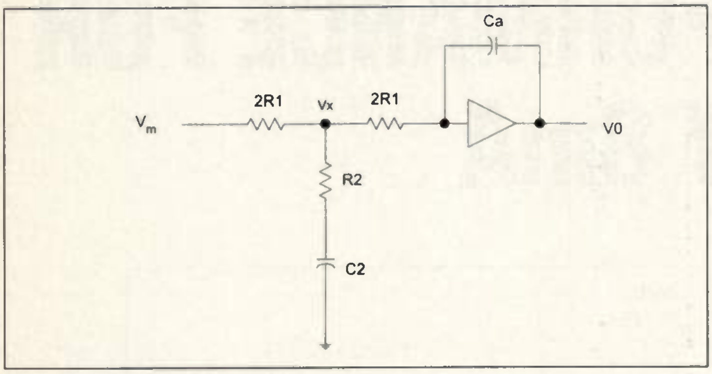

Figure 9a. Realization of $K_lF(s)/s$.

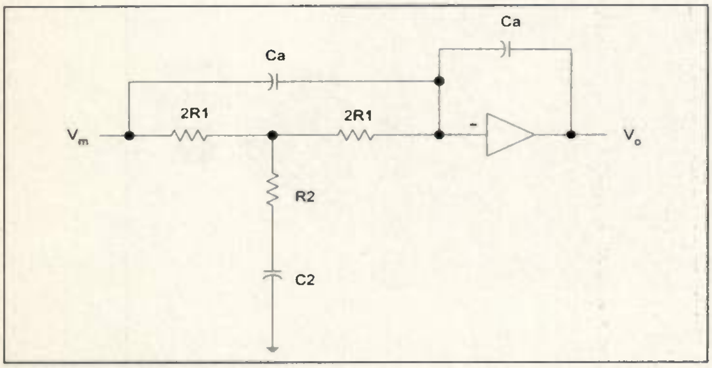

Figure 9b. Realization of $1 + K_lF(s)/s$.

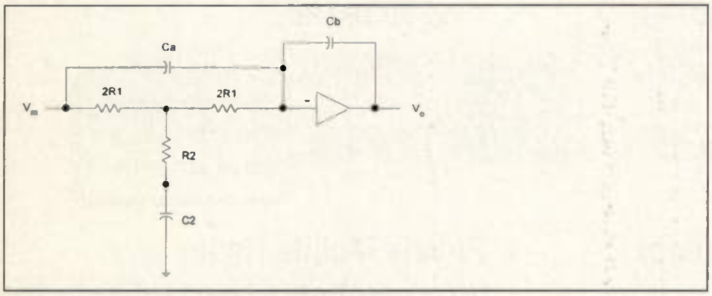

Figure 9c. Changing modulation sensitivity.

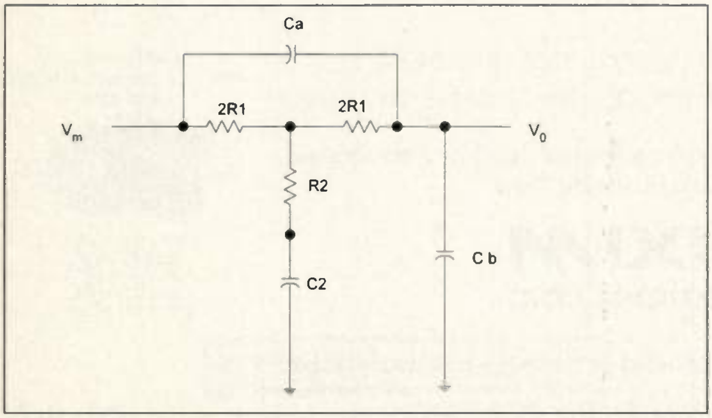

Figure 10. Passive modulator network.

$$R = 20/[2\pi f_{min}(C_1 + C_2)] \quad (30)$$

then extract C_a from (27), C_b from (28), and build a model for analyzing and optimizing the PLL as described in Reference 7. At this point it is possible to determine a better solution with any standard optimization program.

Element Scaling

If the resistors, R, in the modulation network shown in Fig. 12 are too big, element scaling can be done. Attention should be paid to the fact that the scaling is only in the modulation network and not in the loop filter.

Set the following:

$R_2' = R_2/m$
$C_1' = mC_1$
$C_2' = mC_2$

Substituting in (16) &. (17) leads to:

$Z'(s) = Z(s)/m$

Scaling should also be applied to the passive network,which yields:

$R' = R/m$
$C_a' = mC_a$
$C_b' = mC_b$

Substituting in (26), with D untouched, leads to $K_m' = K_m$, which means that the modulation sensitivity is invariant with that element scaling. This technique gives us versatility in choosing element values.

Practical configuration

A practical configuration culminates the project by combining both the low-pass loop filter, shown in Figure 8, and the modulation network, shown in Figure 10, is shown in Figure 13. The varicap diode of the VCO is biased by the loop filter at its anode and by the modulation network at its Cathode. This port should have a RF short and a DC return. Sometimes this return is accomplished by the modulation source itself. If not, a large resistor can be connected in parallel to maintain that function.

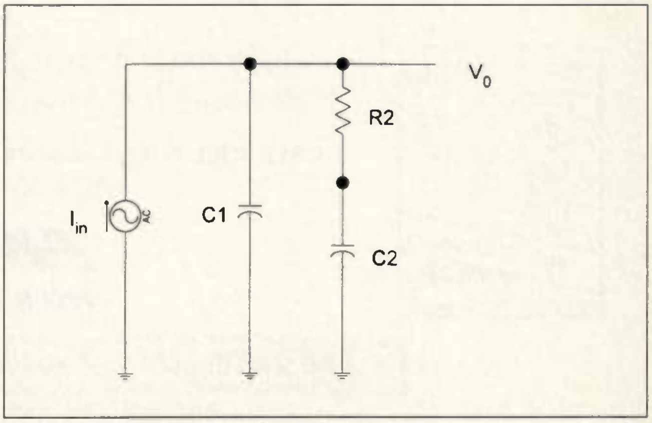

Figure 11. Charge-pump loop filter.

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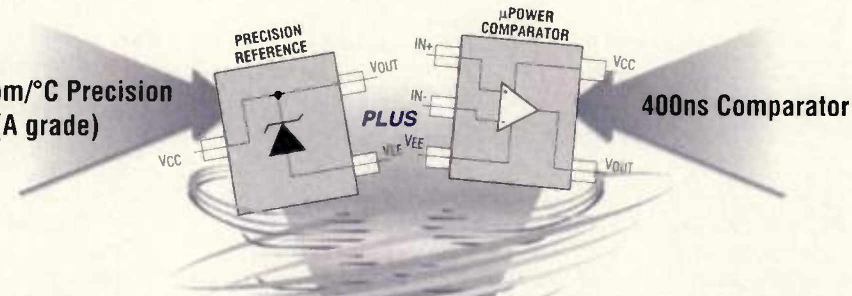

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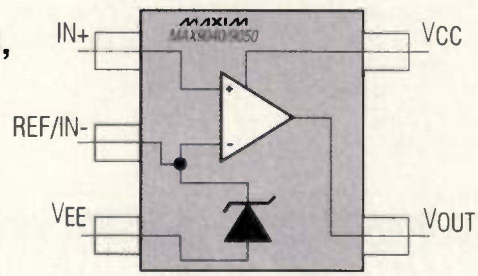

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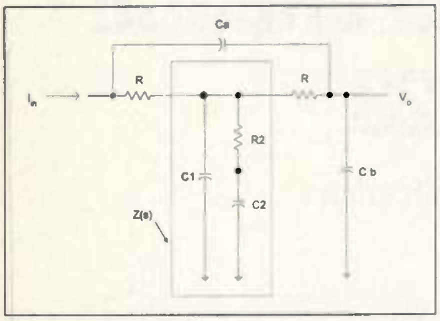

Figure 12. Modulation circuit of the charge-pump PLL.

Conclusion

A very detailed look at the concept of frequency modulating PLL circuits has been presented in this document. It is hoped that this technique will provide the designer with practical tools to assist them in their functionality, and the information is found useful.

RF

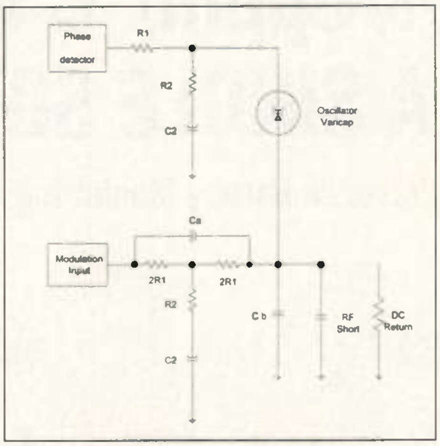

Figure 13. The practical circuit schematic.

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About the author

David Rosemarin is an RF industry consultant. He was graduated from Technion—the Israel Institute of Technology in 1962. He received his M.Sc. from there in 1973. He has worked in various Israeli industries as an R & D engineer and manager in RF communications. He has also worked with companies such as Watkins-Johnson, Microwave Semiconductor and Q-Tech. He can be reached at 011.972.39063632 or P.O. Box 739, Shaarei Tiqwa, Israel 44810.

Automatic gain control in burst communications systems

This simple and fast analog AGC for phase modulated burst signals improves threshold and facilitates accurate RSSI, bandwidth and noise figure measurements.

By Pankaj Goyal

Editors note: Due to the complexity and length of some of the formulas used by Mr. Goyal, they have been moved to the end of the article (page 56).

This article presents a practical approach toward the design of a fast automatic gain control (AGC) and discusses the design issues related to the circuit performance. The main points addressed in this article include: power control techniques and dynamic range, basic design of analog feedback AGCs, the effect of important control loop elements on the response time, signal spectrum and measurements. A feedback topology is simulated and the circuit behavior is explained with the help of graphs and tables.

Though generic cases are discussed wherever possible, the article is mainly based on the work done to design a similar circuit for the base station receive chain of a time-division multiple-access (TDMA) based point-to-multipoint radio. Derivation of accurate received signal strength indicator (RSSI) from the control loop and the measurement methods for systematic evaluation of the receive chain performance are described.

The AGC circuit was implemented along with an L-band downconverter on the same printed circuit board (PCB). The module was tested in the base station of a TDMA-based point-to-multi-point system where the gain–controlled IF at 32.768 MHz was fed to a digital quadrature phase shift keying (DQPSK) demodulator and performance improvement was verified.

The links

In a typical TDMA based stationary point–to–multipoint radio (see Figure 1), the base station broadcasts on frequency f_1 to all the remotes. The remote stations demodulate continuously, but each remote processes only the relevant information meant for it. All of the remote stations transmit on the same frequency f_2 toward the base station, but only during specific time slots assigned by it using TDMA. The base station receives the signals in the form of modulated bursts sent by the different remote stations at frequency f_2 with a guard time T_g separating the bursts. Depending on the distance of a particular remote from the base, the propagation delay and the strength of the burst reaching the base varies from one remote to the other. There is a high probability of different remotes transmitting in consecutive time slots and, as a result, the slot timing and power control in uplink become major design issues.

— *Timing slots in the uplink frame:* When a remote is powered on, the downlink is established first, and the remote synchronizes its timing clock to that of the base station. As far as transmission is concerned, it is likely that a burst transmitted by this remote will interfere with the burst transmitted by the other remotes. To avoid this clash, auto-ranging is performed. the remote transmits a predefined burst of short duration during the signaling slot. The base station calculates the possible positioning of this uplink slot and tells the remote to advance/delay its transmission accordingly. This process is continued until the remote transmission is adjusted to a required accuracy. Although there can always be a finite

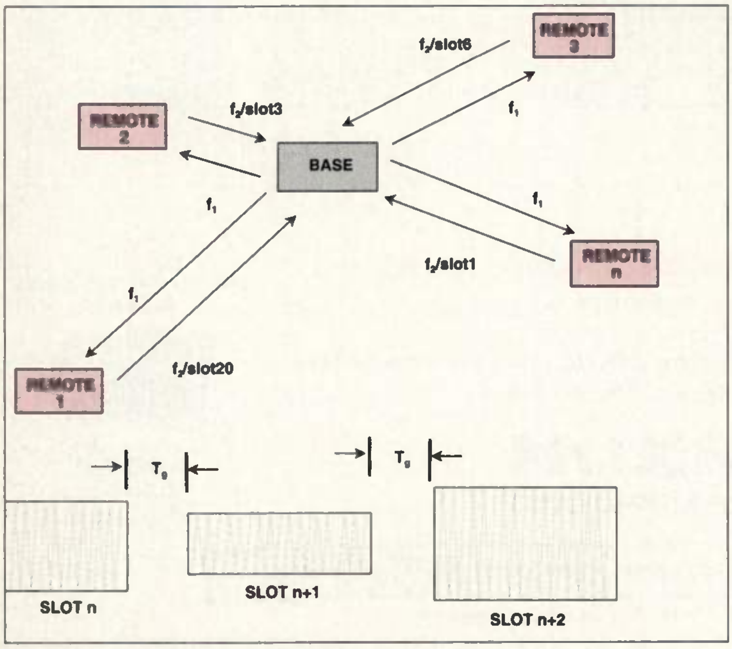

Figure 1. Uplink and downlink block diagram.

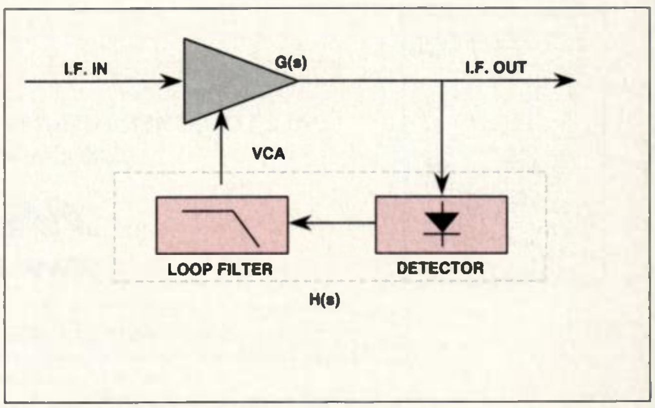

Figure 2. A feedback AGC circuit.

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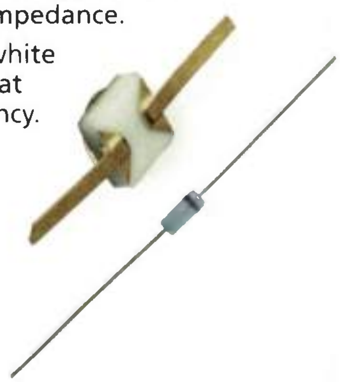

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NC506/15	0.2 MHz – 5 GHz	31 dB
NC513/15	0.2 MHz – 2 GHz	51 dB

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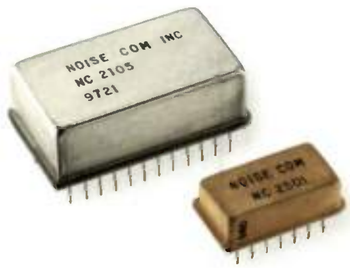

NC2000 SERIES Standard Models		
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NC2105	500 Hz – 10 MHz	0.15 Vrms
NC2201	1 MHz – 100 MHz	+5 dBm
NC2601	1 MHz – 2 GHz	-5 dBm

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UFX7108	100 Hz – 500 MHz	+10 dBm
UFX7112	1 MHz – 2 GHz	+0 dBm
UFX7218	2 GHz – 18 GHz	-20 dBm
UFX7911	5 MHz – 1 GHz	+30 dBm

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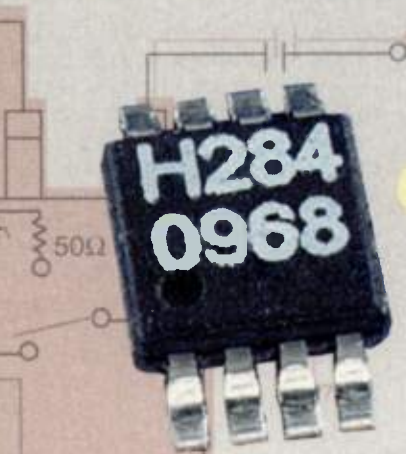

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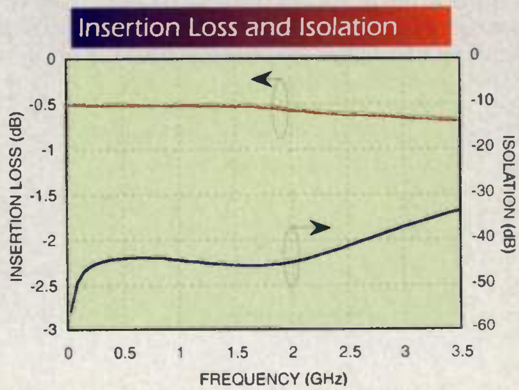

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HMC194MS8	DC - 3.0	0.7/50	+43	MSOP8	Hi Isolation/Reflective
HMC221	DC - 3.0	0.4/28	+45	SOT26	Low Loss/Reflective
HMC190MS8	DC - 3.0	0.4/27	+50	MSOP8	Low Loss/Reflective
HMC239S8	DC - 2.5	0.4/29	+50	SOIC8	Industry Standard
HMC224MS8	5.0 - 6.0	1.2/31	+42	MSOP8	Hi Linearity T/R, +3 to +5V
HMC174MS8	DC - 3.0	0.5/25	+60	MSOP8	Hi Linearity T/R, +3 to +5V
HMC226	DC - 2.0	0.5/20	+61	SOT26	Hi Linearity T/R, +3V
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error in this timing, the guard time T_g prevents any transmission clash in the uplink.

— *Power control and dynamic range:* Irrespective of the modulation scheme used, some sort of amplitude control is needed over the uplink bursts at the base receiver. This practice ensures that a constant level can be fed to the demodulator to keep it functioning at its design point. For example, a phase locked loop (PLL) based FSK demodulator can misbehave [1] because the phase detector output and, hence, the operating point of the loop may shift as the input signal amplitude varies. Many demodulator circuits use ADCs to digitize the down-converted signal and then perform demodulation in the digital domain. Any excessive power level variation at the ADC input can cause serious degradation in receiver performance [2].

Implementing amplitude control

— *Power control at the remote*: When the dynamic range requirement is high, uplink power control becomes more cumbersome because any control system would require a finite time to change the gain value and settle within a desired accuracy. Transmit power control at the remote can aid to a large extent in reducing the dynamic range requirement of base receiver.

The downlink signal is received continuously by all the remotes. The RSSI (a DC reference voltage) generated by the remote receiver can be easily manipulated to control the gain of remote transmitter. This function is called open loop power control. It assumes the uplink and downlink path loss and fading to be identical. This technique is not very accurate, as is the case with any open loop control system. If the transmitter power is less than required, there can be a serious threshold degradation in the uplink of this particular remote. By ensuring that the remote transmitter gain is slightly higher than that determined by the RSSI, a reasonable reduction in the dynamic range of the base receiver can be achieved.

In a closed loop power control method, the base detects the power in the uplink of each remote and instructs the remote station to adjust its transmitter power accordingly. Although this method is certainly more accurate than open loop power control, the reduction in dynamic range resulting at the base receiver may not be worth the complexity of implementation. Moreover, the downlink for each remote station needs to have additional power control bits, which will reduce the system efficiency.

— *Power control at the base:* Whether uplink power control is used at the remote transmitters or not, it is a "must" at the base receiver. A limiter or an AGC circuit can be used for keeping the IF amplitude at the demodulator's design point (A limiter is generally an amplifier driven in saturation.) Its response is as instantaneous as that of other IF amplifiers. However, the nonlinear nature of the limiter distorts the signal waveform. This distortion is seen as spectral spreading, intermodulation products and AM/PM conversion. The out-of-band components can be filtered out, but there is no way of removing the in-band distortion. Although a limiter can perform well in FM/FSK systems, a linear amplification is highly desirable in the systems employing QPSK and higher-order phase modulations. This goal can be achieved by an AGC circuit, where a voltage-controlled amplifier (VCA) is used and its gain is varied depending on the strength of the received signal. Thus, only the required amount of gain is given to the signal and saturation is avoided. The behavior of basic elements of AGC may be nonlinear, but the signal amplification is, nevertheless, linear. A considerable amount of literature has been published about AGC circuits by several authors. [3], [4], [5], [6], [7].

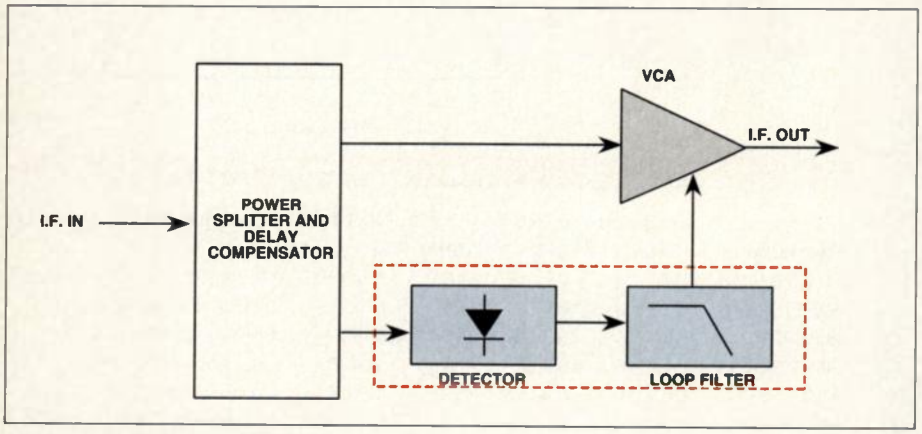

Figure 3. A feedforward AGC circuit.

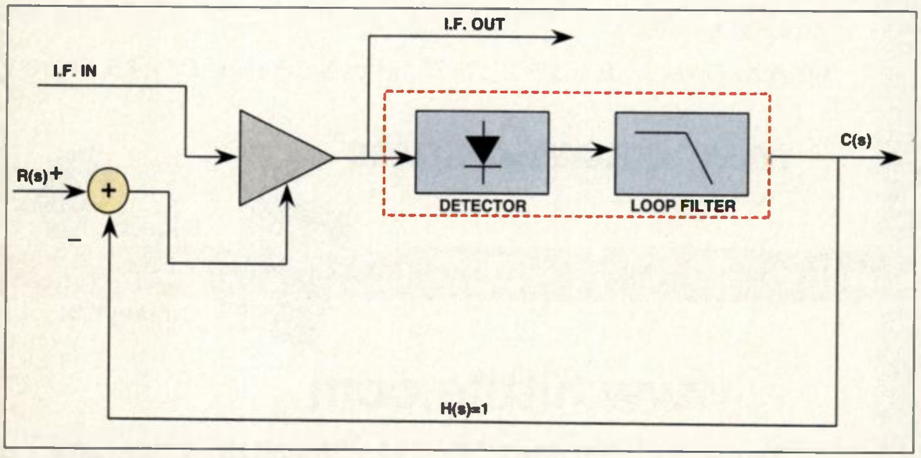

Figure 4. Linearized model of Figure 2.

AGC techniques

Figure 2 shows a feedback AGC, the most commonly used method of amplitude control. The signal is passed through a VCA, detected, filtered and then fed back to the VCA in a manner

so as to adjust its gain to remove unwanted time variations in the input signal envelope. Delay introduced by each element in the control loop adds up and determines overall delay in circuit response. Thus, a feedback AGC is inherently slow.

A feed-forward AGC (see Figure 3) has a faster response because the signal detection and gain control are parallel. The incoming signal is split into two paths; one goes to the VCA and the other to a detector. The detector is designed to have a response that ensures the VCA gets the required control voltage and gives a gain exactly as required by the input IF amplitude. The transmission delays of these two parallel paths are equalized by introducing an extra delay in one of them as required. Being an open–loop control system, this method has limited accuracy. The output varies with the input, but over a relatively small range. The pattern of this variation cannot be defined in a simple manner because the characteristics of detector and VCA do not remain constant over the entire dynamic range. The VCA gain, detector gain and other circuit parameters also show some variation, however small, over the operating temperature range also. Among the best available high–performance ICs is a linear V/dB detector that was used along with a linear dB/V, VCA. This configuration showed an error of the order of 4 dB over a dynamic range of 40 dB. In some cases, the demodulator may tolerate this variation in the input signal level. Otherwise, a small amount of feedback can be used to correct this error in the output level.

An adaptive gain control technique

The base receiver can maintain a record of the RSSI voltage for each uplink slot and can store it in memory. The uplink slot allocation for remotes is done by the base and it knows which remote will transmit next. It can then apply the required control voltage to the VCA just before the burst arrives at base receiver. In a stationary TDMA environment, the fade depth is not severe and the frequency of signal fading is not high compared to the frame time. So, for a particular remote/base uplink, the probability of the received power variation from one frame to the other is small. This is a feedback correction method where the delay between the detection and correction depends on system dynamics such as how frequently a remote transmits, frame length, etc. A small amount of instantaneous feedback is needed to eliminate the amplitude error caused by this delay. The dynamic range of this feedback circuit, however, is small. Toward the end of each remote transmission, the corrected value is updated in the respective memory location.

This technique is superior to the others in the sense that the approximate value of control voltage is known before the burst actually arrives and is, therefore, very fast. Because no remote transmits during the guard band, other techniques have to perform amplitude correction over a larger range, which can only be done after the burst arrives at base.

Thus, we see that amplitude control problems can be solved one way or the other. Because different circuits may suit different situations, a rule of thumb generally never applies in a communication system design. Whatever may be the method adopted for amplitude control, a feedback AGC is inevitable for maintaining the output at an exact IF level. And, if it is possible to sacrifice a bit or two in the beginning of the burst, a simple, but fast, feedback AGC alone may be able to do the job without the complexity of the other techniques discussed earlier.

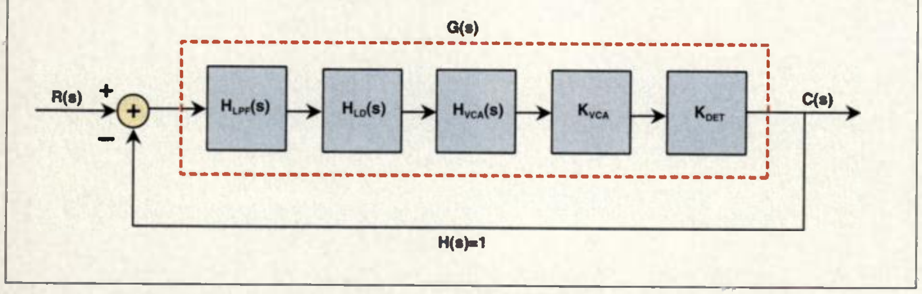

Figure 5. A modified block diagram of the circuit elements for response time limitation analysis.

The design

Control theory analysis cannot be directly applied to the AGC shown in Figure 2, where the input is a modulated IF and the control voltage is a DC signal. It is not possible to define the error signal simply as the difference of these two. Thus, a linearized model is used as shown in Figure 4. The feedback transfer function is unity in this case.

Strictly speaking, feedback control system design is a recursive process of mathematical calculations, Basically it involves four easy steps. [8]

1.) Write the closed-loop transfer function for an acceptable, initially chosen block diagram:

$$\frac{C(s)}{R(s)} = \frac{G(s)}{1 + G(s)H(s)}$$

where C(s) is output, R(s) is input, G(s) is open loop transfer function and H(s) is feedback transfer function. Here, H(s) is unity and the feedback elements are included in G(s).

So:

$$\frac{C(s)}{R(s)} = \frac{G(s)}{1 + G(s)} \quad (1)$$

2.) Define a deterministic test signal R(s). A step function is used to mathematically describe the AGC's quickness to respond to an amplitude step change at the input.

Let the input step amplitude be:

$$r(t)=A$$

Then:

$$R(s) = \frac{A}{s} \quad (2)$$

3.) Find c(t) by taking the inverse Laplace transform of C(s). c(t) explains the time domain behavior of control loop.

4.) Calculate the steady state error, e_{ss}, by applying final value theorem to error signal E(s). This is a measure of accuracy with which the control-loop is able to correct variations in the input signal level (see equation 3, page 56). Following these steps, it is possible to optimize the overall response of con-

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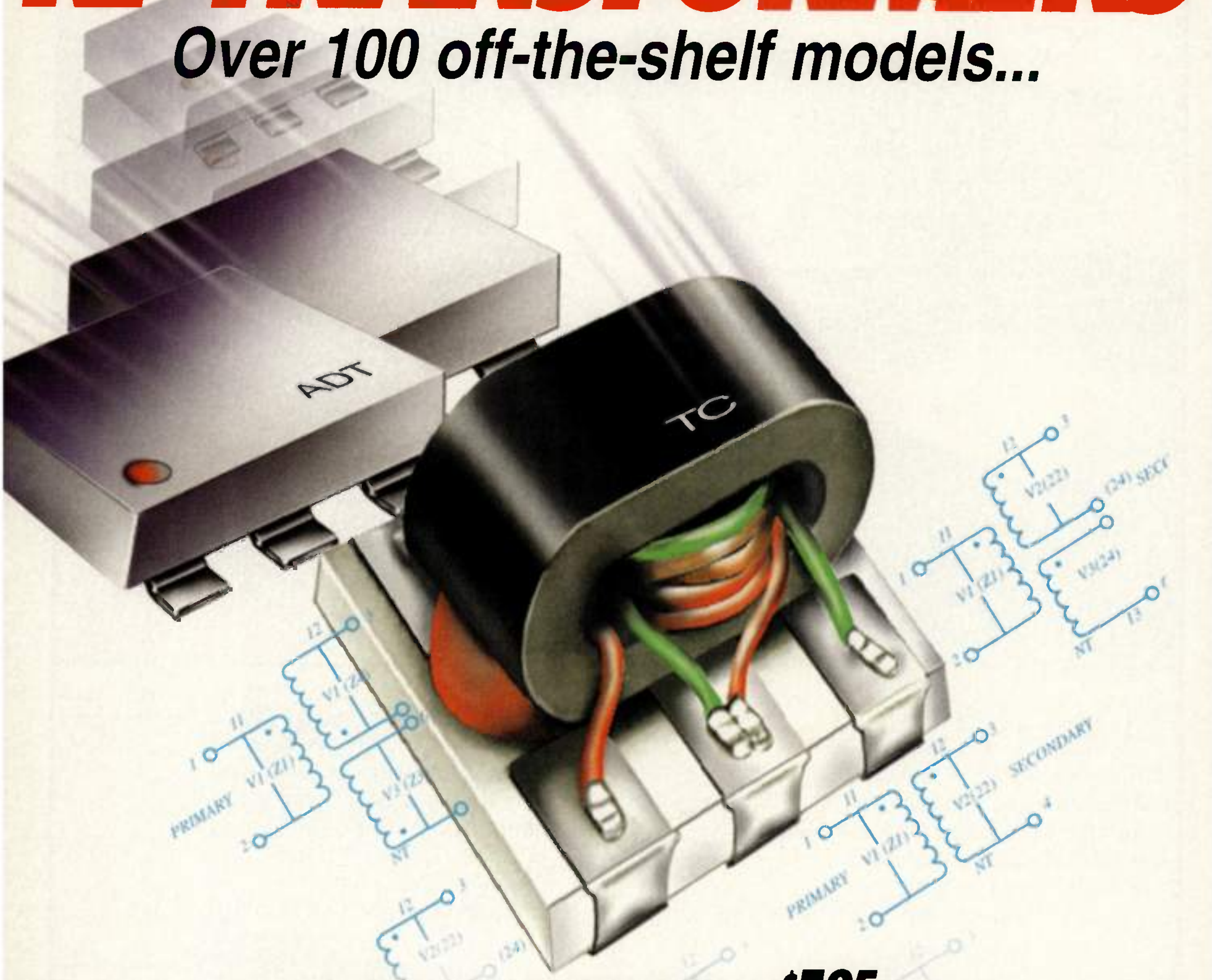

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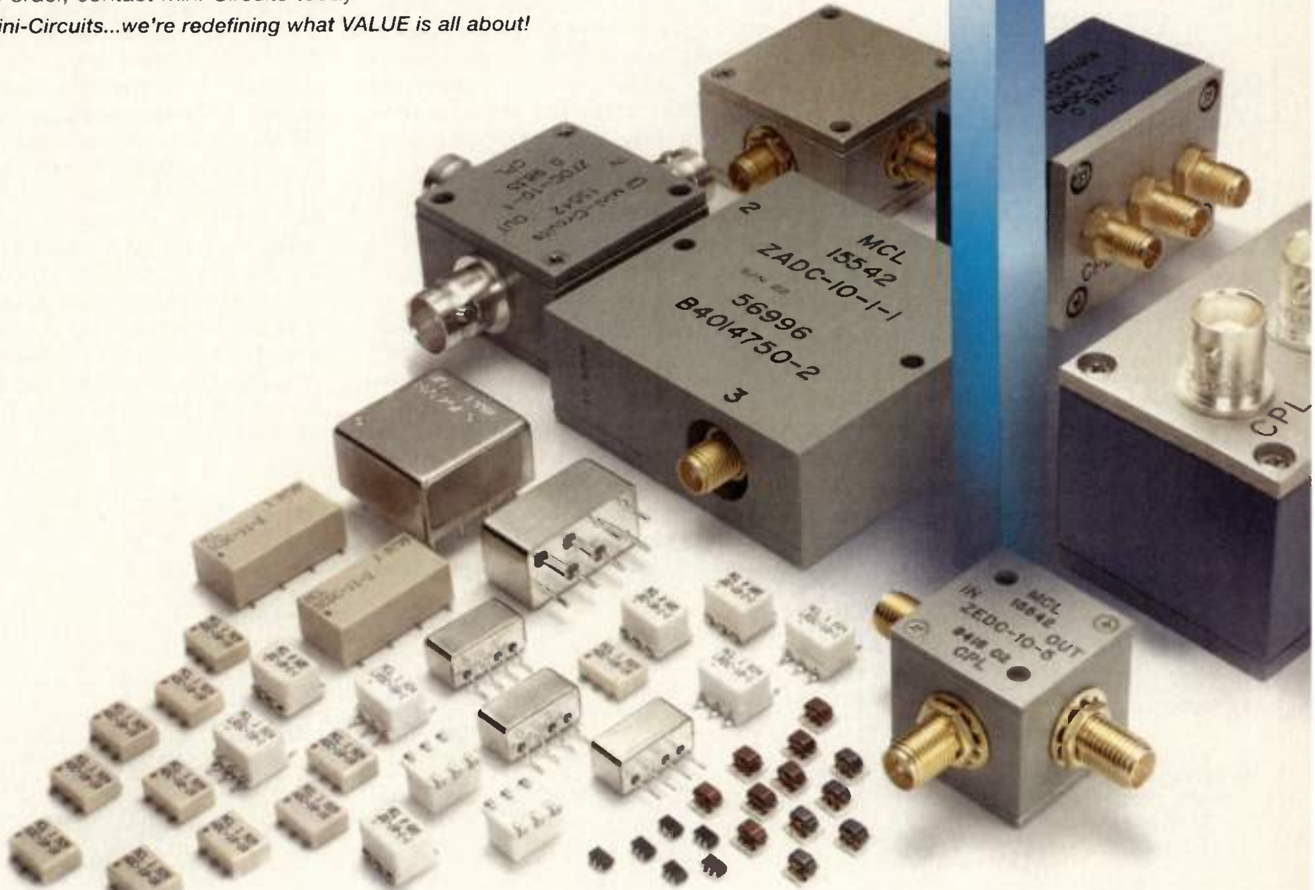

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trol loop by selecting appropriate components.

Figure 5 describes a modified block diagram that takes into account the response time limitations of circuit elements. The open-loop transfer function is given in equation 4 (see page 56). Further, equation 4 terms are defined as follows:

$H_{LPF}(s)$ is the transfer function of the loop filter.
$H_{LD}(s)$ is the transfer function of lead network.
$H_{VCA}(s)$ models the VCA's control interface.
K_{VCA} is the VCA gain, indicating the gain change per unit variation in the control voltage.
K_{DET} is the detector gain, indicating the voltage change per unit variation in input signal power.

The loop filter

Numerous configurations are possible for a loop filter design. These range from a simple RC lowpass section to complex active filters. Active filters give gain, which helps to reduce the steady state error. The transfer function of op-amp integrator shown in Figure 6a is:

$$H_{LPF}(s) = \frac{sR_2C_1 + 1}{sR_1C_1}$$

When the input signal amplitude changes, the detector identifies it and the integrator output ramps up/down, searches and settles at the best point on the control voltage axis where the VCA can give a desired gain to correct the output signal amplitude. This process lasts for a small fraction of time determined by transient response of c(t). For very small response times, the bandwidth of the loop filter has to be high enough. A carefully chosen zero in the filter transfer function improves stability of the control loop while ensuring the required loop bandwidth. The loop filter follows the detector and thus limits the detector performance at threshold if noise performance of op-amp is not good.

The open loop transfer function of the op-amp must be considered when the response time of loop is critical. The DC gain of the op-amp sets a limit on the value of $H_{LPF}(s)$ at s=0, and bandwidth of op-amp sets a limit on the filter bandwidth. Thus, in this type of application, a low-noise op-amp with high gain-bandwidth is needed. Sometimes, the bandwidth limitations of the op-amp can be positively utilized to reject high frequency noise from the detector.

Lead compensation

The op-amps in active loop filters have an output voltage swing much higher than the control voltage range of VCAs. In some cases, it may be required to limit the VCA control voltage within the specified range. One way to do this is to add a resistor in parallel with the feedback RC arm of loop filter. But this will also reduce the DC gain of integrator resulting in steady state error that can be verified by replacing $H_{LPF}(s)$ in equation (7). Another way is to use a resistor divider network at the integrator output. This practice also reduces the loop gain, subsequently increasing the response time. For clarification, a lead network's function is shown in Figure 7. It is:

$$H_{LD}(s) = \frac{sC_2R_3 + 1}{sC_2R_3 + p}$$

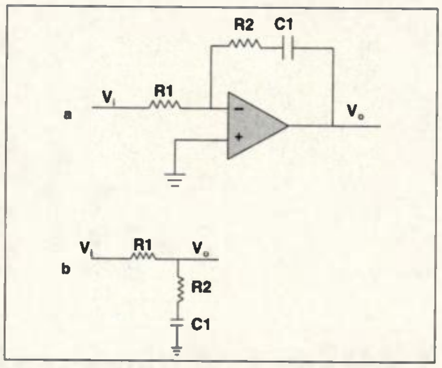

Figure 6a, b. Transfer functions of the op-amp integrator.

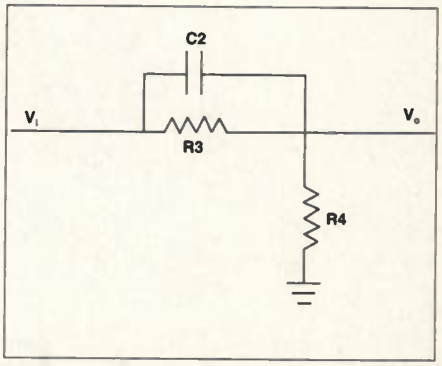

Figure 7. A lead network for limiting the control range.

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Where:

$$p = 1 + \frac{R_3}{R_4}$$

The capacitor C_2 effectively passes the filtered step signals coming from the detector, particularly at the beginning of an uplink burst, and reduces the delay caused by resistors R_3 and R_4.

The VCA

As the heart of an AGC circuit. the VCA must support the required gain range at the desired IF frequency with sufficient bandwidth. The VCA can be either a voltage-controlled amplifier or a voltage-controlled attenuator. Voltage-controlled amplifiers are more advantageous in the sense that the noise figure of the chain is less. Moreover, it is better to give only the required gain to the input signal rather than first amplifying it fully, and then attenuating it as the incoming signal level goes high. This lowers the noise figure and intercept point specifications of fixed amplifiers. For high dynamic range applications, VCAs like the KGF2441 and RF2607 are available with a combination of gain and attenuation on the same gain vs. control voltage curve.

The receiver sensitivity is directly related to the noise figure of the receive chain. The sensitivity, in volts, is given as:

$$\sqrt{\frac{FKTBZS}{N}} \qquad (6)$$

where:

F = noise figure
K = Boltzmann's constant.
T = Temperature in Kelvin
B = IF bandwidth
Z = System impedance
S/N = Required signal-to-noise ratio for specified quality of demodulated output.

The combination of a high-attenuation stage like a surface acoustic wave (SAW) filter and a high-noise figure VCA can cause serious degradation in overall noise figure and, hence, receiver sensitivity.

The noise figure of commonly available fixed IF amplifiers is typically 3 to 4 dB. Noise figures of VCAs can be typically 5 dB to 10 dB. The lowest noise figure is obtained only at maximum gain (or minimum attenuation). Because the input signal level is very low at threshold, it requires the noise figure of the chain to be the minimum possible. At higher input SNRs, it is clear from equation (6) that errorless detection is possible even with a high VCA noise figure.

In continuous transmission systems, control loops can be slow and the VCA response to control voltage is generally much faster than the control loop response. But, in burst communication systems, where the response time requirement of the AGC is critical, the VCA response with respect to its control voltage (control/modulation bandwidth) becomes a limiting factor. Many data sheets specify the VCA response in detail. Sometimes this information is not readily available, particularly if a multiplier or a balanced mixer is used for gain control. It is important to determine the response time of the VCA. For more precise analysis, HVCA(s) should be measured, which sets a limit on the quickness of how a loop responds to a step change. It can be measured experimentally as shown in Figure 8. Let a(t) and b(t) be the IF input and output respectively, and c(t) is the control input to the VCA. The control interface will generally have a low-pass characteristic and c'(t) is assumed to be controlling the gain. Let:

$a(t) = A_c \sin(\omega_c t)$,
$c(t) = A_m \sin(\omega_m t)$,
$\omega_c = 2\pi f_c$,
$\omega_m = 2\pi f_m$,
$\pi = 22/7$

a(t) and c(t) are sinusoids at IF and the lower frequency, respectively. The output signal b(t) appears on the spectrum analyzer as amplitude modulation of a(t) by c(t) and the frequency components seen are:

f_c, $f_c + f_m$, $f_c - f_m$.

As f_m is increased to $f_{m(max)}$, keeping A_m constant, the sidebands are seen moving away from f_c and towards higher values of f_m. Thus, the level of the sidebands are seen as decreasing gradually. $f_{m(max)}$ should be an order of

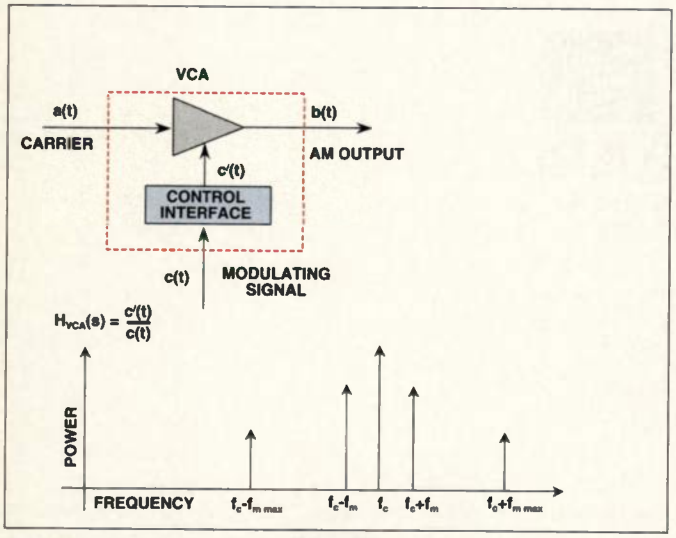

Figure 8. Results of loop measurements.

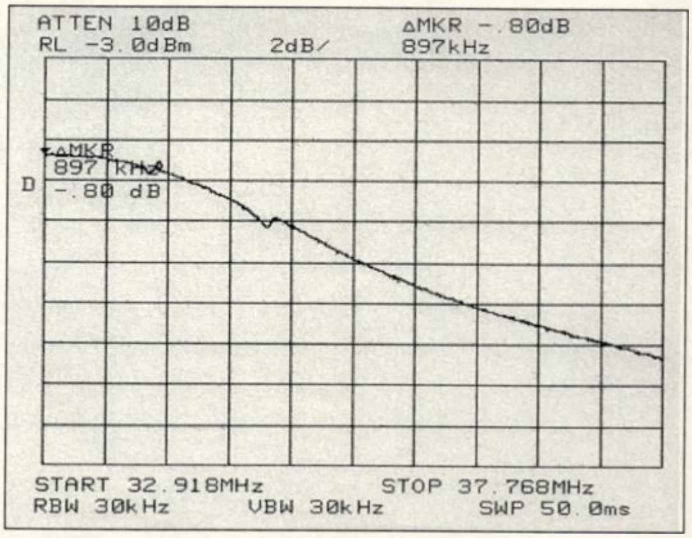

Figure 9. Measurement of control/modulation bandwidth, $H_{VCA(s)}$.

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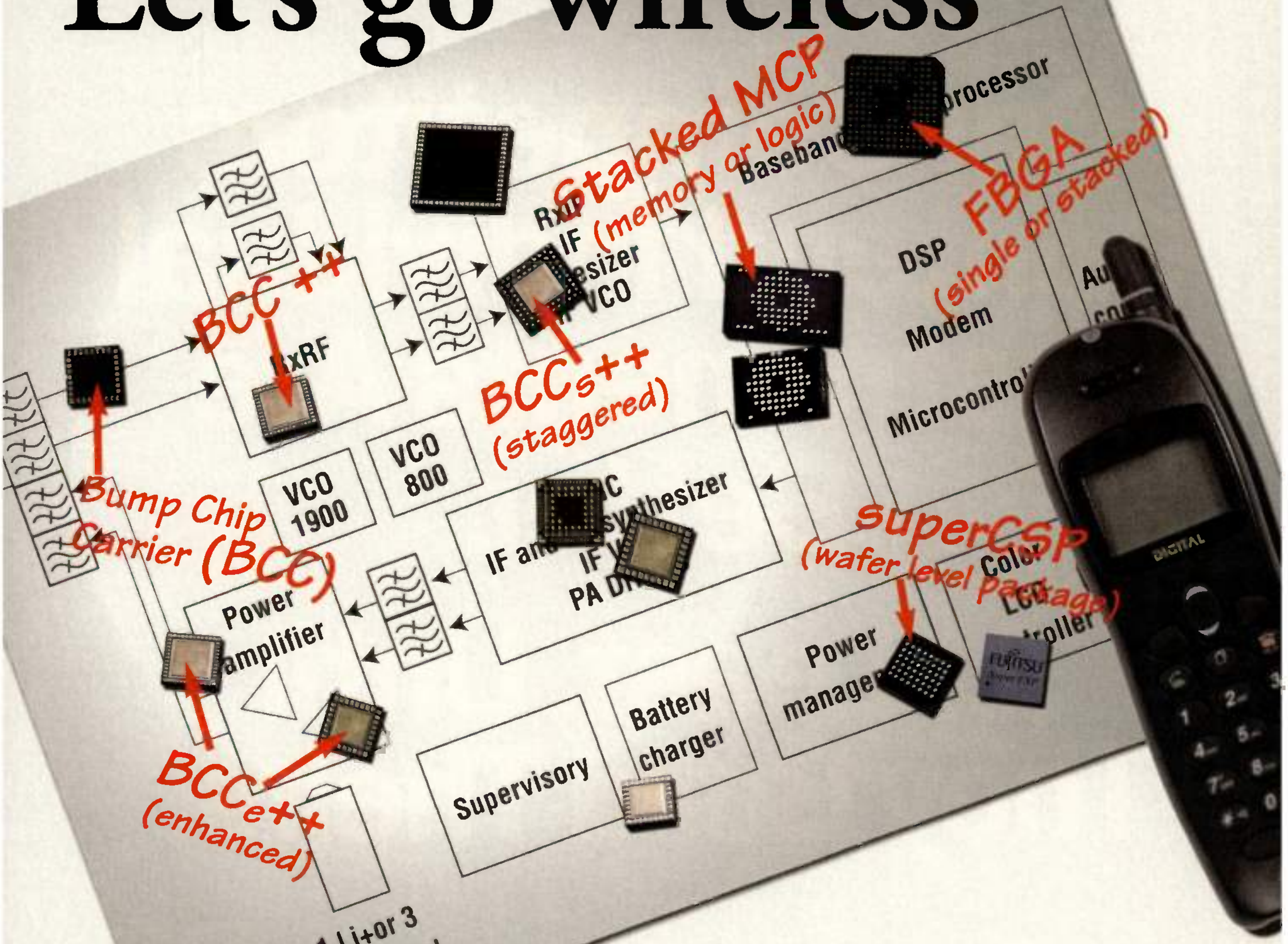

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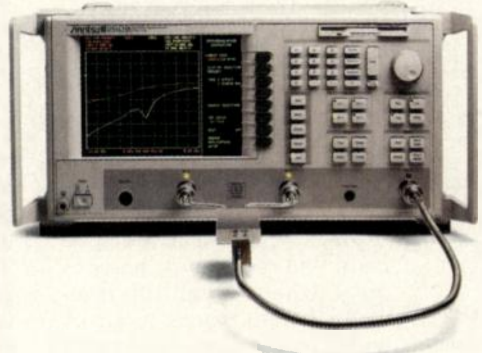

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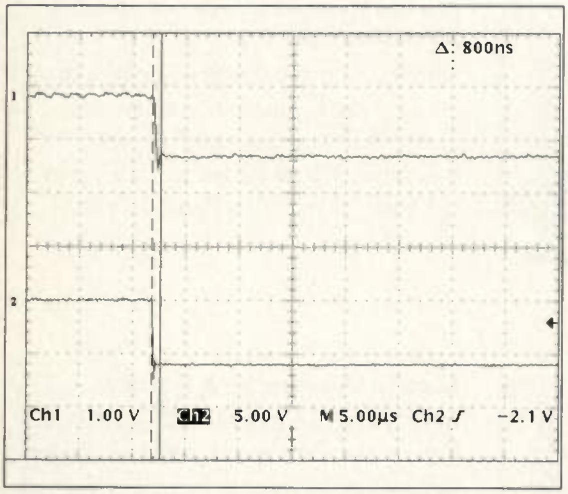

Figure 10a. Loop control voltage vs. modulator switch control voltage.

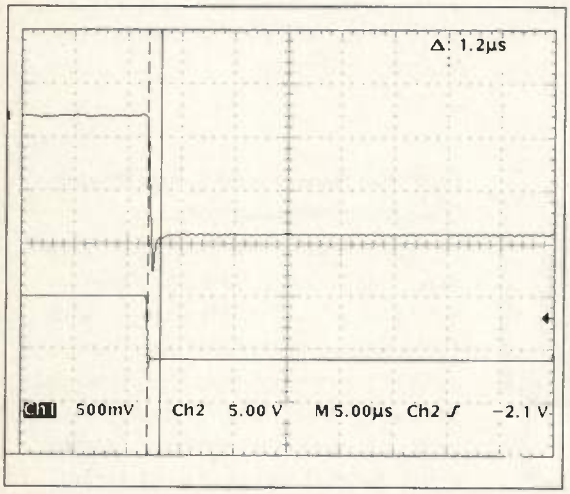

Figure 10b. Loop control voltage vs. modulator switch control voltage–driven at higher levels.

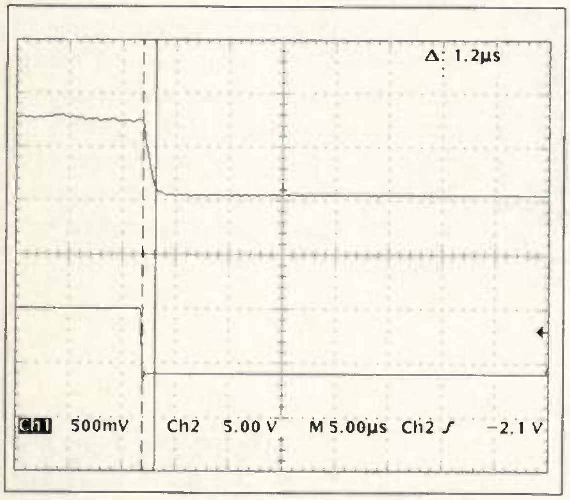

Figure 10c. Loop control voltage vs. modulator switch control voltage–near threshold.

magnitude higher than the inverse of required response time. It is important to mention that the settling time is specified for a percentage of the final value, and it will be higher as the required precision increases. The curve in region f_c to $f_c + f_{m(max)}$ represents HVCA(s) and can be modeled by an RLC circuit for simulation purposes. If this measurement is carried out carefully, the VCA behavior can be approximated with a reasonable accuracy.

The detector

The simplest envelope detector is a half-wave diode rectifier. Schottky diodes with sensitivities as good as –40 dBm are readily available. Some of them can give a DC voltage on the order of 100 mV at an input power level of –10 dBm, even in the absence of biasing. To filter out the AC components, an R-C filter is used at the output. This introduces a finite time delay.

This diode detector conducts only during half of the cycle time and, thus presents a varying impedance at its input. This can affect the main line return loss, particularly, when a high intermediate frequency is used. A buffer at the diode input may be a viable solution. This detection is asynchronous, and its performance degrades at low SNRs. This leads to amplitude error in the output level toward threshold.

Another asynchronous detection method is the use of a squaring circuit. Several high-speed multipliers are available with high input impedance and high operating frequency range. The high input impedance does not load the main line. The output consists of DC equivalent of the input power and AC components at around twice the IF frequency. In this case-filtering can be easily done with a high cut-off low-pass filter (LPF), which has a somewhat shorter delay. In short, this detector is faster than a diode detector because, along with carrier frequency, the noise components are also translated to higher frequencies after squaring. This detector performs slightly better than a diode rectifier at a low SNR. A lower noise floor of the multiplier also ensures better performance at the threshold.

Asynchronous envelope detection is not efficient at low SNRs, and the input compression point of the VCAs is not high (0 dBm being a typical figure). As a result, it is difficult to implement a high dynamic range AGC even when the VCA's gain range is sufficient. Synchronous or post-demodulation envelope detection is a solution, but the circuit is complex and loop delay sets a lower limit on the response time. Taking a look at the closed loop transfer function of the detector in figure 5 yields formula (7) (see page 56).

To achieve a 65 dB dynamic range with a fast response requires a fast VCA. Among the fast VCAs available, one with a gain range of 40 dB for 1 V variation in its differential control voltage was selected. A cascade of two devices with a parallel gain control ensures a much wider control bandwidth. The loop filter op-amp is chosen to operate on +5 V supply and has a +4 V output swing. The lead network resistors R_3 and R_4 were chosen to be of equal value, limiting the swing to +2 V. The permitted common mode control voltage range of VCA is between –1.2 V to +2 V by keeping the negative control terminal V_n within 0 V and +1 V (Flexibility is kept for RSSI tuning as described later.) The loop control voltage is applied to the positive control terminal Vp. Now the transfer function of lead network becomes:

$$H_{LD}(s) = \frac{1 + sC_2R_3}{2 + sC_2R_3} \qquad (8)$$

The modulation bandwidth was measured for the cascade of two VCAs as shown in Figure 9. The response was approximated as:

$$H_{VCA}(s) = \frac{1}{1 + sR_vC_v}$$

Using equations (5), (8) and (9) in equation (7) yields equation (10) (see page 56).

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One way to analyze c(t) is to reduce the right-hand side by partial fractions and then take the inverse Laplace transform. Another way is to simulate the circuit.

A block level simulation can be done for this closed-loop transfer function using Eesoft-Omnisys. By substituting G(s) from equation (4) in equation (3), the steady state error is shown in equation (11) on page 56. It can be seen that steady state error reduces to zero mainly because of the pole at s=0 in $H_{LPF}(s)$. If the loop filter shown in Figure (6a) is replaced by the one shown in Figure (6b) then:

$$H_{LPF}(s) = \frac{1 + sC_1R_2}{1 + s(R_1 + R_2)C_1}$$

No pole at the origin now, and the steady state error is shown in equation (12) on page 56.

This shows that the steady state error in the output varies with input step amplitude. Thus with the varying input levels, the AGC output will also vary but over a small range. From equation (12) it is clear that in the absence of a pole at the origin, the error can only be minimized and not eliminated, and only by making the loop gain high.

The comparator

Before applying the control voltage to the VCA, it is important to compare it with a reference voltage. This determines the direction in which correction is to be applied and the steady state output level of the AGC circuit. This function can be incorporated along with the integrator circuit. A reference voltage, V_{REF} can be applied to the non-inverting input of op-amp. The transfer function of the circuit is found to be:

$$\frac{V_o}{V_i} = (V_{REF} - V_I)\frac{1 + sC_1R_2}{sC_1R_1} + V_{REF} \qquad (13)$$

In this case, that, for the loop to work, V_I and V_{REF} must be of the same polarity.

Loop gain, response time and dynamic range

Transient analysis of the closed loop transfer function shows that the settling time is less when loop gain is sufficiently high. In this circuit, the product $K_{VCA} \times K_{DET}$ is not a constant and varies over the dynamic range. This is because the VCA gain (dB/V) remains constant throughout its dynamic range (linear in dB), while the detector output expressed in V/dB is not a constant over the input range of detector. This manifests itself as a variation in loop gain and, consequently, response time over the dynamic range. As a result, even though the circuit can maintain a constant output with less error over a wider input range, the useful range with short settling times is limited.

Noise in the control loop

The noise can be caused by ripples in the detector output, IF leakage and other active components. Any DC-to-DC converters in the vicinity can also induce considerable noise. Any noise on control voltage can result in unwanted amplitude modulation of IF high gain VCAs, which are more sensitive to control voltage noise because a small change in control voltage can alter the gain significantly. As seen in the process of measuring HVCA(s), the modulation index reduces for higher modulating frequencies. This property helps in filtering out the detector noise (provided that the IF is sufficiently high). A squaring detector output has AC components at twice the IF frequency, which further improves the noise rejection. High frequency noise results in spurii that lie outside the IF bandwidth and can be filtered out. More prominent is the effect of low frequency noise seen as spurii within the IF bandwidth. Because low-pass filtering of control voltage makes the loop slow, extra care should be taken for power supply filtering and the PCB layout, ensuring a proper shielding of the control line.

Based on the above considerations, the devices selected were:

1.) A four-quadrant active multiplier with a fast settling time of around 20 ns for 0.1% full-scale voltage and an adder port to introduce DC offset. Positive detection is implemented by squaring the IF.

2.) An op-amp with a gain-bandwidth of 600 MHz, input voltage and current noise of 2 nV/√Hz and 1.5 pA/√Hz, respectively, and a settling time of 65 ns to 0.1% of full scale value when operated from +5 V supply.

3) A VCA with a high-impedance differential control interface.

The received signal spectrum

The burst signal spectrum consists of the following components.

1.) Quadrature phase-shift keying modulation (intelligence).

2.) Amplitude shift-keying (ASK) modulation due to burst mode switching at the remote transmitters. The spectrum at the base receiver looks like a multilevel ASK modulation of the actual QPSK spectrum because of random sep-

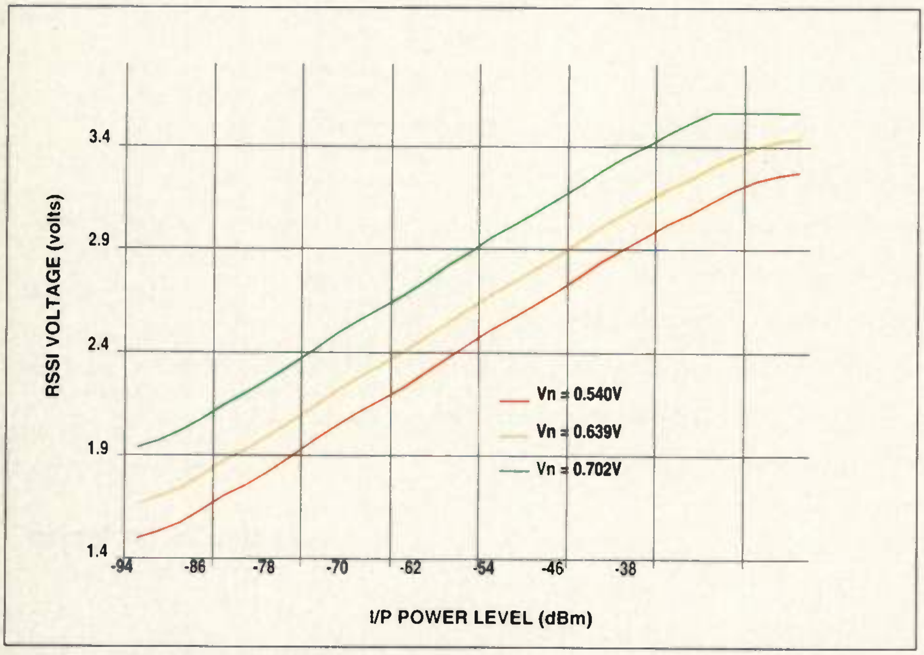

Figure 11. RSSI tuning for three different settings of V_n.

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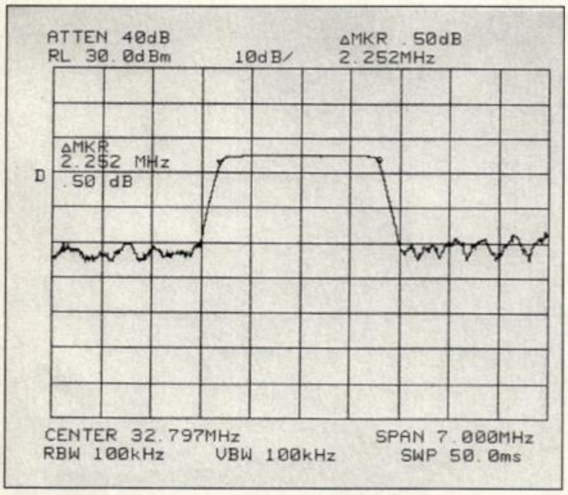

Figure 12a. IF bandwidth measured with control loop enabled.

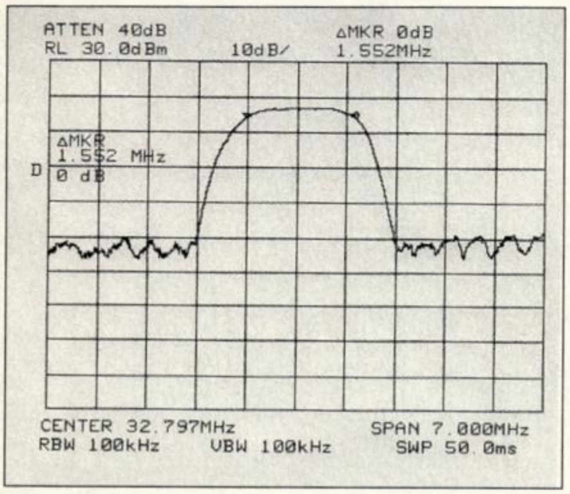

Figure 12b. IF bandwidth measured with control loop disabled.

RF i/p (dBm)	RF o/p (dBm)
-98	4.17
-97	4.33
-96	4.33
-95	4.50
-94	4.67
-93	4.67
-92	4.67
-91	4.83
~	~
-74	5.00
~	~
-30	5.00

Table 1.

arations of remotes from the base. So, frequency domain measurement of received signal at the base, does not give any qualitative information.

3.) Amplitude modulation by multipath fading, the effect of which can be neglected here because of extremely slow amplitude variations compared to the correction speed of AGC.

These factors decide the measurement methods to be used for testing the circuit. The response time measurement is done by feeding an IF burst. This step is done with the help of a switch similar to the one used in the remote transmit chain. The control voltage of this switch and that of the VCA are monitored together on the oscilloscope (See Figure 10a.) Variation of response times over the operating range (as explained earlier), can be observed by introducing a variable attenuation at the IF input to the AGC. It is seen in that at higher levels, the gain is very high and the control voltage overshoots before settling (See Figure 10b.) Towards threshold, the response is rather damped (See Figure 10c.)

Dynamic range and RSSI

The dynamic range measurements are done with a single-tone continuous signal. This AGC circuit has been integrated with an L–band downconverter. The variations in IF o/p level vs. RF i/p level is given in Table 1.

Received signal strength indication is necessary for power control purposes such as monitoring the link health, and should be provided by the downconverter. The signal level detection at IF is much easier than at RF. One method is to tap the main stream IF signal and apply to an envelope detector. Another is to tap the loop control voltage if an AGC is used.

An advantage of the second method is that the stabilized loop control voltage directly reflects the VCA characteristics and is independent of the detector. Thus, use of a linear (in dB) VCA gives an RSSI voltage that varies linearly with input signal variation (in dB) and can be easily processed by baseband circuits. In burst communication systems, the RSSI is generally sampled in the middle of an uplink time slot after the loop control voltage has settled to its final value.

While tapping the AGC loop control voltage, care should be taken not to disturb the normal functioning of the control loop. In this circuit, a non-inverting op-amp buffer was used for the purpose. The response time of this op-amp determines how fast the RSSI information becomes available.

The downconverter gain can vary from piece to piece by 1 to 2 dB, which results in a shift in the RSSI curve. The use of VCA with a differential control helps to tune out this offset. This circuit used only one terminal (V_p) of differential control interface for control action, while the other (V_n) was tied to a DC voltage set by a potentiometer. The RSSI tuning is shown in Figure 11 for different settings of V_n.

Noise figure and IF bandwidth

The parameters of the downconverter can be measured only when the AGC circuit is disabled and the VCA gain is at maximum.

In most of the non-coherent AGC circuits, as the threshold is approached output levels start reducing as the i/p level is reduced further. Up to a certain point, this reduction is not proportional and is mainly caused by the tracking limitations of the circuit (detector) and not because the loop is out of lock. Though this region of operation is of little use from the system's point of view, the control loop is still active and VCA does not operate at its maximum gain.

The noise power used by the test instrument can be comparable to the threshold power and be well within the AGC input range. Thus a correct noise figure measurement of the chain requires the feedback loop to be forcibly disabled and the VCA be put in maximum gain (or minimum attenuation in case of a voltage controlled attenuator). The bandwidth test is sometimes necessary to verify the downconverter/demodulator interface. This single tone measurement is done by time-sweeping the input RF frequency.

Because the adjacent channel rejection of the IF filter is typically around 40 dB. The AGC circuit, having a comparatively wider bandwidth and a large dynamic range, will try to correct the level variations in time domain. Hence, the frequency response of IF filter will

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$$e_{ss_{(t\to\infty)}} = \text{Lt. } e(t)_{(s\to 0)} = \text{Lt. } sE(s) = \text{Lt.}_{(s\to 0)} \frac{s.\ R(s)}{1+G(s)} = \text{Lt.}_{s\to 0} \frac{A}{1+G(s)} \quad (3)$$

$$G(s) = H_{LPF}(s) \bullet H_{LD}(s) \bullet H_{VCA}(s) \bullet K_{VCA}(s) \bullet K_{DET} \quad (4)$$

$$\frac{C(s)}{R(s)} = \frac{H_{LPF}(s) \bullet H_{LD}(s) \bullet H_{VCA}(s) \bullet K_{VCA}(s) \bullet K_{DET}}{1+G(s) = H_{LPF}(s) \bullet H_{LD}(s) \bullet H_{VCA}(s) \bullet K_{VCA}(s) \bullet K_{DET}} \quad (7)$$

$$C(s) = \frac{\left(\frac{A}{S}\right)(1+sC_1R_2)(1+sC_2R_3)K_{VCA}K_{DET}}{sC_1R_1(2+sC_2R_3)(1+sR_VC_V)+(1+sC_1R_2)(1+sC_2R_3)K_{VCA}K_{DET}} \quad (10)$$

$$\text{Lt. } e(t)_{(t\to\infty)} = \text{Lt.}_{(s\to 0)} \frac{AsC_1R_1(2+sC_2R_3)(1+sC_VR_V)}{sC_1R_1(2+sC_2R_3)(1+sC_VR_V)+(1+sC_1R_2)(1+sC_2R_3)K_{VCA}K_{DET}} = 0 \quad (11)$$

$$\text{Lt.}_{(s\to 0)} \frac{A(1+sC_1R_1+sC_1R_2)(2+sC_2R_3)(1+sC_VR_V)}{(1+sC_1R_1+sC_1R_2)(2+sC_2R_3)(1+sC_VR_V)+(1+sC_1R_2)(1+sC_2R_3)K_{VCA}K_{DET}} = \frac{2A}{2+K_{VCA}K_{DET}} \quad (12)$$

look flatter than it actually is. One solution is to reduce the input power to a level well below the threshold, where the control loop is out of lock. At such low input levels, it is difficult to measure the filter rejection, so disabling the loop is the solution (The VCA should give maximum gain.)

A correct noise figure and bandwidth measurement also requires that saturation of the final IF stages be avoided, particularly when this type of testing is required at the IF port. Devices with sufficiently high intercept points should be used in final IF amplifier stages.

To switch to maximum gain mode, a –ve DC voltage, V_{TEST}, of around 0.5 V is added to the loop through the adder port of the multiplier IC. When the loop is disabled, the IF input signal should be kept small enough to protect the final I.F stages. As long as $|V_{TEST}| > |V_{DET}|$, (where V_{DET} is the detector output voltage for a given IF signal level used for testing), the feedback loop remains disabled, the loop-filter op-amp remains in saturation at +ve rail and the VCA is at maximum gain. The noise figure of the downconverter was measured to be less than 2.5 dB. The IF bandwidth measured with AGC enabled and disabled is given in Figures 12a and 12b respectively. The measurement error can be clearly observed.

The IF output level can be easily varied by + 1 dB by tuning V_{REF} input to the loop filter without affecting the response time or any other circuit parameters.

Conclusion

An AGC circuit was designed for a burst receiver and response time related issues were stressed. This design is suitable for commercial applications based on TDMA or time-division duplex (TDD) schemes that employ phase modulation. Measurement procedures for evaluating the performance of a feedback AGC were discussed. The discussion provides a deep insight into the circuit dynamics and supports an effective design of almost any type of feedback AGC for communication systems.

RF

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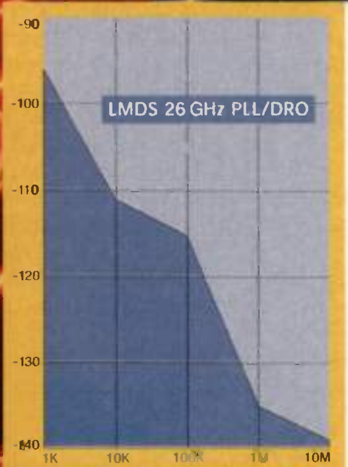

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3G: Deciphering the future of wireless

Are the next generation of handsets destined to be just an Internet interface?

By Ernest Worthman,
technology editor

One thing nice about an event such as a millennium is that it is "leverageable." 1999 saw virtually every cellular player and many related (3COM for example) industry players attempt to use the changing of the guard as a milestone to what we would be using as communicators of the 21st century. The last few years of the 20th century have touted the imminence of third-generation (3G) phones and all of the services they will have to offer. Forecasters said that the next century will bring about technological changes, the likes of which most of us can only image.

Now that the 21st century is officially here, it looks like 3G may not have the face that it originally started out with, or be what it was originally envisioned to be. It's not for lack of technology, however. It's being carried along, as are many other technologies, by the momentum of the Internet. One need only look at the graphical user interfaces (GUI)of the current generation of phones to see their resemblance to the famous (or infamous, depending on which side you stand) Microsoft Windows GUI.

History is full of great products that died on the vine because they didn't find the favor of the consumer. This happens for a number of reasons, but in this case it seems simply to be the momentum of the "net wave." It is economic suicide to try and circumvent this bandwagon, especially as the Internet drives to become the universal gateway to all types of communications.

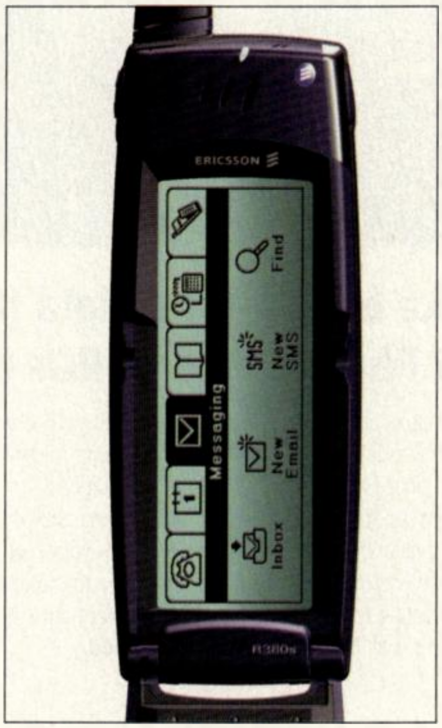
And it does make sense. As I have often said, the computer and the communicator will soon be one. One might ask if there is logic in trying to make 3G phones with dedicated or proprietary e-mail services if the user is accustomed to getting their e-mail over the familiar Internet interface? And do users really want a proprietary and expensive video format if they are used to sending and receiving Internet video and stills? The Internet may, indeed, be the ultimate peacemaker.

The present

Today's second generation phone standards vary all over the map (literally), based upon country or region. Current 2G and has three basic technologies to contend with: Groupe Spécial Mobile (also called Global Standard for Mobile communication) in Europe; Personal Digital Cellular (PDC) in Japan; and analog cellular/personal communications systems (PCS) in the United States. Of that, there are additional technologies that make up many of these parent systems.

For example, the U.S systems are both time-division multiple access and code-division multiple access. (TDMA and CDMA). Furthermore, each region is proposing their own migration path to 3G. Proposals for the standard include:

US—CDMA2000, UWV-136, WIMS, WCDMA
Japan—WCDMA
Korea—CDAM-1, CDMA-2
Europe—EP-DECT, WCDMA
China—TD-SCDMA



Multiple functionality is the first step to the inevitable link to the Internet. 2.5G digital-based phones incorporate voice, messaging, and stress interoperability.

2.5G—the intermediate step

If you go back a few years, there was a great deal of chest thumping as to who was going to be first with what. Yet as the millennium turns, there is not a single 3G phone available. And the first of the finish lines is now less that one year away.

As a result, the road to 3G is littered with patchwork technologies thrown into the ring on an ad-hoc basis. These are implemented mostly to provide the digital voice and data platform that was promised with 2G, but they also provide bridging technologies to maintain compatibility with older analog technology—which, by the way, hasn't become obsolete as quickly as everyone thought.

However, one should not diminish the potential of these technologies. Referred to as 2.5G, some of them are indeed impressive. As stand-alone technologies designed for the different platforms, these technologies (see Figure 2 for platform support) can, theoretically, deliver some hefty data rates. And, these are the enabling portals that deliver the array of features offered in today's mobile communications devices. Technologies such as high-speed circuit switched data (HSCDS), general packet radio services (GPRS), enhanced data rates for GSM (EDGE), as well as enhanced versions of TDMA (IS-136+ and IS-136HS), CDMA (IS-95B) and the universal wireless communications consortium (UWCC), a platform to support TDMA technology (Why?) are all means to the 3G end. Additionally, the patron saint of the current Internet protocols—IP routing and flexible modulation schemes are also a part of this 2.5G stage.

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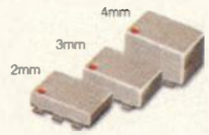

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ADE-1	4	0.5-500	+7	5.0	55••	15	1.99
ADE-1ASK	3	2-600	+7	5.3	50••	16	3.95
ADE-2ASK	3	1-1000	+7	5.4	45••	12	4.25
ADE-12	2	50-1000	+7	7.0	35	17	2.95
ADE-4	3	200-1000	+7	6.8	53**	15	4.25
ADE-14	2	800-1000	+7	7.4	32	17	3.25
ADE-901	3	800-1000	+7	5.9	32	13	2.95
ADE-5	3	5-1500	+7	6.6	40••	15	3.45
ADE-13	2	50-1600	+7	8.1	40••	11	3.10
ADE-20	3	1500-2000	+7	5.4	31	14	4.95
ADE-18	3	1700-2500	+7	4.9	27	10	3.45
ADE-3GL	2	2100-2600	+7	6.0	34	17	4.95
ADE-3G	3	2300-2700	+7	5.6	36	13	3.45
ADE-30	3	200-3000	+7	4.5	35	14	6.95
ADE-32	3	2500-3200	+7	5.4	29	15	6.95
ADE-35	3	1600-3500	+7	6.3	25	11	4.95
ADE-18W	3	1750-3500	+7	5.4	33	11	3.95
ADE-30W	3	300-4000	+7	6.8	35	12	8.95
ADE-1LH	4	0.5-500	+10	5.0	55••	15	2.99
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ADE-1MHW	4	0.5-600	+13	5.2	53••	17	6.45
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ADE-35MH	3	5-3500	+13	6.9	33••	18	9.95
ADE-42MH	3	5-4200	+13	7.5	29••	17	14.95
ADE-1H	4	0.5-500	+17	5.3	52••	23	4.95
ADE-10H	3	400-1000	+17	7.0	39	30	7.95
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It is unlikely that any one of these platforms or enabling technologies will emerge the clear winner. Rather, the IMT-2000 platform will be a common set of interfaces that will accommodate the 3G technologies such as wide and ultra-wide CDMA as well as UWC-136 and cdma2000 (Qualcomm's proprietary technology). For a more detailed description of some of these interim or transition technologies, see Figure 3.

The standards

Perhaps the most looming of all issues that 3G players will have to contend with will be the final standards. There is currently a great deal of posturing going on within the 3G (now formally called IMT-2000 by the International Telecommunications Union {ITU}) camp. There are deadlines looming on the horizon that need to be met. The Internet, however, is forcing the 3G community to move away from the traditional squabbling that occurs with multiple-players and multiple-agendas. To stay the course would mean we are back where we started with the current 2G standard maze.

IS-95B—64kbp/s data rate (combines code channels).

EDGE—384kbp/s, modified 8PSK modulation scheme.

GPRS—115 to 160 kbp/s data rates sharing time slots, supports new packet network elements on the current voice infrastructure. Also calls for better communal resource management.

UWCC—Support for IS-36+ at 43.2 kbp/s and IS-136HS at 384 kbp/s and 2 Mbp/s data rates.

HSCSD—Support for circuit switched data on the existing infrastructure using 4 time slots to provide up to 57.6 kbp/s data rates.

Figure 2. What 2.5G digital platforms support.

cdma2000—provides backward compatibility with IS-95, uses direct sequence spread spectrum (DSSS), provides one carrier with data rates up to 3.688 Mbp/s and multiple carriers with data rates up to 1.288 Mbp/s.

ultra w-cdma—also uses DSSS, provides backward compatibility with universal mobile telephone systems (UMTS) and provides 4 Mbp/s, 8 Mbp/s and 16 Mbp/s data rates.

ARIB w-cdma—same as ultra w-cdma.

UWC-136—provides compatibility with advanced mobile phone service (AMPS), IS-54, IS-136, GSM, and TDMA. Provides data rates from 48 kbp/s to just over 5 Mbp/s.

Figure 3. What 2.5G technologies provide.

IMT-2000

As I had mentioned earlier, rather than try to develop a specific set of standards that is sure to set off a new round of posturing and positioning by the major players, the ITU has taken what seems to be much more logical approach to a 3G interoperability platform. IMT-2000, is supposed to develop a set of standards that will allow seamless worldwide roaming and provide the platform for the digital-based technologies to flourish—not define the standard, but define the playing field. IMT-2000's intent is not to define a technological standard, but to define an interoperability standard. But the momentum of the Internet over the last two to three years is hard to ignore and it has become a platform to reckon with.

So the ITU has had to make somewhat of a paradigm shift. And this shift is reflected in its latest direction.

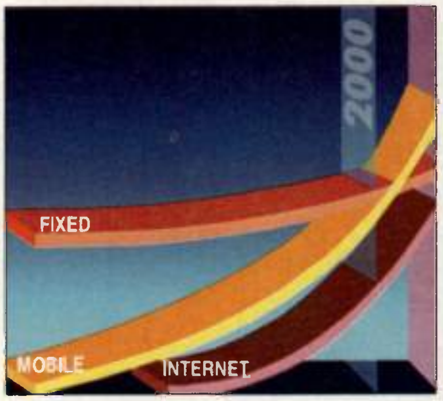
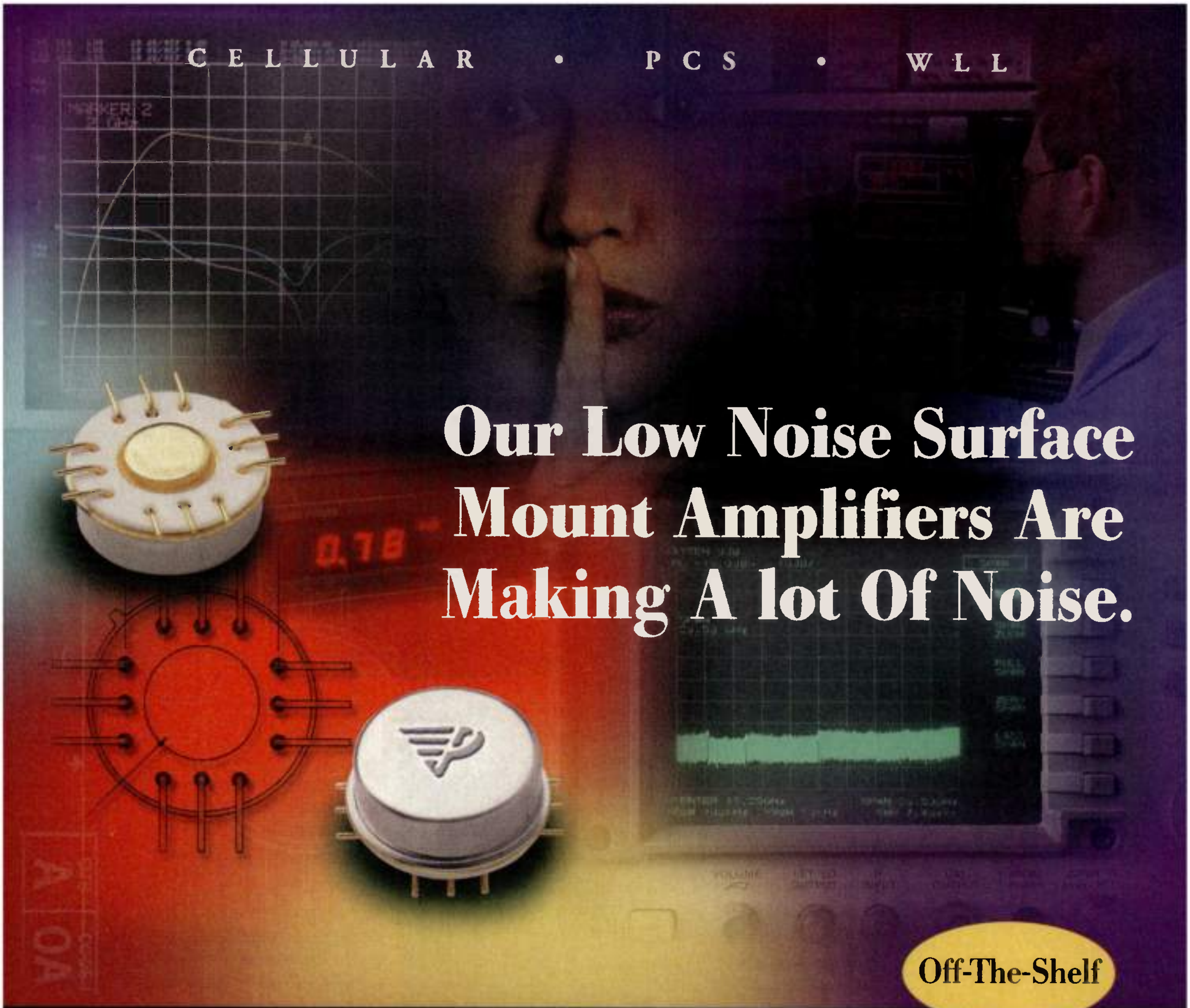


Figure 4. The IMT-2000 third generation mobile standard enables mobile users to harness the full power of the Internet through efficient high-speed radio transmission, optimized for multimedia communications (courtesy ITU).

The specification that the ITU is grappling with concerns issues such as supporting networks, signalling protocols, security requirements, functional modeling and end-to-end seamless voice, data, and video. Currently the following have been established by the ITU to bring end-to-end connectivity to the mobile infrastructure. They have been identified as the following ITU-T recommendations:

- *Q.1521* Requirements on underlying networks and signalling protocols to support universal personal telecommunication (UPT). This recommendation deals with the requirements on supporting networks and signalling protocols for the support of UPT Service Set 1. UPT is a personal mobility telecommunications service wherein a subscriber/user can register at a terminal on any connected network and be provided with UPT service at that terminal location. This applies whether the terminal is fixed (wireline) or mobile (wireless), and independent of the type of network serving the terminal.
- *Q.1531* UPT security requirements for Service Set 1. This recommendation specifies UPT security requirements.
- *Q.1542* UPT stage 2 for service set 1 on capability set (CS2) covers procedures for universal personal telecom-



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Reverse Isolation (dB.)	42	38	38
Pout @ 1 dB. compression (dBm.)	+20.0	+18.0	+18.0
IP3 (dBm.)	+30.0	+29.0	+29.0
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munication functional modeling and information flows.

• *Q.1721* Information flows for IMT-2000, Capability Set 1 (CS-1). This recommendation specifies stage 2 information flow procedures for the support of end-to-end inter-family and inter-system IMT-2000 CS-1 services and network capabilities.

• *Q.1731* Radio-technology independent requirements for IMT-2000 Layer 2 Radio Interface. The scope of this recommendation is the definition of common services, functions and primitives for the radio technology independent parts of the Layer 2 of the IMT-2000 radio interface, to ensure maximum commonality between IMT-2000 networks.

• *Q.1751* Internetwork signalling requirements for IMT-2000 CS-1. This recommendation contains signalling requirements for the network to network interface protocol (NNI).

Other issues

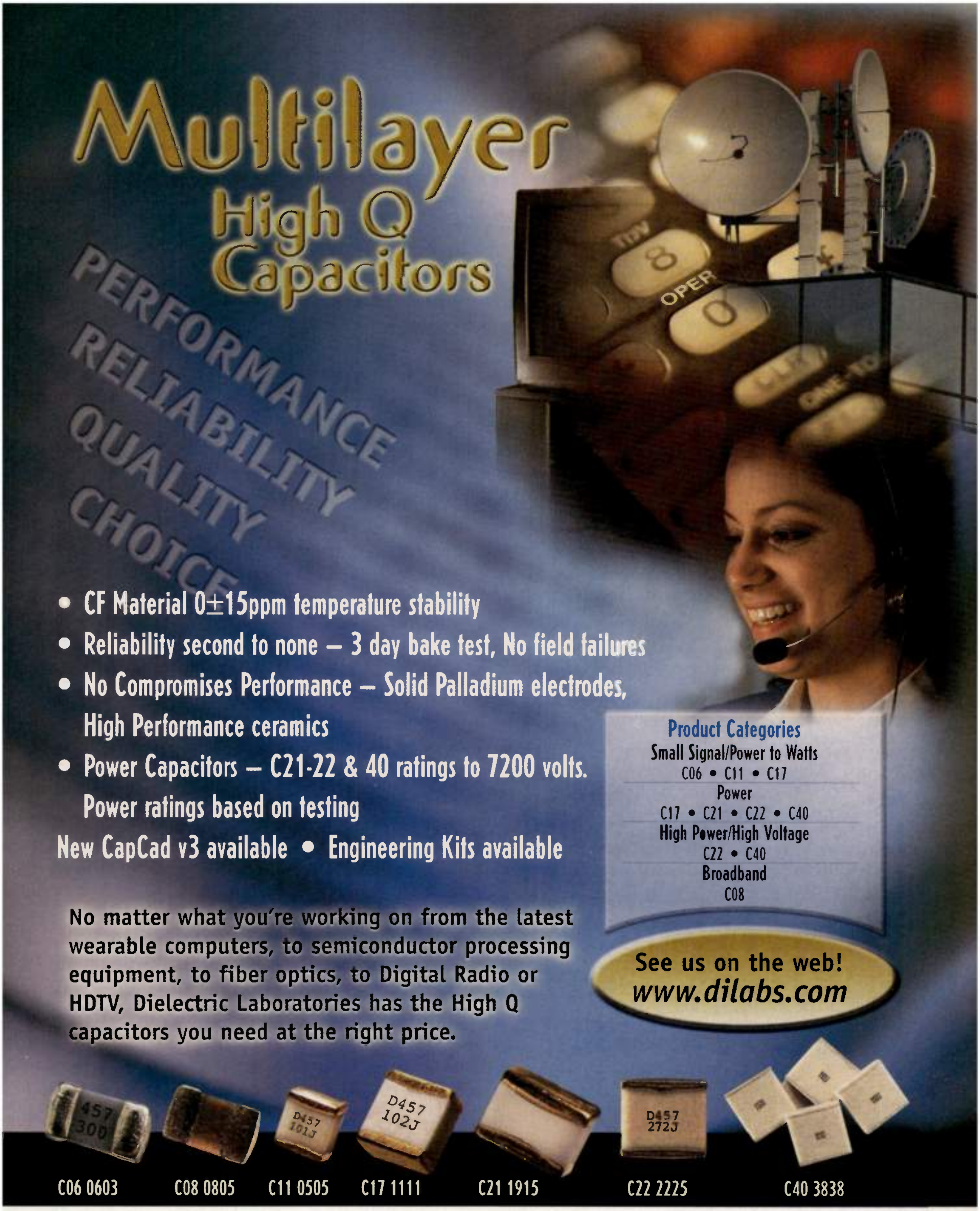
These requirements only deal with interoperability within the network. There are still the issues of terrestrial/satellite interfaces as well. To deal with these issues there is also a set of interfaces that the ITU may make the IMT-2000 standard. These consist of IMT-DS (direct spread), IMT-MC (multicarrier), IMT-TC (time code), IMT-SC (single carrier) and IMT-FT (frequency time). These interfaces will allow the various low, medium and geosynchronous (LEO, MEO, GEO) satellite systems to interface with terrestrial systems and support CDMA, TDMA and FDMA. Furthermore, these standards, platforms and technologies will be able to integrate with Internet Protocol standards to provide the proverbial anywhere/anytime goal.

If all goes well, under what the ITU calls their "fast-track approval" procedure, it is expected that these recommendations should become the standard by mid-2000. However, even if all of this comes to pass with minimal political infighting, there still remains the usual issues of the state of each regions physical infrastructure, governmental control and private industry politics. But it would be nice to have, at least, a common platform for all to develop upon.

And to be fair, there are some promising signs that 3G is gathering momentum. In late 1999, eight of the major carriers met in London to discuss some of these issues. They signed a "contract" to form the joint initiative towards mobile media (JIMM). The players include T-Mobile of Germany, AT&T wireless services, France Telecom, NTT Mobile Communications Network, Singapore Telecom Mobile, SK Telecom of Korea, British Telecommunications and Vodaphone Airtouch.

It's nice that organizations like the ITU and the above mentioned carriers, and the rest of the industry seems to understand that this is the coming thing. But it is the technology (or lack of) as well, that shares responsibility for the setting the pace.

At any rate, technology is moving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along, and not wanting to have to wait until all of the world is in step, 3G technology is marching to its own drummer.

What the chips say

While the 3G standards have been struggling to find the platform that all can live with, chip makers have been working to "get the millions of instructions per second (MIPS) cranking." This is no easy task. The requirements for real-time multimedia are demanding. W-CDMA, which is likely to become the platform, places stiff demands upon digital signal processors (DSPs). And they have to handle bridging the current GSM and other technologies (FDMA, TDMA) and hybrids (combinations of FDMA, TDMA and CDMA) that still exist . It is only recently that such processing power has reached the desktop PC. And it is still lacking. I challenge anyone to say that the current Internet infrastructure can provide the bandwidth for unbuffered, real-time, full-frame audio and video. To wit, there was a remote video interview on CNN last December 31st, with a famous scientist. As I was watching the broadcast, the video was terrible. The picture was jerky and even stopped moving from time to time. The issue is that if the big-buck guys like CNN are willing to put such poor video on the air, imagine what technological challenges lie ahead for the wireless industry, who had to contend with smaller, lighter and more feature rich devices, on even less bandwidth.

However, if technological challenges were the only challenges, it could be met head on with tenacity. But in this case, chip makers face a second stiff challenge—the lack of a unifying 3G standard as well.

3G phones will require processing power twice that of current GSM phones. This heavy processing rate still can't be handled by today DSPs, even with the logarithmic developmental advances made in the past few years. This leads to peripheral designs and support circuits that can offload some of the DSP's functions. Today's devices cannot handle the front-end correlator and detector functions, and video is still the biggest headache.

Further, not everything can be handled in software. Current schemes call for a separate CODEC to offload the video processing and hardware coded processor to handle Vertibi decoding, despreading and other basic and redundant tasks. This approach, however, places pressure on the manufacturers in terms of board real estate and power conservation (3G phones are expected to increase power consumption by 60% over today's digital phones). The current thinking is to hold power consumption and board real estate to the present device footprint.

Other approaches being considered are different rates for upstream and downstream data speeds. The uplink can be slower than the downlink (as is the case with some of the current Internet connect schemes) based upon the thinking that users will upload a query, but download data. But, this could be a can of worms, especially if two-way video becomes a feature the user likes.

So, development on next generation ASICs has begun. Because there isn't a uniform standard as of yet, ASIC development is being focused on programmability. Designs based upon reduced instruction set computing (RISC) promise 300,000 to 500,000 gate densities of laser-programmable gate array logic for front-end, mixed-signal and the digital baseband. Such devices allow for laser-cutting of custom defined logic, allowing a great deal of programming latitude. Work is also progressing on designing dual-mode chipsets that integrate a RISC processor, a DSP and a 16/32-bit microcontroller

One of the major issues that comes with the development of multifunction, high speed logic is the need for data management, and hence, storage. Not only will there need to be a need for a reasonable amount of memory, but it needs to be fast. Dual ported random access memory (RAM) is the current front runner because it is fairly fast and inexpensive. Designing this type of integrated chip isn't that easy. Again, power, real estate and data storage are the driving factors.

Furthermore, just developing chips to handle the current demands isn't the goal. Since it is likely that phones will be out before the standard is inked, chip designers are striving to grab as much extra headroom as they can get. Developers are worried that short-sighted design will force a rapid, and costly, change in device redesign within the next year or two. For example, certain protocols like handoffs, higher data rates, multiple duplex modes, power control and complex cell searches, will surely require additional overhead.

Finally, the two likely candidates for the transmission standard, time-division duplexing (TDD) and frequency-division duplexing (FDD) are fundamentally different. TDD uses only one wide frequency for both up and downlink, while FDD uses two separate, but narrower frequencies—they are not compatible.

So what about the Internet connection

It it still unclear what the interface between 3G and the Internet will be. There are major players getting behind it. There has been talk that Windows CE, the mini-OS from Microsoft designed to run on CE terminals could be the software interface. Also, there is discussion about 3G phones loosing the traditional phone profile. That is already evidenced by the larger screens and keyboards of today's latest generation 2G phones and 3G concept models. It is even probable that 3G phones will have a range of form factors, from the "Dick Tracy" wristwatch design to palm-pilot types to videophones and radio modem cards.

It seems almost guaranteed that the pervasive platform of services such as video on demand, high speed multimedia, e-commerce and mobile Internet connectivity, being envisioned by the 3G players, will migrate to the Internet. The IP-based network is currently the vehicle of choice for 3G transmission protocols. It means we will be on-line, anytime, anywhere.

Given that most of the world is Internet-enabled and the computer industry absorbed the learning curve shock, it makes a lot of sense. By 2005 expect to see over one billion user inextricably linked to the information infrastructure. Also, 3G is being touted as the enabling technology that will finally bridge the gap between wireless connectivity and desktop platforms. It may well be the stage that plays the final act and connects the portable computer with the portable phone, and breeds a new generation of portable communications devices and users. **RF**

(I wish to thank Qualcomm, Ericsson and Motorola for supplying the mobile phone models for the cover.)

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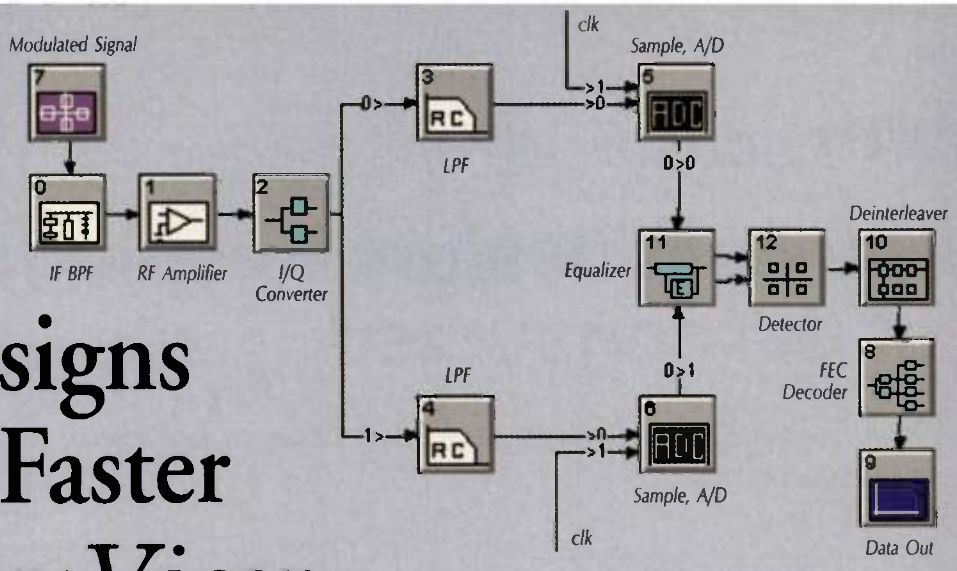

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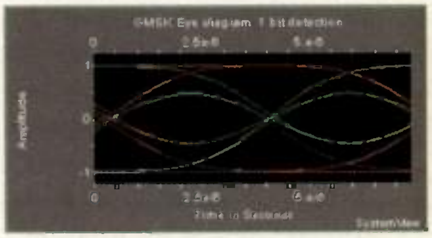

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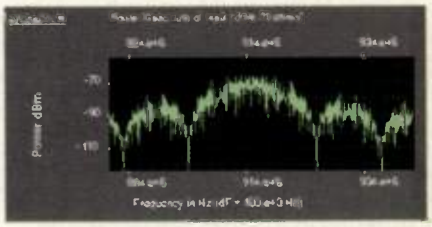

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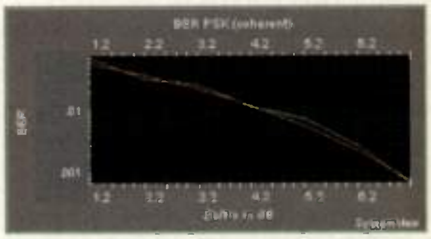

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INFOCARD 45

Handset design: Keeping ahead of the consumer

So, who dictates what the next generation of handsets will offer? The designer or the consumer?

By Ramona Isbell, executive editor

Choosing a mobile phone from today's colossal menu of choices isn't easy. From its size to its color, the process can be almost overwhelming.

Although the general wireless service subscriber may still prefer to stick to the basics when it comes to outfitting their handsets, the more technological-savvy individuals expect more for their money. The defining features of talk-time, standby time and weight have been replaced by personalized color choice, ergonomic styling and feature-rich functions. As consumers realize what they want in a handset, they've told their service providers. And, having listened, carriers are returning to handset manufacturers with their new lists of standard features. And, in turn, this demand continues to send engineers and designers back to the proverbial drawing board.

Beyond the handsets

Other market issues driving the handset market are stimulated by several carrier concerns. Intense competition in the global digital wireless arena continues to underline the carriers' need to design wireless systems robust in coverage and capacity, but minimal in deployment costs. To meet these goals, carriers rely on technological advancements and innovative subscriber services to stay ahead of market rivals.

While carriers continue to support the newest "bells and whistles" available in handset design to drive up user minutes, they are also relying on innovative technology to assist in addressing coverage and capacity issues. For example, recent advancements in base station design represent a cost-effective way of increasing coverage, adding capacity, launching new wireless services and supporting newly developed handset functions.

New generations of base stations rely more on software, offering carriers computerized control over a network of smaller base stations. Current base station technology is reported to assist the carrier in reducing the costs of construction, real estate and zoning. Repeater technology represents another behind-the-scenes factor affecting the wireless handset market. By augmenting the traditional deployment of base stations with repeater technology, carriers can expand coverage, minimize wasted capacity, reduce real estate requirements and dramatically reduce initial capital outlay. These savings can be passed down to the subscribers, increasing a carrier's competitiveness in the marketplace.

So, what's new?

Manufacturers are taking advantage of the service providers' push to retain — and attract subscribers by designing highly advanced features into their latest handset models. Alcatel, for example, has filled out its One Touch line, launching several new versions, all of which offer a hands-free mode. Other cutting-edge features from Alcatel include Euro conversion, adaptability to Chinese and Arabic characters, international code table and the ability to function as an integrated organizer and e-mail productivity tool that accesses Microsoft Outlook.

Web-enabled technology is making a statement as manufacturers adopting WAP, which is a microbrowser especially developed for mobile use. To date, it is being accepted as a standard for providing Internet communications and advanced services on digital mobile phones and other wireless terminals. The CDM-4500, which Audiovox premiered at Telecom '99 in Geneva, is a dual-mode, code division, multiple-access (CDMA) handset that uses WAP/fax capability to interface with the Internet. In September 1999, Ericsson globally unveiled its third WAP product, the R320, which offers a WAP-browser and access to Internet content. As a bonus, it comes with a built-in modem and infrared communication capability, which allows the user to send and receive electronic business cards, ring melodies and phone book entries from one phone to another.

The NeoPoint 1000 CDMA smartphone offers Web browsing and personal information management functions. It features an 11-line LCD, which can display as many as 10 times the number of characters compared to other wireless phones. It also houses a personal information manager/organizer that stores as many as 1,000 contact, schedule and to-do items. The smartphone's features and functionality garnered it the title of "Phone of the Year" by *Gentlemen's Quarterly* (GQ) magazine.

Speaking of awards, Nokia's PCS 8800 series brought home an "Innovation" award for best design in the wireless communications category from the CES International 2000 show, sponsored by the Consumer Electronics Association (CEA). Its glossy chrome finish and sliding keypad cover caught the CES judges' eyes.

Ericsson's T28, the second in its series of "World Phones," operates on the GSM 900 and 1900 bands. Users who rely on the phone to travel throughout Europe, Asia/Pacific and the Americas will find the automatic zone update. In addition to providing automatic zone and time updates, the handset functions as a world clock, alarm, calculator and stopwatch. And, as an added bonus to the bored traveler, it features the popular games of Tetris and Solitaire.

Just when you've heard the latest in design terms, along come a few new ones. First, a new line of "clamshell" style cellular handsets is available from Audiovox. These compact handsets feature large, easy-to-read display panels and full-sized keypads in a small palm-sized design. To date, the series in-

cludes premier model PCX-3500XL, a CDMA handset being produced exclusively for PrimeCo; and the PCX-3500 and CDM-3300 models pictures. These 4.4-ounce phones feature 4-line x 14-character display on their upper portion – or "lids" for enhanced viewing options. Motorola offered two new design options at CES. The first is a slim "candy bar" style; the second is what the company is claiming to be "a radical new design with fluid contours that comfortably fit the shape of the face." These colorful models are expected to debut in the United States, Asia and Europe during the first quarter of 2000.

Innovation: the key to success

As the trendy term "convergence" continues to hammer its way into the industry, designers and engineers are responding with innovative products to complement wireless handsets. Some of the technology being launched goes beyond the practical to being the stuff science fiction buffs dream of. Consider, for example, some of these recent product announcements:

- Nokia's 3210 picture-messaging application: A handset user can create and download picture messages into his Nokia 3210 and send to another 3210. (The Nokia 8850 will also support this feature.)
- Ericsson's HPR-08 FM radio (picture): The plug-in HPR-08 lets you listen to FM radio through the earpieces between calls. Incoming calls are channeled through both earpieces, and the cord features a microphone. This innovative accessory may be the first of its kind on the market.
- Ericsson's Chatboard: This accessory transforms the mobile phone into "something else." The Chatboard is a snap-on keyboard for mobile phones that lets consumers send SMS and e-mail messages, as well as editing a personal Internet page.
- Samsung's SCH-M220 TV phone: Looking for the device to keep you connected at all times? Well now you can watch television on your mobile phone, allowing you to keep up with your favorite sports and still catch those important calls. Samsung Electronics has mounted a 1.8-inch high-resolution TFT-LCD on a folder-type mobile phone handset and built in a miniature TV receiver, providing phone and TV access. The development is complete, and company officials say it will be available in Korea early next year. (A miniature, high-performance TV receiver and antenna, plus a 1.8-inch color TFT-LCD are included.

So, what's next?

Where does the industry go from here? Handsets of the future may make the advances noted above as technology- challenged as the old "beepers" are to today's pagers and yesterday's cellular "bricks" are to the modern pocket- sized handsets. I can't wait.

RF

A quick primer on bonding wire parameters

Knowing the ins and outs of lead bonding and wire interconnects is a must for anyone working with board design and packaging.

By Mike Greenelsh

Ongoing demands for higher integrated circuit (IC) I/O with minimal board real estate are resulting in high densities of connections between chips and the packages. As a result, lead wire bonding, used for the formation of interconnects in ICs, has become perhaps the most sophisticated process of all the IC assembly operations. This situation has made the proper selection of bonding wire materials more critical.

Making judgement calls

Over the years the specification of bonding wire has been somewhat of a moving target. Although IC manufacturers and the American Society for Testing and Materials (ASTM) have adopted standard specification and test method guidelines, in truth, many IC designers must make judgement calls about factors affecting wire bonds, such as burnout rate, metal fatigue and current-carrying capacities. This is mainly because wire bonding parameters are based on what are believed to be typical samples. Yet the complexities involved in bonding interconnects, not to mention uncertainties surrounding their applications, may be well outside the realm of "typical."

There are also a number of issues surrounding the fabrication, shelf life and durability of bonding wire—issues that will be reference from a manufacturer's perspective.

Popular bonding wire elements

Generally speaking, the elements most commonly used to make bonding wire are gold and aluminum. Bonding wire is usually specified because of its strength, based on the metallurgical characteristics of "elongation" and "breaking load." Both gold and aluminum are strong. Both are ductile. Both also have similar resistance in most environments.

Gold — Gold is used because it is normally inert, is well suited to the ball bonding process and demonstrates excellent loop formation and cycle performance. However, in a high heat situation, gold presents problems because it tends to absorb the radiated energy, making it unstable, which is especially a problem in outer space. Gold wire can be stabilized with several different dopants including beryllium, calcium and other proprietary dopants. Gold wires for ball bonding are normally supplied in the annealed condition to prevent unwanted "break-off" partial annealing during ball formation. The proven reliability and flexibility of gold wire bonding have made it the most widely used technology in the IC industry.

Aluminum — Small-diameter aluminum wire is commonly used for ultrasonic wedge bonding. Aluminum alloys also provide the advantage of relative fatigue resistance. In practice, the lightweight silicon-aluminum alloy has proven quite reliable for ICs in billions of devices. Since aluminum is too soft to draw for small-wire dimensions, an alloying metal (normally silicon) must be added to meet necessary breaking load and elongation parameters. Unfortunately, silicon and aluminum do not combine readily, and when heated, silicon alloy particles can cause stress risers, resulting in cracking of the wire. Therefore, the small-diameter aluminum-silicon wire must be heat treated (partially annealed) in such as way to cause the silicon to disperse evenly before it is drawn. In larger diameters, the metal wire can be heat-treated to stabilize the silicon before the wire is drawn, then heat treated again in the final draw to get the elongation and break point

Figure 1. Example of perfectly laid wire due to well Implemented quality control.

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MSW-2-20 (Reflective)	DC-2.0	1.0	+24	34	2.95
MSWA-2-20 (Absorptive)	DC-2.0	1.3	+27	40	3.45
MSWT-4-20 (Transfer)	DC-2.0	1.8 TX** 2.0 RX***	+28 TX** +20 RX***	30	3.95

*Midband, 500MHz-1000MHz. **Transmit. ***Receive.

Package:
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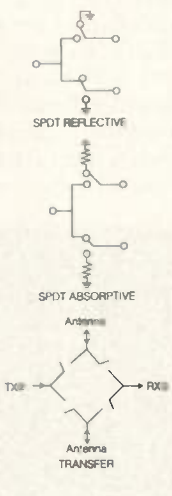

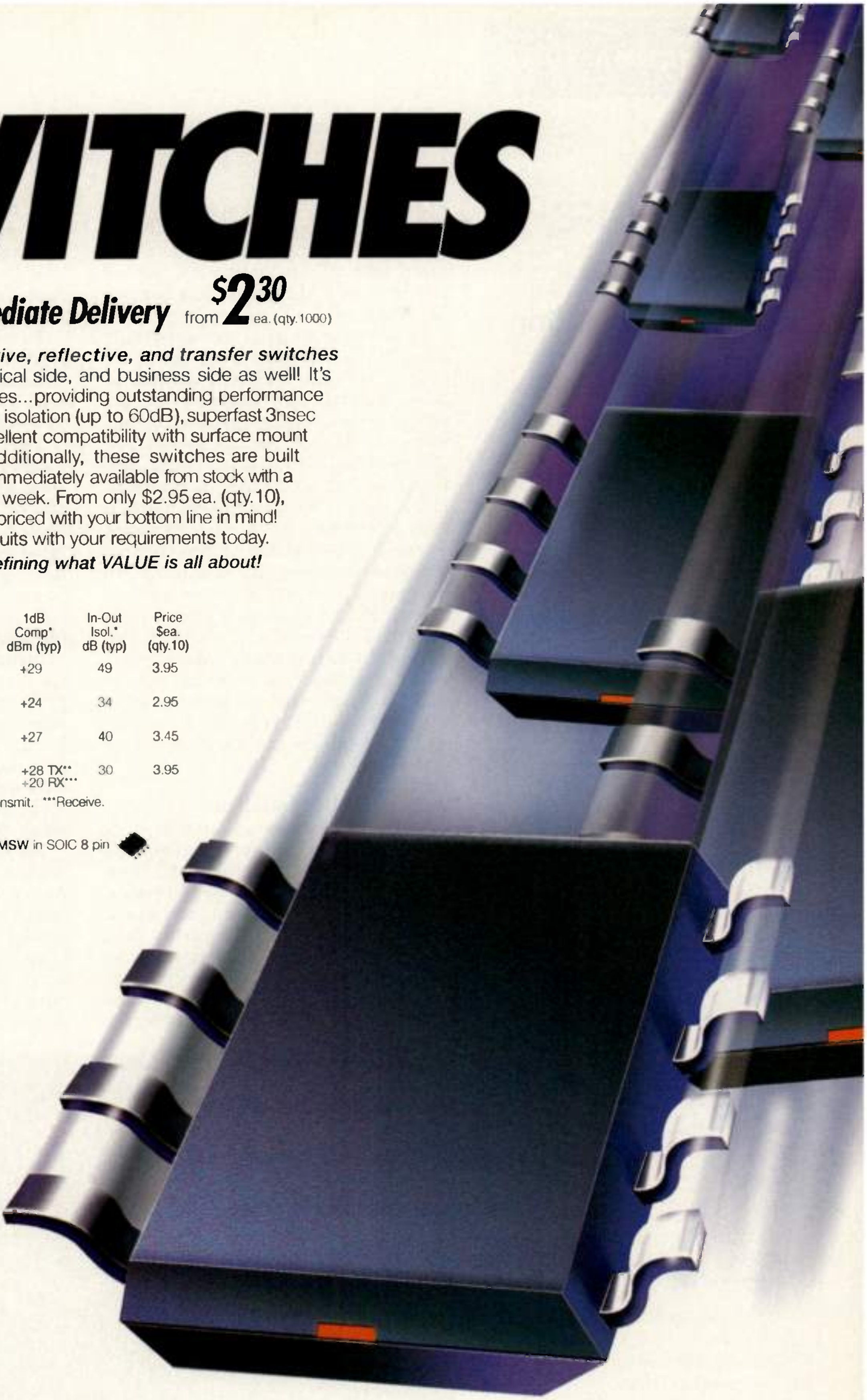

being sought (noted that magnesium-doped aluminum wires have advantages including better fatigue resistance than silicon-doped wire, but the silicon-doped aluminum has become the standard).

In addition to gold and aluminum many IC manufacturers are opting for copper, palladium-alloy, platinum or silver bonding wire because of the potential for substantial gains in conductivity and, thereby, circuit speeds. The choice of copper for interconnections requires that structures be encapsulated with a barrier layer (usually with a thin film layer) to achieve the required adhesion and protect against diffusion of copper atoms into silicon devices, which will degrade performance. Palladium-doped gold wire is used for ball bonds on IC chips for flip chip applications and ball-in-the-corner interconnects. Platinum wire is sometimes specified for high-temperature semi-conductor devices. For speed, silve is the best conductor of all materials.

Concerns about shelf life

Some companies adopt a discretionary policy of discarding bonding wire after three to six months. The principle here is that they would rather toss out perfectly good wire than risk a change in metallurgical properties that could affect the yield of a given machine setup.

Several years ago, tests were completed that determined hard, as-drawn wire began to weaken within six weeks of manufacture. Specifically, the breaking load decreased between 5% and 15% in that period, then decreased more slowly for the balance of the two-year period of the test.

However, stress-relieved and annealed wired wires (both gold and aluminum) stayed within their breaking load specifications for the entire two-year test period.

Test results for elongation were somewhat more ambiguous. It appears that annealed or stress-relieved wire can be used for up to two years, although elongation may vary slightly. However, the wire must be stored at near room temperature and without exposure to sunlight or drafts.

Metallurgical fatigue

Metal fatigue is usually an installation question, rather than a field problem. It is the result of repetitive stress, such as the repeated bending of a wire. As we know from everyday experience, recurring bending can break a wire even though this stress is much lower than is required to fracture it in a single bend or pull.

Microprocessors get warm because it takes a lot of current to operate them. And, device manufacturers are usually pretty cautious about using fans or radiators to cool devices, This thermal cycling in ICs constantly flexes bonded wires, and can produce failures. Also, during thermal cycles, any undispersed silicon in aluminum-silicon wire may

Figure 2. Failure of a teflon coated wire caused by poor QC during the teflon application process.

enlarge and serve as stress risers, making the wire prone to crack and fail. Loop height can affect thermal cycling as much, or more than the properties of the wire itself. Such problems must be considered when designing ICs that will encounter appreciable temperature variations.

Many IC designers no doubt find themselves having to use limited data to make estimates concerning wire fatigue life. According to the ASTM, the practical solution to limiting wire fatigue in open-cavity IC packages is to increase the loop-height to bond-length ratio, which limits the amount of flexing in wire bonds.

Wire burnout

This is related to metallurgical fatigue that results from certain factors causing the current-carrying capacity of wire to be exceeded and fuse the wire. Most of these factors are metallurgical, including resistivity, thermal conductivity, temperature coefficient of resistance and melting point. Another major contributor is the length of the wire—the longer the wire, the lower the current needed for burnout.

Even plastic-encapsulated devices, which comprise the majority of ICs, are subject to burnout when the encapsulating material is melted, becomes thermally insulating and quickly burns out.

Recognizing the difficulty in predicting the maximum current a wire can carry and the likely incidence of wire burnout, many designers simply overspec wire diameter or use multiple wires. In fact, wire burnout is not a common problem in the field.

Elongation and breaking load parameters

Trade-offs exist between elongation and breaking load, two fundamental metallurgical characteristics of bonding wire that influence wire specification.

Elongation pertains directly to the elasticity of a particular wire in a certain state of hardness, depending on the requirements of an application, or how much a wire can stretch under various stress-strain conditions before plastic deformation (permanent stretching) occurs. Breaking load is the amount of elongation a wire can sustain before the breaking point.

There are instances when an IC manufacturer may want to exceed the normal elongation of a certain type of wire without encountering plastic deformation or compromising breaking strength. This can be accomplished to some extent by slightly annealing (stress relieved) or fully annealing the wire. It is possible to successfully double the elongation of a customer's specified wire without sacrificing break strength because these processes are routinely employed.

Wire quality factors

Quality is acutely critical for the manufacture of bonding wire. Of course, most wire producers do some things differently throughout the various manufacturing processes, but there are standards and practices that should be in place throughout the industry.

Metal purity — Base metals must meet ultra-pure standards; for example, gold has to be 4/9 minimum. It is desirable to exceed the minimums to assure that component manufacturers will have a quality product. The higher the quality of melting stock, the fewer contaminants (such as oxides) that could cause fatigue or wire drawing problems. After dopants are added (e.g. beryllium with gold), quality control is stressed to ensure a good melt. For example, specialized crucible with a nitrogen cover to protect the melt can be used with aluminum. It is also prudent to make sure that dopants, especially silicon, are mixed properly to prevent problems with drawing the wire or wire fatigue.

Shape — If the wire was slightly out of round, it might not pass through the bonding machine capillary and possibly slip or not run smoothly. Here, again, it is important not to have stress risers in silicon-based alloys, or the silicon "chunks" may cause capillary blockage or compromise bond integrity.

Thickness - Most fine wire takes about 50 draws through a wire machine to reduce it to the final finish size. When you consider that a manufacturer may start with 0.250 inch stock and finish with 0.00125, you can appreciate the size of the reduction and number of dies involved.

Annealing - Heat treating (annealing) is an important process in making bonding wire. Raw materials can be treated as soon as they are received. With aluminum-silicon alloy, heat-treating insures that the silicon is dispersed properly. A second heat-treating, after the wire is drawn down to finish size, is done in order to stabilize the alloy. During this final heat treating process the wire gets a degree of external protection in the form of a light patina of oxidation, which helps to prevent rapid oxidation.

Tensile strength — Tensile tests are crucial to determining a product's tensile strength, yield strength, gram breaking load (GBL) and elongation.

Handling — Wire being damage at the customer level due to handling is a common issue. This seems to be a result of mishandling the little spools by accidentally dinging them with fingernails as they are removed from packages. It is always prudent to include complete handling instructions with every product to advise bonding machine operators how to handle the spools to minimize potential damage.

The future

Many opportunities are available for wire manufacturer, design engineers, purchasing agents and the operators of the wire bonders to consider.

The future of the use of bonding wire is going to change with the advent of higher density packages. Wire manufacturer will be producing smaller diameter wire. Sizes of 0.00125-inch (0.0375 mm) are common today. Tomorrow, sizes could possibly be as small as 0.0005-inch (0.0125mm).

We will also see changes in the materials that will be used in the manufacturing of semiconductors and integrated circuits. Factoring in this as well, design engineers will have much to consider when designing the devices of the future.

RF

About the author

Mike Greenelsh is President of California Fine Wire, a manufacturer of specialty wire and a leading supplier bonding wire to the microelectronics market. He has been involved in the wire manufacturing industry for 35 years. He can be reached at 805.489.5144, or **www.calfinewire.com**

Modeling RF IC transceivers

Designing next generation portable communications products is difficult without the right tools. Modeling saves time, money and aggravation.

David C. Lee

The global market for portable communication products such as pagers, two-way radios, cordless phones, cellular phones, personal global positioning system (GPS) receivers, wireless internet browsers and portable video phones is growing at a rapid pace. These small wireless handsets carry voice, data, image and video, and will revolutionize the way people communicate and access information. Manufacturers of these high-performance communication systems must compete on the basis of power consumption, cost, size, weight and features. The RF transceiver is the critical hardware that dictates the performance, as well as the cost, the size and the useful battery life in a portable handheld communication product. However, design and verification of the RF transceiver can be difficult or impossible without the right tools.

Architecture of an RF transceiver

Figure 1 is the RF transceiver architecture in a digital cellular phone chipset. Typical RF carrier frequency is in the range of 1 GHz to 2 GHz with the baseband modulation data rate in the kb/s range in both current second-generation (2G) wireless systems and future third-generation (3G) systems.

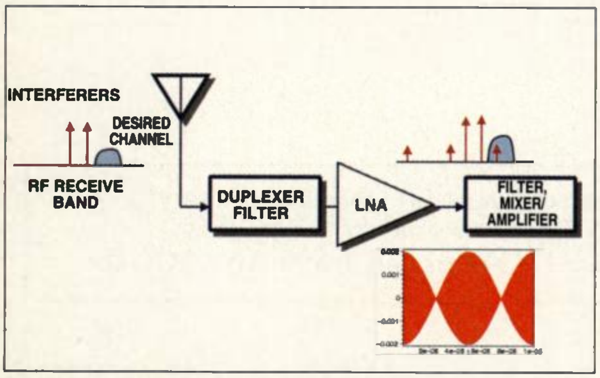

Figure 2. Diagram of nonlinear products created by interferers.

The RF receive path consists of a low-noise amplifier (LNA), an image reject (IR) filter, and a low-noise mixer that translates RF signals to intermediate frequency (IF). This is followed by a channel select filter (not shown), an IF amplifier (not shown), and a demodulator that down converts IF data to quadrature baseband components (I/Q). The RF transmit path has a modulator that translates baseband I/Q data to RF, followed by a bandpass (BP) filter and a high-efficiency power amplifier (PA). The frequency synthesizer consists of one or more phase locked loops (PLLs) that generate stable periodic signals for the mixers, which must perform channel selection. It contains circuit blocks such as voltage-controlled oscillators, crystal oscillators, frequency dividers and multipliers, phase detectors, etc. For optimal performance, the transceiver may also have an automatic power control (APC) loop for the RF transmitter, an automatic gain control (AGC) loop for the RF receiver, and an automatic frequency control (AFC) loop for the frequency synthesizer.

The RF chip can be implemented using a number of advanced process technologies including silicon bipolar, bipolar complementary metal-oxide semiconductor (BiCMOS), gallium arsenide (GaAs), silicon germanium (SiGe) and CMOS. It has several thousand transistors and some on-chip spiral inductors. The filters in the RF transceiver are typically implemented using off-chip surface acoustic wave (SAW) filters and perhaps micromechanical (MEMS) filters in the future. And, chip packages and substrates also have an impact on transceiver performance.

In the baseband chip, which is large and complex, transmit and receive data are processed in the digital domain. The baseband transmitter performs channel encoding, pulse shaping and D/A conversion. The baseband receiver performs complex functions such as

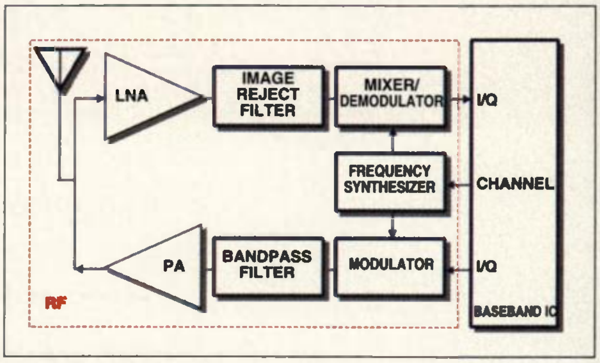

Figure 1. Typical transceiver architecture for a digital cellular phone chipset.

A/D conversion, multipath delay estimation, channel estimation, interference cancellation and data decoding. Baseband processing can also compensate for small distortions in analog filters and signal path nonlinearities.

Accuracy and capacity of RF simulators

Although the RF transceiver is a small part of a complete portable communication system, it is by far the most complex to design and verify. It takes twice as many design iterations as other mixed-signal chips when conventional time-domain simulators are employed. One complex reason that the verification of the RF transceiver has been difficult is because the signal path contains thousands of active devices, high-Q components such as crystal oscillators, and distributed elements such as SAW filters, transmission lines, and chip packaging. SPICE uses first- or second-order polynomials to represent transient voltage and capacitor charge

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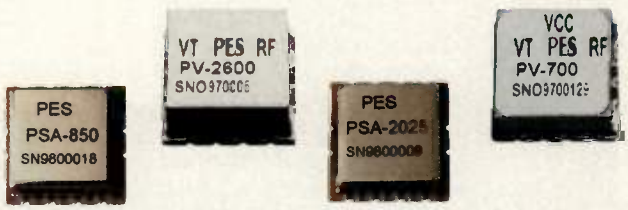

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PV 1103 VCO	1100-2000	-100 dBc/Hz	10V, <25mA
PV 925 VCO	925-975	-105 dBc/Hz	5V, <25mA
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waveforms locally in time, and approximates capacitor current waveforms by polynomial differentiation. Long transient runs are required to simulate high-Q circuits with widely separated time constants. A time-domain RF simulator will accumulate numerical errors and exhibit false convergence when solving for the steady-state waveforms. Distributed elements are routinely measured and characterized using tables of S-parameters. It is difficult to model frequency-dependent distributed elements in the time domain. Even when this is possible, the simulation results are inaccurate and are obtained only at a great computational expense.

Frequency-domain solution methods are better suited for simulating high-frequency communication circuits containing high-Q components, distributed elements and sophisticated nonlinear transistor models with non-quasi-static effects. Frequency-domain simulators use Fourier series to capture steady-state voltage and capacitor charge waveforms and obtain accurate steady-state capacitor current waveforms by exact time-differentiation of a Fourier series.

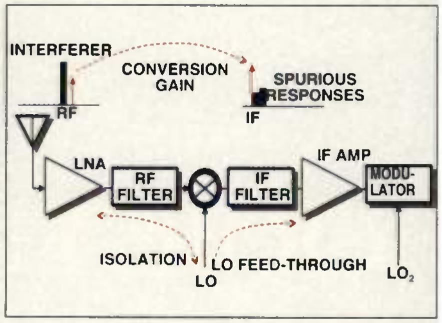

Figure 3. Complex design issues include port-to-port isolation and spurious responses.

The principle limitation of traditional harmonic balance algorithms is capacity — run time grows as the cube of the circuit size and the number of Fourier components, making it impractical to simulate circuits containing tens of transistors except on supercomputers. Recent advances in multitone harmonic balance algorithms have overcome this limitation.

Modern RF simulators that employ Newton-Krylov solution methods exhibit linear memory complexity and almost linear time complexity. Some of these new methods are also perfectly parallelizable, ideal for today's multiple-processor computers. In a highly optimized simulator, sparse, narrow-band and multi-rate structures of the signal frequency spectrum found in different parts of the RF transceiver and the baseband interface are fully exploited, making it possible to simulate RF integrated circuits containing thousands of transistors in minutes.

Selectivity and dynamic range

The high selectivity and resistance to interference required of modern wireless communication systems present another challenge. GSM cellular phones operate within a narrow band

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EC 1078	19.5 dB	21 dBm	37 dBm	120 °C/W	60 °C	DC - 3 GHz
EC-1119	14.8 dB	18.6 dBm	36 dBm	TBD	TBD	DC - 3 GHz

EiC Corporation is an RFIC company and operates its own GaAs HBT fab in Fremont, CA. All product lines cover a wide range of applications such as wireless handset, base station, WLL, and satellite communications in the RF and microwave frequency range.

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near 900 MHz and each channel utilizes 200 kHz of bandwidth. The LNA in the RF receiver is designed to amplify weak, narrow-band signals without adding excessive noise. Because the transmission medium is shared by many users, there exists interferers within the RF receive band. When two or more interferers are near the desired channel, nonlinearity in the LNA creates intermodulation products within the channel that may block reception (see Figure 2). Subsequent filter, mixer and amplifier stages must select the desired channel and process the weak signals despite the presence of interferers. The GSM air interface calls for phone operation in the presence of strong interferers (blockers) that are 56 dB to 99 dB above the desired signal. A RF simulator must faithfully simulate these extreme operating conditions. Dynamic range, the ability to accurately resolve weak signals in the presence of strong blockers, and spectral resolution, the ability to resolve signals that are closely spaced in frequency, are key considerations.

The time-domain integration methods used in SPICE are optimized to compute large-signal waveforms. SPICE gains speed by ignoring small variations and adjusting the size of the time-step accordingly. It has a numerical noise floor of 60 dBc, and is not designed with dynamic range in mind. Accuracy can be improved by using a tight simulation tolerance and very small time-steps, but run times will still be inversely proportional to spectral resolution. For example, a standard two-tone intermodulation test of the RF front-end requires pure sinusoidal tones applied at two closely spaced frequencies—say 900 MHz and 900.2 MHz. Precise measurement will be needed to determine the small third-order intermodulation products at 899.8 MHz and 900.4 MHz, and fifth-order intermodulation products at 899.6 MHz and 900.6 MHz. Transient integration takes a minimum of Q = fc/BW = 900 MHz/200 kHz = 4500 cycles of the RF frequency. Millions of cycles would be necessary if we were to include the mixer in the simulation. Each cycle requires many time points.

It is fair to conclude that SPICE transient simulations will necessarily be both slow and inaccurate. It should be emphasized that any solution method that uses the SPICE transient algorithm (including shooting methods) will have dynamic range limited by the numerical noise floor of SPICE.

Frequency-domain methods are much more appropriate for these circumstances. While a large number of time-points are necessary to capture the steady-state waveform accurately, the frequency spectrum is sparse, so frequency-domain simulations are inherently efficient for high-frequency circuits where majority of the signals are band-limited. Frequency-domain solution methods solve the dynamic range problem too—an accurate implementation of multi-tone harmonic balance has a numerical dynamic range

that exceeds 200 dBc.

RF receive path challenges

The RF receive path must be designed to withstand interference and amplify very weak signals without introducing excessive noise and distortion. The mixer in the RF receive path performs the translation of RF signals to a lower IF band. Conversion gain, image rejection, 1 dB compression point (P1 dB), 3rd order intercept point (IP_3), and noise figure (NF) are commonly used metrics that can readily be extracted from multi-tone harmonic balance simulations. The design issues are quite complex. For example, both noise figure and conversion gain are degraded in the presence of blockers, which are strong interferers that can be 70 dB bigger than the desired signals. Figure 4 shows the noise figure of a mixer as a function of local oscillator (LO) power, with and without blocking interference. It illustrates that noise performance worsens when a blocker is present and underlines the need to analyze noise in RF integrated circuits under realistic multi-tone, large-signal excitations.

In a homodyne (zero-IF) receiver,

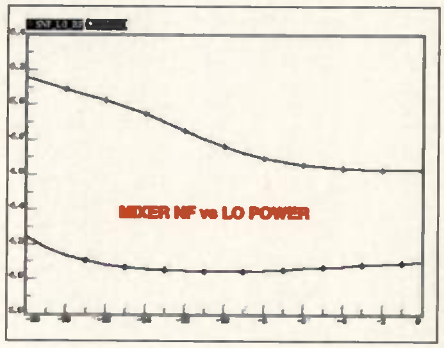

Figure 3. Diagram of LO feedthrough phenomenon.

poor port-to-port isolation due to coupling through layout parasitic, substrate and chip packaging can cause a strong LO signal to find its way into the receive chain, distorting the weak RF signals and saturating the subsequent stages (see Figure 3). The LO signal can also reach the antenna causing in-band interference to nearby receivers. A strong interferer can leak to the LO port and mix with itself causing a DC offset. In-band blockers result in even-order intermodulation products near DC, and can appear as spurious responses due to a direct feedthrough from the RF port to the IF port. Another concern is system stability, because the total signal gain from the antenna to the baseband analog interface is more than 100 dB and undesired oscillations can arise due to parasitic feedback paths.

RF integrated circuits must function over a wide range of frequency and temperature, despite manufacturing variations and power supply voltage variations. So nominal simulations are rarely sufficient. RF and analog simulators must be designed to run long sequences of simulations under many operating conditions. Parametric sweep of input power to extract 1 dB compres-

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Narrow Bands: Up to 20 GHz
Insertion Loss: < 0.2 dB
VSWR: < 1.08
Isolation: > 35 dB
Power Handling: < 100 W
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sion point, and frequency sweep to compute the large-signal conversion gain and image rejection in an image-reject receiver are two basic examples. In a time-domain simulator, the initial conditions used to start a transient analysis must satisfy the circuit differential equations. Hence time-domain simulation is inherently slow because every point in a parametric sweep is an independent simulation run. In a frequency-domain simulator, the frequency-domain solution at one point in a parametric sweep is often an excellent initial guess for the next point, so harmonic balance simulation is both fast and reliable.

Conclusions

Detailed multitone distortion, noise and stability analysis of an RFIC chip under extreme operating conditions are essential for detecting unforeseen problems before a design is committed to silicon. Time-domain simulation approaches cannot handle distributed elements and high-Q components accurately and efficiently. Only frequency domain methods can take advantage of the sparse, narrowband and multi-rate structures inherent in the signal frequency spectrum encountered in RF transceivers. Recent algorithmic advances in multitone harmonic balance simulation offer the speed, the capacity, the spectral resolution and the dynamic range required to verify today's high performance radio frequency transceivers.

RF

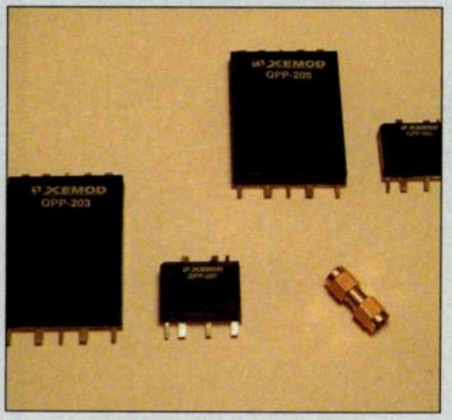
About the author

As an RFIC Scientist at Mentor Graphics, David C. Lee is responsible for defining and developing future-generations of CAD methods for verifying extremely large and complex mixed-signal and RF chips. Previously, Lee has worked in the area of circuit simulation and modeling for 10 years at Bell Laboratories of Lucent Technologies (1992-98) and Bell Northern Research of Nortel (1988-92). Lee is also the founder of the Atlantic Research and Development Center in Allentown, Pennsylvania. Lee earned bachelor's of science and master's of science degrees in Systems Design Engineering from the University of Waterloo in Waterloo, Canada. He can be contacted at 610.770.6210 or e-mail: *david_lee@mentor.com*

Amplifiers

Each month, the product focus highlights a specific area of RF products and provides selected product information. This month, the product focus features amplifiers.

Power modules for PCS, DCS and 3G applications



Xemod has released its first product modules from the QuickPAC line for PCS, DCS and 3G applications. The QPP-301 (IMT-2000) is a 100 W module designed for use with 2.11 to 2.17 GHz band 3G equipment. The PCS products include the QPP-201 and QPP-205, the DCS products include the QPP-207 and QPP-211, The 201 and 207 models feature a power rating of 25 W while the 205 and 211 offer 120 W of power. Additionally, these products are built using LDMOS semiconductor technology.
Xemod
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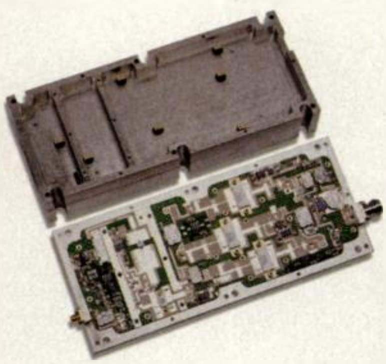
High–capacity TDMA PCS power amplifier

AML Communications offers an 80 W TDMA single channel power amplifier with a microprocessor con-



trol function. The amplifier features an array of alarm and monitoring functions. The unit features an RS485 communications protocol and an automatic, fail-safe shutdown mode in the event of extreme environmental, power, or RF conditions. It operates from any DC source between 20 VDC and 29 VDC and offers a signal gain of 50 dB. The amplifier uses LDMOS technology and offers stability and reliability in a modular product for high-capacity TDMA PCS systems.
AML Communications
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Dual mode TWT amplifier

The model 37 TWT amplifier from Applied Systems Engineering is a dual mode (pulse and CW) amplifier suitable for frequency application between 2.0

GHz and18.0 GHz. Selection of mode can be accomplished with the unit in either standby or operation mode. Phase noise is less than ± 1 degree and all spurious signals are less than –50 dBc. The status display has a four-line, green vacuum phosphorus display with two page modes of information.
Applied Systems Engineering
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120, 60, 30 W RF, microwave amplifiers

Amplifier Research has expanded its "S" line of microwave amplifiers by adding the 120S1G3, 160S1G3 and 30S1G3, which offer 120, 60 and 30 W, respectively. They are similar to the company's standard "S" products but offer more power and narrower

bandwidth. The microwave amplifiers operate in the 1 GHz to 3 GHz and offer infinite VSWR tolerance, more than minimum power at 3 dB compression, flat output and low harmonics. They also include IEEE-488 and RS 232 interfaces.
Amplifier Research
INFO CARD 118

900 MHz Si power amplifier with overramping output

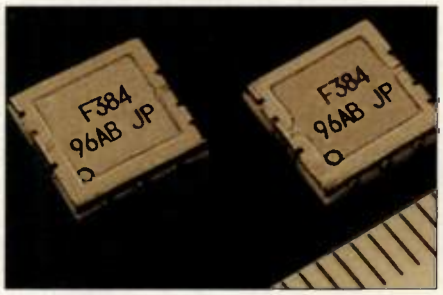
Maxim Integrated Products MAX2235 900 MHz Si power amplifier offers an autoramping output capability. The 1 W device uses an external capacitor to control the RF output ramp-up and ramp-down during turn-

on and turn-off. This minimizes unwanted output transient noise and spectral splatter found in typical pulsed TDMA systems. The device delivers an output power of +30.3 dBm at +3.6 VDC with a power-added efficiency of 47%. A power control pin allows the gain to be adjusted over a 37 dB range while the bias is automatically changed to maintain optimum efficiency, even at lower power output levels. Additionally, a shutdown mode reduces the supply current to less than 10μA to reduce battery drain.

Maxim Integrated Products
INFO CARD 119

GaAs FET RF amplifier module

Mitsubishi Electronics America offers a low-voltage, low-current, high-efficiency three-stage GaAs field effect transistor RF amplifier module for PCS band (1.85 GHz to 1.91 GHz) CDMA cellular phone applications. The amplifier, model FA01384, features a low idle drain current (Idq) of 85 m, typical,

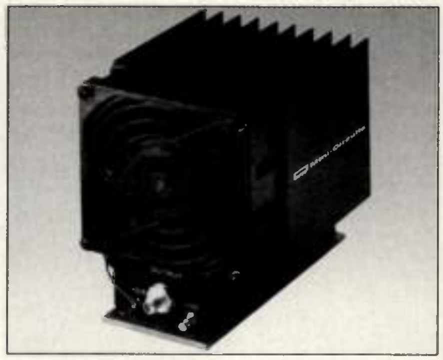


improved power efficiency to 37%, and a 3.2 V operating voltage that allows for 10 % more conversation time in cellular phone applications. The amplifier also maintains 700 mW of output power with an excellent linearity of –29 dBc. The module is input/output matched at 50 Ω. The module also offers a compact 7.5 x 7.5 x 1.7 mm footprint.

Mitsubishi Electronics America
INFO CARD 120

High power coaxial VHF amps

Mini-Circuits has introduced the model ZHL-03-5WF, a 5 W (typical) high output power coaxial amplifier for



use in the 60 MHz to 300 MHz frequency range. At an operatingvoltage of 24 VDC, the devicedelivers typical gain of 35 dB (± 1.0 dB flat), maximum power output of +36 dBm at 1 dB compression and typical +47 dBm IP3. The units can be used with voltages to 28 VDC and are equipped with a heat sink and include a built-in fan with thermal shutoff.
Mini-Circuits
INFO CARD 121

Dual-power amplifier package

Motorola has integrated two complete power amplifier chains for dual-band/dual-mode TDMA cellular phones in a single chip -The design is based on advanced GaAs technology. The device is a single-chip unit that uses pHEMT GaAs technology that provides improved linearity and efficiency performance over older MESFET GaAs process devices, which translates to lower distortion performance and longer battery life. The product integrates two three-stage power amplifiers in a single, high-power surface-mount package that reduces parts count and PC board space. The two power amplifier chains in the MRFIC1856 are specifically designed to operate in frequency ranges of 824 to 849 MHz for TDMA and AMPS cellular handsets, and 1,85 to 1,91 GHz for PCS TDMA phones. The device operates from a 3.6 V power source, offers excellent output power, noise power, and low harmonic output specifications. The two power amplifier chains have adjacent channel power and alternate channel power specifications of –29 dBc and –48 dBc, respectively, for both TDMA and PCS TDMA applications. These specifications are realized while maintaining power–added efficiency performance of 45% for 800 MHz band TDMA, and 35% for 1.9 GHz band PCS TDMA applications.
Motorola
INFO CARD 122

High-efficiency 3 V linear amplifier

RF Micro Devices' RF2153 is designed for use as the final RF amplifier in 1.7 to 1.9 GHz CDMA/TDMA/PACS handheld digital PCS equipment and PACS base stations. The unit operates from a single 3

V power supply, delivers 29 dB of linear output and 30 dB of linear gain. The device's frequency response can be optimized for linear performance, resulting in 33% linear efficiency with CDMA and 40% with TDMA. Additionally, an onboard power–down mode helps extend battery life. Manufactured on an advanced GaAs HBT process, the component is offered in a 4 mm x 4 mm LCC package.
RF Micro Devices
INFO CARD 123

FET-based large signal amplifier

Ericsson RF Power Products has developed a new FET based on their GOLDMOS technology. The device is a large signal amplifier with applications to 1.0 GHz. It is rated at 6 W minimum output with 18.5 dB typical power gain and 57 percent efficiency.
Ericsson RF Power Products
INFO CARD124

FM high wage power amplifier

A new RF power amplifier designed for the FM frequency range of 30 to 90 MHz has been released by LCF Enterprises. The amplifier is a DC module capable of power output of 150 W with typical gain of 25 dB. It runs class AB linear and is powered from a 28 VDC supply. The unit is also available in a full AC configuration offering automatic current limiting, forced-air cooling, current meter, over-current and thermal protection.
LCF Enterprises
INFO CARD 125

Broadband RF power amplifier

Aethercomm is offering the 30005-201 S band power amplifier designed for applications in broadband commercial and military RF systems. The unit is a solid–state power amplifier that offers greater than 20 dB of gain from 1.0 GHz to 3.2 GHz. It has a 1 dB compression point of 39 dBm typical. The SSPA operates from 15 VDC with quiescent current of 2.0 A. Input VSWR is

typically less than 2.0:1 and output VSWR is typically less than 1.5:1. Noise figure is less than 4 dB, with power added efficiency greater than 25%.
Aethercomm
INFO CARD 126

Second–generation Bluetooth power amplifier

The model PA2423M is a second generation of SiGe's Bluetooth power amplifiers. It is based on the SiGe platform and boosts class II Bluetooth radios to class I, 100 meter applications. The sys-

tem features low current (160 mA total including the bias network current), better than 45% power added efficiency,

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

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

DESIGNER'S AMPLIFIER KITS:

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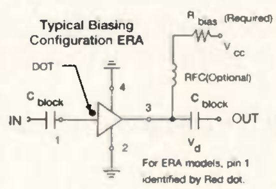
K1-ERASM: 10 of each ERA-1SM,-2SM,-3SM (30 pieces) only $49.95
K2-ERA: 10 of each ERA-4,-5 (20 pieces) only $69.95
K2-ERASM: 10 each ERA-4SM,-5SM (20 pieces) only $69.95
K3-ERASM: 10 each ERA-4SM,-5SM,-6SM (30 pieces) only $99.95

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

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

ACTUAL SIZE



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F 214 Rev F

+23.5 dBm with 20 dB gain and includes power down and output power control pins. It can operate from a single 2.7 to 3.6 VDC power supply with up to 6.0 V applied during battery charging.
SiGe Microsystems
INFO CARD 127

High power CDMA amplifier for base stations

MPD Technologies' 15 W CDMA amplifier covers the range of 1.93 GHz to 1.99 GHz with an average CDMA power of 15 W. The unit is designed for base station or tower-top mountings and features a baseplate temperature of –30° C to +65° C. Circulator protection is provided for transmission into any load mismatch and the unit meets all specification over an input voltage range of 24 to 26 VDC. Additionally, monitors are provided for over temperature, over current, VSWR and device failure status.
MPD Technologies
INFO CARD 128

3 V tri-mode dual band power amplifier

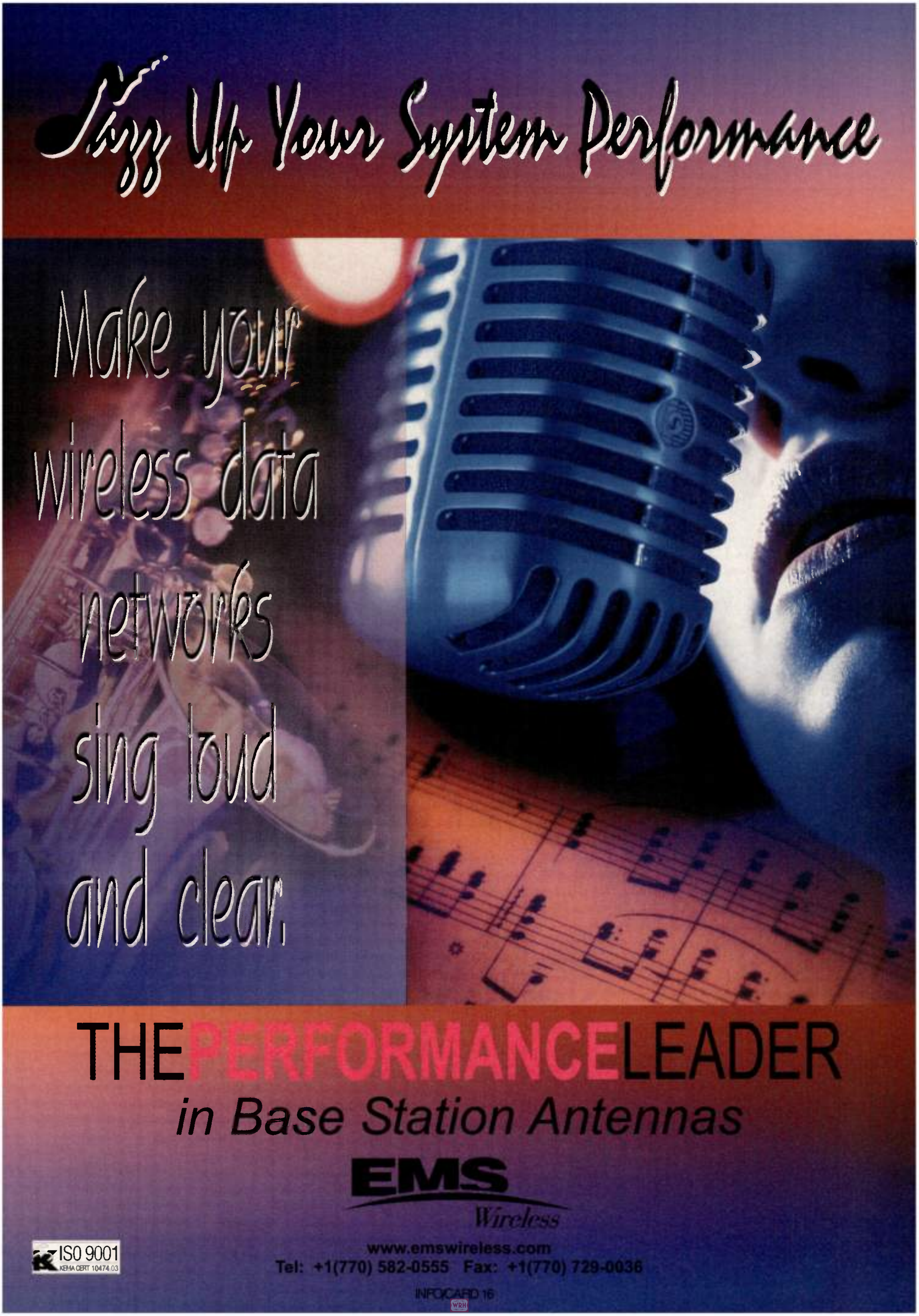
Anadigics has introduced two RFICs that can be designed into new smaller, lighter multimode and multiband handsets. The models AWD5201S4 and AWD4502S4 power amplifiers offer 3 V operation, a small footprint, and 50 W input/output impedance. The devices measure 4 mm x 5 mm in dimension and offer features, depending on model, such as dual band operation, PCS, TDMA and AMPS support and on-chip bias. The devices come in 16-pin SSOP packages.
Anadigics
INFO CARD 129

Programmable-gain difference amplifiers

A new series of programmable-gain difference amplifiers has been released by Burr-Brown. The INA145 and INA146 are designed for low-cost applications in industrial process control, test and measurement, medical equipment, telecom, data acquisition and signal transmission. The INA145 features ±28 V common mode voltage, resistor-programmed 1 V/V to 1000 V/V differential gain and 86 dB of common mode rejection. the INA146 features ±100 V common mode voltage, resistor-programmed to resistor-programmed 0.1 V/V to 100 V/V differential gain and 80 dB of common mode rejection. Both models offer less than 600 mV quiescent current, wide supply voltage and low (0.025%) gain error.
Burr-Brown
INFO CARD 130

High dynamic range amplifier

A GaAs amplifier has been introduced by Watkins-Johnson. The device is called the AH4 is another in the WJ line of Ball Grid Array (BGA) GaAs ampli-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fiers. The amplifier is designed for applications such as wireless local-area networks (WLANs), wireless local loop (WLL), and UNII receiver gain blocks and transmit line-ups where high dynamic range is required. The AH4 is designed to extend the OIP3 of the AH1 line to higher frequencies. It can deliver and output IP3 of 41 dBm from 0.1 GHz to 6.0 GHz. It also exhibits a noise figure of 3.5 dB at 3.5 GHz and draws only 150 mA from a single 5 V supply.

Watkins-Johnson
INFO CARD 131

Competitive silicon germanium amplifiers

Stanford Microdevices has developed a broad new line of SiGe components directed to the wireless communications market. The line of products comes packaged in standard SOT363, SOT89 and SOT23-5, 85 mil surface mount configurations. The devices boast high gain and high linearity and offer the price/performance advantages of SiGe.

Stanford Microdevices
INFO CARD 132

Ultra-miniature wideband amplifiers

California Eastern Labs has released a new series of wideband amplifiers. The UPC2708TB and UPC2710B are performance and pin-compatible with its earlier line of T products. The model 2708 is designed as a gain stage for cellular, PCS and GPS receivers. It can also be used in DBS applications. It features high output and wide bandwidth, with a gain of 15 dB and a noise figure of 6.5 dB. The model 2710 is the power amplifier driver for the same applications as the 2708. The 2710 is also a high-power, wide bandwidth with gain given as 33 dB and its noise figure as 3.5 dB. Saturation power is 10 dBm for the 2708 and 13 dBm for the 2710.

CEL
INFO CARD 133

RF

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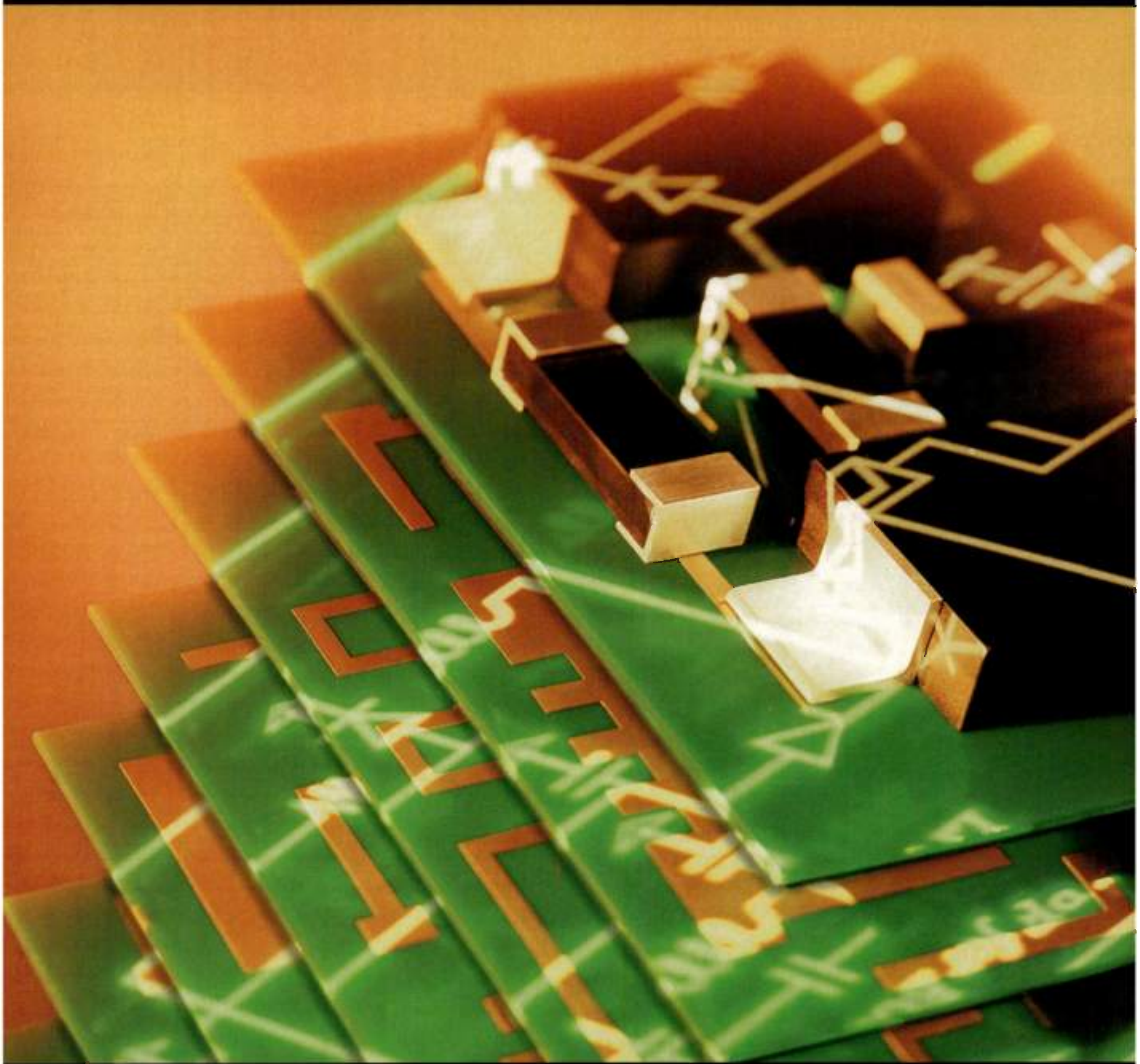

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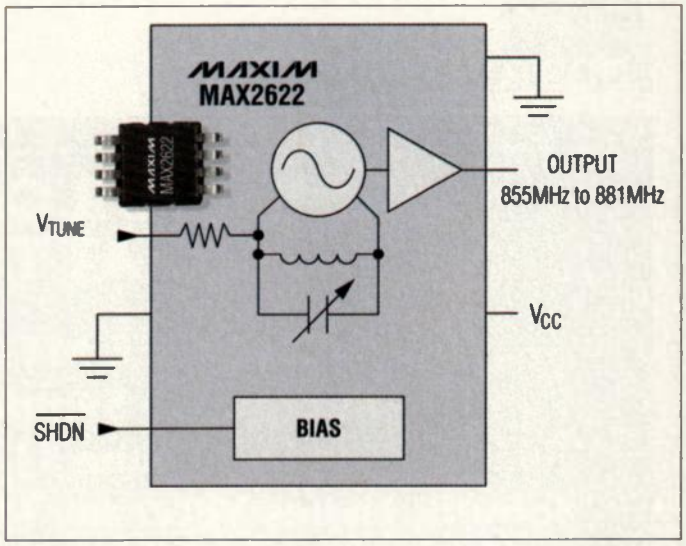
Monolithic 900 MHz SiGe VCO

The MAX2622/MAX2623 self-contained VCOs combine an integrated oscillator and output buffer in a miniature 8-pin μMAX package. The inductor and varactor elements of the tank circuits are integrated on-chip, simplifying application of the part. In addition, the center frequency of oscillation and frequency span are factory preset to provide a guaranteed frequency range versus control voltage. The output signals are buffered by an amplifier stage (matched to 50Ω), using only capacitors to provide higher output power and isolate the devices from load impedance variations. The MAX2622/MAX2623 operates from a +2.7V to +3.3V supply voltage and require only 9mA of supply current. In shutdown mode, the supply current is reduced to 0.1μA. Applications for the devices include ISM band and DECT with frequency ranges from 855 to 851 MHz and 885 to 950 MHz.
Maxim
INFO CARD 134



Voice dialing chip for hands free use

Sensory has developed the VoiceDialer 364 ASSP designed to add voice dialing capabilities to hands-free car kits, mobile phones, PDAs

and other personal electronic devices. The chip uses Sensory Speech Technology 5.0, offers a 40% increase in accuracy, low power consumption and numerous on-chip features that can support up to a 20% reduction in overall system costs. Feedback time is less than 290 ms with a 32–word vocabulary, allowing larger directory sizes and storage. The device also requires less training time allowing the user to enter names and numbers more quickly.
Sensory
INFO/CARD 135

High-power WLL amplifier

Mitsubishi Electronics offers a GaAs FET amplifier for C-band wireless local-loop applications. The devices operate in the 3.4 to 3.6 GHz frequency band and offer high linearity, low third-order intermodulation (IM3) and are input/output internally matched to 50 W. The family of devices are optimized to operate in class

A mode and intended for use in the driver and output amplifier stage. Typical P1dB power output ranges from 4 to 30 W, with IM3 distortion typically at –45 dBc at up to +34.5 dBm.
Mitsubishi Electronics Device Group
INFO/CARD 136

Hub antennas for LMDS

Remec Magnum has introduced the SectorShape antenna for LMDS hubs. Designed to be unobtrusive and with a process that uses advanced EM analysis, the

antenna design eliminates nulls and provides uniform coverage as a function of range. Downtilt is achieved electronically and shaped azimuth patterns ensure uniform sector coverage, reduced spillover and lower backlobes.
REMEC Magnum
INFO/CARD 137

Telecommunications infrastructure DSPs

The ADSP-TS001 DSP from Analog Devices targets infrastructure equipment

with the ability to process 8-, 16-, and 32-bit fixed-point and floating-point data types on a single chip. Applications include IMT-2000 (3G wireless) and xDSL. The device integrates 6 Mb of SRAM, fixed- and floating-point cores, four bi-directional link ports, a 64-bit external port, 14 DMA channels and 128 registers. For large-scale applications, link port technology enables direct chip-to-chip connections without the need for complex external circuitry.
Analog Devices
INFO/CARD 138

NEW PRODUCTS NO.67

RF/IF MICROWAVE COMPONENTS

RF TRANSFORMERS HAVE 4:1 IMPEDANCE 1.5 TO 600MHz

These broad band TCM4-6T surface mount RF transformers from Mini-Circuits operate in the 1.5 to 600MHz band with 4:1 impedance ratio. Referenced to midband loss (0.6dB typ), insertion loss is 1dB from 3MHz to 350MHz, 2dB in the 2 to 400MHz range, and 3dB band wide when operated within -20°C to +85°C (max.). Open case design has plastic base with solder plated leads, and applications include CATV plus VHF/UHF transmitters and receivers. RF power is 250mW (max.).

0.07" MIXERS PERFORM IN HIGHER FREQUENCY DESIGNS

Mini-Circuits patented family of Blue Cell™ mixers deliver a unique combination of low conversion loss, superb temperature stability, thin profile, and low cost to higher frequency designs. This level 7 (LO) MBA-671 model spans 2400MHz to 6700MHz with 36dB L-R, 26dB L-I isolation and low 6.5dB midband conversion loss (all typ). Operating temperature is -40°C to +85°C (max.) and applications include satellite, ISM, and PCMCIA. Available off-the shelf.

LEVEL 7 (LO) MIXERS IDEAL FOR VHF/UHF RECEIVERS

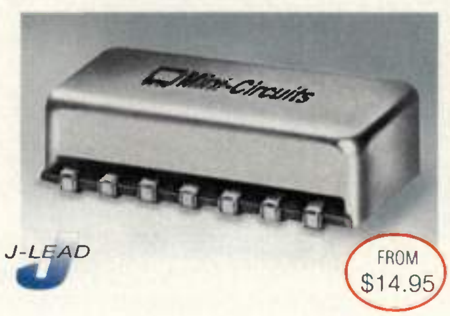
Mini-Circuits low profile 2500MHz to 3200MHz ADE-32 frequency mixers measure only 0.112" (max.) in height allowing engineers to develop smaller surface mount wireless products. Open case design also allows water wash to drain eliminating the possibility of residue entrapment. Electrically, these mixers typically display low 5.4dB conversion loss, +15dBm IP3 at center band, and good 32dB L-R, 30dB L-I isolation. Maximum RF power rating is 200mW. Patent pending.

DC TO 5GHz SPDT SWITCH HAS VERY HIGH ISOLATION

Mini-Circuits ZASW-2-50DR is a DC to 5GHz connectorized single pole double throw (SPDT) reflective switch incorporating a high speed TTL driver for fast 10nsec (typ) switching speed. Typically, isolation is 75dB at 2GHz, 1dB compression is 19dBm at center band, and maximum operating temperature range is -55°C to +100°C. The switch is ideal for transmitter/receiver isolation and automated switching networks. Available from stock.

2WAY 150 TO 350MHz SPLITTER FOR SURFACE MOUNT DESIGNS

Mini-Circuits has unveiled the JSPQ-350, a 2way-90° power splitter/combiner operating in the 150 to 350MHz band with 20dB isolation, 0.5dB amplitude and 1 degree phase unbalance, and very good 1.28:1 in/out VSWR (all typ.). Insertion loss is 0.5dB typical, which is an average of coupled outputs less 3dB. Package height is 0.250" (max.).



12V VCO PROVIDES 50 TO 100MHz OCTAVE BAND TUNING

Mini-Circuits has introduced a compact, value priced 50 ohm voltage controlled oscillator. Typically, this 12V, 20mA (max. current) ROS-100 model provides 50 to 100MHz octave band tuning, low -105dBc/Hz SSB phase noise at 10kHz offset, and excellent -30dBc harmonic suppression. The miniature 0.5"x0.5"x0.18" size conserves real estate, and applications include test instruments such as signal generators. Maximum operating temperature is -55°C to +85°C.

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SUBSYSTEMS

Multiplier modularized subsystem

The SYSX20-3A is an integrated three-stage, (X20) multiplier subsystem. It is suitable for receiver LO generation using a reference VHF stabilized or voltage-tuned input source. Industry-standard size amplifier and multiplier modules are used internally to make the unit modified for custom frequencies with 55dBc spurious levels.
MITEQ
INFO/CARD 139

Spread spectrum data transceiver

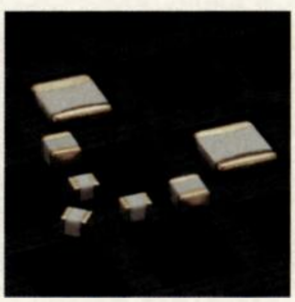
The SS9600 spread spectrum data transceiver can be used in point-to-point systems as well as point-to-multipoint systems. It features a full transceiver with a built-in modem. It is capable of 9600 bps over the air rate, and large systems with as many as 238 units can be configured. The SS9600 operates in the 2.4 GHz band and has a built-in self-adjusting power control.
RF Neulink
INFO/CARD 140

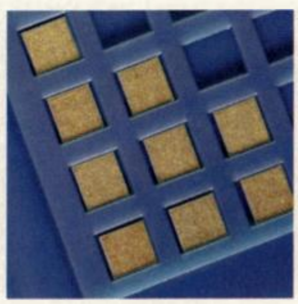
Wireless MMDS transceiver allows fast Internet access

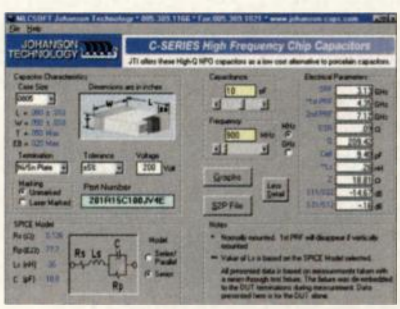
The wireless MMDS transceiver carries high-speed two-way data for fast Internet access, interactive video/voice and telephone. This unit accommodates data over cable service interface specification (DOCSIS) or other customer specified plans. The transceiver delivers a transmitter output power of 20dBm into the 50 Ω antenna port and provides a receiver IF output level of –30 dBm into a 75 Ω connector. The unit operates with a 12 V, 650 mA DC power supply. Unit dimensions are 6” x 6” x 1.25”. The modular approach makes the design flexible to support other wireless interfaces such as PCS, MDS, WCS, WLL and LMDS frequencies.
Renaissance Electronics
INFO/CARD 141

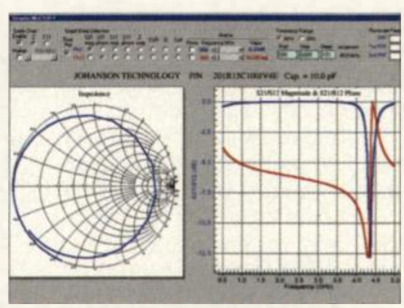
SDH digital microwave radio systems

The FRX series of radio systems are synchronous digital hierarchy SDH digital microwave radio systems that enable carriers to build high-capacity networks in areas where it is difficult to construct a network. The series supports a range of frequency bands from 4 GHz through 26 GHz that dictate the number of STM-1 channels that are used. Each system accommodates as many as seven working channels and one protection channel in a single rack. This capacity can be doubled to 14 working channels and two protection channels using dual polarization, or co-channel operation that allows two systems to use a single frequency band. The output power is 32 dBm, and is packed into a 5 cm x 70 cm x 30 cm transmission unit. Tunable transmitters enable one transmission unit to cover a complete half band; thus, the number of frequency-dependent equipment spares are minimized. The FRX series uses a modulation technique that allows car-









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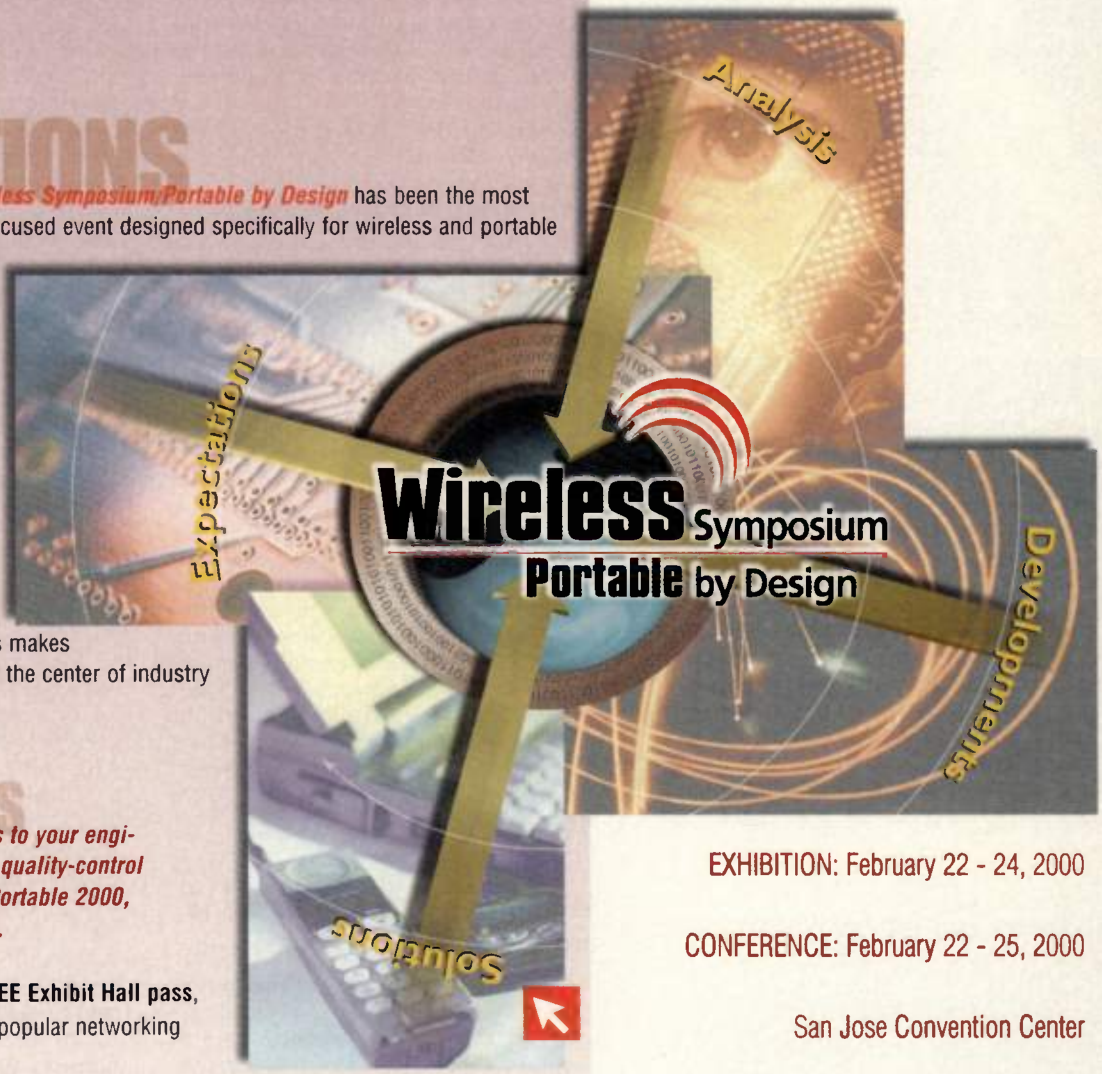

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INFO/CARD 25

riers to make use of their available bandwidth by reducing occupied bandwidth to a minimum. This narrow bandwidth approach improves resistance to fading. These systems can be equipped with a choice of interfaces for a variety of applications. Coaxial cable interfaces are used for short-haul applications, while fiber-optic interfaces provide longer-distance interconnections up to 85 km.
Fujitsu
INFO/CARD 142

TEST EQUIPMENT

PC-hosted debug and design logic analyzer

The HP Logicwave logic analyzer is a tool for hardware debug and FPGA design because it can help pinpoint debug and design problems. This logic analyzer provides 34 channels with 100 MHz state and 250 MHz timing analysis and 128 K samples of depth per channel. Logicwave's Microsoft Windows user interface allows use of the analyzer's most commonly used features while simultaneously having data accessible on the same screen. Less frequently used features are accessible through separate dialog boxes. In addition, Logicwave features off-line analysis of data acquired from any target board or system, and a small, lightweight design (11.5" x 9" x 2.5").
Hewlett-Packard
INFO/CARD 143

Multimode communications antenna test system

The CATS 76000E in-site RF performance monitor includes a spectrum analyzer and RF power meter as well as an antenna VSWR and fault analyzer. The spectrum analyzer monitors receive antennas and displays channel activity, interfering signals and rogue transmitters. The RF power meter scans each transmit antenna and displays all transmitted signals. In addition, it measures CDMA power on each carrier, signal channel AMPS power or NAMPS power, and total transmitted power on a selected antenna. The antenna VSWR and fault analyzer performs antenna VSWR measurements at any time on demand or automatically while it determines the distance to fault in antenna feed lines. The CATS 7600E is designed to be permanently installed in each site. Additionally, it includes Windows software for data display and analysis.
Narda Microwave-East
INFO/CARD 144

2.5 GHz oscilloscope calibrator

The OCS2500 oscilloscope calibrator provides a programmable, automated system for frequencies up to 2.5 GHz. The Next-cal-date tracking feature even lets the user know when the next calibration is due. Built-in self-test routines and hardware features check the operation of all major circuits each time the system is activated. It can be operated locally, or remotely via external GPIB data bus. The OCS2500 is a modular system consisting of the SG5050 leveled sine wave generator, CG5011 calibration generator and TM5006A mainframe. The SG5050 provides calibrated output voltages from 4.5 mV to 5.5 V peak-to-peak into 50 Ω. Absolute amplitude accuracy is ±1.5% from 10 kHz to 50 kHz with flatness from ±1.5% to ±4% over the remainder of the frequency range up to 2.5 GHz. A standard remote leveling head plugs directly into the oscilloscope in order to ensure a level calibration signal at the scope's input connector. Frequency accuracy is ±3 ppm (+0.3 Hz) below 50 kHz and ±3 ppm (+3 Hz) from 50 kHz to 2.5 GHz. Second harmonic distortion is –25 dBc or less, depending on output frequency range and amplitude. The CG5011 calibration generator included in the OCS2500 has a remote pulse head as a standard accessory that provides pulse rise times of 160 ps. The amplitude mode provides voltage, current, low-edge, high-edge and fast-edge functions. The timing mode provides markers to facilitate calibration of the oscilloscope time bases. Trigger rates can be programmed from 100 ns to 5 seconds.
TEGAM
INFO/CARD 145

PASSIVE COMPONENTS

Versatile SPST non-reflective switch

The latest broadband 1.0 GHz to 18 GHz SPST non-reflective switch from Micronetics features 1 W hot switching, 30 ns switching speed, –60 dBm in

band video transients, a 9-pin mini D connector and two non-reflective ports. Other specifications include +5 at 90 mA/V supply, –15 at 70 mA/V supply, 60 dB isolation and a 3.5 dB insertion loss. This switch can be used in a variety of applications such as pulse modulation for test equipment and in EW applications.
Micronetics Wireless
INFO/CARD 146

Sub-miniature voice/data coupling transformers

The SPT-010 and SPT-011 are dry, (0DC) 600 W to 600 W coupling transformers for voice and data applications. Suited for applications requiring minimal use of PC-board, these transformer's maximum height is 0.385". The SPT-012 is designed for data applications only and offers a maximum DC unbalance of 30 mA. Each transformer's longitudinal balance meets FCC Part 68.310 (a) requirements. Maximum above–board height is 0.385". Board area usage is only 0.945" x 0.810". Dielectric strength rating is 1,500 VAC. Each part is UL-recognized.
Prem Magnetics
INFO/CARD 147

Snap-in aluminum electrolytic capacitors

The EYX snap-in aluminum-electrolytic capacitors are designed for use at high ambient temperatures and with high alternating currents. They are intended mainly for use in automotive and consumer electronics and telecommunications. They will withstand temperatures of up to 125° C and loads of up to 400 V. At a temperature of 40° C°, the life of the new power capacitors will exceed 500,000 hours (about 60 years). At a continuous temperature of 125° C and a nominal voltage of up to 100 V, they will last for at least 3,000 hours. The capacitors are available in capacitance values from 47 µF to 33,000 µF with nominal voltage ratings of 10 V to 400 V. They come in industry–standard sizes between 22 mm x 25 mm and 35 mm x 50 mm.
Vishay Intertechnology
INFO/CARD 148

Power moisture resistors for harsh climate conditions

SOTA's new power moisture chip resistors are designed specifically for harsh environments such as in engine controls, navigation systems and other applications where the circuits are exposed to excessive moisture or humidity that can damage components. The compact, lightweight resistors come in 15 thick film case sizes from 0.030" x 0.020" to 0.250" x 0.125". They are also available in 10 thin film case sizes from 0.050" x 0.050" to 0.225" x 0.125". High reliability versions of the power moisture resistors are also available in 10 sizes IAW DESC specifications #94025 through #94018. Testing includes group A and B per MIL-PRF-55342 and MIL-PRF-55324 moisture testing with 10% power applied. The resistors are available in standard termination styles. Metalization options include solderable, epoxy bondable and wire bondable. The resistors are constructed with an alumina body and a proprietary film resistor element that enhances performance and reliability while minimizing susceptibility to moisture and humidity.
State of the Art
INFO/CARD 149

Low profile Inductors only 2 mm high

The DO1606 power wafer inductors are designed for applications that need high inductance and the lowest possible profile. These power inductors are 2 mm high and have a 5.3 mm x 6.5 mm footprint. The series includes 19 different inductance values from 1 µH to 1 mH, and custom versions are also available. The DO1606 inductor comes in versions capable of handling up to 2.5 A. A ceramic cover provides the best possible surface for pick and place handling. PSPICE models on the Web or a CD-ROM are provided in order to assist engineers in incorporating these parts into their designs. Free evaluation samples and a designer's kit (#C138) with examples of all standard versions are available.
Coilcraft
INFO/CARD 150

ANTENNAS/CABLES/CONNECTORS

Low-profile antennas for Orbcomm satellite system

Model ASP-5740RB and ASP-

5740RBGPS are two land mobile antennas designed specifically for the Orbcomm low-earth orbit (LEO) satellite-based data communications system. The double-tuned models are appropriate for transmit and receive frequencies; thus, eliminating the need for field tuning. Model ASP-5740RBGPS offers additional built-in GPS capability. These 4" low-profile antennas, which are made for severe service environments, can be used for mobile asset tracking of tractor trailers, transit buses, train cars, construction equipment, barges and fishing vessels. The antennas may also be used for monitoring utility meters, oil/gas storage tanks or pipelines, as well as gathering environmental data. The high-impact, ASA molded white radome ensures reliable performance and offers protection in inclement weather. Both antennas have been tested to MIL-STD-810E for humidity, high and low temperature, temperature shock, and salt fog. Also, they have been tested to EIA/TIA-3290B-1 for shock and vibration. Model ASP-5740RB has a 137 MHz to 138 MHz receive and a 148 MHz to 150 MHz transmit frequency range. The ASP-5740RBGPS also offers 1575 MHz coverage. The unit is 4.1" x 17" x 3.25", and it can handle as much as 10 W of power. It has a front-to-back ratio of 10 dB (VHF). Polarization is vertical for VHF and right hand circularly polarized (RHCP) for GPS. The VHF beamwidth is 75° ±5° in the E-plane and 85 °±5° in the H-plane.
Allen Telecom
INFO/CARD 151

6.5 m antenna offers high gain

The 6.5 m dual-reflector earth station antenna is for high-density data, voice communications networks and broadcast applications. It has a dual-reflector Gregorian optical system to give high gain and closely controlled pattern characteristics. The antenna can have C- or Ku-band capabilities, and it includes several labor-saving features for reducing field installation time and costs. A self-aligning main reflector eliminates the need for field alignment. In addition, a two-port circular receive and transmit C-band combiner can be field-switched from circular to linear polarization. The antennas are compliant with FCC 25.209 specifications from 1° to 180° at C- and Ku-bands, Brasilsat, ASIASAT, EUTELSAT, APSTAR and INTELSAT F-2 at C-band and E-3 at Ku-band. The ESA's steel ground mount assembly is hot-dipped galvanized and has stainless steel hardware. It has a guaranteed wind survival factor of up to 125 mph in any operational position. Modular equipment options include anti-icing equipment, pressurization systems, microprocessor steptrack control, and manual or motorizable mounts.
Andrew
INFO/CARD 152

Application-specific cable assemblies

The RTI series of application–specific cable assemblies (ASCA) is targeted at applications in the communications market requiring low passive intermodulation distortion. The series has been designed and tested to a measured third–order passive intermod level of better than –110 dBm (–153 dBc) with two +43 dBm tones at 1800 MHz and 1850 MHz. The RTI series features brass connectors with Technaplate plating. The assemblies are constructed of a flexible low loss, double shielded cable with a FEP Teflon jacket. The electrical performance is 35 dB attenuation per 100–foot attenuation, 1.3:1 VSWR at 12 GHz (1.15:1 VSWR at 2 GHz) and greater than –85 dB leakage at 12 GHz and greater than –100 dB at 2 GHz. Standard connector styles include SMA, type N, TNC, 7/16, MCX (to 6 GHz) in straight or right–angle configurations. Also, custom configurations and designs are available. Standard RTI series cable assemblies are available from stocking distribution in lengths of 6, 12, 18, 24 and 30 inches and diameters of 0.110", 0.150" and 0.180".
Semflex
INFO/CARD 153

Smart antenna reduces interference

The Spotlight GSM smart antenna system for GSM networks uses beam-switching technology to improve the capacity and performance of GSM networks. It provides GSM operators with a flexible means for expanding GSM capacity. The system reduces to achieve greater capacity gains. By maximizing network efficiency, operators can to leverage their capital infrastructure investment and lower operating costs

to boost their bottom line. The Spotlight GSM system is designed to be a non-invasive applique to GSM base stations. It has a narrowbeam antenna array, system hardware, signaling-processing hardware and a browser-based graphical user interface with configuration tool. The standard GSM system supports eight-channel operation serving one sector of a site and is expandable to support multiple sectors and multiple cell sites.
Metawave Communications
INFO CARD 154

SEMICONDUCTORS/ICs

Ultra-thin double-side polished silicon wafers

Ultra-thin, double-side polished wafers range in thickness from 25 mm to 500 mm.. They are available in diameters from 2" to 300 mm. All IWS ultrathin wafers have TTV/TIR of less than 3 µm and SEMI standard flats. The wafers are for MEMS applications currently being developed in the drug, chemical, semiconductor, automotive, machining and optical industries as well as university research programs.
International Wafer Service
INFO/CARD 155

Transmit and receive switches for DC to 6.0GHz

These new GaAs transmit and receive (T/R) switches are designed to cover frequencies from DC to 6.0 GHz, and offer 3 V and 5 V positive control. Applications include wireless handsets, LANs, data base stations and other wireless applications. ITTS502AJ is a SPDT medium-power, low-insertion loss T/R switch, with a useable frequency of dc to 3.5 GHz. It features positive control and insertion loss of only 0.5 dB at 1 GHz. The isolation is 28 dB at 1 GHz and P1 dB is 33 dBm. This switch is packaged in a MSOP-8 plastic package which is compatible with standard T/R switches. ITT505AJ is a SPDT T/R switch with a useable frequency of 4.5 GHz to 5.0 GHz. The insertion loss is 1.7 dB and isolation is 14 dB at 1 GHz. This switch is also packaged in the MSOP-8 standard plastic package. ITTS506AJ is a SPDT T/R switch for the 5.0 to 6.0 GHz frequency range. This switch is targeted specifically for the emerging U-NII and 5.8 GHz ISM markets. The insertion loss is 1.7 dB at 1 GHz, and the isolation is 17 dB at 1 GHz. A standard MSOP-8 package is also used for this switch.
GaAsTEK
INFO/CARD 156

Efficient low-voltage and high-frequency MOSFET

A new family of MOSFETs offers a combination of low on-resistance and low gate charge that provides optimum performance and high efficiency for switching applications such as DC–DC conversion. The HDMOS range includes eight N-channel devices. The MOSFETs have drain source voltages up to 30 V, and are suited for low-voltage switching applications. On-resistance ranges from 40 mΩ max up to 180 mΩ, so on-state losses are minimized. Threshold voltages of 0.7 and 1 V minimum allow the MOSFETs to be driven from low-voltage sources. To minimize switching losses and increase the efficiency of high frequency operation, gate charge (Q^g) is small. The maximum Q^g varies from 3.4 nC to 16 nC across the range of devices. C_{rss} (Miller capacitance) is also as low as 30 pF (typical) for the 30 V device. The devices are provided in the miniature surface-mount SOT23, SOT23-6 and MSOPS packages. Single and dual MOSFET versions of the MSOP8 part are available as well as N/P combination duals. The MOSFETs have a high-density lateral geometry that offers a trade-off between DC and AC switching characteristics.
Zetex
INFO/CARD 157

Quarter-micron silicon germanium technology

High-performance SiGe integrated circuit technology for network transport and wireless communications applications features bipolar NPN transistors with cutoff frequencies higher than 70 GHz. Smaller transistors at currents as low as 450 mA have cutoff frequencies that are still above 60 GHz. Chips recently fabricated in the process demonstrate essential optical network interface functions in support of the synchronous optical network (SONET) OC192 and synchronous digital hierarchy (SDH) STM64 standards of 10 gbp/s. The devices can be combined on the same chip with DSP, RF and memory blocks as well as other CMOS-based intellectual property cores for SoC implementations. They draw on the same CAD system, ASIC cell and macrocell libraries used in Lucent's COM-1 quarter-micron CMOS technology, while providing bipolar performance suitable for wired and wireless communications systems for 10 GHz and higher. Lucent is initially targeting the technology at 10 gbp/s SONET/SDH applications where most high-speed ICs are fabricated in gallium arsenide (GaAS) technology. SiGe technology also includes a modular integrated high-Q inductor featuring Q factors of greater than 15. The ability to optimize and fabricate this component is critical for integrated OC192/STM64 applications. The SiGe module requires four additional masks over the core COM-1 CMOS process for either a 2.5 V or 3.3 V NPN transistor. The use of five additional masks over the core process enables both transistors for mixed voltage applications.

Lucent Technologies
INFO/CARD 158

SIGNAL SOURCES

DROs for LMDS and MVDS

The NXPLOS series PLDROs are designed to achieve a pure spectral phase noise in the Ku band while keeping a low material and labor content. The NXPLOS oscillators feature output frequencies of 13 GHz to 16 GHz, output power of +13 dBm minimum, and power variation of (–10°C to +65°C) ±1 dB. Furthermore, they offer immunity effects to power supply ripple and microphonics commonly found in phase-locked sources when integrated to the systems. The NXPLOS series PLDROs can be applied to the LMDS, MVDS and local oscillators for many frequency conversion applications. It weighs 3.5 oz and is 2.25" x 2.25" x 0.65".

Nexyn Corporation
INFO/CARD 159

Stable oscillators for multipoint communications

The series MDR5530 phase-locked sources are internally referenced phase-locked, dielectric-resonator oscillators for high-volume applications such as LMDS and mm-wave point-to-point radio links. They are available at frequencies from 9 GHz to 13 GHz and are for use in systems that use second or third harmonic mixing to achieve frequencies from 23 to 38 GHz for up and down-converter local oscillators. An internal, ovenized crystal oscillator maintains the stability at ±2 ppm with all spurious signals maintained at levels lower than –85 dBc. The units have +17 ± 2 dBm power output; maximum phase noise at 1 kHz offset is –95 dBc/Hz and at 10 kHz offset is –105 dBc/Hz.

REMEC Magnum
INFO/CARD 160

Subcompact surface mount VCXO for telecom

This range of 5 mm x 7 mm HCMOS surface mount VCXOs are specifically designed for telecom applications. They are offered in both 3.3 V and 5 V designs with frequency ranges from 4 MHz to 45 MHz at 3.3 V, and 1 MHz to 52 MHz at 5 V. Temperatures range from 0° C to 70° C with frequency tolerances to 25 ppm and deviations to ±100 ppm. An extended temperature range of –40° C to +85° C is available. All models are available in pin 2 or pin 5 configurations for the tristate E/D function, and are hermetically sealed in a leadless ceramic package.

Connor-Winfield
INFO/CARD 161

Miniature oscillators with maximum capabilities

These miniature SMD oscillators from ICM offer a frequency range from 1.8 GHz to 50 GHz. The IS07.505B offers a frequency stability of ±100 ppm (STD) while the IS07505B50 offers a frequency stability of ±50 ppm. The TTL/HCMOS compatible units are designed for high-density packaging with industry standard footprint, and provide fast rise/fall times.

International Crystal Manufacturing
INFO/CARD 162

High frequency fundamental VCXOs

Frequency Management has introduced a line of high frequency fundamental VCXOs. The FMVC series is available in frequencies up to 60 MHz with 3.0 or 5 V supply voltage. Applications include microwave and satellite systems. Pull ranges are available from ±50 to ±500 ppm. Stability options are available to ±15 ppm. Jitter is less than 5 ps and phase noise to –150 dBc/Hz at 10 kHz.

Frequency Management
INFO/CARD 163

Ultra high stability crystal oscillator for wireless apps

Piezo Technologies has introduced a broad array of crystal-based oscillators for wireless infrastructure devices. The products address the issues of low cost manufacturing and stability/reliability. The XO5080/3080 series offer a wide assortment of characteristics (depending upon model), which include stabilities as low as 0.02 ppm (SC) at temperature ranges from –30° C to +70° C, sine or HCMOS logic outputs, a 5 V supply and a true SMT package.

Piezo Technologies
INFO CARD 164

TRANSMISSION COMPONENTS

Low insertion loss high frequency drop-in isolator

The model 1260IED is a small, high frequency drop-in isolator which provides 22 dB isolation with low insertion loss of 0.35 dB over frequency bandwidth of 12.7 GHz to 14.5 GHz. The circuit tabs are designed to provide assembly yield during system integration. The VSWR over the frequency bandwidth is 1.25:1. Isolators/circulators in other frequency bands are available in a similar package. The unit can be optimized for solder reflow assembly when required for system integration. It can be operated from –40° C to +85° C and can be stored at temperatures of –50°± C to +125°. The package size is 0.35" x 0.5" x 0.25" with delivery from stock.

Nova Microwave
INFO/CARD 165

Miniature surface-mount isolator

A miniaturized surface-mount isolator from Alcatel covers the PCS band of 1.930 GHz to 1.990 GHz. It has an insertion loss of 0.4 dB maximum (±0.3 typical), isolation of 20 dB minimum (22 dB typical), VSWR of 1.25:1 maximum (1.18:1 typical). In addition the isolator features a 10° window for insertion phase, phase flatness of 0.3° peak-to-peak, two tone IMD of –65 dBc at +16 dBm per tone and +19 dBm average, an operating temperature of 0° C to +85° C, and a load rating of 4W CW. The product measures 0.440" x 0.500" x 0.250".

Alcatel Ferrocom Ferrite Products
INFO/CARD 166

High power three way cellular/PCS power splitter

The FXR model d3-24FD three way power splitter for high–power,

dual–cellular/PCS band applications uses gasketed 7 mm-16 mm DIN connectors, and can withstand extreme weather conditions. The splitter can be used for base stations, "leaky line" and similar applications in the 800 MHz to 2.2 GHz frequency range. It evenly splits high-power signals with minimal reflections, PIM or insertion loss, up to 700 W average power. Its mechanical shape allows simple attachment to pole or wall using a provided bracket.
Microlab/FXR
INFO/CARD 167

Cellular/DCS/PCS crossband coupler

The WSD-00150 is a crossband coupler offering high isolation, low insertion loss and high–power capability designed for application in the 800 MHz to 980 MHz and 1.7 GHz to 2.0 GHZ bands. Insertion loss is 0.3 dB maximum.
K&L Microwave
INFO CARD 168

EMC/RFI

Low-profile clip-on shielding gaskets

The 125LP55C070 and 12LP75C070 durable, low-profile, clip-on beryllium copper gaskets are designed for the bi-directional applications found on electronic enclosures. They require a low closing force and provide 360° of snag-free operation. They have shielding effectiveness up to 100 dB attenuation levels. The finger stock gaskets measure 0.08" x 0.55", and 0.12" x 0.75". The smaller gasket effectively closes gaps down to 0.025". Clip-on mounting provides reliable mechanical installation when there is an accessible mounting flange. Optional lances can be used to enhance the holding force to the flange.
Tech-Etch
INFO/CARD 169

Two-part easy access EMI shield

The Boldt Shield II is a standard off-the-shelf, two-part EMI (electromagnetic interference) shield packaged for automated board-level installation. Its design, with removable lid, provides easy access to inspect or repair important electronic components without having to de-solder the SMT shield. The shield is packaged in standard EIA410 tape and reel formats for automated surface mount installation. It is available in many JEDEC sizes, including 52-pin quad flat pack (TQFP), 256-position ball grid array (BGA) and 84-pin plastic leadless chip carrier (PLCC) packages. It combines high shielding performance, SMT reliability and newly added flexibility for prototype adjustment.
Boldt Metronics
INFO/CARD 170

Diode array protection for HF data I/O ports

The PMAD and PMMAD series of low distortion steering diodes are intended for use on high-frequency analog or digital data I/O ports for protection against electrostatic discharge (ESD), and electrical fast transients (EFT) such as IEC 1000-4, -2 and -4. They are connected between rail-to-rail voltage bus or rail-to-ground for clamping and diverting over-voltage transients for the protection of sensitive network interface circuits. These diodes provide low capacitance that ensures signal integrity up to 900 MHz while complete isolation between adjacent diodes keep cross talk to a minimum. Applications include microprocessor-based equipment; hand-held electronics; telecommunications equipment on ISDN, T1/E1, or ASDL transmission lines; and computer interface networks such as USB, SCSI, Ethernet or similar high-frequency circuits. The PMAD series is available in a 14-pin DIP (through hole) package. The PMAD1108 is available in a 16-pin DIP package. The PMMAD series is available in a SO-14 (surface mount) package. The PMMAD1108 is available in the SO-16 package.
ProTek Devices
INFO/CARD 171

Antenna analysis program offers two versions

The SuperNEC Version 1.0 is a hybrid method of moments (MoM)/unified theory of diffraction (UTD) antenna analysis program based on NEC2. It is available in sequential and parallel execution versions. The MoM/UTD hybrid engine features a UTD hybrid at the level of the impedance matrix interactions. The input interface is Matlab-based, and it can be extended and modified by the user. Different parameters compared to frequency can be viewed, including impedance, VSWR, gain, F/B ration return loss, efficiency and coupling.
Poynting Software
INFO/CARD 172

Wavelets for signal, large data sets analysis

Mathsoft's wavelets extension pack, is designed for Mathcad 8 Professional and offers the mathematical and statistical routines needed to perform analysis of signals and large data sets. The software provides advanced techniques for signal reconstruction, denoising, data compression and special numerical methods. Applications include signal compression, signal reconstruction, time-frequency analysis and spectral analysis; wavelet packet pulses, discrete wavelet multitone modulation; wave propagation and acoustics and a number of other applications.
Mathsoft
INFO/CARD 173

Time-domain software predicts waveforms

Optotek's MMICAD Waveform time-domain, transient analysis simulator allows the prediction of waveforms in fast, nonlinear circuits where accurate S-parameter data can be imported and used in the simulation. It can be used in the design of GaAs ICs for high-speed optical communication modules, improved microwave packages and nonlinear transmission lines. Designers can address complex, frequency-dependent effects in passive circuits such as the variation of effective dielectric constant and loss of a microstrip line with frequency for a broadband microwave circuit. package, but interfaces with the other components of the MMICAD CAE/CAT software suite, such as the MMICAD linear simulator and LASIMO transistor parameter extractor.
Optotek
INFO/CARD 174

For more information on these software products check out **RF Design Online** for direct links to the companies.

Guide details signal processing ICs

Signal Processing Technologies' product selection guide has been updated to include recent additions to its data conversion and signal processing IC product line. Included are product charts with detailed information such as resolutions, sample/conversion rate, power dissipation, linearity and I/O specifications. Products include analog-to-digital converters, digital-to-analog converters (DACs), video DACS, comparators, video line drivers and processors and track-and-hold amplifiers.
Signal Processing Technologies
INFO/CARD 175

RF, coaxial cables for wireless communications

Montrose/CDT offers a 16-page catalog featuring low-loss wireless communications cables including coaxial antenna feeders, jumper cables and low inductance power cables. The catalog describes the WCX series that offers gas-injected foam polyethylene dielectrics for ultra low-loss characteristics and the RGX series with irradiated dielectrics that are electrically equivalent to Teflon.
Montrose/CDT
INFO/CARD 176

Interconnection, packaging solutions featured

Aries Electronics' short-form catalog features its interconnection and electronic packaging products. Highlights include the company's correct-a-chip adapters, BGA products and high-frequency RF sockets. The correct-a-chip adapters and sockets allow any SMD package to mate with any socket providing plug-in/plug-out capability for devices including ICs, add-on circuitry and emulator cables.
Aries Electronics
INFO/CARD 177

Short form catalog features capacitors, resistors

A short form catalog from AVX features the company's line of capacitors, resistors, filters, timing devices, thin-film products and piezoelectric devices. The catalog also features Elco connector products and TPC products including ferrites, high energy and high-voltage power capacitors, ceramic capacitors, varistors and non-linear resistors.
AVX
INFO/CARD 178

Brochure describes coaxial cables, assemblies

Insolated Wire offers a brochure describing the company's new line of phase stable coaxial cable assemblies for microwave applications. The cables and assemblies offer smaller diameters, lighter weights, lower insertion loss and enhanced electrical stability versus temperature and flexure. The brochure offers cable specifications, cable assembly specifications attenuation curves and power curves.
Insolated Wire
INFO/CARD 179

Semiconductor replacement guide offers 81 new devices

Phillips ECG Semiconductor's supplement to its master replacement guide (ECG212T) offers 81 new devices and as many as 4,450 additional crosses. The devices include power MOSFETS, general-purpose diodes and rectifiers, Schottky Barrier industrial rectifiers, polymeric fuses, high communication, logic level and sensitive gate TRIACS. The guide provides technical data including outlines, diagrams and specifications.
Phillips ECG Semiconductor
INFO/CARD 180

Test equipment catalog offers 1,400 products

Tektronix's 2000 measurement products catalog features 1,400 test and measurement products. Test products include low-cost instrumentation and handheld products to conventional measurement products and advanced mixed-signal test products. The catalog is available in a print version or as a CD-ROM.
Tektronix
INFO/CARD 181

Measurement and automation catalog

National Instruments' computer-based measurement and automation products are described in the company's measurement and automation catalog 2000. The catalog offers detailed product specifications, a selection guide and tutorials. The catalog features Labview RF and the RF series of data acquisition boards for real-time and embedded applications.
National Instruments
INFO/CARD 182

Catalog offers microwave, RF products

Renaissance Electronics offers the 8th edition of its RF and microwave products catalog. The catalog features broadband, narrowband and dual junction coaxial isolators and circulators. Other isolators and circulators include broadband and narrowband drop-in, mini drop-in pill and mini drop-in flange, flange/square drop-in and other devices. Also included in the catalog are high-power terminations, custom capabilities, sub-systems and an engineering reference.
Renaissance Electronics
INFO/CARD 183

Book explains DSPs techniques

Analog Devices' *The Scientists and Engineers' Guide to Digital Signal Processing* covers a number of topics including elementary techniques of convolution, Fourier analysis and analog-to-digital conversion. Additional chapters describe the methods used in audio and image processing, data compression and neural networks. Also featured is an extensive section on digital filters that describes how easy-to-use algorithms can solve difficult filtering problems. A downloadable copy of the book is available at Analog Devices' Web site. A direct link is available through **RF Design Online**, editorial links.
Analog Devices
INFO/CARD 184

RF Design Online

For more information on items noted in the literature column, check out the *RF Design* Web site **www.rfdesign.com** editorial links, for direct links to company Web sites.

RF Literature/Product Showcase

LF/HF Linear Power Amplifiers

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ULTRA 2022	250 kHz - 20MHz	50W linear / 175 W sat.	Analog / Digital

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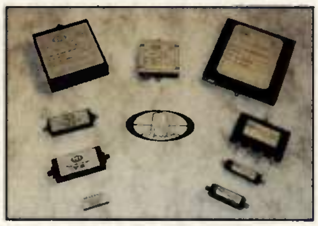

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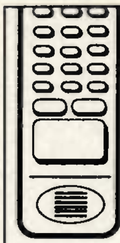

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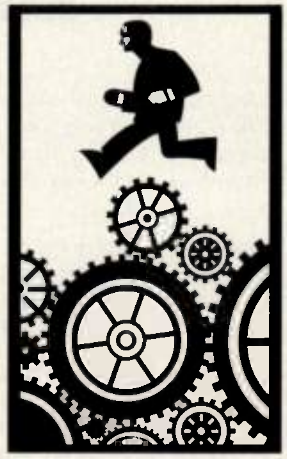

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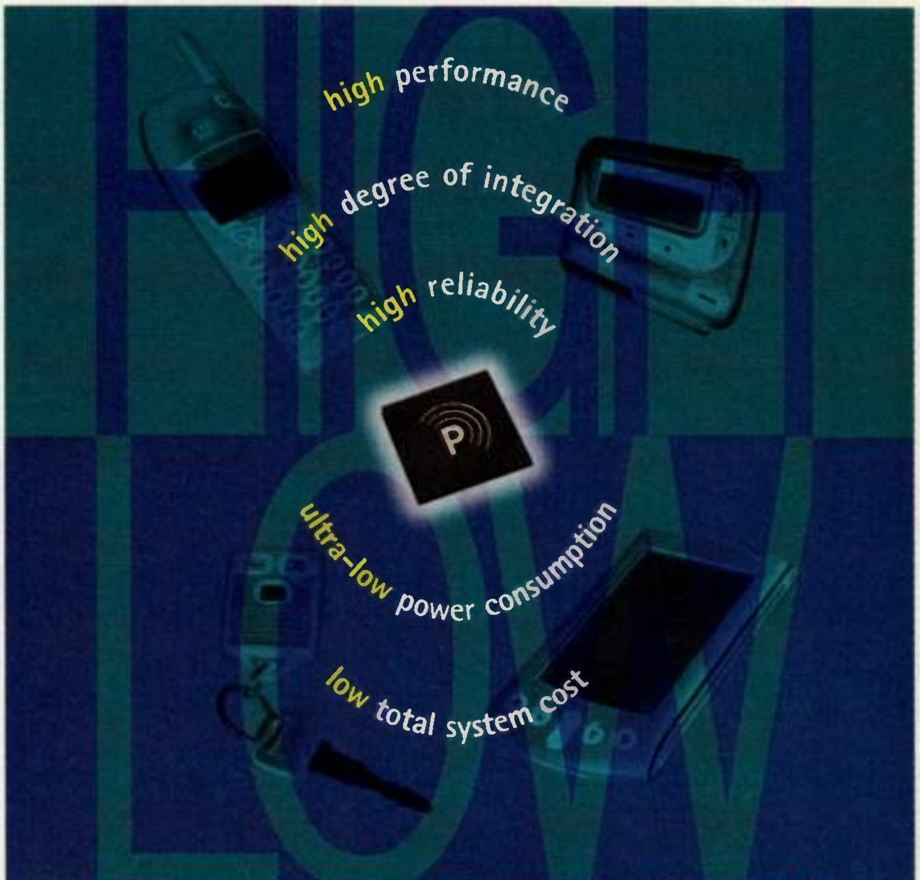

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E-nough.com

by Ernest Worthman

If I hear about another dot-com I'm going to go nuts.

Not a day goes by that I don't hear about another (or 10) dot-coms. dot-com this and dot-com that. Buy it, sell it, learn it, fix it, get a date, get a divorce, improve you health, change your image, buy groceries, get loans, get a mortgage...e-nough.com already.

It is getting to the point where everyone is coming up with a Web site. It's becoming ridiculous, especially when it comes to using the Web to find useful information. Furthermore, most of the sites are so bogged with "gee-whiz" graphics and links that navigating them is truly a test of patience. Why *anycommunucationscompany.com* has a banner ad for Volkswagen is beyond me. Or does some self-anointed marketing-educated "Webwiz" expect me to run right out and buy one after seeing the banner—e-nough.com.

Generally, most of my site searches turn up information that isn't even in the same galaxy as what I'm looking for. I understand the Boolean operators and relational associations that search engines use to pull results. Then there are the regular "sorry, what you're looking for doesn't exist, please get unstupid and try again (that, along with a suggestion to bug your system administrator)—e-nough.com

I understand this is an emerging science (and I use the term "science" loosely), but if this is the best our Webmasters can come up with, we're in big trouble. It seems we've been listening to the Webmasters way too long about how the site should look and what it should contain. Who decided that a Webmaster was the greatest thing to come along since the transistor? And why do we bow to the Webmasters and awe at the mess they create? Is it because we're afraid of the unknown, and therefore turn to digital charlatans, wizards and psychics? I have to wonder what kind of program it takes to get a degree in Web Guruing. It wouldn't surprise me if some core courses were titled "Alternative Jungian introspective philosophies for convoluted Web site design" and "Creating endless loop Web sites with complex XML (extensible markup language)".

Perhaps the worst offender is the site that kills your trail. You know, the one that once you've decided it wasn't the site you wanted keeps reloading-over and over every time you hit the back button on your browser. And you can't get out of the loop to get back to your search results under any circumstances. So you have to go back and reload the search from the beginning and scroll forward several hundred entries to get you back to where you were—e-nough.com.

And there are the sites that give you a pop-up window about a 3.9% MasterCard, or a car loan, or a discount long distance service, etc. Which, of course, means you have to take another diversion to close it since it obscures most of your window—e-nough.com.

Recently I was searching a site for a company's product. I must have spent 20 minutes entering the data in every format, yet was unable to locate the product. I found every product before and after, but not the one I wanted. I knew the product existed, but it just didn't show up—e-nough.com.

And aren't you tired of all of the junk that these dot-coms dump onto your computer? These consist of cookies, gifs, html files, and assorted other digital garbage that takes up megabytes of disk space. And all because the current log-jammed Internet highway is so painfully slow to transfer data, that sites must store most of their information on your computer, to give the perception that there is any real-time data actually being sent

And no industry is immune.

I think it's time we all take a serious look at where the Web is heading. It's easy to get caught up in the momentum, and fear that not being on the bleeding edge means being on the sidelines. If you think that just creating another dot-com is the solution to effective information exchange and getting customers to your site, I'd think again. Nothing says unprofessional like a site that takes forever to load, is difficult to navigate and contains dead links. We may buy into it for now because we're afraid of what we don't understand. But sooner or later we'll get wise. The novelty will wear off, and Web sites will be just another choice of marketing.

Ah what a truly convoluted Web we spin—ok Webmasters, take your shot.

Ernest Worthman is RF Design's technology editor. He is a fellow of the Radio Club of America and a member of the IEEE. He holds a B.S. in electronics engineering technology and teaches college courses in electronics and computers. Ernest is easily recognizable at conferences by the coffee cup surgically attached to his hand. You can contact Ernest by e-mail at ernest_worthman@ieee.org, ernest_worthman@intertec.com or though the letters to the editor on the RF Design Web site, www.rfdesign.com.

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BW-S5W2	5	±0.40	.85
BW-S6W2	6	±0.40	.85
BW-S7W2	7	±0.60	.85
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