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Report from the ARMMS Meeting

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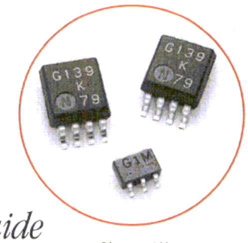

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COVER STORY

The story of Hewlett-Packard Co., and subsequently Agilent Technologies, is a capsule history of test-and-measurement techniques and equipment for the microwave industry.

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Special Section

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Article Credibility

PLEASE TELL ME that the article "Raise Bandwidth Efficiency With Sine-Wave-Modulation VMSK" in the April 2001 issue (p. 79) was just an April Fools' joke. Something tells me that it is not, however, because other credulous articles about VMSK have appeared for years in this and other trade publications—even the *IEEE Transactions on Broadcasting*.

When I first learned about VMSK in an August 2000 article of *EDN*, I found that elementary signal theory was enough to completely debunk the bandwidth and performance claims of Harold Walker and his equally confused colleagues. See the website: www.people.qualcomm.com/karn/papers/vmsk.

I encourage *Microwaves & RF* to keep utter nonsense like this article from getting into print and confusing readers who do not know any better.

Phil Karn

Defends Article

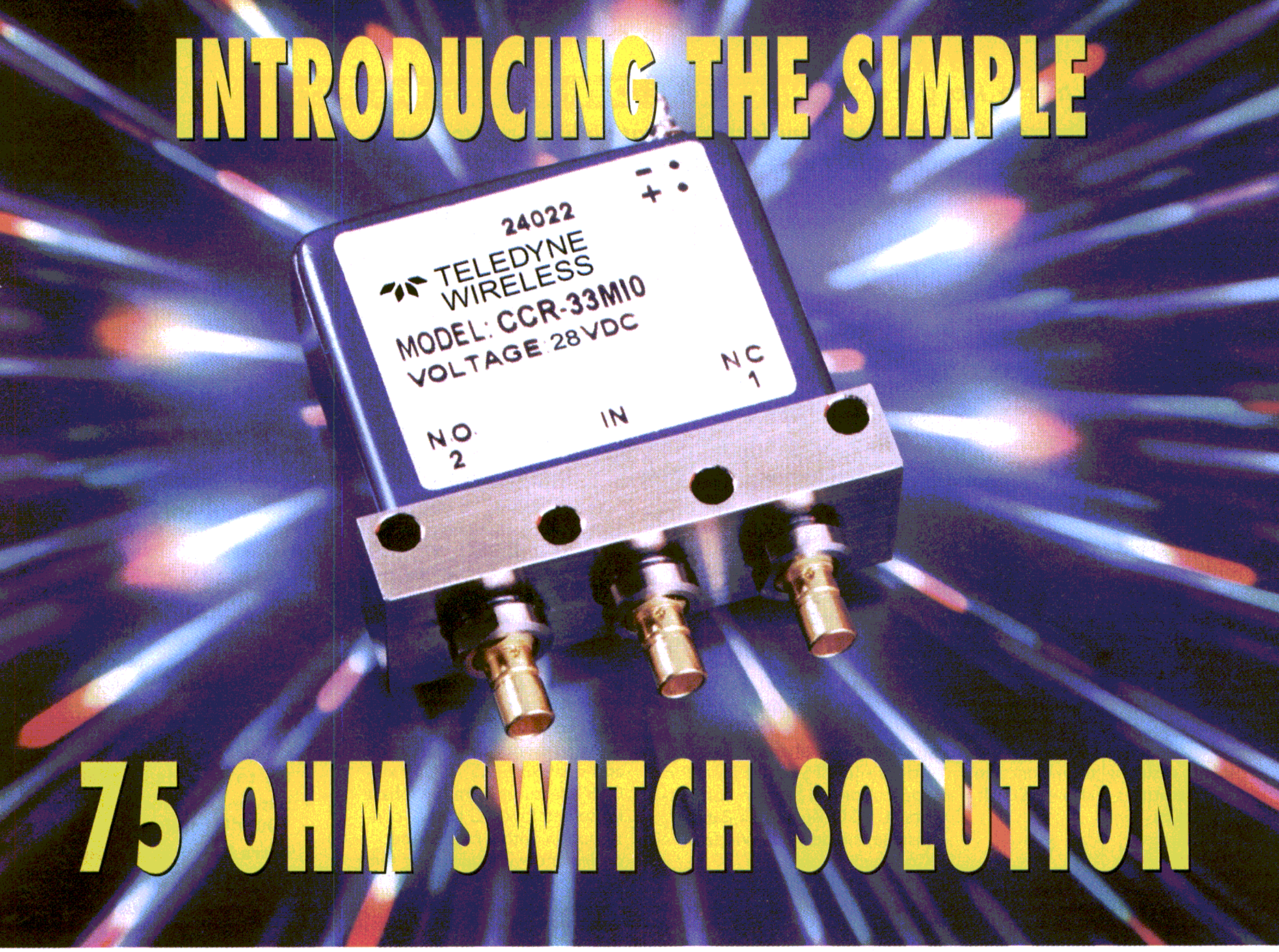
PHIL KARN OF Qualcomm has been on a one-man crusade to prove that VMSK and similar "Ultra Narrow Bandwidth" modulation methods do not work. The reason for this is rather obvious—if a satisfactory method were proven in the marketplace, Qualcomm would be out of business. Karn, however, denies any Qualcomm interest.

VMSK is not the only narrowband method. It has predecessors going back 16 years. VMSK just happens to be the first one to be successfully tried over the air. Two cellular operators have made frequencies available for VMSK testing—after they witnessed the first successful demonstrations. Over-the-air tests are continuing in the US and Europe. Karn is very annoyed that we will not mention names so that he can pester them.

I would like to quote Dr. W.C.Y. Lee from his latest book, *Essentials of Wireless Communications* (McGraw Hill), "AlphaCom technology can also be used. It can send a 48 kb/s MD3 data stream through a 2 kHz filter and receives with good quality. The idea is to slightly mark the states of the modulation using VMSK so that less distortion of the carrier waveform can be achieved. Of course, we know that the undistorted CW carrier only needs a 1 Hz filter in principal." Having been present when Dr. Lee made his own VMSK measurements at Vodafone, I can say that he had adequate test equipment and demo hardware available.

VMSK does work. The only question is how well? Those who wish to participate in the debate should visit <VMSK.org>. Karn's comments are posted there also. His negative comments have been helpful to many experimenters, professors, and students. I personally congratulate K.H. Sayhood and Wu Lenan on their eye-opening paper.

H.R. Walker



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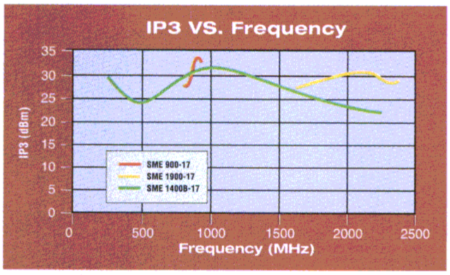

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SME 1400B-13	1-2200	1-2200	1-2000	+13	+9	+22	6.5	30
SME 1400B-17	1-2200	1-2200	1-2000	+17	+13	+27	6.5	30
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Learning From A History Lesson

HISTORY LESSONS CAN be instructive and insightful. Assembling this 40th Anniversary issue required a look back through four decades of articles, news events, products, companies, technologies, and people. And sometimes we forget that there may be people around us who may be able to teach us the greatest lessons of all.

If you are fortunate to work alongside a Bob Traut or a Phil Cheney, do not take the time for granted; learn what you can from these valuable resources.

To learn from history, numerous visits were made to different companies on both Coasts, to a variety of individuals usually with considerable tenure at their companies. Originally, these "company histories" were to appear in this issue. A few do, such as the story of ARRA (Bay Shore, NY) and the Isaacsons. But the majority of these company histories, companies such as Anritsu/Wiltron (Morgan Hill, CA), M/A-COM (Lowell, MA), Raytheon (Lexington, MA), and even a few companies that didn't survive through the years, such as Avantek (Santa Clara, CA), will appear in subsequent issues in 2001. Apologies to all those companies and people who took the time to sit before our tape recorders in the hopes of appearing in August—we will run your stories, but later than expected. It is a way to extend our 40th Anniversary celebration throughout the rest of the year!

There is much to learn from some of the "elder statesmen" in this industry. Compiling these stories provided an opportunity to sit with some knowledgeable people, such as Bob Traut of Rogers Corp. (Rogers, CT), Tom Rose of M/A-COM, and Phil Cheney of Raytheon Co. In terms of longevity, Bob Traut would be an award winner in most contests, with more than 51 years at Rogers.

Similarly, Phil Cheney, who will retire from his spot as Vice President of Engineering for Raytheon at year's end, has enjoyed 40 years at the company, bridging the years from when vacuum tubes were king and transistors were first developed to our current technologies of microminiaturization and solid-state integration.

In sitting with people like Bob Traut, Tom Rose, and Phil Cheney, there is always that one additional detail that one would like to extract from these "living history books." It was certainly cherished time spent with these folks. On this magazine, there have been a number of these teachers over the years, people like Howard Bierman, Stacy Bearse, and that legendary salesman, Harry Dolan.

Perhaps the lesson for today is this: If you are fortunate to work alongside of a Bob Traut or a Phil Cheney, do not take the time for granted. Learn what you can from these valuable resources. For they have been where you are going, and they have done what you are trying to do, and this wisdom is never easy to come by.

Jack Browne

Publisher/Editor

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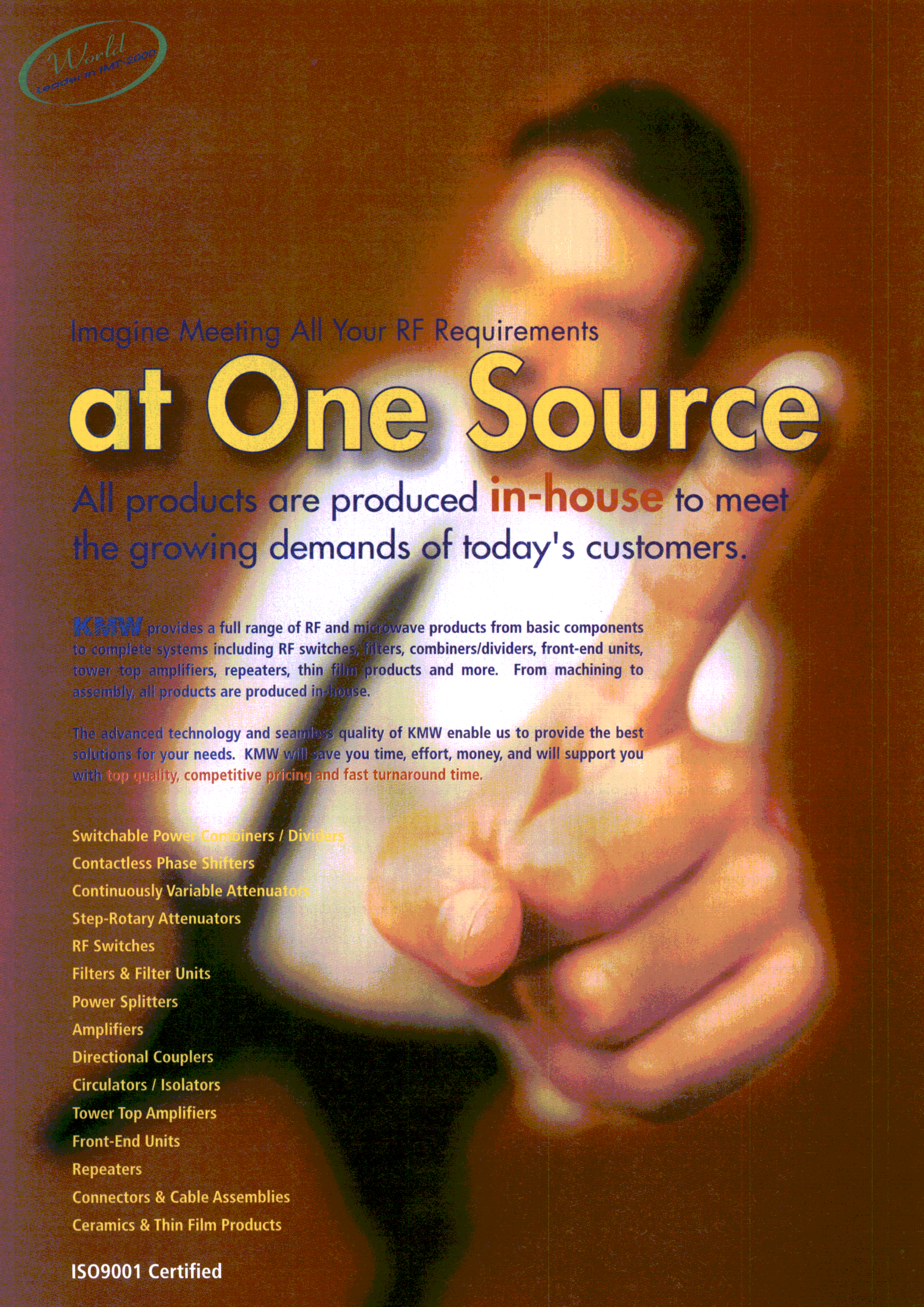
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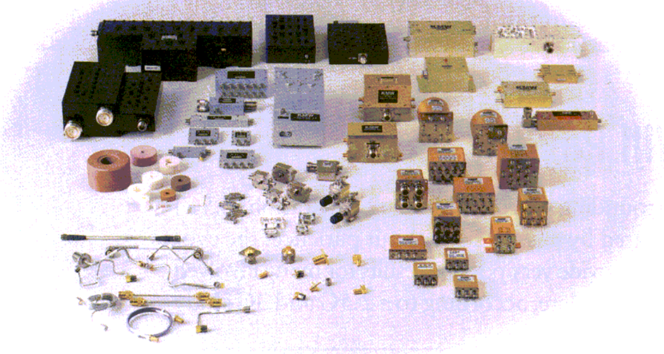

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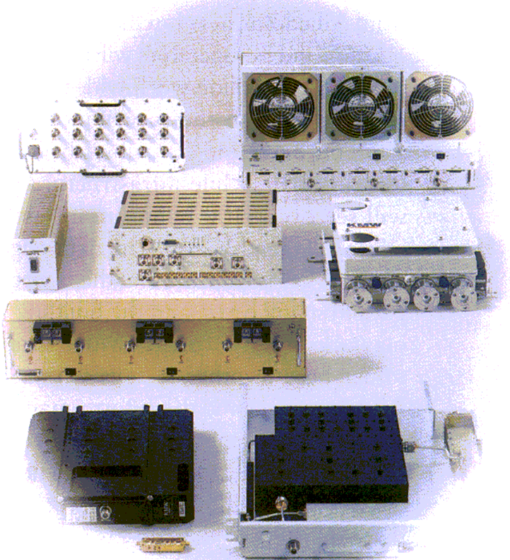

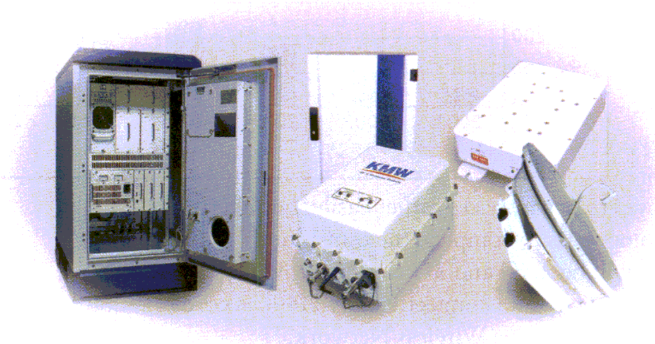

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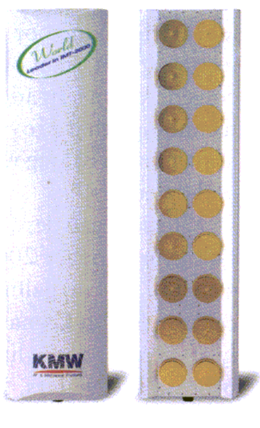

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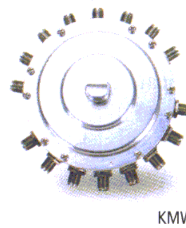

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the front end

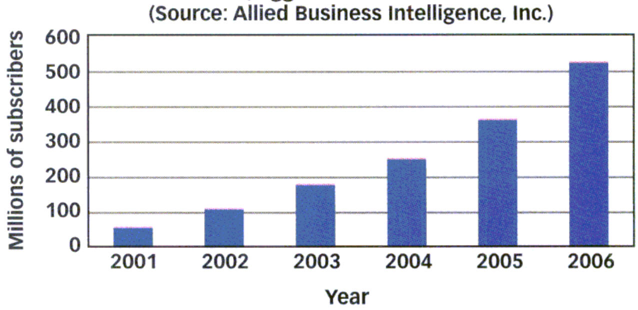
News items from the communications arena.

2G And 3G Evolution Will Pay Off

OYSTER BAY, NY—Despite the negativity surrounding second-and-a-half generation (2.5G) and third generation (3G) that has been created by pessimists without patience, the evolution of second-generation (2G) networks will provide very positive results for many involved in the wireless industry once the migration is complete, according to a 2.5G and 3G study from Allied Business Intelligence, Inc. (ABI).

2.5G and 3G operators will realize approximately $300 billion worldwide in subscriber revenues from an audience of more than half a billion 2.5G and 3G subscribers in 2006 **(see figure)**, while infrastructure vendors will see over $100 billion in infrastructure sales of 2.5G and 3G base stations through 2006.

2.5G and 3G subscribers
World market, aggressive forecast: 2001 to 2006
(Source: Allied Business Intelligence, Inc.)



"The key is realizing that this is an upgrade path in many cases, and the building of new networks by large carriers with a sizable customer base in others," says Larry Swasey, ABI's president and the report's main author. "In both cases, subscribers can be turned over to new services rather easily, but like any other evolution in technology it will take some years to complete the transition."

More than half of all handset shipments will be 2.5G and 3G compliant, while over three-quarters of all handsets will have some type of data connectivity by 2006, according to ABI's report, "2.5G and 3G—The Evolution of the Wireless Network."

InP Process Enables OC-768 Performance

CAMARILLO, CA—Vitesse Semiconductor Corp. has announced its latest process technology for the manufacture of analog and digital integrated circuits (ICs) for data transmission at rates in excess of 40 Gb/s. The process is built around indium-phosphide (InP) heterojunction bipolar transistors (HBTs). The first generation of the InP HBT process will be used to manufacture physical-layer ICs for Synchronous Optical Network (SONET) OC-768 applications and circuitry for 10-Gb/s systems that use return-to-zero (RZ)-encoded data. Succeeding generations will provide ICs with up to 100-Gb/s levels of performance and integrated optical devices, thereby providing the capability to manufacture true monolithic optical ICs (OEICs).

The first generation of the InP HBT process uses a vertical, mesa-isolated NPN bipolar transistor having a demonstrated peak f_{au} of 150 GHz and a peak f_{max} of 160 GHz. The transistor performance is consistent with the bandwidth and edge-rate requirements of circuits operating from 40 to 50 Gb/s.

"InP is the only IC technology that combines the high-frequency performance and high breakdown voltage required to implement all transmit, receive, and clock-recovery functions for 40-Gb/s systems," states Alan Huelsman, Ph.D., Vitesse's director, InP Program. "All other IC technology choices result in compromises in system performance or complications in architecture for thermal or functional partitioning considerations. In addition, InP is the only IC technology that provides a path to monolithic integration of long wavelength optical sources and detectors."

Vitesse began development of InP HBT technology in January 2000, using the company's 4-in. (10.16-cm) gallium-arsenide (GaAs) production line in Camarillo, CA. Approximately 50 percent of the line has been converted to process InP wafers. First HBT devices were successfully completed in December 2000.

CTIA Signs Agreement With Chinese Counterpart

WASHINGTON, DC—The Cellular Telecommunications & Internet Association (CTIA) announced that it has signed a Memorandum of Understanding with the Chinese Institute of Communications (CIC), the pre-eminent telecommunications trade association in China. The agreement, which was signed in Beijing, China, recognizes that "a close, cooperative relationship between the two organizations will contribute to the sound growth of the wireless communications industries of the United States and China, the two largest wireless markets in the world."

"China and the United States are the two largest wireless countries in the world. With five million new subscribers per month, the size of the Chinese wireless industry will soon pass that of North America," says Tom Wheeler, CTIA's president and CEO. "This agreement establishes strong cooperative ties between those two powerhouse markets and pledges that CIC and CTIA will work to build successful relationships between the carriers and suppliers of the two countries. It is the foundation for opening even more doors and advancing the wireless industry to benefit both regions."

The memorandum further states, "CTIA and CIC pledge to work together to support development of the wireless industry in both the United States and China through a variety of means, including the exchange of information, joint seminars and shows, study programs, and regular meetings."

"China and the United States are the two largest wireless countries in the world. With five million new subscribers per month, the size of the Chinese wireless industry will soon pass that of North America."

Electronic-Chemical Demand To Grow 10 Percent Annually Through 2004

CLEVELAND, OH—World demand for electronic chemicals is forecast to grow more than 10 percent per year to $17.6 billion in 2004, outpacing gains in electronic-component shipments due to an above-average performance in the key semiconductor segment and a steady shift toward higher-performance chemicals. After a relatively weak showing in 1998 and early 1999 due to a slump in the global semiconductor industry, electronic-chemical suppliers should benefit from aggressive spending on new and upgraded chip-making facilities, particularly facilities dedicated to next-generation 300-mm wafers and sub-0.25-µm design technology. Based on imperatives to invest in this new technology, long-term prospects for chemicals remain favorable despite periodic volatility in the semiconductor industry, such as the weakness that emerged in the first quarter of 2001, particularly in the US. These and other trends are presented in *World Electronic Chemicals,* a study from the Freedonia Group, Inc., an industrial market-research firm.

Photoresists will post the strongest long-term growth as the industry shifts from conventional g-line resists to advanced I-line and deep-ultraviolet (DUV) resists. Constant improvements in the performance parameters of photoresists are directly linked to the ability of chipmakers to squeeze an increasing number of transistors onto their chips (thus increasing processing speed), making this segment the focus of much of the industry's research-and-development (R&D) efforts. For instance, even as DUV resists are just gaining widespread use, a consortium of suppliers and government labs is working on a new generation of extreme-UV (EUV) resists, which should hit the market in approximately 2005 and offer features down to the 30-nm level.

Digital Head-End Systems To Be Delivered And Integrated

DENVER, CO AND SUNNYVALE, CA—Broadband network provider WINfirst has selected Harmonic, Inc. open-system solutions for digital head ends in Sacramento, CA and Dallas, TX where WINfirst is building a fiber-to-the-home network.

Harmonic has also contracted to provide professional services, including system design and integration with other third-party technologies supporting the WINfirst interactive TV platform.

The WINfirst deployment features Harmonic's digital-TV (DTV) head-end systems, including the DiviCom family of encoders, MN20 multiplexers, SimulCrypt conditional-access interfaces, the Narrowcast Services Gateway for video-on-demand applications, and the InterSect Internet-protocol (IP) set-top gateway. These systems will enable WINfirst to offer more than 200 channels of video and audio, enhanced pay-per-view, and video-on-demand services.

Wireless Prices Drop As Competition Increases

WASHINGTON, DC—The Federal Communications Commission (FCC) has released a report detailing a number of wireless industry indicators, including price per minute, number of competitors per market, and minutes of use. The report reflects increased growth in the number of consumers, climbing minutes of use, falling rates, and heightened competition.

"The growth of the wireless industry has benefited consumers on all fronts, delivering lower prices, broader coverage, new services, and a tool which can help save lives," says Tom Wheeler, president and CEO of the Cellular Telecommunications & Internet Association (CTIA). "It's a record we are proud of."

"CTIA would like to see US spectrum for next-generation services aligned with that of the rest of the world, which is migrating to the 1710-to-1855-MHz band."

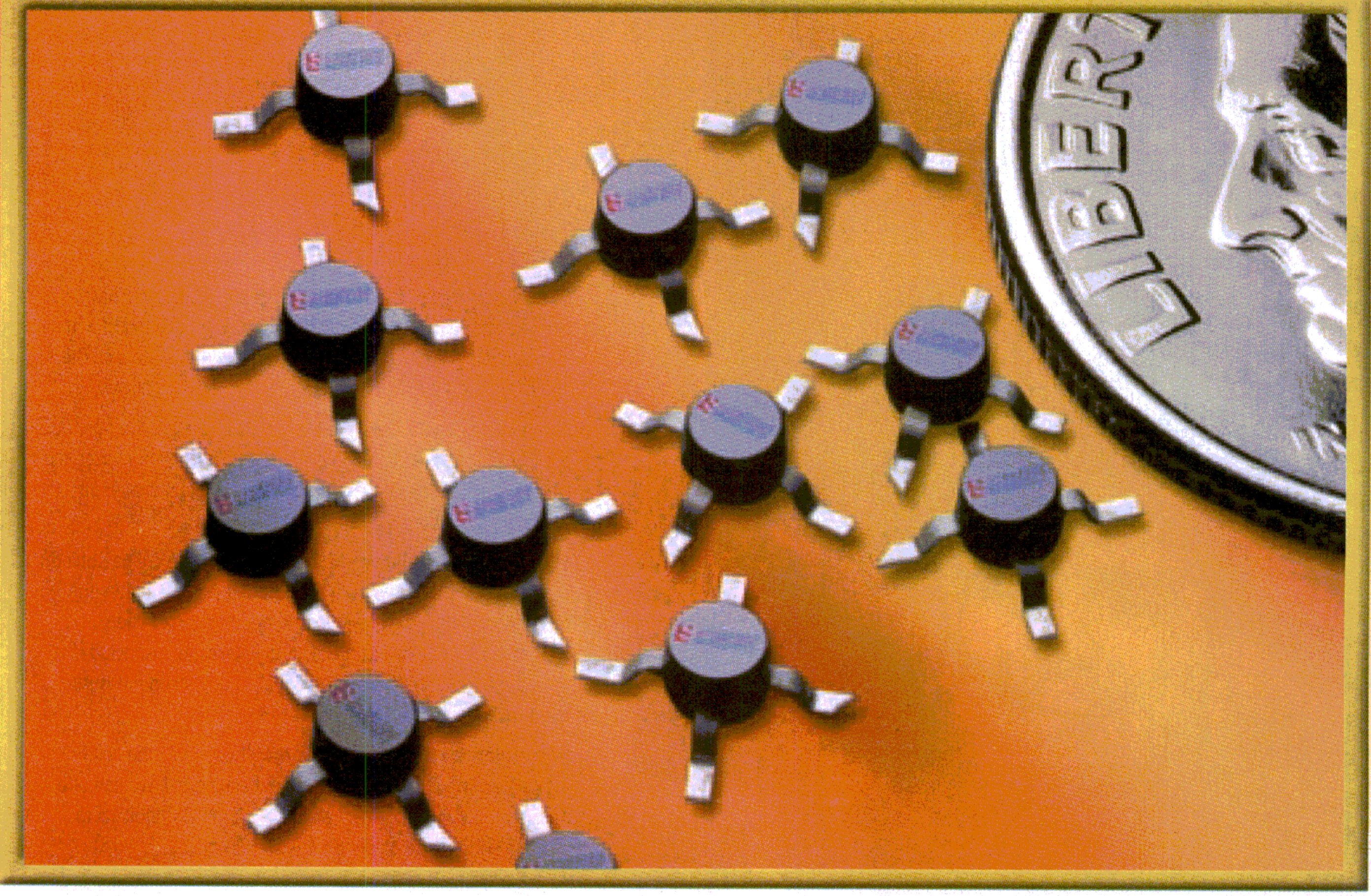
The report found that the wireless industry experienced "another year of strong growth and competitive development." As of December 2000, the report cited 109.5 million US subscribers, a penetration rate of 39 percent. The FCC cited US Department of Labor Bureau of Labor statistics and found that prices fell 12.3 percent during the year 2000.

The report further states, "Since late 1999, seven major mobile-telephone operators have begun offering mobile data services, including "wireless web," short-messaging service, and e-mail on mobile-telephone handsets. Four of those seven operators reported their mobile Internet usage at the end of 2000 and had a combined total of 2.5 million mobile Internet users."

CTIA has asked the FCC for more spectrum to make room for the expected growth of the industry in voice and wireless data. Specifically, CTIA would like to see US spectrum for next-generation services aligned with that of the rest of the world, which is migrating to the 1710-to-1855-MHz band.

Kudos

Flarion announced that Rajiv Laroia, its founder and CTO, was selected for the *BUSINESS NEWS New Jersey* "40 Under 40." *BUSINESS NEWS New Jersey* bestows "40 Under 40" recognition every year to business achievers, including entrepreneurs and corporate executives, willing to take risks and assume responsibility. Laroia was recognized for researching and developing the next generation of mobile wireless technology...The US House of Representatives has approved a resolution by Congressman Mark Udall (D-CO) and Congresswoman Connie Morella (R-MD) honoring the National Institute of Standards and Technology (NIST) on its 100th anniversary...Tektronix was awarded a Gold Medal for its advanced network-monitoring system at the 2001 International Telecommunication Show (ITS), which was held earlier this year in Lodz, Poland. The Intertelecom Gold Medal, first awarded in 1994 to innovative products presented by ITS exhibitors, recognizes Tektronix' Net-7 network-monitoring system as one of the "most interesting products or technology solutions demonstrated at the ITS"...International Crystal Manufacturing has met the standards required for ISO-9002 certification, according to Beth Freeland, ICM's president...ITT Industries, Cannon announced that revenue of $265,000 was raised at a golf tournament benefiting the Muscular Dystrophy Association (MDA) attended by many companies in the electronics industry. The ITT Industries, Cannon "Golf Classic" is the longest-running golf tournament held on behalf of MDA, a voluntary health organization dedicated to eradicating 40 neuromuscular diseases, some of which are fatal. Funds raised at the ITT tournament are used by MDA for patient care and research...Global distributor Avnet, Inc. has garnered seventh place among *Computerworld* magazine's annual listing of the "100 Best Places to Work in IT"...Cambridge Silicon Radio (CSR) has won the award for Best Bluetooth Component 2001 at the Bluetooth Congress in Monaco. CSR's BlueCore™ single-chip solution was awarded the winning trophy at the Special Award Ceremony, which took place at Monte Carlo's Hotel de Paris preceding the Bluetooth Congress exhibition...Valtronic was honored at Mentor Graphics 15th Annual PCB Technology Awards. Each year, Mentor Graphics hosts a competition that includes entrants from the computer, consumer-electronics, industrial-control, military/aerospace, transportation, telecommunications, data-communications, and wireless-communications industries. Valtronic's winning entry in the industrial-controls category, a Picture Reader for Barcode 2D, was designed by Gabriel Gay and Van Ly Mai of Valtronic's Switzerland facilities...Agere Systems announced that the ORiNOCO™ USB Client is the first and only universal-serial-bus (USB) wireless-networking radio on the market to receive the Wi-Fi and USB Compliance Test certifications. MRF



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Part Number	Freq (GHz)	P1dB (dBm)	OIP3 (dBm)	Gain (dB)	NF (dB)	Vd, Id (V, mA)	Rth (°C/W)
NGA-186	DC–8.0	14.7	31.7	12	4	4.1, 50	120
NGA-286	DC–6.0	15	31.2	15	3.4	4.0, 50	120
NGA-386	DC–4.0	15	27	19	2.7	4.0, 35	144
NGA-486	DC–8.0	17.5	39.5	14.5	4.5	4.2, 80	118
NGA-586	DC–6.0	19	38	19	4.5	5.0, 80	121
NGA-686	DC–4.0	19.2	35	11	6.1	5.9, 80	121

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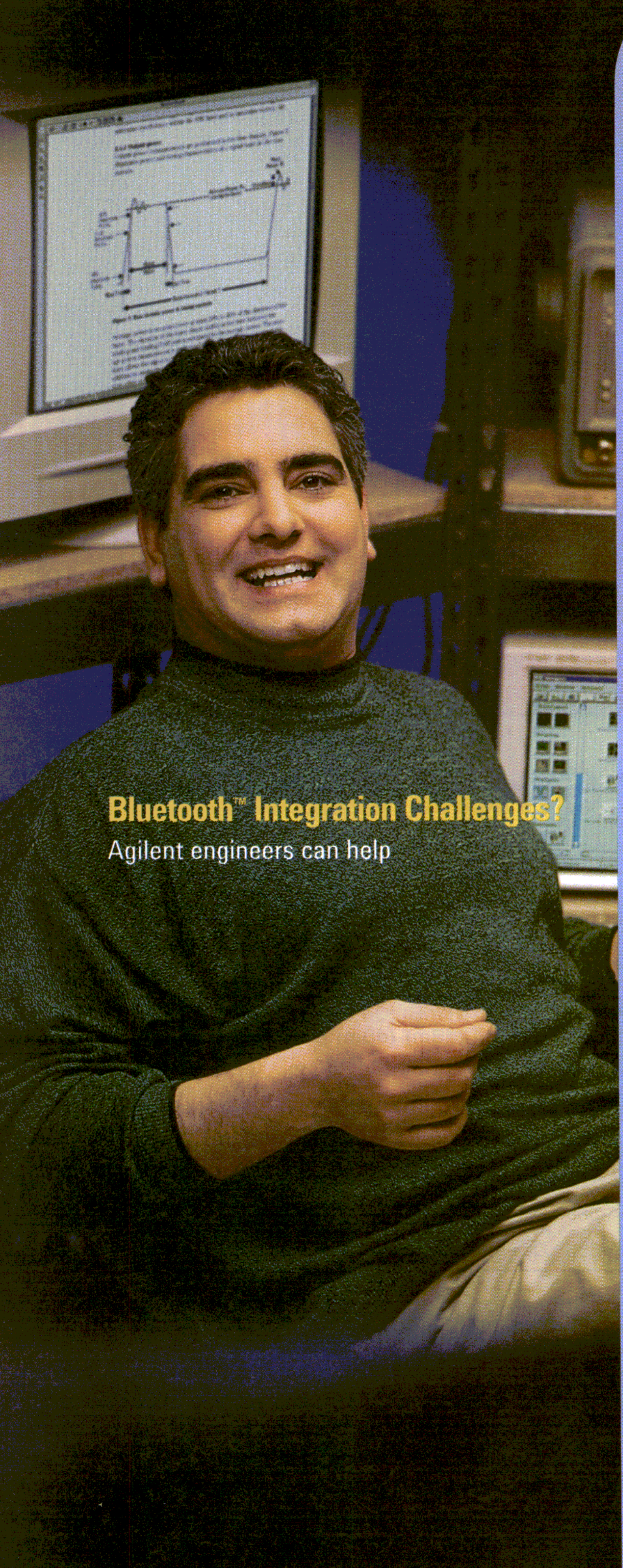


It probably started with a conversation over in marketing: "*Bluetooth* wireless technology is the next big thing! We have to put it in all our products! Details? Bah, all you do is add an antenna. The engineers will figure it out. Let's go see if they're finished yet."

And now you and a few thousand other engineers are figuring out that *Bluetooth* integration is not a trivial task. From baseband DSP to RF interference, you've got an integration challenge worthy of legendary King Harald himself.

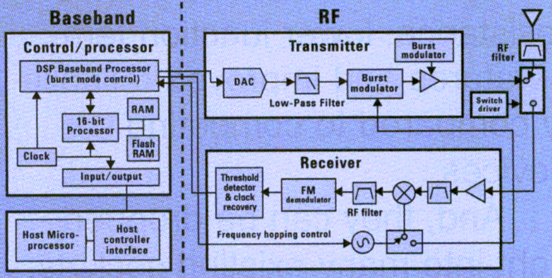
Welcome to the wild world of RF. New to RF? We've pooled the talents of our digital, DSP and RF experts to identify the most important signal checks you'll need to make when integrating *Bluetooth* designs. Our online resources include everything from an RF basics seminar to advanced measurement techniques.

Something for the RF experts, too. If you have the luxury of approaching *Bluetooth* from an RF background, we can offer advice on the most-efficient test procedures and toolsets to tackle a wide range of *Bluetooth* measurements.

The *Bluetooth* big picture. Most of the *Bluetooth* work we're seeing today involves the integration of a *Bluetooth* module into a new product design:

- Evaluating module performance and characterizing interoperability
- Understanding host-module integration issues
- Designing and debugging the host-module interface
- Conducting pre-qualification RF testing
- Getting *Bluetooth* Qualification
- Manufacturing quality products

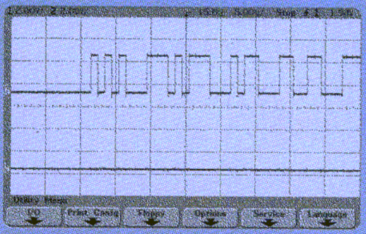
Some of the more interesting problems show up in the second stage, as you bring the RF transceiver into your host products.



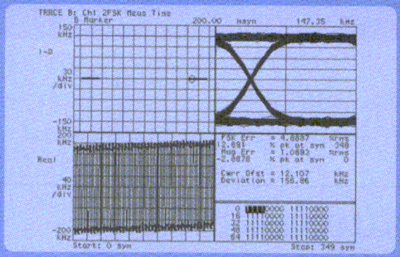
Watch out for some interesting interoperability problems when you integrate a Bluetooth module into your host device

Baseband signal integration. Challenges here include verifying transmission and receipt of data packets, viewing the actual data values transmitted, quantifying system bottlenecks, identifying logic errors, and resolving DSP and mixed-signal issues.

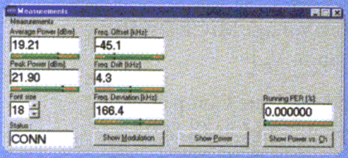
For instance, once you've found the preamble, you can identify the entire bit stream, including the access code, header and payload. Learn more in our free *Bluetooth* baseband application note.



The first two pulses in this idealized transmit signal correspond to the 0101 pattern of the preamble; the access code follows immediately after



Bluetooth measurement tools range from powerful design analysis to fast, automated tests for the production line. Above, a modulation characteristics test verifies proper performance of the modulation circuitry to ensure reliable data transfer over the Bluetooth communication link.



At left, an automated test combines pass/fail indications with numerical readouts

RF receiver tests. RF receiver performance is key to both *Bluetooth* qualification and overall product performance. For example, a sensitive radio that is immune to interference will reduce file transfer times and therefore increase battery life. You need to make sure the RF receiver will not be adversely impacted by the harmonics of high-frequency digital signals or other noise sources likely to be present in your system.

Receiver performance is tested in a number of ways for qualification, including carrier/interference and blocking tests. You probably won't need to run all the tests if you're integrating someone else's module, but they can be complicated so clear information and simplified procedures are important.

RF transmitter tests. The *Bluetooth* specification covers a wide range of transmitter tests, some to insure interoperability between *Bluetooth* devices (e.g., modulation characteristics) and others to meet regulatory limits (e.g., spurious emissions). Given the concerns about interference with other wireless systems, output spectrum tests are also important.

Integrating a module can create problems that affect transmitter performance, sometimes in unexpected ways. For example, power supply ripple coupled through your system can degrade the modulation characteristics.

You must be able to show that your device stays within both *Bluetooth* and regulatory limits, and the more of this work you can do on your design bench, the better. Some of the tests are complex and potentially time-consuming to understand and perform. Our free online application resources can help you look for and fix problems quickly.

Get the complete *Bluetooth* test story—FREE. Talk to one of our *Bluetooth* measurement specialists to learn more or tap into our free technical resources at www.agilent.com/find/bt.
Among the features you'll find there:

- A comprehensive measurement guide: *Performing Bluetooth RF Measurements Today* featuring descriptions and examples of the many RF measurements you might need
- Interactive measurements that show some key *Bluetooth* measurements in action, starting with frequency drift and frequency settling—explore these real-life measurements before you need to make them on your own system

We can't do much about your enthusiastic friends in marketing, but we can definitely help you through the *Bluetooth* integration experience.

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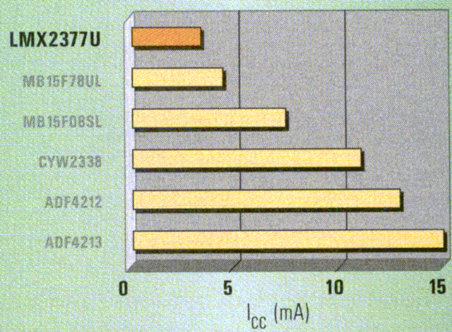

New Generation 'U' Family

Product	Active I_{CC} (Typ @ 3V)	Operating Frequency
LMX2330U	3.3 mA	2.5 GHz / 600 MHz
LMX2331U	2.9 mA	2.0 GHz / 600 MHz
LMX2332U	2.5 mA	1.2 GHz / 600 MHz
LMX2335U	2.5 mA	1.2 GHz / 1.2 GHz
LMX2336U	3.5 mA	2.0 GHz / 1.2 GHz
LMX2377U	3.4 mA	2.5 GHz / 1.2 GHz

Previous Generation 'L' Family

Product	Active I_{CC} (Typ @ 3V)	Operating Frequency
LMX2330L	5.0 mA	2.5 GHz / 510 MHz
LMX2331L	4.0 mA	2.0 GHz / 510 MHz
LMX2332L	3.0 mA	1.2 GHz / 510 MHz
LMX2335L	4.0 mA	1.1 GHz / 1.1 GHz
LMX2336L	5.5 mA	2.0 GHz / 1.1 GHz
LMX2370	6.0 mA	2.5 GHz / 1.2 GHz

National Semiconductor
The Sight & Sound of Information

cover story

Garage Gives Birth To Measurement Giant

The story of Hewlett-Packard Co., and subsequently Agilent Technologies, is a capsule history of test-and-measurement techniques and equipment for the microwave industry.

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BARRY MANZ
Presidentt
Manz Communications, Inc., 350 Main Rd., Montville, NJ 07045; (973) 316-0999, E-mail: barry@manzcom.com.

beginning in 1939 with only $538—an amount that today barely covers a month's electric bill in Palo Alto, CA—Bill Hewlett and Dave Packard started a company in the garage behind the home they shared at 367 Addison Rd. These two Stanford University graduates were responsible not only for starting a test-and-measurement technological revolution, but for a business philosophy that has been taken to heart by Silicon Valley's most accomplished companies.

And it is comforting to remember that RF and microwave technology was HP's primary driver for more than 25 years, and that this technology and the HP philosophy live on today, in the form of Agilent Technologies.

The story of HP's foray into microwave technology, and the development of its RF and microwave products have been chronicled less frequently than the story of how Walt Disney provided the company with its first big boost by ordering eight of its model 200B audio oscillators for use in the film *Fantasia*. Or the story of how Packard created "management by walking around," or even the story of the role played by Stanford professor Frederick Terman in shaping the "HP Way" and his vision of an electronics industry knowledge center in the Valley. Nevertheless, that foray and its subsequent developments were every bit as important for the US economy, for the tens of thousands of people who participated in them, and for what the microwave industry has become today.

The company's entry into the RF and microwave instrumentation marketplace came about gradually. Soon after the company's founding in 1939 **(Fig. 1)**, Hewlett entered the US Army Signal Corps for technical assignments in radar at Ft. Monmouth, NJ. Packard remained in Palo Alto, managing the fledgling company and its wartime production operation. The company's entire product line consisted of the 200A audio oscillator, the 400A voltmeter, an audio signal analyzer, and some crystal-stabilized frequency standards.

The company produced its first RF measurement product in 1943. The Model A signal generator covered 500 to 1350 MHz, and was designed for the US Navy. A commercial version, the 610A ultra-high-frequency (UHF) signal generator, was introduced in 1948. In the late 1940s, Varian Associates, founded in Palo Alto by Russell and Sigurd Varian, inventors of the klystron tube, offered HP a small line of waveguide test equipment. The Varian brothers felt that development of the line would detract from their tube business. The product line consisted of some waveguide slotted lines and other components such as directional couplers.

In the same period, the US Naval Research Laboratory contracted with HP to design klystron signal generators, which led to a commercial product, the 616A signal generator, with coverage to 4.2 GHz. It was followed by generators working to 21 GHz.

By 1950, the product line had grown to include the 430A power meter and a double-tuned 475 bolometer sensor. Other innovations expanded the HP line of coaxial equipment, such as the 805A "parallel-slab" slotted line, which cleverly constrained the RF fields mostly at the side walls, and effectively made the 3/4-in. (1.91-cm) open-slot function as a slot only a few thousands of an inch wide.

Part of the reason for HP's continued attention to microwave research was Hewlett's recruiting of several engineers from wartime research facilities on the East Coast **(Fig. 2)**. Several of these engineers would ultimately become primary participants in the company's future. Bruce Wholey, who later advanced to Microwave Division Manager in 1962, came from Terman's Radio Research Lab at Harvard, working in electronics countermeasures. Art Fong had been working in radar at MIT's Radiation Lab.

1. The starting place for a multibillion-dollar international company was a simple garage in Palo Alto.

AGILENT/HP

From the early days of thermistor power sensors, HP heeded the cry for a thermistor sensor that would not respond to the warmth of the human hand, introducing the 431A temperature-compensated power meter in 1961.

When Hewlett was setting up European distribution for this product, he bought the patent rights to a novel noise-figure measurement concept from the Swedish company Magnetic AB. This led, in 1958, to the 340A noise-figure meter. Later, the 524B frequency counter, with its plug-in versatility, launched HP into the frequency and time business.

By the mid 1950s, the proliferation of product lines was creating problems in managing different product and business strategies. To provide more specialization, the corporate research-and-development (R&D) lab was divided in 1958 into four product groups: audio-video, frequency and time, microwave, and oscilloscopes. Total worldwide business in 1959 was $47.7 million, and HP's 165-page catalog that year boasted 150 products.

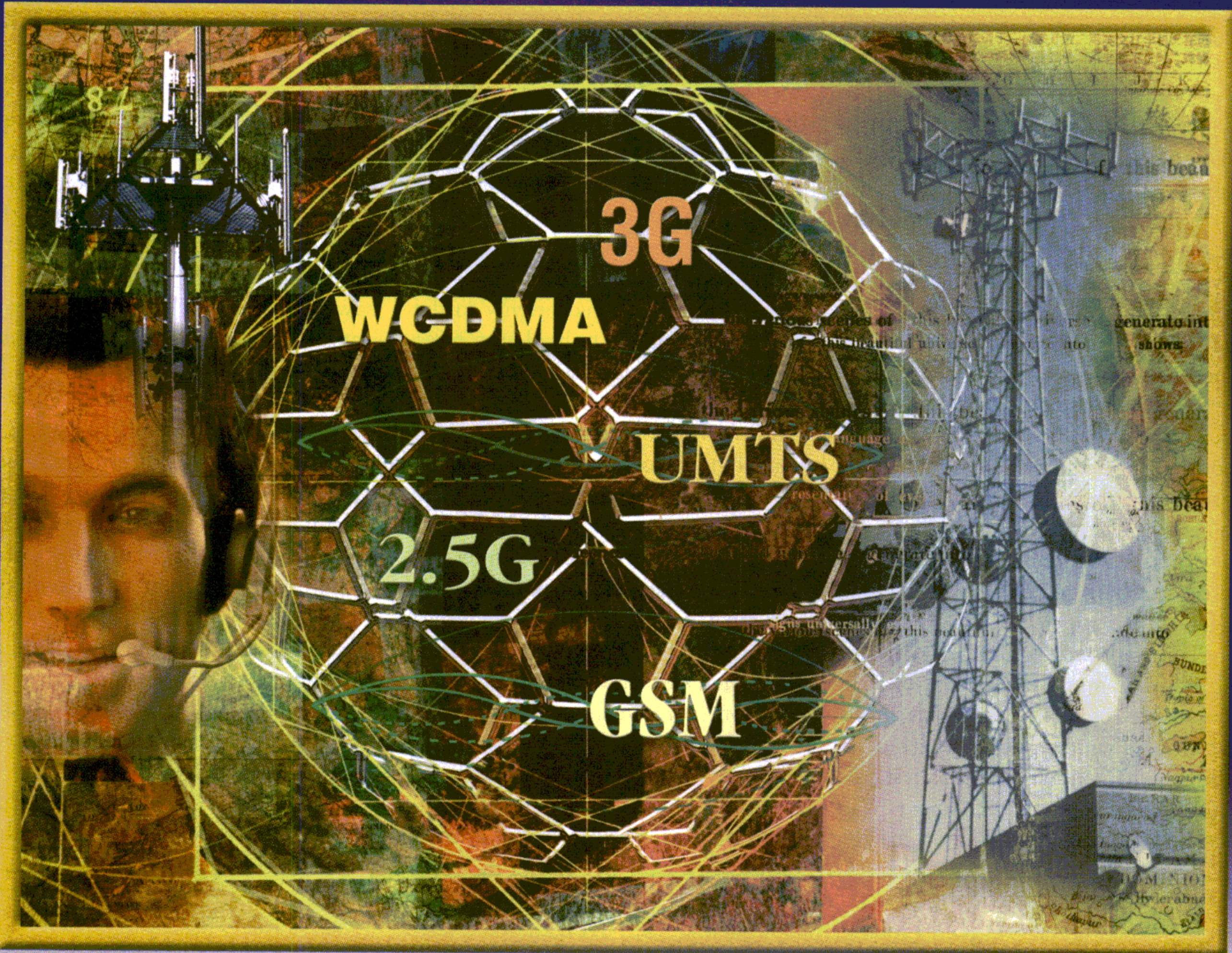
Focusing on individual product lines in the design labs worked well, and by 1962 the company's sales had grown to $109 million. Manufacturing operations expanded to Europe and Colorado, and several technology-company acquisitions were made.

This reorganization continued in 1962, as the four major product lines became full operating divisions, of which the microwave division was one. Bruce Wholey was named general manager, but soon acquired other responsibilities.

In 1964, John Young became division manager of the microwave division, and filled out his management team with John Doyle in manufacturing and Paul Ely in R&D. John Minck became marketing manager. Ely was already known for his microwave management experience at Sperry Microwave in Florida. Young managed the Microwave Division for approximately six years, and then progressed through various vice-presidential positions to become the company's CEO in the 1980s.

The Microwave Division hit its stride in the 1960s, and its new product lines changed the face of microwave measurements. In 1964, the Model 8551 spectrum analyzer put HP into the spectrum-analyzer market and, in the process, expanded the market five-fold, since it made measurements in ranges that previous analyzers could not reach.

In 1968, the 8410 vector-network-analyzer (VNA) product line revolutionized microwave-component design with the concept of characterizing the scattering parameters of test devices. The project's slogan was "stamp out slotted lines." Major accomplishments



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SOT-89 Package

The wide frequency range and power efficiency of our SXA/SXT amplifiers make them an excellent choice for driver functions in repeaters and other infrastructure equipment covering the cellular, PCS, WLL, GSM, WCDMA, UMTS, ISM, IF and LO bands. And, exceptional linearity makes them an ideal option for multicarrier digital applications.

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Part Number	Frequency Range (MHz)	P1dB (dBm)	IP3 (dBm)	Gain @1950 MHz	Supply Voltage (V)	Current (mA)
SXA-289	5-2000	+24	+42	15.5	5.0	105
SXT-289	1800-2500	+24	+41	15.0	5.0	105

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were also made in signal generators, sweepers, power meters, and measurement components.

A crucial element of HP's success was a management innovation started by the Microwave Division in the mid-1960s. This was the now well-accepted "triad" management concept, which focused three-person teams from marketing, R&D, and production-on-product planning. Those product teams, consisting of young engineers, devised product strategies based on their combined knowledge of the market, applications, and technology, and then presented the strategy to division management for approval.

This approach contrasted with the strategy of many companies of that time, which created product plans from a central planning group. The genius of the arrangement was that the best creative ability of all team members was used, while also employing the insight of the company's marketing and business upper management during the reviews. Many of those young team members of the 1960s went on to become division and executive managers throughout the corporation.

HP has contributed heavily to the development of new technologies, most of which have found their way into the company's products. The step-recovery diode was one of HP's more important contributions to signal synthesis. In the early 1960s, engineer Frank Boff was working on harmonic-comb generators to extend the range of counter frequency converters. One circuit showed nonintuitive results, with high-frequency harmonics that were more powerful than what seemed theoretically possible from a nonlinear resistive device such as a diode.

To investigate further, he borrowed an early lab prototype of the HP sampling oscilloscope to display a time-domain picture of what was producing such rich signals in the frequency-domain. When Boff finally got the fuzzy picture focused, he did not see the expected chopped-off top of a sine wave produced by a diode, but rather, he saw a sine wave that rose smoothly to approximately full amplitude, then suddenly crashed to near-zero amplitude.

At that point, serendipity entered the scene. Boff remembered seeing a paper in the *IEEE Proceedings* which theorized that this waveform might exist if a device exhibited a nonlinear charge-versus-voltage curve instead of the nonlinear current-versus-voltage curve that defined a diode. Boff reviewed the article, looked again at the strange wave shape, and proclaimed that what he had taken to be a nonlinear resistor or diode was actually a nonlinear capacitor under certain conditions.

What he had developed was a variation of the well-known P-N diode that

enhanced the stored carrier phenomenon and achieved an abrupt transition from reverse-storage conduction to cutoff. The device was able to switch tens of volts or hundreds of milliamps in less than a nanosecond. The result was the ability to generate milliwatts of harmonic power at 10 GHz from stable oscillators running at 200 MHz. The device was called the "Boff diode" for a number of years, and later changed to the more generic "step-recovery-diode."

2. The founders of Hewlett-Packard Co., Dave Packard (seated) and Bill Hewlett, worked with very little operating capital but quickly built a giant test and measurement business.

HP capitalized on this new capability. HP counters used the harmonic-comb signals to downconvert test signals for counter coverage to 18 GHz. The 8410 series network analyzer used a two-channel version to downconvert microwave signals for characterizing S-parameters to 18 GHz. Sampling oscilloscopes used the diode to generate the large sampling impulses needed to measure transitions in the picosecond range. A generation of HP signal generators and sweepers used those harmonics to stabilize microwave signals, via indirect frequency synthesis.

HP also became the world leader in exploiting a family of sophisticated feedback loops, using synthesis techniques such as programmable "divide-by-N" loops. Not only did they discipline microwave oscillators and reduce their phase noise, they provided exact and programmable output frequencies.

Another variation of the P-N diode was the PIN version, which acted at low frequencies like a regular diode, but at RF/microwave frequencies similar to a programmable microwave resistor. This became the centerpoint for broadband control of signal amplitudes for leveling loops, and for a pulse generator with nanosecond rise and fall times.

HP also pioneered the development of sophisticated phase-locked loops (PLLs), which were optimized for fast switching, high stability, and spectral purity for extremely-low single-sideband (SSB) phase noise. It was a never-ending quest, and HP later designed specific instruments for characterizing SSB phase noise, as well as analysis of loop gain and stability.

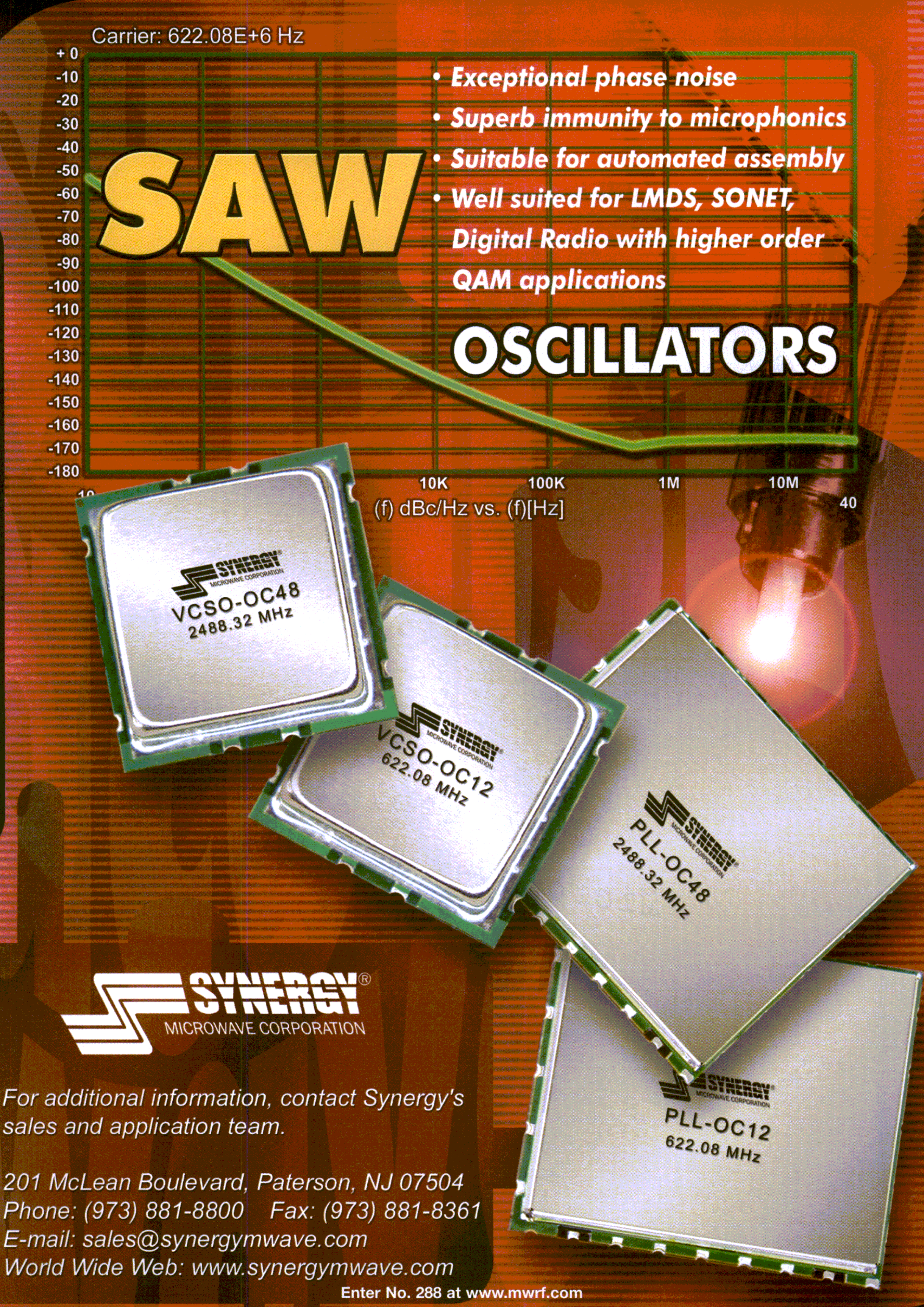
The 40-year history of *Microwaves & RF* magazine coincides with a period of enormous advancement in test and measurement. The contributions of HP were large and broad, as were the contributions of the people who brought them to fruition.

The distinction between signal generators, sources, and sweepers (or swept-signal generators) always seemed to confuse customers. Signal generators were intended for signal simulation, carrying modulation such as amplitude modulation (AM)/frequency modulation (FM)/pulse, and later phase and digital modulation. Later, in wireless test sets, the modulation would include the entire system of handshakes, protocols, and other functions. In contrast, sources were pure continuous-wave (CW) oscillators, generally without modulation, used for general-purpose and bridge drivers. Sweepers allowed the signal to be swept over a range of frequencies, and have been dominant in component design. In recent decades, with the power of microprocessors, the distinction between the basic types blurred as instruments were created that could perform multiple tasks.

Probably the most popular signal generator of the 1950s and 1960s was the 608C/D family. HP built tens of thousands of these very-high-frequency (VHF) instruments, and their vacuum-tube oscillators and power amplifiers (PAs) provided superior spectral purity and stability. Their semiconductor replacements, the 8640A/B of 1973, had cavity purity, with phase locking and a frequency counter.

What went unsaid was the superiority of vacuum tubes, including klystrons, for signal generation. The oscillator voltages of those tuned tank circuits or cavities provided outstanding signal-to-noise characteristics that took years for solid-state generators to match. Yet, the operating advantages of microwave transistors and yttrium-iron-garnet (YIG)-tuned oscillators in reliability and size were too much to resist, and after much development, methods such as phase-locking greatly improved spectral purity.

In its transition into synthesizer technology, HP found a way to stabilize PLLs with a VHF instrument, the 8708A. It was used to discipline and add narrowband FM to the 608E/F. However, the first integrated indirect synthesized signal generator was the 8660A unveiled in 1971, with versatile plug-ins that allowed its owner to choose from many modulation formats and frequency bands to 2.6 GHz. It was also programmable. The microwave synthesizer that revolutionized automated test systems with its general-purpose -inter-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-180
10K
100K
1M
10M
40
(f) dBc/Hz vs. (f)[Hz]
SAW
• Exceptional phase noise
• Superb immunity to microphonics
• Suitable for automated assembly
• Well suited for LMDS, SONET, Digital Radio with higher order QAM applications
OSCILLATORS
SYNERGY MICROWAVE CORPORATION
VCSO-OC48
2488.32 MHz
VCSO-OC12
622.08 MHz
PLL-OC48
2488.32 MHz
PLL-OC12
622.08 MHz
SYNERGY®
MICROWAVE CORPORATION
For additional information, contact Synergy's sales and application team.
201 McLean Boulevard, Paterson, NJ 07504
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World Wide Web: www.synergymwave.com
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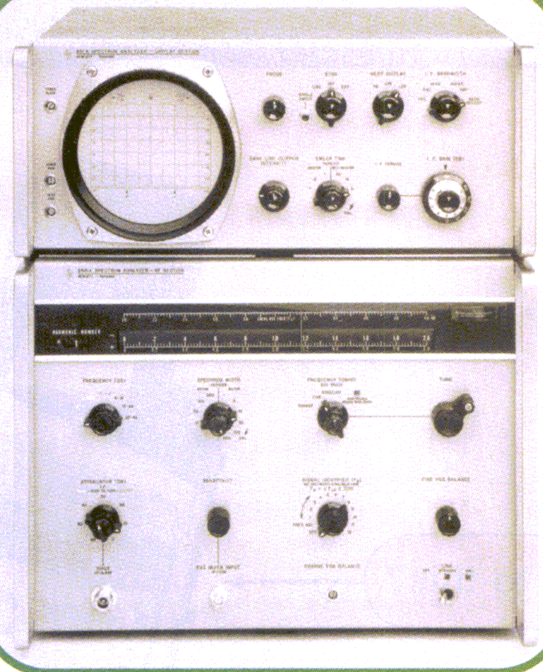
face-bus (GPIB) programming bus was the 8672A. Introduced in 1977, it covered 2 to 18 GHz.

Continuing developments yielded products such as Agilent ESG-series of digital signal generators, which generate the most complex modulation formats used in modern communications systems, including Global System for Mobile Communications (GSM), code-division multiple access (CDMA), time-division multiple access (TDMA), Digital European Cordless Telecommunications (DECT), Enhanced Data rates for Global Evolution (EDGE), as well as broadband in-phase/quadrature (I/Q) modulation.

The Model 5100A frequency synthesizer introduced in 1964 was developed in response to the US Navy's need for a fast-switching, direct-synthesized, high-resolution signal source for secure communications. The product covered DC to 50 MHz with a resolution of 0.01 Hz and crystal frequency stability of one part in 10^{10}.

The emergence of high-frequency digital circuits provided HP with the tools to create powerful digital-direct-synthesis (DDS) generator technology for use in secure communications. The Model 8770A arbitrary waveform synthesizer in 1988 created completely arbitrary waveforms from DC to 50 MHz using a fast digital-to-analog converter (DAC). This frequency-agile technology made it possible to hop from one frequency to another in 8 ns, the time that is required to move to a different sequence. Next, came fixed upconverters that could translate this 50-MHz band to microwave frequencies.

In 1991, the Model 8791A frequency-agile signal simulator (FASS) added frequency-agile upconverters that achieved a typical 100-ns agility to 18 GHz. In addition to impressive carrier agility, FASS used a special waveform-generation language that allowed users to program wide-bandwidth modulation of arbitrary formats such as nonlinear chirps, TDMA, and CDMA. These powerful simulators were able to recreate entire



3. HP's first spectrum analyzer in 1964, Model 8551/851A, became a frequency-domain oscilloscope, indispensable for RF and microwave workbenches.

channels of signals, noise, and interference, providing real-life signal environments for the qualification of receivers (Rxs).

As source technology moved from the backward-wave oscillators (BWOs) of the 1960s to solid-state YIG oscillators, sweepers for the more advanced network analyzers had to be programmable, as well as frequency repeatable, so that data-correction routines could be ensured. To do this, synthesized sweepers were required.

Synthesized signal generators were also required for automatic test systems that were designed to evaluate electronic-warfare (EW) Rxs. These tests required simulated modulations and programmable test frequencies. Landmark sweepers such as the 8340A and, more recently, the Agilent 8360, packed remarkable functionality into user-friendly packages.

Wholey launched HP into the spectrum-analyzer market in 1964, partly driven by pressure from field sales engineers who were looking for a new market area. The business was dominated by the Polarad Co. (Long Island City, NY), which was a prime contractor for military analyzers. They mostly used single-band, tunable klystrons as the first local oscillator (LO), with a sweeping second LO for 100-MHz sweep width (dispersion, in the jargon of the day). The Panoramic Co., also on Long Island, was soon building a multiband unit, capable of 2 to 12 GHz, downconverted with harmonics of the first LO.

The project engineer assigned to the HP analyzer was Fong, whose experience at MIT had involved signal generators and spectrum analyzers, including waveguide components. By designing a sweeping first LO using a BWO for the source, it was possible to provide a sweep width of 2 GHz. The BWO used a tracking, phase-locked, VHF sweeping oscillator in the narrowband mode that quieted the noise of the BWO tube.

The prototype of the first HP spectrum analyzer, the Model 8551/851A **(Fig. 3)**, was first shown to key customers during the 1963 IEEE show in New York City, in a private suite in the Essex House Hotel. The unit was draped with a tablecloth to conceal the powerful fan connected to a laundry dryer hose that piped cool air to the bulky circuitry. The customers left impressed—and HP had a year before the launch date to work out any problems. One year later, production units were on display at the IEEE show in the New York Coliseum. Within the first year of production, HP sold more than 75 a month, and it soon became the company's first $1 million-a-month product.

The performance of this product was demonstrated by application engineer Lyle Jevons, who uncovered an interesting application at Edwards AFB, approximately 50 miles north of Los Angeles. The problem faced by the Air Force was that three long-range S-band surveillance radars operated by National Aeronautics and Space Administration (NASA), the Air Force, and the Federal Aviation Administration (FAA) that were located on mountain peaks in the area interfered with each other. The colonel's job was to sort out the signals.

To help, Jevons, accompanied by the US Air Force colonel who was the frequency-control officer at Edwards, parked alongside a phone booth at a desert intersection north of the base, where they could monitor the signals and the colonel could call his radar technicians.

AGILENT/HP

The Model 8551, with its broad 2-GHz sweep, could experience all of the signals at once, and its 60-dB dynamic range also identified the sidelobes that overlapped each other. The colonel stepped into the phone booth, called each radar technician, and quickly unsorted the signals. Jevons reported that the colonel offered him $100,000 to keep the analyzer.

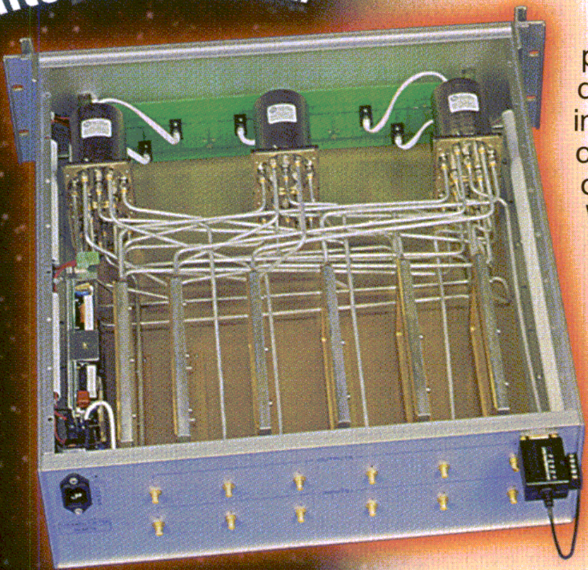
It was little wonder that this instrument was soon merchandised as a "frequency-domain oscilloscope," since it could display baseband frequencies from 10 to 2000 MHz, and it became an indispensable instrument for RF and microwave engineers. In succeeding generations, smaller size, absolute amplitude calibration, and innovative features such as tracking generators made frequency-response measurements simpler. Solid-state LOs made the products more stable, reliable, and portable.

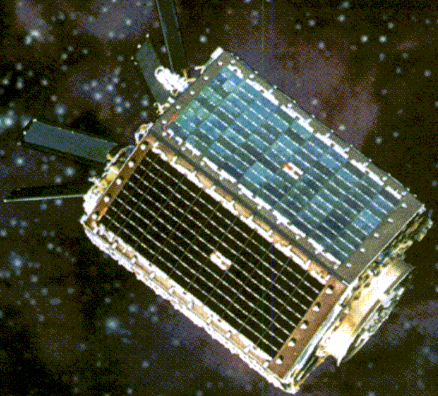
The 8566 and 8568 spectrum analyzers of the late 1970s were a new generation of instruments that took advantage of microprocessors—and each employed three. These analyzers had better frequency-tuning accuracy, narrower resolution, lower phase noise, and better phase-lock stability.

Their most impressive feature was their human interface. These were among the first instruments with a lower panel that looked like a calculator keyboard. A single rotary knob provided a selectable analog feel for tuning, but the keyboard offered digital precision. More important, they offered powerful onboard signal data computation.

A fellowship grant made to Al Bagley, a young graduate student at Stanford University in 1948, led to the development of HP's frequency-counter business. Hewlett and Packard personally asked Bagley to study the measurement needs of the nuclear-physics industry. From that study came requirements for a faster nuclear-pulse-counting technology that could resolve two nuclear events only 0.1 ms apart. Bagley determined that new, low-capacitance semiconductor diodes might enable faster digital circuitry. He built a prototype for the project—and asked for a job at HP.

From that work came the model 520A high-speed decimal scaler, which was able to condition very short nuclear pulses occurring at up to 10 MHz, and to divide down by factors of 10 or 100. Although the 520A had only minimal commercial success, Hewlett envisioned a different measurement process that gated those scaled-down, high-speed pulses into a slower-speed





accumulator (counter). Thus, the frequency counter was born.

Frequency counters were a huge commercial success and in great demand from the 1950s onward. They were used to measure everything from transmitter (Tx) frequencies to the accelerometers on which ballistic missile-guidance systems were based. HP became the industry leader in electronic counting in the early 1950s with the 524A frequency counter, which boasted a 0.01-Hz-to-10-MHz measuring range.

In 1954, plug-in downconverters were introduced as the model 524B electronic counter. Plug-ins eventually extended the measurement range to 18 GHz after the introduction of the step-recovery-junction diode.

RF-interference (RFI)-measuring Rxs of the 1970s were generally mechanically tuned and cumbersome. By modifying some early spectrum analyzers, HP was able to enhance the RFI measurement technology with the addition of common antennas and probes. The 85650A quasi-peak adapter (circa 1982) was an early example of an instrument which, when added to spectrum analyzers, provided a broad electronic sweep capability and offered the designer a wide bandwidth in which to search for leakage signals. It also provided precise, calibrated data.

The earliest power-measuring techniques were primitive by today's standards. The story has been told that Russell Varian cleverly drilled a small hole at the appropriate position in the klystron cavity wall and positioned a fluorescent screen alongside it. The screw provided a gross indication that the cavity was in oscillation.

A major improvement to this measurement technology was made in 1961, when the 431A power meter, with a dual-thermistor design to reduce drift 100-fold, could measure power levels as low as 1 μW. The 478/86A line of power sensors covered 100 kHz to 40 GHz, and later to 110 GHz.

The next big step in microwave power measurement came in 1974 with the introduction of the Model 435A power meter and its associated power-sensor family. This sensor family was a clever exploitation of a silicon (Si)-chip fabrication process that placed a broadband microwave termination on one side of a thin Si web, and a sensitive metallic thermopile on the opposite side. The meter measured the absorbed heat down to 3 μW and up to 20 mW. Since the sensor was a true heat-sensing device, it provided "square-law" linear response over its entire range.

In 1997, the latest family of power meters and sensors was introduced. The Agilent EPM-series power meters took advantage of new ultra-wide-dynamic-range sensors (the E-series power sensors), to measure from −70 to +20 dBm in a single sensor.

The 185A and 187A sampling oscilloscopes (circa 1960) were giant leaps ahead in RF and digital measurements. Using sampling technology, they permitted engineers to measure exceedingly fast transition times for repetitive, pulsed waveforms. They featured sophisticated triggering circuitry for viewing actual RF waveforms to 1 GHz.

The ability to view the time-separated reflections from a coaxial transmission structure enabled engineers to diagnose reflections from individual elements. For example, the individual attenuation elements of the model 355A VHF attenuator could be seen and each tweaked for exact 50-Ω performance. If all were lumped together in a standing-wave-ratio (SWR) measurement, no corrective adjustments could be made. The advancement helped circuit engineers working on components that relied heavily on coaxial and stripline transmission structures.

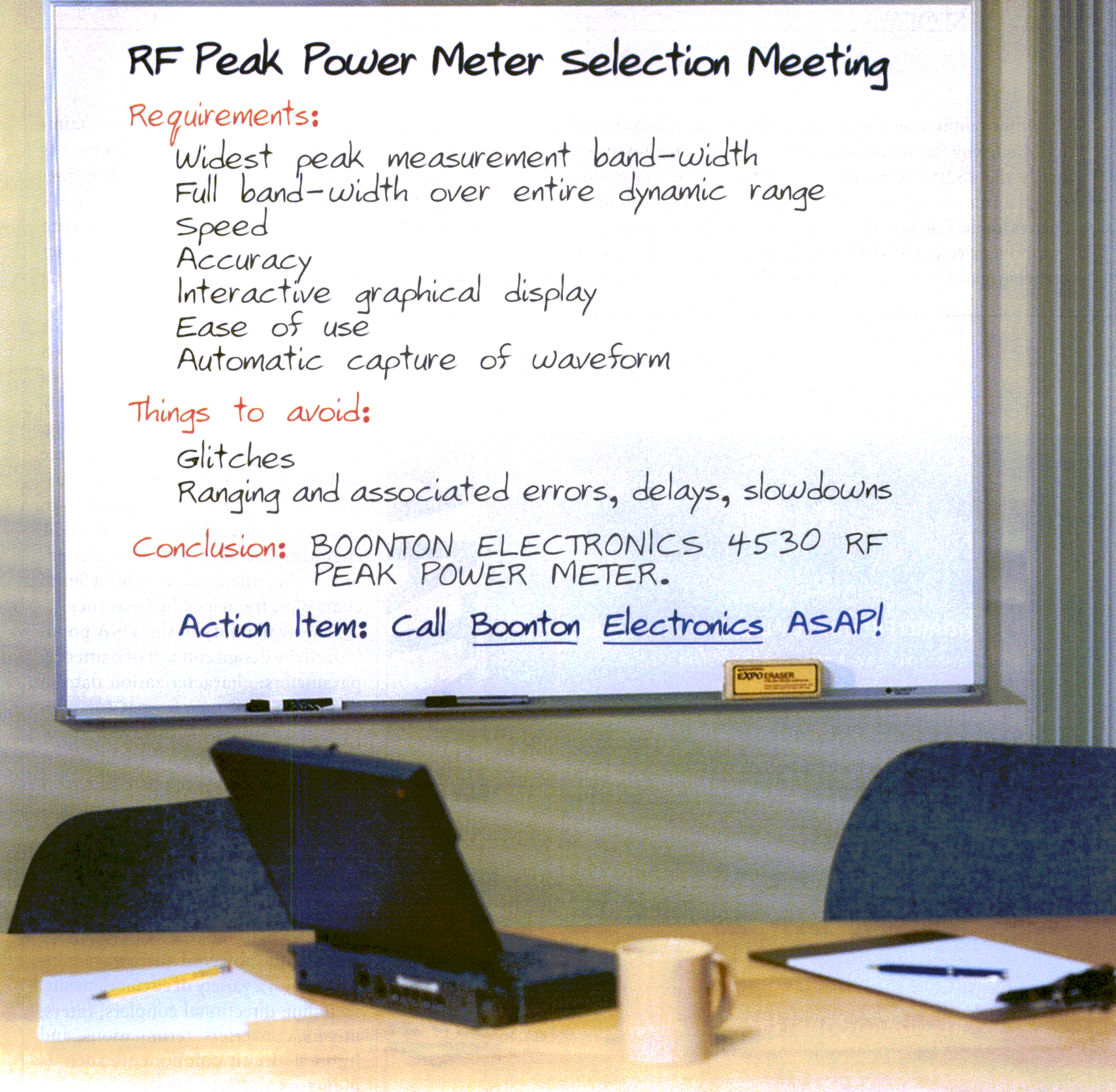
Picture a mechanical, motor-driven klystron signal source, driving two back-to-back directional couplers, two diode detectors, and a 1-kHz ratio meter. This was the state of reflectometers in 1954. Scalar parameters were considered entirely adequate for production-line test assurance, and these analyzers measured SWR and reflection coefficient, as well as transmission parameters. Systems were developed for waveguide bands from 2.6 to 40 GHz, and for most coaxial bands.

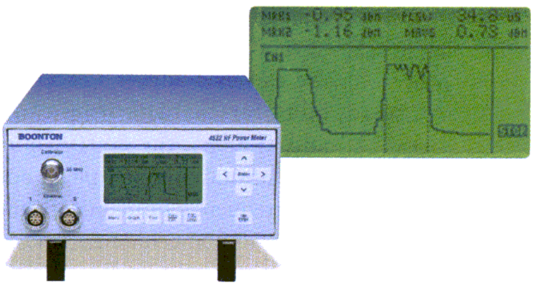
Next came the 890-series sweep oscillators, which exploited BWOs for signal generation, making the sweep electronic. This led to oscilloscope displays with calibrations grease-penciled onto the cathode-ray-tube (CRT) screen. The 1416A SWR display (circa 1966) offerd a scope plug-in with calibrated reflection and transmission data.

ABOUT THE AUTHORS

John L. Minck joined Hewlett-Packard Co. in 1958 and retired in 1995, enjoying a rich 37-year career with the company. He held technical-marketing assignments, mostly in microwave areas, and was RF and microwave marketing-communications manager for several decades. In the early 1970s, Minck managed a venture product group that designed and introduced light-emitting diodes (LEDs) to the market, contributing LEDs to HP's first Model HP-35 pocket calculator. Since 1972, Minck has been active with NCSL International, a trade association, with interest in metrology and calibration issues. He was National President of NCSLI for 1977, and since 1979 has been editor of the organization's NCSLI Newsletter. Minck lives in Palo Alto, CA, with Jane, his wife of 45 years. He has three grown children.

Barry Manz is president of Manz Communications, Inc., of Montville, NJ, which he founded in 1986. The company conducts media relations campaigns and produces technical print and Web-based editorial for companies in the electronics industry. Manz was editor of *Microwaves & RF* magazine during the 1980s. He can be reached at (973) 316-0999 or barry@manzcom.com.


RF Peak Power Meter Selection Meeting
Requirements:
Widest peak measurement band-width
Full band-width over entire dynamic range
Speed
Accuracy
Interactive graphical display
Ease of use
Automatic capture of waveform
Things to avoid:
Glitches
Ranging and associated errors, delays, slowdowns
Conclusion: BOONTON ELECTRONICS 4530 RF PEAK POWER METER.
Action Item: Call Boonton Electronics ASAP!
EXPO ERASER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Other families of sweep oscillators followed, with the 8690 series and eventually the 8620A series (circa 1970), which featured solid-state YIG oscillator sources for the first time. HP's microwave-component research labs contributed coupling microwave transistors with YIG technology to yield exceptionally stable and high-power sources. Later came the 8350- and 8340-series signal sources.

HP continued to introduce new RF and microwave scalar analyzers, starting with the 8755 frequency-response measuring system of 1972. This was a plug-in for the 180-oscilloscope family, which was specifically designed as a system for scalar parameter testing. The 8756A and 8757A scalar network analyzers followed in turn, each with more measuring capability and higher frequency ranges, ultimately reaching 60 GHz in 1985.

Following 1967's two-channel 8405A vector voltmeter, the 8410A VNA in 1968 revolutionized the characterization of microwave components from 10 MHz to 12 GHz, and soon to 18 GHz **(Fig. 4)**. With its swept microwave source and signal-separation test sets, it easily exceeded its original objective—to stamp out slotted lines. Before this, engineers had to use tedious slotted-line measurements to compute a Smith chart plot, frequency by frequency.

The availability of the VNA popularized the design concept of scattering parameters: characterization data in complex impedance format for two-port and N-port microwave components. Provided with actual Smith-chart oscilloscope displays or phase-gain plots versus frequency, component designers gained powerful insights into their circuitry. In the microwave semiconductor revolution of the 1970s, designers raced to develop thin-film-on-sapphire integrated-circuit (IC) technology to combine the power of microwave transistors with a variety of circuit elements, including directional couplers, filters, mixers, converters, terminations, and lumped-circuit components such as inductors and capacitors.

The 8510A network analyzer of 1985 built on the tremendous insight that component design engineers first realized with the 8410A. Combining the new power of the microprocessor with the earlier analyzer's extensive capability for characterizing components and systems, the 8510A launched a revolution. For example, it could process frequency-domain data and render a time-domain characteristic of the signal passing through a complex subsystem on a chip.

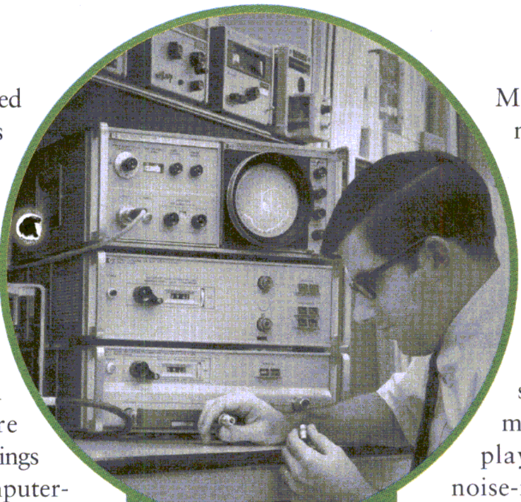
Agilent's latest network-analyzer family, the PNA series, is built on the legacy of the 8510 family. However, these

are totally new products, and some of the first to truly take the integration of microprocessor and microwave instrument to its highest level. They employ the Windows 2000 Professional operating system that brings the full complement of personal-computer (PC) and networking capabilities to the world of microwave instruments, and employ powerful digital signal processing (DSP) to implement 160 digital resolution bandwidth filters.

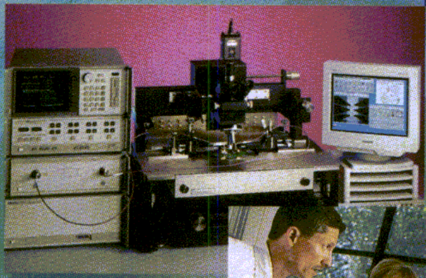
The measurement capability provided by the 8510T network-analyzer system was combined with RF and microwave circuit-design modeling software. This process provided the verification feedback needed to confirm that circuits and fabrications worked according to the design model. EEsof (later acquired by HP) and pioneers such as Les Besser, then with Super-Compact, delivered sophisticated microwave circuit-design models that have never stopped improving. As new computing power became available, more powerful modeling followed. Agilent's Advanced Design System (ADS) software suite currently brings microwave computer-aided-design (CAD) performance and functionality to its highest level.

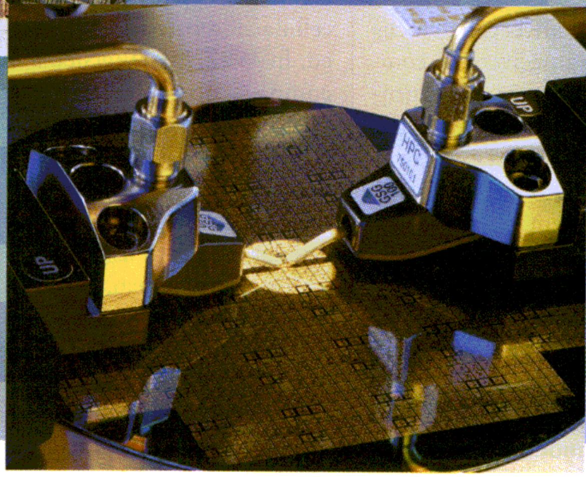
The 340A noise-figure meter was designed for radars, not for characterizing components, a clear need that had been mentioned by customers. Based on a 1982 landmark market-research study led by Mike Cuevas, a new noise-figure product was envisioned. The resulting 8970A noise-figure analyzer pleased circuit designers since they could measure and display the gain and noise-figure parameters of amplifiers, mixers, and converters at the same time.

Since circuit designers will gladly trade-off gain to improve the noise figure of an input amplifier, this capability proved popular for applications such as satellite Rx front ends. The 8970A had enough sensi-



4. A young John Minck is shown with the 8410A vector network analyzer, an instrument that revoloutionized the way that microwave components were characterized.





tivity to measure its own noise figure, and thereby compute out the error effect of its own front-end noise. Agilent's NFA series of noise-figure analyzers continue to expand the possibilities of noise-figure measurement, providing a real-time display of noise figure or gain versus frequency, easy measurement set up, built-in data storage, and printer connectivity.

In the late 1970s, HP began to focus on testing mobile transceivers. By combining a desktop computer, signal generator, frequency counter, power meter, various modulation sources, power supplies, and switching, the 8950A transceiver test system (Bigfoot) was born. It provided all of the measurement capability necessary to completely characterize an FM mobile transceiver.

HP had traditionally supplied general-purpose instruments for transceiver measurements. But starting around 1979, the 8901A modulation analyzer directly targeted the mobile Tx test market. The analyzer was essentially a 1-GHz-calibrated Rx that accurately and precisely measured the AM, FM, and phase modulation of mobile Txs.

By combining the 8901A with the 8662A microwave synthesizer and 8903A audio-modulation analyzer, along with some signal switching, specialized test systems such as the 8957S cellular-radio test system were created. In 1992, HP launched a family of compact, portable cellular test sets, many of which are still in use today. The Agilent 8920A RF communications test set combines 22 instrument functions for transceiver testing of land-mobile and cellular applications.

Yet another system, the Model 8924C, targeted CDMA. Test sets were customized for GSM/digital-communications-services(DCS)/pulse-code-modulator (PCM) DECT, and pager applications. Today, base-station testing is accomplished with the Agilent 8935-series base-station test sets for CDMA and TDMA technologies.

With the 10 wireless communications test sets of the Agilent 8960 series that were introduced in 1999, mobile-phone manufacturers could achieve breakthrough speed that improved test throughput up to 300 percent in a system designed to test multiple communications formats.

HP has always played a commanding role in the computerization of instrumentation. The 2116A instrument computer that was introduced in 1968 yielded its first major application in the 8540A automatic network analyzer. Despite an interface which used a clacking teletypewriter and programming with punched paper tape on the floor, component designers were awed at the power of data-corrected measurements, and the insight they got into their circuit performance. By coupling the 2116A to HP spectrum analyzers, the 8581 automatic spectrum monitor was born. It enhanced long-term signal characterization for satellites and antennas.

True egalitarian automation became reality with the IEEE approval of the IEEE-488 GPIB of 1962. This emerged as desktop computers were becoming popular, and priced so that every test bench could afford them. HP led development of the bus technology, and arranged for an industry committee to take over and make it an open system.

Today's communication technology relies heavily on synchronized transmission frequencies, and cellular base stations, broadcast-television stations, and GPS satellites must reference these precise and stable standards. In fact, cesium beam standards can arguably be credited with standardizing the technology clocks of the world. HP engineers undertook the first "Flying Clock" project in 1964, flying two atomic clocks to Europe to precisely compare the US Naval Observatory time and the national standards at the National Bureau of Standards (NBS) with official clocks in Switzerland.

Atomic frequency standards had been developed in many countries to serve as

the basic reference based on the atomic resonance principle, unvarying and fundamental. The 5060A became the first commercial product of choice in industrial primary-standards labs.

HP celebrated its 60th birthday in 1999 in a whirlwind of change. For a quarter century of the company's history, test and measurement was its core business, and within it RF and microwave measurements played an enormous role in the company's success. Over those 60 years, HP had recorded an impressive record, including a compound annual growth rate of 18 percent.

But the marketplace, and HP's role within it, had changed. The company that dedicated itself so steadfastly to test and measurement had become a leader in many other areas of electronics technology, most notably in computing. The question for the future of HP became increasingly how to continue its success in every market area.

Agilent Technologies was the answer. In March 1999, HP announced that it would split the company, with Agilent focusing on communications and life sciences, and HP focusing on computers and imaging. Agilent CEO Ned Barnholt encapsulates the opportunity:

"The split gave us a greater strategic focus. We were a communications and life-science company trapped in the body of a computer and imaging company. We now had an opportunity to go out and tell our story, and to focus more aggressively on our markets. We felt, and I think this has been proven to be true, that we've become a lot faster and more responsive. So anything we want to change, anything we want to do differently, we can do. We decided to bring forward the best of the HP values and culture, and to look also at new ways to become more successful."

Although less than two years have passed since Agilent was formally created, the results of this line of thinking have already borne fruit—perhaps most noticeably in the area of RF and microwave instrumentation. Agilent is introducing significant new RF and microwave instruments that solve key measurement problems, at a rate much faster than when it was HP.

Agilent recently made the decision to sell its life-sciences interests. So, as it was for so long at HP, test and measurement is Agilent's primary focus. MRF

Editors note: Readers can request a copy of a 36-page Agilent brochure that reviews a broad array of HP and Agilent communication test products, starting with the model 200A by requesting literature number 5890-2090E from the website at www.agilent.com.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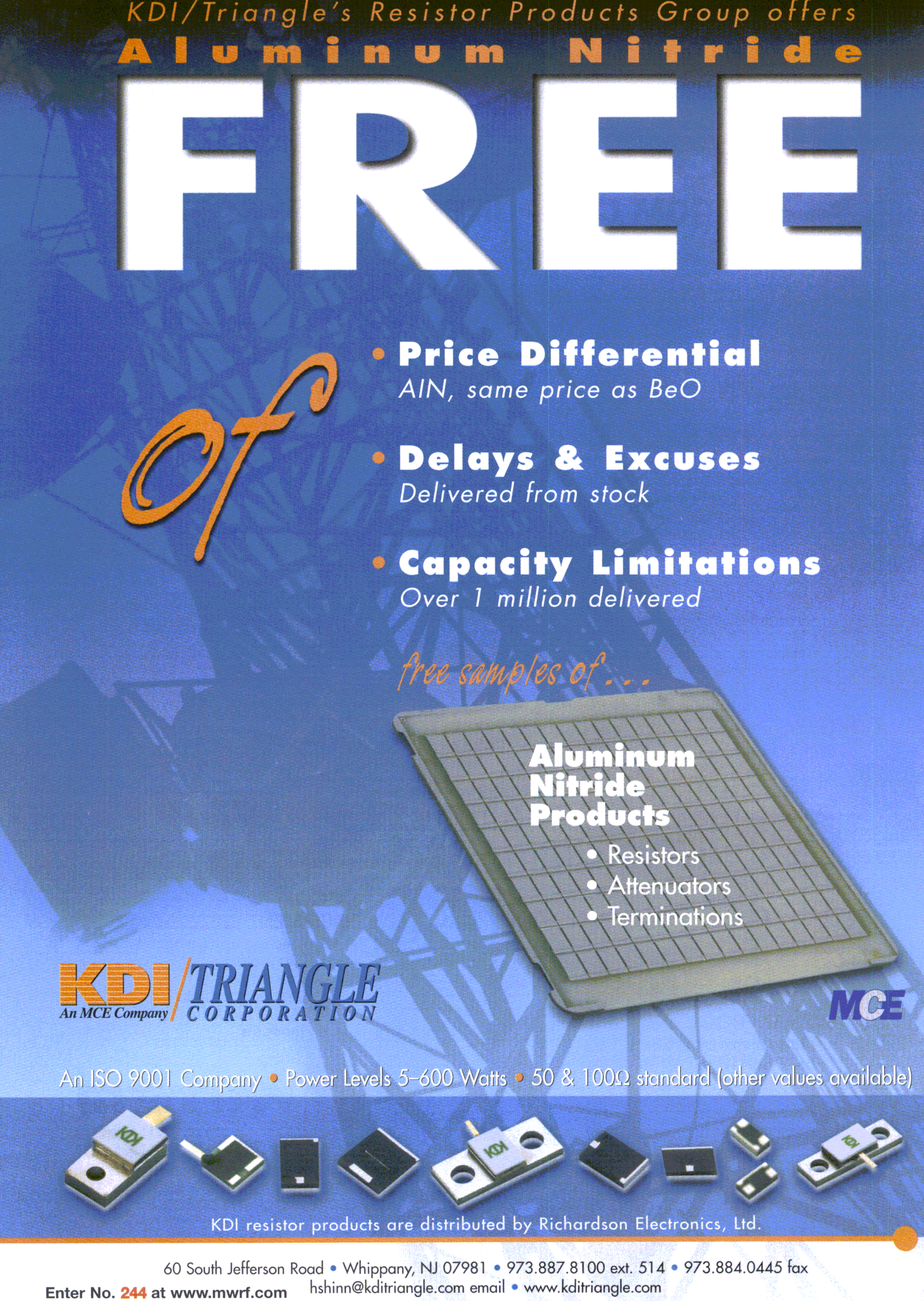

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ARMMS Meeting Melds Simulation And Testing

The most recent gathering of a British-based RF and microwave technical society covered a wide range of topics, including component and system modeling and testing.

JACK BROWNE
Publisher/Editor

Technical societies offer their members the opportunity to share ideas in a relatively noncompetitive environment. One of the small, but important RF and microwave societies in the UK is the ARMMS RF & Microwave Society, with two meetings each year devoted to the design and measurement of devices and products operating at RF and microwave frequencies. The most recent meeting/ conference, held from April 30 to May 1, 2001 at Burleigh Court, Loughborough University (Loughborough, England), featured 16 talks on design, simulation, and test of devices, components, and automotive systems.

The technical program was coordinated by Steve Evans-Pughe of Applied Wave Research, Inc. (El Segundo, CA). To start things off, Malcolm Edwards of Applied Wave Research explored the design automation of RF and microwave computer-aided engineering (CAE) based on Microsoft's component-object-model (COM) capability. The COM is a technology that allows multiple programs resident in a computer's random-access memory (RAM) to communicate with each other simply and effectively. The COM capability can be used for a number of purposes, such as extending the capability of an existing software program by adding functions that were not originally included in the program.

The COM capability is built into the Microwave Office suite of CAE tools from Applied Wave Research and can be controlled from any programming language or scripting engine such as Visual Basic, Java Script, or a compiled language such as Visual C++. The Microwave Office program includes a scripting language that uses standard Visual Basic syntax that allows advanced users to automate the design process through the creation of macros and utilities.

The built-in scripting language allows operators to explore concepts and perform tests on new functions before extending the process into the realm of compiled code. This capability can help speed the design process as part of a Rapid Application Development (RAD) environment. The automated approach was demonstrated on measurements and analysis of the resonator and the source of negative resistance for a microwave oscillator.

As a sequel to Edwards' presentation, Chris Potter of P&H Technology Consultants (Cambridge, England) also addressed COM with an examination of automated prototype testing. Potter notes that it is fairly straightforward to write RF test sequences by

applying COM with programs such as Microsoft Excel, Microsoft Word, Agilent VEE, and National Instruments' TestStand. He adds that the SoftPlot program and its COM interface is well-suited to RF test automation. SoftPlot can take care of a general-purpose interface bus (GPIB) and ask it to send command strings to an instrument.

At the system level, J.A. Flint and A.R. Ruddle of MIRA (Warwickshire, England) detailed Guidelines for Electromagnetic Compatibility modeling for Automotive Requirements (GEMCAR). This is a three-year European project aimed at producing guidelines for the numerical modeling of automotive EMC situations. One goal of the project is to highlight the potential uses of modeling in the design and test phases of the vehicle-development life cycle. Another goal is to define the practical issues which need to be addressed before embarking on modeling the automotive environment. The GEMCAR document is meant to be a two-way learning tool for EM software developers and the automotive industry.

Advances in computational EMs (CEM) and computing power have allowed these systems to be applied not only to microwave devices and components, but also to the simulation of complex designs, such as automobiles and aircraft. CEM methods used in automotive modeling include the transmission-line-modeling (TLM) method, the finite-difference-time-domain (FDTD) method, the method of moments (MoM), the boundary-element (BE) method, and the finite-volume (FV) technique.

The authors described two of the simplest of the GEMCAR validation models: an antenna model and a vehicle model. The antenna model is based on a log-periodic-dipole-array (LPDA)/biconical hybrid design. The widely available antenna type is commonly used for immunity-type EMC testing. The particular antenna for modeling spans 20 MHz to 1 GHz, which is the main band of interest in the European Automotive EMC Directive 95/54/EC.

Engineers at MIRA placed the antenna into a semianechoic chamber and used it to illuminate a volume of space. The electric field strength was then measured at various points in front of the antenna in horizontal and vertical polarizations. These points were chosen to represent the envelope of a vehicle that would be placed. A reference point was chosen in the chamber and the relative field strength at each of the other calibration points was recorded for use in a comparison with the model. A model was constructed of the experimental setup and a prediction for the relative field strength was calculated.

Since a vehicle represents an extremely complex three-dimensional (3D) model, the computer-aided-design (CAD) data for the vehicle were simplified before any attempts were made to apply meshing techniques for numerical modeling. For a TLM analysis, the vehicle data were discretized on a tartan mesh, essentially a Cartesian grid with variable cell dimensions. Surface currents were computed for a vertically polarized plane-wave incident on the front of the vehicle.

Both models were found to agree closely with the measured data, except at lower frequencies. Below 100 MHz, the effects of the chamber walls dominated the measurement results due to the poor low-frequency response of the absorbing material. At higher frequencies, the accurate placement of the measurement probes becomes a major issue due to the decreasing wavelengths of the test signals. The various modeling techniques yielded similar results, although with some methods requiring greater computational resources and processing time. For example, the MoM approach is well-suited for analyzing the antenna, but is less effective when modeling geometrically complex structures such as the vehicle. These are some of the issues that the GEMCAR program must address.

In a less complex vein, Mats Jansson of Nera Networks AS (Kokstad, Norway) spoke about the design of waveguide filters using a 3D simulator. Jansson explained that although many EM computer programs exist for the design

of waveguide filters, these programs are limited to specific filter topologies or coupling structures. Due to these limitations, there is still a real need for a general-purpose tool for waveguide design. His solution is based on applying well-known circuit-theory synthesis methods in combination with the High Frequency Structure Simulator (HFSS) from Ansoft (Pittsburgh, PA). By optimizing one dimension of the waveguide structure in each step, the simulation can be performed quickly with fast convergence. Couplings are optimized for the correct K-inverter values at the desired center frequency. Resonators are optimized by calculating the resonator length and then performing fine tuning until the structure resonates at the center frequency.

The approach was applied to the design of a waveguide filter with inductive posts for use at 15.35 GHz. The filter, which is tunable from 14.90 to 15.35 GHz, was measured at 15.32 GHz. Measurement results agreed closely with the simulation data.

Bernhard Wagner of Computer Simulation Technology (Darmstadt, Germany) offered a presentation on Perfect Boundary Approximation (PBA). The PBA is an extension to the time-domain modeling technique of finite integration (FI). The PBA approach provides accurate simulation of thin objects without requiring long computation times. It avoids the small time-integration step width of other time-domain modeling methods and avoids the poor matrix conditions for certain structures that result from the use of some frequency-domain methods. Compared to conventional FI and finite-element (FE) methods, the PBA approach can perform complex calculations on 3D structures in a fraction of the time. The technique was applied successfully to a number of different structures, including a planar patch-antenna array, a diplexer, and a human-body specific-absorption-rate (SAR) study.

Kelvin Clarke of Ansoft spoke on modeling and optimizing photonic-bandgap (PBG) structures. The behavior of these devices is analogous to the characteristics of atomic crystal structures in optical and solid-state physics. These structures can occur in bulk form (as substrates) or in a surface form (as circuits with or without ground planes). The surfaces of these devices reflect incident waves in phase rather than as out-of-phase images. These structures have a type of array symmetry which results in repeating signal characteristics. Also, they do not propagate EM waves at certain frequencies within the bandgap region. Clarke notes that PBGs could be useful as novel transverse-EM (TEM) model waveguide for feed structures, as reduced-loss antenna substrates, as dielectric-filled waveguide feeds with built-in band-rejection filtering, and as non-imaging ground planes to improve antenna-element performance.

Since the HFSS program includes certain features, such as a full-featured finite-element-analysis (FEA) solver, linked boundary conditions, an Eigenmode solver, and a field calculator, the software is well-suited to the analysis of PBGs. Several modeling methods are possible with HFSS, including the use of the direct-transmission method (for 3D PBGs), the use of the dispersion diagram method (for surface PBGs), and the use of the reflection-phase-analysis method (also for surface PBGs). The latter two approaches also employ the use of the company's Optimetrics parametric-sweep program for analysis of unit cells.

The direct-transmission method generates S-matrix data which can be used to obtain the PBG "forbidden band," where EM transmission does not occur. Of course, the transmission parameters are only accurate for the direction of propagation that is modeled; propagation in the other direction must be modeled separately. Also, the transmission parameters are only accurate for a number of periods in the direction of propagation that is modeled. The approach was applied to the modeling of a dielectric-rod PBG substrate with a top frequency of 15 GHz.

In the dispersion diagram method, the Optimetrics program is used to generate a parametric sweep using a nominal HFSS project design. A dispersion curve is generated by plotting Eigensolutions versus appropriate input variables in Optimetrics. The results are plotted as Eigenmodes versus boundary-condition phases. As a sample project, the dispersion diagram method was used to model a high-impedance PBG lattice etched on a dielectric substrate with a dielectric constant of 2.2.

In the reflection-phase analysis method, an HFSS nominal project is a unit cell of the repeating PBG circuit or structure, imaged with linked boundaries on each side. Incident plane-wave excitation is directed toward the PBG surface, and an additional integration plane is identified internal to the radiation boundary face for use with phase-data extraction.

The PBG structures offer great promise for microwave and millimeter-wave design, and they can be modeled with the HFSS. But Clarke notes that the choice of modeling approach should be guided by finding the simplest solution possible, obtaining a good starting design, not using too many variables at once, and using a well-adapted mesh for the quickest possible convergence.

Mark Eidem of Castle Microwave (Twyford, Berkshire, England) explored the nature of passive intermodulation (IM), which can cause poor performance in cellular base stations. It can be caused by bad solder joints, poor alignment of parts, inadequately torqued screws and fasteners, poor plating processes, the nonlinear behavior of ferrite materials, and environmental degradation. Forms of passive IM include reflected or reverse IM and through or forward IM. Passive IM is measured by injecting multiple signals to a device under test (DUT), boosted by a linear power amplifier (PA), and measured with a sensitive receiver (Rx) [capable of −140 dBm or better sensitivity]. One of the trends in passive-IM testing is a move toward swept-frequency testing, rather than static two-tone tests, to reveal the true passive-IM behavior of microwave components. Swept tests were performed on a personal-communications-services (PCS)-band diplex-

er filter to show differences in results from static-IM testing. Tests were performed with a test system from Summitek Instruments, Inc. (Parker, CO) consisting of an agile Rx and an integrated RF module with frequency synthesizers, diplexers, filters, PAs, a power combiner, and a low-noise amplifier (LNA). The system supports measurements of IM products as a function of frequency or as a function of time.

In other presentations, Richard Ranson of Filtronic (Keynes, Buckinghamshire, England) provided an introduction to third-generation (3G) cellular systems, reviewing frequency allocations, air interfaces, and coding. Kal Kalbasi and Steve Tucker of Agilent Technologies (Santa Rosa, CA) offered a detailed examination of digital intermediate-frequency (IF) design for 3G systems, while Yngve Thodeson of Nera Networks ASA detailed a new field-effect-transistor (FET)-based frequency tripler with 13-GHz output signals.

Finally, Dominic FitzPatrick of Milmega Ltd. (Ryde, Isle of Wight, England) reviewed the benefits of solid-state versus traveling-wave-tube (TWT) amplifiers for various applications. He compared output-power levels, efficiency, distortion characteristics, noise, gain, and reliability. In addition, Emil Entchev and associates from Farran Technology Ltd. (Bodmin, Cornwall, England) addressed the design of high-power amplifiers using commercial gallium-arsenide (GaAs) monolithic microwave integrated circuits (MMICs) and a waveguide-based power combiner. They achieved better than 2-W (+33-dBm) output power from 36.00 to 37.25 GHz.

The next meeting of ARMMS is scheduled for November 12 and 13, 2001 at the Hilton Hotel, Bracknell, Berkshire, England. For more information about ARMMS, please contact the society's Secretary, Duncan McIntosh, **ARMMS RF & Microwave Society, P.O. Box 1215, Shirley, Solihull B90 4JH, England; 01212-432694, FAX: 01983-616864, e-mail: duncanmcintosh@ieee.org, Internet: www.armms.org.** MRF

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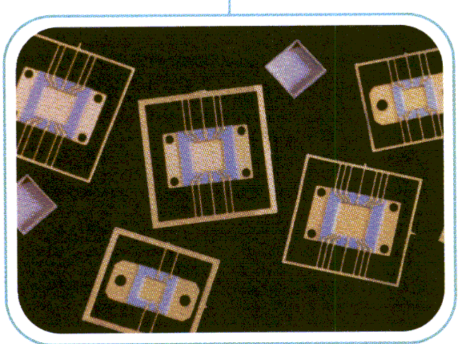

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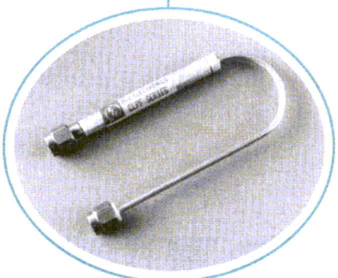
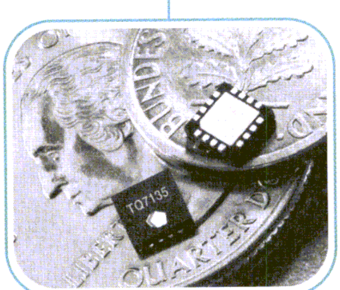


RLC ELECTRONICS CABLE FILTERS



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RLC Electronics, Inc., 83 Radio Circle, Mt. Kisco, NY 10549; (914) 241-1334, FAX: (914) 241-1753, Internet: www.rlcelectronics.com.

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TriQuint Semiconductor, 2300 NE Brookwood Parkway, Hillsboro, OR 97124; (503) 615-9000, FAX: (503) 615-8900, Internet: www.triquint.com.

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Broadband Giants Slug It Out

Number 3 tries to take over number 1 and war breaks out for the control of CATV services in the US. Comcast Corp., the third largest cable provider recently made an unsolicited $58 billion bid to take over the cable operations of AT&T Broadband, the largest cable company. About a week later, AT&T's board of directors rejects the bid saying that it does not reflect the full value of its cable unit. Comcast attempts to sidestep AT&T's board by getting stockholders to pressure the board into making the deal, now considered a hostile takeover move.

At stake in the battle is king-of-the-hill status in the broadband business. A Comcast-AT&T merger would give the combined company 22 million subscribers, one-third of the US market. AOL Time Warner, in second place, has 12.7 million customers.

The deal is clouded by the highly unsettled state of AT&T's businesses. The company is splitting itself into four separately traded businesses, one of which is the Broadband unit. While it is ostensibly looking for either a sale or partnership with a cable company, another option is spinning off Broadband into a separate business unit. However, the spinoff move did not take place when AT&T rejected Comcast's offer, which is considered a positive step toward the eventual merger of the two companies.

When the dust settles, Comcast will probably get its way. For one thing, it has a very good track record of integrating previous acquisitions and running a profitable operation, while AT&T does not. It claims that the savings on AT&T's combined cable operations could amount to more than $1 billion per year. Second, when Comcast's offer was announced, AT&T's stockholders responded positively by sending the stock up 12 percent (Comcast's shareholders did not do likewise, sending the stock down by 7 percent). Under the terms of the Comcast offer, AT&T stockholders would own shares in the new company, and maintain their shares in the core AT&T stock.

When all of the maneuvering ends, Comcast will likely have to sweeten the deal by many billions to keep AT&T from looking for different suitors or using a number of delaying tactics at its disposal. MRF

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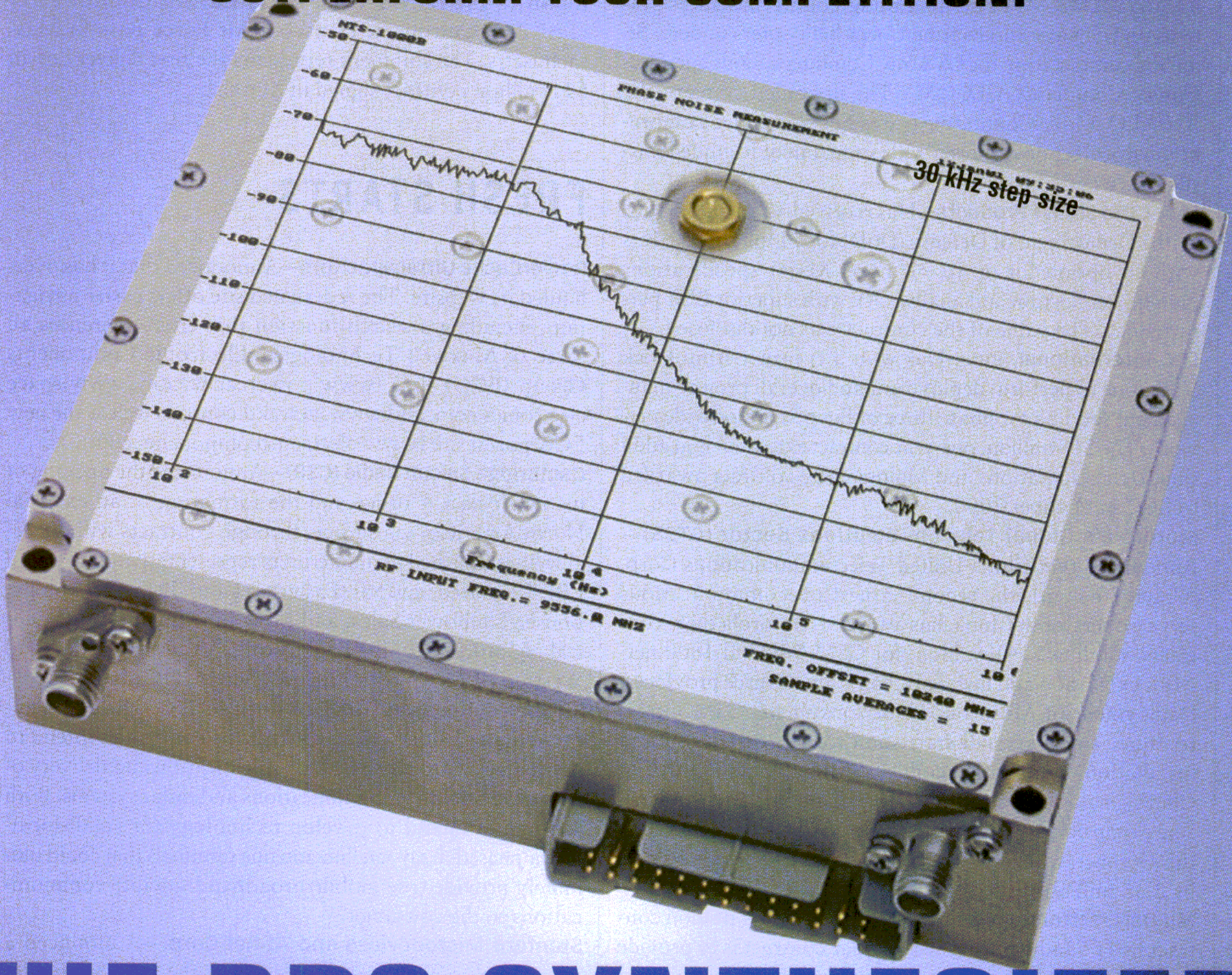

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CONTRACTS

BAE SYSTEMS—Will be upgrading countermeasures systems on US Navy and Marine Corps helicopters under a $6 million contract from the US Army Communications and Electronics Command (CECOM). The upgraded system—the AN/ALQ-144A Countermeasures Set—provides comprehensive protection against a wide spectrum of Ir-guided missile threats.

M/A-COM SIGINT Products—Has received a contract award by the Department of Defense (DoD) for 71 microwave Rxs with an option for up to 71 more. Major specifications involve a collection and analysis Rx with superior BER performance. The value of the contract was not disclosed.

LCC International, Inc.—Has won a contract from Click Vodafone to perform deployment and overall project-management services for phase three of Egypt's nationwide network. The $16 million, one-year contract extension is in addition to the Operations and Maintenance contract awarded to LCC in October 2000.

Motorola's Global Telecom Solutions Sector (GTSS)—Announced that China United Telecommunications Corp. (China Unicom), the second-largest telecommunications service operator in China, has awarded Motorola three contracts, totaling $141 million, for GSM-900 and 1800 network expansion and installation in China's three provinces. Deployment of Motorola's Horizon*systems* GSM infrastructure solutions will start soon for the expansion and installation of China Unicom's GSM networks in three of China's major provinces—Jiangsu, Shandong, and Xinjiang. The expansion projects, which are slated for completion by this October, will increase the capacity in the three provinces by 2.68 million subscribers.

Mu-Del Electronics, Inc.—Was awarded a $3.4 million contract by ITT Industries. The two-year contract is to provide the Rx frequency generator and pulse-forming circuits for a new ITT radar program.

EMS Technologies, Inc.—Announced the award of a seven-year contract with the US Department of Transportation (DoT) for technical services relating to wireless technologies and network services. The contract was awarded by the DoT's Transportation Administrative Services Center (TASC) under a new program known as STATUS—Specialized Technical and Technology User Services. STATUS is designed to provide all government agencies—federal, state, and local—with immediate access to specialized technical expertise in a number of information-technology and infrastructure-support areas, including artificial intelligence, geographic/geospacial information systems, e-learning and learning-management systems, operational maintenance support, and wireless technologies/networks. Under the contract, EMS will compete in the Wireless Technologies/Networks area for task orders submitted by various government customers to perform wireless communications and connectivity systems and services.

Harris Corp.—Has completed initial shipment of its Falcon II AN/PRC-117F(C) multiband/multitransmission manpack radios to the US Air Force's Tactical Air Control Party (TACP) squadrons at Hanscom Air Force Base in Massachusetts. The shipment represents the first delivery of an $11 million contract signed in March.

FRESH STARTS

PowerCache Ultracapacitors—Announced that it has overhauled its website. The redesigned site offers easier navigation, including a search function that cross-references all three of Maxwell Technologies' Electronic Components Group (ECG) sites (www.powercache.com, www.spaceelectronics.com, and www.sierrakd.com), as well as the new ECG portal site (www.electroniccomponents.com).

Cambridge Silicon Radio (CSR)—Announced the opening of its San Jose, CA office and the formation of an external North American sales force, through contracts with several well-established manufacturers representative companies: EIR, J-Squared, and SSI (Eastern region); Beta Technology, Bonser-Philhower Sales, and Luscombe Engineering (Central region); Luscombe Engineering, Moulthrop Sales, and Westrep (Western region); and J-Squared (Canada).

SRI International and GeoLink Corp.—Have signed a Memorandum of Understanding where the companies intend to work together to advance the sophistication and delivery of pervasive satellite-communications and radar systems. Both companies intend to develop technology for small-form-factor phased-array satellite-antenna terminals that could ultimately provide true mobile broadband satellite communications to the consumer.

Stanford Microdevices and Atmel Corp.—Announced a joint-development agreement, where the two companies will collaborate on the design and development of wireless communications products based upon silicon-germanium (SiGe) products.

Tru-Connector—Unveiled their new website, which was designed by Strand Marketing. Located at www.tru-con.com, the site offers telecommunications, wireless, semiconductor, and military designers a variety of standard and custom connectors and cable assemblies to choose from. In addition to a completely redesigned user interface, visitors can use Tru-Connector's "Build Your Own Connector" tool that takes them through a step-by-step specifications process and enables submission directly to Tru-Connector's technical sales team for price and delivery.

Mitel Corp.—Has introduced a new global identity—Zarlink Semiconductor(TM)—under which it will deliver communications-connectivity solutions to the world's leaders in voice and data networking. Zarlink will provide highly specialized ultra-low-powered chip sets for use in medical applications. MRF

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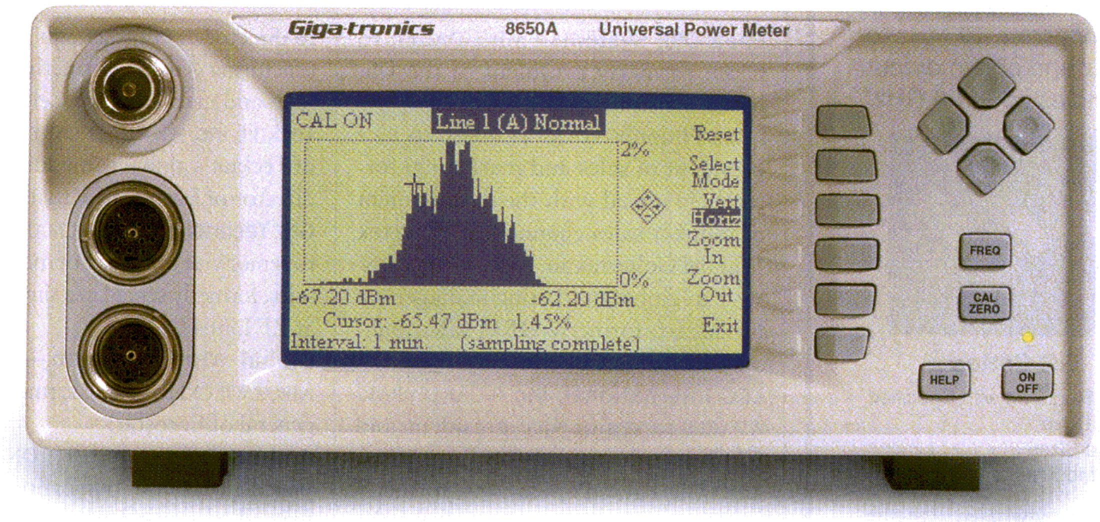

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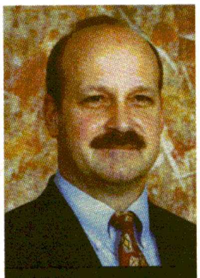


QUINLY

DY 4 Systems Names Quinly As President

TOM QUINLY has been appointed to the position of president at DY 4 Systems, Inc. Mr. Quinly has been with DY 4 for four years, most recently serving as DY 4's acting vice president of operations. He will be located in the Leesburg, VA office.

Enea OSE Systems—MIKE DAGER to CEO; formerly president of the US-based division.

I-Bus/Phoenix—ULRICH DIEHL to vice president of sales and marketing; formerly involved with the development of indirect sales channels at Wavetek Wandel Goltermann. Also, ANDY CONWAY to global marketing manager for broadcast; formerly OEM sales manager for the UK operation.

LCC International, Inc.—CARLO BARAVALLE to senior vice president and CEO of the Europe, Middle East, Africa, and Asia Pacific operations; formerly managing director responsible for the development and management of international operations at Exchange, plc.

Scott Specialty Gases—DAVID HERMANCE to director of national accounts; formerly vice president of sales and marketing for the US Gauge Division of Ametek Corp.

The Cellular Telecommunications & Internet Association (CTIA)—DIANE CORNELL to vice president for regulatory policy; formerly associate bureau chief at the FCC's Wireless Telecommunications Bureau.

Quake Global—POLINA BRAUNSTEIN to vice president of operations; formerly director of operations at Space Electronics. Also, JENNIFER FORMAN to business development director; formerly marketing manager.

CTS Corp.—VINOD M. KHILNANI to senior vice president and CFO; formerly vice president and CFO at Simpson Industries, Inc.

REMEC, Inc.—DAVID L. MORASH to executive vice president and CFO; formerly CFO for Wireless Knowledge.

ITT Industries, Cannon—PAUL H. ESLING to director of contract equipment manufacturing (CEM); formerly director of sales and marketing for Celestica Corp.

Tecknit, Inc.—JOHN CROSBY to president of Tecknit's global companies; formerly director of European activities.

GHz Technology, Inc.—CHARLES WEEKES to senior vice president of marketing and sales; formerly served in a similar position at ZF Linus Devices.

Global Opticom, Inc.—RAYMOND NIEDZWIECKI to COO; formerly director general of Eurostar.

Andrew Corp.—PAUL R. COX to group president for communication products; formerly vice president of communication products.

Hybrid Networks, Inc.—ANAND KHOKHA to the board of directors; remains as president of Durkee/Sharlit Associates.

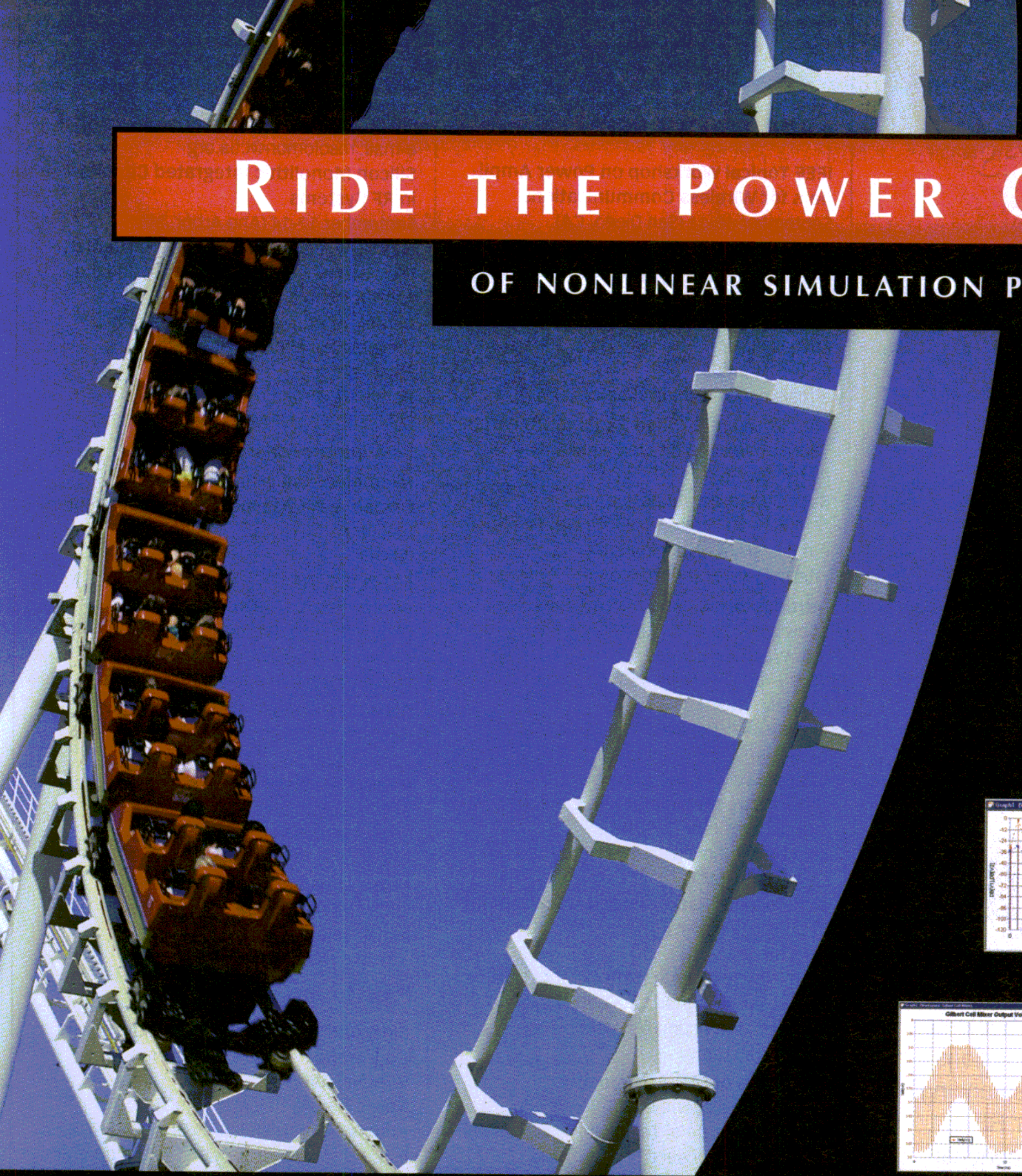
Celerity Digital Broadband Test—DAVID SPRENKLE to Eastern regional sales manager; formerly marketing specialist with RDL, Inc.

Century Tel, Inc.—ANDREW AULTZ to vice president for the southern region; formerly vice president of the Competitive Local Exchange Co. (CLEC) at Alltel.

AULTZ

COLEMAN

Zentrix Technologies, Inc.—KENNETH COLEMAN, JR. to vice president of sales; formerly president of Technical Sales and Solutions. MRF



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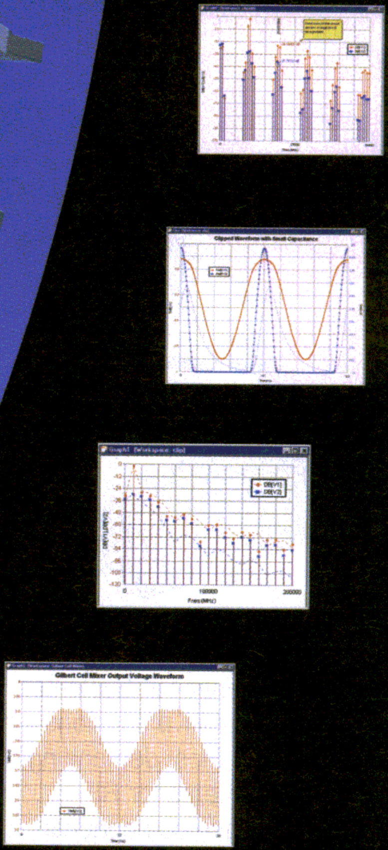

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SHORT COURSES

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IEEE Microwave Theory and Techniques Society (MTT-S) in collaboration with the UCSD Center for Wireless Communications
University of California-San Diego
Michell Parks
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e-mail: parks@ece.ucsd.edu

The Software Defined Radio (SDR) Forum
September 11-13 (Madrid, Spain)
Ricca Silverio
Bock Communications, Inc.
(714) 540-1030 ext. 15, FAX: (714) 540-1060
e-mail: rsilverio@bockpr.com
Internet: www.sdrforum.org

Introductory RF and Microwaves
September 20-21 (Lake George, NY)
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Future Directions in IC and Package Design Workshop (FDIP)
October 27 (Royal Sonesta Hotel, Cambridge, MA)
Components, Packaging and Manufacturing Technology Society
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e-mail: epd@engr.arizona.edu
Internet: www.cpmt.org/conf/fdip01/fdip.html.

Principles of Modern Radar
October 29-November 2 (Atlanta, GA)
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MEETINGS

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September 10-11 (Dallas, TX)
IEEE Dallas Section
Jon Veihl
IEEE ETS
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CTIA Wireless IT and Internet 2001
September 11-13 (San Diego Convention Center, San Diego, CA)
The Cellular Telecommunications Industries Association (CTIA)
Michelle Solomon, Registration Manager
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CMOS delta-sigma modulator samples IF in digital FM radio Rx

IN DIGITAL RADIO Rxs, baseband signals have traditionally been processed using analog techniques. But development trends for these Rxs are pushing toward full integration onto a single CMOS chip, which would permit complete mixed-signal (analog and digital) processing on a single device. And moving the analog-to-digital interface closer to the antenna would permit IF digitization. This would confer several advantages to the Rx. Mainly, it would maintain the quality of downconversion by avoiding analog imperfections, 1/f noise, and DC offsets. But IF digitization can become a bottleneck for the system, and requires high-performance analog-to-digital conversion. Since the analog-to-digital conversion is performed prior to channel-selection filtering, the ADC must have a wide dynamic range to guarantee sufficient signal resolution, especially in the presence of a large adjacent channel. Paolo Cusinato of Texas Instruments, Davide Tonietto of Conexant Systems, Fabrizio Stefani of STMicroelectronics, and IEEE Senior Member Andrea Baschirotto have devised a sigma-delta modulator for this type of ADC. The sixth-order bandpass sigma-delta modulator operates at 42.8 MHz over a 200-kHz bandwidth with a dynamic range of 74 dB. The modulator was fabricated using standard 0.35-μm, 3.3-VDC CMOS technology. See "A 3.3-V CMOS 10.7-MHz Sixth-Order Bandpass $\Sigma\Delta$ Modulator with 74-dB Dynamic Range," *IEEE Journal of Solid-State Circuits*, April 2001, Vol. 36, No. 4, pp. 629-638.

Piezoelectrically actuated microstrip antenna offers variable frequency, bandwidth, and gain

MICROSTRIP ANTENNAS ARE used in many military and commercial applications because they conform to surfaces, are durable, and easy to manufacture. But they are limited to applications that support relatively narrow banwidths and low antenna gain. Some tuning techniques have yielded moderately increased bandwidth, but with an accompanying reduction in efficiency and no increase in instantaneous bandwidth. Parasitic elements, added to a microstrip antenna to increase gain, can also affect the antenna's bandwidth. To overcome these limitations, IEEE Member Jennifer T. Bernhard, E. Keily, and Gregory Washington of Ohio State University have developed a variable-bandwidth microstrip antenna that is actuated by layers' piezoelectrical material. The antenna's resonant frequency, bandwidth, and gain change as a function of the vertical spacing between the primary radiator and its parasitic director. The researchers found that this method provides good mechanical performance while avoiding electromagnetic interference. The vertical spacing between antenna and parasite was varied from 2.28 to 10.2 mm using a stack of high-deflection, piezoelectrical actuators. The antenna's resonant frequency generally increased, and the bandwidth generally decreased, as the space between the plates increased. Also, at the smaller spacing values, the instantaneous bandwidth was larger than that for a single patch antenna or comparable varactor-tuned patch antennas. See "A Smart Mechanically Actuated Two-Layer Electromagnetically Coupled Microstrip Antenna with Variable Frequency, Bandwidth, and Antenna Gain," *IEEE Transactions on Antennas and Propagation*, April 2001, Vol. 49, No. 4, pp. 597-601.

SiGe RF front end achieves GaAs performance while conserving power

WIRELESS COMMUNICATIONS SYSTEMS continue to stimulate demand for a semiconductor process that would support high integration and high performance at a reasonable price tag. For low-noise RF front ends, the process of choice traditionally has been GaAs. But the outstanding performance of GaAs MESFETs comes at the expense of a relatively high price and high DC power consumption, especially in LNA design. CMOS has become a more economical alternative for higher integration, and significant progress has been made in designing inexpensive CMOS RF front ends —but their performance is limited. Searching for an alternative, substantial research effort has been put into the development of SiGe bipolar technology. IEEE Student Member Osama Shana'a, IEEE Member Ivan Linscott, and IEEE Fellow Len Tyler have developed a SiGe bipolar RF front end that achieves GaAs-like performance but consumes much less DC power. The circuit is a scaled 1.8-GHz front end built on a 30-GHz SiGe bipolar process. The authors also developed a low-noise Gilbert active mixer. Both circuits use a frequency-scalable optimization technique to ensure the best noise factor for a given DC power. See "Frequency-Scalable SiGe Bipolar RF Front-End Design," *IEEE Journal of Solid-State Circuits*, June 2001, Vol. 36, No. 6, pp. 888-895.

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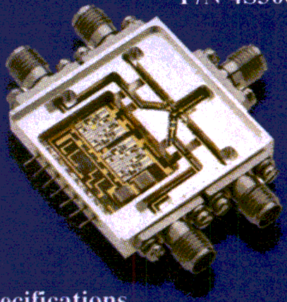

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Switching Speed	50 ns max

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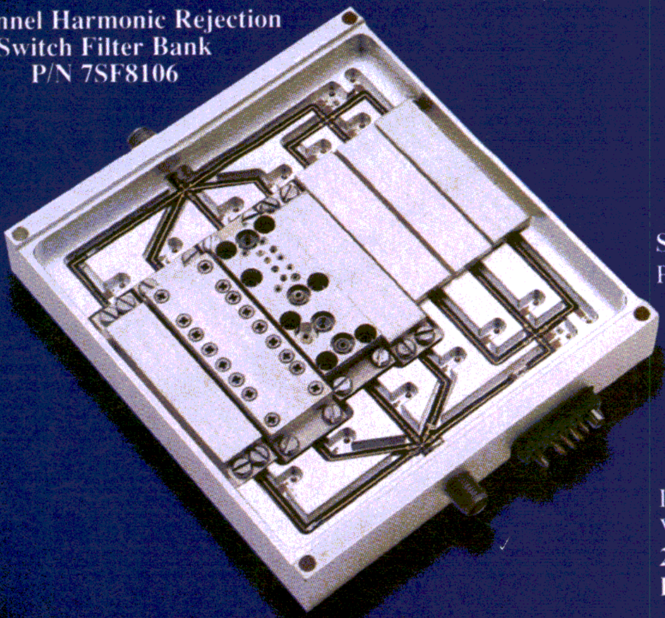

Specifications

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	2.0 - 3.5
	3.5 - 6.0
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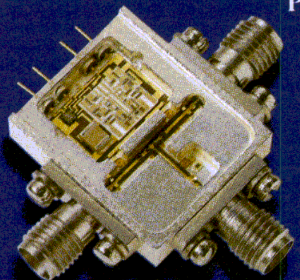

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Isolation	70 dB min
VSWR	2.0:1 max
Switching Speed	100 ns max

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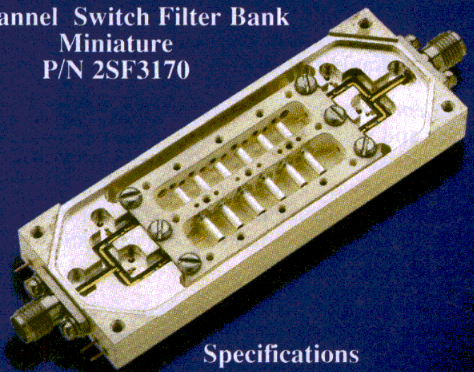

Specifications

Pass Bands (GHz)	6.66 - 7.66 7.66 - 8.66
Insertion Loss	3.0 dB max
VSWR	2.0:1 max
Switching Speed	100 ns max
Size(Inches)	3.0 x 1.1 x .35

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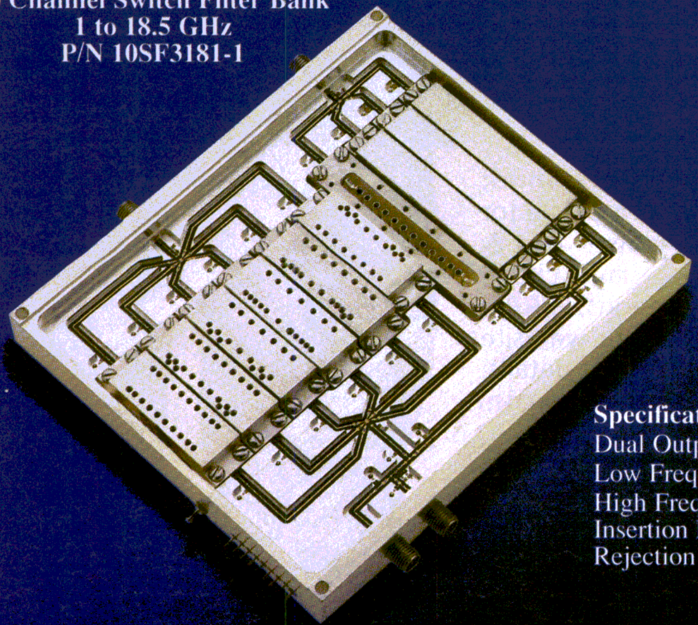

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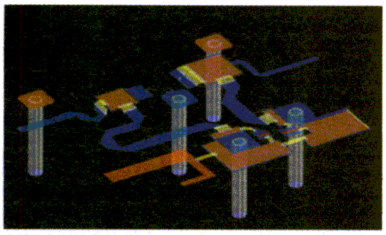

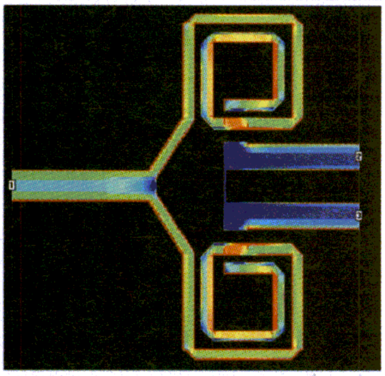

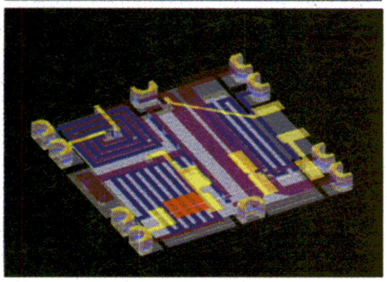

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Simulate IMD In RF Amplifiers With Memory Effects

This article presents a model that provides helpful predictions of multi-tone IMD in systems having long time-constant memory effects.

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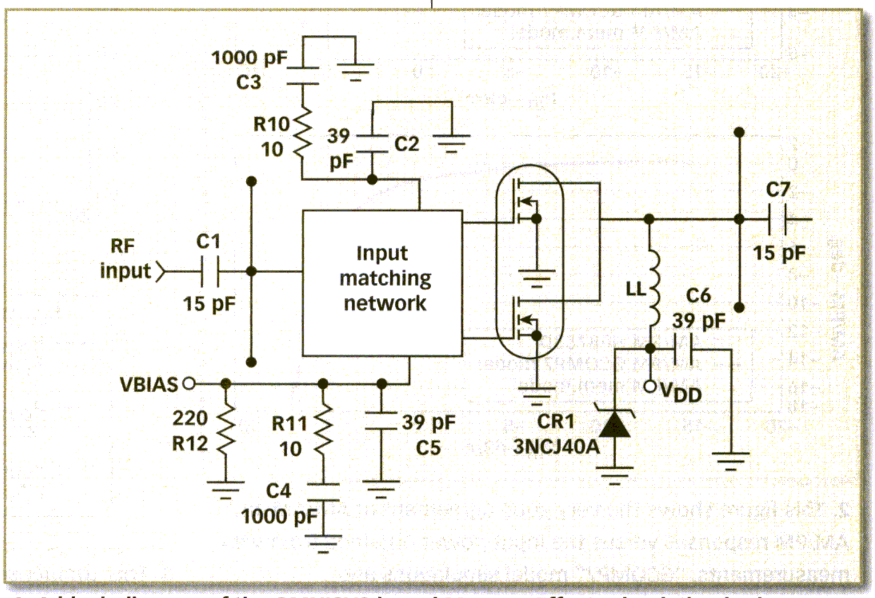
Spectral regrowth resulting from nonlinear distortion in RF amplifiers is a tremendous problem for designers and users of digitally modulated and multicarrier communication systems. Intermodulation distortion (IMD) occurs when mixing two or more carriers and is caused by the nonlinearities of the active devices used in the mixing circuits. Today, IMD in multi-tone spectral communication systems is evaluated using figures of merit such as adjacent-channel power ratio (ACPR) or noise-power ratio (NPR). Commercial measurement systems are now available for these multi-tone figures of merit[1] and many studies continue to clarify correlations between them and the more-familiar, two-tone, third-order intercept point (IP3) and single-tone amplitude-modulation/amplitude-modulation (AM/AM) and AM/phase-modulation (PM) standards.[2-4] In ref. 5, it is shown that NPR can be accurately predicted with a current commercial system simulator, such as OMNISYS, by



1. A block diagram of the OMNISYS-based Memory Effects simulation is shown here.

using the measured AM/AM and AM/PM characteristics of the RF amplifiers under test as input data. Nevertheless, this approach concerns only quasi-memoryless systems—that is, systems where the amplitude and phase distortions at a particular instant depend only on the input signal level at that instant. Most systems exhibit a quasi-memoryless behavior, except those that have large time constants due to biasing circuits, feedback loops, or thermal effects. Several works have been performed on that subject, giving rise to specific measurement techniques and simulations.[6,7] The purpose of this article is to provide a simulation approach that features three advantages: it can be implemented easily in most commercial system simulators, it allows any designer to perform a systematic analysis, and it provides helpful predictions of multitone IMD in systems where long time-constant memory effects are identified or suspected. As in ref. 5, this article makes use of the functions and models available in the OMNISYS software from Hewlett-Packard Co. (Palo Alto, CA). It presents a specific model where amplitude and phase distortions are controlled, affording a time-delay representation of memory effects. To illustrate the model's capabilities, the article presents two analyses describing the expected behavior of commercial amplifier modules in the presence of memory effects—first in the case of two-tone excitation, then in the case of a mutitone excitation—to investigate NPR.

Model Configuration

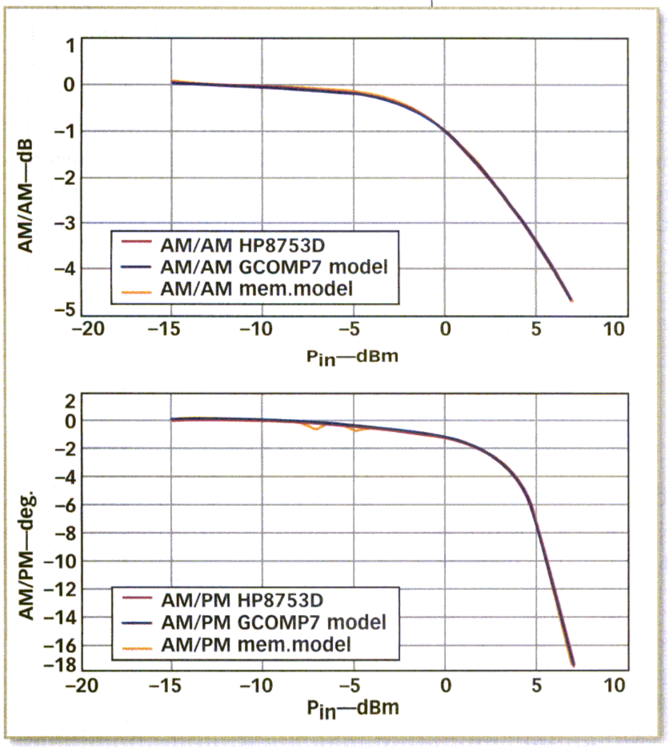
The model, which is built in order to monitor the complex distortion of a particular amplifier, is based on the assumption that the AM/AM and AM/PM characteristics have been previously measured and that the time-constant τ of the memory effect has been clearly evaluated. With these requirements fulfilled, the principle of the model lies in the realization of the following relationship:

$$V_{out}(t) = V(t)\cos[\omega t + \phi(t)] = V(t)\cos \omega t \cos \phi(t) - V(t)\sin \omega t \sin \phi(t) \quad (1)$$

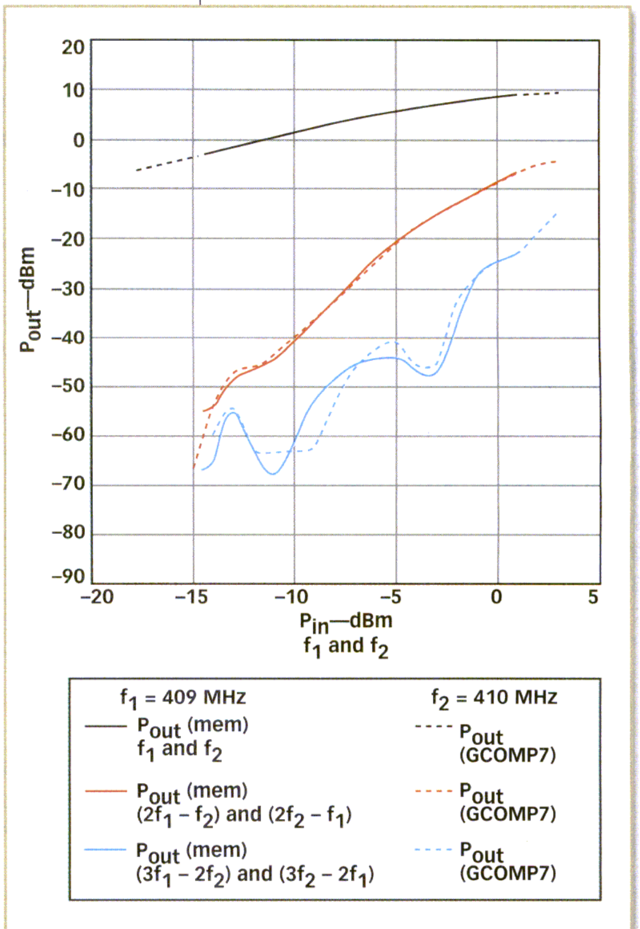
This represents the amplifier's output voltage V_{out} at time t.

In this relationship, the memory effect can be taken into account by making the voltage amplitude V(t) and the phase deviation $\phi(t)$ depend on the input voltage V_{in} at instant $t - \tau_1$ and at instant $t - \tau_2$, where τ_1 and τ_2 are delays characterizing memory time constants. **Figure 1** shows the complete block diagram built with OMNISYS elements to achieve these functions.

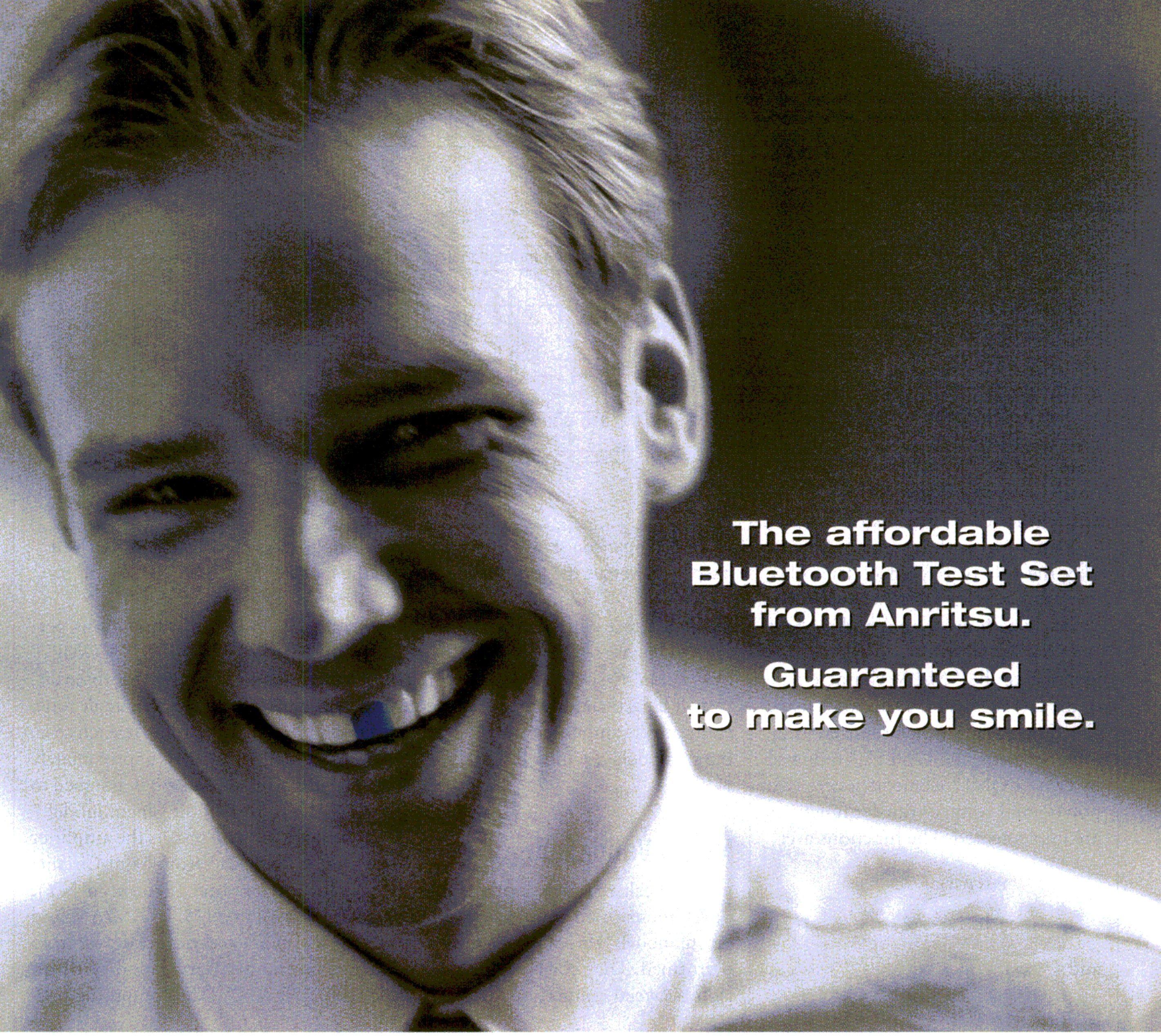
In this simulation setup, V(t) is compressed by the gain-controlled ampli-



2. This figure shows the very good agreement of AM/AM and AM/PM responses versus the input power obtained from VNA measurements. "GCOMP7" model simulations and "mem.model" simulations for the module "MAR 3" from Mini-Circuits at 410 MHZ are illustrated above.



3. This comparison shows the good fit between IM responses obtained with the "GCOMP7" model and "mem.model" for the module "MAR 3."



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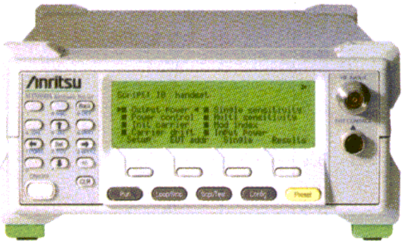

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fier element "VGAIN2." This is tabulated according to the equivalent voltage gain (assuming a 50-Ω standard) of the device under test (DUT) derived from its power gain. The "VGAIN2" control loop is fed by the input signal through a delay element of duration τ_1 and an envelope detector. Achieving the phase deviation, $\phi(t)$ is slightly more complex. The input signal is first delayed through a delay element of duration τ_2. Then, the phase deviation $\phi(t)$ is extracted by using the phase comparator element "PCOMP." For this operation, the working signal is divided into two paths. One consists of a direct transmission without phase shift to play the role of reference. The other comprises a "GCOMP7" element conditioned with unity gain and a phase response with respect to the signal level identical to the AM/PM characteristic of the DUT. Then, the sine and cosine functions of $\phi(t)$ are synthesized using a splitter element, "CSPLIT," followed by two "EQN1" elements where two polynomial voltage-transfer functions are implemented. The functions are:

$$\cos\phi(t) = 1 - [\phi(t)]^2/2 \qquad (2)$$

and

$$\sin\varphi(t) = \phi(t) - [\phi(t)]^3/6 \qquad (3)$$

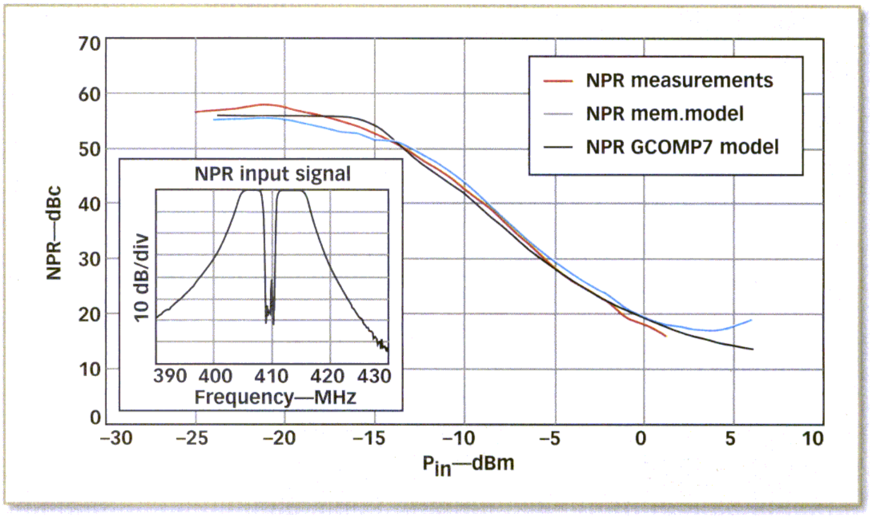
Another splitter element, CSPLIT, and a +90-deg. phase-shifter element provide the amplitude-modulated RF signal V(t) cos ωt and its quadrature form V(t) sin wt. Two "EQN2" elements, where the multiplication operation is implemented, produce the products V(t) cos ωt cos $\phi(t)$ and −V(t) sin ωt sin $\phi(t)$. Finally, a summation element "CSUM" yields the desired output RF voltage:

$$V_{out} = V(t)\cos\omega t\cos\phi(t) - V(t)\sin\omega t\sin\phi(t) = V(t)\cos[\omega t + \phi(t)] \qquad (4)$$

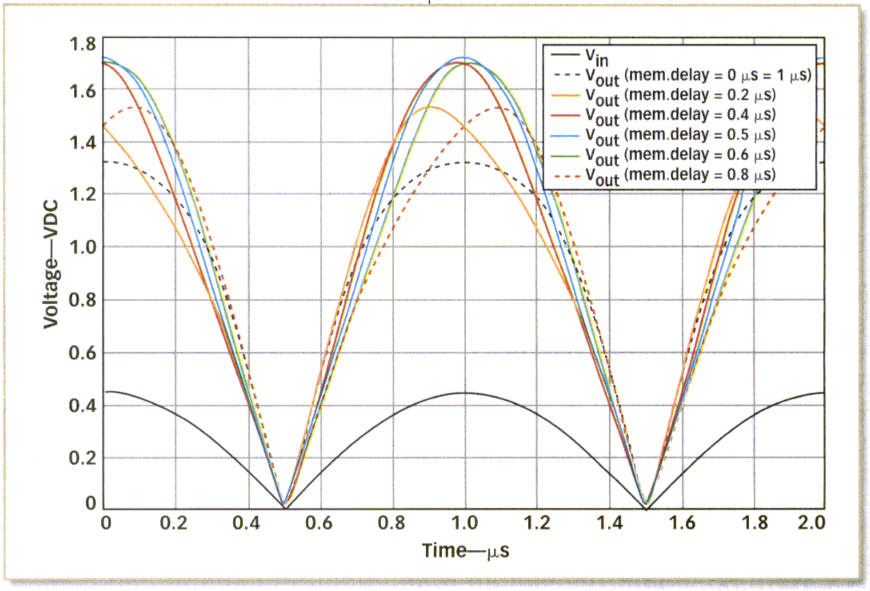
Note that this modeling supports separately delaying (τ_1 and τ_2) of the memory effects, influencing the amplitude and phase of the RF signal. In fact, this capability should be used sparingly since a particular memory effect generally affects amplitude and phase with the same delay, which results in: $\tau_1 = \tau_2 = \tau$.

Model Validation

To check the fitness of the previously mentioned model, known as "mem.model," three kinds of tests were performed. They consist of a comparison between simulations performed with this model and simulations performed with the OMNISYS "GCOMP7" standard amplifier model for three different types of input signal: single tone, two tone, and multi tone. In each case, the working frequency is approximately 410 MHz and the delay τ is assumed to be equal to zero in the "mem.model." The DUT in these tests is the amplifier module "MAR3" from Mini-Circuits Laboratories, Inc. (Brooklyn NY), already used in ref. 5. Its AM/AM and AM/PM characteristics are drawn from measurements performed with an HP8753D VNA. The computing pro-



4. This comparison shows the good fit between the measured and simulated NPR responses versus the total input power for the module "MAR 3."



5. This is the signal envelope obtained under two-tone excitation with the memory delay τ varying from 0 to 1 µs for the module "MAR 3."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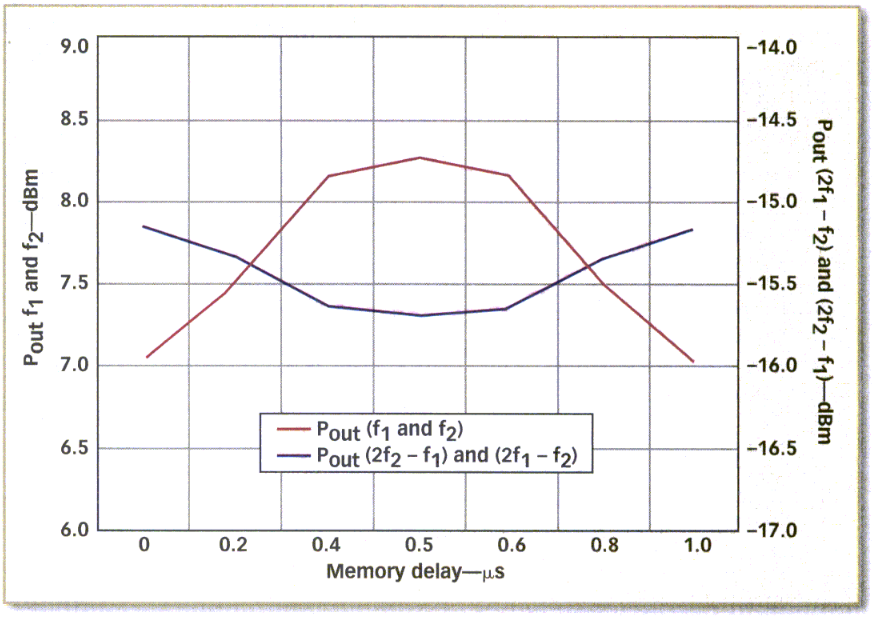
cedure used for all the simulations is the Fast Fourier transform (FFT).

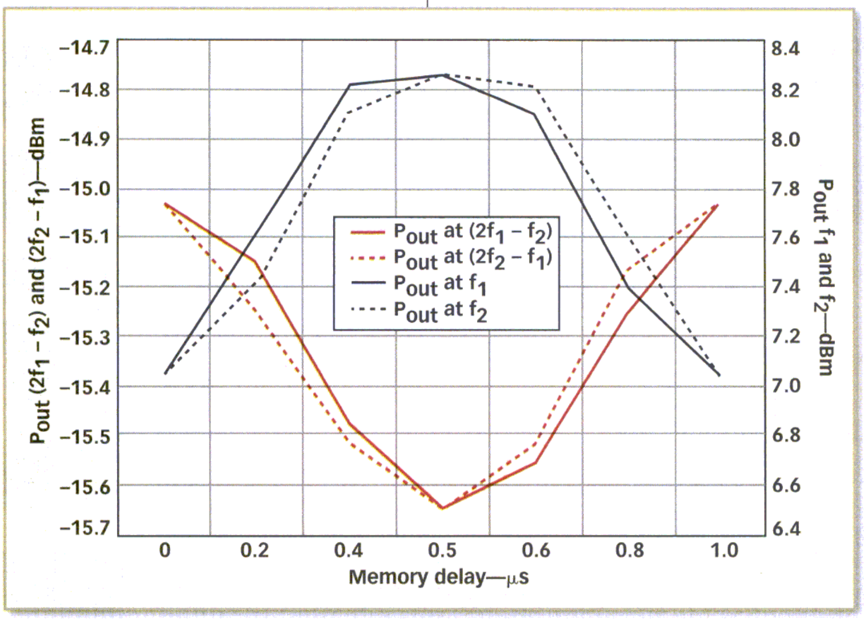
The single-tone test led to very good agreement between the models and the measurements. Indeed, as shown in **Fig. 2**, AM/AM and AM/PM results obtained from "GCOMP7" simulations, "mem. model" simulations, and vector-network-analyzer (VNA) measurements are quasi-identical.

The two-tone test was also very satisfactory, as demonstrated in **Fig. 3** by the fundamental-, third-, and fifth-order power responses resulting from the two models. Slight discrepancies became perceptible only for the fifth-order response.

For the multi-tone test, an NPR spectrum excitation was chosen. It consisted of a 10-MHz-wide white-noise band with a 1-MHz-wide, 50-dB-deep notch centered at 410 MHz. The test was first performed through real measurements with a practical setup based on an avalanche-diode noise source similar to that described in ref. 5, but with filtering centered to 410 MHz. Then the simulation was performed with the "GCOMP7" model and with the "mem.model" using the simulation setup of ref. 5 after appropriate modifications of the filtering band and the multi-tone "RFCOMB" source. Remember that this test, to be similar to band-pass Gaussian white noise, consists of a large number of equal-amplitude, equally spaced carriers having independent, random phases. For the "GCOMP7" model, this number is 10,000, but is limited to 600 for "mem.model" due to its higher complexity. Consequently, it required more computer random-access memory (RAM) [HP 9000C200]. Despite the substantial differences between the operating conditions of the measurements and the two simulations, NPR results obtained in the three cases were all in good agreement. As shown in **Fig. 4**, discrepancies between these results are within a margin of a few decibels on the major part of the input-power range. So the NPR test, as well as the single-tone and two-tone tests, show that the developed "mem.model" is fully valid. Therefore, it is now reasonable to make use of its potential for delaying amplitude and phase distortions and to apply it to the analysis of memory effects in two cases of great interest: the two-tone excitation and the NPR excitation.



6. This figure shows the two-tone output-power spectrum versus the memory delay τ with only AM/AM distortion for MAR3 as DUT. $P_{in\ total}$ = 0 dBm, f1 = 409 MHz, f2 = 410 MHz.



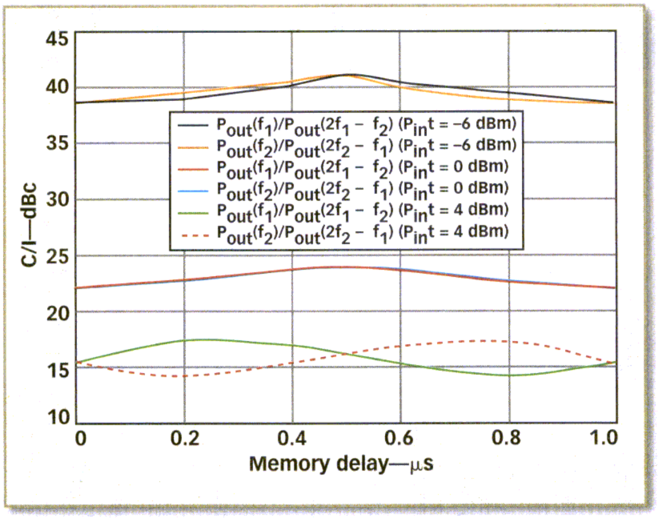
7. This figure shows the two-tone output-power spectrum versus the memory delay τ with AM/AM and AM/PM distortions for "MAR3" as DUT. $P_{in\ total}$ = 0 dBm, f1 = 409 MHz, f2 = 410 MHz.

Two-Tone Excitation

In this study, the "mem.model" is applied to the "MAR3" module and the input is driven by the "RFCOMB" source with two equal-amplitude carriers at 409 and 410 MHz. The computing procedure is still the FFT.

The first aspect to be examined lies in modifications to the signal envelope caused by memory effects. This is shown

in **Fig. 5**, in the case where the total input power is 0 dBm. Without any memory effect—that is, with τ = 0—the output voltage V_{out} is clearly affected by a hard compression which, from Fig. 3, corresponds to a power-gain compression of approximately 2.5 dB. But as τ varies from 0 to 0.5 μs, it can be seen that the V_{out} compression decreases progressively. At τ = 0.5 μs, which is half the beat period between 409 and 410 MHz, V_{out} is almost exempt from compression and the corresponding power-gain value is very close to that of the linear zone in Fig. 3. For τ varying from 0.5 to 1.0 μs, an inverse evolution can be seen and τ = 1 μs leads, as expected, to a situation identical to that of τ = 0. This example clearly shows how the presence of memory effects can completely confuse the understanding of the familiar two-tone test. It must be pointed out that only the AM/AM distortion is involved in these envelope modifications. AM/PM distortion plays no role. This is supported by the fact that, in the previous examples, the envelope shape has exactly the same appearance at the final output and at the "VGAIN2" output of the "mem.model."



8. This figure shows the two-tone C/I ratio versus the memory delay τ with AM/AM and AM/PM distortions for MAR3 as DUT. $P_{in\ total}$ = –6 dBm, 0 dBm, and +4 dBm, f1 = 409 MHz, f2 = 410 MHz.

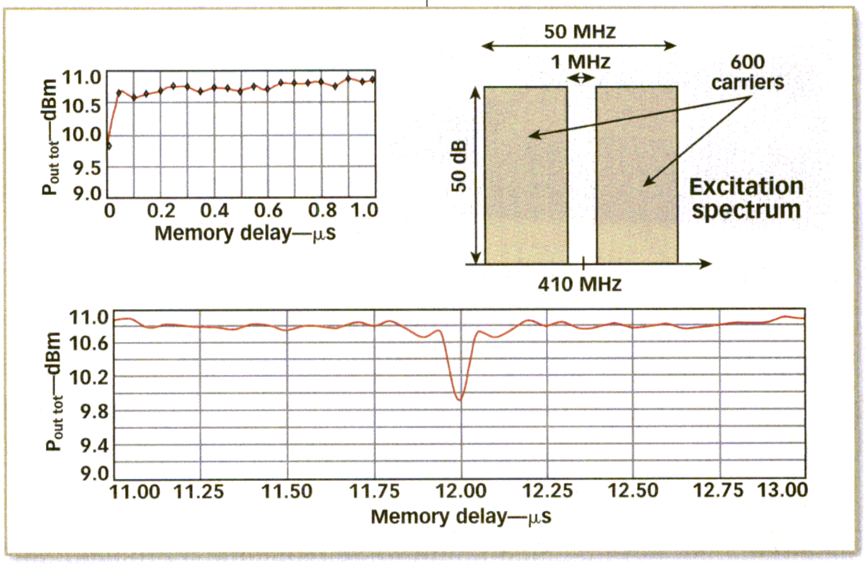
The second aspect to be considered deals with spectrum modifications resulting from memory effects. Contrary to the case of the signal envelope, AM/AM and AM/PM distortions are involved in these spectrum modifications. Nevertheless, the AM/AM distortion still has a major contribution. This is illustrated in **Fig. 6**, which presents the variations of the fundamental and third-order spectrum components versus the memory delay τ at "VGAIN2" output—that is, with only the AM/AM contribution. An important piece of information that is provided in this figure lies in the symmetry of the spectrum with respect to the center frequency, and the symmetry of the spectrum variations with respect to the τ value 0.5 μs. Curiously, this symmetry is somewhat disturbed with the introduction of the AM/PM distortion contribution, as shown in **Fig. 7**, which provides the complete spectrum at the final output of the "mem.model." Comparing this figure with Fig. 6 makes it clear that the only contribution of the AM/PM distortion is the addition of a slight asymmetry to the spectrum at a particular value of the delay τ and a slight asymmetry of the variations of this spectrum versus τ, except for the particular values 0, 0.5, 1.0 μs, and their multiples.

To conclude these investigations, it would be of great interest to see to what extent carrier/intermodulation (C/I) measurements can be exploited in the presence of memory effects. **Figure 8** reveals the answer to this question. It shows three examples of C/I variations versus the delay τ obtained at the final output of the "mem.model." They correspond to input-power levels of –6, 0, and + 4 dBm. Note that many variations of the ratio C/I are possible, depending on the power level and the value of the delay τ. Deviations, with respect to the case where τ = 0 (no memory effect), can reach approximately 2 dB at worst, which is far from negligible.

NPR Excitation

In this study, the "mem.model" is always applied to the "MAR3" module but its input is now driven by an NPR excitation. This is provided by the "RFCOMB" source and has a 50-MHz bandwidth centered around 410 MHz and is filled with 600 carriers having

Continued on page 207



9. This figure deals with an NPR simulation on a "MAR3" module and shows the variations of the total output power versus the memory delay τ, with the previously discussed excitation spectrum and 0-dBm total input power.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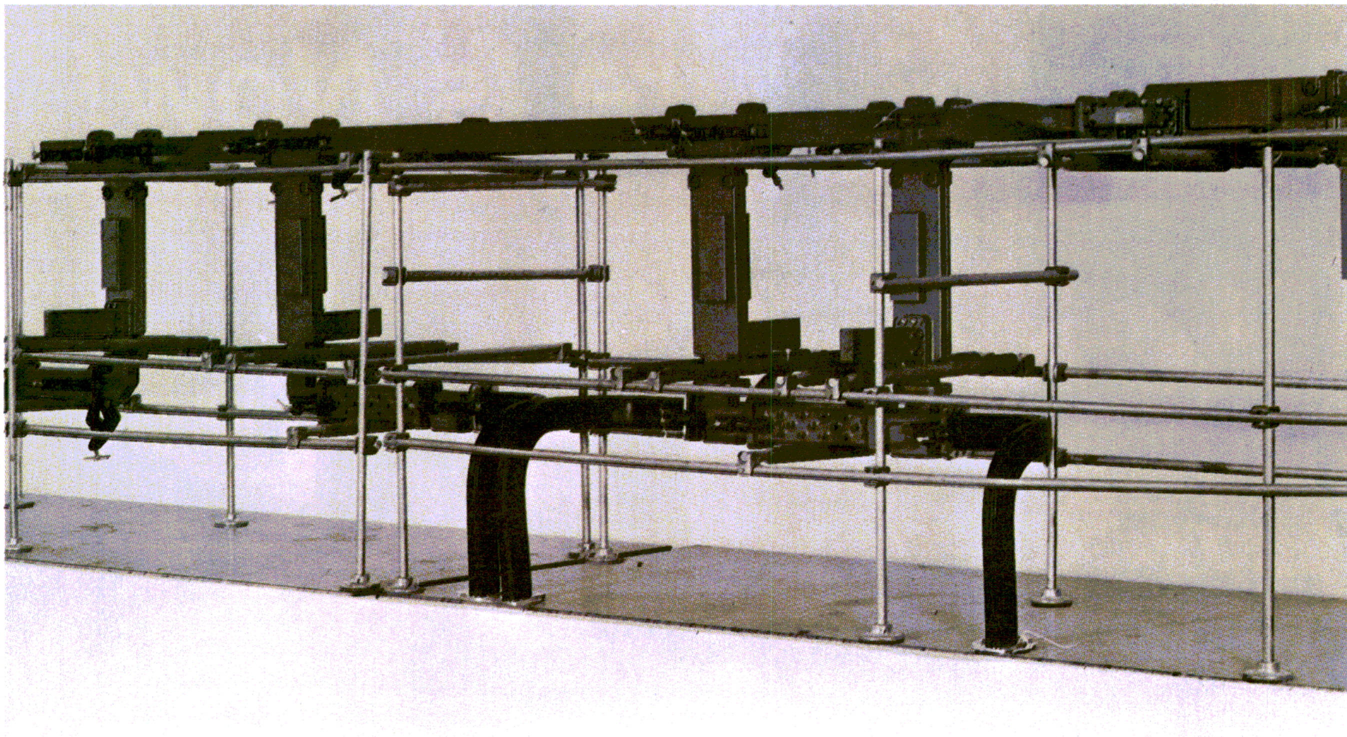

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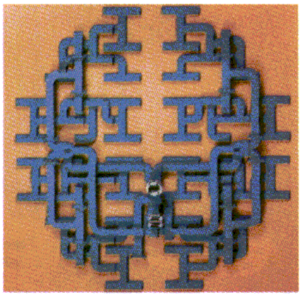

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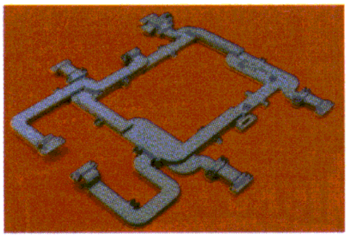

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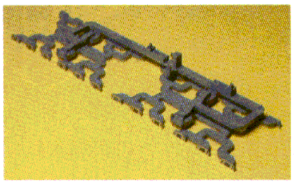

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DESIGN

Construct An FMCW Front End For Anticollision Radar

This novel front end uses a GaAs MESFET VCO for high output power and wide tuning range, as well as a balanced resistive mixer for low IM and 1/f noise.

Anticollision radar plays one of the most important roles in developing intelligent traffic systems (ITS). In this application, the distance between moving vehicles and other obstacles must be measured accurately, so frequency-modulation continuous-wave (FMCW) radar is usually employed. This article describes the design and performance of a low-cost, X-band, integrated front end that can be used in an FMCW anticollision radar system. Its main components are a voltage-controlled oscillator (VCO), a buffer, a circulator, and a mixer. The system operates at 9 GHz and has a linear tuning range of more than 300 MHz. The VCO employs a gallium-arsenide (GaAs), metal-semiconductor field-effect transistor (MESFET) and strikes a good balance between high output power and wide tuning range. A GaAs FET balanced resistive mixer provides low intermodulation (IM) and low 1/f noise even at very low intermediate frequencies (IFs) [down to tens of Hertz].

Basically, the frequency of an emitted signal varies according to the known time function $\phi(t)$ **(Fig.1)**. Ignoring the Doppler effect, any additional modulation by the target or the amplitude difference, the received signal has a time delay $T_d = 2d/c$ when compared with the emitted signal. By mixing the emitted and received signal, this small time difference is replaced by a frequency difference f_b. Compensation for the inevitable Doppler frequency shift f_d is described in the ensuing text.

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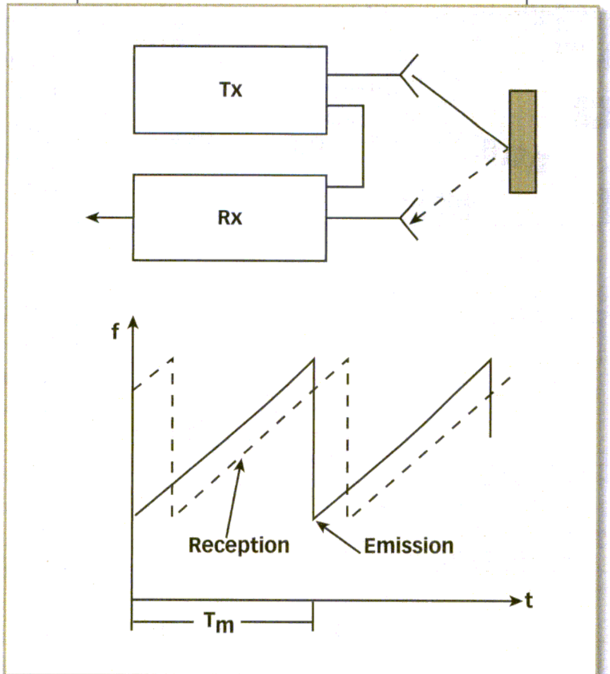


1. This figure shows the principle of distance measurement.

The distance between the vehicles can be deduced from the following relationship:

$$|f_b| = f_d + KT_d \qquad (1)$$

when:

$$f_d = 0, |f_b| =$$

$$KT_d = \frac{2\Delta fd}{T_m c} \qquad (2)$$

then:

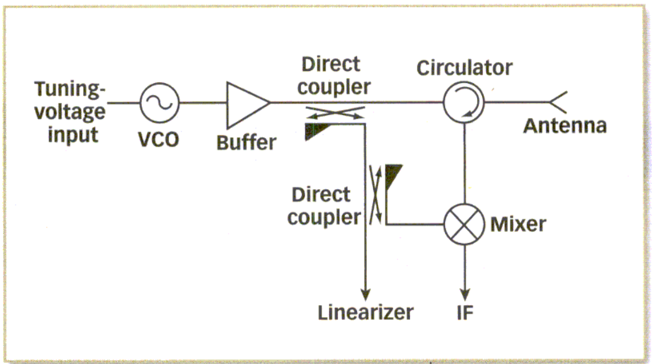
$$d = \frac{cT_m f_b}{2\Delta f} \qquad (3)$$

where:

f_d = the Doppler frequency shift,
f_b = the frequency difference,
T_d = the time delay, and
$K = \Delta f / T_m$ = the frequency-modulation (FM) slope.

Circuit Design

The integrated transceiver presented here has a single antenna and a circulator to isolate the emitted and received signals. It includes a varactor-tuned VCO, a buffer amplifier, a single balanced resistive mixer, as well as a circulator **(Fig. 2)**.

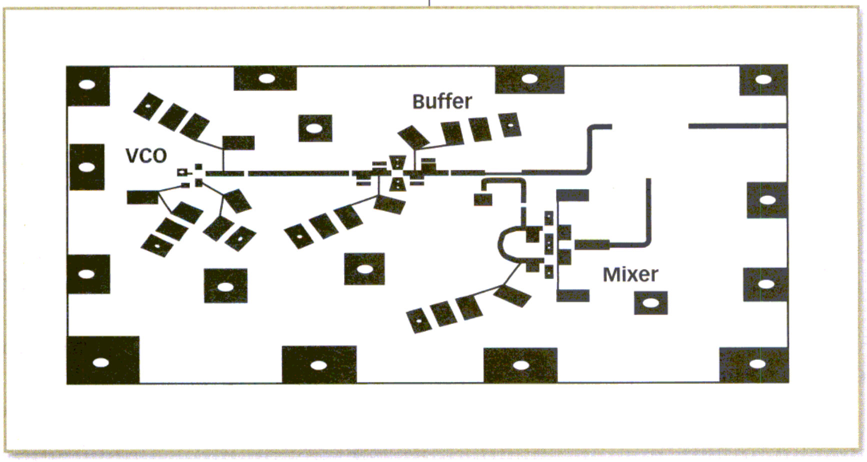


2. This block diagram shows the front end designed for use in an anti-collision radar system.

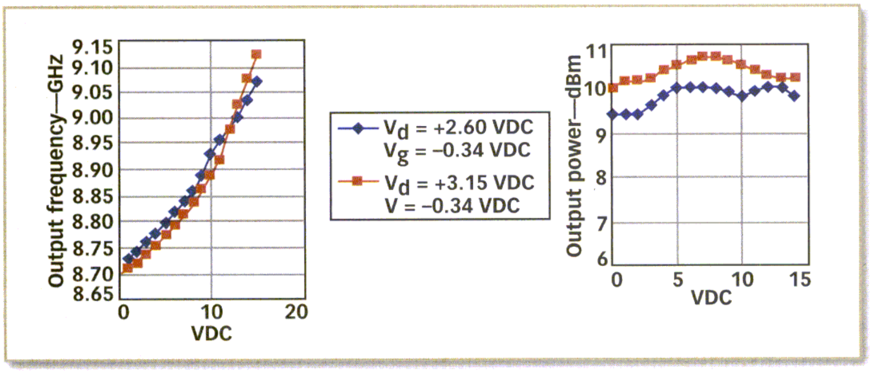
The varactor-tuned VCO contains a GaAs FET common-source capacitive-feedback oscillator that is tuned by changing the varactor's capacitance. An NE76084 FET was chosen as the active device for this particular design since it has sufficient high-frequency power output. The specification for the oscillator involves a single-polarity bias supply, so a self-bias circuit was used to supply the FET's gate voltage.

The VCO output signal must be made insensitive to load variations, otherwise the output frequency and power would vary with the load and the radar's normal operation would be affected. A good solution to this problem is adding a GaAs FET small-signal amplifier as a buffer at the VCO's output terminal. It provides high isolation (−47 dB) and, as a bonus, a small amount of gain (approximately 4 dB). The most important factor to consider is the absolute stability of the buffer. So, unlike the VCO's self-bias circuit, a double bias is used to supply the buffer FET with suitable voltages and currents.

To maintain excellent performance, FMCW radar requires that the receiver (Rx) has very low IM and noise. However, the Schottky-barrier diode that is used in most microwave mixers cannot provide these required characteristics because it is a strongly nonlinear device. This system that is described here employs a new type of resistive mixer (linear mixer) that uses the time-varying channel resistance of a GaAs MESFET to achieve frequency mixing. Due to the very weak nonlinearity of this resistance when no DC bias is applied to the FET's drain, the mixer generates very low IM as well as lower noise when compared with a diode mixer having the same conversion loss. Two FETs with well-matched I/V characteristics are chosen for the single balanced mixer. The FET gates are driven with a 180-deg. local-oscillator (LO) phase difference that is achieved by a loop of transmission line, which causes the channel resistance to show a



3. This photograph shows the front end's PCB layout.



4. These graphs show the output characteristics of the front end.

time-varying characteristic. The drains are in parallel at the RF and are fed through a quarter-wave transformer that matches the 50-Ω RF input to the 25-Ω input impedance of the parallel channels. The IF currents in the channels are 180-deg. out of phase. Therefore, they are combined using a 180-deg. combiner—in the form of a super-low-noise operation amplifier. The mixer demonstrates superior performance, even at very low IF (down to tens of Hertz).

[*Each functional circuit within the front end, as well as the entire front end as a whole, were designed and simulated in a computer using CAD software.*]

Simulation And Fabrication

Each functional circuit within the integrated front end, as well as the entire front end as a whole, were designed and simulated in a computer by using advanced HP EEsof RF CAD software until the design targets were met.

The circuit, including the circulator and coupler, as well as the main functional units mentioned earlier, was fabricated on a substrate (having $\epsilon_r = 2.65$ and H = 0.5 mm) and housed in an aluminum (Al) box along with DC power-supply circuits and an IF amplifier. The entire package size measures 60 × 30 × 20 mm. All of the active devices that are used in this front end are GaAs MESFETs (NE76084) to ensure consistent operation. **Figure 3** shows the printed-circuit-board (PCB) layout of the front end. **Figure 4** shows the front end's output frequency and power versus tuning voltage.

The front end of FMCW anticollision radar described in this paper operates across the frequency range of 8.8 to 9.1 GHz. Its FM linearity is better than 3 percent due to the constant ν varactor diode used as the VCO's tuning element (ν is the index of the rate of the varactor's capacity to voltage). The output power of the transceiver is +10.3 dBm (±0.3) since it provides 10-dBm LO power to the mixer. The conversion loss of the resistive mixer is 8 dB at 9 GHz. MRF

FOR FURTHER READING

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2. "GaAs Monolithic Circuit for FMCW Radar," IEEE Microwave and Millimeter-wave Monolithic Circuits Symposium, 1988.
3. "Noise Calculations and Experimental Results of Varactor Tunable Oscillator with Significantly Reduced Phase Noise," *IEEE MTT-43*, No. 2, 1995.
4. "A GaAs MESFET Balanced Mixer with Very Low Intermodulation," *IEEE MTT-S Digest*, 1987.
5. Stephen A. Maas, *The RF and Microwave Circuits Design Cookbook*, Artech House, Boston, 1998.

Introduction To 3G Mobile Communications

JUHA KORHONEN, Editor

THIRD-GENERATION (3G) mobile communications systems represent the future of cellular technology. Ushering in an era of digital multimedia handsets with high data-transmission rates, 3G will take the end user beyond the realm of basic cellular services and into the brave new world of wireless communications.

Juha Korhonen's *Introduction To 3G Mobile Communications* provides the reader with an easy-to-understand primer on 3G-technology principles, concepts, and applications. The first chapter covers the history of mobile cellular systems from first generation to the present. The overview examines proposals for 3G Standard, including WCDMA, Advanced TDMA, OFDM, and IMT-2000, as well as addressing 3GPP and 3GPP2.

Chapter 2 highlights principles of CDMA, radio-channel access schemes, spread spectrum, power control, and TDD. Chapter 3 examines the physical layer of WCDMA air interface. Chapter 4 concentrates on modulation techniques and spread spectrum.

Chapter 5 features orthogonal, pseudo-noise, and synchronization codes, as well as auto-correlation, cross-correlation, and intercell interference. Chapter 6 examines channel-coding processes and theories, including block codes, convolutional codes, turbo codes, and channel coding in UTRAN. Chapter 7 investigates the Protocol Stack of WCDMA air interface.

Chapters 8, 9, and 10 focus on network basics, planning, and management, respectively. In these chapters, UMTS and GSM radio-access networks are analyzed, interfaces are discussed, and telecommunications-management architecture is explored.

Chapter 11 examines RRC, random-access, and radio-bearer procedures; data transmissions; and handovers. Chapter 12 introduces new concepts in the UMTS network, including location services, opportunity-driven multiple access, super and turbo chargers, and multimedia messaging services. Chapter 13 explores 3G services, including teleservices, bearer services, supplementary services, QoS classes, and service capabilities.

Chapter 14 lists examples of 3G applications, including voice, messaging, Internet access, and location-based applications. Finally, Chapter 15 offers examples of the future of 3G mobile communications. A glossary of acronyms is included. (2001, 559 pp., hardcover, ISBN: 1-58053-287-X, $95.00.) **Artech House, 685 Canton St., Norwood, MA 02062; (800) 225-9977, (781) 769-9750, FAX: (781) 769-6334, Internet: www.artechhouse.com.** MRF

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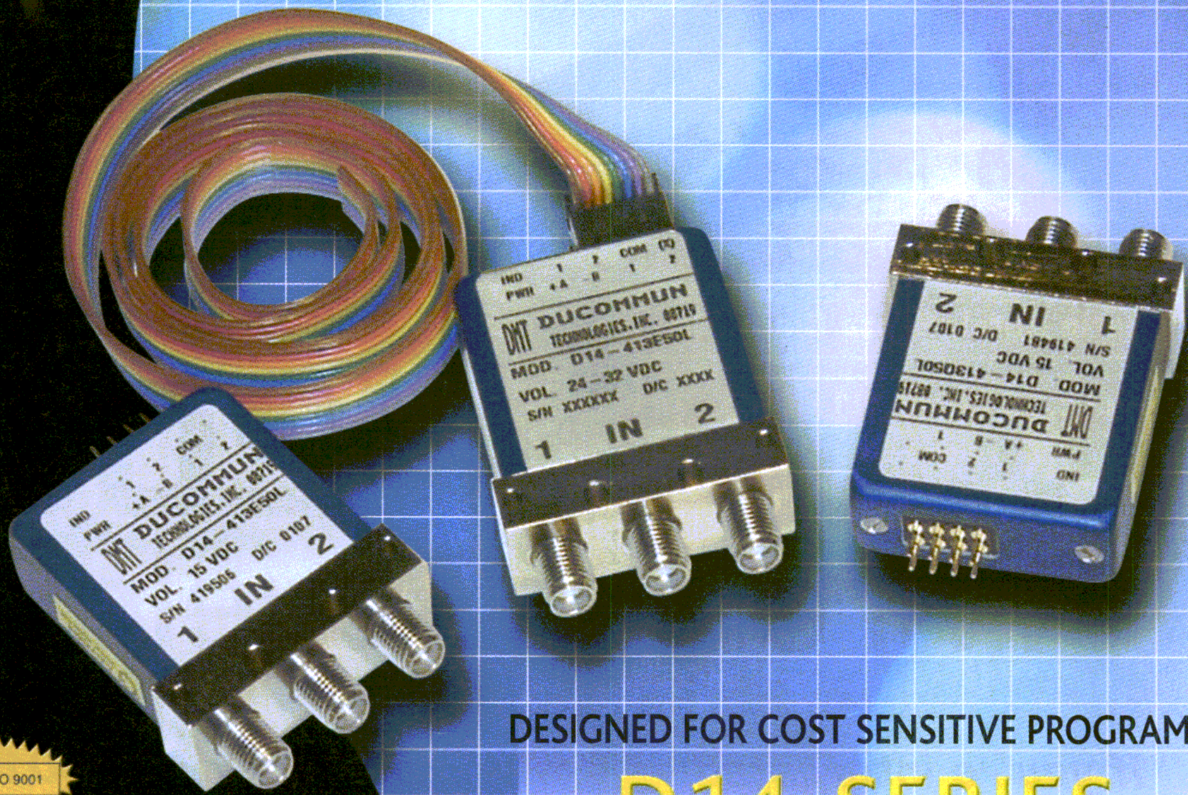

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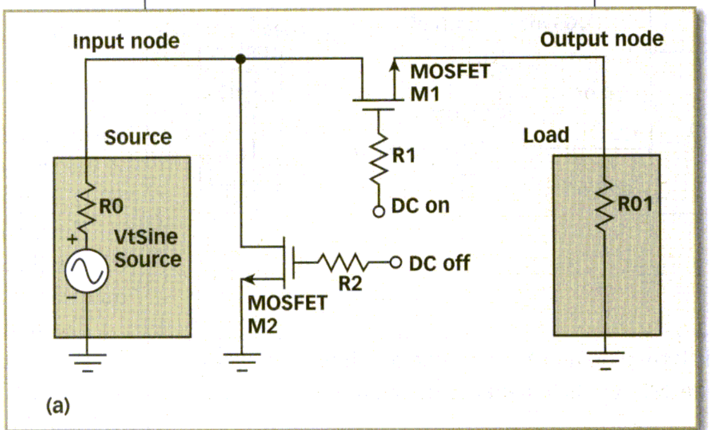
Switching RF and microwave signals is a fundamental function in all radio applications. Accordingly, there are a great variety of switch products and forms, from the basic single pole, single throw (SPST) to a large crosspoint matrix. This article explains basic RF semiconductor switch functionality and reviews switch parameters and limitations. It examines the basic theory of an RF switch and the trade-offs between power handling, insertion loss, and isolation.

Although there are diode-type switches, the focus here is on complementary-metal-oxide-semiconductor (CMOS) metal-oxide-semiconductor field-effect-transistor (MOSFET) types, the main technology for wireless applications. Switches can also be classified as reflective and absorptive, but this article addresses only the reflective type.

Most high-frequency switches use gallium-arsenide (GaAs) technology. Peregrine Semiconductor's Ultra-Thin-Silicon (UTSi) Technology enables the realization of quality RF switches using dielectric isolation between UTSi MOSFETs that are fabricated in CMOS. UTSi is a Si-CMOS process that is fabricated on a sapphire insulator, known as Si-on-sapphire (SOS). This enables the manufacture of simple to highly integrated RF switches with modest-to-high-power capability (+10 to +37 dBm). Stacking devices allows UTSi RF switches to handle any practical power level. The complete isolation afforded by UTSi makes this switch impossible to fabricate in conventional Si-CMOS, bipolar CMOS (BiCMOS), and Si-germanium (SiGe) technologies. UTSi switches can be further integrated with complex digital CMOS control and other components in order to realize excellent on-chip isolation and insertion loss over a broad range of frequencies and supply voltages.



1a. The basic MOSFET SPST switch consists of two devices (M1 and M2) that either pass or block an RF input signal depending on the bias voltages that control M1 and M2.

Simple mathematical expressions can be used to describe the operation of MOS-

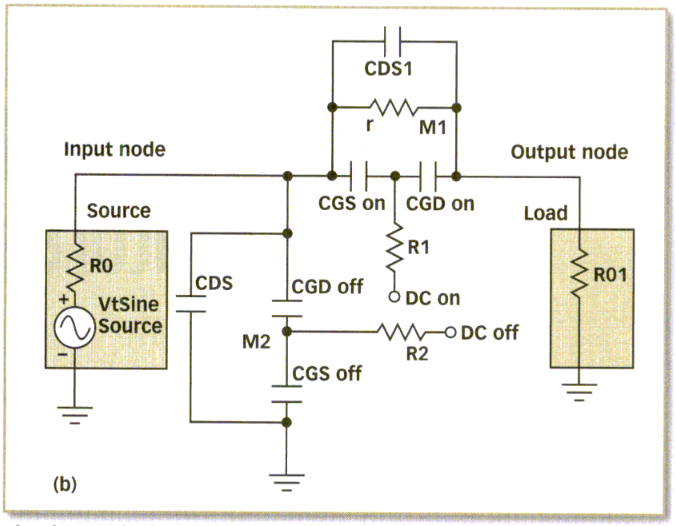
FET switches. An SPST switch schematic is shown in **Fig. 1a**. An RF signal presented at the input node is either blocked from or passed through to the output node, depending on the DC bias of MOSFETs M1 and M2. Actual values of DC bias depend on the polarity and threshold of the MOSFETs. Resistor R0 isolates the bias from the AC signal and is essential for optimal switch action. The on- and off-states of the switch are explained using **Figs. 1b and c.**

Figure 1b illustrates the equivalent small-signal values of MOSFETs M1 and M2 when the RF switch is on. M1 is primarily resistive, with a through coupling of r, while M2 is primarily capacitive, with coupling to ground through capacitors CGS off, CGD off, and CDS. The importance of the gate resistor R1 is clearly illustrated. If R1 is too small, the gate node of M1 would be held at the DC bias voltage, resulting in negative feedback via capacitors CGS on and CGD on. This feedback has the effect of increasing r, resulting in larger Ohmic loss. A small value of R2 prevents the voltage dividing action of M2 capacitors CGS off and CGD off, reducing the 1-dB compression point up to 6 dB (as explained later). R, therefore, needs to be large enough so that RF signals feeding onto the gate node are AC isolated from the DC bias. That is:

$$f_{min} = 5 / \pi R C_{offp} \sqrt{2} \qquad (1)$$

where:

R = the series resistor of the gate node **(Fig. 1b)**, and f_{min} = the minimum frequency at which the switch can operate. Since R is much larger than 50 Ω, C_{offp} for M2 is the parallel value of CGS off and CGD off (the off-capacitance was chosen since it results in the largest f_{min}). It is important to realize that Eq. 1 is based on simple resistive-capacitive (RC) calculations and has no lower limit due to semiconductor material limitations. By contrast, GaAs switches may have switching speed limitations as a result of slow states that may be present in the GaAs.



1b. The equivalent small-signal parameters of M1 and M2 in Fig. 1a show the dominant characteristics of each device. M1 is primarily resistive while M2 is capacitive.

The insertion loss of the switch is the difference between the maximum available power at the input and the power delivered to the output. At low frequencies, most of the power is lost across r, resulting in the following expression for insertion loss:

$$IL = 10LOG_{10}\left[\left(1 + \frac{r}{2R0}\right)^2 + \left(\frac{\omega C_{offs}(R0 + r)}{2}\right)^2\right] (in\ dB) \qquad (2a)$$

where:

R0 = the impedance of the source and load (50 Ω),

r = the resistance of M1 when the switch is on, and

C_{offs} = the series value of CGS off and CGD off in parallel with CDS of M2.

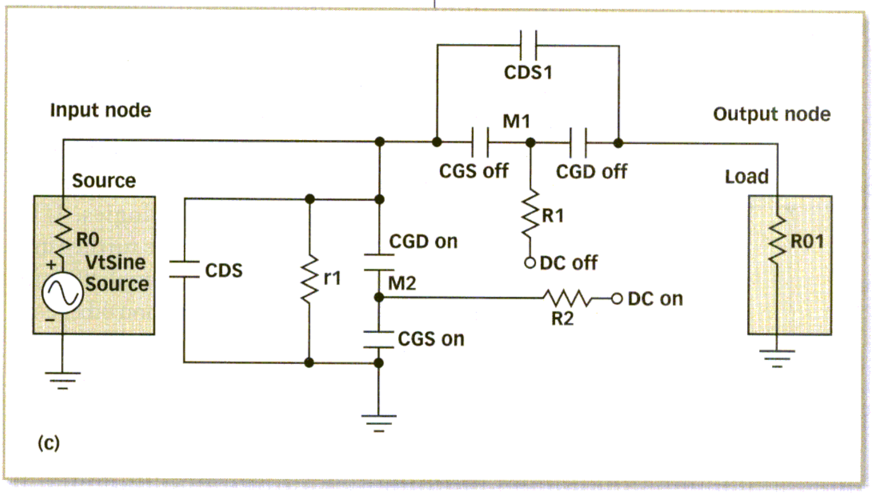
Equation 2a becomes invalid when the capacitive reactance of M2 becomes comparable to r. However, Eq. 2a can serve as a guide in estimating insertion loss. Usually, r is much less than R0 in real switches. Equation 2a is simplified as follows:

$$IL \approx \frac{10r}{R0ln(10)} \approx 0.087r \qquad (2b)$$

within 5 percent at low frequencies ω × C × R0 ≤0.1 for r <10 Ω and R0 = 50 Ω

Thus, at low frequencies, a 3-Ω value for r will result in approximately one-quarter-of-a-decibel insertion loss.

The small-signal equivalent circuit for the off-state of the switch in Fig. 1a is provided in Fig. 1c. For simplification, M1 and M2 are chosen identically, so



1c. In the normal off-state, M1 is turned off and M2 is turned on, thus blocking the input signal from the output node. M2 serves to increase the input-to-output isolation of the switch.

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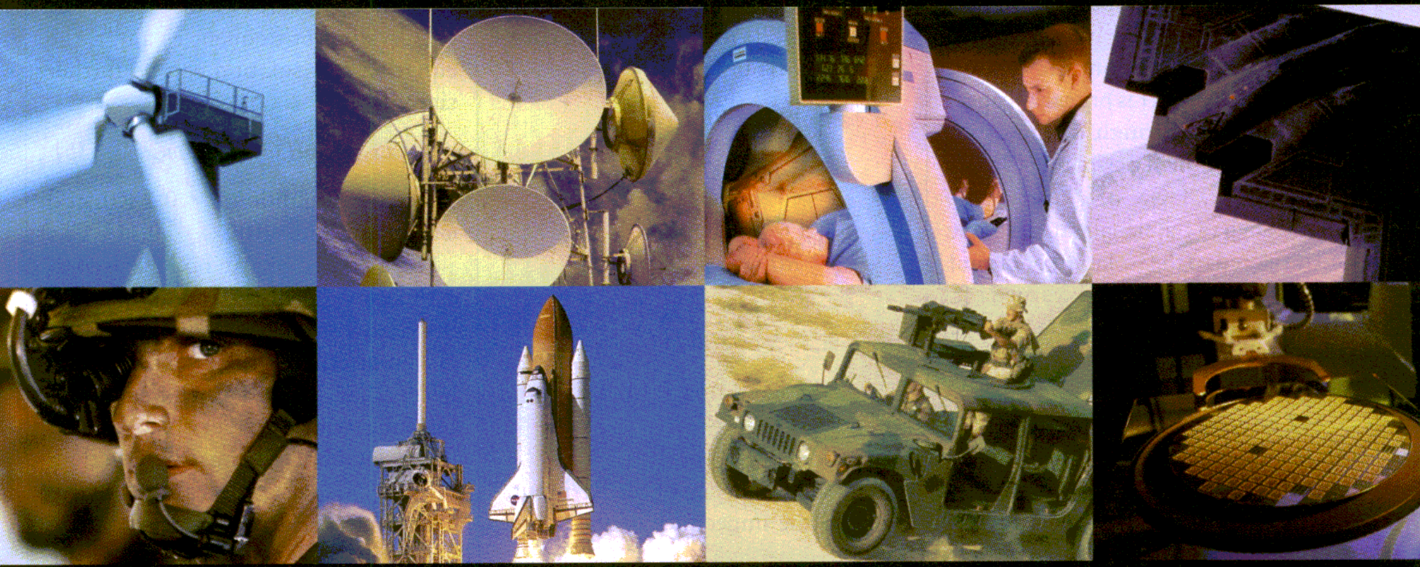

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the values of capacitance and resistance are identical to those in Fig. 1b. However, for an actual circuit design, M1 and M2 may have different sizing for overall performance optimization.

In the off state, M1 has the role of blocking the input from the output. When turned off, M1 is primarily capacitive with feedthrough of the input determined by the series/parallel values of CGD off, CGS off, and CDS. Feedthrough of the signal is undesirable and is related to the isolation of output to input when the switch is turned off. To reduce the magnitude of the feedthrough (i.e., increase the isolation), M2 comes into play.

M2 is turned on when M1 is turned off. In this condition, M2 is primarily a resistor with value r. By design, this value is much less than the characteristic impedance of the RF source, so r greatly reduces the voltage at the input of M1. When the value of r is much less than R0 and the feedthrough capacitive reactance of M2, isolation can be easily calculated. Isolation for the off-switch is the difference between the maximum available power at the input to power at the output. The circuit analysis results in the following equation for isolation:

$$IS = -10LOG_{10}\left[4r^2\omega^2{C_{offs}}^2 \Big/ \left(1+\frac{r}{R0}\right)^2 + \omega^2{C_{offs}}^2R0^2\left(1+\frac{2r}{R0}\right)\right] \quad (3a)$$

For the condition r <0.1 R0, and ωrC_{ons} <0.1,

where:

ω = the frequency of the RF input,

R0 = the impedance of the source (50 Ω),

C_{offs} = the feedthrough capacitance of M1 in the off condition,

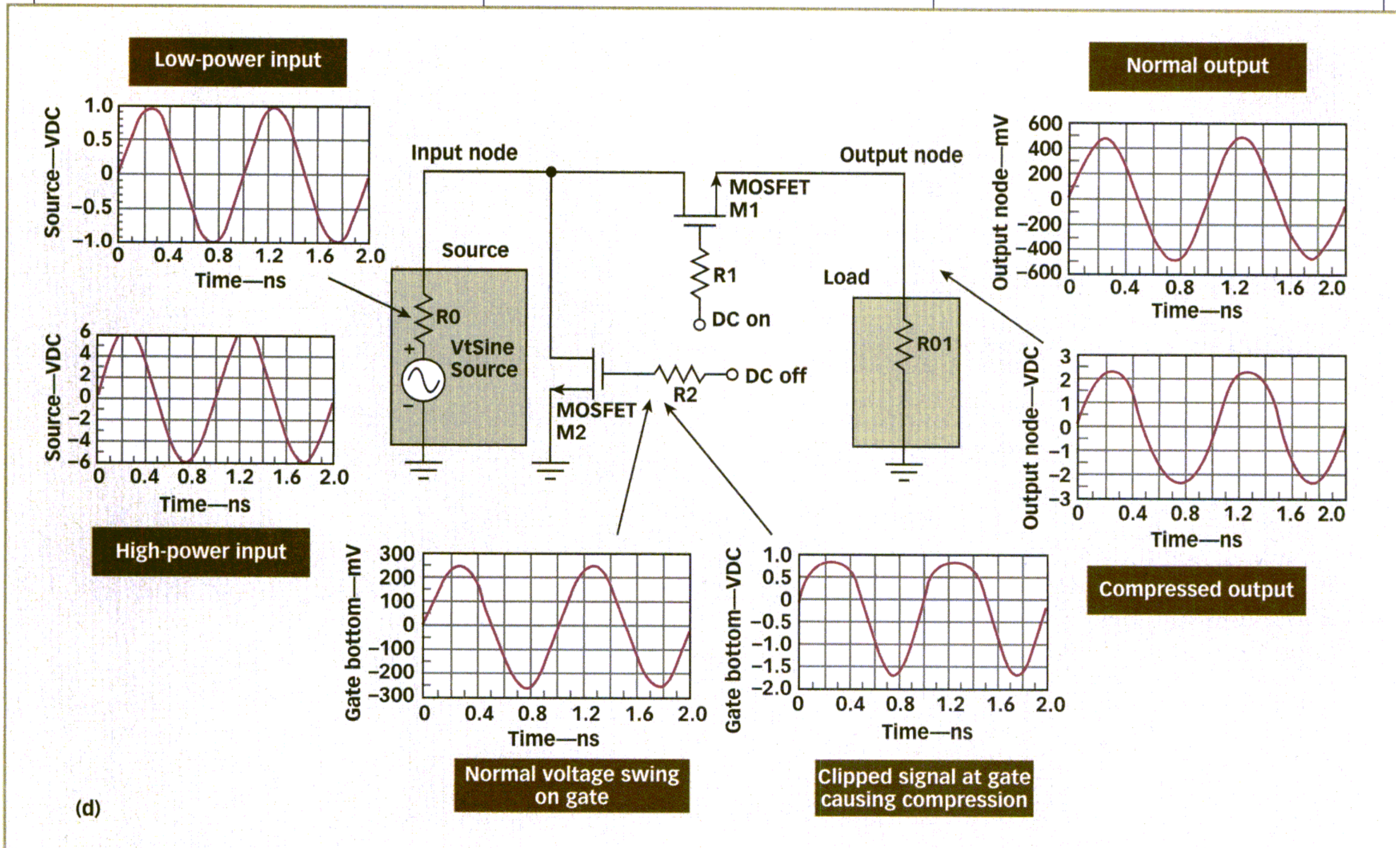
r = the on resistance of M2 in the on condition, and

C_{ons} = the shunt capacitance of M2 in the on condition. Equation 3a is derived by assuming that the coupling to ground is primarily through r. For small values of frequencies and r, the equation for isolation can be further simplified:

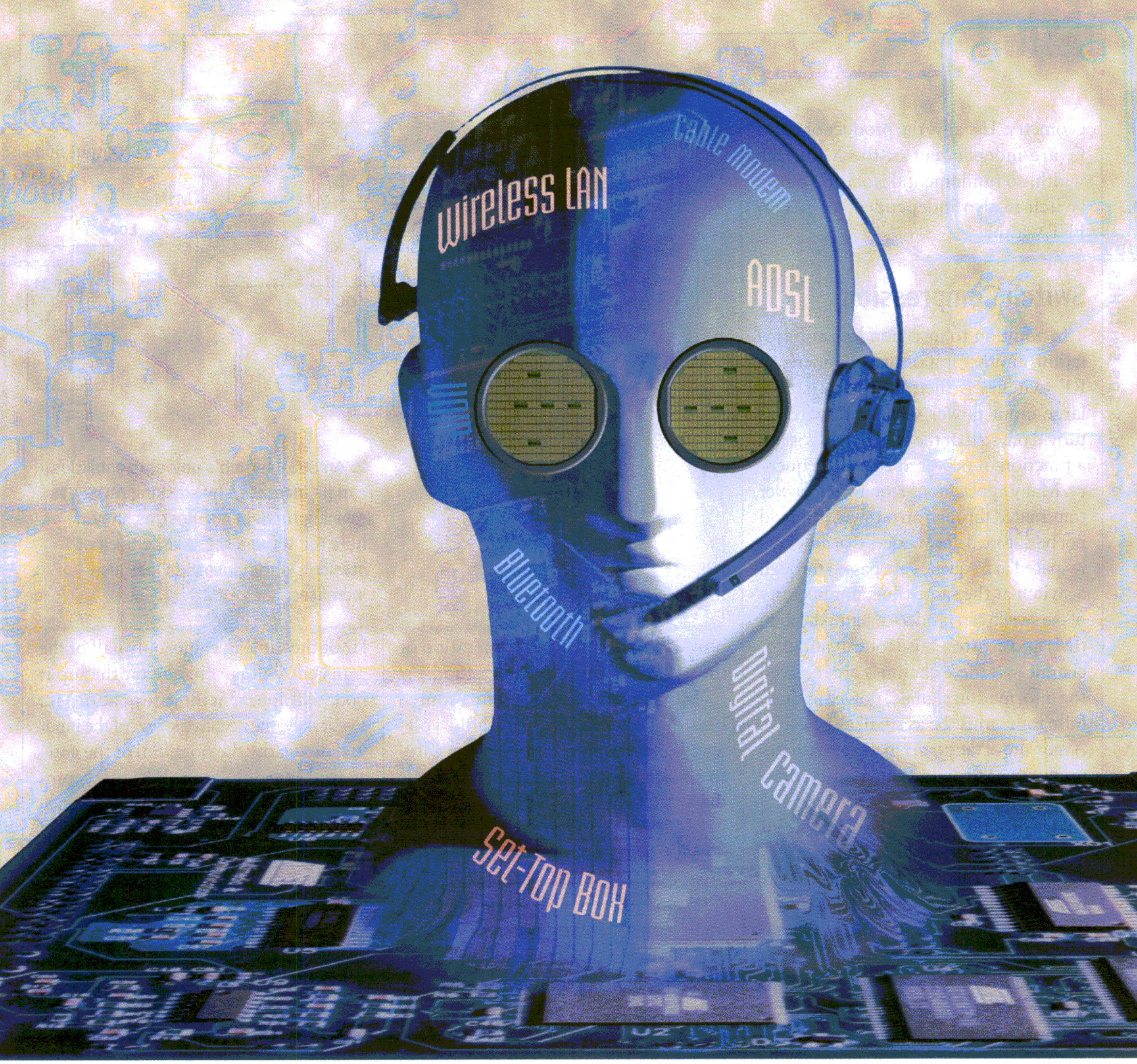
$$IS = -20LOG_{10}(2r\omega Ct) \quad (3b)$$

for the condition, r <0.1 R0, and ωrC_s <0.1 and $\omega R0C_{offs}$ <0.1

Eqs. 2b and 3b can now be used to estimate values of r and C_t if target insertion loss and isolation are known. For an insertion loss of 0.6 dB, r must be less than 7 Ω in a 50-Ω system. For the same switch, a target isolation of 35 dB at 1-GHz C_{offs} must be less than 0.25 pF. Usually, the values of C_{offs} and r cannot be decoupled and both are determined by the geometry of the device. Thus, the limits of insertion loss and isolation of the switch in Fig. 1a can be determined for a particular device



1d. Various types of compression result in the circuit shown in Fig. 1a, depending on the bias voltages at the gates of M1 and M2. A compressed output is caused by the turning on of the shunt switch (M2), thereby diverting the input signal from appearing at the output node.



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geometry. Usually, the product of r and C_t are independent of the MOSFET width, so fundamental isolation of the switch is also independent of MOSFET width.

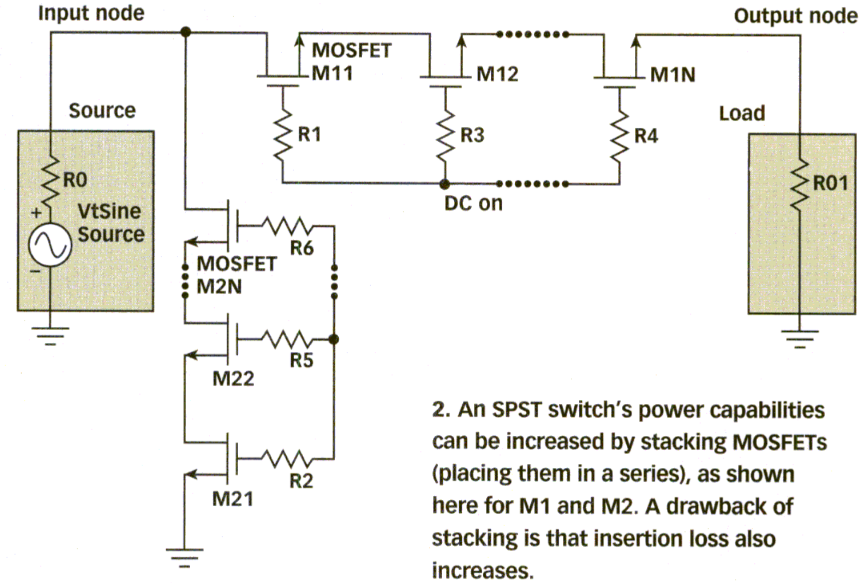
Switch Compression

In addition to insertion loss and isolation, another important parameter of RF switches is their ability to handle large input power when the switch is turned on, so that the insertion loss is not a function of power at a fixed frequency. Many applications require that power transmitted through an on switch should not be distorted. If two tones that are closely spaced in frequency are passed through a switch at the same time, nonlinearity of the switch can produce intermodulation (IM) and create a false tone in adjacent channels. If these channels are reserved for information signals, power in these false tones must be as small as possible. A measure of the power in these false tones is known as the input third-order intercept point (IP3). Switches with large IP3 values produce little power in adjacent channels, which is important in applications such as antenna switches. IP3 is usually 17 to 20 dB larger than the largest input power a switch can handle without distortion.

An indicator of a switch's ability to handle power is known as the 1-dB compression point (P1dB). It is defined as the input power at which the insertion loss has increased by 1 dB from its low-power value.

$$IL(P1dB) - IL(P \rightarrow -\infty) = 1.0\ dB \qquad (4)$$

To understand what causes compression, voltage levels at various nodes are drawn for the simple switch in Fig. 1a in the on-state and presented in **Fig. 1d**. The source is represented by a sine wave with a peak-to-peak amplitude of 2 V_o. DC levels required to turn the MOSFETs on and off are V_{on} and V_{off}, respectively. A normal, uncompressed signal is shown on the output node, as well as curves showing the compression modes at the output. To understand



2. An SPST switch's power capabilities can be increased by stacking MOSFETs (placing them in a series), as shown here for M1 and M2. A drawback of stacking is that insertion loss also increases.

how compression occurs, operation of the MOSFET must be understood.

MOSFETs require a gate-to-source bias that exceeds the threshold voltage, V_t, to turn on. Likewise, the gate-to-source bias must be less than V_t for the switch to be off. V_t is positive in "type-N" MOSFETs and negative for "type-P" MOSFETs. For the switch in Fig. 1a, "type-N" MOSFETs were chosen. The source of an "type-N" MOSFET is the node with the lowest potential.

The reason for the first type of compression can now be explained using the previous concepts. If a transient voltage on M2, shown in Fig. 1c, results in turning on M2 during part of the cycle, input power will be routed to ground and lost to the output. This loss of power becomes larger for larger input powers and will cause compression. P1dB for this case can be estimated.

Assuming CGD and CGS are similar or the same in value, only half of the transient voltage change on the input node will appear at the gate node of M2. Eventually, the negative swing of the input will dip below the potential of the gate, as well as below ground (thus becoming the source). When this difference becomes V_t, M2 begins to turn on and compression begins. P1dB from this effect is:

$$P1dB_{VT} = 10LOG_{10}\left(\frac{2\left(V_t - V_{off}\right)^2}{R0}\right) + 30\ (in\ dBm) \qquad (5)$$

where:

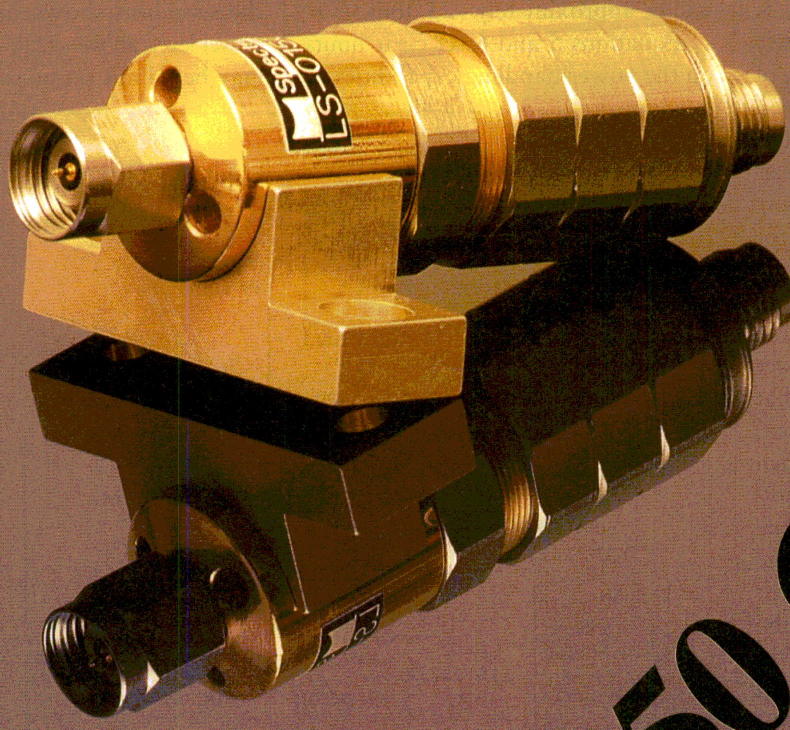
$P1dB_{VT}$ = the onset of compression for the switch in Fig. 1a.

This compression is caused by the turning on of a normally off gate in the shunt leg of the switch. Suppose V_t is approximately +0.7 VDC and V_{off} is cho-

Power capability versus insertion-loss trade-offs

Number in stack	Vth (VDC)	V_{on}/ V_{off}	IL at 1 GHz	IS at 1 GHz	IL at 2 GHz	IS at 2 GHz	IL at 4 GHz	IS at 4 GHz	Onset of comp. (dBm)
1	0.7	3.0/0	0.16	41	0.24	35	0.55	30	13
3	0	3.0/ –3.0	0.39	41	0.40	35	0.43	29	31
6	0	3.0/ –3.0	0.75	42	0.75	36	0.76	30	37

C_{offs} = 0.5 pF
r = 1.5 Ω



sen to be 0 VDC. Substituting in Eq. 5, compression will begin at approximately +13 dBm. A negative value for V_{off} of −1 VDC will increase the compression to approximately +21 dBm. For the circuit in Fig. 1d, compression can be greatly increased by using a negative supply to turn off the devices. Note that for normal low input power, half of the source voltage is dropped across the output load. With low input power, the potential on shunt MOSFET gate never exceeds +0.7 VDC, thus ensuring that it does not turn on. At high-power input, the voltage swing on the output is much less than half of the source voltage, indicating that the compression is occurring. The compression is caused by the extreme swing in gate voltage on shunt MOSFET, which turns it on during the positive half of the input cycle (Fig. 1d).

The second type of compression occurs when the source and drain of M2 break down at excessive voltages. For submicron Si-on-insulator (SOI) devices, this voltage may be approximately only +1 VDC above the supply. Clipping occurs at the two extremes of the large transient input voltage. If the source-to-drain breakdown voltage is V_{bk}, the onset of compression from this effect is:

$$P1dBbk = 10LOG_{10}\left(\frac{V_{bk}^{2}}{2R0}\right) + 30 \text{ (in dBm)} \qquad (6)$$

where:

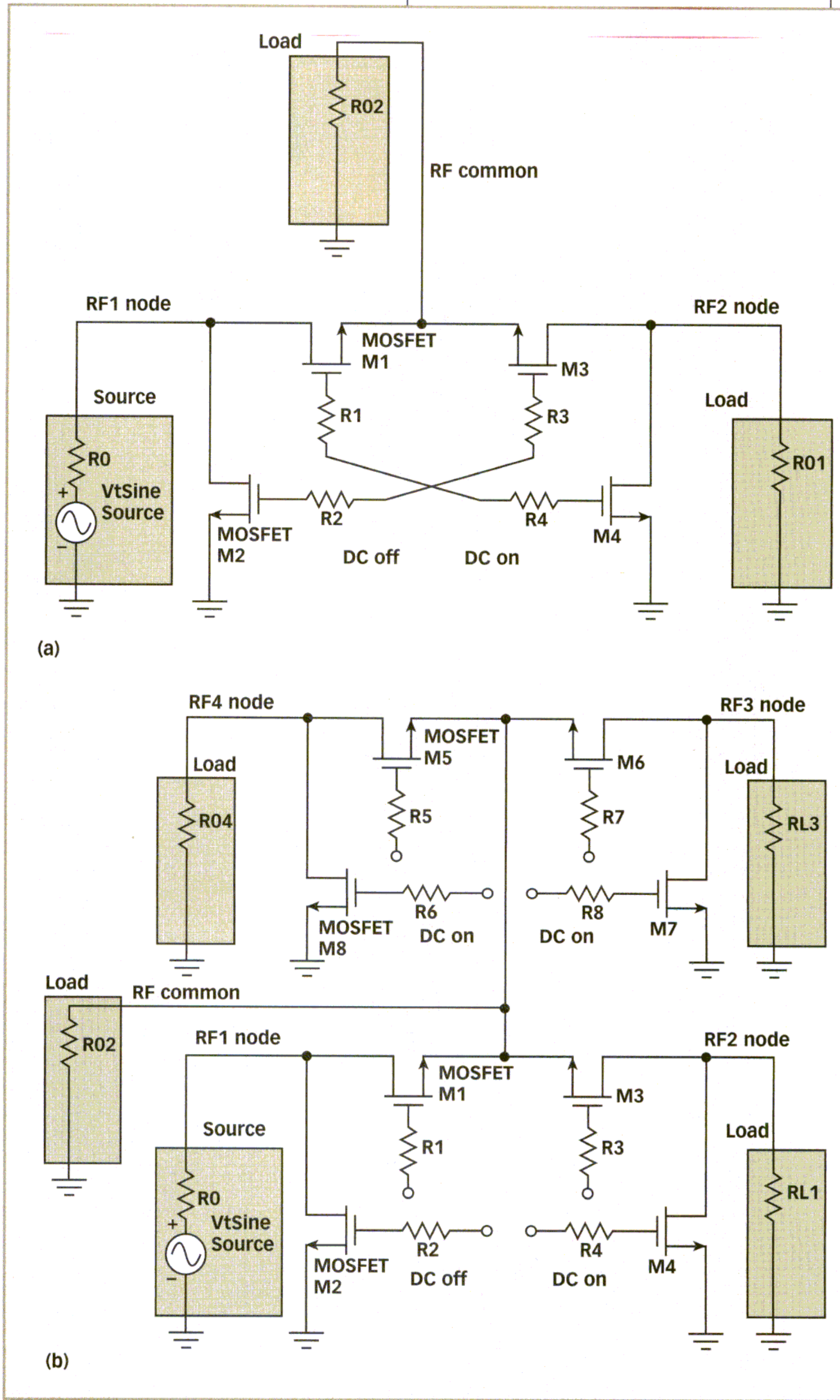
V_{bk} = the source-to-drain breakdown, and

$P1dB_{bk}$ = the estimate of compression for a switch where the source and drain of the off leg break down at large input voltage excursions. For example, suppose the switch in Fig. 1a has the following characteristics:

V_{off} = −3.0 VDC,
V_t = +0.7 VDC, and
V_{bk} = +4.0 VDC,

What will cause compression and what will its value be? To answer that, Eqs. 5 and 6 are used to calculate $P1dB_{vt}$ = +27 dBm and $P1dB_{bk}$ = +25 dBm. Since $P1dB_{bk} < P1dB_{vt}$ for this example, the cause of compression will be source-to-drain breakdown and compression will be approximately +25 dBm.

Equations 5 and 6 set clear limits on the power-handling capabilities of the switch as shown in Fig. 1a. For power levels above +22 to +25 dBm, there may be a limit set by source-to-drain



3. The basic SPST switch is the building block of more-complex switches such as the SPDT type shown here. Stacking can also be used here to increase power-handling capability (a). A more complex switch than that shown in Fig. 3a is the SP4T type that appears here. In this example, RF1 is turned on. Integrating devices of this complexity in ICs is not complex using UTSi technology (b).

breakdown. If not, the difficulty of producing negative supplies below $-V_{dd}$ (−3 VDC) demands other circuit solutions. Also, there is the very real issue of placing too much electrical-field stress across a gate oxide. If the simple switch can stand off, by +30 dBm for example, at with a negative supply of −3 VDC, the gate oxide will experience up to +8 VDC. For a 100-Ågate oxide, this will pose a reliability problem.

Figure 2 is a SPST switch with N MOSFETs placed in series (or stacked) for the through and shunt legs. This switch has the advantage of increased power-handling capability, which is traded off against increased insertion loss. Layout of stacked devices is simple and does not require any contacts at the diffusion connection of the MOSFETs, thus device-area penalty is moderate. Each gate has its own resistor R that AC-isolates the MOSFETs from DC bias.

Using small-signal analysis similar to that used in Fig. 1a, the insertion loss for the on-state of a stacked SPST switch is derived. In general, stacked devices will have less off capacitance (by 1/N) and greater resistance than a single device. Thus, the insertion loss becomes:

$$IL(N) = 10LOG_{10} \left\{ \left(1 + \frac{Nr}{2R0}\right)^2 + \left[\frac{\omega C_{offs}(R0 + Nr)}{2N}\right]^2 \right\} \quad (7)$$

where:

IL(N) = the calculated insertion loss of the stacked switch in Fig. 2.

For small values of r, doubling it will double the insertion loss at low frequencies, while at higher frequencies, feedthrough through capacitor C_{offs} to ground will begin to increase IL further.

The calculation of the isolation of stacked devices is made in a similar fashion as insertion loss. Since the net value of capacitance for the off-leg is proportional to 1/N and the on-value of resistance in the on-leg is proportional to N, Eq. 7 predicts that the isolation of a stacked switch will be insensitive to the number of stacked devices (at least to zero order). Including the effect of N thereby creates:

$$IS = -10 \times LOG_{10} \left[4r^2\omega^2 C_{offs}^2 \Big/ \left(1 + \frac{Nr}{R0}\right)^2 + \frac{\omega^2 C_{offs}^2 R0^2}{N^2} \left(1 + \frac{2Nr}{R0}\right)^2\right] \quad (8)$$

for N_r <0.R0, $\omega r C_{onp}$ <0.1

where: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C_{offs} = the capacitance of a single through device in the off-state and r = the resistance of a single shunt device in the on-state.

The Table illustrates that stacking devices and the ability to generate negative onboard voltage sources enables the realization of high-power, high-isolation, and low-insertion loss switches in UTSi technology. With actual packaged parts, inductances and mutual coupling become the limiting factors in isolation and insertion loss. When a part is packaged, care must be taken in order to achieve proper matching, so the final part can approach the theoretical limits of the technology. A balance between target costs and final packaged switch characteristics must be made. However, values that are outlined in the table are more easily realized in highly integrated applications where RF switching is only required between two on-chip locations. In these applications, point- to-point inductances are much smaller than those in wirebonded parts.

The process that is used to build this type of SPST switch lends itself to high levels of integration. Since the process is based on standard CMOS process flows, digital interfaces can be created with little impact on area, design time, or yield. For example, matrix switches that have three-wire serial-to-parallel interfaces are simple to implement, and, when combined with NAND-NAND-type logic, complex control can now be integrated on-chip. SPST switches can be combined into more complex switch functions, including single-pole, double-throw (SPDT) and single-pole, four-throw (SP4T) configurations as shown in **Figs. 3a and b**. Again, digital control with correct digital-to-RF buffering is easily integrated. Gate resistors, which are located near RF switch components, provide excellent isolation. For high-power applications, negative supply generators are integrated by using standard techniques. These techniques require low frequency and low-current oscillators. With proper layout, they are isolated from RF. Sidebands from the negative supply generators are too small to be measured in the laboratory.

The availability of low threshold voltages enables the realization of low-voltage parts in UTSi. For example, switches can operate below +2 VDC with trade-offs in RF characteristics. For +1-VDC applications, onboard voltage triplers can be used to realize the full potential of a switch as shown in the table with a trade-off in chip area. Low-frequency digital interfaces are affected little by low-voltage applications. As RF integrated solutions move toward lower voltages, such as in Bluetooth applications, UTSi switches can still be used with modest trade-offs in performance. MRF

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UPP1001

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- 0.75 Ohm resistance
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APPLICATIONS
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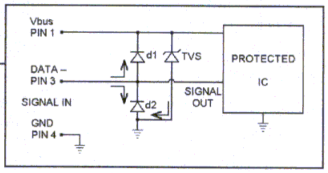

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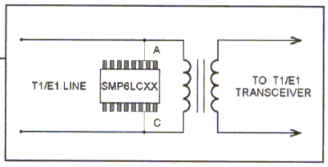
APPLICATIONS
- T1/E1 Protection
- Data line Protection



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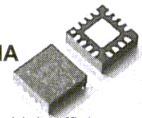

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- 70mA Idle Current
- 3mm 16 Pin MLP or Flip Chip

APPLICATIONS
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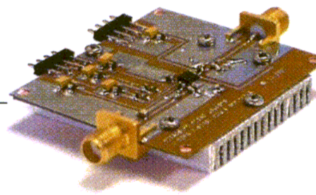
- 1850-1910 MHz CMDA2000 Handsets
- Spread Spectrum Systems



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EDA Software Improves Accuracy Of Microstrip Filter Designs

The simulation and optimization of microstrip coupled-line filters for WCDMA are quick and simple by using a popular EDA package.

Research work has focused recently on the development of wideband-code-division-multiple-access (WCDMA) mobile-communication systems throughout the world. RF filters are important components in WCDMA base-station transceivers (BTS) to reject unwanted signals. In an RF receiver (Rx), a filter is generally required between the low-noise amplifier (LNA) and the downconverter to reject image noise. In an RF transmitter (Tx), a filter is also required after the upconverter to reject image spurs, local-oscillator (LO) leakage, and other unwanted signals.

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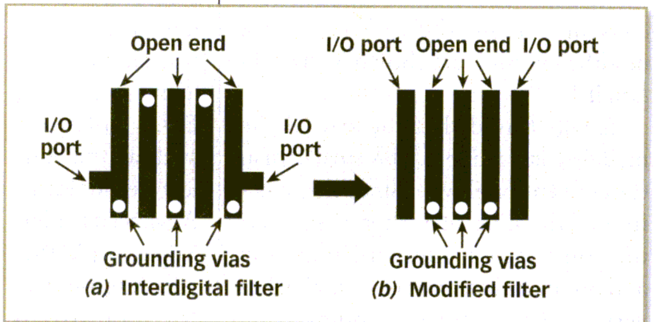
Compared with RF surface-acoustic-wave (SAW) filters and RF dielectric filters, microstrip filters have advantages such as low cost, high-power rating, and good flexibility. Since the frequency of WCDMA is high, the dimensions of microstrip filters are reduced and can be integrated with other RF circuits such as LNAs and mixers. In mobile-communication systems, the size and cost of the components should be taken into consideration during the design. Microstrip interdigital filters feature low loss, high out-of-band rejection, and small size. The traditional microstrip interdigital filter, however, is DC shorted, so high-frequency capacitors are needed as DC blocks when the filter is used with active circuits where a DC bias exists. The traditional interdigital filter is modified in this article. The modified filter has a simpler configuration that requires less computation and is DC opened, making it suitable for direct integration with active circuits.

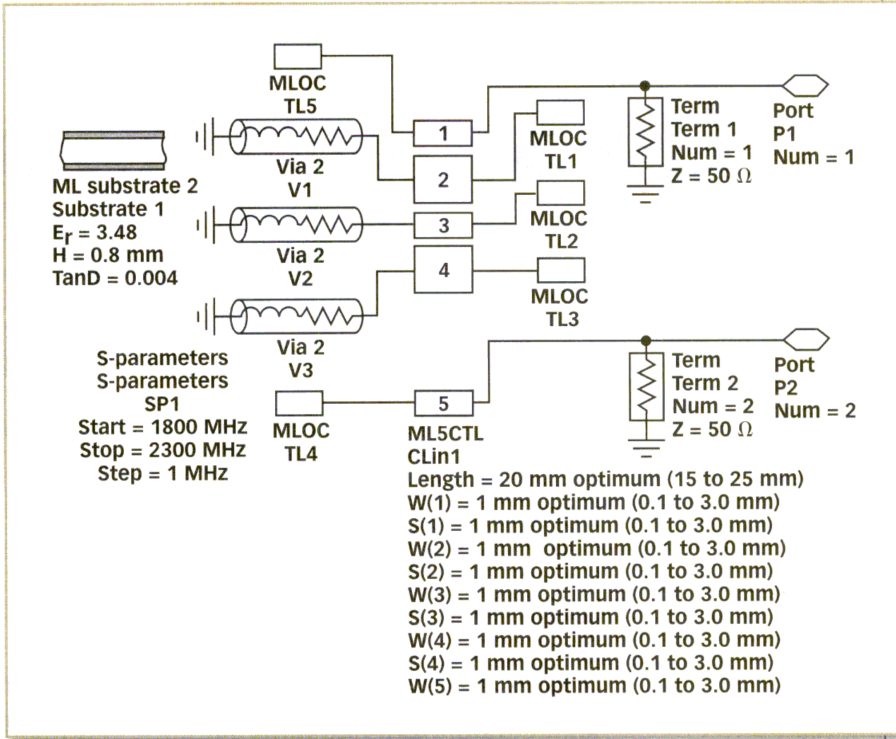
Simulation and optimization of the filter is carried out with the aid of elec-



1. A conventional interdigital filter has DC-shorted I/O ports (a), whereas the modified version for this design has DC-open I/O ports (b).

tronic-design-automation (EDA) software. Traditional synthesis tools have limitations, and do not yield acceptable results. They require more trials, tuning, and adjustments. With the aid of advanced EDA software and selecting accurate models, one can obtain satisfactory filter designs quickly and easily. The accuracy of the simulation is improved significantly by employing proper models for microstrip multiple-coupled lines and discontinuities, and the losses introduced by the substrate and metallization are taken into account. The simulation results agree closely with experimental results.

Using EDA software such as the Agilent Technologies Advanced Design System (ADS), accurate models for microstrip multiple coupled lines can be developed.



2. The schematic of the microstrip filter as depicted in the ADS format shows the range of values of the filter dimensions along with the optimized value for each dimension.

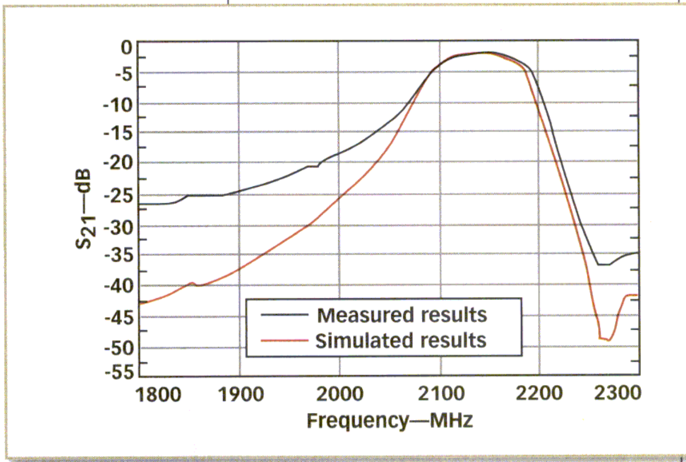
Simulating A Filter

There are many types of microstrip bandpass filters, including parallel side-coupled line filters, interdigital filters, and others.[1] Generally, interdigital filters have smaller size, lower insertion loss, and good out-of-band rejection.[2] Since the input/output (I/O) ports of the traditional interdigital filter are DC shorted, the configuration provided here is slightly modified so that the I/O ports are DC opened. The schematic of a conventional interdigital filter and the modified version are shown in **Figs. 1a and b.**[3]

It was found that the size of the modified filter is appreciably smaller than the conventional type. Since the structure of the modified filter is simpler, the computation time of simulation and optimization are reduced, which is very important for the optimization procedure. Moreover, those filters are DC blocked, so no additional capacitors are needed when they are used with other circuit components, especially active circuits that need DC bias. This makes the implementation very simple.

Traditional analysis and synthesis methods are available for these filters. Since the coupling of non-neighboring lines, losses in the substrate, metallization, and other discontinuities are neglected in traditional methods, the simulated results are not sufficiently accurate. Using EDA software such as the Agilent Technologies Advanced Design System (ADS), accurate models for microstrip multiple coupled lines can be developed.[4] The accuracy of the simulation can be improved by considering the effect of discontinuities such as grounding vias, open ends, and others which are simulated by ADS. The schematic of the filter as described in ADS is shown in **Fig. 2.**

Using the optimization tools pro-

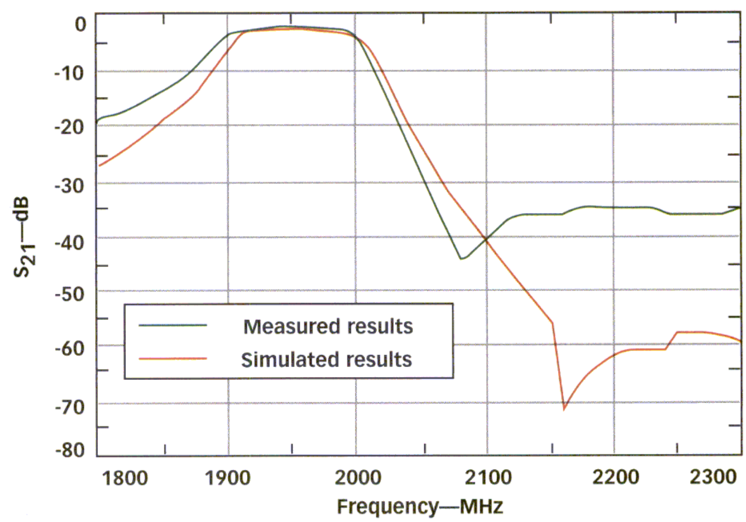


3. Experimental (measured) and simulated curves of the transmit filter show almost perfect agreement in the passband, but the out-of-band performance of the simulated filter is better than that of the physical filter.

vided by ADS, the filter design can be executed without tightly restricting the initial values of approximately all of the important parameters, such as the length of the coupled lines, the width of each strip, and the gap between two neighboring lines. The computation time of the optimization routine can be shortened considerably if a reasonable range of values of the parameters is provided. For example, the initial value of the length of the coupled lines can be selected near the quarter-wavelength of the central frequency in the passband.

The optimization goals are determined by the required passband loss and out-of-band rejection. These goals are very important and should be carefully selected. It is highly recommended that an estimate be calculated for the specified order of the filter. The higher the order of the filter is, the higher the out-of-band rejection is, and the higher the insertion loss in the passband will be. The optimization procedure will take too much calculation time to yield an acceptable result if the optimization goals are set too high. On the other hand, if the optimization goals are set too low, the optimization procedure calculates quickly, but the specification of the filter will not be satisfied for the specific application.

The transmit frequency band used in the WCDMA BTS transceiver ranges from 2110 to 2170 MHz and the receive frequency band spans 1920 to 1980 MHz. According to this, two filters are designed—one for the forward-channel frequency band, and the other for the reverse-channel frequency band. The substrate used in the simulation is RO4350 from Rogers Corp. The initial length of the coupled lines is 20 mm, while the strip width of each line and the gap width between two neighboring lines are initially set to 1 mm. The optimization ranges of these parameters are given, as shown in Fig. 2. Five-coupled line is used in the design of the filters. The corresponding optimization goal of the passband insertion loss is 3 dB, and the optimization goal of the out-of-band rejection is more than 20 dB.



4. A comparison of the experimental (measured) and simulated curves of the receive filter is similar to that of the transmit filter (shown in Fig. 3) in terms of passband and out-of-band performance.

With the optimized results, five receive filters and five transmit filters were created on the RO4350 substrate. The dimension of each filter is 15 to 25 mm, quite a bit smaller than that of either a parallel side-coupled-line filter or a traditional interdigital filter. The coincidence of these filters is perfect. The comparison of the experimental results and the simulated results is shown in **Figs. 3 and 4.**

Simulated Versus Real

When comparing the simulated and experimental results, the results in the passband of the simulation and the experiment perfectly agree with each other. The out-of-band rejection in the simulation is better than that in the experiment. One possible reason is that the physical filters have finite ground planes, while the filters in the simulation have infinite ground planes. Actually, in this experiment, to reduce size of the filter, the area of the ground plane is a little larger than that of the coupled lines. A finite ground plane affects the out-of-band rejection significantly, especially in the lower frequency band. Another possible reason is the radiation coupling between the lines, which is neglected in the simulation. Accurate simulation of radiation requires three-dimensional (3D) electromagnetic (EM) solvers. The optimization procedure may become impossible since the computation time is too long if 3D EM solvers are used in the filter design.

Although the out-of-band performance of the actual filters is not as good as the simulated results, these filters are usable for many applications. In the transmit filter, the insertion loss in the passband is approximately 3 dB, while the rejection in the receive band is more than 20 dB, which is acceptable as an image and LO leakage-rejection filter. In the receive filter, the insertion loss in the passband is approximately 3 dB, while the rejection in the transmit band is more than 35 dB, which is suitable for rejecting image noise and transmit noise. In a word, these filters are suitable for image-rejection filters or spur-rejection filters in WCDMA BTS RF transceivers and other infrastructure of WCDMA RF systems. MRF

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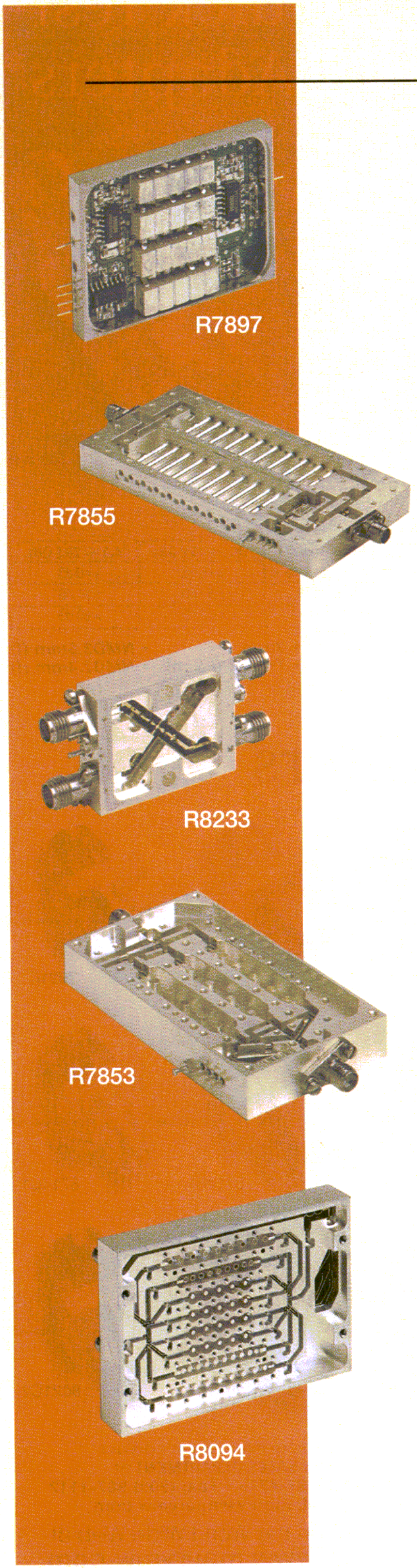
switch filters



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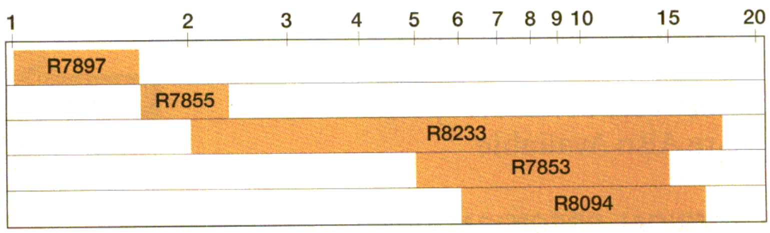
Frequency Range	10MHz to 26 GHz
Number of Channels	2 to 12
Insertion Loss	2 to 8 dB
Isolation	40 to 75 dB
VSWR	1.3:1 to 2.0:1
Switching Speed	10 nsec to 1μsec
Input Power	up to +27 dBm CW
Control	TTL Binary Coded Decimal
Power Supply	+5 volts
	-5, -12 or -15 volts
Size	1 x 1.25 x .35 (.44 in^3)
	to 7 x 4.6 x 1.63 (52 in^3)



PART NO.	TYPE	FREQUENCY (GHz)	DIMENSIONS (in)
R7897	SP4T	1.1-1.7	2.0 x 1.5 x 0.25
R7855	SP2T	1.7-2.4	4.0 x 2.0 x 0.50
R8233	SP3T	2.0-18.0	1.0 x 1.25 x 0.35
R7853	SP3T	5.0-15.0	3.0 x 1.7 x 0.50
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Parameter Describes Mixer IM Performance

A new figure of merit known as IP3 efficiency, or E-factor, can be helpful in evaluating the effective IM performance of FET-based and diode-based mixers.

Mixers perform the critical frequency-translation chores in modern communications systems. With the increasing use of complex, phase-based modulation schemes in communications, dynamic range has become a key performance parameter in comparing mixers. While third-order intercept point (IP3) has served as a measure of dynamic range in mixers, the specification can be misleading. A proposed new figure of merit for mixer dynamic range is IP3 efficiency.

Engineering Dept.
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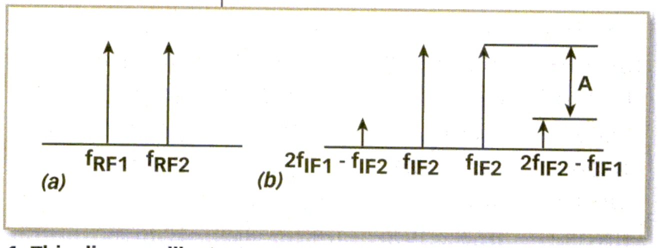
To achieve increased subscriber capacity, modern receivers (Rxs) and transmitters (Txs) must handle multiple-carrier signals (desired or not). When multiple carriers arrive at the input of a mixer, they combine with each other to generate intermodulation (IM) products. The most troublesome product to remove by filtering is the third-order IM product. The tolerable level of this product is dictated by the system requirements. Higher IP3 performance, within limits, can be obtained in a mixer by careful design or at the expense of local-oscillator (LO) power in a particular design. But an increase in LO power also requires an increase in DC power and additional hardware. By accurately evaluating the IP3 performance of a mixer, however, it may be possible to avoid unwanted power consumption and expense in a communications system's design, by using IP3 efficiency as a figure of merit.



1. This diagram illustrates a two-tone signal that is processed at the input of a mixer (a), with the resulting signals (b) produced at the mixer's IF output port.

It may be useful to first define IP3. When two RF signals of equal amplitude arrive at a mixer's input, IM frequencies are generated due to the nonlinearity of the mixing device. **Figure 1a** shows a spectrum of two RF signals—f_{RF1} and f_{RF2}—that are close in frequency. **Figure 1b** shows a simplified spectrum at the intermediate-frequency (IF) output of a mixer. The third-order products, $2f_{IF1} - f_{IF2}$ and $2f_{IF2} - f_{IF1}$, are predominant IM frequencies, closest to the desired IF output. The spacing between IM products and the adjacent carrier is the same as the spacing between the carrier signals. For example, if the carriers are 1 MHz apart, the IM product will be 1 MHz from the nearest carrier. If the carriers are spaced 1 kHz apart, then the IM product will be only 1 kHz removed from the nearest carrier. If the two carriers are close, it is difficult to filter the unwanted IM product.

If the difference in power level between the main signal and the generated IM product is A dB (Fig. 1b), then IP3 can be defined as:

$$\text{Input IP3 (dBm)} = P_{in}\ (\text{dBm}) + A / 2 \qquad (1)$$

Within the linear region of a mixer, in most cases, the IM product decreases by 3 dB for every 1-dB decrease in RF power. From Eq. 1, it can be seen that this relationship leads to IP3 being insensitive to RF power level. As a result, IP3 has been used as a parameter to describe mixer IM performance.

In general, a lower level of IM product leads to better Rx or Tx performance. Lower-level mixer IM can be achieved in two ways: by an increase in LO power or by improved mixer design. Unfortunately, there has been no easy way to quantify the effectiveness of a design in terms of IM performance. But it may be possible to use a new figure of merit, IP3 efficiency or E, for this purpose. Parameter E can be defined by Eq. 2 as:

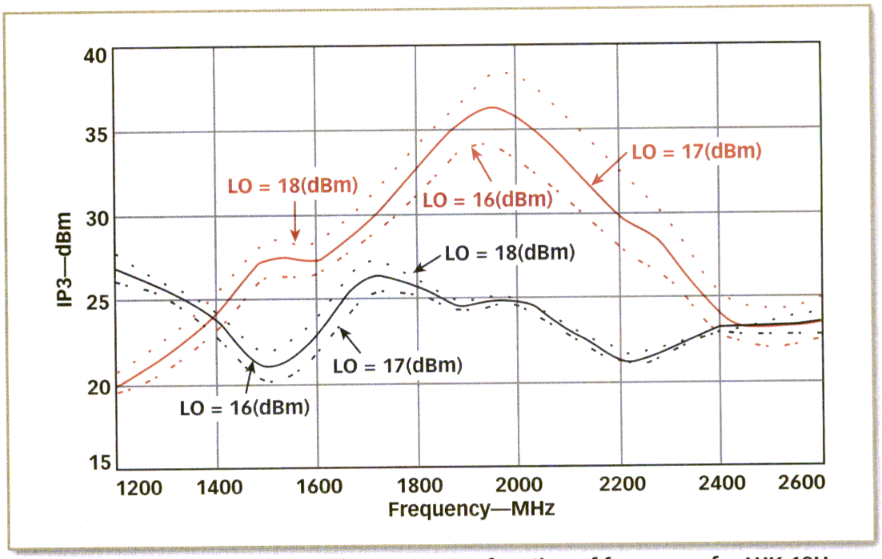
$$E = [\text{IP3 (dBm)} - \text{LO power (dBm)}] / 10 \qquad (2)$$

As a rule of thumb, the IP3 of a well-designed mixer is 10 dB above the LO power. Substituting this relationship into Eq. 2 leads to an E value of 1. A value of E that is higher than 1 signifies a mixer with superior IM performance.

Table 1 lists a series of FET-based mixers that were developed by Mini-Circuits (Brooklyn, NY). The IP3 performance levels of these mixers range from +21 to +38 dBm. At first glance, it is easy to dismiss the mixer with +21-dBm IP3 performance as substandard. On closer examination, however, it can be seen that the LO power used by this mixer is only +7 dBm. For a +7-dBm mixer, IP3 performance of +21 dBm can be considered very good. Still, the IM performance of the mixer has not been quantified by simply evaluating its LO power and IP3 performance. For this mixer, the E-factor is 1.4, which is considerably above the unity value established for a normal mixer with reasonable IM performance. By using the E-factor, selecting mixers with high IP3 efficiency can be simplified.

Table 1 contains FET-based mixers with E-factor values in the range of 1.4 to 2.1. These values are considerably higher than the E-factor values exhibited by conventional diode-based mixers **(Table 2)**. In an examination of typical diode-based mixers, the E-factor is typically 0.8 except for one narrowband model (SYM-10DH). FET-based mixers can be produced with very repeatable performance compared to diode-based mixers, and require no tuning to meet their specified performance levels. As a result, for a given set of performance characteristics, the cost of manufacturing FET mixers is considerably less than that of diode-based mixers.

To compare the swept performance of the FET-based and diode-based mixers, the two types of mixers were tested across their RF ranges. **Figure 2** shows



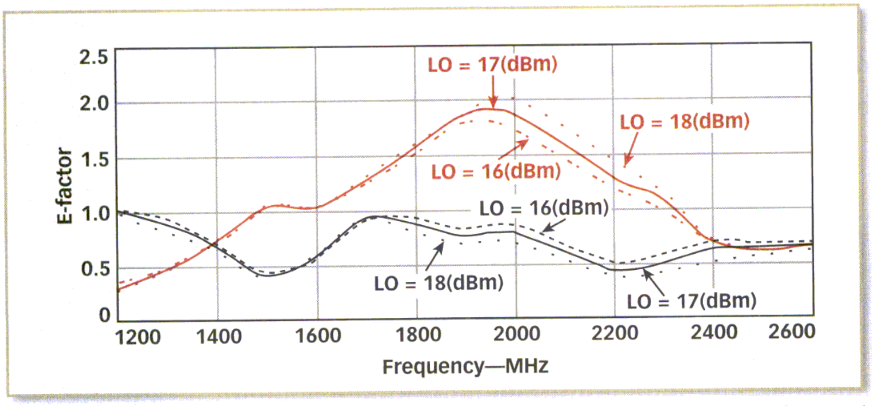
2. These plots show the IP3 performance as a function of frequency for HJK-19H (red curves) and SYM-25H 9 (black curves) mixers.

Table 1: High-efficiency FET mixers

MODEL NO.	RF FREQ. (MHz)	LO FREQ. (MHz)	IF FREQ. (MHz)	LO POWER (dBm)	IP3 (dBm) typical	E-FACTOR
HJK-9	818 to 853	753 to 778	40 to 100	+7	+22	1.5
HJK-19	1850 to 1910	1780 to 1840	70 to 130	+7	+21	1.4
HJK-21	1850 to 1910	2090 to 2150	180 to 300	+7	+22	1.5
HJK-9LH	818 to 853	753 to 778	40 to 100	+10	+27	1.7
HJK-19LH	1850 to 1910	1780 to 1840	70 to 130	+10	+25	1.5
HJK-21LH	1850 to 1910	2090 to 2150	180 to 300	+10	+25	1.5
HJK-9MH	818 to 853	753 to 778	40 to 100	+13	+31	1.8
HJK-19MH	1850 to 1910	1780 to 1840	70 to 130	+13	+30	1.7
HJK-21MH	1850 to 1910	2090 to 2150	180 to 300	+13	+29	1.6
HJK-3H	140 to 180	160	0.5 to 20	+16	+37	2.1
HUD-3H	140 to 180	160	0.5 to 20	+16	+37	2.1
HJK-9H	818 to 853	753 to 778	40 to 100	+17	+33	1.6
HJK-19H	1850 to 1910	1780 to 1840	70 to 130	+17	+34	1.7
HJK-21H	1850 to 1910	2090 to 2150	180 to 300	+17	+36	1.9
HUD-19SH	1819 to 1910	1710 to 1769	50 to 200	+19	+38	1.9

Table 2: Conventional diode mixers

MODEL NO.	RF FREQ. (MHz)	LO FREQ. (MHz)	IF FREQ. (MHz)	LO POWER (dBm) typical	IP3 (dBm)	E-FACTOR
SYM-10HJ	400 to 1000	400 to 1000	DC to 400	+17	+25	0.8
SYM-10DH	800 to 1000	800 to 1000	20 to 200	+17	+31	1.4
SYM-25H	10 to 2400	10 to 2400	1 to 1100	+17	+25	0.8
SYM-36H	1500 to 3600	1500 to 3600	DC to 600	+17	+25	0.8



3. These plots show the E-factor as a function of frequency for HJK-19H (red curves) and SYM-25H 9 (black curves) mixers.

the IP3 performance of FET-based (HJK-19H) and diode-based (SYM-25H) mixers. The IP3 of the FET-based mixer is approximately 7 to 10 dB higher than that of the diode-based mixer in the 1800-to-2000-MHz personal-communications-services (PCS) frequency region. With increasing bandwidth, the IP3 performance of the diode and FET mixers tends to be similar.

Figure 3 shows the E-factor values for the same two mixers. The IP3 efficiency or E-factor for the FET-based mixer is 0.6 to 0.9 higher than that of the diode mixer in the 1800-to-2000-MHz range. Over a wider frequency range, however, the diode mixer provides higher E-factor values than the FET-based mixer. In addition, the diode mixer has a more constant E-factor over a wider bandwidth. Thus, for narrowband applications, FET-based mixers can provide superior dynamic range compared to diode-based mixers. MRF

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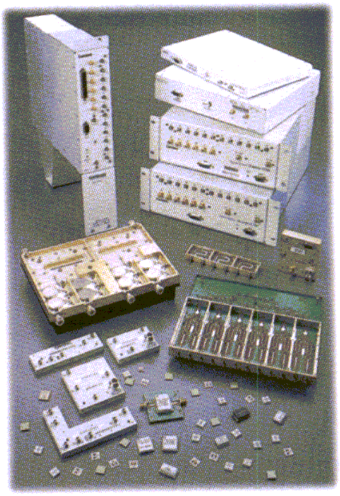

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Design A Low-Noise Synthesizer Using YRO Technology

This article describes the advantages of the YIG replacement oscillator, and offers a design for a low-noise, fast-switching YRO synthesizer.

ELIOT FENTON AND ANDY GODDARD
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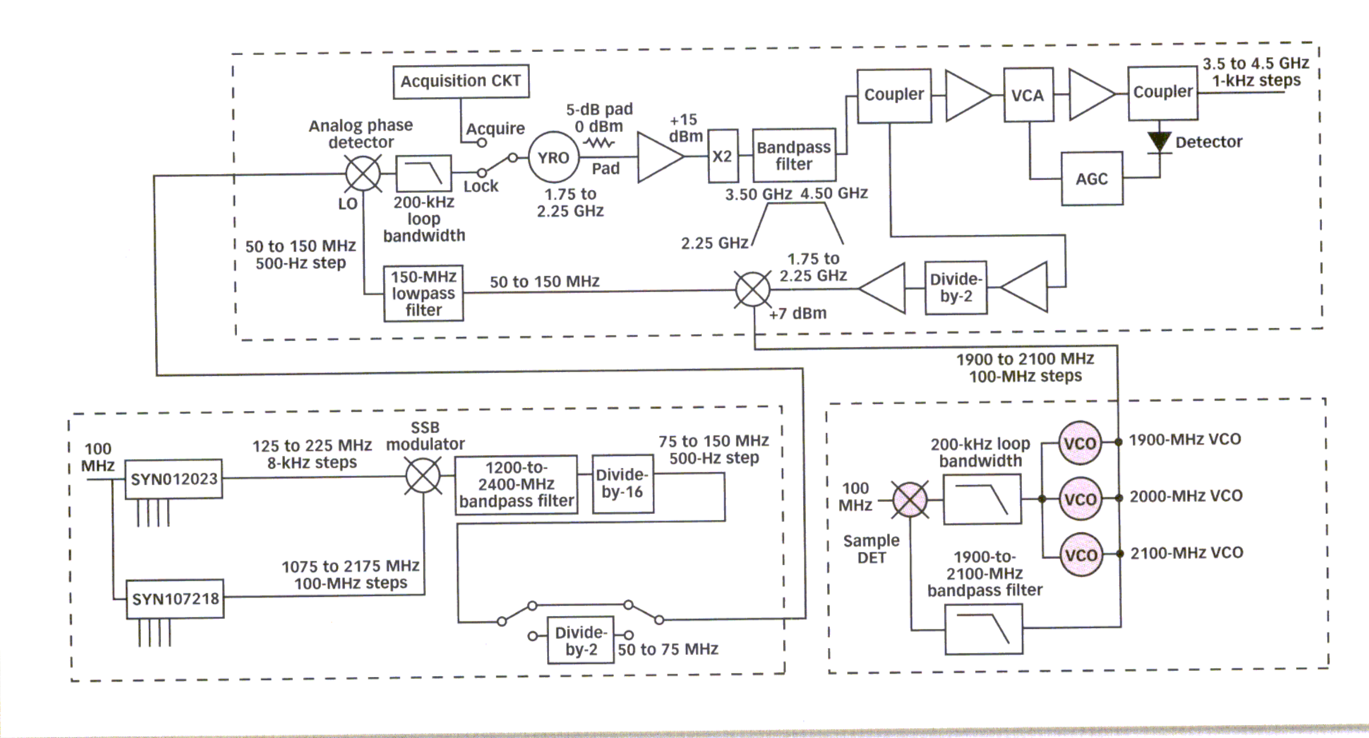
Yttrium-iron-garnet (YIG)-based oscillators are renowned for their ability to generate clean sine waves at very high frequencies, but they are not known for their frequency agility. Nor are they immune to vibrational effects such as microphonics, phase hits, and frequency-modulation (FM) effects. This article describes a novel device called a YIG-replacement oscillator (YRO™), which can serve as a direct substitute for YIGs and dielectric-resonator oscillators (DROs) in applications such as frequency synthesizers, upconverters, downconverters, phase-locked oscillators, microwave communications, test equipment, radar, local multipoint-distribution systems (LMDS), and multichannel multipoint-distribution systems (MMDS). This article describes voltage-controlled oscillators (VCOs), DROs, and YIGs, and points out the advantages that YROs have over these devices. It also describes the design of a fast-switching, low-noise, 3.5-to-4.5-GHz synthesizer that makes use of a YRO.

Traditionally, digital-radio and test-equipment manufacturers used one of two types of oscillators for their products: DROs or YIGs. Mechanically adjustable DROs are used for fixed-frequency applications. Although effective, these components do not have the frequency agility needed for radio manufacturers who build and test their own products. Initially developed for military applications in the 1960s, DROs have a legacy of good performance, albeit with the associated manufacturing difficulties for repeatable performance in high volume at low cost.

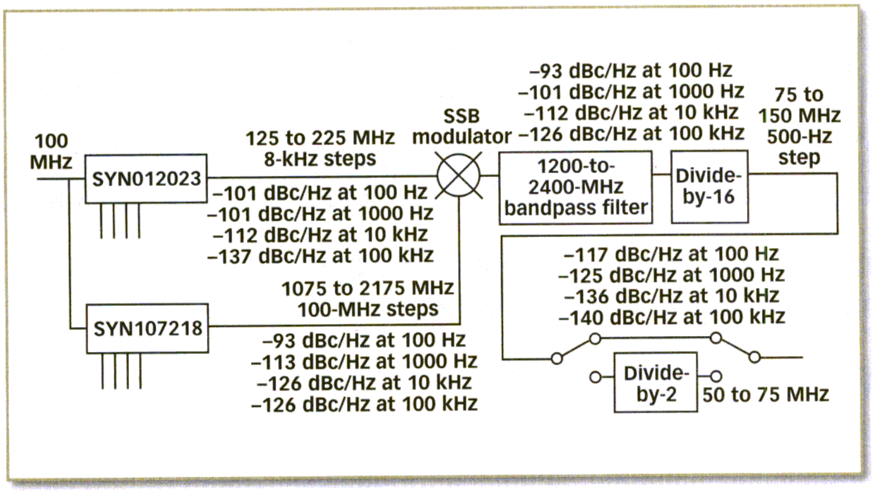
DRO-based radios have limited utility in the LMDS market due to their fixed-frequency nature. To be useful in LMDS applications, they must be combined with additional frequency-agile sources such as VCOs. However, combining DROs and VCOs increases the cost beyond LMDS price points and performance. The fixed-frequency nature of the DRO also precludes their widespread use or adoption in the test-and-measurement market.

To solve the frequency-agility issue, radio manufacturers that serve the point-to-point and point-to-multipoint markets would prefer to use a synthesized application that could emulate the good phase-noise performance of a DRO, yet eliminate the crude DRO-VCO combinations and deliver much higher transmission speeds.

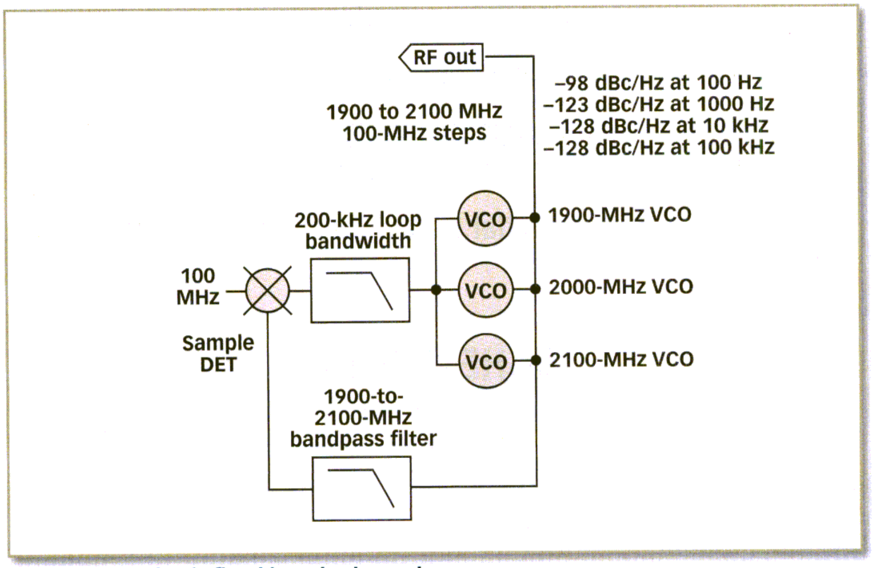
One major technological challenge to increase data rates and improve modulation schemes for digital-radio manufacturers is synthesizing the high-frequency "carrier" wave. To achieve that



1. The three loops that comprise the synthesizer are illustrated above.



2. This diagram shows the synthesizer's reference loop.



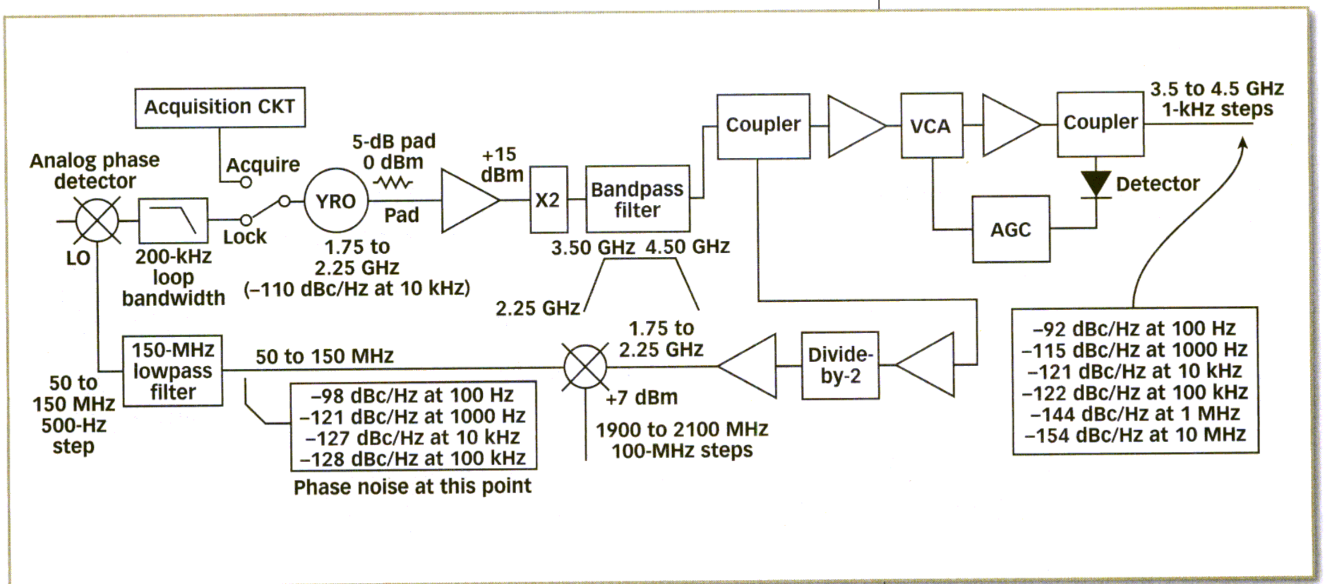
3. The synthesizer's fixed loop is shown here.

objective, LMDS manufacturers have turned to YIG oscillators. These "analog" devices are capable of generating very-high, very-clean microwave signals that are critical to data transmission. However, YIGs incorporate a rare-earth material that can be difficult to obtain, and the devices must be properly configured in a machined metal housing to be effective.

YIG-based technology has been in use for many years, but it has several inherent weaknesses. For example, YIGs are very expensive to manufacture because they require a substantial amount of manual labor and are prone to manufacturing defects. Also, YIGs can be tuned to different frequencies, but only very slowly.

Unlike conventional VCOs, a YIG-based oscillator's quality-factor (Q) performance increases with frequency, particularly at millimeter-wave frequencies. YIG-based synthesizers provide a superior noise profile, and tuning bandwidths are more than twice that of standard VCO designs. However, YIGs require a significant amount of power, which generates excessive heat that may harm the other electronic components in the transceiver. YIGs also require an environment that is free from vibration and electromagnetic interference (EMI).

In outdoor settings such as a rooftop,



4. The synthesizer's main loop can be seen here.

YIGs are prone to wind, vibration, rain, and lightning, all of which have a detrimental effect. For example, YIGs in LMDS systems hanging from rooftops are subject to phase hits, a severe problem affecting the radio's bit-error rate (BER). Interruptions in the carrier signal stemming from a YIG's vibration sensitivity slows and then drops data transmission. This does not bode well for the LMDS system manufacturers in meeting the industry's five-nines (99.999 percent on-signal disruption) standard for reliability. And when a YIG-based synthesizer is destabilized, it is slow to react and re-establish phase lock. This slow reaction contributes to lost transmission bits, increasing BER.

In outdoor settings such as a rooftop, YIGs are prone to wind, vibration, rain, and lightning, all of which have a detrimental effect.

In contrast, YROs have several distinct advantages over YIG technology. First, YROs are silicon (Si)-based devices that can be inexpensively manufactured to very high standards with high repeatability. Second, YROs can change frequencies very rapidly—orders of magnitude faster than a YIG—providing them with a broader range of applications. Third, since YROs oscillate without the need for expensive housing or cumbersome electronics, they are not prone to many of the physical limitations of YIG technology, such as wind, vibration, rain, and EMI.

YROs are fundamental-mode devices that combine the size, ease, and speed of tuning that is associated with a VCO and the phase-noise characteristics of a DRO. Depending on frequency and bandwidth, phase noise can vary from −110 to −120 dBc/Hz at 10-kHz offset.

The following discussion provides a sample design for a 3.5-to-4.5-GHz

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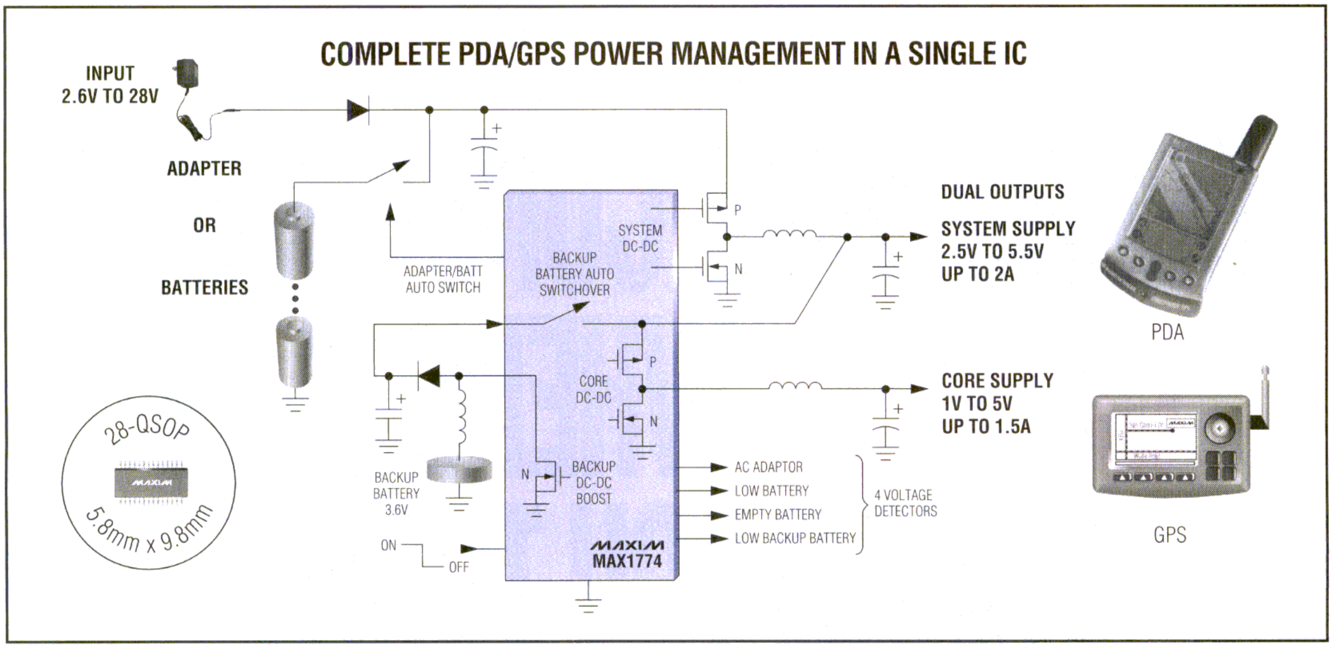

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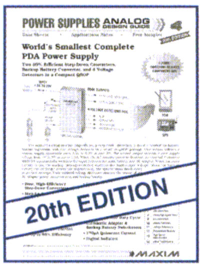

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synthesizer that offers a step size of 1 kHz and spurious response of −80 dBc.

Design Methodology

When designing low-noise, fast-switching synthesizers, the designer must often assess conflicting requirements to create a balanced product. Covering a gigahertz of bandwidth becomes a challenging proposition if the goal is fast switching, particularly if the frequencies covered are in the 5-GHz spectrum. By adhering to a few simple rules, the design process becomes much easier:

1. Design in excess margin. Start with 10 dB better phase noise than what is required. This will provide the necessary cushion as the design moves forward.

2. Map out an appropriate architecture. This has the largest effect on the design by far, as different architectures accomplish very different roles. Additionally, be sure to analyze the frequency plan for the mixer and other spurious sources.

3. Use local voltage regulation for all VCOs. A clean power supply is crucial for a VCO to operate within its specifications. VCOs in reality have three tuning ports: RF_{out}, which is subject to load pull (pulling), V_{cc}, which is subject to noise modulation (pushing), and, of course, the main tune port. Referring to basic FM modulation theory, noise on the V_{cc} port appears as narrowband FM of the carrier according to the following relationship:

$$L(fm) = 20 \log [KvVnrms \sqrt{2}/(2 fm)]$$

For example, assume that a VCO with a 1-MHz pushing specification (a common value) and a phase noise of −100 dBc/Hz at 10-kHz offset has 1-μVRMS noise on the V_{cc} line. At first glance, this does not appear as excessive noise, but the resulting phase noise at 10 kHz offset will now be degraded to −83 dBc/Hz—which is a significant amount. Additional bypassing would be required to reduce the noise to acceptable levels.

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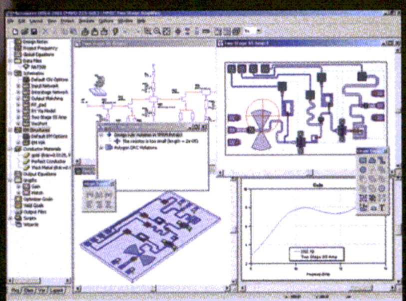

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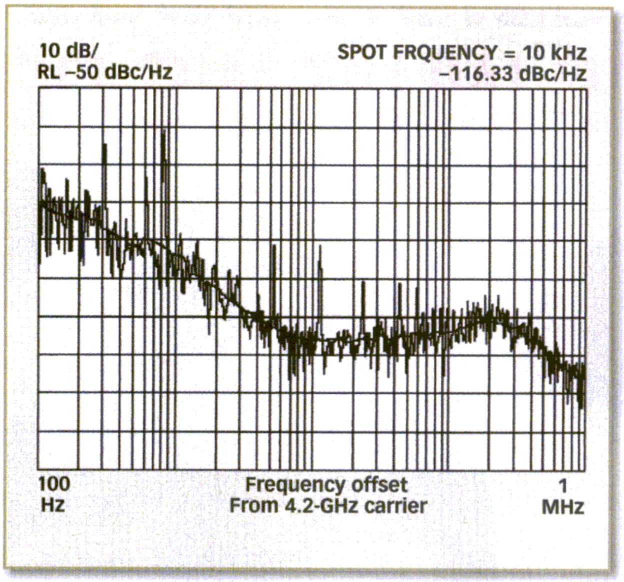
Referring to **Fig. 1**, the synthesizer contains three loops: a reference loop covering 50 to 150 MHz in 500-Hz steps, a fixed loop covering 1900 to 2100 MHz in 100-MHz steps, and a main loop that uses the other two loops in a mixing/doubling architecture. This architecture minimizes phase noise and spurious response by maintaining a low division ratio.



5. This HP 8563E Analyzer plot shows the synthesizer's phase noise.

The reference loop **(Fig. 2)** provides a low-noise reference that steps in small increments and is essentially free of spurious response. It may be tempting to use a direct-digital-synthesizer (DDS)-based scheme. But for spurious-free performance, a DDS requires extensive filtering and is limited in spurious-free bandwidth due to its sampling-based structure. An alternative approach would be a "mix-and-divide scheme," where successive stages are mixed with fixed carriers and divided down to improve phase noise and spurious response. This is often referred to as "direct analog synthesis."

In the reference loop, a 1000-to-1800-MHz, fractionally based synthesizer is divided down by eight, yielding a 125-to-225-MHz, low-noise source that steps in 8-kHz increments. This is mixed with a 1075-to-2175-MHz synthesizer that steps in 100-MHz steps, yielding a 1200-to-2400-MHz signal that steps in 80-kHz increments. An analysis of this mixing scheme does not show any spurs of consequence (<–65 dBc) within ±5 MHz from the desired carrier, although there are numerous low- and high-order spurs farther out. The higher-order spurs are reduced by using appropriate lowpass filtering, and the resultant signal is then divided down by a factor of 16 (or 32), yielding a 50-to-150-MHz, low-noise signal that steps in 500-Hz increments, with less than –85-dBc spurious response.

This loop **(Fig. 3)** uses a sampling phase detector (SPD) and three VCOs to generate 1900 to 2100 MHz. A sampling phase detector consists of a step-recovery diode (SRD) capacitively coupled to two back-to-back Schottky diodes, which act as a mixer. The SRD, when properly driven by a 100-MHz source, generates harmonics through several gigahertz. These harmonics mix with the desired carrier (at the Schottky diodes) yielding an intermediate frequency (IF) that is suitable for phase lock. For example, to phase lock the 2100-MHz VCO, the SRD is driven by a 100-MHz signal and generates a 100-MHz comb, which includes a 2100-MHz signal. This 2100-MHz signal is mixed with the VCO's carrier, and the resultant IF signal controls an active loop filter which, in turn, adjusts the VCO's tuning voltage to compensate for phase and frequency fluctuations.

The advantage of using an SPD as opposed to a digital phase detector is the SPD's superior phase-noise characteristics, and the improvement in overall loop gain. A typical SPD-based loop has a noise floor of –155 dBc/Hz at the diodes, and a loop-division ratio of one. This would yield a theoretical noise floor of –127.4 dBc/Hz at 2.1 GHz ([20 log(2400/100)]–155). Compared

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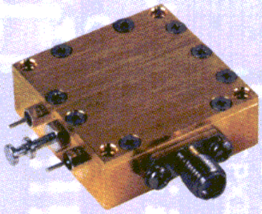

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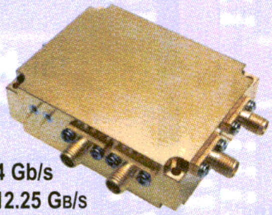

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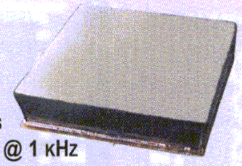

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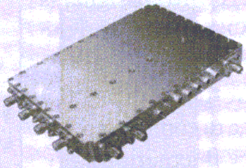

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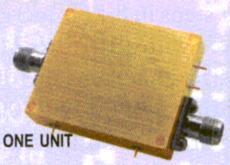

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to a digital phase detector, this is a 27-dB improvement. The disadvantage of an SPD is the requirement for pre-steering the VCO to aid in acquisition. Unlike a digital phase detector that will lock and acquire more than a ±2-Π range, the analog phase detector has limited acquisition capability and requires the assistance of an external circuit.

Main Loop

The goal of the main loop **(Fig. 4)** is to generate a spurious-free 3.5-to-4.5-GHz signal. As with the fixed loop, an analog phase detector must be used to satisfy the phase-noise requirements. This, however, brings additional problems in signal acquisition. APA Wireless has developed proprietary patent-pending techniques that fully leverage the superior phase-noise characteristics of analog phase detectors with the wide-tuning and acquisition capabilities of digital phase detectors. Referring to the main loop section shown in Fig. 1, the acquisition circuitry will set the YRO to the exact desired frequency in less than 10 μs, and does so in parallel with the other loops, regardless of step size.

YROs are fundamental-mode devices that combine the size, ease, and speed of tuning associated with a VCO and the phase-noise characteristics of a DRO.

Circuit Description

In order to satisfy the phase-noise requirements at offsets that are far from the carrier, a signal source (VCO or YIG) that can cover wide bandwidths, yet maintain good phase noise must be used. Although a YIG would satisfy this requirement, it lacks the frequency agility needed for sub-100-μs switching and requires additional circuitry for phase-lock operation. APA developed its line of YROs to address this issue, with phase noise rivaling YIG solutions but without the driver complexity.

Referring to the block diagram that is shown in Fig. 3, a 1.75-to-2.25-GHz YRO drives a doubler to achieve a 3.5-to-4.5-GHz output. Although a 3.4-to-4.5-GHz YRO could have been used, the doubled approach offers the following advantages:

- The divider provides isolation between the fixed-frequency loop and the main output. Without the divider, frequencies close to the desired final frequency would have to be mixed into the main loop. These frequencies would appear at the main output, and would be virtually impossible to filter or remove.
- The divider eases the fixed loop-frequency requirement. Half as many frequencies are needed.

The doubled output is then divided by two, and drives a series of isolation amplifiers, which drive a mixer whose RF port is driven by the fixed loop. The resultant IF signal drives the local-oscillator (LO) port of an analog phase detector whose RF port is driven by the reference loop. In this way, the reference loop provides fine frequency control over 100-MHz bandwidths, with the fixed loop incrementing the coarse frequency in 100-MHz steps.

Since the phase noise of the YRO is −130 dBc/Hz at a 100-kHz offset and the noise floor of the fixed loop is −128 dBc/Hz, the loop-bandwidth crossover point for phase noise is set at the 100-kHz point. Of course, since the fixed loop sets the noise floor for this architecture, improvements in this area will yield better phase noise, up until the limit that is set by the reference loop (−140 dBc/Hz at 100-kHz offset). The doubled output is filtered in order to remove subharmonics, then drives an automatic-gain-controlled (AGC) final amplifier.

Figure 5 is a phase-noise plot (using an HP 8563E spectrum analyzer) of the output of the previously described synthesizer at 4.2 GHz—clearly at the limits of the analyzer. MRF

DESIGN

Wideband VCO Designs Are Independent Of Circuit Parameters

A set of generalized tuning parameters helps speed the design of various types of wideband voltage-controlled oscillators with either bipolar or FET devices.

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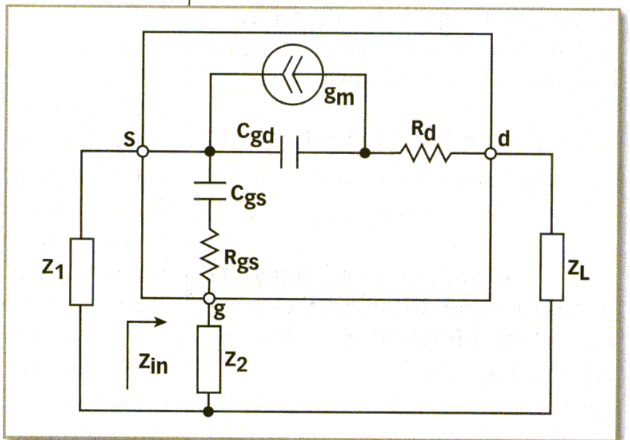
Voltage-controlled oscillators (VCOs) are important components in a variety of RF and microwave systems, including broadband measurement equipment, wireless and TV applications, as well as military electronic-countermeasures (ECM) systems. In many applications, particularly ECM, system performance improves significantly when VCOs have wide tuning bandwidths using linear varactor tuning, and high-speed switching characteristics. Only varactors support this high-speed frequency agility while affording small size and more than octave-tuning bandwidths. The recent progress in transistor technology has ensured significant improvement of a VCO's frequency and power characteristics. It is known that the common-base and common-collector connections of a bipolar transistor are the most effective to realize wide VCO frequency-tuning.[1] Varactor properties of fast settling time and low post-tuning drift make wideband hybrid and monolithic bipolar VCOs suitable for modern ECM systems, such as frequency-agile local oscillators (LOs) in receiver (Rx) systems and fast-modulation noise sources in active jamming systems.[2,3]

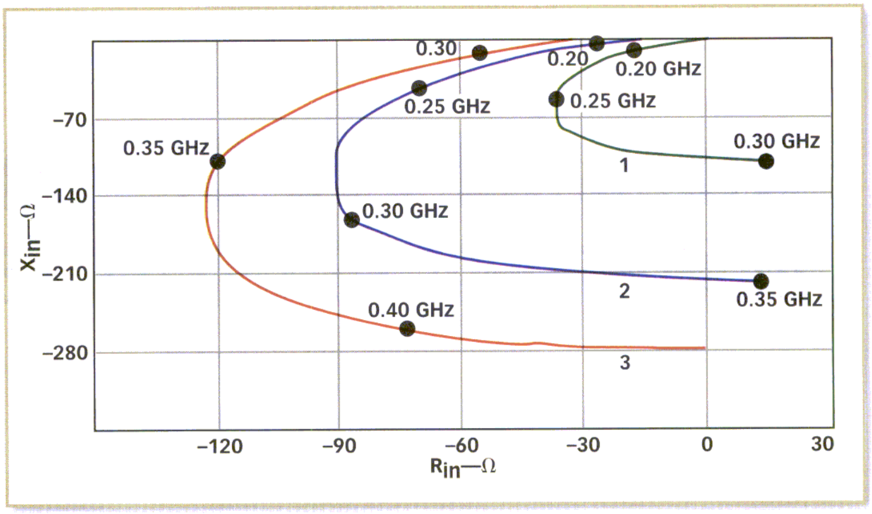


1. The equivalent circuit of a common-gate MOSFET VCO shows the device's drain-to-source capacitance, C_{ds} and gate-to-source capacitance, C_{gs}.

Gallium-arsenide (GaAs) field-effect transistors (FETs) are another option for designing wideband VCOs. A typical wideband GaAs FET microwave VCO circuit consists of a common-gate transistor with a gate series inductance and two hyperabrupt varactors connected to the gate and source terminals, respectively.[2]

This article offers an analysis of wideband VCO properties in different frequency ranges when bipolar or FET devices are used. The tuning-bandwidth parameters are provided in a generalized form that contributes to faster design procedures for wideband VCOs, regardless of their specific parameters. Also, small-signal circuit analysis and practical examples are presented in the article.

For an analytical evaluation of the



2. These theoretical impedance curves for the circuit of Fig. 1 illustrate how the input resistance varies with the input inductance, L and load inductance L_L.

tuning range of a metal-oxide-semiconductor-FET (MOSFET) VCO resonant circuit, it is often sufficient to consider the simple device-equivalent circuit, especially when the operating frequencies are not very high. In **Fig. 1**, the common-gate MOSFET-VCO equivalent circuit is shown where $Z_1 = 1/j\omega C$ is the capacitive source feedback impedance, $Z_2 = j\omega L$ is the inductive gate impedance, and $Z_L = R_L + j\omega L_L$ is the load impedance. Since the device-feedback capacitance C_{gd} is usually much smaller than the device input capacitance C_{gs}, it is possible to neglect its influence on the VCO characteristic, which simplifies the analytical calculations significantly.

The start-up conditions for this oscillator can be written by:

$$Re\ Z_{in} < 0 \qquad (1)$$

$$Im(Z_{in} + Z_1) = 0 \qquad (2)$$

where input impedance Z_{in} is determined through the device small-signal common source Y-parameters by:

$$Z_{in} = 1 + Y_{11}Z_2 + (Y_{22} + Z_2 \Delta Y)Z_L \; / \; Y_{11} + Y_{12} + Y_{21} + Y_{22} + \Delta Y(Z_2 + Z_L) \qquad (3)$$

Substituting the small signal Y-parameters expressed through the parameters of the MOSFET equivalent circuit into Eq. 3 yields:

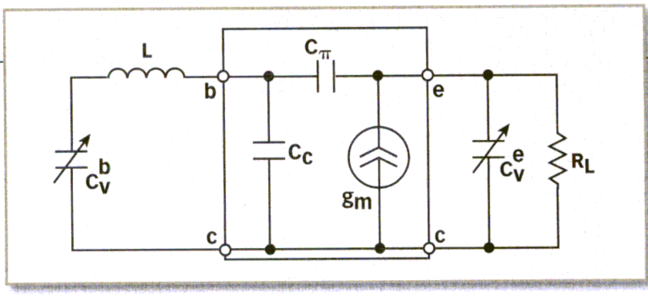
$$Z_{in} = (1 - \omega^2 C_{ds} L_L)(1 - \omega^2 C_{gs} L) - \omega^2 C_{ds} C_{gs}(R_L + R_d) R_{gs} + / \; g_m - \omega^2 C_{ds} C_{gs}(R_L + R_d + R_{gs}) + \rightarrow$$

$$j\omega\left[(1 - \omega^2 C_{gs} L) C_{ds}(R_L + R_d) + (1 - \omega^2 C_{ds} L_L) C_{gs} R_{gs}\right] / \; j\omega\left[C_{gs} + C_{ds} - \omega^2 C_{gs} C_{ds}(L + L_L)\right] \qquad (4)$$

Figure 2 illustrates the theoretical impedance curves with frequency as the independent variable for different values of the input and output inductances L, L_L, and $R_L = 50\ \Omega$ where:

curve 1: L = 200 nH and L_L = 50 nH;
curve 2: L = 200 nH and L_L = 0 nH; and
curve 3: L = 100 nH and L_L = 0 nH.

An RF MOSFET device with a 5-µm gate length and the small-signal parameters of its equivalent circuit, g_m = 27 S, C_{gs} = 5 pF, R_{gs} = 25 Ω, C_{ds} = 3.6 pF, R_d = 70 Ω were chosen. These relationships show that for decreasing values of the inductances L and L_L, the input resistance R_{in} becomes more negative in the frequency range of 200 to 400 MHz. Also, a decrease of the load inductance L_L indicates that the negative-resistance frequency range moves



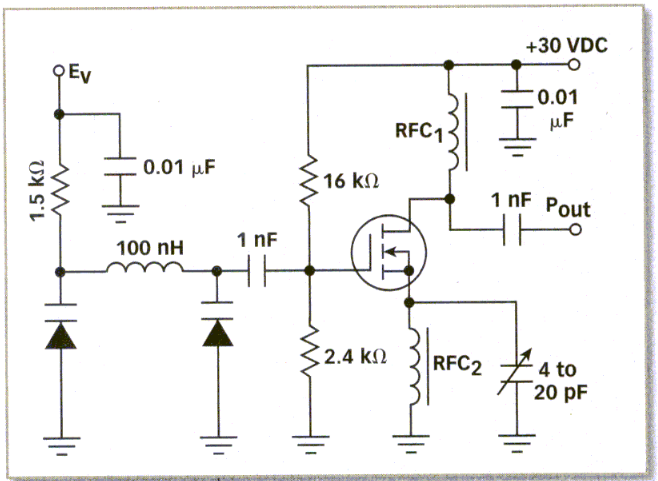
4. This is the equivalent circuit of a bipolar common-collector VCO showing the interterminal capacitance and a current source represented as small-signal transconductance g_m.

in the direction of higher frequencies. The feedback inductance L appears also to have this effect, but in practice, it does not influence the width of the frequency range over which there is negative resistance.

Figure 3 shows the practical realization of this common-gate MOSFET VCO using two hyperabrupt varactors with $K_c = 10$, where K_c is the varactor capacitance ratio, and $C_{vmin} = 2$ pF. This achieves the output power of 17 ±5 dBm in the tuning bandwidth of 170 to 390 MHz with varactor biasing in the range of +0.4 to +30 VDC. The variable capacitance connected to the device-source terminal provides the phase-balance condition over the entire varactor-tuning bandwidth. As a result, despite some design simplification, the experimental results are in very good agreement with the theoretical tuning-bandwidth evaluation using the device's small-signal parameters.

A Common-Collector VCO

An analytical evaluation of a bipolar VCO resonant circuit begins with the simple equivalent circuit presented in **Fig. 4** where the collector terminal is common and is usually grounded in the practical realization with a bypass capacitor. The simplified equivalent circuit includes the collector capacitance C_c; the base-emitter capacitance $C\pi$, including diffusion-and junction capacitances; and current source described by small-signal transconductance g_m. To provide wideband tuning, two varactors—C_v^b and C_v^e—are used in the base and emitter circuits, respectively.



3. An actual common-gate VCO uses a pair of hyperabrupt varactors in the gate circuit to obtain the necessary capacitance values to sustain oscillations.

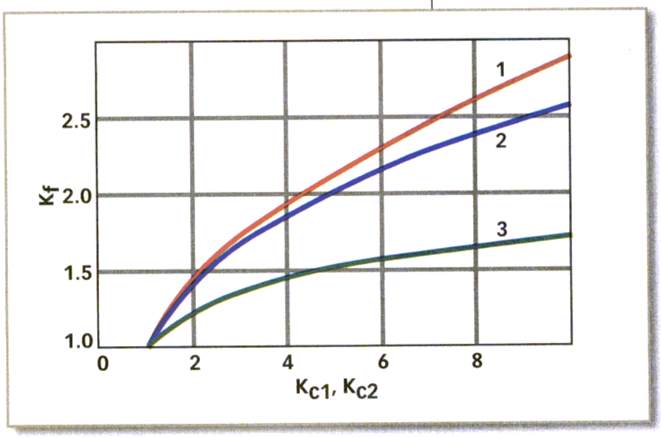
For such a common-collector bipolar VCO, the equation for resonant frequencies in steady-state operation is provided by:

$$\omega^2 L C_v^b \left(C_c + \frac{C_\pi C_v^e}{C_\pi + C_v^e} \right) = C_v^b + C_c + \frac{C_\pi C_v^e}{C_\pi + C_v^e} \quad (5)$$

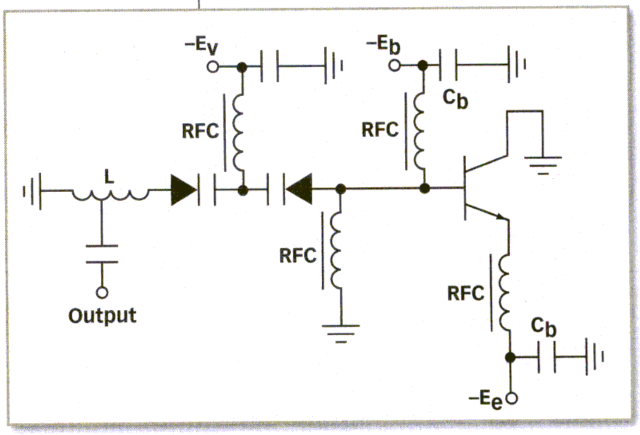
To characterize the VCO band properties, it is convenient to use the generalized functions $K_f(K_{c1}$ and $K_{c2})$ where K_f = the frequency tuning ratio, $K_{cl} = C_{vmax}^b/C_{vmin}^b$, $K_{c2} = C_{vmax}^e/C_{vmin}^e$. In a common case, to obtain the results regardless of the particular values of the circuit parameters, the normalized parameters should be used. So, if the following normalized parameters:

$m_0 = \omega_T C_c/g_{m1}$, $n_0 = 1 + \omega_T R_L C_c$, and

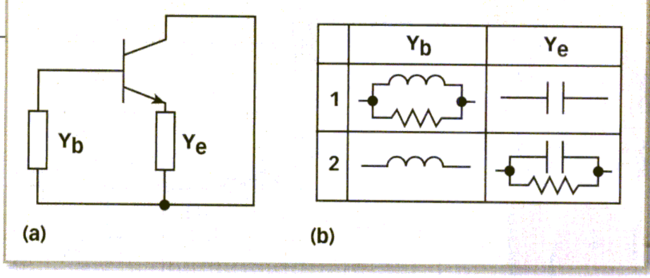
$q_1 = C_c/C_{vmin}^b$, and $q_2 = C_c/C_{vmin}^e$,



5. Curves 1, 2, and 3 can be used to determine the tuning bandwidth of a common-collector VCO. The largest tuning bandwidth—Curve 1—results from simultaneous varactor tuning of the base and emitter circuits.



6. The implementation of a typical grounded-collector lumped VCO circuit is shown here with back-to-back varactors that are in the base circuit in order to provide tuning over a wide bandwidth.



7. A common-collector VCO (a) can be designed with different combinations of admittances in the base and emitter circuits (b).

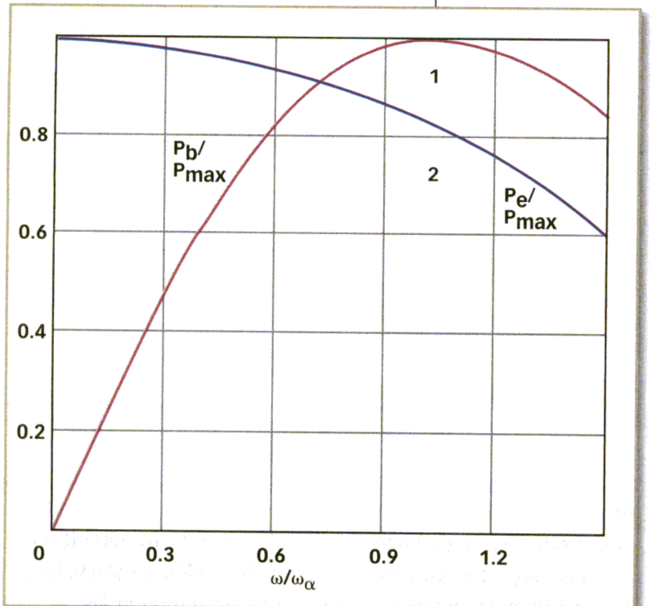
where g_{m1} is the averaged large-signal transconductance put into operation, and ω_T = the transition frequency, Eq. 5 in a generalized form can be written as:

$$K_f = \left\{ K_{c1} \frac{(1+q_1)}{(q_1 + K_{c1})} \cdot \frac{(m_0 + q_2) + q_1 K_{c2}(1+m_0) + q_2}{(m_0 K_{c2} + q_2) + q_1 K_{c2}(1 + m_0 + q_2)} \right\}^{0.5} \quad (6)$$

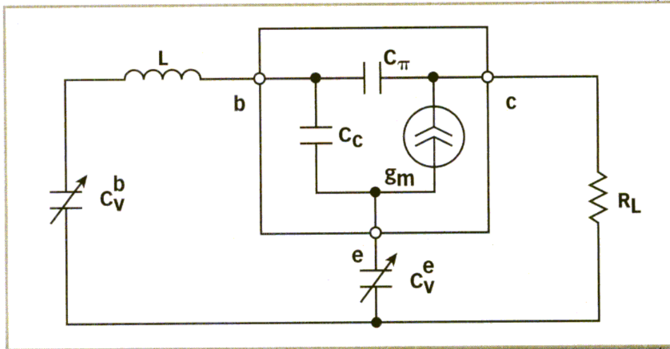
In **Fig. 5**, the different functions, K_f, K_{c1}, and K_{c2} for various values of the normalized parameters q_1, q_2, and m_0 = 0.012 are presented. Here, curve 1 is plotted for $q_1 = 1$ and $q_2 = 0.5$ with simultaneous varactor tuning in the base and emitter circuits. Curve 2 is characterized by $q_1 = 1$ and $q_2 = 0.05$ with varactor tuning only in the base circuit when $K_{c2} = 1$. Curve 3 is calculated for $q_1 = 0.1$ and $q_2 = 0.5$ with varactor tuning only in the emitter circuit when $K_{c1} = 1$. A comparison of the curves shows that, for simultaneous varactor changes with $K_c = K_{c1} = K_{c2} = 10$ (in the base and emitter circuits), maximum tuning bandwidth is achieved (curve 1).

Using varactors in the base circuit only (curve 2) yields a larger tuning bandwidth than in the case of varactor tuning only in the emitter circuit (curve 3). In this case, decreasing q_2 and increasing q_1 can increase the tuning bandwidth. To increase the tuning bandwidth with only an emitter varactor, it is necessary to reduce the parameter q_2 to its optimum value of 1. The change of the parameter n has no essential effect upon tuning bandwidth.

Figure 6 shows a typical fundamental grounded-collector lumped VCO circuit where two back-to-back varactors provide wideband tuning and output power is dissipated in the load conductively connected to a resonant circuit inductance.[4] The RF chokes (RFCs) and bypass capacitors (C_b) form a DC-coupled lowpass filter that is intended to pass power-supply inputs and modulation frequencies, while having high impedance at the fundamental frequency to minimize direct leakage through the bias circuits. Using abrupt varactors with a



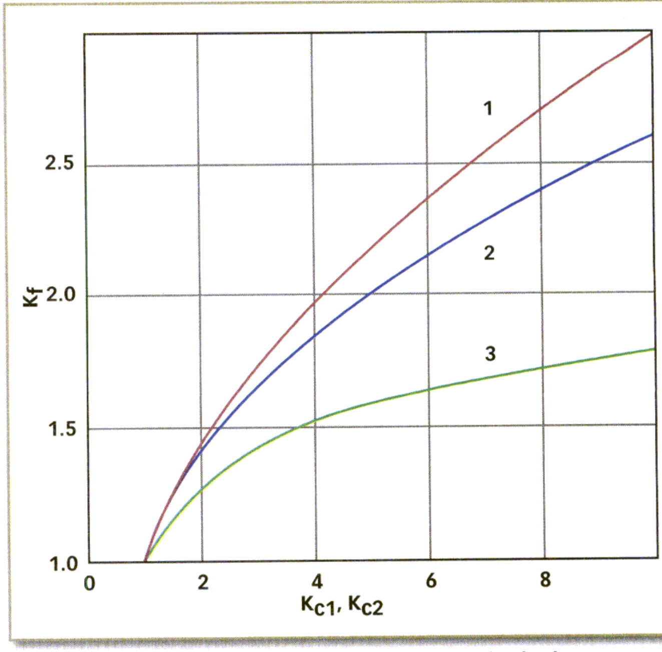
8. Curves 1 and 2 illustrate the power versus frequency response of the circuits shown in Fig. 7b, cases 1 and 2. Tuning over a wide frequency range is possible using a variable-series inductor in the base circuit (shown in Fig. 7b, case 2) as shown by curve 2.



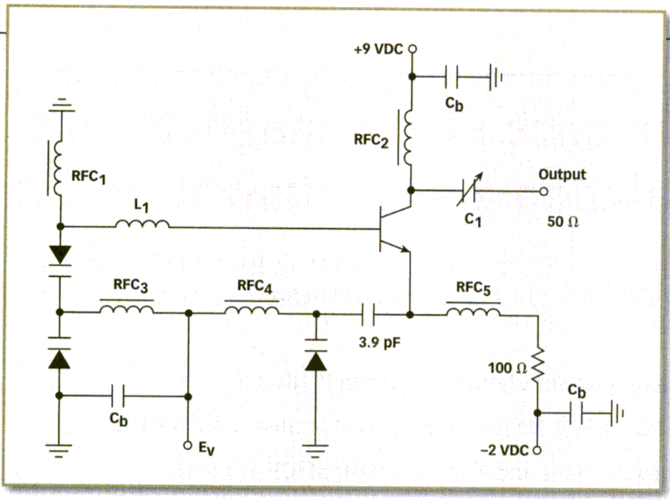
9. This is the equivalent circuit of a common-base VCO showing the interterminal capacitances and the capacitances of the varactors in the base and emitter circuits.

capacitance ratio, $K_c = 3$, in a bias-voltage range of 0 to +5 VDC with minimum capacitance $C_{vmin} \sim 0.6$ pF, it follows from curve 2 in Fig. 5, that it is possible to provide the wideband tuning in a frequency range with $K_f \geqslant 1.6$. Taking into account that the equivalent device-output capacitance $C_t = 1.5$ pF, the frequency-tuning bandwidth of 5.5 to 8.0 GHz is realized when tank inductance L = 1.9 nH.

However, for the common-collector VCO, the conductive-load connection is not the only way to realize the maximum output-power level. It is very important to provide minimum flatness over the entire tuning bandwidth. Another approach that is advisable is to connect the load to the emitter terminal, thus decreasing the influence of the load impedance on the resonant circuit that enables the realization of its higher quality factor (Q). **Figure 7a** provides the simplified common-collector VCO schematic and **Fig. 7b** shows two possi-



10. Curves 1, 2, and 3 are plotted for varactors in the base and emitter circuits, base circuit only and emitter circuit only, respectively. The bandwidth can be controlled by the values of the collector and emitter capacitances shown in Fig. 9.



11. An implementation of the circuit of Fig. 9 uses hybrid integrated circuits (ICs) and hyperabrupt varactors in the base and emitter circuits to provide the tuning.

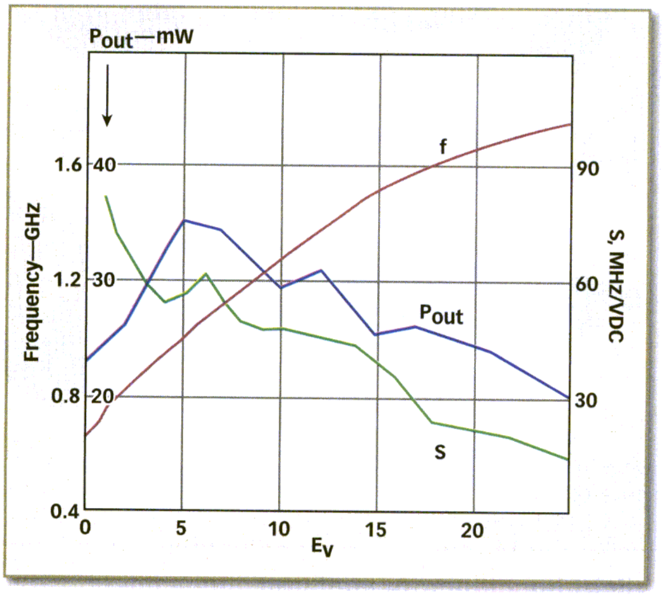
ble combinations of the admittances in the base and emitter circuits. In the first case, the load is connected to the resonant circuit conductively or inductively provided the impedance in the emitter circuit is capacitive. The second combination requires inductive impedance in the base circuit when the load is connected in parallel to the device emitter and collector terminals.

In **Fig. 8,** the calculated functions of the normalized output power versus normalized frequency for these two cases are shown.[5] In case 1, the load is connected to the base circuit and the maximum output power occurs when $\Omega = \Omega_\alpha$. In case 2, the output power comes from the device emitter and its level changes negligibly up to $\omega = 0.5\ \omega_\alpha$. As a result, in the latter, the VCO can tune easily in a very-wide frequency range through simple tuning of the series inductance in the base circuit using a varactor diode in reverse-bias operation. And it should be noted that the series or parallel resistance-capacitance (RC) circuit with constant capacitance and load could realize the capacitive impedance in the emitter circuit.

A Common-Base VCO

In **Fig. 9,** the schematic of the common-base VCO with varactors in the base and emitter circuits is shown. The resonant frequencies can be found from:

$$\omega^2 LC_v^b\left[1+\frac{C_v^e}{C_c}+\frac{\omega_T C_v^e}{g_{m1}}(1+g_{m1}R_L)\right] = \left(1+\frac{\omega_T C_v^e}{g_{m1}}\right)\left(1+\frac{C_v^b}{C_c}\right)+\frac{C_v^e}{C_c}+\frac{C_v^e+C_v^b}{C_c}g_{m1}R_L \qquad (7)$$



12. These curves show the power and frequency performance of the circuit in Fig. 11 as a function of the tuning varactor bias voltage E_V. The curve labeled S is the maximum-to-minimum tuning slope (S_{max}/S_{min}) of the circuit.

In generalized form, Eq. 7 can be written as:

$$K_f = \left\{ K_{c1} \frac{q_2(q_1 + n_0) + q_1(n_0 + m_0) + m_0}{q_2(q_1 + n_0K_{c1}) + q_1K_{c2}(n_0 + m_0) + m_0K_{c1}K_{c2}} \left[\frac{q_2 + K_{c2}(n_0 + m_0)}{q_2 + n_0 + m_0} \right] \right\}^{0.5} \quad (8)$$

In **Fig. 10**, the functions K_f, K_{c1}, and K_{c2} for various values of the normalized parameters q_1, q_2, and $m_0 = 0.012$ and $n_0 = 1.6$ are presented. A comparison of the curves shows that, for the simultaneous varactor change with $K_c = K_{c1} = K_{c2} = 10$ in the base and emitter circuits, a threefold frequency overlapping (curve 1: $q_1 = 1$ and $q_2 = 0.5$) has been achieved. At the same time, the bipolar VCO with varactors only in the base circuit (curve 2: $q_1 = 1$, $q_2 = 0.05$, and $K_{c2} = 1$) is characterized by greater sensitivity to the varactor capacitance change than the emitter varactor VCO configuration (curve 3: $q_1 = 0.1$, $q_2 = 0.5$, and $K_{c1} = 1$). For the purpose of frequency-bandwidth widening, it is advisable to reduce q_2 and to increase q_1. The influence of the parameter n is negligible and cannot be taken into consideration.

In **Fig. 11**, the practical L-band bipolar VCO electrical circuit manufactured using hybrid-integrated technology is presented. To provide wideband tuning, silicon (Si) hyperabrupt varactors with a minimum capacitance value $C_{vmin} = 1.2$ pF and capacitance ratio $K_c > 10$ within a reverse bias-voltage range of 0 to +25 VDC were used. The required value of the base inductance L_1 is realized by using the lead inductances of the bipolar transistor and varactors. The experimental results are shown in **Fig. 12**. The minimum VCO output-power ripple is provided with the tuning of the variable capacitor C_1 in limits of 0.5 to 2.0 pF. The tuning varactor bias voltage E_v required to tune from 0.65 to 1.76 GHz is 0 to +25 VDC, and the maximum-to-minimum tuning-slope ratio S_{max}/S_{min} is less than 6:1 across the frequency-tuning range. MRF

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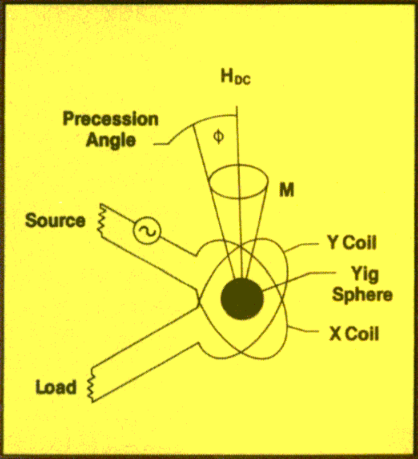

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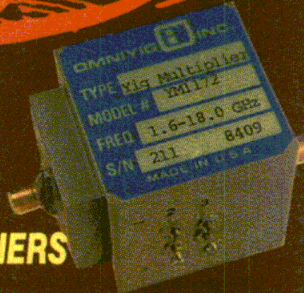

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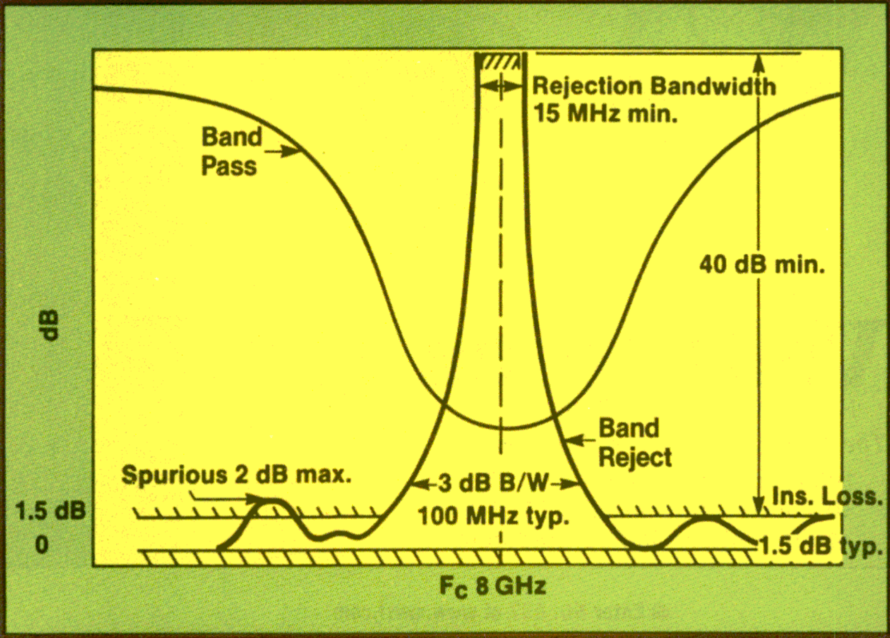
YM 1001	1-2 GHz	2-13	6 dBm
YM 1002	100 MHz	1-12	−33 dBm
YM 1003	200 MHz	1-12	−28 dBm
YM 1004	500 MHz	1-12	−10 dBm
YM 1026	1-2 GHz	2-18	4 dBm
YM 1027	100 MHz	1-18	−40 dBm
YM 1028	200 MHz	1-18	−34 dBm
YM 1029	500 MHz	1-18	−22 dBm
YM 1087	1-.2 GHz	1-12	−30 dBm

*RF input power on all models 0.6 to 1.0 watts.



DUAL 10-STAGE BAND PASS/BAND REJECT FILTERS

Model No.	M138	M139
Frequency Range	2-8 GHz Band Pass	8-18 GHz Band Pass
Insertion Loss	4.5 dB	4.5 dB
3 dB Bandwidth	25-50 MHz	25-50 MHz
No. Stages	4	4
Off Resonance Isolation	70 dB	70 dB
	Band Reject	Band Reject
30 dB Rejection Bandwidth	15 MHz Min.	75 MHz
3 dB Bandwidth	125 MHz Max.	150 MHz
VSWR	2:1	2.5:1
No. Stages	6	6
Model #	M138	M139

FAST SWITCHING – 800 MICROSECONDS FULL BAND TRACKING YIG FILTER/YIG OSCILLATOR WITH INTEGRATED ANALOG OR DIGITAL DRIVERS

The newest design at Omniyig is the integrated Fast Switching Yig Tuned Filter/Oscillator build in multioctave frequency ranges. This is achieved by Omniyig's proprietary fast switching magnetic shell design, and integrated tracking capability between oscillator and yig filter. The units are built to meet the MIL-STD-5450 Specification with the extreme temperature ranges between −55°C to +85°C. Some of the RF Specifications are outlined as follows:

Technical Data:

Omniyig Model No.	Frequency Range (GHz)	Filter IL (dB)	Oscillator RF Power (dBm)	Frequency Tracking Between Os./Filter (MHz)	Filter 3 dB BW (MHz)
M129YTO	0.5-2.0	5.5	+17	±5	15-30
M120YTO	2-8	5.0	+17	±7	23-40
M121YTO	8-18	5.0	+17	±8	25-45

Additional RF Performance Specifications:

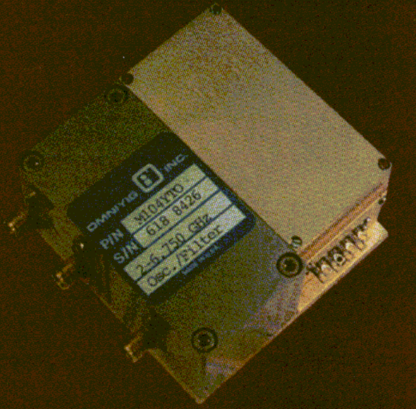
a) Oscillator frequency range is typically 160 MHz above the filter bandwidth. The oscillator frequency can also be factory adjusted to any other frequency requirements.

b) Pulling Figure (1.25:1 VSWR) is less than 3 MHz.

c) The Second Harmonic is typically 17 dBc and 14 dBc minimum below fundamental frequency.

For final specification data sheet, call Omniyig's Sales Department at:

3350 Scott Boulevard, #66
Santa Clara, CA 95054-3125
Telephone: (408) 988-0843



THIN FILM YIG BAND OSCILLATORS

- **1-4 GHz.** RF power output 20-60 mW. 2nd harmonic 16 dB.
- **1.7-4.3 GHz.** RF power output 30 mW. 2nd harmonic 20 dB.
- **4-8 GHz.** RF power output 10 mW. 2nd harmonic 15 dB.
- **8-12 GHz.** RF power output 10 mW. 2nd harmonic 15 dB.
- **12-18 GHz.** RF power output 10 mW. 2nd harmonic 12 dB.
- **2-6 GHz.** RF power output 15 mW. 2nd harmonic 12 dB.
- **2-8 GHz.** RF power output 10 mW. 2nd harmonic 12 dB.
- **8-18 GHz.** RF power output 20 mW.
- **6-18 GHz.** RF power output 20 mW.

STANDARD COMB GENERATORS

Omniyig Model No.	Input Freq. (MHz)	Output Freq. Range (GHz)	Output Power (dBm)
OHG 10118	100	0.1 to 18.0	−40
OHG 20218	200	0.2 to 18.0	−35
OHG 51026	500	0.5 to 18.0	−28
OHG 61026	1000	1.0 to 18.0	−18

YIG FILTERS

Omniyig Model No.	Frequency Range (GHz)	Ins. Loss (dB)	Bandwidth at 3 dB (MHz)
2-STAGE			
P102	0.5-1.0	4	17-30
L102	1.0-2.0	3	24-35
S102	2.0-4.0	2.5	25-40
C102	4.0-8.0	2.5	25-40
X102	8.0-12.4	2.5	25-40
Ku102	12.4-18.0	2.5	30-45
3-STAGE			
P103	0.5-1.0	5	14-25
L103	1.0-2.0	3.5	20-35
S103	2.0-4.0	3	20-35
C103	4.0-8.0	3	25-40
X103	8.0-12.4	3	25-40
Ku103	12.4-18.0	3.5	30-45
4-STAGE			
P104	0.5-1.0	6	12-23
L104	1.0-2.0	4.5	20-35
S104	2.0-4.0	4	20-35
C104	4.0-8.0	4	25-40
X104	8.0-12.4	4	25-40
Ku104	12.4-18.0	4	28-45
DUAL 2-STAGE			
P1022	0.5-1.0	3.5	17-30
L1022	1.0-2.0	3	24-35
S1022	2.0-4.0	2.5	25-40
C1022	4.0-8.0	2.5	25-40
X1022	8.0-12.4	2.5	25-40
Ku1022	12.4-18.0	2.5	30-45

YIG BAND REJECT FILTERS

6-Stages & 8-Stages

Omniyig Model No.	Freq. Range GHz	40 dB (min.) MHz	Loss (max.) dB
P106RX	0.5-1.0	10	1.5
L106RX	1.0-2.0	10	1.5
S106RX	2.0-4.0	15	1.5
C106RX	4.0-8.0	20	1.5
X106RX	8.0-12.0	20	1.5
KU106RX	12.0-18.0	20	1.8
M102RX	4.0-12.0	8	1.5
M103RX	4.0-12.0	10	1.5
M104RX	4.0-18.0	8	2.0
M105RX	2.0-8.0	10	1.5
M107RX	8.0-18.0	20	1.5

Contact Omniyig's sales department for comprehensive specifications, price and delivery information.

3350 Scott Blvd., Bldg. #66
Santa Clara, California 95054-3125
(408) 988-0843 TWX 910/338-7356

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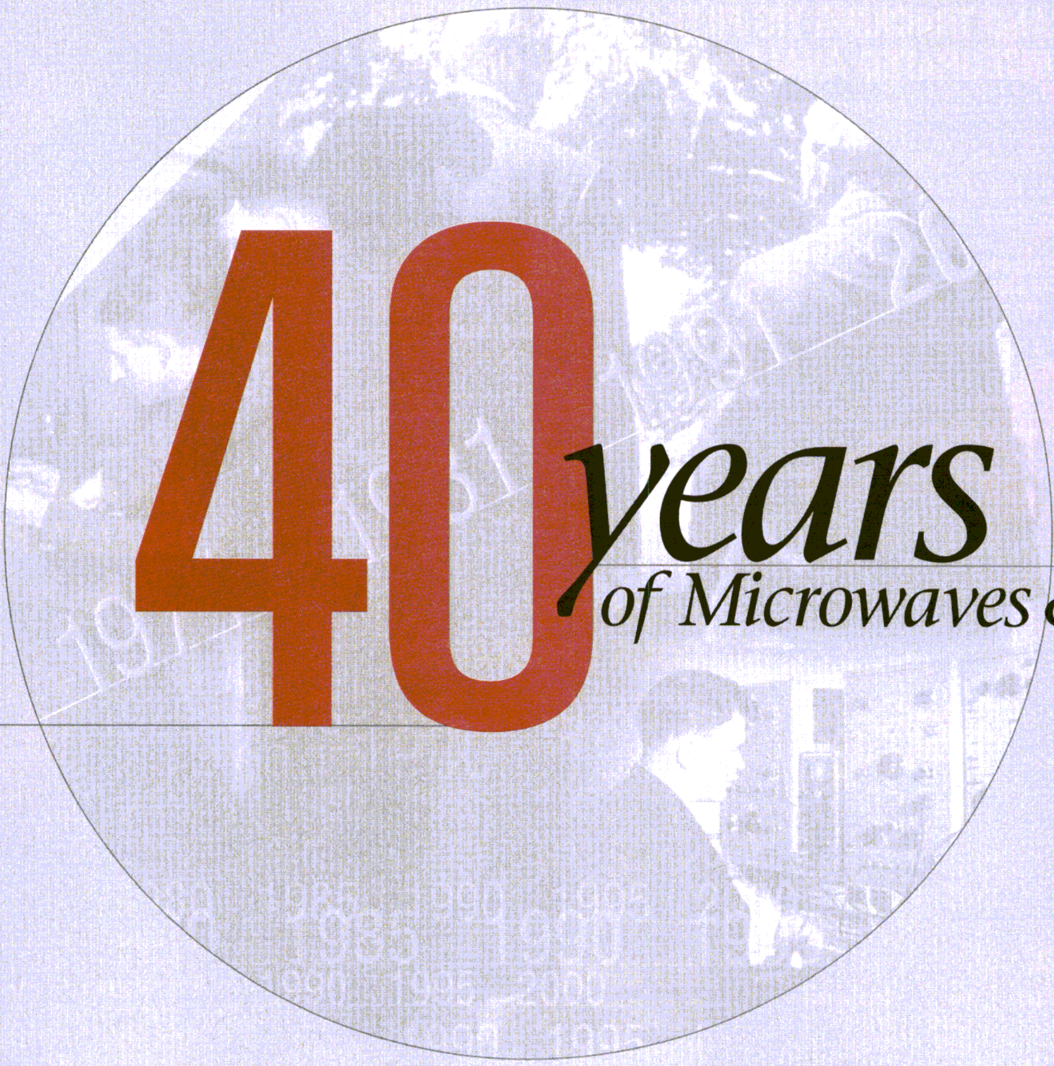
OMNIYIG INC

40 years of Microwaves & RF



Forty years is a lifetime for some folks, and a considerable period in the history of an electronics industry. For the microwave industry, as chronicled by 40 years of publication by *Microwaves & RF* magazine, that time was spent in wild growth spurts throughout the 1960s through 1980s, until finally reaching a state of "commercial maturity" in the 1990s through 2001. Yet, as this magazine celebrates its 40th year of publication, the industry is poised for further changes, as many companies eye fiber-optic communications as a potential growth market.

In looking back over four decades, the changes that took place to this industry were dramatic, including a shift from vacuum tubes to solid-state devices and from military markets to commercial business.

Microwaves & RF started life under the name *MicroWaves,* and as an insert section within sister publication *Electronic Design* of Hayden Publishing Co. (which was founded by Jim Mulholland, Jr.). The first full issue of *MicroWaves* was issued on March 15, 1962, with Robert Ahrensdorf as publisher, Manfred Meisels as editor, and John Weber as sales manager. Meisels, who guided the editorial content of the magazine through its first decade, contributed a news report to that first issue, on fast-tuning hydraulic magnetrons for jam-proof radar systems. In another story, he noted an increase in microwave papers at the IRE Show, an indication that perhaps a separate microwave technical conference was needed.

The cover story **(Fig. 1)** for that first issue featured an inverted tunable coaxial magnetron from SFD Laboratories, a subsidiary of Varian Associates (Union, NJ). The device yielded 50-W average power and 100-kW peak output power at Ka-band. Transistors were yet to achieve reliable production levels in 1962, and so tubes dominated the market. Tubes were featured in several other product features, including the X-1100 TWT from Eitel McCullough (San Carlos, CA), with 5-W linear output power from 5.9 to 7.5 GHz, and the N1029 TWT from English Electric Valve with similar output power from 5.9 to 7.2 GHz. In these years prior to the adoption of Hertz (Hz) [after Heinrich Hertz] as the unit of measure for frequency, frequency ranges were listed in cycles per second.

Advertisers for that first issue included Varian Associates (Palo Alto, CA) for klystrons, Sylvania (Mountain View, CA) for silicon varactor diodes, Narda Microwave Corp. (Plainview, NY) for ferrite isolators, Philco (Lansdale, PA) for a microwave diode switch, Hughes Aircraft Co., Microwave Tube Div. (Los Angeles, CA) for miniature S-band traveling-wave tubes (TWTs) for space applications, Frequency Engineering Laboratories (Asbury Park, NJ) for a microwave tube test set, Microwave Electronics Corp. (Palo Alto, CA) for Ku-band TWTs, AMP, Inc. (Elizabethtown, PA) for high-frequency connectors, Phelps Dodge Corp. (New York, NY) for coaxial cables, Polarad Electronics Corp. (Long Island City, NY) for microwave signal generators, Litton Industries, Electron Tube Div. (San Carlos, CA) for a variety of high-power vacuum tubes, Microwave Associates (Burlington, MA) for waveguide components, Airtron (Morris Plains, NJ) for waveguide components, TRAK Electronics Co. (Wilton, CT) for BWO sweepers, ARRA (Westbury, NY), for coaxial variable attenuators, PRD Electronics (Brooklyn, NY) for signal sources and power meters, Microlab (Livingston, NJ) for off-the-shelf microwave components, Raytheon Co. (Waltham, MA) for ferrite circulators and vacuum tubes, and RCA Electron Tube Div. (Harrison, NJ) for a unique "coupled-cavity" magnetron.

The following issue appeared in June 1962, with a semiconductor on the cover: a very-high-frequency (VHF) silicon multiplier varactor capable of 100 W at 100 MHz on the cover. The model CK303 diffused-junction diode was developed by Raytheon's Semiconductor Div. (Lowell, MA) for solid-state VHF/ultra-high-frequency (UHF) transmitters. In his editorial that issue, Manfred Meisels celebrated the 25th anniversary of the klystron. By August 19,

1. The first cover story in MicroWaves magazine featured a tunable coaxial magnetron developed by SFD Laboratories, a subsidiary of Varian Associates.

ARRA, Inc.

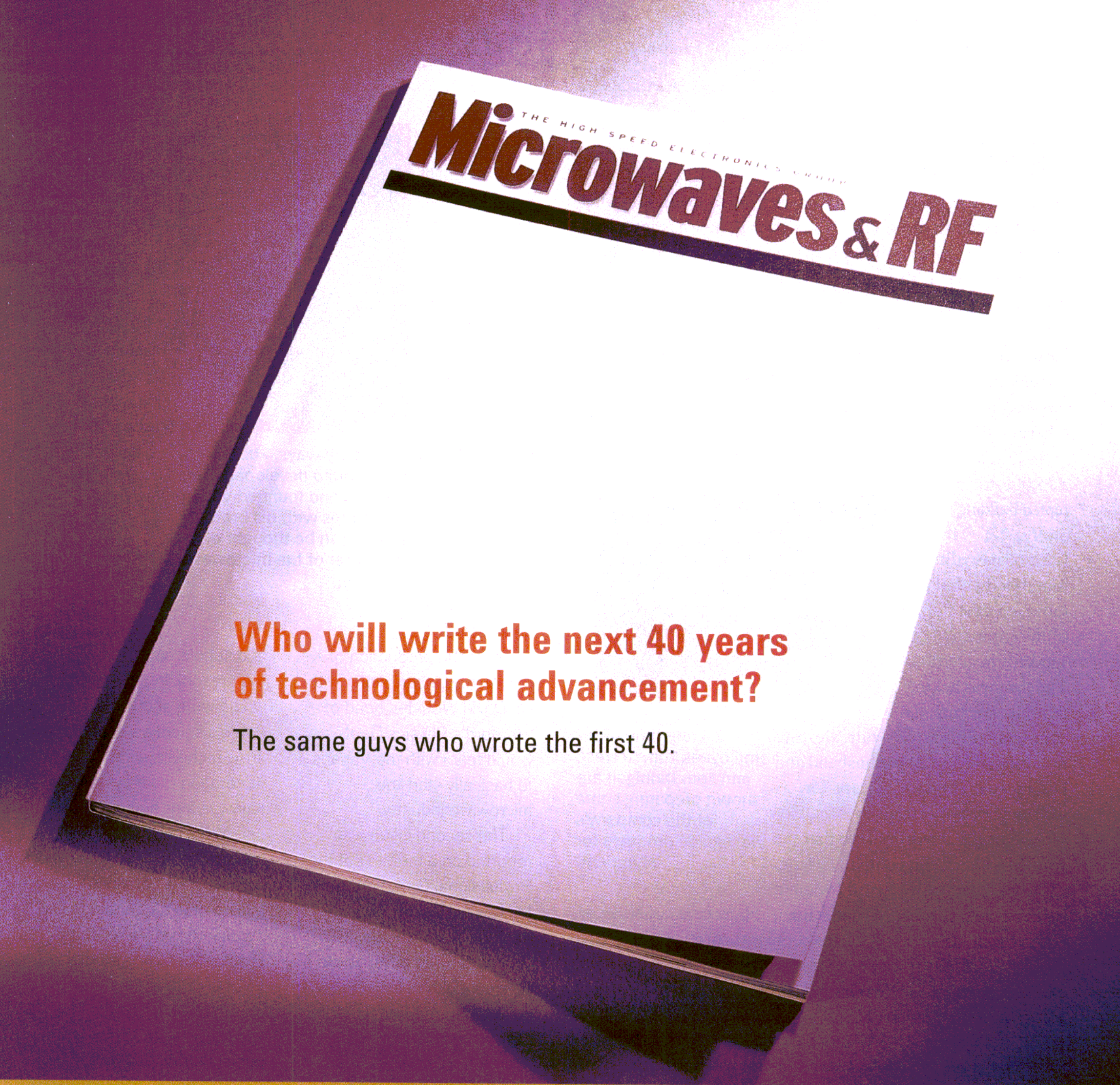
One of the first advertisers in the first issue of *Microwaves & RF* was ARRA, Inc. (Bay Shore, NY) which, after 44 years in business, is still a loyal advertiser (see inside back cover). The small but thriving company features a strong family atmosphere, with approximately 100 employees devoted to the design and production of literally tens of thousands of different custom coaxial and waveguide passive RF components, such as continuously variable attenuators, phase shifters, power dividers/combiners, directional couplers, waveguide attenuators, assemblies, switches, and terminations. The range of applications for these products includes satellites, earth stations, cellular/personal-communications-services(PCS) networks, radar systems, and medical systems.

ARRA was started in 1957 by Harold B. Isaacson. As with many older microwave companies, ARRA was started on a "wing and a prayer" without external financing. By giving his word to pay the monthly rent, and with a handshake between himself and the landlord, Harold secured a room in Westbury, NY to house the fledgling company. ARRA's initial growth was due to Harold's ingenuity, his talent as an electrical engineer, his imagination, and his willingness to work around the clock. When asked of her early involvement with ARRA, Harold's wife Florence notes that she was involved from the very beginning of the company: "I remember taking dictation for that first letter to Westinghouse, which helped us get our first customer, Westinghouse."

Harold's ability to achieve the highest quality in a timely fashion formed the foundation for the growth of ARRA. He never accepted the word "impossible" or that something could not be done. By providing the drive and inspiration for his employees, Harold was able to expand the company from its initial small space to the landlord's adjoining two-story building.

1. ARRA, Inc. (Bay Shore, NY) was founded by Harold Isaacson and is run today by Harold's widow, Florence (right) and son Robert (left).

Harold's son, Robert, now runs the day-to-day operations of the company **(Fig.1)**. Even though his father was busy with a startup business, Robert can remember quality time spent with his father. When Robert was six years old, Harold would take Robert and the family dog to the company on weekends and let the inquisitive boy explore his surroundings. One weekend in particular remains strong in Robert's memory, when he sat next to his father, who was working on ARRA products and Robert was working on his model airplane. The model was similar to the one that his father had piloted for


THE HIGH SPEED ELECTRONICS GROUP
Microwaves & RF
Who will write the next 40 years of technological advancement?
The same guys who wrote the first 40.

ARRA, Inc.

the US Army Air Force. When Robert ran into snags, his father helped him finish his model. "Even though he was there to do his own work, he was able to help me with that plane, to make it the best possible plane that we could put together," recalled Robert.

That philosophy—to do the best possible job—guided the growth of ARRA over the years and even after Harold's untimely death due to Hodgkin's Disease in April 1968. Robert Isaacson was only 11 years old when his father died, but he had already inherited the older Isaacson's values and ethics.

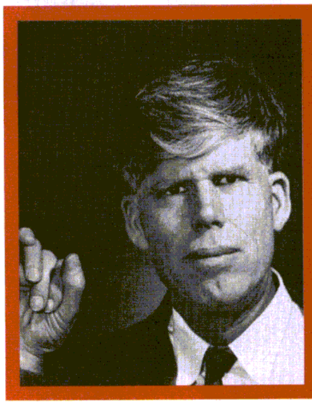
In January 1968, with high hopes, ARRA was relocated to a 25,000-square-foot rented building in Bay Shore, NY. Harold Isaacson passed away four months after the move, and the future of the company was suddenly in question. The firm was having trouble meeting its financial obligations but, despite mourning the loss of her husband and having two children to care for, as well as a home mortgage to meet, Florence Isaacson never doubted that she wanted to keep the company going. "It was a labor of love, and I wanted to keep going what Harold had started," Florence says. She devoted herself full-time to solving the company's problems. The first thing she did was to call everyone who was owed money and ensure them that they would be paid as soon as the company solved its cash-flow problems.

2. Long-time ARRA employees Tom Cortese and Tom Dinnigan are shown preparing some of the company's waveguide products for shipment.

Fortunately, each creditor accepted her word, and even thanked her for calling. Many noted that when someone owes money, they are usually difficult to reach, but it is unusual to hear from someone who owes money and to be reassured by them that the debts would be paid. Florence also petitioned the town of Bay Shore to change the name of the street from Ekorb Court (which was "broke" backwards and a developer's idea of humor) to Harold Court. In 1979, Florence ignored advice from lawyers, accountants, and family members and purchased the building.

Florence and Robert attribute much credit for the company's longevity and success over the years to Chief Engineer Ernie Miller, who joined the company as a technician shortly after Harold's death. Miller has been instrumental in designing many of the company's unique coaxial and waveguide components. He is known for his determination and unwillingness to give up or admit that something cannot be done. He is also known for being unable to say "no" to Florence!

1937, scientist Russell Varian, urged on by his energetic brother Sigurd, developed the first klystron with an operating frequency of 2.3 GHz. While at Stanford University, Russell had studied under Professor William Hansen who had been developing resonant structures for the production of X-radiation. Hansen, along with Dr. David Webster, head of Stanford's Physics Dept., would team with the Varians to basically start the microwave industry



2. In many ways, Russell Varian, who developed the klystron and founded Varian Associates with his brother Sigurd, can be thought of as the father of the microwave industry.

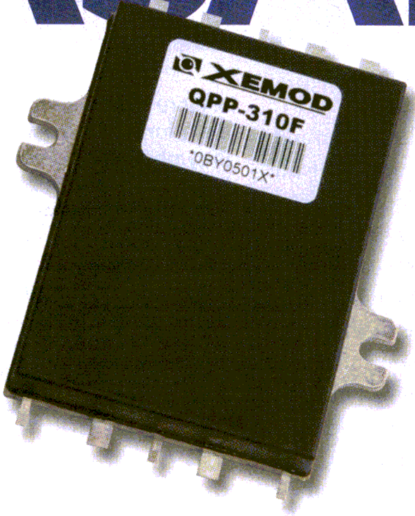
The second issue also reported on a meeting of the Professional Group on Microwave Theory & Techniques held in Boulder, CO, which featured advances in semiconductors including a 6-GHz paramp from General Motors Defense Systems (Santa Barbara, CA). The meeting also featured a report on a superconducting delay line from Martin-Marietta. The 1200-ft. line exhibited only slight transmission loss at 1 GHz.

One of the more useful articles to appear in that issue was authored by Leo Young of the Stanford Research Institute (Menlo Park, CA), who offered 20 useful Smith chart formulas, including calculations for maximum and minimum conductance and susceptance for a particular reflection coefficient. In the same issue, Owen Falor of Raytheon's Spencer Laboratory (Burlington, MA) explained how to select microwave tubes for reliability.

With that June issue, *MicroWaves* had become a regular monthly magazine, with monthly issues and supplements through the present. In July, Meisels would write about the Air Force's selection of phase-array technology for next-generation radar systems in a news story, and cover the use of optical masers for microwave applications in his editorial. The cover featured a low-noise tunnel-diode amplifier from Micro State Electronics Corp. (Murray Hill, NJ). Based on the company's gallium antimonide tunnel diode, the amplifier achieved a 3.5-dB noise figure at L-band.

In August 1962, a report on the 1962 WESCON show highlighted new tube and parametric amplifier (paramp) developments, but also included a call for papers for the 1963 Professional Group on Microwave Theory & Techniques, to be held May 20-22, 1963 in Santa Monica, CA. The editorial that issue focused on the Telstar communications satellite and how it presented an example of an application other than military for

3G ASAP.



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ARRA, Inc.

Florence overcame her lack of technical expertise with help from Miller, who possesses more than 33 years of experience and knowledge of ARRA components. Tom Cortese joined the company in 1971, and is now Quality Control Manager **(Fig. 2)**. The company's first salesman, Paul Bleifer, was selling ARRA products for almost two decades until his death in 1977 at the age of 38. The company boasts many loyal employees, with an average time at ARRA of 10.5 years, contributing to the firm's stability, low turnover rate, and continued success.

Florence remembers many times when the dedication and loyalty of her people helped to rescue an otherwise difficult situation. For example, one year before his death, ARRA had qualified Harold's existing design of a 100-dB variable attenuator, but a contract was awarded to a competitor. Several years later the customer, Teledyne, suffered a reliability problem and asked ARRA to bid again. Although this time, ARRA would have to submit its design technique using the competitor's package (since that form factor had been designed into the system). Although this represented a tremendous challenge, "Florence insisted that we could do it," recalls Miller, who was a technician at the time. With Florence's motivation and the perseverance of Miller and the ARRA team, the goal was met and ARRA was awarded several major contracts lasting over a decade. The company is still supplying units for the Teledyne system.

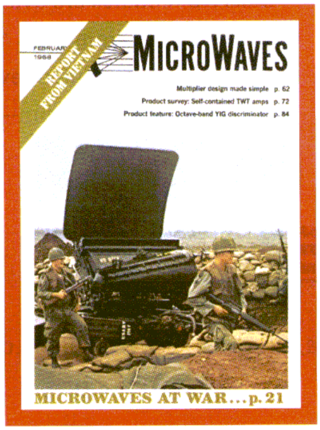
3. Florence Isaacson's devotion to her husband is symbolized by keeping her late husband's blue 1967 Cadillac because "his hands had been on the steering wheel." The car features a custom cruise control installed by Ernie Miller using a piece of WR229 waveguide as a mount.

At another time, a Marconi order required a special effort. "I gave names to our projects, such as the Duke and the Cyclone, so I would remember them," Florence says. "The Duke was a miniature attenuation trimmer for the Inmarsat satellite. A box of resistors that we needed to complete the job had spilled out on the floor, and it wasn't practical to recover them," Florence recalls. "So I hired a limousine driver to go to New Jersey to pick up another package of resistors from our supplier. We managed to finish the Duke order by the end of the day and meet our delivery date just prior to our Christmas closing," she adds.

"Running ARRA has been good therapy for me," says Florence. "Harold was my hero and the love of my life. We wrote music together—he wrote the music and I wrote the words. In running the company, I feel that we're still writing music together **(Fig.3)**."

the microwave industry, and how the industry would benefit from the proper balance of commercial and military markets, rather than focusing on just military business. On the cover, a "centipede" TWT from Sylvania used a slow-wave interaction structure to develop 1.8-MW output power at X-band (8.3 to 10 GHz). An advertisement from Polarad featured a story on the company's mobile calibration laboratory, housed in an air-conditioned van that would travel to different microwave facilities to perform calibration on microwave instruments.

In the design section, Robert O'Nan of Sandia Corp. (Albuquerque, NM) described the design of super-regenerative microwave receivers (Rxs) and their place in radar systems. Floyd Johnson of Varian Associates explored a procedure for the measurement of very small insertion losses in waveguide, and Harvel Dawirs of the Antenna Laboratory of Ohio State University (Columbus, OH) described how to design impedance-matching transformers using the Smith chart.



3. The conflict in Vietnam became a proving ground for a number of microwave systems, examined in a special report.

The opening advertisement in September, from Varian Associates, was a commemoration of the 25th anniversary of the klystron, with a striking photograph of Russell Varian (1898-1959) by Ansel Adams **(Fig. 2)**. On the cover, a line of frequency-selective limiters from Watkins-Johnson Co. (Palo Alto, CA) were being promoted as RF-interference (RFI) killers. The C-band limiters, which were made of lithium-ferrite material, could be used from 4.5 to 6.5 GHz. In the design section, Ed Aslan of the FXR Division of Amphenol-Borg Corp. (Woodside, NY) presented guidelines for selecting a swept-signal source.

Through the remainder of that first year, Meisels brought up the theme of millimeter-wave technology,


You'll always get the highest level of reliability with our customized RF power transistors.
It's easy to see why GHz is part of so many avionics, radar and wireless applications, especially compared to ordinary off-the-shelf alternatives. Our customized RF power transistors, fully optimized for your specific project, eliminate endless tuning and rework that can cause productivity to take a nosedive. Plus, ready as we are to help your latest CW applications, we're also committed to providing unending support for pulsed applications. Ready to see more? You'll find us at www.ghz.com or at 408-986-8031, ext. 350. Give us a buzz.
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about the growing number of products for millimeter-wave frequencies, but a lack of applications. A product survey in October by New Products Editor Alan Serchuk offered a roundup of available millimeter-wave tubes, while William Blanchard of Bendix Corp. (Baltimore, MD) offered a nomogram to speed the selection of diffused-junction varactor diodes for multiplier circuits. In November, the theme of new millimeter-wave tubes continued in a special report on tube research, including BWOs with 150-W CW power at 55 GHz from Hughes Research Laboratories (Malibu, CA). An advertisement from Microphase Corp. (Greenwich, CT) presented coaxial filters, couplers, video detectors, and hybrid splitters for use through 10 GHz.

That first year concluded with a spectrum analyzer from General Electric's Light Military Electronics Dept. (Utica, NY) on the cover of the December issue. The instrument operated from 45 MHz to 11 GHz with −40-dBm sensitivity, 70-dB total dynamic range, and ±1-dB accuracy. Editor Meisels wrote a news story on the development race for GaAs laser-diode devices, including such companies as General Electric and International Business Machines (IBM), while Paul Jensen of Hughes Aircraft Co. (Fullerton, CA) contributed an article on a procedure for designing Cassegrain antennas, and Richard Moore of the University of Kansas (Lawrence, KS) described the acoustic simulation of radar signal returns for achieving an accurate ultrasonic model of a microwave system.

The cause of millimeter waves was strengthened in 1963 with a January cover story from Westinghouse Electric Corp. (Baltimore, MD) on the model WD4328 tunable varactor-based Ka-band multiplier, which provided coverage from 32 to 38 GHz. A news story detailed plasma tubes as potential alternatives to vacuum tubes, with work being done at Stanford University, Microwave Associates, and Elcon Laboratory (Cambridge, MA). Dick Sparks of Emertron (Silver Spring, MD) reported on microwave phase measurements, and provided a review of the various methods and commercial solutions available for making phase measurements, while Koryu Ishii of Marquette University explained a method for making low-noise measurements with high-noise test equipment, using a novel relative noise-power-measurement technique.

Of significance to future oscilloscope development, the February cover featured a fast coaxial deflection cathode-ray tube (CRT) from Tektronix, Inc. (Beaverton, OR). With a 3-GHz bandwith and 0.13-ns rise time, the tube became the basis for the company's model 519 oscilloscope. That same issue included an article authored by Cliff Moulton of Tektronix (Beaverton, OR) which explained the principles of a sampling oscilloscope. The following month, Murray Feigenbaum of Polarad Electronics Corp. contributed an introduction to spectrum analyzers, explaining how these sensitive Rxs work and the definitions of key operating parameters. An accompanying survey of spectrum analyzers featured products from Polarad, the Panoramic line from Singer Metrics (Bridgeport, CT), and Lavoie.

4. This cover depicted the trials and tribulations of starting a microwave company. An accompanying special report questioned numerous startup companies on the difficulties and triumphs of their first year in business.

In May, the magazine explored the world of microwave transistors, including a silicon (Si) device from RCA Semiconductor (Somerville, NJ) with 5 W at 500 MHz and a germanium (Ge) device from Bell Telephone Labs (Murray Hill, NJ) with 1 W at 1 GHz. Research sponsored by the US Army Electronic Research and Development Lab (Fort Monmouth, NJ) would soon be directing the development of a device for 10 W at 500 MHz. At the same time, Fairchild Semiconductor (Mountain View, CA) announced their model 0002 transistor, capable of 1-W output power and 13-dB gain at 500 MHz. The transistor consists of four devices on a single wafer interconnected within a metal TO-5 housing. Other manufacturers in the race for 1-GHz transistors included Motorola (Phoenix, AZ) and Texas Instruments (Dallas, TX). Arnold Frisch and Morris Engelson of Pentronix Associates (Brooklyn, NY) explored five useful measurements that could be performed with a spectrum analyzer, including the analysis of pulsed signals and the measurement of noise figure. This was the first of many articles that Engelson, who would later join Tektronix, would contribute on spectrum analysis.

The remainder of that year included a news report on ultrasonic structures for microwave use, including a YIG rod terminated with coaxial lines capable of coupling in and out signals from 5 to 500 MHz developed by researchers at Bell Telephone Labs; an editorial announcing the first International Microwave Symposium in 1964, in New York City; an article on the application of harmonic generator sources for producing higher-frequency signals by Marion Hines of the Solid State Circuits Div. of Microwave Associates (Burlington, MA); new high-power tubes from Varian and Litton; a solid-state C-band klystron from Fairchild Semiconductor (Mountain View, CA) with single-screw tuning from 5.4 to 5.9 GHz and 10-mW output power; and the introduction of a new magazine department called Laser

Technology, recognizing the relationship and importance of laser technology to the microwave industry.

The first issue of 1964 featured the new Laser Technology section, which would appear on a regular basis within *MicroWaves* for many years. The first installment featured a 240,000-J laser pump from Kemlite Labs (Chicago, IL). The tube had rise time of 0.3 ms; the 240,000 J was the limit of the capacitor banks. The section also contained a table of laser frequencies, an article by Richard Daly of TRG (Melville, NY) on measuring laser performance, and an advertisement from Manson Laboratories (Stamford, CT) on a 9-kW pulse modulator with 20-ns rise/fall time. The main cover story that issue was a 1-to-120-dB continuously variable attenuator using coaxial TM mode from Narda Microwave Corp. (Plainview, NY). The component used circular waveguide cutoff sections and symmetrical 3-dB hybrids to achieve 1-dB maximum insertion loss from 1 to 2 GHz. In the news, the Naval Research Laboratory (Washington, DC) pushed for the development of micro-miniature circuitry for VHF/UHF use while, in the design section, Jesse Taub and Harvey Hindin of AIL (Deer Park, NY) addressed the design of quasi-optical components for use at frequencies beyond 300 GHz.

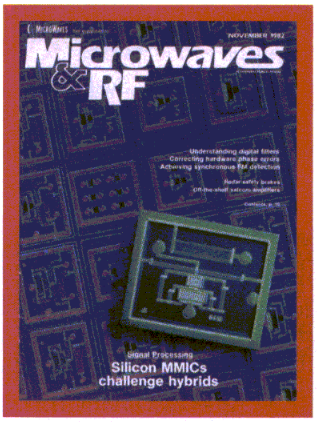
That year saw the continual emergence of solid-state devices, including a 2-GHz Si transistor from Texas Instruments, with 50-mW output power, 12-dB typical gain, and 6-dB typical noise figure at 1 GHz, housed in a TO-18 package. The May cover story offered a YIG-tuned preselector/preamplifier from Watkins-Johnson Co. (Palo Alto, CA), with models covering bands of 1 to 2 GHz, 2 to 4 GHz, 4 to 8 GHz, and 8 to 12 GHz with 80-dB image rejection, 30-MHz bandwidth, and 100-dB gain. That same issue provided a preview of the Professional Technical Group for Microwave Theory and Techniques (PTGMTT) meeting scheduled for May 19-21 at the International Hotel at Kennedy Airport (New York, NY). Additional cover stories featured the model HP 851A/8551A BWO-based spectrum analyzer with 2-GHz bandwidth from 10 MHz to 40 GHz, 60-dB dynamic range, and −100-dBm sensitivity from Hewlett-Packard Co., and a complete L-band front end weighing only 2 oz. from Western Microwave Laboratories (Santa Clara, CA), based on high-density solid-state circuitry and dielectric-loaded slow-wave structures.

A contributed article from Robert Adams of Sichak Associates (Nutley, NJ) on design opportunities in digital microwave communications, cited that a large share of long-haul communications, particularly for the military would be digital within 10 years. He also noted that digital information would place great demands on the modulation schemes used with microwave transmissions. Also, a news article in July highlighted the acceleration of research on bulk-effect microwave devices, such as hot-carrier and Gunn diodes (named after J.B. Gunn of IBM who discovered the effect of high-voltage fields across a thin slice of n-type GaAs can generate microwave power. This discovery was apparently an accident since Gunn had been plotting the resistance curves of thin material samples and the applied voltage exceeded the oscillation threshold of the material.)

In a ViewPoynt column that year, Peter Lacy of Wiltron (Mountain View, CA) explained the need for more automated equipment due to the growing sophistication of microwave systems while Bill Bourke, President of Narda Microwave Corp. (Plainview, NY), felt that the growing use of integrated circuits (ICs) would change the requirements for microwave test equipment.

In addition, a study by Hofstra University (Hempstead, NY) predicted that aviation would eventually become the largest commercial market for microwave technology, with annual expenditures of $130 million by 1970 for air-traffic-control and microwave landing systems. The report also predicted a gradual reduction in defense spending from about $51 billion in 1964 to approximately $40 billion by 1970. Statements by former president Dwight D. Eisenhower were cited as evidence for this downward spending trend.

Weinschel Engineering (Gaithersburg, MD) kicked off 1965 with a January cover story on an AGC-stabilized SWR meter capable of measuring VSWR as low as 1.06:1. A news story detailed the Molecular Electronics for Radar Applications (MERA) program sponsored by the Air Force with the intent of developing an all-solid-state, phase-array radar system, a 600-element array, with each element producing 1 W at X-band.



5. The name MicroWaves was changed to Microwaves & RF for the first time with the November 1982 issue. The cover story featured silicon MMICs from Avantek.

An editorial in February detailed the emergence of miniature coaxial components as a major market area for microwave companies, while the editorial in March would bemoan the lack of a "real" microwave show that was not part of the larger IEEE and WESCON shows. A news story in March would explore the potential growth for microwaves in industrial heating markets, such as processing hops for beer, drying textiles, and producing potato chips. Transistors continued their rise to prominence in an April news story that described the increasing power levels available from microwave transistors, now 1 W at 2 GHz from Texas Instruments and 20 W CW at 400 MHz from RCA. Meanwhile, an advertisement appeared from Fairchild Semiconductor on the model MT-1038, a microwave power transistor with typical efficiency of 50 percent that was capable of 1-W output power at 1 GHz.

In the May ViewPoynt column, Harold Isaacson, founder of ARRA, detailed the changing marketplace in the microwave industry and how there were really two types of competitors: those who made the types of products that your company makes, and the system houses, who must decide whether it makes more sense to purchase a component or to build it themselves. Issacson noted that it was important for microwave companies to make their parts with as much quality and as inexpensively as possible in order to make the decision by the system house one to buy the components from a microwave supplier. Paul Meyerer of Siemens wrote about a new approach to permanent magnet focusing that supported creation of a low-noise magnetic field with much less weight than ellipsoid magnets and that led to the creation of much smaller TWTs.

In August, *MicroWaves* switched to a smaller trim size (8.25 × 11.25 in.) [20.96 × 28.58 cm] and added an antenna-like symbol was added to the left of the logo on the front cover. The news that month covered the gradual shift of millimeter-wave systems from tubes to solid-state devices, while designers Eugene Katz of Grumman Aircraft Engineering (Bethpage, NY) and Heinz Schreiber of Republic Aviation Corp. (Farmingdale, NY) provided design equations for the development of microwave-phase discriminators.

The September cover story unveiled a fundamental transistor oscillator from Fairchild Semiconductor capable of 200-mW output power at 1.7 GHz without frequency multiplication while the October cover story highlighted YIG technology, with a filter from the Advanced Products Division of Loral Electronic Systems (Bronx, NY), capable of tuning from 1 to 10 GHz with 3-dB insertion loss and at least 50-dB rejection of out-of-band signals. The October news section offered a new 7-mm precision connector specified by the Subcommittee on Precision Coaxial Connectors of the IEEE's Group on Instrumentation and Measurements, capable of low-VSWR operation to 18 GHz. The story also reported plans for a 3.5-mm connector.

In the October ViewPoynt section, Bill Jarvis, President of Wiltron Co. (Palo Alto, CA), discussed how the Vietnam situation was affecting his company, with many inquiries about growth and expanded production capabilities and how there was growing interest in his company's capabilities for producing military-grade test equipment.

In 1966, NASA's projections for deep-space communications required higher-power microwave sources, such as 10 kW CW power in S- and X-bands. Cover stories included the model MA-2016 a miniature UHF TWT from Microwave Associates (Burlington, MA) with 5-W output power from 200 to 400 MHz and weighing only 5.5 lbs.; a pair of Ge transistors with 5.5-dB noise figure at 3 GHz and an $82.50 price tag, usable to 4 GHz from Texas Instruments; and an X-band sampling scope from HP, with scope displays and time-domain reflectometry possible through 12.4 GHz.

In June 1966, the magazine's first publisher, Bob Ahrensoff, departed in favor of John Weber, who shared publisher's responsibilities with Hayden company president Jim Mulholland Jr. In July of that year, the Depart-

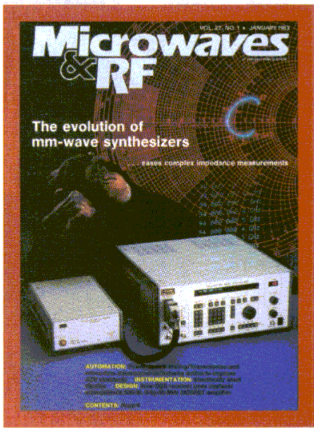
ment of Defense (DoD) launched MIL-STD-461/462/463, a unified tri-service electromagnetic-compatibility (EMC) standard meant to supercede 13 separate documents that were used as EMC standards. The new standard covered conducted emissions, radiated emissions, conducted susceptibility and radiated susceptibility.

The August issue carried news on the world's largest microwave system, at Stanford University, the linear accelerator was two miles long and powered by 240 24-MW S-band klystrons, generating a total of 5760 MW in 2.5-μs pulses at 2856 MHz. In September, Boonton Electronics Corp. (Parsippany, NJ) introduced their model 41A microwattmeter, which featured a 70-dB dynamic range from −60 to +10 dBm over a frequency range from 1 MHz to 6 GHz. The Business and Defense Services Administration of the Department of Commerce reported that shipments of key microwave components reached $258 million in 1965, which was up from $152 million in 1964. Microwave tube shipments increased from 229,000 to 290,000 units, although the dollar volume only increased from $104 to $113 million.

In October, a survey of 43 electronic firms conducted by editor Meisels revealed that the average electronic salesman earned $12,898 per year and brought in $603,871 of business each year. The average cost was 11.3 cents to sell a dollar's worth of equipment, and $48.70 was spent on average for each sales call.

In other news that year, one story featured the world's largest radio telescopes, a 500-ft. dish for radio astronomy, being built by the Cambridge Radio Observatory Committee (CAMROC). The dish would have a frequency range of 0.3 to 6.0 GHz. CAMROC includes scientists and engineers from Harvard, the Smithsonian Astrophysical Observatory, and MIT Lincoln Labs. A story by News Editor J.B. Brinton proclaimed that with solid-state devices making steady advances, tubes would need a good market in 10 years, such as in microwave-oven-equipped kitchens. At the time of the story, The Tappan Co. (Mansfield, OH) was the only producer of home microwave ovens, with a magnetron in each microwave oven.

News in 1967 included a competition between RCA's Missile and Surface Radar Division (Moorestown, NJ) and Sedco Systems (Farmingdale, NY) for the retrofit of the Atlantic Range Instrumentation Ships (ARIS) shipboard monopulse radar system to a phase-array configuration. The Sedco approach is based on the use of waveguide transmission lines while the RCA approach employs coaxial transmission lines but with more phase shifters. That June, a successful Microwave Exposition/67 was held at the New York Coliseum. Donald Cazzens of MITRE Corp. (Bedford, MA) offered a nomogram for determining the safe distance from high-power microwave sources. WESCON 67 was held that year in San Francisco, CA (August 22-25). Also in the news, Limited Space Charge Accumulation (LSA) diodes showed promise for X-band phased-array radar, with a shift from waveguide to stripline transmission lines, according to papers at a Cornell University conference. And women started appearing in advertising, including a long-legged blonde woman holding a poster for a plug-in VHF-UHF power oscillator from Microdot (Pasadena, CA).



6. A chimpanzee graced the January 1983 cover to point out the evolution of millimeter-wave sweep generators from the Millimeter-Wave Products Division of Hughes Aircraft Co. (Torrance, CA). The sweepers operate through 110 GHz.

In a ViewPoynt column, the question "What is the biggest problem facing the microwave industry today," was posed to key executives attending the Wescon 67 show. Comments from John Young, General Manager of the Microwave Division of Hewlett-Packard Co., who felt that the training and education were needed by engineers to fully exploit changing technology. Neil Blair, President of Amphenol, felt that it was the industry was still relying on customer business, and lacked large-volume applications. He points to the astronomical cost of a television set if it had been built by the microwave industry. And William Bourke, President of Narda Microwave Corp., pointed to the critical shortage of engineers as the main problem.

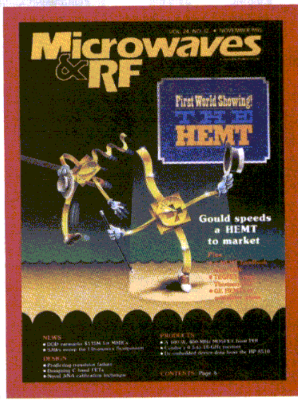
Finally that year, the Air Transport Association of America issued a shopping list of requirements for a new collision-avoidance system. The four preferred frequencies for use were at 1575, 1580, 1585, and 1590 MHz. The ATA proposed the entire 1540-to-1660-MHz band to make room for the possible addition of a communications satellite-relay system within the band.

In 1968, the February issue **(Fig. 3)** featured a dramatic cover of the war/conflict in Vietnam, with a special report on microwave electronics in Vietnam based on a visit there by News Editor Thomas Kilpatrick. Opening with a memo from General William Westmoreland on the reliability of microwave-communications systems in the war effort, the story explained that this was not a conventional war, and that equipment would be used in hostile, jungle environments. The story detailed several systems, including AN/PPS-6 manpack counter-intrusion radar system from General Instrument, and the MPQ-4 counter-mortar radar from

General Electric, used to monitor activity at the demilitarized zone (DMZ). The MPQ-4 system could only scan in 25-deg. segments, and must be mechanically shifted to cover larger areas.

Stories that year also covered an international military project called Mallard that was in its $100 million study phase, with a target date for getting hardware in the field between 1975 and 1977. The project included US, England, Canada, and Australia and administrative offices were in Fort Monmouth, NJ. Another story carried on a plea by the FAA for a low-cost collision-avoidance system for small aircraft, a potential $100 million market.

On the first cover that year, a watch-spring attenuator from General Microwave (Farmingdale, NY) operated from 50 MHz to 8 GHz. The "watch spring" was a tiny spiral used to form a lowpass filter in a bias line. The component achieved as much as 40-dB attenuation across the operating frequency range. Also on the cover that year, the model 2600 spectrum analyzer from Polarad Electronic Instrument used backward-wave oscillator (BWO) and cavity oscillators to tune from 10 MHz to 90 GHz. The IEEE 1968 show was held March 18-21 that year in New York City. The MICROWAVE EXPOSITION/68 was held June 4-6 in San Francisco, CA. In April, the magazine provided results from a survey of microwave engineers. One-half of those surveyed had BSEE degrees, while one-quarter had Master's level degrees. The typical engineer was less than 40 years old and had stayed many years at one job. About 43 percent of those surveyed had spent time in military service.



7. The "dancing HEMT" cover of November 1985 featured the first commercial GaAs HEMT device, from the Microwave Products Division of Gould, Inc. (San Jose, CA)

In 1969, January featured one of the more innovative covers ever produced by *MicroWaves*—a cartoon of two engineers attempting to start their own company **(Fig. 4).** The cover was part of a special survey of new microwave companies, why they were started, how difficult was it to get financing, and other key points. The survey included Olektron Corp. (Dudley, MA), Wavecom (Chatsworth, CA), Zeta Laboratories (Mountain View, CA), Microwave Semiconductor (Somerset, NJ), Electromagnetic Sciences, Inc. (Atlanta, GA), California Microwave (Sunnyvale, CA), and Comtech Laboratories (Plainview, NY).

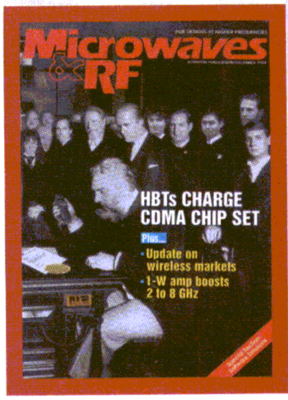
The news story in that issue highlighted a presidential Task Force on Communications Policy panel to assess the state of communications, spurred on by a trail-breaking application from Microwave Communications, Inc. (MCI) of Washington, DC to provide special common-carrier service to businesses with offices in St. Louis, MO and Chicago, IL for less than the cost of service offered by AT&T. The task force felt that the entry of MCI and other common carriers into the market could spur technology developments.

On the February cover, a yttrium-iron-garnet (YIG) filter from Watkins-Johnson Co. offered electrical tuning from 1 to 18 GHz. This was the first YIG filter with that type of bandwidth in a single package, and opened the door for the development of wideband test equipment, including spectrum analyzers. As a followup, the March cover featured a YIG-tuned spectrum analyzer (based on the WJ YIG) from NYTEK Electronics (Sunnyvale, CA) with coverage from 0.7 to 18 GHz. The June cover featured a low-cost version of a precision 7-mm connector from Amphenol RF Division (Danbury, CT), selling for only $7 each in 1000 quantities. That year, the IEEE Convention was held on March 24-27 in the New York Coliseum.

The first editor of *MicroWaves,* Manfred Meisels, ended his near-decade-long run at the beginning of 1970, and was replaced by Elmer Ebersol. Howard Bierman joined the staff that year as the new publisher, and would go on to guide the growth of the magazine for the next 10 years. Bierman was former editor of *Electronic Design* magazine and a graduate of City College of New York. Before year's end, editor Ebersol would leave the magazine and Bierman would become Publisher/Editor.

In the news that year, a story described the Environmental Science Services Administration's use of pulsed Doppler radar for monitoring and analyzing severe storms and other turbulent weather conditions. The news also contained information about a microwave oven developed by Litton Industries for maritime use. With 600-W microwave power at 2450 MHz. A special report detailed an Automatic Microwave Collision Avoidance Radar (AMCAR) system developed by Bentley Associates (Chelmsford, MA). The X-band Doppler radar system detected objects directly in the path of a vehicle and actuated a mechanism that depressed the brakes and pulled back on the accelerator. The July cover featured Fairchild's X-band oscillator, a Gunn device selling for only $5 in 100,000 quantities. It offered 60-mW CW output power from 8.0 to 12.4 GHz. The November cover showed Hewlett-Packard's model HP 8555A spectrum analyzer, with a frequency range of 10 MHz to 18 GHz and an amplitude range of −130 to +30 dBm. The analyzer's RF section had a hot-carrier diode mixer on a sapphire substrate.

In 1971, RCA Laboratories (Princeton, NJ) announced the development of a GaAs amplifier capable of operating from 3 to 20 GHz with 0.2-mW output power. Communication Transistor Corp. (San Carlos, CA) introduced a VHF transistor with 70-W CW output power, from 130 to 200 MHz, a +12-VDC device. Scientists at Bell Telephone Laboratories discovered the Barrier Injection Transit Time (BARITT) diode fabricated from a thin slice of Si between two Schottky barrier contacts. The device yielded as much as 57-mW power at 4.9 GHz with 2.3-percent efficiency.



8. This classic remake of the Alexander Graham Bell photograph featured personnel from RF Microdevices and QUALCOMM and was symbolic of the growing reliance of the microwave industry on wireless markets.

In 1972, Avantek (Santa Clara, CA) developed a fundamental transistor oscillator for use from 4 to 8 GHz, and, without multiplying, the YIG-based source used Si bipolar active devices. Microwave Semiconductor Corp. (Somerset, NJ) unleashed a new transistor structure called the MICROGRID, capable of 5-W CW output power at 4 GHz. Westinghouse announced an L-band transistor amplifier with 1-kW output power at 1250 MHz for 1-ms pulses. Four 25-W transistors were combined to form a 100-W module, then 12 100-W modules were combined to achieve the 1-kW output power. The project was funded in part by the US Air Force Rome Air Development Center (Rome, NY).

In 1973, an impedance-matched transistor from Power Hybrids (Torrance, CA) delivered 20-W CW power at 2 GHz, an negative-positive-negative (NPN) planar transistor, while Avantek (Santa Clara, CA) developed a fundamental transistor oscillator for use from 6 to 12 GHz with 5-mW output power. In October that year, Stacy V. Bearse joined *MicroWaves* as Associate Editor.

In 1974, the February issue featured news from MIT Lincoln Laboratory (Lexington, MA) on surface-wave pulse-compression filters capable of achieving a 500-MHz bandwidth at 1 GHz. The new type of filter used the reflection of surface acoustic waves (SAWs) to achieve large time-bandwidth product pulse compression. The cover story in June focused on improving circuit design through computer timesharing, with an article by Nick Kuhn of HP on how to make circuit design a true science by applying graphical techniques with computer analysis.

In 1975, an economic forecast article series on electronic-warfare markets predicted a $2.17 billion market for electronic countermeasures (ECM). The March cover story, by Algie Lance and Wendell Seal of TRW (Redondo Beach, CA), addressed a new way to measure noise that offered simplicity and accuracy over conventional Y-factor measurements.

In 1976, the model 451 frequency counter from EIP Microwave (Santa Clara, CA) made news with its capability of measuring the frequency of pulsed signals as narrow

as 100 ns from 925 MHz to 18 GHz. A special report in the December issue pointed to increased interest on the part of the military for integrated components with multiple functions, known then as supercomponents. Ash Gorwara, President of Planar Microwave in Sunnyvale, CA, noted that the mean-time before failure (MTBF) of the supercomponents could be as much as five times better than that of the individual components taken as a group, due, in turn, to the lack of connector failures, usually due to improper torquing of the connectors.

In February 1977, Stacy Bearse was named Editor-In-Chief. In his first editorial with the new title, he wrote about gigabit logic and its rightful place in a microwave magazine and these devices as important building-block components for future high-speed communications systems. Bearse would eventually become Publisher as part of an almost 16-year career with the magazine, bringing onboard and training future Editors Barry Manz, Mike Kachmar, and Jack Browne.

A news story in June covered a new superconducting device, a Superconducting Quantum Interference Device (SQUID) that was being considered by the National Bureau of Standards as a new RF attenuation standard, while a special report on acousto-optics described the basics of Bragg cell operation and explored the use of this relatively new technology in ESM receiver design. And monolithic devices began to be reported at the International Electron Devices Meeting.

In 1978, a survey of microwave engineers conducted by *MicroWaves* found the average microwave engineer to be male, age 30 to 34 years old, and earning $20,000 to $25,000 annually. The typical educational level was BSEE and the typical position or title was project engineer or senior engineer. Most respondents enjoyed a 7 percent or higher annual salary increase. Of the 314 respondents to the survey, only one was a woman. That same year, Ron Hirsch, president and founder or RHG Electronics Laboratory (Deer Pak, NY) offered an article called "Plain talk on log amps" that demystified the use of intermediate-frequency (IF) logarithmic amplifiers. In the August Calculator Corner, a program offered by Don Sanders of GTE Laboratories (Waltham, MA), transition frequency of a transistor from its S-parameter data was computed. That November, the HP 8566A spectrum analyzer was introduced by HP. With an impressive $47,500 price tag, the analyzer was the most powerful spectrum analyzer available on the market, with a frequency range of 100 Hz to 22 GHz, 10-Hz minimum resolution bandwidth, and a minimum measurable signal level of −137 dBm.

Computers began to make an impact in 1979. A special report discussed the impact of digital computers on test-and-measurement techniques. How the computer was being used to automate measurement routines and speed productivity has discussed. That year, the model 560 scalar network analyzer (SNA) was introduced by Wiltron Co. (Mountain View, CA). It had 10-MHz-to-18-GHz coverage and 70-dB dynamic range for less than $10,000. Tektronix (Beaverton, OR) introduced its model 492 portable spectrum analyzer with coverage from 50 kHz to 21 GHz and optional coverage to 220 GHz with external harmonic mixers. And the MTT-S 1979 International Microwave Symposium was held in Orlando, FL (April 30 to May 2). Approximately 1000 people would attend the conference and exhibition that year.

In 1980, a report by Frank Moncrief, Western Editor, detailed Japan's efforts to advance communications technology. The report explained how Sony hoped to grab a share of the direct-television market for satellites using a small 90-cm-diameter disk and a two-stage GaAs preamplifier at bands of 12 and 14 GHz. The cover featured Dr. Koji Kobayashi, Chairman of the Board and CEO of NEC. In February of that year, Walter ("Hap") Bojsza joined the staff of *MicroWaves* as Associate Editor. Hewlett-Packard Co. introduced the HP 8350A sweeper with plug-in modules for frequency coverage to 26.5 GHz. Narda advertised their model 7000A, a lightweight automatic microwave multimeter capable of measuring power, insertion loss, gain, VSWR, and generating signals with interchangeable RF heads for different frequency ranges. And the 1980 International Microwave Symposium was held that year in Washington, DC (May 26-30). Also, in 1980, Associate Editor Hap Bojsza assembled a masterful profile of Raytheon's maverick Bill Brown that explored Brown's theories on microwave power transmission from space.

The February 1981 cover story featured Comsat's plans to put a dish on every roof in the hopes of supporting a widespread market for direct-broadcast-satellite (DBS) services. Uplink frequencies occupied the 17.3-to-18.1-GHz band while downlink signals occupied the 12.1-to-12.7-GHz band. In the August issue, a special report heralded the coming of optical components and high-speed optical communications systems, and how microwave companies could play in this potentially large market. That year, the staff of *MicroWaves* would grow by two, with the addition of Associate Editors Jack Browne and Barry Manz.

MicroWaves underwent a dramatic transformation in November 1982, with an increase in circulation and a change in name to *Microwaves & RF.* The name change signified more dedicated coverage of lower-frequency issues from 10 MHz to 2 GHz. That November issue featured a cover story **(Fig. 5),** written by Craig Snapp of Avantek, on the company's Si monolithic-microwave-integrated-circuit (MMIC) technology, and amplifiers with flat gain past 2 GHz. The following issue would feature a masterful interview by Associate Editor Barry Manz with two of the pioneers of the microwave industry—Dean Watkins and Dick Johnson—founders of Watkins-Johnson Co.

In 1983, Hughes Aircraft Co. cleverly portrayed a chimpanzee on the January cover to highlight an evolutionary line of new millimeter-wave sweepers. **(Fig. 6).** That same year, Hewlett-Packard Co. introduced the 8902A measuring Rx capable of making power measurements down to −127 dBm at frequencies from 150 kHz to 1300 MHz. In July, the news section offered a story about a unique industry-university alliance between Raytheon Co. and the University of Massachusetts (Amherst, MA) where Raytheon-employed students could earn a master's degree in microwave engineering. The program, which began in 1980, continues to this day. That June, Carl Sagan spoke to the MTT-S awards banquet audience in Boston, MA. Later that year, Wiltron's Bill Oldfield introduces the K connector, for coaxial coverage to 45 GHz, and Avantek introduced a YIG oscillator with coverage from 26 to 40 GHz and 10-mW output power. And by the end of that year, Hewlett-Packard Co. would shake up the entire industry with the introduction of the

HP 8510A vector network analyzer (VNA). By the end of 1984, the company would make another big splash with its Modular Measurement System (MMS) line of customer-configurable modular instruments, a project that had been in development for more than 10 years.

In the decade that would follow, the microwave industry would begin to wean away from its dependence on military markets, and start to cultivate commercial business. But the transition was slow and painful for many companies, and a great deal of consolidation would take place in the latter half of the 1980s. For example, by 1986 Anzac Adams Russell had acquired RHG Electronics Laboratories (Deer Park, NY). Shortly thereafter, Anzac, in turn, was acquired by M/A-COM. During the 1990s, M/A-COM would be acquired by AMP, Inc. (Harrisburg, PA) and AMP, in turn, was acquired by Tyco Electronics.

In November 1985, Gould's Microwave Products Division (San Jose, CA) would introduce an alternative to the GaAs FET **(Fig. 7)**, in the form of a high electron-mobility transistor (HEMT). Offering lower noise and higher gain than equivalent-sized MESFETs, the HEMT would eventually make its mark on the industry, especially in low-noise, higher-frequency applications.

In January 1986, Hewlett-Packard Co. bought new hope to RF engineers planning to start their own company, with the introduction of the HP 8753A. This first RF vector analyzer, priced for the masses, brought 3-GHz coverage with performance specifications similar to its "big brother," the HP 8510A. In March that year, a "Technology Closeup" highlighted the current explosion in GaAs developments, in the form of analog and digital ICs.

After several years as Chief Editor, Barry Manz would leave the staff of *Microwaves & RF* during 1987 to start his own company, Manz Communications (Montville, NJ). Michael Kachmar, who had joined the staff years earlier as Copy Editor, would take the reins as Chief Editor at the end of 1987, a position he would hold until 1990. Along the way, the staff added Ron Schneiderman as News Editor and Victor Perrote as Associate Editor to handle the Design Features section. And beginning with the May 1990

Continued on page 202

The digital radio Rx revisited

LAST MONTH'S APPLICATION Notes column reported on an Analog Devices paper explaining the underlying concepts of a multichannel digital radio Rx. This month, that subject is further explored with another one of the company's reports. This one is on the design aspects of an IF-sampling digital Rx, "Designing a Super-Heterodyne Multi-Channel Digital Receiver."

This Rx has one RF front end rather than several; a single IF-sampling ADC rather than several; and a special filter bank that contains devices, such as digital decimating Rxs. The note details the subtle differences between a full super-heterodyne Rx and an IF sampling type.

Proceeding through each stage at a time, the note covers the factors involved in component selection. The LNA and band-select filter are similar to those of a single-channel Rx, but the mixer must be selected carefully. It must be a low loss, low noise figure type with high intercept points. This is because increasing input signal levels can gradually degrade the IM performance.

IF filtering is an important consideration in an IF-sampling Rx, since that device must prevent aliasing of unwanted signals by the ADC. The choices are the traditional SAW filter and the conventional LC filter. A problem with SAW filters is that multichannel types can exhibit higher insertion losses than the single-channel variety. Conventional LC filters can introduce phase distortion, but have better insertion-loss characteristics than SAWs.

IF amplifiers and the IF-sampling ADCs are key components of the design. For the amplifiers, IF gain blocks are the clear choice over optical amplifiers, which are too noisy and lack the spurious performance necessary for IF sampling. A gain block, however, can introduce harmonics, which must be filtered out to prevent interaction with ADC harmonics. Advances in semiconductor technology have led to much improved IF-sampling ADCs, but harmonic performance and two-tone IMD are factors that can impair Rx performance.

A number of possible Rx designs for various digital wireless systems are offered at the end of the note. The standards include CDMA, PHS/PACS, GSM, and even AMPS, which is still a factor in multimode radio designs. Similar to the earlier note, this one is included in the company's CD-ROM, "Advanced Signal Processing for Wireless."

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Stick to the basics for low-noise designs

ONE OF AN engineer's worst nightmares is when noise problems prevent the completion of a design and delay the introduction of a product. But according to an 11-page brochure from Washington Laboratories Ltd. entitled "The 10 Basic Steps to Successful EMC Design," many fundamental design mistakes are routinely made. The brochure states that "Most of the reasons for equipment failure during EMC testing can be traced to less than a dozen common, predictable design flaws. Most designers can improve their EMC performance by observing relatively uncomplicated design guidelines." That being said, Part One of the brochure explains the first five steps in avoiding the pitfalls that lead to noise problems.

Three areas contribute to most problems: circuit boards, cables, and enclosures. At the board level, it is imperative to control the flow of current to get control of the noise. The current generated by a noise source must be returned to the 0-VDC reference point of that source through the lowest impedance path possible.

The note claims that 80 percent of EMC problems involve a system's cables. Using shielded cables is mandatory, but the type of shield and how it is grounded can make a difference in EMC performance. For example, the pigtail ground should be avoided at high frequencies since it has inductance which can contribute considerable impedance to the ground path.

With reference to enclosures, the note points out that potential EMC problems must be addressed first at the circuit-board level and then at the enclosure. The point is that doing the job properly from the bottom up yields greater margin, better performance, and fewer delays in the qualification process.

The least-expensive method of noise control is the careful location of components to minimize coupling between high-frequency circuits, I/O, and the outside world. The application note is the first of two parts, both of which can be obtained by contacting the company.

Washington Laboratories Ltd., 7560 Lindbergh Dr., Gaithersburg, MD 20879; (800) 839-1649, e-mail: info@wll.com, Internet: www.wll.com

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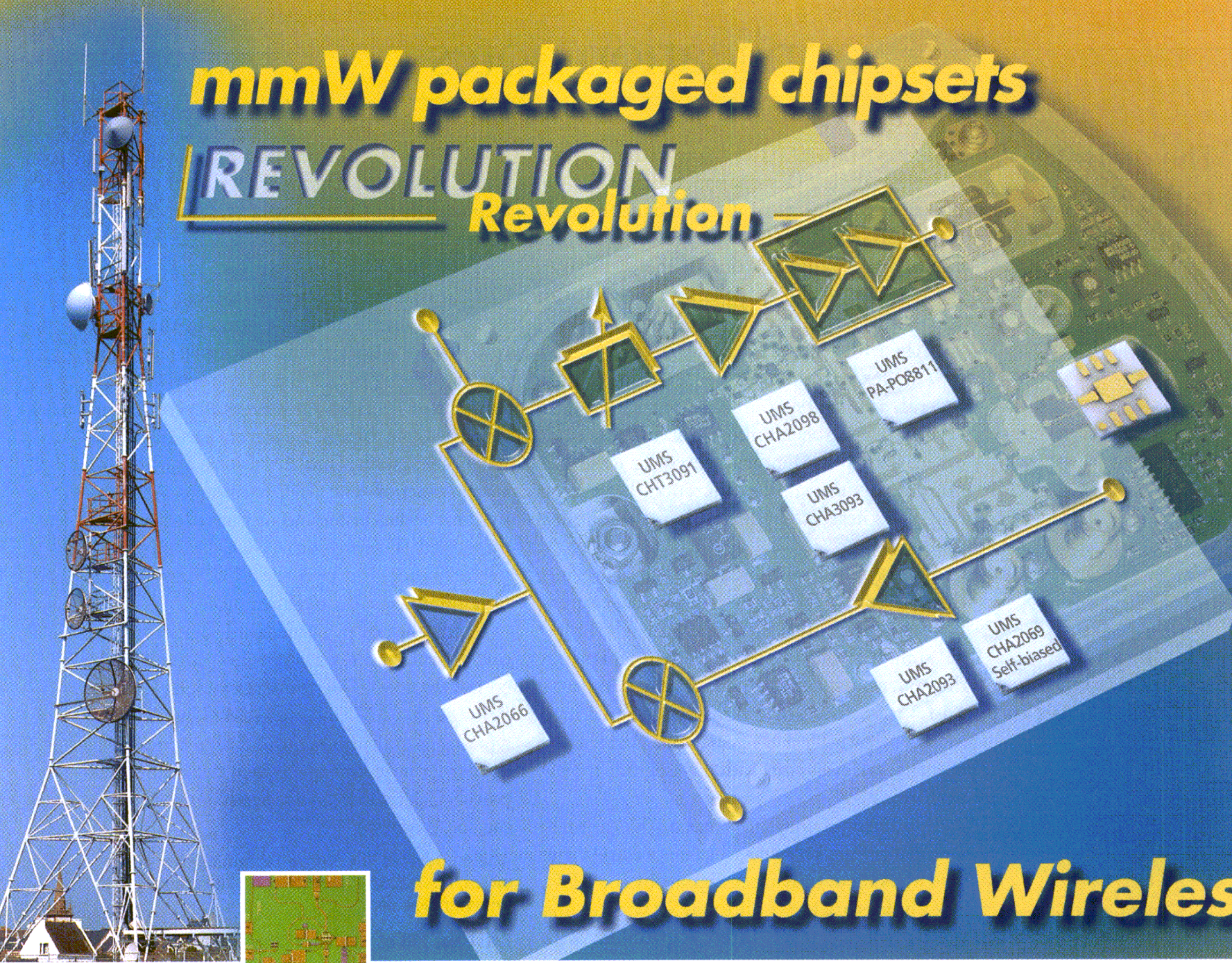

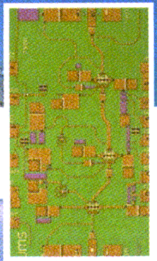

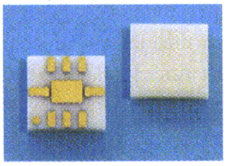

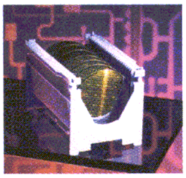

SMD MMICs Chipset
26 - 28GHz Radiolink

Function	P/N	Operating Frequency	Gain	Gain Control	Noise Figure	P-1dB	Bias
LNA (*)	CHA2066-XXF(**)	10-16GHz	15dB	—	2.5dB	9dBm	4V, 45mA
LNA (*)	CHA2069-RAF	18-31GHz	19dB	—	3dB	9dBm	4.5V, 55mA
LNA	CHA2093-RBF	20-30GHz	14dB	—	3dB	12dBm	4V, 45mA
Attenuator	CHT3091a-RCF	DC-40GHz	—	-4,21dB	—	14dBm	0V,-5V, 0mA
Buffer	CHA2098a-RBF	20-40GHz	18dB	—	—	15dBm	3.5V, 150mA
MPA	CHA3092-RBF	20-33GHz	21dB	—	—	18dBm	3.5V, 300mA
MPA	PA-PO-8811-TBF(***)	24-30GHz	25dB	—	—	24dBm	5V, 460mA

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PRODUCT technology

LDMOS Delivers 500 W For IFF Systems

A high-efficiency, Class AB linear LDMOS high-power FET is well-suited for boosting the short-duration pulsed signals found in IFF Tx systems.

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LEE MAX
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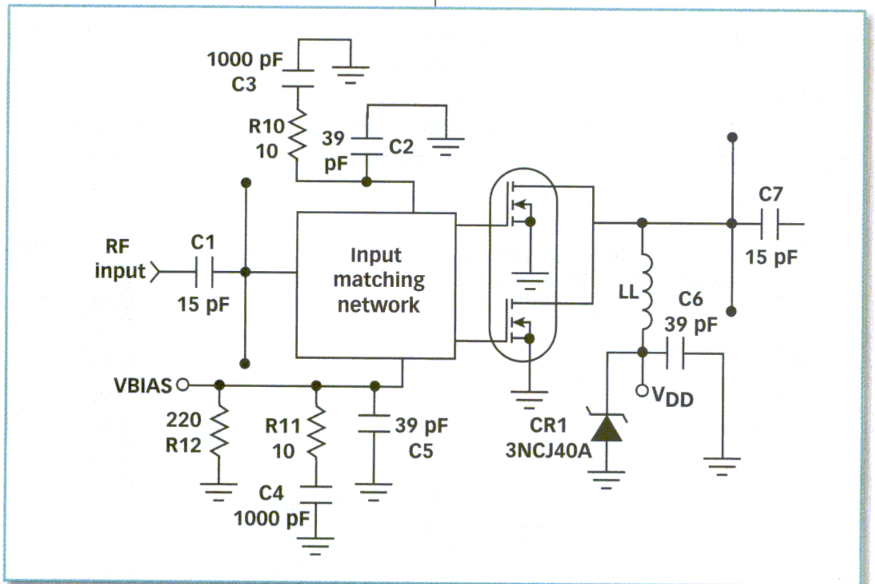
Laterally-diffused-metal-oxide-semiconductor (LDMOS) field-effect transistors (FETs) have been the devices of choice for high-power commercial base-station linear amplifiers for several years. These powerful transistors have been designed into a multitude of linear power amplifiers (PAs) used within the 500-to-2500-MHz frequency range. The high gain, good efficiency, and excellent Class AB linearity of LDMOS FETs make them suitable for a wide variety of RF and microwave high-power applications. Typically, these high-power transistors have been associated with commercial applications, such as cellular base stations. But the devices also provide the type of performance benefits well-suited for many military applications as well.

In a military Identification Friend or Foe (IFF) system, for example, configuring an entire PA (including the 500-W output devices) using high-gain, Class AB linear transistors provides significant system advantages. These

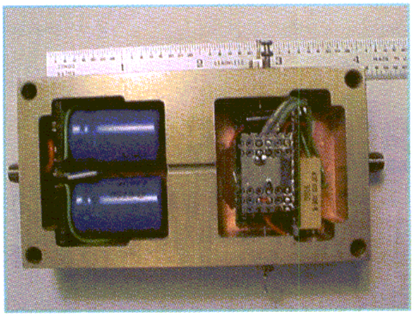


1. This amplifier circuitry was used to optimize the performance of a high-power LDMOS device for IFF applications.

advantages include IFF Mode S and Mode 5 capability, reduced cost and size, increased reliability, and improved thermal performance.

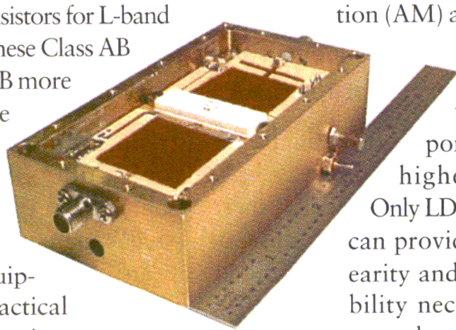
Designers of military IFF PAs have looked longingly at the proliferation of +28-VDC continuous-wave (CW) microwave LDMOS FETs and waited patiently for a device and circuit that was optimized for their IFF high-voltage (greater than +35-VDC), high-power (greater than 500-W), and 1030/1090-MHz, pulsed applications. Fortunately, an LDMOS FET has been developed by GHz Technology (Santa Clara, CA) with the performance and reliability needed for these IFF systems. What follows is an examination of the device and its associated circuitry under a variety of low-duty-cycle, and extended-length message formats.

Since the emergence of high-power LDMOS FETs for 900-MHz cellular base-station PAs, RF circuit designers have envisioned LDMOS transistors for L-band avionics applications. These Class AB devices offer at least 4 dB more gain and 15 dB more dynamic range than the Class C common-base bipolar transistors used in the present distance-measuring equipment (DME), Joint Tactical Information Distribution (JTIDS), Tactical Air Navigation (TACAN), and IFF systems. This significant improvement in single-stage gain and linearity will dramatically simplify and reduce the cost of traditional avionics transmitter (Tx) subsystems. For example, the linear LDMOS devices will not require the pulse-shaping circuits commonly used with Class C devices.



2. Charge storage for the LDMOS' DC drain circuit and the gate DC bias circuit are mounted under the RF PCB.

In new multimode IFF-enhanced data systems, even greater performance, reliability, and cost benefits are available by using LDMOS FETs. These new systems use amplitude modulation (AM) and phase modulation (PM). Furthermore, they must support substantially higher data rates. Only LDMOS-based Txs can provide the high linearity and thermal capability necessary to fully meet the requirements of next-generation avionics systems.



3. This push-pull module can operate in phase as a single-ended device within a larger architecture.

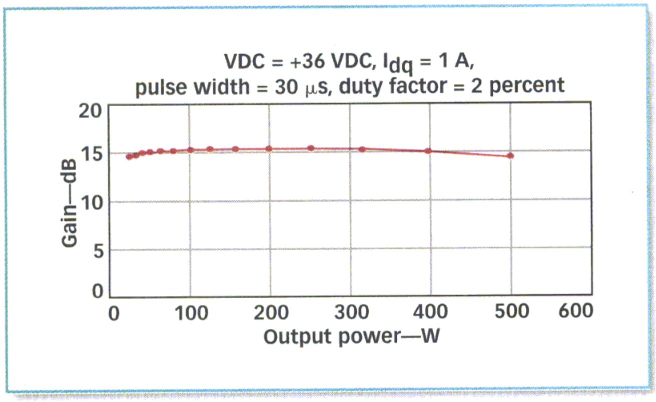
Unfortunately, device and circuit designers have struggled to achieve an LDMOS device/circuit combination suitable for the higher-voltage pulse requirements of L-band avionics applications. RF power-circuit designers have been stymied by several unexpected device problems associated with LDMOS in avionics applications.

Some of the major problems encountered when using standard LDMOS FETs in an avionics application are:

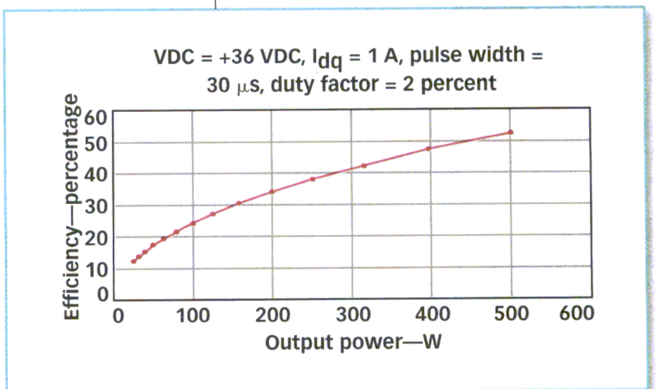
- The fragility of the devices when used in pulse applications with fast rise and fall times.
- The inherent threshold drift in LDMOS FETs increases dramatically as the DC operating voltage is increased.
- The internal balance of an LDMOS die becomes significantly worse as the DC operating voltage is increased.
- RF power devices that contain aluminum (Al) bond wires have displayed poor reliability in high-power pulsed applications due to bond-wire failures.

Engineering development staffs at GHz Technology and Zeta (San Jose, CA) carried out an extensive investigation focused on identifying the causes of these LDMOS problems in IFF applications. That research was followed by a device/circuit-development program that provided realistic solutions, including a single Class AB LDMOS FET device which is capable of more than 500 W of peak output power.

As PA designers started to use LDMOS FETs in pulse applications or systems with high-speed digital modulation, unexplainable failures often occurred. It was later found that large voltage spikes were appearing on the drain of the



4. In short-pulsed applications, the high-power LDMOS device provides more than 15-dB gain with over 500-W output power.



5. The efficiency is better than 50 percent for the high-power LDMOS device in short-pulsed applications.

LDMOS FET due to the very-fast fall times of the DC drain current. These short-duration voltage spikes were triggering and "turning on" the parasitic bipolar transistor inherent in the LDMOS FET structure, creating a self-destructive device condition.

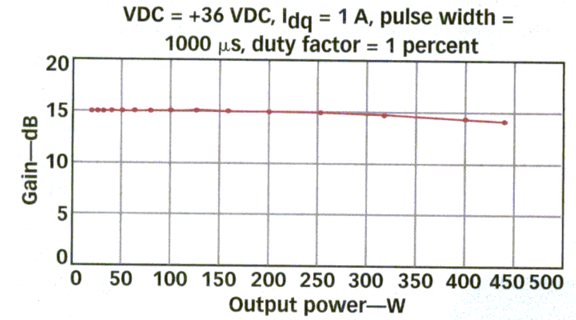
In IFF systems, fall times are generally controlled between 50 and 200 ns. However, to minimize the risk of LDMOS self-destruction due to fast DC-drain-current spikes, the GHz/Zeta team took several steps. The first involved increasing the drain breakdown voltage capability of the LDMOS die. In the second step, the value of the inductor was used to deliver the DC current to the drain of the LDMOS FET (inductor L1 in **Fig. 1**) in the amplifier circuit was minimized as much as possible, consistent with the RF circuit impedance requirements. In the third step, a fast, high-peak-current Zener diode (diode CR1 in Fig. 1) was added to the drain DC feed network to clip voltage spikes at +5 VDC above the operating DC drain voltage.

Threshold drift with operating time has historically been a problem for PA designers using LDMOS FETs. Device suppliers have been reducing the drift of their devices to the point where today's newest LDMOS FETs have minimal threshold drift when operating at +26 to +28 VDC. However, when LDMOS FETs operate at the higher DC voltages of pulsed avionics applications (above +35 VDC), the threshold drift increases. Two primary techniques for managing the threshold drift in an IFF system are: 1. preconditioning the devices (typically 72-to-168-h system burn-in) and 2. using a self-adjusting bias circuit that periodically samples the quiescent current of the device and adjusts the DC voltage on the gate of the LDMOS FET to hold the quiescent current at its initial value.

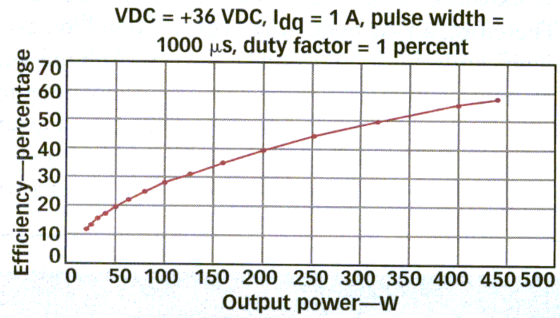
As seen in **Fig. 2**, the charge storage for the DC drain circuit and the gate DC bias circuit are mounted under the RF printed-circuit board (PCB) using the backside ground plane to shield the sensitive bias circuitry from RF interference (RFI).

Balancing the die is the single biggest challenge for the device and circuit designers when trying to extract the maximum performance from this high-voltage RF metal-oxide semiconductor field-effect transistor (MOSFET). As seen in **Fig. 3**, there is approximately an inch (side to side) of die in this very-large push-pull LDMOS FET.

The GHz device team has incorporated a variety of balancing techniques on die and in the assembly of the device inside the package. The Zeta circuit-design team has developed proprietary circuit techniques that force extraordinary



6. For use with high-data-rate IFF modulation, LDMOS amplifier circuitry was developed to handle pulse widths of 1 ms at a 1-percent duty cycle.



7. For use with long pulse widths, the LDMOS circuitry delivered approximately 15-dB gain and more than 50-percent efficiency.

balance across the die. These techniques allow the entire push-pull device to operate in phase as a large single-ended device (**Fig. 3**).

A wear-out mechanism that is frequently overlooked in active-device studies is the failure of the bond wires. Under certain conditions, bond wires can actually fatigue and break. As the device is driven with RF energy, current flows through the bond wires. The bond wires then increase in temperature and expand in length. The bond wire is attached at both ends. Therefore, each time the wire expands, the connection point at the bond foot is flexed. This does not present a problem under CW operation or for applications that do not have a time-varying waveform. However, amplifiers for pulse applications such as radar and avionics, as well as many modern modulation formats, produce a range of time-varying waveforms.

Al bond wires are at far greater risk of failure than gold (Au) bond wires. Electrical and thermal resistance of Al is higher than Au and its thermal coefficient of expansion is much higher than Au. Therefore, an Al bond wire will flex significantly more at the bond foot than an equivalent-size Au bond wire. Since Al work hardens readily (Au does not), multiple flexing of the Al wire at the bond foot causes the wire to fatigue and break. It typically requires at least 10 million cycles to produce this type of Al bond-wire failure. Unfortunately, documented examples [an ultra-high-frequency (UHF) radar amplifier and a very-high-frequency (VHF) TV Tx] have shown that this type of design-defect failure can occur in less than a month of normal operation.

The exact level of risk for a particular application is uniquely dependent on the construction of the specific microwave power device and the operating conditions of the system. However, Au-metallized LDMOS FETs that use Au bond wires are likely to be significantly more reliable than the Al metal systems that some device manufacturers currently use in their high-power cellular base-station LDMOS FETs.

As seen in **Figs. 4 and 5,** the LDMOS FET pulse-amplifier circuit has very high gain, excellent dynamic range, and exceptional efficiency. With a standard 30-μs pulse width at 2-percent duty cycle, the 1-dB compression point is 500 W. The LDMOS amplifier circuit also exhibits more than 15-dB gain with a gain flatness of ±0.5 dB over a 13-dB output-power dynamic range (i.e., P_{out} versus P_{in}), and better than 50-percent efficiency.

To estimate the performance under the new high-data-rate IFF modulation modes, another circuit was optimized for operation at a pulse width of 1 ms at 1-percent duty cycle. The device/circuit combination operated so well, even under this extremely long pulse width **(Figs. 6 and 7),** that the 1-dB compression point was well over 400 W, the gain was approximately 15 dB, and the efficiency exceeded 50 percent.

The GHz/Zeta team has created device/circuit techniques that enable the single-device amplifier to operate comfortably at peak output-power levels above 500 W. With this much linear Class AB peak power out of a single IFF device/circuit, high-data-rate, multi-kilowatt IFF systems using modern complex modulation schemes can be configured with simple low-level modulators, followed by an all-LDMOS FET-based, open-loop, high-gain, linear PA. **GHz Technology, Inc., 3000 Oakmead Village Dr., Santa Clara, CA 95051; (408) 986-8031, FAX: (408) 986-8102, e-mail: mmallinger@ghz.com, Internet: www.ghz.com.** MRF

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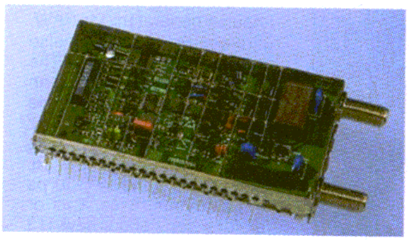
RF Subsystem Enables Cable Telephony

This RF transceiver provides an integrated solution for modern cable-telephony network interface units with a migration strategy to future VoIP systems.

KEVIN LYNAUGH
Advanced Development Engineering Manager
Microtune, Inc., 2201 10th St., Plano, TX 75054; (972) 673-1600, FAX: (972) 673-1602, E-mail: sales@microtune.com, Internet: www.microtune.com.

Cable services are rapidly expanding to include upstream (from the customer to the service provider) and downstream (from the service provider to the customer) communications, including Internet access through cable modems and cable telephony. In many applications, the cable system's customer-premises equipment (CPE) is evolving beyond the cable modem and set-top box to a res-idential home gateway that mounts outside the home. This home gateway contains the network-interface unit (NIU), which is the hub for all up and downstream communications at the residence, including cable-television (CATV), cable-modem, and cable-telephony functions. In the past, the original equipment manufacturers (OEMs) of these cable home gateways were required to have in-house RF transceiver expertise to develop custom solutions based on a proprietary technology. A commercial-off-the-shelf (COTS) solution with significant price/performance advantages could open up the market and speed the development of cable broadband services such as cable telephony.



The MT4950 is an integrated transceiver subsystem that enables voice, video, and data services across a broadband CATV network.

The MT4950 RF-NIU Subsystem **(see figure)** from Microtune™, Inc. (Plano, TX) is standards-based solution that, when integrated into an NIU, enables voice, video, and data services across the broadband cable network. It is a standards-based product that is designed to migrate to future voice-over-Internet-Protocol (VoIP) implementations.

Based on a hybrid circuit-switched/intellectual-property (IP) architecture, the RF subsystem supports circuit-switched and Data Over Cable Service Interface Specification (DOCSIS)-based implementations. The basic building blocks of the product include the company's RF single-conversion tuner and a new higher performance MicroStreamer™ MT1540 upstream amplifier, RF automatic gain control (AGC), and intermediate-frequency (IF) circuitry, along with the functions of a network bias tap, high-voltage safety capacitors, primary lightning protection, cutoff relay, and network coupler. These functions are integrated into a single, cost-effective RF subsystem. A built-in DC-to-DC converter allows the system to be biased from a single +5-VDC supply.

Power consumption is a critical concern for cable-telephony systems due to the requirements of backup power to ensure lifeline telephone service. In order to minimize power consumption, a variant of the RF-NIU subsystem is designed using an IF amplifier structure, which provides fixed IF gain and corrects gain variations that occur with the fluctuations in temperature experienced in an outdoor environment (−40 to +75°C).

The MT4950 features an 88-to-862-MHz downstream range and a 5-to-42-MHz (or 5-to-65-MHz) upstream range. Band selection and tuning is performed using an I^2C bus, and the transmit amplifier is controlled using a three-wire bus. The MT4950 is equipped with two F connectors for cable and television connections.

Housed in a 2 × 4-in. (5.08 × 10.16-cm) package, the RF-NIU subsystem features maximum insertion loss of 2 dB from 88 to 862 MHz and 2.5 dB from 862 to 1000 MHz. Return loss is better than 15 dB from 5 to 862 MHz. Integrated into the MT4950, the MT1540 upstream amplifier, part of the company's MicroStreamer device family, offers +67-dBmV linear output power. The generous output power provides enough margin to overcome losses incurred from the system coupler and diplexer. Upstream harmonics are better than −47 dBc from 10 to 88 MHz.

Since it is mounted outside of the home, the NIU and home gateway have to be equipped with primary lightning and surge protection, stipulated in the US by standards developed by Underwriters' Laboratory (UL) and the IEEE. The RF-NIU transceiver subsystem is designed with safety capacitors, a high-current bias tap, as well as creepage and clearance spacing in order to meet these safety regulations.

Microtune will work with OEMs and cable-equipment suppliers to customize the RF-NIU transceiver subsystem to specific price/performance targets. The MicroStreamer MT1540 Upstream Amplifier is also available as a stand-alone component. It is designed for operation from a single +5-VDC supply and features a selectable transmit-disable function that can be accessed through an external control pin. P&A: $35.00 (MT4950) (10,000 qty.) and $2.00 (upstream amplifier alone) (10,000qty.). **Microtune, Inc., 2201 10th St., Plano, TX 75074; (972) 673-1600, FAX: (972) 673-1602, e-mail: sales@microtune.com, Internet: www.microtune.com.** MRF

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PLLs Shine With Sapphire Technology

The use of CMOS-on-sapphire technology has led to a line of low-power PLLs capable of low-phase-noise operation in +3-VDC systems operating to 3 GHz.

JACK BROWNE
Publisher/Editor

Sapphire is more than a gem. As a true insulator at high frequencies, with superb thermal conductivity, it is a near-ideal substrate material. Peregrine Semiconductor (San Diego, CA) has been able to produce sapphire substrates cost-effectively for use in a line of PLLs with excellent phase noise and low current consumption. The PLLs include integer-N and fractional-N models for use through 3 GHz.

The company's patented Ultra-Thin-Silicon (UTSi) CMOS-on-sapphire process is a variation of SOI technology that supports the integration of analog, RF, and digital active devices. In addition, Si is optically transparent, making it a suitable platform for the integration of fiber-optic components. The company, with UTSi design centers in the US and France, also boasts an advanced 6-in. (15.24-cm), 0.5-μm wafer-fabrication facility in Sydney, Australia. Last year, the firm announced a series of high-performance components, including a high-linearity mixer, a series of switches, and lines of PLLs. The PLLs are noteworthy for their low phase noise and low power consumption.

For example, model PE3236 is a 2.2-GHz integer-N PLL with a divide-by-10/11 dual-modulus prescaler. It has an internal phase detector and can be programmed through serial, parallel, or hard-wire connections. The main divider handles input signals from 200 to 2200 MHz at levels of −5 to +5 dBm, while the reference divider operates at a maximum frequency of 100 MHz. The PLL draws 30-mA current at +3 VDC. It is supplied in a 44-pin PLCC package. The model PE3240 PLL offers similar performance to the PE3236, but is supplied in a 20-lead TSSOP or 24-lead BCC package.

The model PE3336 integer-N PLL extends the frequency of operation to 3 GHz. It includes the internal phase detector and divide-by-10/11 prescaler, and is pin-compatible with the PE3236 PLL, but works with divider frequencies from 200 to 3000 MHz and reference frequencies to 100 MHz. For lower-frequency applications, the model PE3238 integer-N PLL offers the phase detector and divide-by-10/11 prescaler, but with a main divider frequency range of 200 to 1500 MHz. The maximum reference frequency is 100 MHz.

The company also offers the model PE3291 dual (1200- and 550-MHz) fractional-N PLL and the model PE3293 dual (1800- and 550-MHz) fractional-N PLL. **Peregrine Semiconductor, 6175 Nancy Ridge Dr., San Diego, CA 92121; (858) 455-0660, FAX: 455-0770, Internet: www.peregrine-semi.com.**
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2. A short professional biography (50 words maximum).
3. Proposed session title and a 150-word abstract. This material must be included or your submission will not be considered.

   Please indicate what type of session you are proposing. We offer three types of sessions at the Wireless/Portable Symposium & Exhibition:

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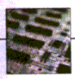
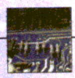
   - Full-Day Workshop Tutorial Session: 1 or 2 day session presented by an expert instructor.

4. If you will be speaking elsewhere within the next twelve months, please indicate where.

Submit your session proposal by September 7, 2001 to Betsy Tapp, Conference Manager, via fax 201-393-6297 or e-mail btapp@penton.com.



SAW Filter Screens PS Receive Signals

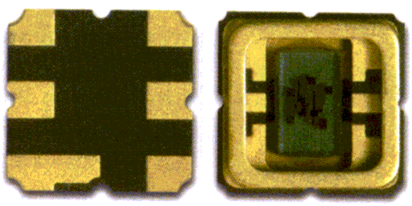
Based on SAW technology, this compact filter provides the out-of-band rejection needed for sensitive GPS receivers, without adding excessive in-band insertion loss.

JACK BROWNE
Publisher/Editor

Location services such as the Global Positioning System have proven invaluable in military theaters, but they are also rapidly gaining acceptance in commercial applications such as in-vehicle systems. In support of this growth, SAWTEK, Inc. (Orlando, FL) has developed a tiny surface-acoustic-wave bandpass filter to combine high rejection of unwanted signals with low insertion loss for desired GPS signals.

The model 855969 filter **(see figure)** provides the critical function of RF filtering in a GPS receiver. In order to minimize signal-recovery errors in the receiver, the filter should exhibit minimal signal loss. At the same time, since a variety of voice- and data-transmission systems operate in the frequency bands surrounding GPS, the filter must also keep these signals from entering the front-end electronics of the GPS receiver where they could cause undesired mixing and IMD effects.

The model 855969 filter achieves these goals with simultaneous low insertion loss and high out-of-band signal rejection. The tiny filter is designed to operate at a GPS center frequency of 1575.42 MHz. It has a bandwidth of 2.4 MHz around that center frequency, with maximum in-band insertion loss of 1.8 dB. The typical insertion loss is only 1.3 dB. It also achieves as much as 50-dB out-of-band rejection of potential interfering signals such as cellular and personal-communications-services (PCS) transmissions. The typical rejection is achieved in the critical 824-to-869-MHz and 1640-to-1926-MHz frequency ranges.



The tiny model 855969 SAW filter is designed to pass GPS RF signals at 1575.42 MHz while rejecting out-of-band signals by at least 50 dB.

The SAW GPS RF receive filter measures 3.0 × 3.0 × 1.2 mm and is supplied in a surface-mount package for ease of installation in crowded printed-circuit boards. It is 94-percent smaller than ceramic filters with similar bandwidth, which should help designers of GPS receivers for embedded applications. It is designed for use at 50 Ω, with an impedance-matched, single-ended source of load ports. **SAWTEK, Inc., P.O. Box 609501, Orlando, FL 32860-9501; (800) 332-8638, (407) 886-8860, FAX: (407) 886-7061, e-mail: info@sawtek.com, Internet: www.sawtek.com.**

Enter No. 54 at www.mwrf.com

Simulator Tackles Tricky EM Problems

The latest version of this EM simulation and optimization package includes flexible simulation engines, a menu-based interface, and a versatile optimizer.

JACK BROWNE
Publisher/Editor

Electromagnetic (EM) simulation has become a well-established tool for the prediction of current flow and field patterns in planar and three-dimensional (3D) structures. The IE3D EM simulation and optimization package from Zeland Software (Fremont, CA) is now in Version 8 with a set of capabilities and features for solving the most demanding EM problems in 3D structures and multilayer high-frequency circuits.

Version 8 of IE3D for Windows is a full-wave, method-of-moments (MoM) simulator that can be used to model the current distribution in a variety of transmission media, including microstrip, stripline, coplanar waveguide, suspended stripline, coaxial lines, rectangular waveguide, high-speed digital transmission lines, interconnections, and filters. The software features a straightforward menu-driven graphical user interface (GUI), and can model a wide range of dielectric materials, handling lossy and high-dielectric-constant layers as thin as 0.1 mm. This latest version of the EM simulator includes advanced iterative matrix solvers (AIMS) for large layouts. The new version can speed up simulations and reduce random-access-memory (RAM) requirements by a factor of 10 for large integrated circuits (ICs) and antenna designs compared to previous versions.

The EM simulator handles models within an enclosure, under open-boundary conditions (such as an antenna) or under periodic-boundary conditions. The software automatically generates a nonuniform mesh around a modeled structure using rectangular and triangular cells. It also automatically generates edge cells for high accuracy when modeling the current distribution along the edges of conductors. In fact, the software can exactly model current on four sides of a metallic strip.

Rather than assuming models with infinite ground planes, IE3D allows operators to solve antenna and circuit problems with finite ground planes, as well as circuits with differential feed structures. The software enables the modeling of conductor thickness, rather than assuming an infinitely thin conductor and neglecting electrical thickness effects.

The IE3D software simplifies the creation of 3D models through its built-in library of circles, rings, spheres, rectangles, circular spirals, cylindrical and conical via holes, and helices. IE3D can import GDSII files, AutoCAD DXF files, and CalTech Intermediate Form (CIL) layout files. It can save files in these formats, in a proprietary 3D Text file format, and in a FIDELITY file format used by the firm's 3D simulation tools for modeling 3D structures with nonuniform dielectric constant. The IE3D program places no limits on the number of ports that can be defined, and enables flexible de-embedding of circuit parameters. Results are provided in the form of S-parameters, although S-parameter data can be optionally converted into Simulation-Program-with-Integrated-Circuit-Emphasis (SPICE) netlists for use with a SPICE simulator. IE3D offers full-color visual displays of S-, Y-, and Z-parameters, with two-dimensional (2D) and 3D displays of current distribution, radiation patterns, and near-field EM radiation patterns. In addition to simulators, operators can define the shape of a circuit as a set of optimization variables and then apply the built-in GeneticEM optimizer to achieve a design that has desired performance levels.

The EM simulator handles models within an enclosure, under open-boundary conditions or periodic-boundary conditions.

Release 8 of IE3D is supplied on a compact-disc-read-only memory (CD-ROM) with full documentation and a series of sample files. The software includes the Intelli-Fit curve-fitting scheme that can be used to extract the frequency response of a complicated structure with multiple resonances. It incorporates periodic Green's functions for analysis of phase-array designs. The software suite includes a simple-to-use circuit simulator that helps to perform functions including finding the characteristic impedance of a transmission line, creating S-parameters for a suitable transmission line, and extracting the S-parameters from a section of a circuit. In addition to the standard package (with no limit to the number of unknowns in a simulation), a version of the software is also available with an upper limit of 1000 unknowns.

In addition to IE3D, the company offers MDSPICE, a wideband SPICE simulator. The S-parameter-based simulator yields precise time-domain waveforms on extremely long transmission lines and electrically long interconnections. The software, written for Windows NT operating systems, features nonlinear modeling for analog and digital circuits. P&A: $17,000 (standard IE3D package), $10,000 (limited IE3D version), and $10,000 (MDSPICE); stock. **Zeland Software, Inc., 39120 Argonaut Way, PMB 499, Fremont, CA 94538; (510) 623-7162, FAX: (510) 623-7135, e-mail: ze land@zeland.com, Internet: www. zeland.com.** MRF

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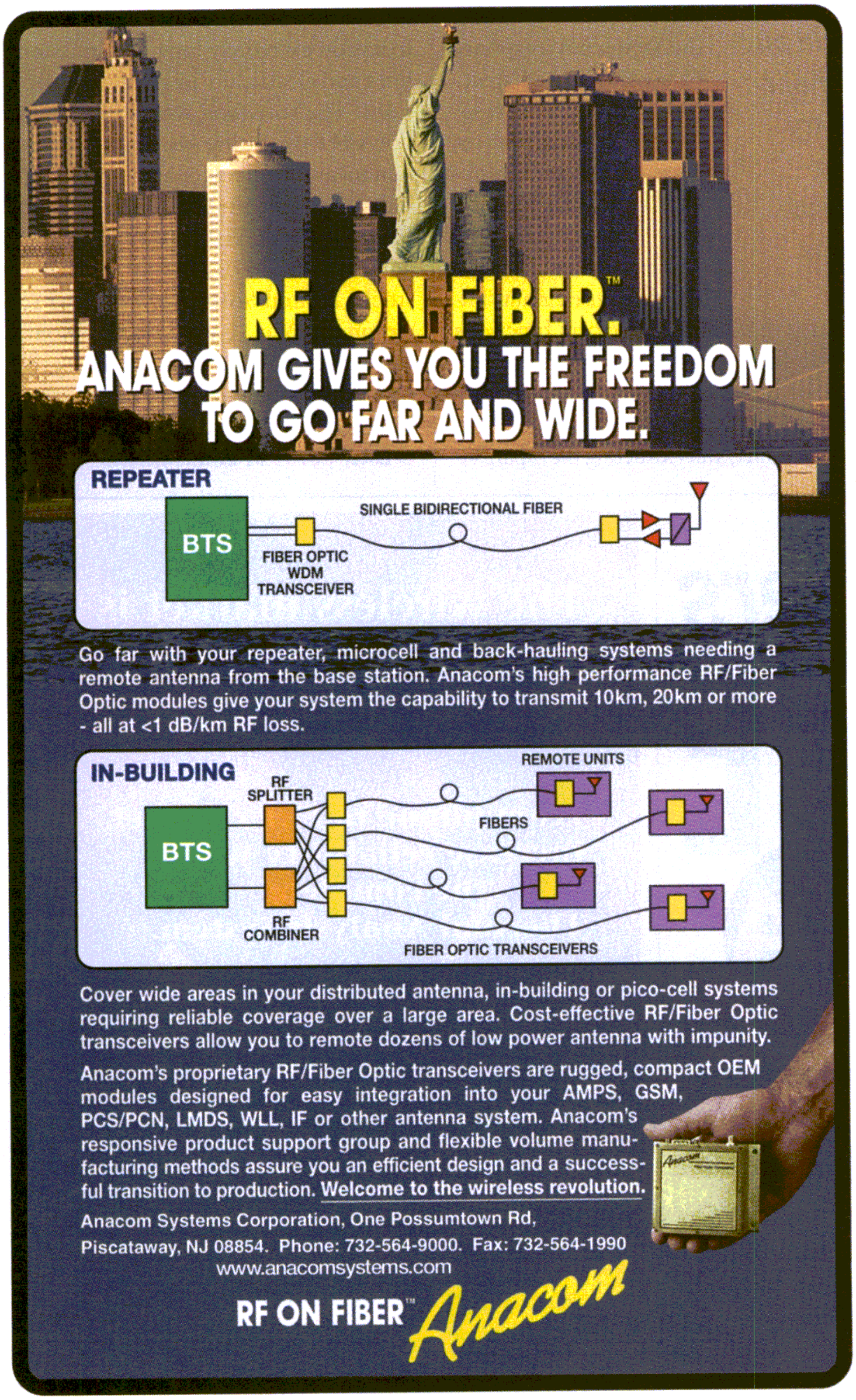
Continued from page 181

issue, Jack Browne would assume the role of Chief Editor, a position that he has held to this day.

In May 1988, a technology assessment offered by Alan Conrad of Configuration Analysis Management (Danbury, CT) would point to the need for speed in signal-processing applications. Alan ("Pete") Conrad remains affiliated with the magazine to the present, now serving as Special Projects Editor. In July of that year, Sciteq Electronics (San Diego, CA) launched a direct digital synthesizer capable of 20-ns switching speed across a 250-MHz bandwidth, using digital control of a digital-to-analog converter (DAC) to create analog output signals.



The 1990s were marked by the growth of commercialism to an industry accustomed to military customers. The cellular telephone replaced the radar system for many companies and numerous IC suppliers, such as RF Microdevices **(Fig. 8)**, Analog Devices, and Maxim Integrated Components, were able to meet the needs of these emerging wireless markets. Since these markets stressed fast delivery times, microwave companies became more concerned with higher-speed test equipment and modeling software. The late 1980s and early 1990s were also marked by the growing sophistication of computer-aided-design (CAD) tools with two companies—EEsof, Inc. (Westlake Village) and Compact Software (Paterson, NJ)—each making major contributions to the development of software tools for the personal computer (PC) during the late 1980s and early 1990s. As the PC has grown in processing power and speed, so have developers of EM simulation tools, including Ansoft (Pittsburgh, PA) and Sonnet Software (Liverpool, NY).

The beginning of 2000 saw a carryover of the economic good fortune enjoyed by many high-frequency companies during the 1990s. But 2001 has seen an economic downturn and a slowdown for many companies. Fortunately, as the 40-year history of this magazine has shown, this is truly a cyclical business with large and small cycles. Ironically, the military markets that were all but abandoned during the commercial gold rush of the 1990s are now the focus of a number of companies seeking growth markets. And the optical-communications market may yet become one of the largest segments of the "microwave" industry. MRF

System Speeds Assembly Of RF Power Devices

This automated system provides preheating of device packages, precision handling and placement of components, and consistent eutectic attachment of semiconductors.

JACK BROWNE
Publisher/Editor

Power RF transistors are generally assembled by hand, with all of the inconsistencies of die placement and bond-wire attachment associated with human handling. But the HotRail Radio Frequency Assembly (RFA) Cell from Palomar Technologies (San Diego, CA) is an automated assembly system that can do away with the inconsistencies found with hand assembly of power devices and amplifiers.

The fully automatic, in-line multichip system provides void-free assembly and programmable steady-state heat control for eutectic die attach, with placement precision of ±10 to 12 μm.

The system **(see figure)** is designed to dramatically increase the throughput of high-power device and amplifier assembly lines. The system can handle wafers from 3 to 8 in. (7.62 × 20.32 cm) in diameter and can handle components in 2- and 4-in. (5.08 × 10.16-cm) waffle and gel packs and in tape-and-reel formats.

The HotRail RFA assembly system couples high-capacity input and output magazine handlers with precision component-assembly capability. It can handle wafers from 3 to 8 in. (7.62 × 20.32 cm) in diameter.

The system incorporates an eight-position turret head that is for a wide range of vacuum tools. The system enables loading of a large quantity of parts at one time, while the component-assembly system can eject and attach fragile die, including 3-mil-thick GaAs devices. The system can be equipped with a vacuum tool for moving components larger than 2 in. (5.08 cm) on a side.

Parts are preheated as they enter the hitch-feed conveyor assembly to gradually reach the required eutectic temperature. A clamping mechanism holds the headers in place at the required eutectic temperature to achieve precision side-by-side placement of die for wire-bonding attachment and consistent wire-loop profiles. The temperatures of the preheat, eutectic, and cool-down zones can be independently programmed by an operator. Palomar Technologies, 2230 Oak Ridge Way, Vista, CA 92083-8341; (760) 931-3406, FAX: (760) 931-3444, Internet: www.palomartech nologies.com.

Enter No. 57 at www.mwrf.com

SPICE-Based Software Fine-Tunes Designs

With its hierarchical format, this powerful program allows engineers to integrate complex circuit designs with analog and digital components to nearly unlimited nested depths.

ALAN CONRAD
Special Projects Editor

Simulation Program with Integrated-Circuit Emphasis (SPICE)-based programs are still among the most widely used of computer-aided-engineering (CAE) tools for high-frequency, high-speed circuit design. The latest version of Orcad PSpice A/D from Cadence Design Systems (Portland, OR) builds on the tradition of SPICE simulation by simplifying the design of mixed analog/digital circuitry and adding new tuning and optimization capabilities. The latest version of PSpice features more than 16,000 component models, including active devices and passive circuit elements.

The first version of PSpice was introduced in 1985 by MicroSim Corp., which was later acquired by Orcad, which was, in turn, acquired by Cadence Design Systems. The popular program has been continuously enhanced and structured to accommodate the latest hardware and operating systems.

Orcad PSpice A/D permits users to simulate mixed analog/digital circuits of any size. Simulation results for analog and digital functions can be viewed in a common plot window using a common time axis. The program automatically recognizes analog-to-digital and digital-to-analog connections within a design. Using a companion program known as the Orcad PSpice Optimizer, designers can fine-tune designs according to prescribed performance parameters and automate the optimization process according to a number of different component values.

The program seamlessly supports hierarchical designs containing components, circuit models, or subsystems that are reused extensively. **Figure 1** illustrates a simple active-filter hierarchical block diagram. Each block, in turn, contains a bandpass resistance-capacitive (RC) biquad active filter **(Fig. 2)**. Clicking within either of the hierarchical blocks and selecting "descend" reverts the active-filter block diagram of Fig. 1 to the simpler structure of Fig. 2. Component values can be changed, performance parameters can be redefined, and probes can be inserted at different locations before quickly re-running a simulation and almost instantly generating a new set of tuned or optimized results

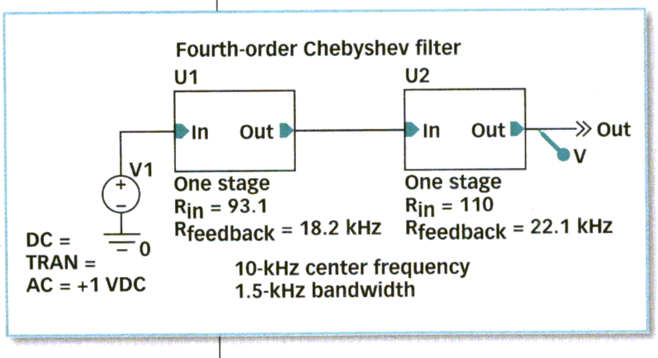
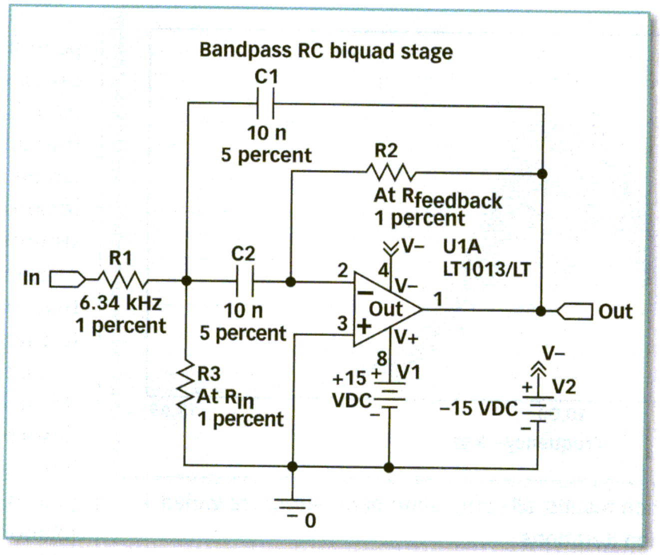


Fig. 1. This hierarchical block diagram represents a simple active fourth-order Chebyshev filter design in the latest version of PSpice A/D from Cadence Design Systems.

that reflect the effects of the changes.

The software allows operators to define specific measurements and plot configurations, or select from a wide variety of standard PSpice plots, such as bode plots, bandwidth plots, group-delay plots, Nyquist plots, and log-linear plots. Plotting functions can be used to display Bode plots of phase and magnitude on separate Y-axes of a single plot or on stacked plots with a common frequency axis.

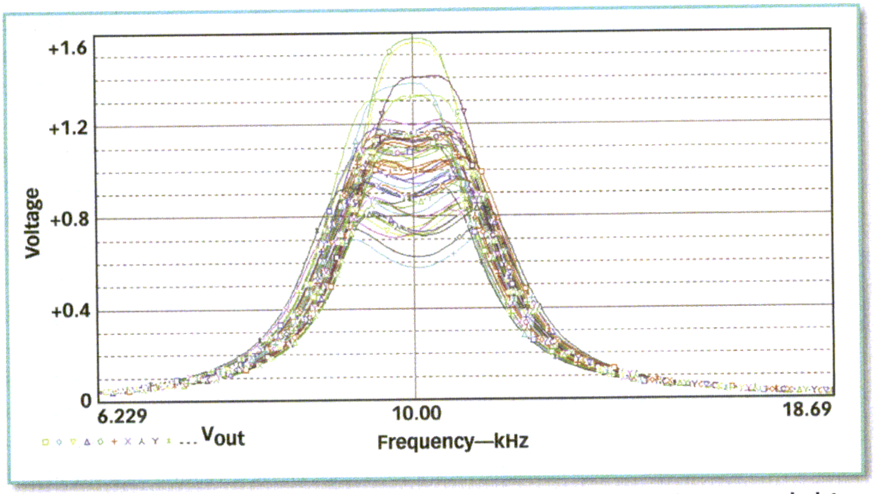
An interactive stimulus editor allows users to define waveform parameters of sine, pulse, exponential pulse, and single-frequency frequency-modulation (FM) waveforms or create freehand linear (PWL) signals by dragging the mouse. Designers can explore circuit behavior using basic DC, AC, noise, and transient analyses, as well as view node voltages, pin currents, and power consumption or noise of individual devices.



2. This bandpass RC biquad stage is contained within the hierarchical block diagram of the active filter.

Designs can include specific local temperature effects on individual devices for more accurate analyses and track circuit behavior variations, as components change with parametric, Monte-Carlo, or worst-case analyses. They also display Fourier transforms of time-domain signals or inverse transforms of frequency-domain signals. Users can vary component values over multiple runs and quickly view results as a family of waveforms with parametric, Monte-Carlo **(Fig. 3)**, and worst-case analyses while plotting waveform characteristics such as rise time versus temperature or supply voltage, using parametric analysis.

The program allows users to monitor the progress of a transient analy-



3. In these Monte Carlo-simulation results, all component parameters are varied 1 percent over 25 design/simulation iterations.

sis and, if necessary, extend it beyond the original end time without restarting the simulation. Users can increase simulation speed by specifying looser tolerances and time steps during non-critical periods of transient analysis.

Users can modify simulation run times without restarting the simulation in the event of convergence problems. The user can pause the analysis in progress, change run-time simulation settings, and continue.

Designers can maximize a circuit's performance with a PSpice optimizer that operates in conjunction with PSpice A/D. The optimization routine tunes the values of up to eight user-specified circuit parameters. Optimization specifications can be set as goals or constraints. Optimizer reports include the margins of each constraint and sensitivity of each specification with respect to each parameter.

Orcad PSpice runs under Windows 95 or higher operating system, Windows NT 4.0 with service pack three or later, and with a Pentium or equivalent processor with 32-MB random-access memory (RAM) and 50-MB available hard-disk memory. **Cadence Design Systems, Inc., PCB Systems Div., 13221 SW 68th Pkwy., Ste. 200, Portland, OR 97223; (503) 671-9500, FAX: (503) 671-9501, e-mail: pcbinfo@cadence.com, Internet: www.cadence.com.** MRF

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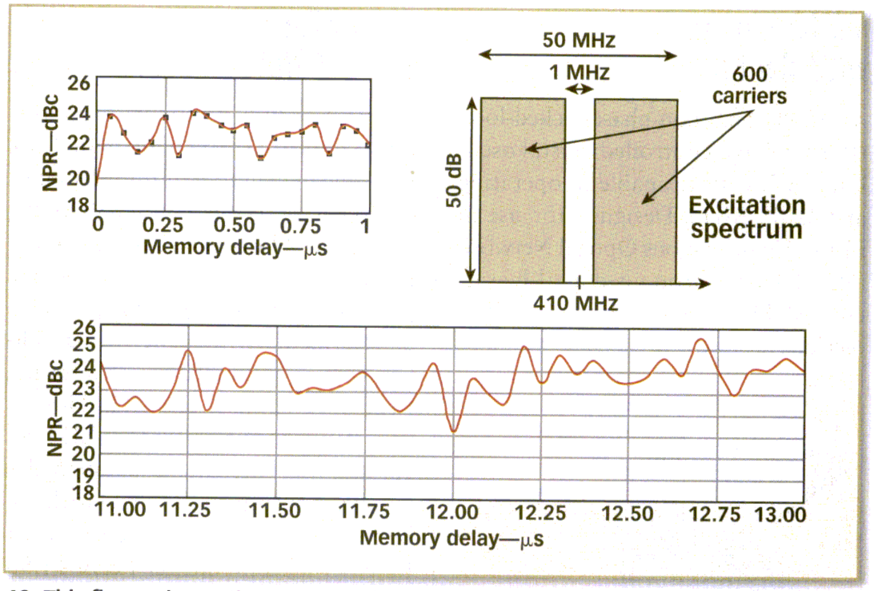
equal-amplitude, random-phase, uniform-frequency spacing and a central, 1-MHz notch that is 50 dB deep. The block diagram of the simulation is roughly similar to that of ref. 5 with appropriate filtering adjustments. A greater number of carriers would have been required to fully satisfy the statistical requirements of this noise simulation. As previously mentioned, though, the "mem.model" greatly increases the computer RAM consumption and, therefore, severely limits the number of sources that can be treated.

Before looking at NPR results, it is of prime importance to see what kind of manifestation arises at the output of the "mem.model" from the combined influences of distortion and memory effects. Displaying the output-signal envelope versus time for different values of the memory delay τ does not reveal any clear modification with respect to the input excitation. As expected, noise resembles noise. It is more appropriate to examine how the corresponding power behaves. This was performed by adding a "SIGPWR" test at the output of the "mem.model." Indeed, this function made it possible to determine the total output power $P_{out\ total}$ over the entire band of the NPR excitation. **Figure 9** shows the result of this investigation versus the memory delay τ for a total input power of 0 dBm. This representation is limited to small intervals of τ due to the fact that the value of $P_{out\ tot}$ versus τ is nearly constant except for 0 μs, 12 μs, and all of its multiples, where it exhibits steep negative impulses of approximately 1-dB amplitude. A relatively simple interpretation of this behavior can be provided. The 12-μs period of $P_{out\ total}$ versus τ can be viewed as a direct manifestation of the beat period relating to the basic 83.33-kHz frequency spacing of the 600 carriers that synthesize the random-excitation process. On the other hand, the fact that these periodic impulses are steep and negative must be interpreted according to a statistical approach. Indeed, for τ = 0 μs and each multiple of 12 μs, the situation can be considered memoryless and distortion occurs instantaneously at each peak of the input signal. Compression of $P_{out\ total}$ is then maximum. But as soon as τ differs from these particular values, the random nature of the signal predominates, which results in less compression and an unvarying value of $P_{out\ total}$. This interpretation is corroborated by the width of the impulses shown in Fig. 9. The 0.1-μs width appears to agree well with the theoretical autocorrelation time constant of the narrowband, quasi-white-noise process involved in this simulation, which is the reciprocal value of the noise bandwidth (here it is 50 MHz).

The foregoing development clarifies the NPR behavior versus the memory delay τ. NPR, which is defined as the ratio of the carrier-power density outside the notch to the IM power density within the notch, is performed in the simulation block diagram through two, 500-kHz-wide bandpass filters followed by adequate calculation. **Figure 10** shows a typical example of the NPR behavior versus τ for a total input power of 0 dBm, as stated previously. NPR, similar to $P_{out\ total}$, exhibits fluctuations around an averaged value (approximately 23 dBc). Nevertheless, the magnitude of these fluctuations is substantially larger than those of $P_{out\ total}$. The most probable explanation for this observation is that the NPR calculation is based on a noise-to-noise ratio and, moreover, is performed on small-analysis bandwidths compared to the total bandwidth of interest. As a consequence, the periodic impulses for τ = 0 μs and the multiples of 12 μs are now nearly imperceptible. Note that these results are based on only five successive simulation runs. Of course, one can reduce the uncertainty of the results by increasing the number of runs. But this requires more computing time. A more suitable improvement lies in a future extension of computer RAM to increase the number of carriers to several thousand. MRF



10. This figure shows the NPR variations versus the memory delay τ obtained from simulation on a "MAR3" module, with the previously discussed excitation spectrum and 0-dBm total input power.

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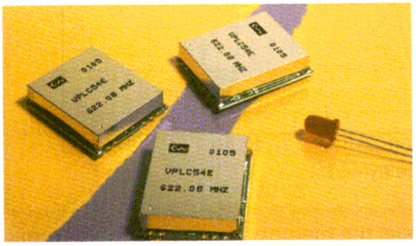
VCXO Works To 622.08 MHz

A LOW-PROFILE, non-phase-locked-loop (PLL) voltage-controlled crystal oscillator (VCXO) is capable of operating at 622.08 MHz. Designed for use in PLLs of Synchronous Optical Network (SONET)/synchronous-digital-hierarchy (SDH) systems, this +3.3-VDC oscillator is based on a fundamental-mode



crystal. The VCXO also minimizes jitter [<1 ps root-mean square (RMS)]. The unit is housed in a low-profile, nonhermetic 1.0 × 1.2-in. (2.54 × 3.04-cm) package with FR4 substrate and grounded metal cover. P&A: $117.00 each.

Connor-Winfield Corp., 2111 Comprehensive Dr., Aurora, IL 60505; (630) 851-4722, FAX: (630) 851-5040, e-mail: info@conwin.com, Internet: www.conwin.com.

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Load Provides Amplifier Stability

THE ZXFV201 IS a high-speed, current-mode amplifier that meets the requirements of video and high-speed signal-processing applications. The unit operates over the −40 to +85°C temperature range and provides a bandwidth of 300 MHz, a slew rate of 400 V/μs, and an output-drive rating of 40 mA. The device maintains stability with up to 400 pF of capacitive load. Differential gain and phase are low at 0.01 percent and 0.01 deg., respectively. Power-supply requirements are ±5 VDC at a current of 7 mA per amplifier. P&A: $2.00 each (1000 qty.).; 4 to 6 wks.

Zetex, Inc., 47 Mall Dr., Commack, NY 11725; (631) 543-7100, FAX: (631) 864-7630, Internet: www.zetex.com.

Enter No. 78 at www.mwrf.com

Gain Block Boasts 2.9-dB Noise Figure

THE SGA-7489 IS a silicon-germanium (SiGe) 50-Ω cascadable gain block featuring high output third-order intercept point (IP3) [+36 dBm at 850 MHz], high gain (22 dB at 850 MHz), and a noise figure of 2.9 dB from a single positive supply voltage. The unit is also an intermediate-frequency (IF) amplifier, with an output IP3 of +38 dBm and P1dB of +23 dBm at 100 MHz. Housed in a standard surface-mount SOT-89 package with backside metallization, this amplifier requires only DC blocking, bypass capacitors, and a bias inductor for external components. P&A: $1.95 each (10,000 qty.).

Standford Microdevices, Inc., 522 Almanor Ave., Sunnyvale, CA 94086; (800) 764-6642, (408) 616-5464, FAX: (408) 739-0970, Internet: www.stanfordmicro.com.

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FET Operates To 500 MHz

THE L2721 IS a 15-W, 11-dB gain, 500-MHz, low-cost laterally-diffused-metal-oxide-semiconductor (LDMOS) field-effect transistor (FET). It is assembled in a two-lead surface-mount package. It is not internally matched and will operate from DC to above the frequency of test. The FET is intended to operate from +12- to +16-VDC power supplies. It is suitable for narrowband or wideband circuits.

Polyfet RF Devices, 1110 Avenida Acaso, Camarillo, CA 93012; (805) 484-4210, FAX: (805) 484-3393, Internet: www.polyfet.com.

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Connectors Target 50-Ω Coaxial Cables

THE RFD-1605-2 and RFD-1630-2 series of 7/16 DIN male and female connectors is silver (Ag)-plated machined brass connectors with Teflon insulation that features the versatile combination head configuration. Since the ferrule stud backnut or cable-clamp assembly screws into the connector body, users have the ability to decide whether to create a straight or right-angle connector, offering maximum flexibility. The cable center conductor is soldered through either the side or the end opening of the connector body. The series is suitable for most 50-Ω coaxial cables.

RF Connectors, 7610 Miramar Rd., San Diego, CA 92126; (800) 233-1728, (858) 549-6340, FAX: (858) 549-6345, e-mail: rfi@rfindustries.com, Internet: www.rfindustries.com.

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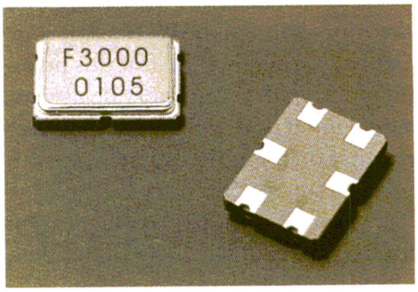
Filters Span 0 to +85°C

THE F3000 FUNDAMENTAL-mode family of monolithic crystal filters is available in two- and four-pole configurations in a variety of bandwidth and rejection characteristics. Typical operating temperature ranges are from 0 to +70°C for indoor applications to −40 to +85°C for outdoor, power-pole environments. The filters are offered in a true surface-mount-device (SMD) ceramic package



measuring 7.0 × 5.0 × 1.4 mm. Applications include cellular telephone, base stations, communications receivers (Rxs), local-area network (LAN), wide-area network (WAN), wireless, and remote-meter reading. P&A: $2.88 (10,000 qty.); stock to 10 wks. (prototypes) and 10 to 12 wks. (production qty.).

Tellurian Technologies, Inc., 1801 Hicks Rd., Suite B, Rolling Meadows, IL 60008; (847) 934-4141, FAX: (847) 934-4175, e-mail: info@telliantech.com.

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Sleeves Cover Antenna Elements

ANT SKINS ARE low-cost antenna sleeves in lengths that cover the 400-MHz-to-2.4-GHz frequency range. The sleeves provide the ruggedness of whip antennas, but are hollow to cover a low-cost internal element such as a wire, rod, or flexible shaft. The sleeve is designed to support a range of mounting options. P&A: less than $0.50 (in production quantities).

Antenna Factor, 575 SE Ashley Pl., Grants Pass, OR 97526; (541) 956-0931, FAX: (541) 471-6251, Internet: www.antennafactor.com.

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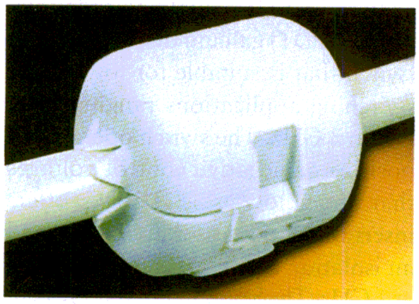
Oscillator Boasts Low Jitter

THE PE1100BV SERIES is a line of differential positive-emitter-coupled-logic (PECL) output oscillators. The series uses a true crystal design for jitter of 3 ps root



mean square (RMS) maximum for >70 MHz. With a frequency range spanning 10 to 170 MHz, the parts have an input voltage of +3.3 VDC ±10 percent or +5 VDC ±10 percent.

Pletronics, Inc., 19013 36th Ave. W., Suite H, Lynnwood, WA 98036; (425) 776-1880, FAX: (425) 776-2760, e-mail: ple-sales@pletronics.com, Internet: www.pletronics.com.

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Filter Features 50-dB Rejection

MODEL NBR MR1004X is a multioctave band-reject filter. Covering 7 to 18 GHz, insertion loss is 2 dB typical, bandwidth is 180 MHz at 3 dB typical, and rejection bandwidth is 20 MHz minimum. Rejection is 50 dB, passband spurious and ripple is 5 dB, limiting level is +10 dBm minimum, and linearity is ±10 MHz. Coil resistance is 110 μH typical.

OMNIYIG, 3350 Scott Blvd., Bldg. 66, Santa Clara, CA 95054; (408) 988-0843, FAX: (408) 727-1373, e-mail: Omniyig@ix.netcom.com, Internet: www.Omniyig.com.

Enter No. 85 at www.mwrf.com

Monitor Detects Gamma Rays To 0.02 MeV

GAMMA-SCOUT IS a handheld radiation monitor. It features a Geiger-Müller tube detector and a large liquid-crystal display (LCD) mounted in an ergonomic, rugged, impact-resistant Novodur housing. Gamma-Scout measures alpha, beta, and gamma rays to 4.00, 0.20, and 0.02 MeV, respectively. The onboard memory and serial port make this device suitable for field-measurement and data-logging applications. An ultra-long-life 10-year battery is included. P&A: $329.95 each.

Scientifics, Dept. A011-C999, 60 Pearce Ave., Tonawanda, NY 14150; (800) 728-6999, (716) 874-9091, FAX: (800) 828-3299, e-mail: cons_order@edsci.com, Internet: www.scientificsonline.com.

Enter No. 86 at www.mwrf.com

Switch Targets DC To 3 GHz

THE SW-456 IS a single-pole, double-throw (SPDT) gallium-arsenide (GaAs) switch that is suitable for low-power switching applications ranging from DC to 3 GHz. The switch operates on positive or negative control voltages that are as low as +2.3 VDC, offers insertion loss of less than 0.4 dB, and an isolation that is greater than 15 dB at 1 GHz. The SW-456 provides switching between two RF inputs and two RF outputs. The switch can be used in low-power time-division-multiple-access (TDMA), code-division-multiple-access (CDMA), as well as wideband-CDMA (WCDMA) wireless systems at personal-communications-services (PCS), digital communications services (DCS), and cellular frequencies, along with many other low-power DC-to-3-GHz systems. P&A: $0.40 each (10,000 qty.).

M/A-COM, Inc., 1011 Pawtucket Blvd., Lowell, MA 01853; (978) 442-5000, FAX: (978) 442-5350, Internet: www.macom.com.

Enter No. 87 at www.mwrf.com

TCVCXO Spans −30 To +80°C

THE S6800 SERIES IS a surface-mount temperature-controlled voltage-controlled crystal oscillator (TCVCXO) that delivers frequency stability of ±2.5 PPM maximum versus temperature, ±0.3 PPM maximum versus supply voltage, ±1.0 PPM maximum per year versus

time, and ±0.3 PPM maximum versus load. With a supply voltage of +3 VDC ±5 percent, the S6800 yields a frequency control range of ±5 to ±12 PPM from a pull voltage of +0.5 to +2.5 VDC. Available in standard wireless frequencies of 12.80, 13.00, 14.40, 19.20, and 19.68 MHz, the unit operates within the temperature range of −30 to +80°C. The S6800 series is especially applicable within tight environments such as Personal Computer Memory Card International Association (PCMCIA) cards and handheld wireless devices.

SaRonix, 141 Jefferson Dr., Menlo Park, CA 94025; (650) 470-7700, FAX: (650) 462-9894, e-mail: saronix@saronix.com, Internet: www.saronix.com.

Enter No. 88 at www.mwrf.com

Amplifier Suits Custom Space Applications

A FIVE-CHANNEL AMPLIFIER has been specifically designed for custom space applications. Each independent channel that is used features a dedicated RF input/output (I/O), along with DC-bias connections. Each channel's RF performance is tailored differently to meet the application requirements. All components were manufactured and screened according to MIL-PRF-38534 Class K requirements.

Cougar Components, 198 Union Blvd., No. 200, Lakewood, CO 80228; (408) 522-3838, FAX: (303) 985-5177.

Enter No. 89 at www.mwrf.com

Duplexer Unaffected By Temperature

A CERAMIC MONOBLOCK duplexer component that suits the wideband-code-division-multiple-access (WCDMA) market provides additional benefits for integrated-circuit (IC) and cell-phone manufacturers, as well as consumers in the WCDMA field. This standard is important in the current market because it allows the world to use one cellular standard, improves efficiency throughout the network, and promises increased functionality, including high-speed Internet, streaming video, location awareness, and m-commerce. Ceramic duplexers, versus other technologies, are unaffected by temperature, vibration, or mechanical shock.

Murata Electronics North America, Inc., 2200 Lake Park Dr., Smyrna, GA 30080; (800) 831-9172, (770) 436-1300, FAX: (770) 436-3030.

Enter No. 90 at www.mwrf.com

Filter Thwarts PCS Interference

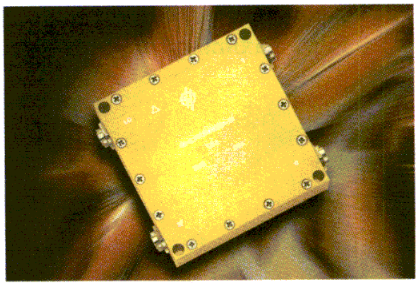
MODEL 14042 BANDPASS filter is used to prevent personal-communications-services (PCS) interference at the ENG receive site. It passes the entire ENG band (channels 1 through 10, from 1990 to 2500 MHz). The unit provides stopband rejection of 25 dB minimum at 1910 MHz and 2580 MHz, with a passband insertion loss of 1 dB maximum. With 50-Ω impedance and standard N female connectors, it is designed for indoor use, but can be provided as a temperature-compensated unit.

Microwave Filter Co., Inc., 6743 Kinne St., East Syracuse, NY 13057; (800) 448-1666, (315) 438-4700, FAX: (888) 411-8860, (315) 463-1467, e-mail: mfcsales@microwavefilter.com, Internet: www.microwavefilter.com.

Enter No. 91 at www.mwrf.com

Demodulator Uses Diplexer At I/Q Ports

AN IN-PHASE/QUADRATURE (I/Q) DEMODULATOR uses a diplexer at the in-phase (I) and quadrature (Q) ports to meet high local-oscillator (LO) and intermediate-frequency (IF) rejection requirements.



All of the components and processing meet MIL-PRF-38534, Class K and MIL-M-28837 requirements. Designs can be specified for space, military, performance, as well as commercial applications.

Cougar Components, 198 Union Blvd., No. 200, Lakewood, CO 80228; (408) 522-3838, FAX: (303) 985-5177.

Enter No. 92 at www.mwrf.com

Synthesizers Span 0.5 to 23 GHz

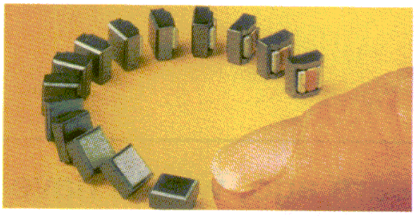
THE MFS SERIES of low-power microwave frequency synthesizers is suitable for applications requiring wider operating temperatures for use alongside smaller power supplies. With a frequency range of 0.5 to 23 GHz, switching speed is less than 50 ms, output-power range is +12 to +18 dBm, spurious output is −70 dBc, and harmonics are −20 dBc. DC power is +12/+18 VDC at 250 mA and +8/+18 VDC at 550 mA. The compact devices employ a single-module design implemented with complementary-metal-oxide-semiconductor (CMOS) application-specific integrated circuits (ASICs), advanced monolithic microwave ICs (MMICs), and a dedicated microprocessor.

Elcom Technologies, Inc., 11 Volvo Dr., Rockleigh, NJ 07647; (201) 767-8030, FAX: (201) 767-6266, e-mail: sales@elcom-tech.com, Internet: www.elcom-tech.com.

Enter No. 93 at www.mwrf.com

Inductor Ranges From 1 to 1000 μH

THE 1008PS SERIES of surface-mount power inductors is suitable for applications requiring magnetic shielding. Inductance values span 1 to 1000 μH with saturation current ratings up to



3 A. Applications include notebook computers, personal-computer (PC) cards, wireless communications, and handheld devices. The unit features a footprint of 3.7 × 3.7 mm. A specially designed ferrite cover provides magnetic shielding.

Coilcraft, 1102 Silver Lake Rd., Cary, IL 60013; (847) 639-6400, FAX: (847) 639-1469, e-mail: info@coilcraft.com, Internet: www.coilcraft.com.

Enter No. 94 at www.mwrf.com

Synthesizers Offer −115-dBc Phase Noise

THE DFS SERIES of dual-output, rugged frequency synthesizers is suitable for microwave and millimeter-wave radios up to 38 GHz. Phase noise is −115 dBc typical at 100 kHz in Ku-band operation. The frequency range is from 0.5 to 23 GHz in-band, switching speed is less than 25 ms, and output-power range is from +12 to +18 dBm. Spurious output is −70 dBc, while harmonics are −20 dBc and frequency stability is less than ±3 PPM from −35 to 70°C. The DFS series has a tuning bandwidth up to 1000 MHz and step sizes ranging from 25 kHz to 10 MHz. DC power consumption for the synthesizers is less than 4 W.

Elcom Technologies, Inc., 11 Volvo Dr., Rockleigh, NJ 07647; (201) 767-8030, FAX: (201) 767-6266, e-mail: sales@elcom-tech.com, Internet: www.elcom-tech.com.

Enter No. 95 at www.mwrf.com

Connectors Target Board-To-Board Stacking

THE SCX ULTRAMINIATURE coaxial connector series is suitable for board-to-board stacking arrangements with a 0.375-in. (0.953-cm) overall mated pair length and 0.165-in. (0.419-cm) maximum height in low-profile R/A configuration. An air dielectric interface is maintained for constant 50-Ω characteristic impedance. VSWR is 1.25:1 maximum per mated pair up to 20 GHz using a quick-disconnect, snap-in mating scheme with detent locking. The cable-mount connectors are designed for a full-crimp assembly with standard crimp tools or solder termination. Other connector types include a blindmate/float-mount board-to-board mounting version, as well as low-profile right-angle configurations for tight right-angle packaging constraints.

Sabritec, 17750 Gillette Ave., Irvine, CA 92614; (949) 250-1244, FAX: (949) 250-1009, Internet: www.sabritec.com.

Enter No. 96 at www.mwrf.com

Oscillators Span 1 To 125 MHz

THE PrO S8002C ceramic series is a line of surface-mount-device programmable oscillators. Operating voltages are +3.0, +3.3, and +5.0 VDC while the frequency range is 1 to 125 MHz. Operating at +3.0 and +3.3 VDC, period jitter root mean square (RMS) is kept to a noise-free level of 50 ps maximum 33+ to 90 MHz, 100 ps maximum 5+ to 33 MHz, and 167 ps maximum 1 to 5 MHz. Operating at +5 VDC, jitter is kept to 17 ps typical 42 ps maximum 33+ to 125 MHz and 33 ps typical 100 ps maximum from 1 to 33 MHz. In all cases, the oscillators contain a unique internal programming feature that allows a distributor to supply the specified frequency in one to two days.

SaRonix, 141 Jefferson Dr., Menlo Park, CA 94025; (650) 470-7700, FAX: (650) 462-9894, e-mail: saronix@saronix.com, Internet: www.saronix.com.

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new literature

Varactor Diodes

A 12-PAGE engineering bulletin (SG-950) offers detailed descriptions of 11 series of diodes that provide designers with a wide selection of capacitance versus voltage characteristics, including super hyperabrupt, wideband hyperabrupt, microwave hyperabrupt, high-quality-factor (Q) abrupt, and microwave abrupt. Product descriptions include features, specifications, outline drawings, applications, and C-V curves. The listings include common cathode models.

Sprague-Goodman Electronics, Inc.; (516) 334-8700, FAX: (516) 334-8771, e-mail: info@spraguegoodman.com.
●Enter No. 60 at www.mwrf.com

DAQ Equipment

AN EIGHT-PAGE brochure offers devices that are suitable for test-and-measurement applications. Products for data acquisition (DAQ), DC sourcing and measurement, optic testing, telecommunications, audio measurements, microwave switching, and device characterization are presented. Specifications include inputs, outputs, frequency, resolution, continuity, resistance, current, and temperature.

Keithley Instruments, Inc.; (888) 534-8453, Internet: www.keithley.com.
●Enter No. 61 at www.mwrf.com

EMI Reduction

A BOOKLET ENTITLED "Applications Guide to EMI/RFI/ESD" offers information on electromagnetic interference (EMI), RF interference (RFI), and electrostatic distortion (ESD) and solutions for design engineers. The guide includes a checklist of products available to provide EMI reduction and ESD suppression, a selector-guide flowchart to assist designers in specifying the correct devices, and a snapshot of international EMI/ESD regulatory standards. The guide provides the top 10 printed-circuit-board (PCB) EMI rules used in the design of low-noise boards, while also explaining actual proven circuit solutions for EMI reduction and ESD suppression. Theories and step-by-step instructions on how to solve various PCB problems are presented.

AVX Corp.; (843) 946-0414, FAX: (843) 946-0626, e-mail: lit@avxcorp.com.
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Logic Analyzers

TEST EQUIPMENT IS available from an 18-page catalog. Pulse generators, logic analyzers, plotters, TV and video devices, meters, RF signal generators, inductance-capacitance-resistance (LCR) analyzers, spectrum analyzers, precision sources, and oscilloscopes are specified. Frequency counters, RF measurement equipment, impedance analyzers, network analyzers, power supplies, audio analyzers, semiconductors, signal generators, as well as data-acquisition (DAQ) equipment are offered from a variety of manufacturers. Pricing and ordering information is included.

Test Equipment Connection Corp.; (800) 615-8378, (407) 804-1299, FAX: (800) 819-TEST, (407) 804-1277, Internet: www.TestEquipmentConnection.com.
●Enter No. 63 at www.mwrf.com

Test Equipment

TEST EQUIPMENT IS the subject of a 56-page catalog. Oscilloscopes, arbitrary function generators, probes, DC power supplies, waveform generators, data-acquisition (DAQ) equipment, pulse generators, spectrum and network analyzers, as well as cable are presented. Reconditioned equipment offerings include power supplies, spectrum analyzers above and below 1 GHz, RF measurement equipment, signal generators, counters, logic analyzers, and meters. A section on new equipment is included.

TestEquity, Inc.; (800) 884-3457, FAX: (800) 272-4329, Internet: www.testequity.com.
●Enter No. 64 at www.mwrf.com

GPIB Programmers

A 200-PAGE catalog contains information on a selection of AC and DC power supplies. Electronic loads, battery testers, power-supply controllers, general-purpose-interface-bus (GPIB) programmers, and rack assemblies for power supplies are presented. Oscilloscopes and signal generators are offered, along with electrical safety testers, jitter meters, as well as test-and-measurement instruments.

IFR; (800) 835-2352, (316) 522-4981, e-mail: info@ifrsys.com, Internet: www.ifrsys.com.

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Proprietary-Bus Systems

A REFERENCE GUIDE outlines a company's line of VME, VXI, cPCI, PXI, and proprietary-bus-systems products. A range of system chassis, enclosures, power supplies, and turnkey solutions for telecommunications, test-and-measurement, military, and related applications is presented. Modified and custom products are offered. Services include printed-circuit-board (PCB) design and assembly, component and software integration, and functional testing.

Tracewell Systems, Inc.; (800) 848-4525, (614) 846-6175, FAX: (614) 846-4450, Internet: www.tracewellsystems.com.

●**Enter No. 66 at www.mwrf.com**

Network Enclosures

A SIX-PAGE brochure illustrates the advantages of the isoNet line of network enclosures. Options that are described include lift-off-style ventilated doors and side panels, multivendor-compatible mounting rails, cable-management features and accessories, power-distribution strips, and a variety of cooling accessories.

Crenlo, Inc.; (507) 289-3371, FAX: (507) 287-3405, e-mail: sales@emcor-crenlo.com, Internet: www.emcor-crenlo.com.

●**Enter No. 67 at www.mwrf.com**

MMIC Products

AN 818-PAGE designer's guide includes 39 monolithic-microwave-integrated-circuit (MMIC) product data sheets. Wireless application selection guides, application notes, and major trade-journal article reprints are featured. More than 135 products spanning the DC-to-40-GHz frequency range are detailed.

Hittite Microwave Corp.; (978) 250-3343, FAX: (978) 250-3373, e-mail: sales@hittite.com, Internet: www.hittite.com.

●**Enter No. 68 at www.mwrf.com**

Subracks/Accessories

A 124-PAGE catalog details a range of subracks and accessories for CompactPCI, VME64x, and other platforms. Accessories, including side plates, injector/ejector handles, front panels, and drive bays are covered.

Pentair Electronic Packaging; (888) 550-9543, Internet: www.pentair-ep.com/schroff.

●**Enter No. 69 at www.mwrf.com**

Card Cages

A FOUR-PAGE brochure provides charts and illustrations detailing the R10 and Bord-Pak® card cages. Mechanical specifications are included. Customization and ordering information are provided.

Buckeye ShapeForm; (800) 728-0776, FAX: (614) 445-8224, Internet: www.buckeyeshapeform.com.

●**Enter No. 70 at www.mwrf.com**

Optics/Lasers

THE 2001 REFERENCE catalog for technical scientists, educators, and engineers contains 100 pages featuring more than 1500 science, laboratory, and optical products. Science-discovery items, optics, biomedical instruments, scales, solar equipment, and magnets are offered.

SCIENTIFICS; (800) 728-6999, (716) 874-9091, FAX: (800) 828-3299, e-mail: cons_order@edsci.com, Internet: www.scientificsonline.com.

●**Enter No. 71 at www.mwrf.com**

Cable Ferrites

AN RF-INTERFERENCE (RFI) cable-ferrite catalog features 126 products for round and flat cables. Expanded universal wideband styles, low- and high-frequency specific-purpose styles, and 2.45-GHz Bluetooth microwave series are offered.

FerriShield, Inc.; (212) 268-4020, FAX: (212) 268-4023, Internet: www.ferrishield.com.

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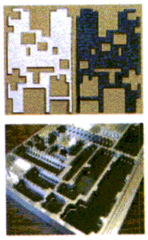

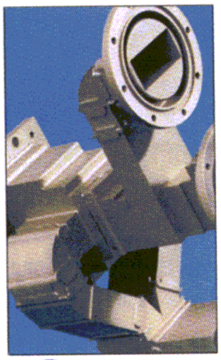

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looking back

FORTY YEARS AGO, the model SFD-307 inverted coaxial magnetron from SFD Laboratories, a subsidiary of Varian Associates (Union, NJ), provided 50-W average power and 100-kW peak power from 33.5 to 35.5 GHz.

next month

Microwaves & RF September Editorial Preview

Issue Theme: Amplifiers & Oscillators

News

At one time, the microwave industry was highly dependent upon the military for its business. With the explosion in wireless markets during the 1990s, however, military customers were often left behind. But in the quest for a more balanced microwave economy, the industry is returning to the military for business. What are the future trends facing the military and what do they require from their suppliers? Do not miss this Special Report, written by Fred Levien of The Levien Group, on the current state of military electronics.

Design Features

In September, the Design Features section offers a variety of contributed articles in support of the issue theme, including a technique for modeling and verifying timing jitter in oscillators, a review of tunable oscillator-design fundamentals, and methods for making triggered measurements with a sampling power meter. September also examines the use of harmonic-balance techniques for modeling nonlinear circuits, such as oscillators and high-power amplifiers, and marks the opening of a three-part article series on the design of LNAs. Finally, an author from Analog Devices will explore various LO architectures for the 5-to-6-GHz unlicensed frequency band.

Product Technology

The September Product Technology section will feature a novel new integrated V-connector design for reliable higher-frequency operation, especially for optical components operating at OC-768 rates. Additional product features will examine a line of Darlington HBT-based amplifiers for applications through 5 GHz, a connector system with interchangeable transition pins and tabs, a precision jitter analyzer from a leading supplier of digital oscilloscopes, and an amazing design-kit collection of 90 small-signal amplifiers and a test fixture that sells for only $10.

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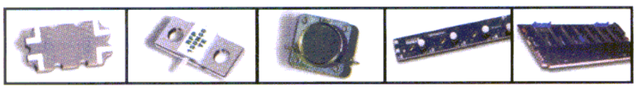

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