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FOR DESIGNERS AT HIGHER FREQUENCIES

Microwaves & RF

Frequency-Control Technology Issue

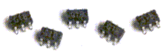
NEWS
Wireless spurs crystal market growth

DESIGN FEATURE
A different twist on VCO tuning

PRODUCT TECHNOLOGY
Power meters boast data-processing capability

Application personalities upgrade powerful EDA software

Worth switching to...



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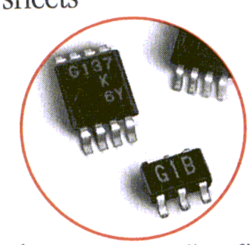

Shown 3X actual size.

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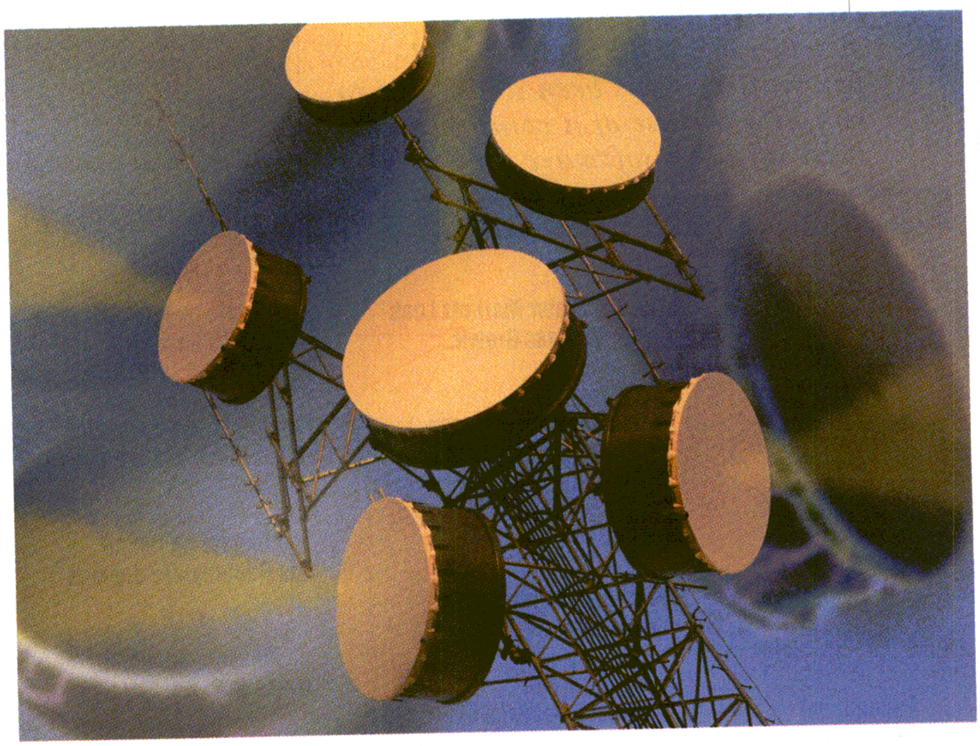

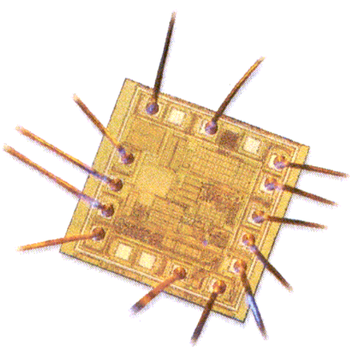

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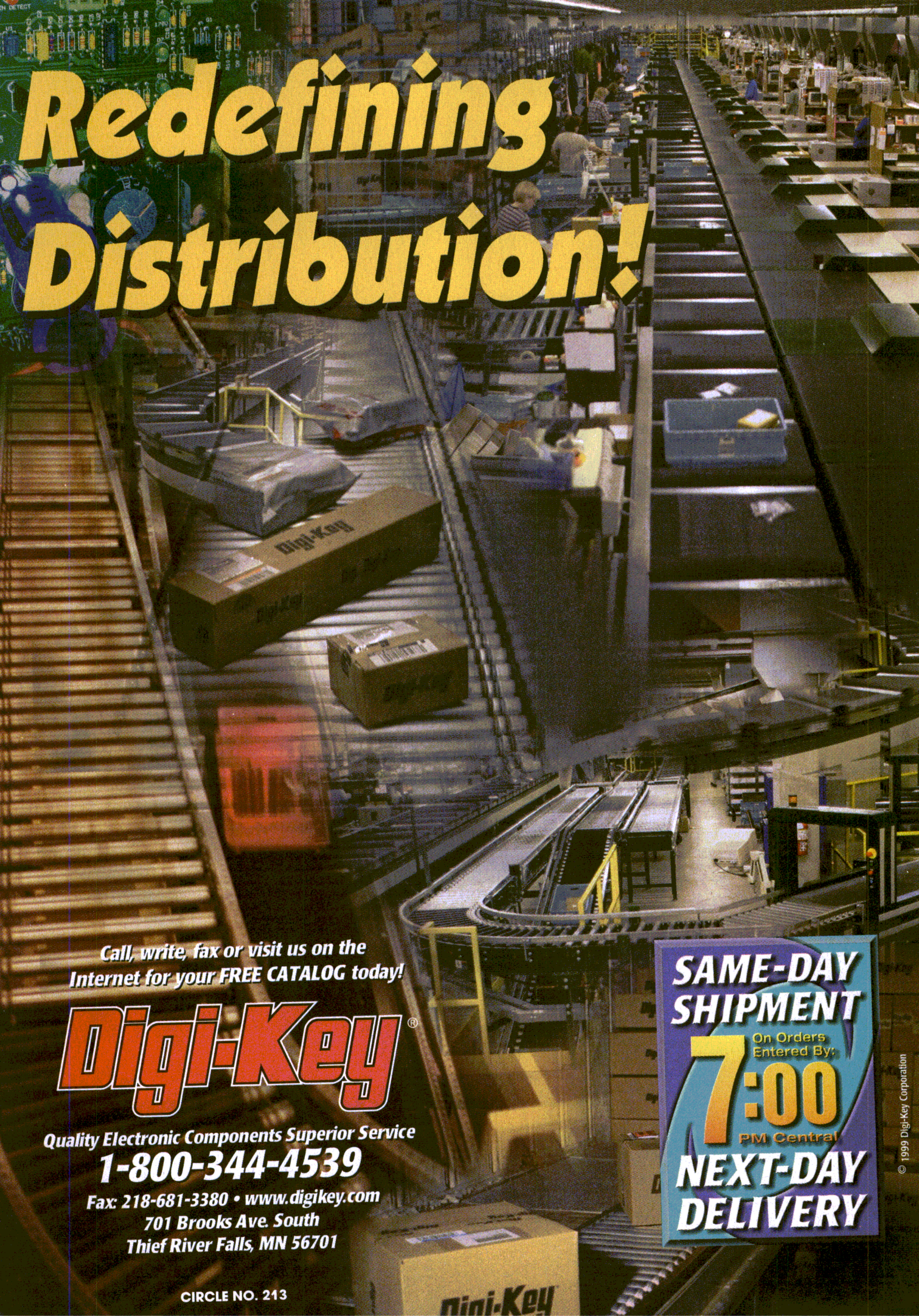
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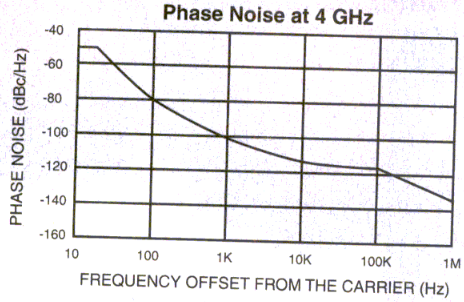

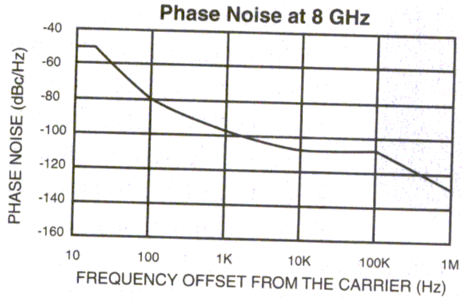

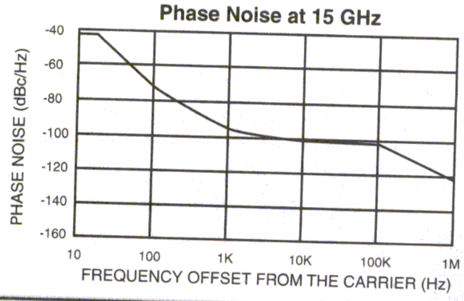

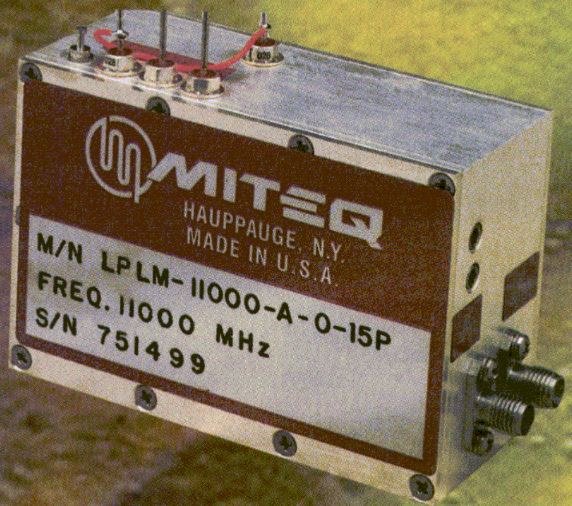

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Output power	+13 dBm, minimum
Output power variation	±1 dB, maximum
Input reference frequency range	1 to 20 MHz
Input reference power range	-3 to +3 dBm
Output spurious signals	-65 dBc minimum
Output harmonics	-50 dBc minimum
Output impedance	50 Ohm nominal
Load VSWR	1.5:1 nominal
DC voltage (Customer specified)	15, 20 or 24 V
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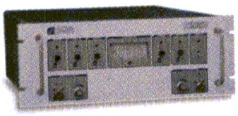

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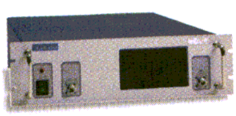

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CIRCLE NO. 280

RMS POWER

To the editor:

Several articles in the September 1999 issue mention root-mean-square (RMS) power. The use of the term is probably an error arising from the belief that VRMS × IRMS = P RMS. In fact, VRMS × IRMS = p average = VDC × IDC. The authors of the September articles "Supplying Power For Wireless Data-Communications Systems," (p. 93) and "Revolutionary RF IC Performs RMS-To-DC Conversion" (p. 140) seem to have fallen into this trap. The equation on page 144 is mathematically correct, but is not useful since the quantity of interest is usually average power.

D.J. Richardson
Gloucester, England

POWER SENSING

To the editor:

In the September article on power sensing, "Wide-Range Sensor Gauges Power Of Complex Signals" (p. 128), there is a sentence that reads "In the square-law region, a diode's detected output voltage is proportional to the (logarithm of the) input power and so measures power directly." The expression in parentheses should not be there (the output voltage is proportional to the input power, not the log of the input power). I regret the error.

Ron Hogan
Development Engineer
Hewlett-Packard Co.

DIRECTIONAL COUPLERS

To the editor:

I read Allen Podell's article with interest (*Microwaves & RF*, August 1999, p. 44). This is because as early as 1974, I published a paper[1] on the design of "homemade" directional couplers down to 1 MHz, where precision impedance measurements could be carried out. This was before when vector network analyzers (VNAs) became widely available—with a real-time Smith chart display facility as an extra bonus.

The couplers were of the "twisted wire" type with directivity being optimized by making the electrical and magnetic couplings equal—the underlying fundamental principle of all couplers. One of these couplers designed for 1-MHz operation was reported to have >50-dB directivity.

Dr. Peter Somlo
FIEEE
Killarney Heights, Australia

Reference

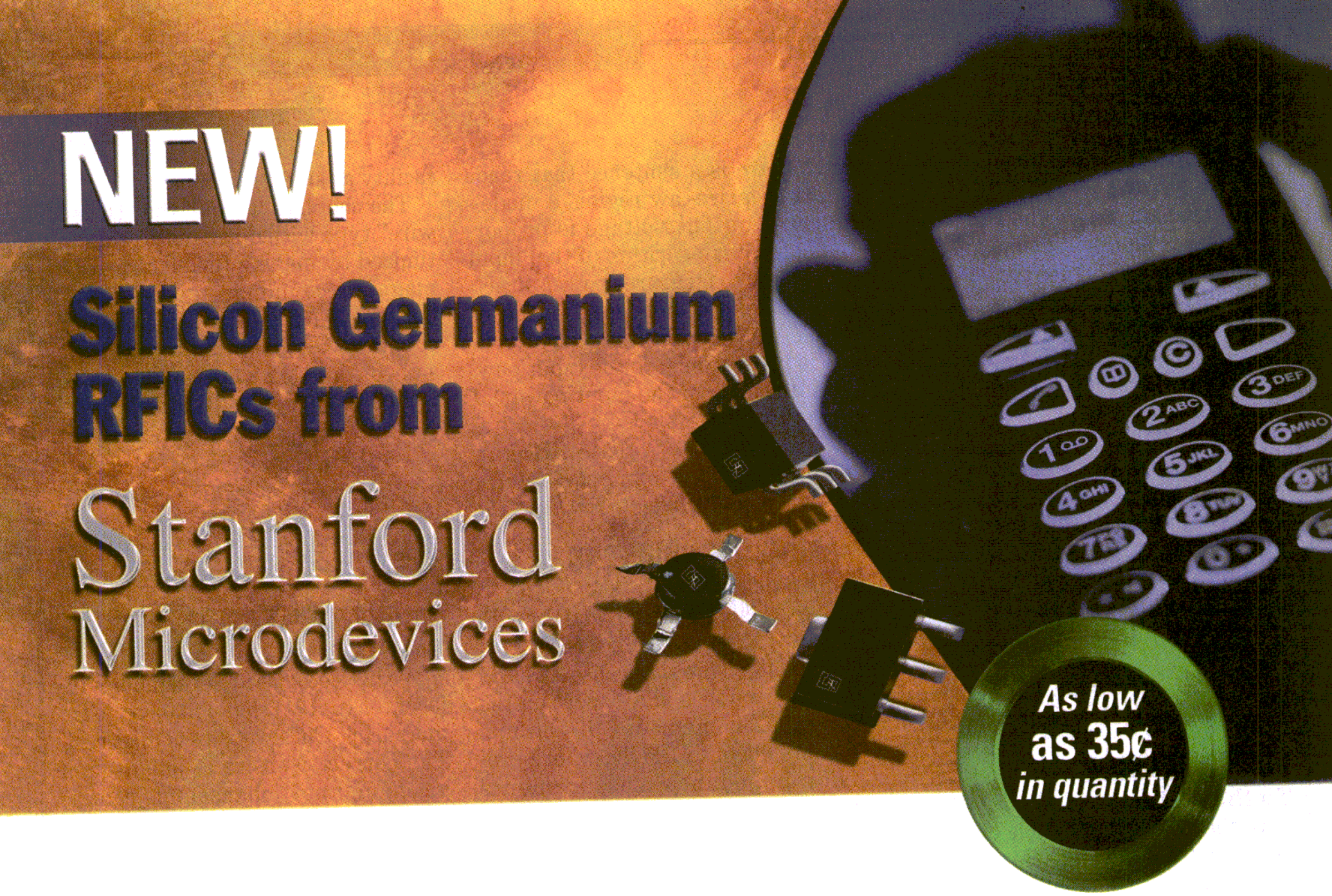
1. P.I. Somlo, "Precision Impedance Measurement and Smith Chart Display with Easily Fabricated Directional Couplers from 1 MHz Upwards," *Proceedings of the IREE (Australia)*, November 1974, pp. 341-345.

INCORRECT WEBSITE

To the editor:

We noticed that in September's Infocenter (p. 191) that Johanson Manufacturing Co.'s website is incorrect. The correct website is johansonmfg.com and not johansonmfr.com as was printed.

Roger Kauffman
Johanson Manufacturing Co.
Boonton, NJ



Silicon Germanium (SiGe), Stanford Microdevices' latest RF semiconductor process, offers benefits not attainable by conventional silicon-bipolar technologies: lower noise figures, lower power consumption, high output power at high efficiency, and high integration level.

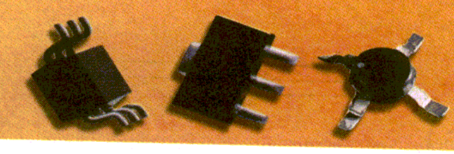
As part of a series of Stanford Microdevices' initiatives to apply silicon germanium technology to a broad spectrum of communications applications, we are now offering the wireless market devices built using a patented silicon germanium manufacturing process. As these devices enter the marketplace, consumers will benefit from cellular phones, pagers, and other wireless communications devices that have extended battery life, carry out multiple functions, and are smaller, lighter, and less expensive.

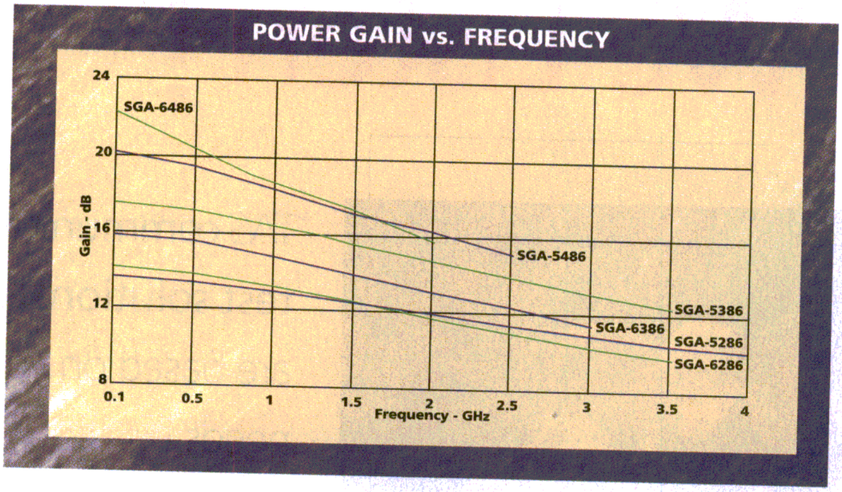
PRODUCT SELECTION GUIDE

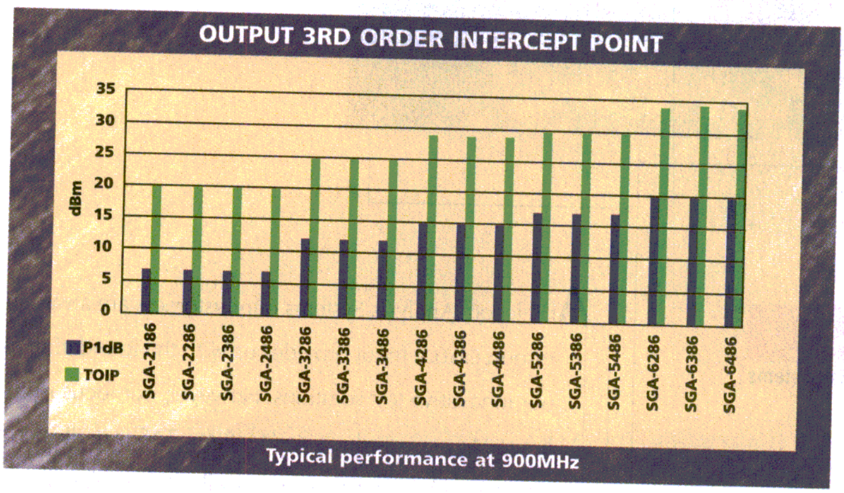
General Purpose Amplifiers

Part Number	Vd (V)	Id (mA)	3dB BW	P1dB (dBm)	IP3 (dBm)	Gain@ 1 GHz	Gain@ 2 GHz	NF 50 Ohm
SGA-2186	2.2	20	DC-5.0	+7.0	+20.0	10.5	10.2	4.1
SGA-2286	2.2	20	DC-3.5	+7.0	+20.0	15.0	14.0	3.2
SGA-2386	2.7	20	DC-2.8	+7.0	+20.0	17.4	16.4	2.9
SGA-2486	2.7	20	DC-2.0	+7.0	+20.0	19.6	18.0	2.5
SGA-3286	2.7	35	DC-3.6	+12.0	+26.0	14.8	13.4	3.5
SGA-3386	2.5	35	DC-3.6	+12.0	+25.0	17.4	16.2	3.0
SGA-3486	2.9	35	DC-2.0	+12.0	+25.0	21.5	19.4	2.6
SGA-4186	3.2	45	DC-6.0	+15.0	+29.0	10.4	10.2	4.6
SGA-4286	3.2	45	DC-3.5	+15.0	+29.0	13.8	12.6	3.3
SGA-4386	3.3	45	DC-2.5	+15.0	+29.0	17.0	15.2	2.8
SGA-4486	3.2	45	DC-2.0	+15.0	+29.0	19.0	16.8	2.5
SGA-5286	3.5	60	DC-4.0	+17.0	+30.0	13.5	12.7	4.1
SGA-5386	3.6	60	DC-3.2	+17.0	+31.0	17.3	16.0	3.5
SGA-5486	3.5	60	DC-2.4	+17.0	+31.0	19.7	18.0	2.8
SGA-6286	4.2	75	DC-3.5	+20.0	+34.0	13.8	12.4	3.9
SGA-6386	5.0	80	DC-3.0	+20.0	+34.5	15.4	13.8	3.8
SGA-6486	5.2	75	DC-1.8	+20.0	+34.0	19.7	16.7	2.9

SGA 2000 through 4000 series are also available in SOT-363
SGA 5000 and 6000 series are also available in SOT-89 & SOT23-5







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CIRCLE NO. 274

WHAT HAPPENS WHEN THE TECHNOLOGY GOES?

An old friend called the other day with a question about that year-end tradition for device enthusiasts—the International Electron Devices Meeting (IEDM). For many years, this has been the premier event for anyone interested in the true state of the art in electron tubes and solid-state devices. The meeting draws researchers from around the world, anxious to make their companies, and their engineering teams, proud. And when my friend called to ask about the number of electron-tube papers, a search through the abstracts was revealing—there were none.

As recently as the 1980s, the IEDM was a place to find new electron-tube developments. Leaders in the technology such as EEV, Varian, Litton, and Thomson-CSF regularly announced advances in traveling-wave tubes (TWTs), klystrons, magnetrons and other high-voltage devices, with presentations on ever-higher power levels and frequencies and increasingly sophisticated micromachining of cathodes and anodes.

Today, the IEDM is all about solid-state devices. According to General Chairperson Gary Bronner of IBM (Hopewell Junction, NY), over 570 abstracts were submitted from 31 different countries, but none on tubes. Instead, papers focused on dynamic-random-access-memory (DRAM) chips, complementary-metal-oxide-semiconductor (CMOS) devices, detectors and displays, electronically erasable programmable read-only memories (EEPROMs), thin-film transistors (TFTs), system-on-chip (SOC) devices, and quantum effects. Some presentations even promoted that latest darling of the semiconductor world, silicon germanium (SiGe), with several papers from IBM touting record transition frequencies along with the compatibility of SiGe with conventional bipolar-CMOS (BiCMOS) processing.

Where did the tubes go? Based on the number of research projects that will be presented at the IEDM (see p. 43 for more information on the 45th IDEM), it is safe to say that research dollars are being spent on solid-state devices, not on electron tubes. Certainly, some fine work continues on product development at the leading firms, and even at companies such as Communications and Power Industries (CPI of Palo Alto, CA and other locations), which owes its heritage to Varian Associates. But it would be difficult to argue that the same level of research funding being spend on, say, SiGe semiconductors is being spent on fundamental magnetron research.

The numbers of engineers working in tube areas are also decreasing. It is not an engineering area with the glamour of the latest semiconductor or communication technology. But electron tubes represent an important technology for high-power, high-frequency electronics, especially in military and broadcast applications.

Without funding, few engineers will be attracted to electron-tube design work. And without new engineers in this area, electron-tube technology will certainly fade away. Will megawatt transistors be ready to take the place of tubes when the time comes? ••

Jack Browne

Publisher/Editor

Microwaves & RF

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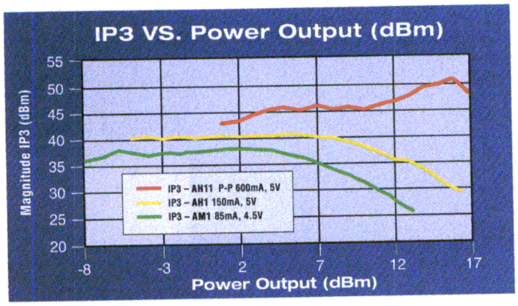

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PBG Composite Glass Materials Are Fabricated

WASHINGTON, DC—Researchers at the Naval Research Laboratory (NRL) have fabricated photonic-bandgap (PBG) nanochannel glass materials for the development of a new class of extremely compact and efficient optoelectronic devices. The new devices will have use in military and commercial applications. The research team consists of Dr. Armand Rosenberg, Elizabeth Bolden, and Dr. Brian Justus, all of the Optical Sciences Division. This work is funded by the Office of Naval Research.

According to Dr. Rosenberg, "Structures that exhibit photonic-bandgap optical effects are composed of alternating layers or rows of dissimilar materials. The thickness of the alternating layers is on the order of the wavelength of light. By manipulating the structures of these materials, it becomes possible to engineer materials with customized optical properties, suitable for a variety of applications. A major application area is controlling the propagation of light in optoelectronic devices, similar to how the flow of electrons is controlled in semiconductor devices. The size of present optical and optoelectronic devices could be greatly reduced and their efficiency increased if the propagation of light could be better controlled and optical losses due to scattering are eliminated. The novel PBG materials we have developed will enable the miniaturization of such optical and optoelectronic devices. In addition, new devices will be possible based on the unusual combinations of optical and electrical properties of these novel PBG materials, which are not found in nature."

New Devices Will Enhance Personal Safety

NEW ORLEANS, LA—Loc8.net and Glenayre Technologies, Inc. recently announced that they have signed an agreement to bring wireless-location services to a host of commercial and consumer applications, from finding lost loved ones to tracking the location of important valuables and commercial equipment.

As part of the agreement, Glenayre will develop a new two-way paging device that can alert police and other emergency officials of the pager location in case of an emergency. Subscribers who feel threatened or witness an accident, for instance, can press a button to immediately alert authorities. The devices will also help find missing loved ones, such as lost children and Alzheimer's patients, by allowing authorized friends and family to have access to pager-location information—down to street-address accuracy—through full-map displays on the Internet or a 911-certified call center.

The locator device, which Glenayre will develop, will be smaller than a pager and enable subscribers who do not need two-way messaging to track valuable goods and belongings. Possible uses include placement inside vehicles and other belongings for quick recovery in case of theft or inside a commercial transportation fleet for location-tracking and planning purposes. The device could even be attached to a pet's collar so that its location could be found through the web or a certified call center in case the pet wanders from home.

Agreement Reached For Gigabit Detector Devices

SAN JOSE, CA—Fujitsu Compound Semiconductor, Inc. (FCSI) has announced a joint agreement between Fujitsu Quantam Devices Ltd. (FQD) and Lucent Technologies, Microelectronics Group to produce a common design for detector devices used in receiver systems for gigabit-rate optical communications.

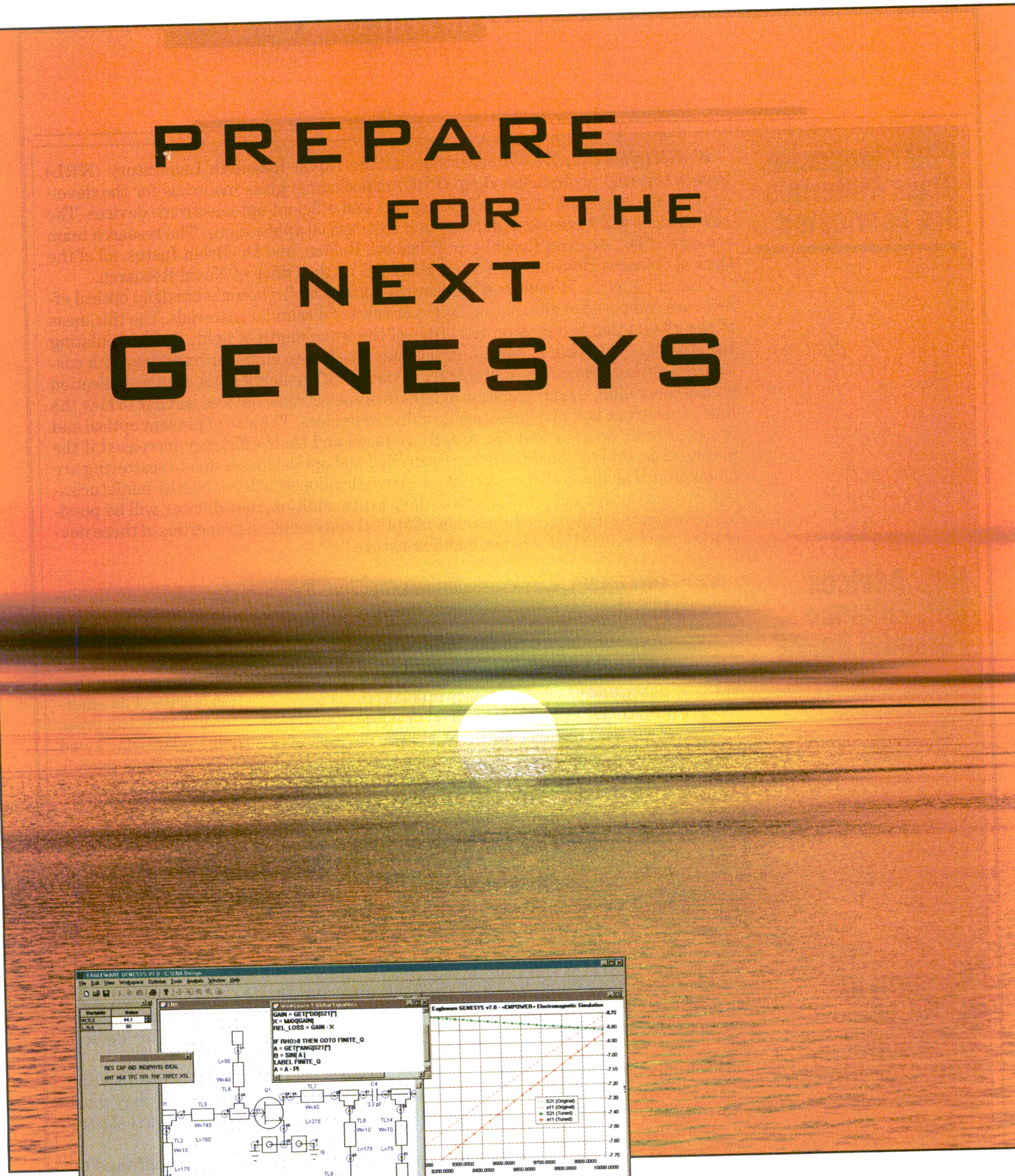
These detector devices are used to receive the weak optical signal from the fiber and convert it to gigabit data-rate logic. To achieve the desired performance, they must combine ultra-high bandwidth and speed, together with very-high optical and electrical sensitivity.

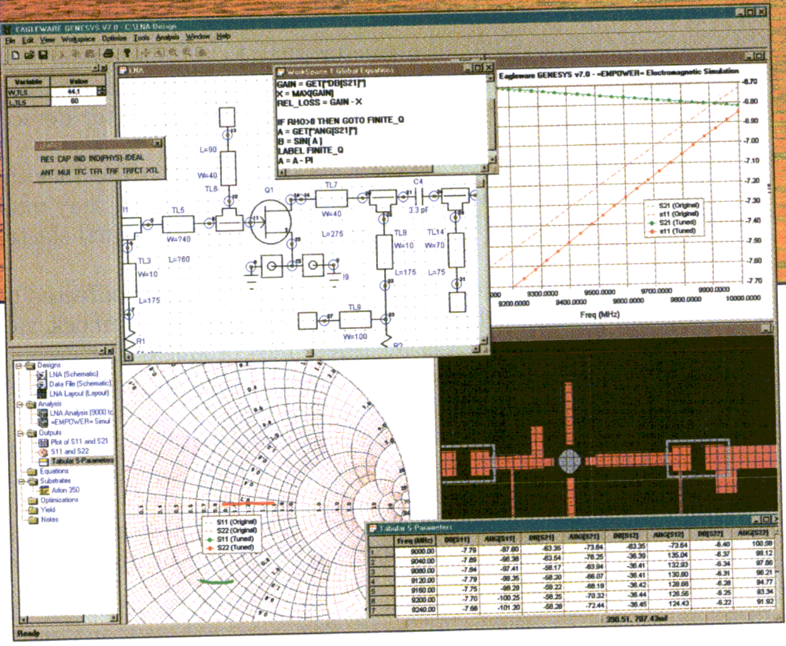
"Until now, optical communications systems growth has been seriously affected by the lack of standard, multisourced detector devices," according to Gene Brannock, vice president of engineering and marketing for FCSI. "These new products also simplify the system design by combining the photodetector diode and the low-noise, transimpedance amplifier into a single, easily mounted package."

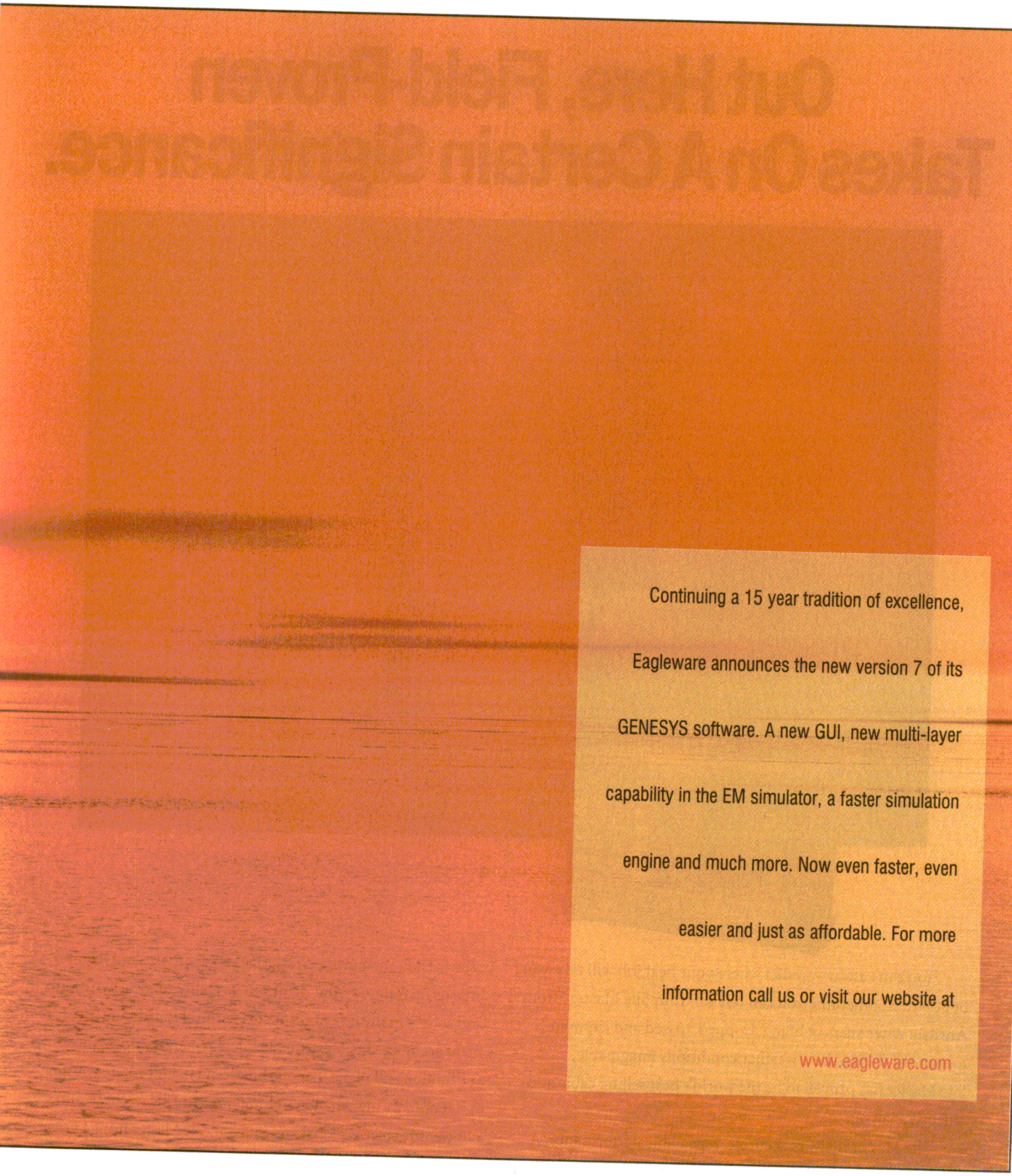
FQD and Lucent have reached an agreement for a common physical design for the outline and pin arrangement of the devices. The devices produced by FQD and Lucent are mechanically interchangeable.

The first products that are being developed by FQD and and will be covered by this agreement are targeted for 10-Gb/s (OC-192/STM-64) single-mode fiber-optical systems.

PREPARE FOR THE NEXT GENESYS






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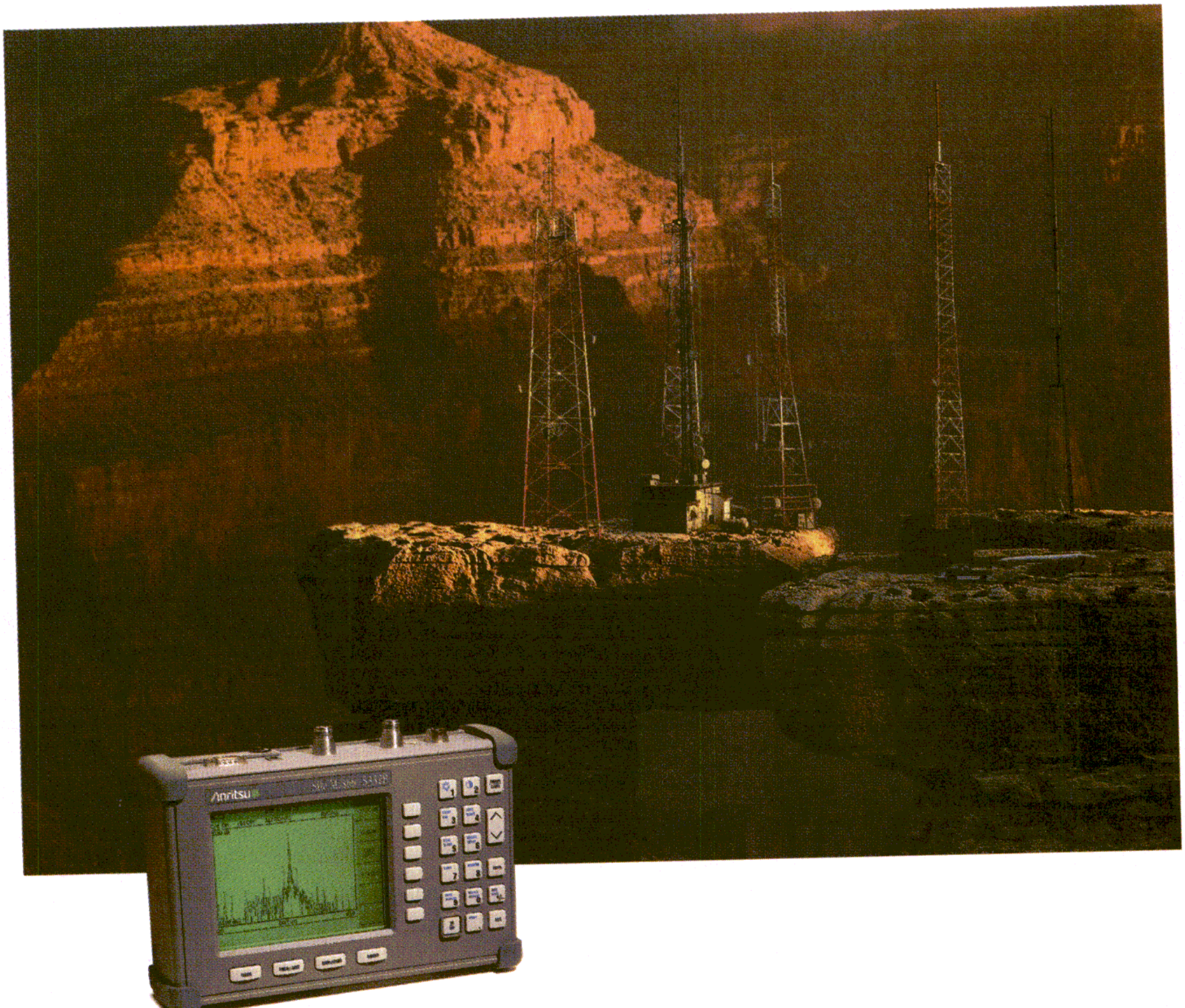

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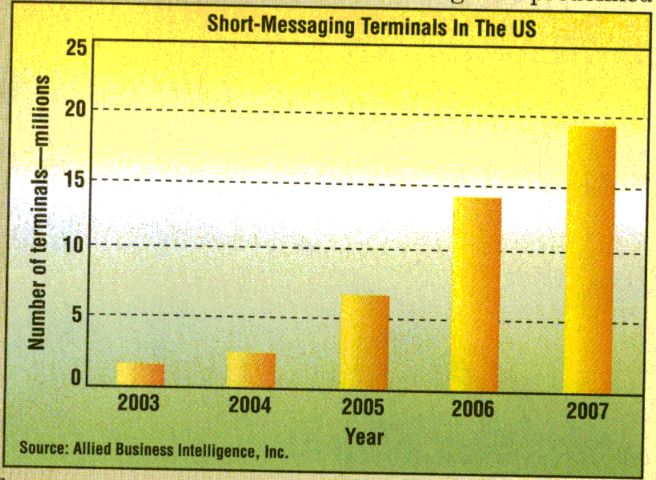
CIRCLE NO. 202

Satellite Systems To Prosper

OYSTER BAY, NY—Despite the early shortcomings of the Iridium system, the satellite market will be a healthy and prosperous segment of the communications industry, says Allied Business Intelligence, Inc. (ABI). According to a new report from ABI, revenues for the voice segment of the market will rise above $10 billion by the end of 2003. The broadband and short-messaging sectors of the market, which are developing at a slower pace than the voice market, will also prove to be multibillion markets, according to the findings in ABI's "Bandwidth On Demand Satellite Systems 1999."

"Iridium has put up a very impressive system, but unfortunately they have had to deal with being the first to commercial market without the advantage of a predefined customer a mature market would have offered," says Larry Swasey, ABI's vice president of communications research. There are many global and regional voice systems that are due to be deployed in the next two to three years, which will quickly find a market, according to the report. Regional systems will have the advantage of local, targeted marketing as well as the lower start-up cost of being a regional geostationary-earth-orbit (GEO) player.



The satellite-based short-messaging arena, which has already seen some early activity, will blossom during the next several years as tracking applications become more widespread with the advent of cheaper Global Positioning Systems (GPS). By the end of 2007, there will approximately be 20 million terminals in place (see figure), says Swasey. Industrialized nations will not realize the large audience of non-industrialized nations, however.

Unidirectional Serial Multiplexer Aids Armed Forces Network

MARCH AFB, RIVERSIDE, CA—The technical staff of the Armed Forces Network (AFN), a radio and television service for US armed forces personnel, recently began looking into improving its affiliate messaging system primarily used to deliver text-based radio and television scheduling changes and updates, in addition to delivering a live wire-service news feed, the main problem with the old system was the slow, aging multiplexers that were used to funnel multiple data streams through their encoded satellite-broadcast link. The fact that the old multiplexer is no longer being manufactured also increased the urgency to find a replacement.

After thoroughly evaluating the limited number of products potentially capable of handling their unique application—including testing the devices across their existing satellite system—they chose a unidirectional serial multiplexer from Champaign, IL-based Data Comm for Business (DCB).

The messaging system component of the signal reaching eight satellites around the world is output by the DCB multiplexer before being encoded and transmitted by the uplink. A total of four DCB multiplexers reside at the Armed Forces Radio and Television Service Broadcast Center (AFRTS-BC) facility—two in active use and two serving as redundant backups. Of the two active units, one generates the data signal sent to the uplink, while a second unit monitors a downlink "echo" from the satellite that is used to verify the quality of the data sent up.

Expanding the system's overall capabilities is possible because the new DCB multiplexer has improved the messaging system's output capacity. Previously limited to a maximum rate of 9.6 kb/s of asynchronous output, the new system can merge up to eight channels of asynchronous data—totaling 64 kb/s—into a 64K synchronous data stream plugged directly into the high-speed synchronous port on the uplink.

Experimental Transmission Of IEEE 1394 Occurs

SUNNYVALE, CA—Philips Semiconductors and Wi-LAN recently demonstrated wireless transmission of IEEE 1394 at 2.4 GHz using Wi-LAN's patented wideband-orthogonal-frequency-division-multiplexing (W-OFDM) technology. The demonstration took place at Internationale Funkausstellung (IFA) 1999, which was held from August 28 to September 3 in Berlin, Germany at the Hotel Berlin.

"The combination of IEEE 1394 and OFDM is ideally suited for wireless in-home multimedia networking environments," says Scott McGregor, senior vice president and general manager of emerging business at Philips Semiconductors. "We're excited to achieve this significant milestone with Wi-LAN, and look forward to continued advances in home networking."

Similar to all modulation schemes, OFDM encodes data inside an RF signal. Radio communications are often obstructed by occurring noise, stray, and reflected signals. By sending high-speed signals concurrently on different frequencies, OFDM technology offers robust communications. OFDM-enabled systems are highly tolerant to noise and multipath, which makes wide-area and in-home multipoint coverage possible.

China To Become World's Largest Market For Fiber-Optic Cable

NEWPORT, RI—China, the world's fastest-growing market for fiber-optic communications, plans to start massive deployment of fiber systems at the access level later this year. And by 2004, China will have installed more fiber in the feeder and access networks than the US, according to KMI Corp.'s report *Optical Fiber and Fiberoptic Cable Markets in China.*

In 1998, China installed 1.6 million kilometers of cable fiber in feeder and distribution systems. Beginning in 1999, cabled-fiber deployment in the access network will increase annually from 2.9 million cabled-fiber kilometers in 1999 to 11.2 million cabled-fiber kilometers in 2004, a compound annual growth rate (CAGR) of 39 percent. This compares with a forecast of similar cabled-fiber kilometers in the US in 2004.

At the end of 1997, China had installed 4.1 million kilometers of cabled fiber, representing more than 11 percent of the world market. According to the KMI report, fiber-optic cable demand will continue to increase from 5.2 million kilometers in 1998 to nearly 13 million cabled-fiber kilometers in 2004. This means that China will be the world's largest market for fiber-optic cable.

Currently, 14 joint-venture cable manufacturers in China supply more than 80 percent of the the country's cable requirement. The annual growth in demand for fiber-optic cable will be 10 to 20 percent from 1998 to 2004 with a market value increasing from $675 million in 1998 to more than $1 billion in 2004.

Kudos

Irwin Jacobs, chairman and CEO of Qualcomm, Inc., and his wife, Joan, have made a $2 million donation to the communications center at the Technion-Israel Institute of Technology. The Irwin and Joan Jacobs Center for Communication and Information Technologies (CCIT)—a project of the New York Metropolitan Region—will expand the interdisciplinary center's contributions to the rapid growth of communication technology worldwide...The Research and Development (R&D) Council of New Jersey has announced the 1999 Thomas Alva Edison Patent Award finalists. One winning patent is selected for each of four categories. In the industrial/defense category, the finalists include Lucent Technologies-Bell Laboratories for their patented "Optical Fiber For Wavelength Division Multiplexing"...RF Micro Devices, Inc. recently announced that it has shipped its one hundred millionth power amplifier (PA)...Dr. S. Francis Paik, president of Hittite Microwave Corp., will retire at the end of this calendar year. Dr. Paik has played the leadership role in the company's growth since 1988. Prior to 1988, Dr. Paik served in the microwave industry for 30 years, with more than 20 years of service to Raytheon Co....The "1999 Los Angeles Technology Fast 50" is an annual awards program that ranks technology companies located in Los Angeles, Riverside, Santa Barbara, San Bernadino, and Ventura counties by revenue growth over a five-year period. Delta Circuits Technology, Inc. placed high in this year's "Fast 50" list with a five-year revenue growth of 333 percent. The Van Nuys, CA-based company is involved in the printed-wiring-board (PWB) industry.

The brightest star on the crystal/oscillator business horizon is the projected expansion of wireless and broadband communications.

Crystal/Oscillator Markets Look To Wireless Growth

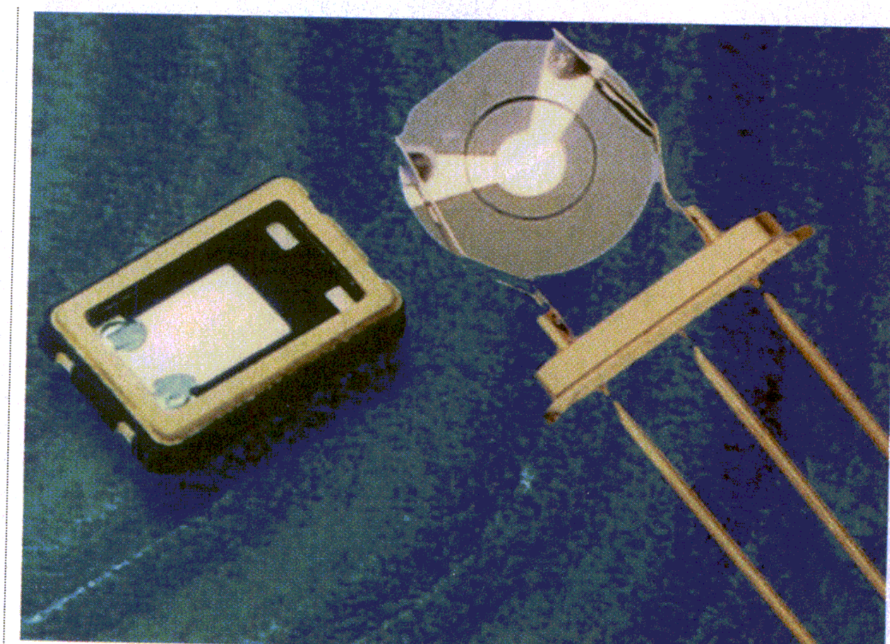
GENE HEFTMAN
Senior Editor

LACKLUSTER performance may characterize much of the crystal and crystal-oscillator industry, but demand from the wireless communications segment and new broadband applications could brighten the picture considerably. In fact, wireless communications accounts for the largest end-use markets for quartz and oscillators, particularly in oscillator products such as temperature-compensated crystal oscillators (TCXOs), oven-controlled crystal oscillators (OCXOs), and voltage-controlled oscillators (VCOs), according to a recent report by Allied Business Intelligence (ABI), an Oyster Bay, NY-based technology research think tank. Increased activity is occurring in the wireless base-station business and wireless local loop (WLL), and there is greater use of fiber transmission in wired communications.

On the technology side of crystals and oscillators, there is increased demand for smaller and lighter components, albeit with higher performance requirements. There is an increased use of ceramic packages to replace metal pin-through-hole and certain surface-mount packages for frequency-control devices. Another trend is coming about due to advances in semiconductor technology: application-specific integrated circuits (ASICs) where the crystal is built in. This eliminates the need for separately packaged crystals and oscillators, reducing system components and cost. Power-supply voltages which are now at +3.3 VDC will soon descend to +1.8 VDC, and that could have consequences for crystal and oscillator makers, but the greater impact will be on the semiconductors used in the end product.

Phase-locked-loop (PLL) modules are now appearing using a blend of crystal and hybrid technologies. In one version, manufactured by Champion Technologies (Franklin Park, IL), the module can be customized for the specific characteristics required by the designer. Parameters that can be specified include output frequency, loop bandwidth, lock time, phase noise, phase error, and jitter. PLLs can be programmed across wide frequency ranges derived form a single crystal frequency.

Frequency stability is an important characteristic of oscillators that generates critical timing signals in



1. Called the HFF or High Frequency Fundamental crystal, the SMCX-1 series device from Vectron International is packaged in a 7 × 5-mm leadless chip carrier (LCC) which is hermetically sealed.

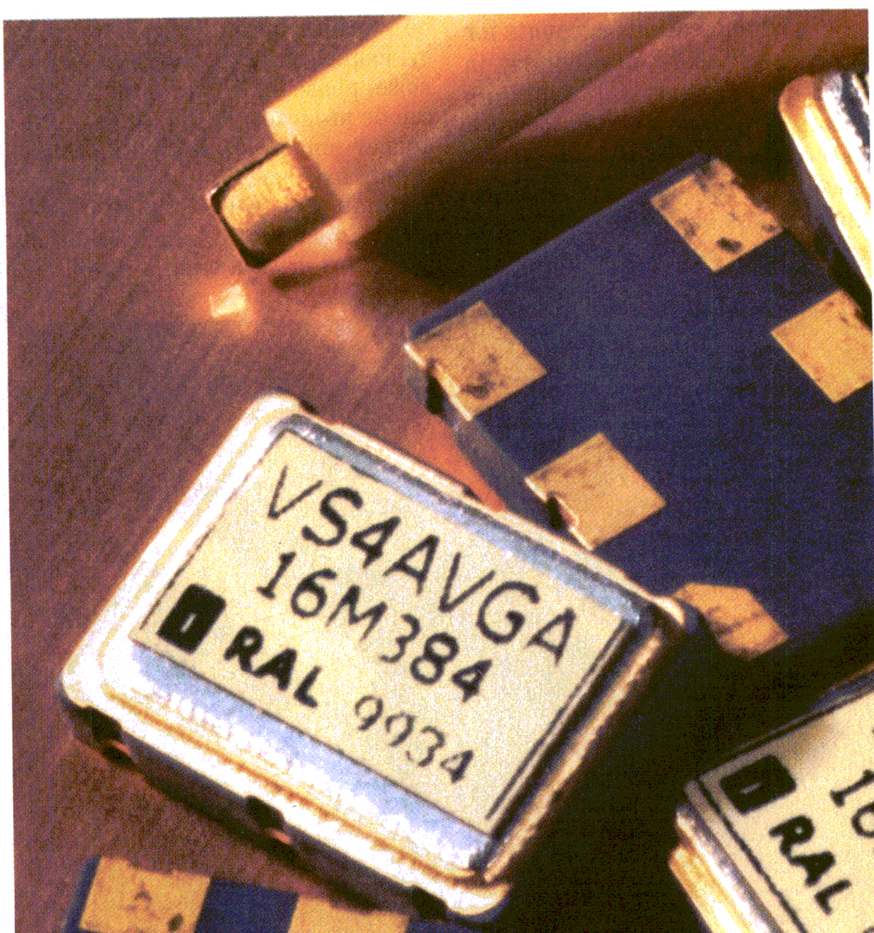
communications systems. Short-term stability is usually described in terms of an oscillator's phase noise and phase jitter. These specifications must continually improve because the operating frequencies of oscillators are spiralling in to the hundreds of megahertz. Thus, even small variations in frequency can cause system errors, particularly in digital data communications.

MESA RIDES HIGH

A year ago, inverted-mesa technology was a buzzword in the crystal business due to its ability to produce the high fundamental frequencies required by wireless and fiber-optic communications equipment (see "Changing Time Challenge The Crystal Industry," *Microwaves & RF*, November 1998, p. 31). This year, the demand for inverted-mesa and its close cousin tab-mesa crystals is showing even-greater growth despite the fact that these crystals are more expensive than the traditional AT-cut variety. Tab-mesa types are finding their way into the ASICs mentioned previously in an attempt to minimize component count, decrease cost, and increase volume. But this integration is not without its drawbacks—a crystal inside an ASIC does not have the same tight specifications on parameters, such as frequency stability and jitter, as a separately packaged device.

Among the companies manufacturing high-frequency crystals is Vectron International (Norwalk, CT), who has recently introduced its High Frequency Fundamental (HFF) precision crystal in a ceramic package (Fig. 1). Called the SMCX-1 series, the crystal is packaged in a small (7 × 5-mm) leadless chip carrier (LCC) that is hermetically sealed and can be specified with aging rates as low as 1 PPM/year. Fundamental-mode crystals can be ordered in the range of 10 to 160 MHz, and overtone types are available with frequencies up to 450 MHz. Applications include the major wireless communications technologies such as code-division multiple access (CDMA), Global System for Mobile Communications (GSM), Digital European Cordless Telecommunications (DECT), as well as precision miniature oscillators.

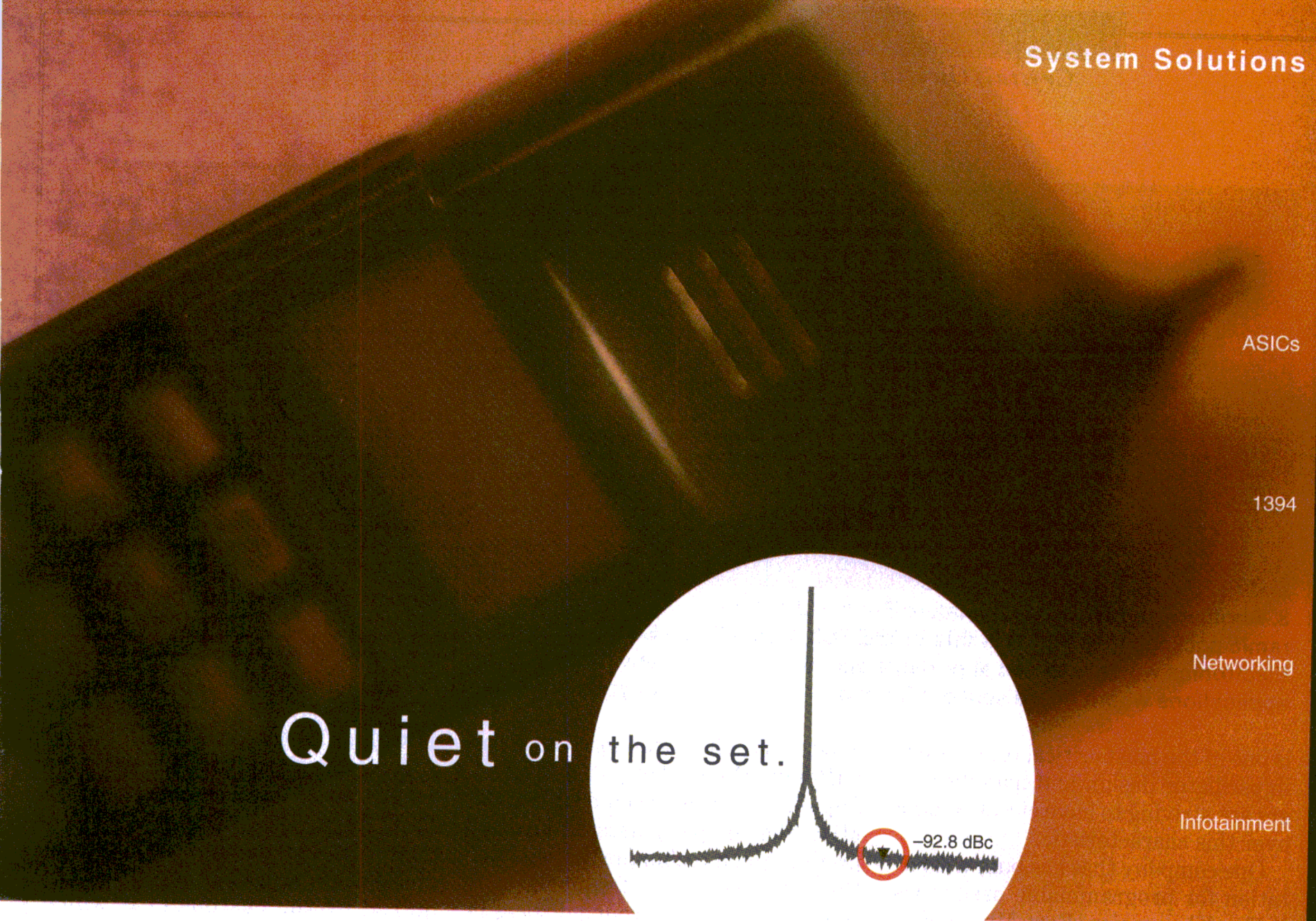
The ceramic-metal 5 × 7 × 2-mm surface-mount (SMT) package is becoming the home of precision voltage-controlled crystal oscillators (VCXOs) such as the VS-9000 manufactured by Raltron Electronics (Miami, FL) (Fig. 2). Intended for high-density applications, the device's predecessor is housed in a much-larger 9.77 × 13.96 × 4.7-mm package. The new version offers useful features such as an optional enable/disable pin that can be use to put the VCXO output in a three-state mode. This is a way of saving power when a complementary-metal-oxide-semiconductor (CMOS) system goes into quiescent mode. VCXOs are available over the frequency range of 1 to 70 MHz, with a 77.76-MHz version under development. Modulation bandwidth is rated at 5 kHz while linearity ranges from ±5 percent to ±20 percent. The output jitter is specified at 50 ps peak-to-peak.



2. High-performance oscillators, such as this VS-9000 VCXO from Raltron Electronics Corp., are being shrunk into smaller packages as evidenced by this miniature 5 × 7 × 2-mm ceramic-metal surface-mount housing.

ON THE FLY

In the past, obtaining a fixed-frequency oscillator for a design was a drawn out process, often taking weeks or months to receive the component from a manufacturer. But a new class of programmable oscillators is on the scene, whose frequencies can be set in a matter of minutes and which are delivered in days instead of weeks. Up to now, the rap on programmables was that they were less accurate and reliable than their fixed-frequency, long lead-time counterparts. Today, however, the only area where programmables fall short is in jitter or phase-noise specifications. That is a result of the programming algorithms used in the frequency-setting process. Phase jitter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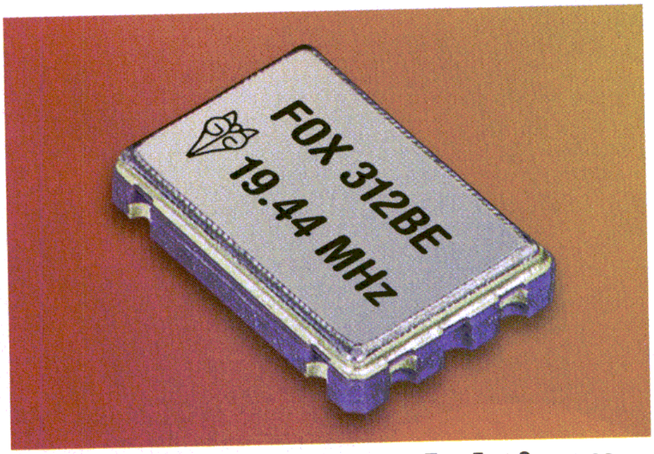
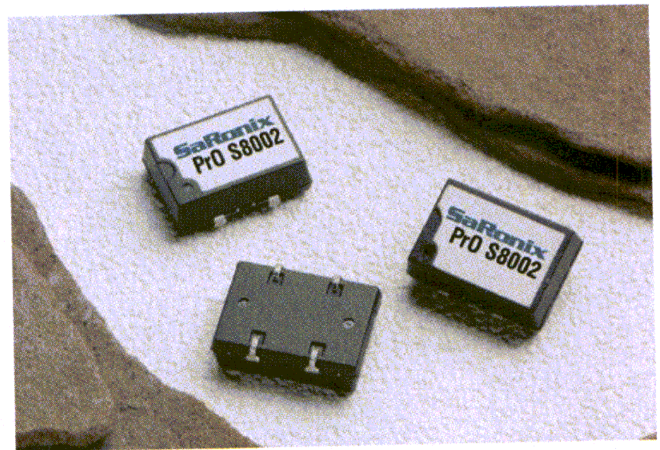
ASICs
1394
Networking
Infotainment
Quiet on the set.
–92.8 dBc



3. Another example of the miniature 7 × 5 × 2-mm ceramic package (see Fig. 2) is this 312BE TCXO from Fox Electronics which is aimed at portable and other applications where board space is limited.



4. Programmable clock oscillators, such as the PrO S8002 series from SaRonix, can be programmed with any frequency between 1 and 90 MHz in a matter of days rather than weeks as in the past.

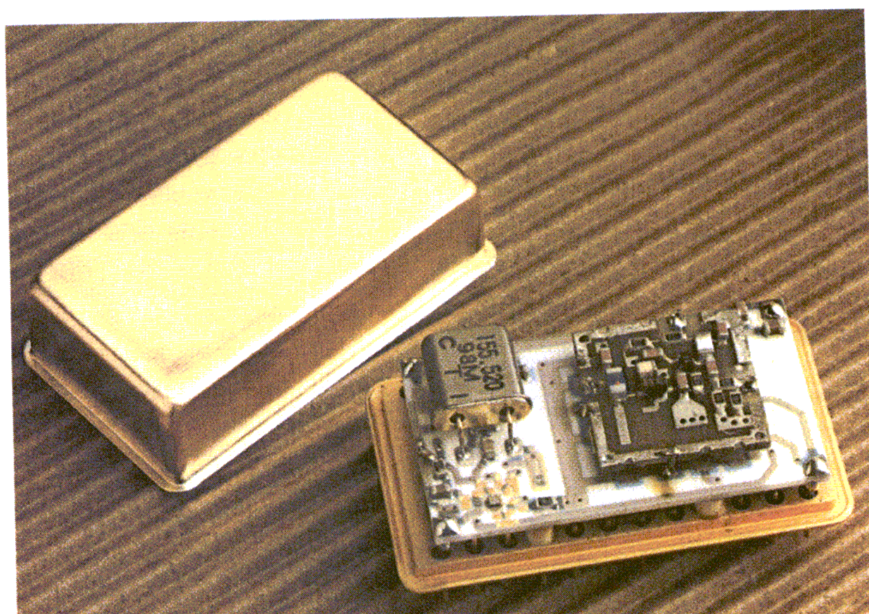
is one of the most critical parameters in oscillator design and manufacturers are striving to have closer control over this characteristic.

One company that has built a reputation for programmable oscillators is Fox Electronics (Fort Myers, FL) with its Just-In-Time or JITO-2 series. These devices offer a 67-percent reduction in phase jitter compared to other programmables and can be shipped in 10 working days to the customer. Typical phase-jitter specifications for JITO-2 oscillators in the 50-to-250-MHz range are a function of the supply voltage and frequency. For example, a 50-MHz type running at +5 VDC has 100-ps peak-to-peak jitter and 16-ps RMS jitter. A 250-MHz type also running at +5 VDC is rated at 40-ps peak-to-peak jitter and 6-ps RMS jitter.

The company recently came out with its 312BE TCXO for applications where good frequency stability is required over a wide temperature range (Fig. 3). Packaged in the popular 7 × 5 × 2-mm low-profile ceramic-base package with a metal cover, the oscillator is available in frequencies from 12,600 to 19,800 MHz with frequency tolerances of ±0.5 PPM at 25°C. The oscillator is well-suited for the new lower-supply voltages coming into vogue, since it is designed to run between +2.85 and +3.15 VDC.

A new family of crystal-controlled, surface-mountable programmable clock oscillators known as the PrO™ S8002 series has been introduced by SaRonix (Menlo Park, CA) (Fig. 4). Supplied in frequencies from 1 to 90 MHz, the company uses an internal programming technique that enables them to program any frequency over the range and turn around devices in a few days. Frequency stability ranges from ±25 PPM for certain frequencies to ±100 PPM for any frequency. These specifications are inclusive, covering calibration tolerance, operating temperature, input-voltage change, load change, aging, as well as shock and vibration. The operating voltage is +3.3 VDC for oscillators of any frequency and +3 VDC for oscillators up to 50 MHz. SaRonix builds and stocks the devices unprogrammed until required by the customer, at which time, they are programmed to user specifications.

To meet the demands of the wireless and broadband technologies for higher-performance components, crystal and oscillator manufacturers have dipped into their bag of tricks to



5. Combining high-frequency hybrid and crystal technologies, this phase-locked-loop (PLL) module from Champion Technologies can be customized to meet specific objectives of the designer.

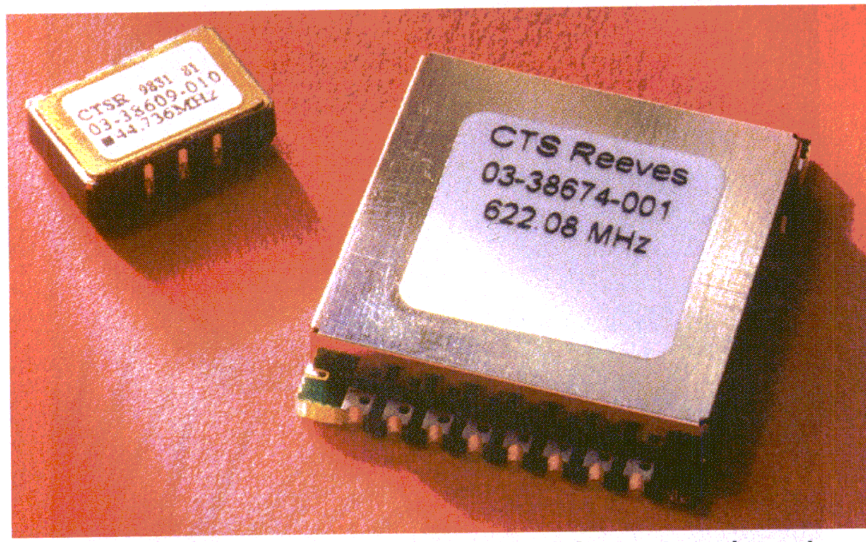
come up with oscillators and PLLs that offer greater integration and provide designers with more flexibility.

NEW DIRECTIONS

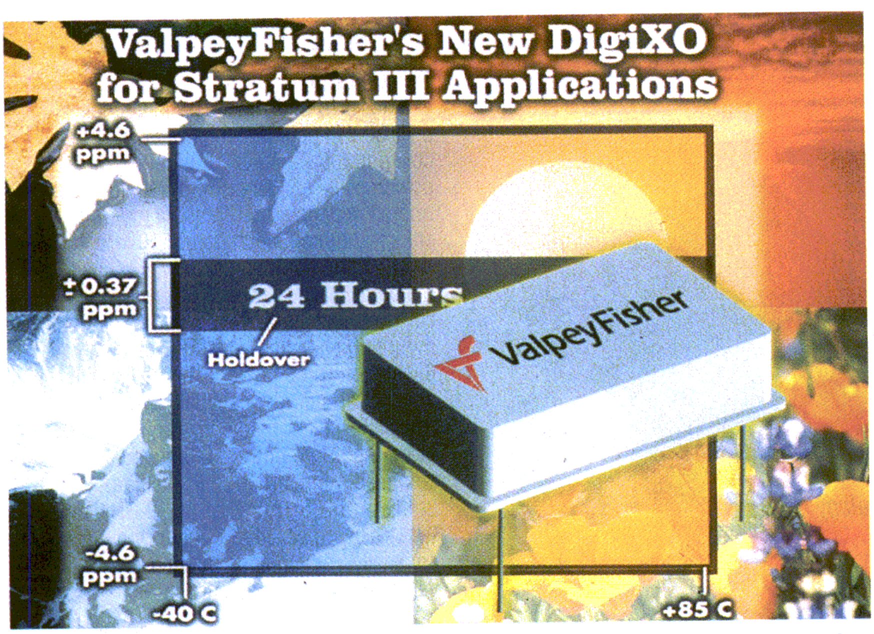
The Champion Technologies PLL module mentioned earlier is one of these new breeds of components that is in that mold (Fig. 5). The device is a thick-film hybrid that incorporates an inverted-mesa crystal that can reach 155.52 MHz. For the VCO portion, the company draws on its CZM4-2000 series of low phase-noise circuits that operates up to 2.488 GHz. Microwave stripline technologies are used for the resonator. In the hybrid portion, 90 percent of the circuit is designed on ceramic, and laser-trimmable thick-film capacitors are used in the VCXO portion to adjust nominal calibration frequencies and set overall modulation sensitivity.

Most system designers are familiar with TCXOs for good frequency stability over broad temperature ranges and OCXOs for very-stable frequency performance over long periods of time (aging is a key parameter of these devices). The new kid on the block from ValpeyFisher (Hopkinton, MA) is the digitally compensated crystal oscillator called the DigiXO (Fig. 6). The company claims that the DigiXO provides greater frequency stability than conventional TCXOs on the market, and in fact, is comparable to that of low-end OCXOs. The advantage of the DigiXO over the OCXO is that it consumes much less power. Frequency stability is specified at ±0.3 PPM over an industrial temperature range of –40 to 85°C. Phase-noise performance (typical) is less than –145 dBc/Hz at offsets greater than 10 kHz from the carrier. Initial samples are available at a frequency of 10 MHz. Packaging is an industry-standard 14-pin dual-in-line package (DIP) which measures 0.8 × 0.5 × 0.5 in. (2.032 × 1.27 × 1.27 cm).

The past few years have witnessed strong growth in wireless base stations to accommodate the vast new hordes of cellular and digital phone users. Among the many companies vying for this lucrative market is CTS Reeves Frequency Products (Sandwich, IL) which has developed a line of VCXOs to satisfy the various packaging needs of the infrastructure (Fig. 7). Oscillators are available in miniature surface-mount versions (Fig. 7, left) and larger surface-mount types having a FR-4 base compatible with the latest board-assembly techniques. The CTS model 348 (Fig. 7, right) delivers crystal stability without a PLL. Instead, the VCXO is designed with direct-frequency multiplication from a lower-frequency crystal so that PLL multipliers are not needed. A low phase-noise device, it runs from – 5.2 VDC and provides complementary outputs that are either ECL-compatible or have a differential sine-wave characteristic. The 348 uses a high-frequency fundamental crystal that offers a frequency stability of ±20 PPM over 0 to 85°C. ••



7. Various size VCXOs are used in the wireless infrastructure—base stations—as shown by these oscillators from CTS Reeves Frequency Products. The devices come in miniature surface-mount packages and FR-4 surface-mount packages.



6. The DigiXO from ValpeyFisher Corp. is a digitally compensated crystal oscillator intended to replace TCXOs and OCXOs with equivalent stability, but much-lower power consumption.

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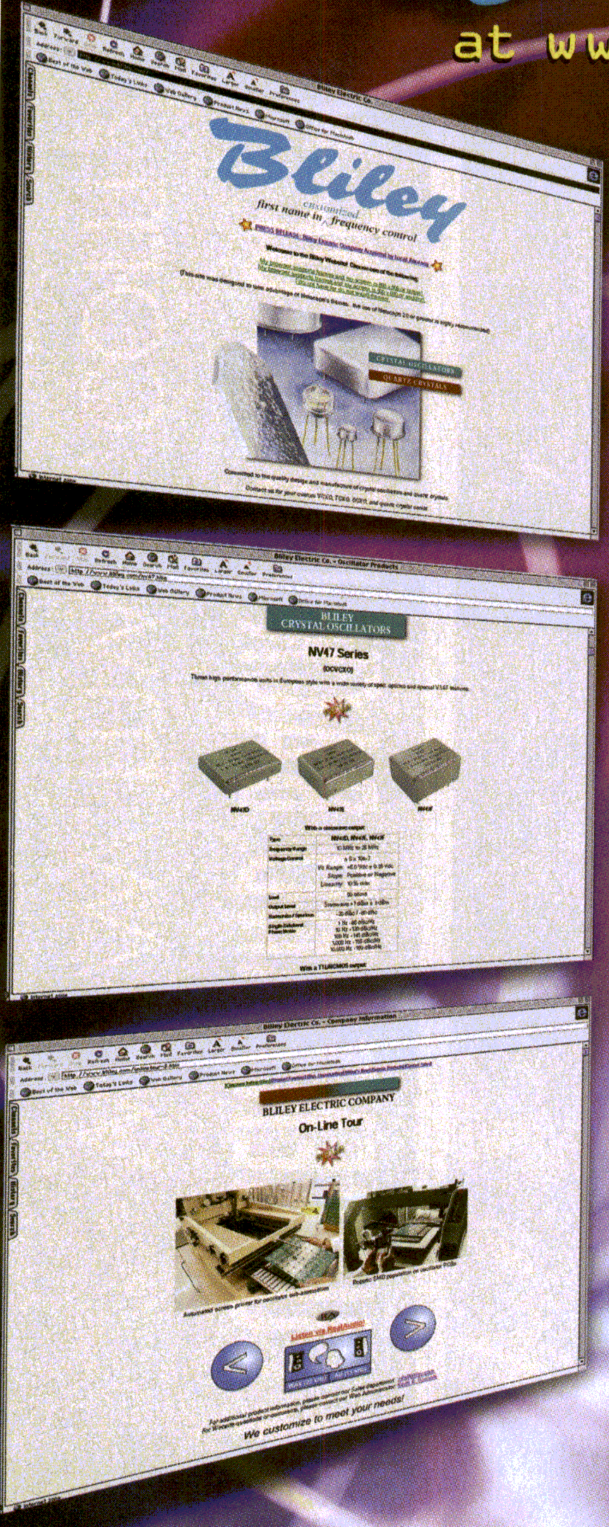

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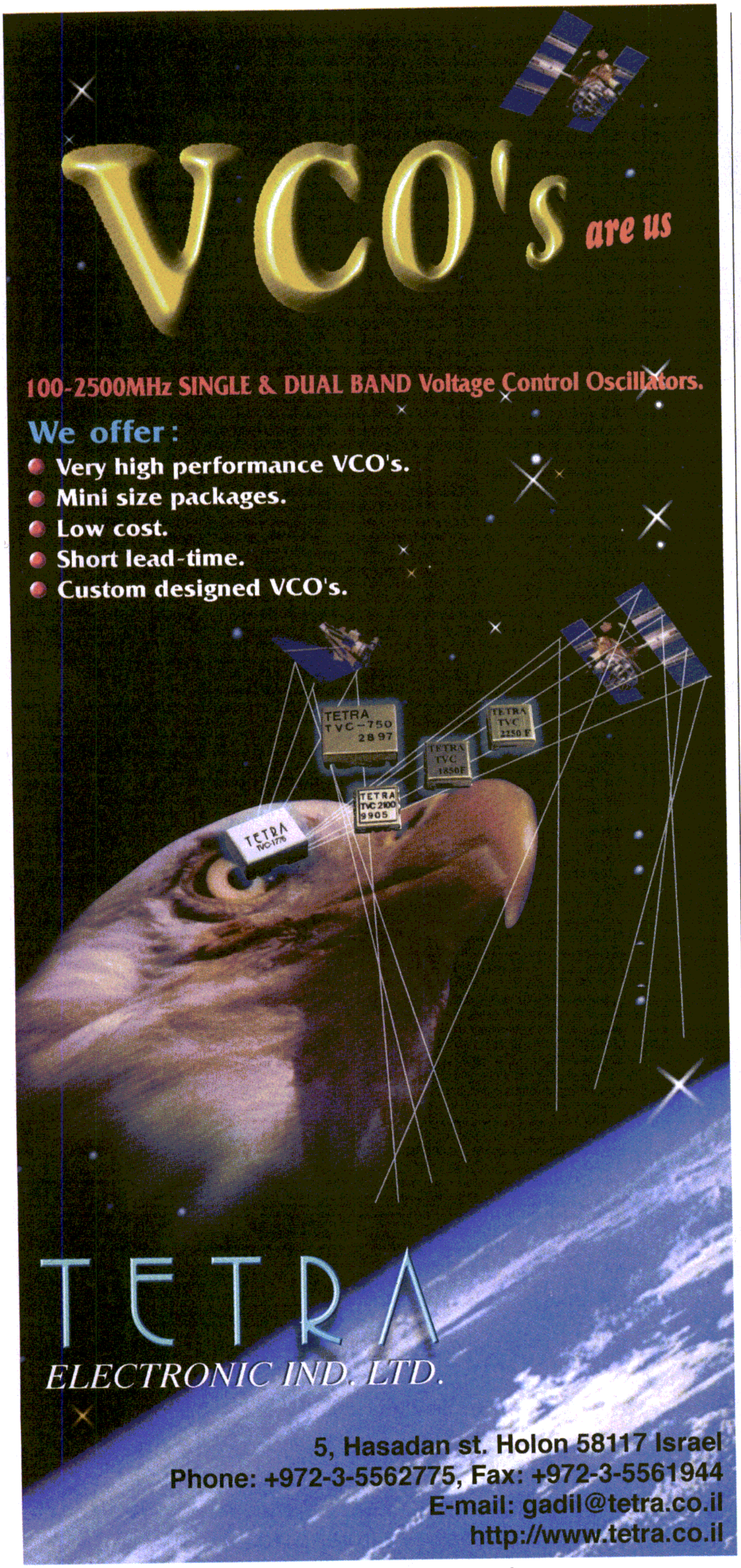
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NEWS

IEDM Preview

Numerous research laboratories will reveal their latest device discoveries, motivated by the need for future high-performance, high-speed communications.

Device Speeds Increase At 45th Annual IEDM

JACK BROWNE
Publisher/Editor

ADVANCES in discrete and integrated-circuit (IC) device technology set the pace for the evolution of electronics. One of the premiere platforms for announcing such advances has traditionally been the IEEE's International Electron Devices Meeting (IEDM), scheduled this year for December 5-8, 1999, Washington Hilton and Towers (Washington, DC). If the preliminary papers from the 45th IEDM are any indication, this year's event promises to be one of the more significant meetings in recent history.

As General Chairperson of the 45th IEDM, Gary Bronner of IBM (Hopewell Junction, NY), notes, the conference is truly an international event: more than 570 abstracts were submitted from over 31 different countries, with a total of 206 papers accepted for the IEDM.

Of interest to microwave and RF designers are several sessions on power and high-frequency devices. In a session on power devices, for example, Shuming Xu and associates from the Institute of Microelectronics (Singapore Science Park II, Singapore) reported on the enhanced performance of laterally-diffused-metal-oxide-semiconductor (LDMOS) transistors with low parasitic feedback capacitance for improved high-frequency performance. Measurements on a modified LDMOS transistor show an increase in output power from 31 to 43 W at 1 GHz by reducing the feedback capacitance from 4.6 to 2.7 pF.

Similarly, Yutaka Hoshino and co-workers from the Semiconductor and IC Group of Hitachi Ltd. (Tokyo, Japan) discuss strategies for boosting the high-frequency performance of LDMOS devices through scaling. Their results indicate great promise for cellular applications, with a device capable of 1-W output power and 60-percent power-added efficiency (PAE) at 2 GHz.

In another session on high-power, high-frequency devices, H. Ishida and co-workers from the Semiconductor Device Research Center of Matsushita Corp. (Osaka, Japan) reported on a 200-W power amplifier (PA) for wideband code-division-multiple-access (WCDMA) base-station applications, based on GaAs modulation-doped field-effect transistors (MODFETs). The MODFET amplifier, evaluated at +15 VDC and 10 A current, achieved a saturated output power of 200 W (+53 dBM) and PAE of 48.7 percent at 2.2 GHz.

Also, K.W. Kobayashi and associates from TRW Electronics and Technology Division (Redondo Beach, CA) described results for a InAlAs/InGaAs-Inp heterojunction-bipolar-transistor (HBT) amplifier capable of operation at 25 GHz. Using a unique oval-emitter-array (OEA) device and thick epitaxial layer, the amplifier achieved +21-dBm output power and 9.5-dB gain with 48-percent PAE at 25 GHz.

Indium phosphide (InP) was also the basis for an impressive 69-GHz frequency divider from TRW. Reported by A. Gutierrez-Aitken, the 2:1 static frequency divider employs the firm's InP HBT process with a cantilevered base metal. The configuration and layout minimize interconnect delays by keeping signal traces as short as possible. The overall chip measures 800 × 500 μm with 17 transistors. It draws only 24 mA from a single −2.9-VDC supply and dissipates 70 mW. The device, said to be the fastest reported static semiconductor divider ever fabricated, boasts input sensitivity of better than +1.5 dBm from 50 to 69 GHz.

Silicon-germanium (SiGe) device technology received a great deal of attention among the world's research laboratories, indicating that SiGe technology promises to become an even greater threat for GaAs and conventional Si processes in the years to come. S. Subhanna and associates from IBM Microelectronics offer an overview of SiGe technology for system-on-a-chip (SOC) designs, reviewing the integration issues and manufacturability concerns for the technology. A trend evident in many of the SiGe papers at IEDM is the manufacturability issue. Most semiconductor houses are now finding ways to build their SiGe processes by adding only a few steps to their existing Si bipolar-complementary-metal-oxide-semiconductor (BiCMOS) processes. In doing this, the desired results should be higher reliability (due to a decrease in process steps) and lower cost.

For example, G. Freeman, D. Ahlgren, and co-workers from IBM Microelectronics, discuss a 0.18-μm SiGe process that is BiCMOS and application-specific IC (ASIC) compatible. Capable of producing HBTs with f_T performance of 90 GHz at a breakdown voltage of +2.3 VDC, the process also offers lower-frequency performance at 25 GHz for a breakdown voltage of +5.5 VDC. The process builds on the firm's +1.8/+3.3-VDC copper (Cu)-metallized CMOS technology to yield a small-emitter BiCMOS process for applications in excess of 40 GHz with SiGe.

A report from Katsuyoshi Washio and associates from the Central Research Laboratories of Hitachi Ltd. (Tokyo, Japan) details a 0.2-μm self-aligned SiGe HBT capable of 6.7-ps ECL gate delays and maximum frequency of oscillation (f_{max}) of 107 GHz. Compatible with standard Si BiCMOS, the new process promises to support high-speed data-communications systems operating in excess of 10 Gb/s.

Also, a paper by K.E. Ehwald and colleagues from the Institute for Semiconductor Physics (Frankfurt, Germany) in conjunction with researchers from Motorola, Inc. (Mesa, AZ) explains how only four additional mask layers are needed to add SiGe:C HBTs to a standard 0.25-μm CMOS process with no changes in the CMOS process flow. The resulting BiCMOS process yields peak HBT transition frequency (f_T) of 55 GHz and f_{max} of 90 GHz at a breakdown voltage of +3.3 VDC.

In addition, C.A. King and associates from Lucent Technologies (Murray Hill, NJ) offer a technique for lowering the cost of SiGe processing. They note that many SiGe technologies are too expensive for low-cost applications due to the additional epitaxial growth procedures that are needed for subcollector formation and deep-trench isolation. The Lucent solution is a low-cost graded SiGe-base BiCMOS technology with the company's existing 0.25-μm CMOS process at the core. The modified, low-cost process requires the addition of only four lithography levels to the existing process, and results in self-aligned SiGe transistors with peak f_T of 51 GHz and peak f_{max} of 53 GHz at a breakdown voltage of +2.5 VDC.••

For more information on the 45th IEDM, please contact Phyllis Mahoney, 1999 IEDM, Suite 400B, 1010 Lakeforest Blvd., Suite 400B, Gaithersburg, MD 20877; (301) 527-0900, FAX: (301) 527-0994, e-mail: phyllism@widerkehr.com, Internet: http://www.ieee.org/conference/iedm.

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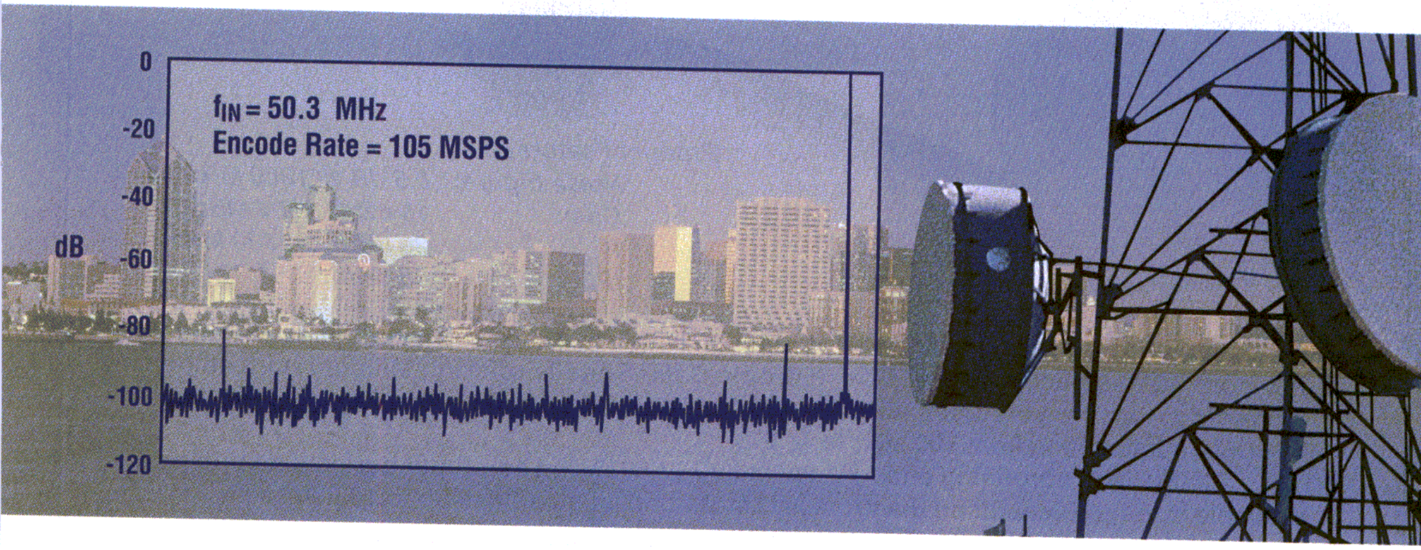

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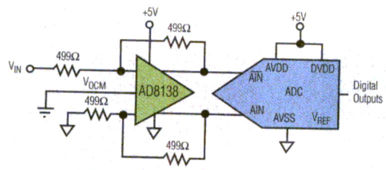

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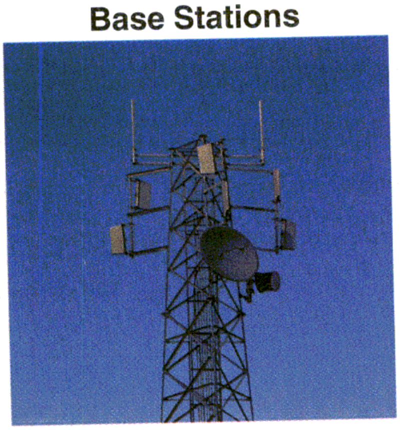
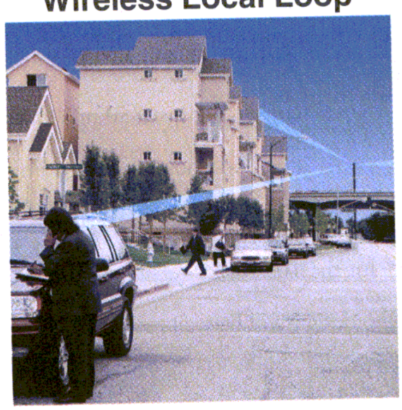
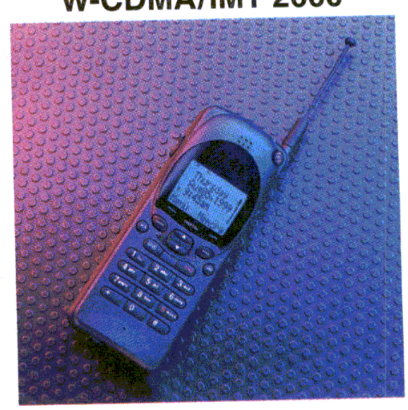
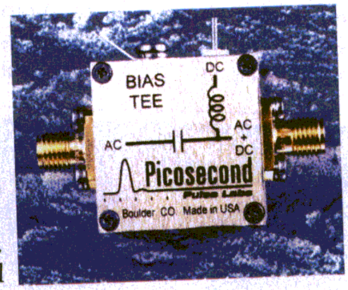






Bias tees boast decade-band coverage

Unlike most high-current bias tees, which typically cover an octave frequency band, the 5585 series of bias tees boast decade-band coverage. The five members of this series operate in overlapping bands spanning 70 MHz to 18 GHz. At an insertion loss of less than 1 dB with a return loss of greater than 10 dB, model 5585 covers 2 to 18 GHz, model 5586 ranges 1 to 5 GHz, model 5587 spans 0.2 to 2 GHz, model 5588 targets 70 to 700 MHz, while model 5589 spans 0.3 to 2.8 GHz. Models 5585, 5587, and 5588 can handle DC currents to 6 A. Model 5589 can handle 7 A and model 5586 can handle 8 A. The maximum DC voltage for all models is +100 VDC. They are specifically designed to support DC injection or retrieval on a coaxial line, but can also be used for DC blocking. The DC input is a solder-terminal, feed-through capacitor. The tees measure 1.0 × 1.0 × 0.625 in. (25.4 × 25.4 × 15.88 mm) and can operate at temperatures from –55 to +125°C. Typical uses include biasing of amplifiers and analog/digital circuits in wireless applications. **Picosecond Pulse Labs, P.O. Box 44, Boulder, CO 80306; (303) 443-1249, FAX: (303) 447-2236, Internet: http://www.picosecond.com.**



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Bus interface streamlines RF test-system design

The model 8210A SmartStep bus interface mediates the control of electromechanical switches, programmable step attenuators, and other peripheral devices to streamline RF test-system design and device integration. The 8210A provides a high-level interface from various industry-standard communications protocols (including IEEE-488 and RS-232/RS-422/RS-485) to the SmartStep serial driver interface bus (DIB), which communicates with the peripheral devices. The 8210A can address up to 125 devices at serial data rates to 100 kb/s. Applications range from controlling a single attenuator in a bench-test or lab environment to streamlining the design and control of a custom, complex, multidevice subsystem of RF switches, relays, and PIN-diode attenuators. **Weinschel Corp., 5305 Spectrum Dr., Frederick, MD 21703-7362; (800) 638-2048, FAX: (301) 846-9116, e-mail: sales@weinschel.com, Internet: http://www.weinschel.com.**

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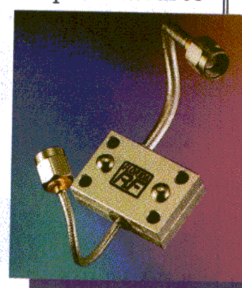
Remote sampling terminations serve PCS

The model 13-5000 series of remote sampling terminations provides high-power termination and a low-level sample of the signal at a location that is remote from the RF power source for personal-communications-services (PCS) test applications. They cover PCS frequencies from 1806 to 1880 MHz and can handle 200-W continuous-wave (CW) power. Maximum input VSWR is 1.065:1 and maximum output VSWR is 1.15:1. The terminations are available with integral cables lengths from 1 to 100 in. (2.54 to 254 cm). Sampling attenuation from 30 to 40 dB ±0.5 dB is available. Each unit is housed in a 1.125 × 0.750-in. (2.86 × 1.91-cm) enclosure and is available in a variety of environmental ratings, housing and connector materials, as well as finishes. **Florida RF Labs, Inc., P.O. Box 899, Stuart, FL 34995; (800) 544-5594, FAX: (561) 283-5286, e-mail: rflabs@rflabs.com, Internet: http://www.rflabs.com.**



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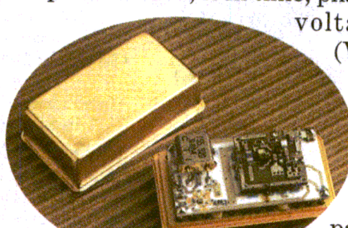
PLL module blends customizable parts

A new phase-locked-loop (PLL) module uses customizable parts to attain design objectives specific to each application. Specifiable parameters include output frequency, loop bandwidth, lock time, phase noise, phase error, and jitter. The voltage-controlled-crystal-oscillator (VCXO) portion incorporates the company's high-frequency, fundamental-mode inverted-mesa crystal, achieving frequencies to 155.52 MHz. The voltage-controlled-oscillator (VCO) portion uses the company's CZM4-2000 series of low-phase-noise designs in frequencies to 2.488 GHz. Microwave stripline technologies are used for the resonator. **Champion Technologies, Inc., 2553 Edgington St., Franklin Park, IL 60131; (800) 888-1499, Internet: http://www.champtech.com.**



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Telecom Giants Plan Mega-Merger

Last month's planned merger between MCI World Com, Inc. and Sprint Corp. was not only the biggest potential telecommunications deal ever, if approved it will be the largest acquisition of one company by another in corporate history. Depending on who's doing the counting, the deal will be in the neighborhood of between $108 and $129 billion. MCI World Com is the number two US long-distance carrier while Sprint is in third place. The deal, approved by the boards of both companies, calls for MCI to pay $76 in stock for each Sprint share, and to swap some of its common stock for Sprint's wireless unit, Sprint PCS, which is a separately traded stock. Before the merger can occur, it must pass muster by the Justice Department and the Federal Communications Commission (FCC), an event not considered by some observers to be a slam dunk. The FCC has expressed concern that such mergers reduce competition.

If MCI and Sprint join forces, the new company—to be called WorldCom—will control more than 30 percent of the $90 billion US long-distance market. But that will leave it well behind AT&T Corp., the leader with close to 45 percent of the market. The acquisition of Sprint will add considerably to MCI's presence in the wireless market, a business where MCI is said to be lacking. The deal could close in the second half of next year.

Just prior to the union of the two telecom giants, MCI engaged in a bidding war for Sprint with BellSouth Corp., the major telephone company for the southeastern US BellSouth made a $100 billion offer to Sprint, prompting MCI to raise the ante with its winning bid of around $115 billion only a few days later.

The spirited bidding for Sprint stems from its perception among telecom watchers and Madison Avenue executives as the preeminent telecommunications brand name in the industry. Sprint has gained a reputation for technological innovation as well as its extensive wireless operations under the Sprint PCS brand name. For example, the company's Sprint ION—Integrated On-Demand Network—enables users to combine voice, video, and data over a single telephone connection.

Sprint has spent heavily on advertising during the past year, increasing its ad budget by a much-larger percentage than MCI or AT&T.

With Sprint in the fold, MCI hopes to increase its wireless voice and data services in its package of offerings. The company will be in a position to offer bundled services, including wireless, local, long-distance, and Internet access, in an attempt to develop new revenue streams as rates drop for traditional telephone services. ●●

Contracts

Berkeley Varitronics Systems, Inc.—Has been awarded a contract by Motorola of Buenos Aires to provide code-division-multiple-access (CDMA) test transmitters that will be used to aid in CDMA system build out.

Sensys Technologies, Inc.—Has received a contract award for $1.8 million for additional Bobcat ESM/threat warning systems from SPAWAR Systems Center in Charleston, SC. The Bobcat systems will be deployed on the MK V fast patrol boats and the Cyclone Class Patrol Coastal (PC).

Sanders—Received an award valued at $43 million for continued production of millimeter-wave transceivers for the Longbow Hellfire Missile System. The missile system is deployed on US Army AH-64D helicopters and will be installed on United Kingdom Army WAH-64 Apache helicopters.

ViaSat—Has received contract additions worth $5.2 million in two separate follow-on orders. The first add-on is for the Joint Communication Simulator (JCS) project for the US Navy and US Air Force, and is worth approximately $3.7 million. The systems generate a simulated airspace that can be used in a lab setting to test and develop communication, navigation, and weapons systems. In addition, the Space and Naval Warfare Systems Command (SPAWAR) has placed a Foreign Military Sale (FMS) order of $1.5 million for ultra-high-frequency (UHF) DAMA satcom modems.

Andrew Corp.—Was awarded a $14 million contract to supply and install equipment shelters along Level 3 Communications' fiber-optic communications network in the US and Canada. The Level 3 network will combine local and long-distance networks, connecting customers end to end across the US as well as in Europe and Asia.

RF Micro Devices, Inc.—Received its first major order from China for RF integrated circuits (RF ICs) used in dual-band Global System for Mobile Communications (GSM) cellular handsets.

Micro Pulse, Inc.—Was awarded an 18-month contract, worth up to $3.4 million, by Qualcomm, Inc. to supply antennas for use on Qualcomm's OmniTRACS mobile-information-management system.

L-3 Communications—Announced that its Global Network Solutions (GNS) business unit has been awarded a contract to provide a complete private digital microwave voice and data network to the Egyptian National Railways (ENR) organization. The contract is valued at $15 million.

MediaOne—Has awarded Lucent Technologies a contract valued at approximately $250 million for communications systems and software to enhance its US network. Under the five-year agreement, Lucent will provide switching and optical networking systems, as well as communications software. MediaOne will incorporate Lucent's solutions into its broadband hybrid-fiber-coax (HFC) network to offer customers local-telephone, high-speed Internet, and broadband TV services simultaneously over a single network.

ADC Telecommunications, Inc.—Has been awarded a contract by Seren Innovations, Inc. for the Homeworx™ cable-telephony system. The contract covers the initial 12 months of product deployments and is expected to be extended for additional years to meet deployment demands. The complete three-year project schedule is valued at $40 million in cable-telephony equipment.

Fresh Starts

Harris Corp.—Revealed that its semiconductor operation, Harris Semiconductor, will change its name to Intersil Corp. when it separates from Harris as part of the previously announced sale. Under its new name, Intersil was scheduled to operate as a subsidiary of Sterling Holding LLC, a Citicorp Venture Capital investment portfolio company beginning in early August, contingent upon financing, regulatory, and certain other approvals.

Omnipoint Technologies, Inc. and the Siemens Information and Communication Networks Group—Formed a joint venture to develop wireless Internet-protocol (IP)-based solutions to integrate mobile radio and Internet technology.

MCE Companies, Inc.—Has acquired DML Microwave Ltd. (formerly Denistron Microwave Ltd.), Essex, England, with DML emerging as one of MCE's wholly owned subsidiaries.

Cardinal Components, Inc.—Has announced that OMNI Sales is Cardinal's newest sales organization. OMNI Sales has been in business since 1980 in the Philadelphia market.

ANADIGICS, Inc.—Has opened an RF integrated-circuit (RF IC) design center in Dallas, TX. The design center will support ANADIGICS' efforts to develop new products to further penetrate RF applications in the wireless communications market and to increase their base of RF design engineers.

Intersil Corp.—Has announced its role as a charter sponsor of the Wireless Ethernet Compatability Alliance (WECA). WECA's goal is to stimulate wider adoption of the IEEE 802.11 high-rate (HR) standard for fast wireless local-area networks (WLANs).

Champion Technologies, Inc.—Has established relationships with two manufacturers' representative companies covering territories in the Southern US. McGhee Group, Inc., which maintains offices in Austin, Dallas, and Houston, TX, will represent Champion in Texas, Louisiana, Arkansas, and Oklahoma. New Age Electronics, whose corporate headquarters are in Huntsville, AL, will work with Champion in Alabama, Mississippi, and Tennessee.

Texas Instruments—Has agreed to purchase ATL Research A/S, a research and development company based in Aalborg, Denmark that specializes in RF engineering, primarily for cellular communications.

TriQuint Semiconductor, Inc. and RF Solutions LLC—Agreed to use RF Solutions' third-party RF integrated-circuit (RF IC) design services in conjunction with TriQuint's GaAs IC foundry services.

Spectrian—Chris Tubis to executive vice president/general manager for the semiconductor business unit; formerly vice president responsible for the design and manufacturing centers of the wireless business unit at National Semiconductor.

ANADIGICS—Dr. Burhan Bayraktaroglu to chief scientist of heterojunction-bipolar-transistor (HBT) development; formerly technical director of advanced technology at Northrup Grumman Corp.


BAYRAKTAROGLU


SHARMA

TriPoint Global Communications—Pushp Kumar (P.K.) Sharma to vice president of information systems; formerly worked as director of management information systems. Also, Barry Watson to vice president of business development; formerly employed as vice president of engineering and technology.

American Technical Ceramics (ATC)—Dave Ott to vice president of New York manufacturing; formerly vice president and general manager of the Ceramics Division with TAM Ceramics.

CTS Corp.—Douglas Rasmussen to vice president and general manager of the CTS Reeves frequency products operations; formerly vice president and general manager of Honeywell Optoelectronics.

Association Connecting Electronics Industries (IPC)—Kim Sterling to vice president of marketing and communications; formerly employed as director of marketing and communications.

Labtech—John Priday to manager of the special projects division; formerly involved in the production of specialist microwave and high-reliability printed-circuit boards (PCBs) for the defense and aerospace markets at GEC Marconi Interconnect.

Andrew Corp.—Leo Messier to business unit manager for HELIAX® connector products; formerly director of operations for Huber+Suhner, Inc., North America.

Cherry Electrical Products—Kevin Krause to smart-card sales manager; formerly western keyboard regional manager. Also, Jessica Robbins to sales engineer with the keyboard group; formerly with Cherry's distribution group.

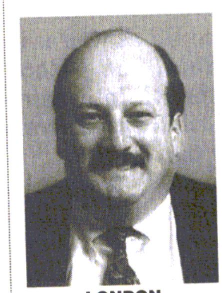
Stellex Electronics, Inc.—Bruce Quinn to director of sales and marketing; formerly director of sales and marketing for semiconductor products at Filtronic Solid State.

Gel-Pak—Patricia Kennedy to sales account manager; formerly with IBM.

Unitek Miyachi Corp.—R. Patterson (Pat) Jackson to senior vice president of marketing and sales; formerly vice president of marketing and sales at Signet Scientific Co.

MYDATA Automation, Inc.—Jay Gauthier to central regional sales manager; formerly sales manager at EMC Global Technologies.

Piconics, Inc.—David J. London to vice president of sales and marketing; formerly vice president at mmTech, Inc.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OWINGS

Trompeter Electronics—Patrick Owings to western regional sales manager; formerly sales and marketing manager for IERC.

The Society of Cable Telecommunications Engineers (SCTE)—Lawrence Moore to director of marketing and communications; formerly editions manager at *TV Guide Magazine*. Also, Melissa Hicks to director of membership services; formerly director of marketing and membership services at GAMA International.

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Electrical Delay	125 psec min.		
Nominal Impedance	50 ohm		
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e-mail: dwalker@boulder.nist.gov
Internet: http://www.arftg.org

Siting Wireless Communications Antennas and Towers
December 1-3 (Madison, WI)
Department of Engineering Professional Development
University of Wisconsin-Madison
432 North Lake St.
Madison, WI 53706
Katie Peterson
(800) 462-0876, FAX: (608) 262-3160
e-mail: custserv@epd.engr.wisc.edu
Internet: http://epd.engr.wisc.edu

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Internet: http://www.ucla.edu/shortcourses

Meetings

Characterization of Broadband Access Technologies
December 2-3 (Westin Peachtree Hotel, Atlanta, GA)
Automatic RF Techniques Group (ARFTG)
Lawrence P. Dunleavy, Conference Chair
University of South Florida
Tampa, FL 33620
(813) 974-2574, FAX: (813) 974-5250
e-mail: l.dunleavy@ieee.org
Internet: http://www.arftg.org

1999 IEEE International Electron Devices Meeting (IEDM)
December 5-8 (Washington Hilton and Towers, Washington, DC)
IEDM 1999
101 Lakeforest Blvd., Suite 270
Gaithersburg, MD 20877
(301) 527-0900, FAX: (301) 527-0994
e-mail: pwmahoney@aol.com

Bluetooth Developers Conference
December 7-9 (Westin Bonaventure Hotel, Los Angeles, CA)
Bluetooth Special Interest Group
Internet: http://www.Bluetooth.com/developers99

7th International Symposium on Recent Advances in Microwave Technology
December 13-17 (Malaga, Spain)
University of Malaga/University of Nevada (Reno, NV)
Professor Banmali Rawat
University of Nevada, Dept. of Electrical Engineering
(702) 784-6927, FAX: (702) 784-6627
e-mail: rawat@ee.unr.edu
Internet: http://www.isramt99.ic.uma.es

International Radar Symposium—India 1999
December 14-17 (Hotel Ashok, Bangalore, India)
The Institution of Electronics & Telecommunication Engineers
IETE Bangalore Centre
Anada Babu K.V.S., IRSI-99 Secretariat
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e-mail: irsi@lrde.ernet.in

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April 10-11 (Dallas, TX)
Dallas Section of the IEEE
Dr. Gallon Brehm, Technical Program Co-Chair
TriQuint Semiconductor
(972) 994-8571, FAX: (972) 994-8502
e-mail: gbrehm@tqtx.com
Abstract deadline: November 22, 1999

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May 20-26 (Dana Point, CA)
Dr. Michael Thorburn
The Aerospace Corp.
P.O. Box 92957, M1/111
Los Angeles, CA 90009-2957
(310) 336-2197, FAX: (310) 336-6225
e-mail: m.a.thorburn@ieee.org
Internet: http://www.ieeeaps.org/ISPAST00
Abstract deadline: December 5, 1999

2000 Symposium on VLSI Technology
June 12-14 (Honolulu, HI)
IEEE Electron Devices Society and Japan Society of Applied Physics
Secretariat for VLSI Symposia (USA)
Widerkehr and Associates
101 Lakeforest Blvd., Suite 400B
Gaithersburg, MD 20877
(301) 527-0900 ext. 311, FAX: (301) 527-0994
e-mail: vlsi00@aol.com
Abstract deadline: January 7, 2000

2000 International Conference On Subsurface Sensing Technologies and Applications (SSTA 2000)
July 30 to August 4 (San Diego, CA)
Cam Nguyen
Texas A&M University, Dept. of Electrical Engineering
College Station, TX 77843-3128
(409) 845-7469, FAX: (409) 845-6259
Internet: http://ee.tamu.edu/subsurface-sensing-conference

4th European Symposium on Electromagnetic Compatibility (EMC Europe 2000)
September 11-15 (Brugge, Belgium)
TI-KVIV, R. Peys
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Abstract deadline: December 1, 1999

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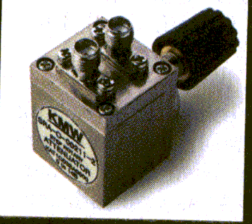

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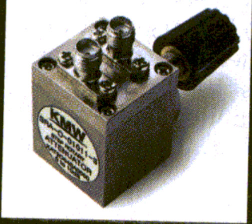
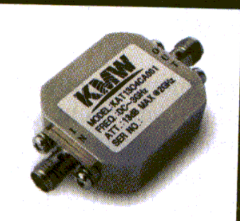


KAT13O4CA000



KAT13O4CA001

■ Step-Rotary Attenuators

Product Code No.	KAT1OO4SA000	KAT2OO4SA000	KAT1SO4SA000	KAT2SO4SA000
Operating Type	Break-Before-Make		Make-Before-Break	
Frequency Range	DC ~ 3GHz	DC ~ 3GHz	DC ~ 3GHz	DC ~ 3GHz
Insertion Loss (max.)	0.2dB	0.2dB	0.2dB	0.2dB
VSWR (max.)	1.15:1	1.15:1	1.15:1	1.15:1
Incremental Attenuation Range (dB)	0 ~ 1	0 ~ 10	0 ~ 1	0 ~ 10
Attenuation Step (dB)	0.2	1	0.2	1
Nominal Impedance	50 ohm		50 ohm	
I/O Port Connector	SMA(F) / SMA(F)		SMA(F) / SMA(F)	
Average Power Handling	2W @ 2GHz		2W @ 2GHz	
Temperature Range	-55°C ~ +85°C		-55°C ~ +85°C	
Dimension (inch)	1.93*1.56*1.51		1.93*1.56*1.51	

■ Continuously Variable Attenuators

Contactless Structure for High Power Handling Capability, up to 2W average @2GHz.

Product Code No.	A type : KAT13O4CA000 B type : KAT13O4CA001		
Frequency Range	DC ~ 1GHz	1 ~ 2GHz	2 ~ 3GHz
Insertion Loss (max.)	0.15dB	0.3dB	0.35dB
VSWR (max.)	1.25 : 1	1.25 : 1	1.25 : 1
Attenuation Range (max.)	4dB @ 1GHz	13dB @ 2GHz	25dB @ 3GHz
Nominal Impedance	50ohm		
I/O Port Connector	SMA(F) / SMA(F)		
Average Power Handling	2W @ 2GHz & 25°C, without Heat-Sink		
Temperature Range	-55°C ~ +85°C		
Dimension (inch)	A type : 1.496*1.102*0.470, B type : 1.225*1.102*0.470		

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CIRCLE NO. 299

Solving the mixed-signal circuit testability dilemma

Mixed-signal integrated circuits (ICs) [analog and digital on the same chip] are becoming more common in telecommunications systems, but the task of testing these devices is extremely complex. It is particularly difficult to access, test, and verify the analog behavior of these circuits according to Gordon W. Roberts and Benoit Dufort of the Department of Electrical Engineering at McGill University (Montreal, Quebec, Canada). In fact, they claim that the cost to produce these devices is dominated by their analog test costs. The authors suggest that very-large-scale-integrated (VLSI) submicron technology makes it feasible to place all or part of the test circuitry on the same die as the circuit itself. This is called built-in self test (BIST) and offers a number of benefits including the integration of test into present day computer-aided-design (CAD) facilities. A variety of approaches for testing mixed-signal circuits is offered including a way to test codec and modem circuits that contain analog-to-digital and digital-to-analog elements. See "Making Complex Mixed-Signal Telecommunication Integrated Circuits Testable," *IEEE Communications Magazine*, Vol. 37, No. 6, June 1999, p. 90.

Micromachined microswitches offer microwave applications

Monolithic microwave integrated circuits (MMICs) require a method for switching electrical signals, but semiconductor devices used as switches suffer from large insertion losses and poor electrical isolation. Authors Paul M. Zavracky, Nicol E. McGruer, and Richard H. Morrison of Northeastern University (Boston, MA) as well as David Potter of Analog Devices (Wilmington, MA) are using surface micromachining to fabricate a microswitch and a microrelay that have switch lifetimes comparable to commercially available reed relays. Microswitches, however, have a number of advantages over relays. They run on very low power (less than 0.05 μW, can be integrated with silicon (Si) microelectronics, and have much higher operating frequencies than reed relays (greater than 100 kHz). In addition, contact resistance is less than 1 Ω and parasitic capacitance is low. See "Microswitches and Microrelays With a View Towards Microwave Applications," *International Journal Of RF and Microwave Computer-Aided Engineering*, Vol. 9, No. 4, July 1999, p. 338.

Test system measures quality of DBS service

Digital direct-broadcast-satellite (DBS) systems are becoming a key technology on the television landscape and service providers need test methods to keep high-quality signals flowing to their viewing audience. A test model for measuring DBS signals has been developed by W. Sohn of Kyunghee University (Yong-In, Korea) and J.H. Kim of the Electronics and Telecommunications Research Institute (Taejon, Korea). Their model measures the three major components of transmission performance—system delay, lip sync, and service-interruption time. These tests can be implemented quantitatively while two other tests—audio and video—can be measured subjectively. Test methodologies are described for all five signal measurements. The authors claim that the quantitative tests can be used by providers to measure the quality of DBS service, but the audio and video results are more useful in determining bit allocations for the channels. See "System Test of Digital DBS System for Video and Audio Signals," *IEEE Transactions On Broadcasting*, Vol. 45, No. 2, June 1999, p. 187.

Class E amplifier improves transceiver efficiency

Power amplifiers (PAs) in wireless personal-communications equipment are known to consume excessive power and are difficult to integrate with other components as designers push for the goal of a single-chip transceiver. One solution is proposed by King-Chun Tsai and Paul R. Gray of the Department of Electrical Engineering at the University of California (Berkeley, CA) who have developed and built a 1.9-GHz, 1-W complementary-metal-oxide-semiconductor (CMOS) PA based on the switching Class E approach to achieve high efficiency over a broad range of output power. The device runs on a low supply voltage (+2 VDC) and is compatible with submicron, low-voltage fabrication technologies. It uses a fully differential topology to minimize potential on-chip interference due to substrate coupling, and offers good prospects for integration into a single-chip transceiver. Included is a compact, low-loss microstrip balun to provide a differential-to-single-ended conversion at the amplifier's output. See "A 1.9-GHz, 1-W CMOS Class E Power Amplifier for Wireless Communications," *IEEE Journal of Solid State Circuits*, Vol. 34, No. 7, July 1999, p. 962.

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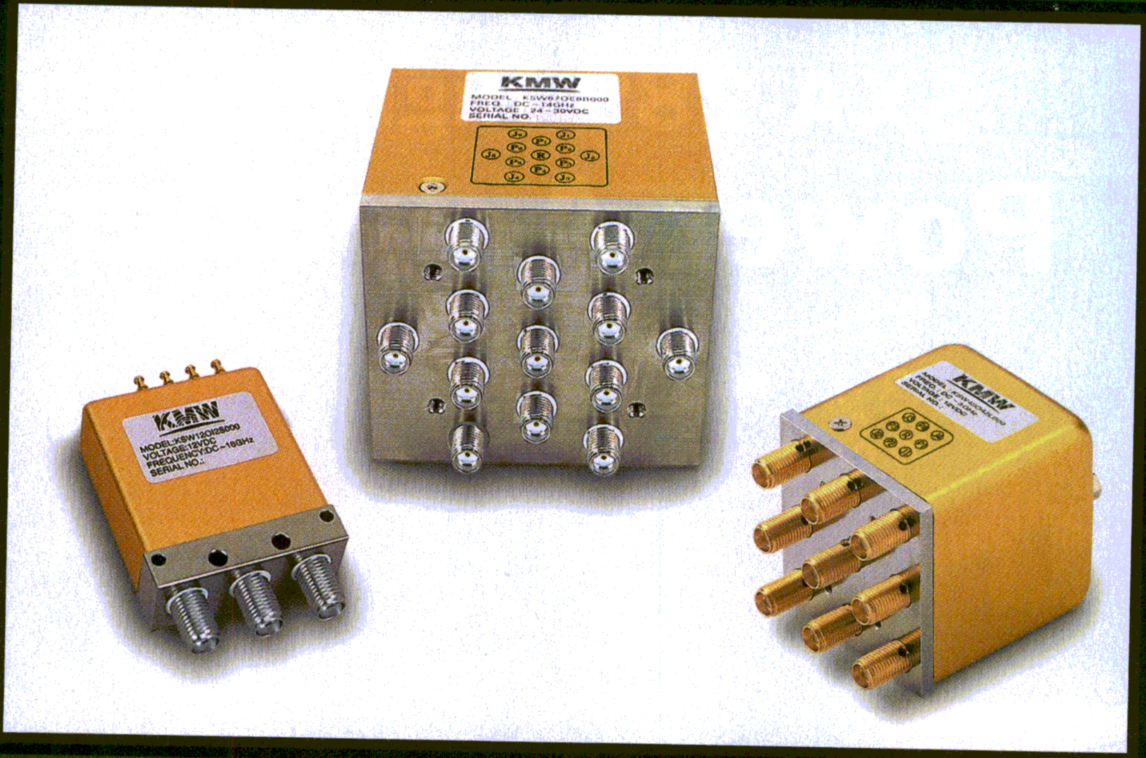

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■ KMW new 6P7T switch is designed for W-CDMA IMT2000.

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Switch Type	SPDT	6P7T	4P5T
Frequency Range	DC ~ 3GHz	DC ~ 3GHz	DC ~ 3GHz
Insertion Loss (max.)	0.2dB	0.2dB	0.2dB
VSWR (max.)	1.15 : 1	1.15 : 1	1.15 : 1
Isolation (min.)	80dB	80dB	80dB
Operating Mode	Latching	Latching	Latching
Actuating Voltage /Current (max.)	12Vdc ± 10% /240mA (@ 12Vdc, 25°C)	12Vdc ± 10% /165mA (@ 12Vdc, 25°C)	12Vdc ± 10% /165mA (@ 12Vdc, 25°C)
I/O Port Connector	SMA(F) / SMA(F)	SMA(F) / SMA(F)	SMA(F) / SMA(F)
RF Power Handling	100W CW (@ 1GHz)	250W CW (@ 1GHz)	250W CW (@ 1GHz)
Dimension (inch)	1.339*1.575*0.528	2.441*2.177*2.165	1.626*1.874*1.626

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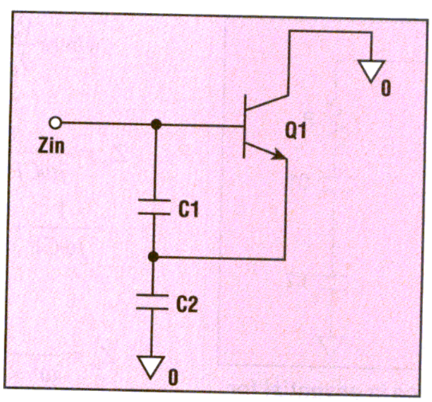
Exploit Leakage Inductance In VCO Designs

The non-ideal characteristics of a transformer lead to a novel tuning method for VCOs.

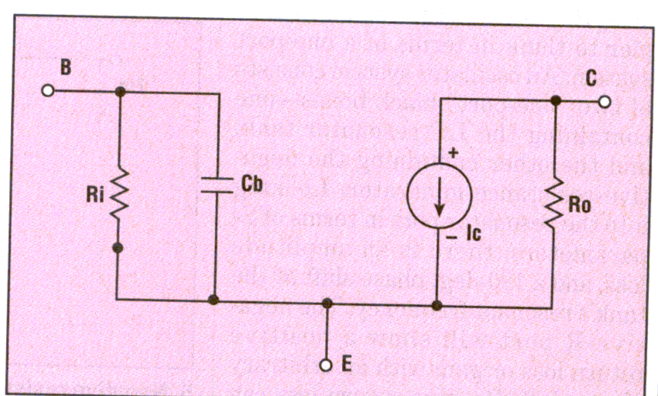
Dien Nguyen
Senior Applications Engineer
Motorola Semiconductor Products Sector, 9665 Chesapeake Dr., San Diego, CA 92123; (858) 541-2169, FAX: (858) 541-1001, e-mail: Dien.Nguyen@motorola.com.

THERE are few methods for tuning or varying the resonance frequency of a voltage-controlled oscillator (VCO), the most common being with a varactor. But varying the frequency with a varactor has limitations such as variation of the oscillation frequency with temperature, K_{VCO} linearity, supply pushing and load-pulling susceptibility, and variation of phase noise with tuning voltage. In certain applications where modulation frequencies are high, the isolation of the modulation input from the resonating tank may pose a problem. Typically, a lowpass RC topology is used as a duplex filter to isolate the oscillation frequency from the modulation frequency. In special applications, the RC time constant may distort the frequency response of the input modulation. Decreasing the value of the resistor to the varactor will only worsen the phase-noise response.

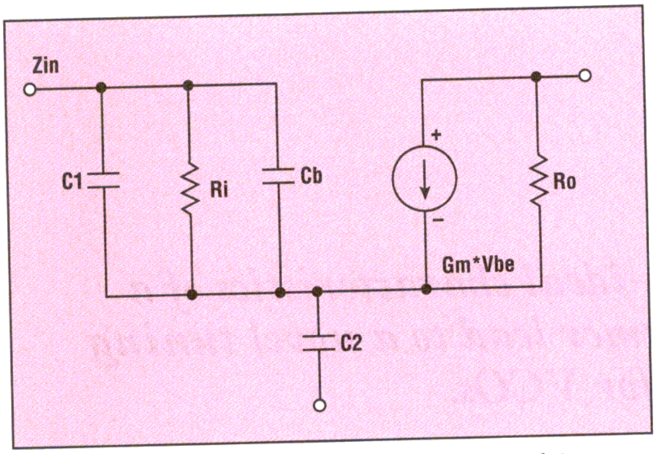
The variation of inductance with a control voltage is the heart of this design. Variation of inductance requires the perturbation of the resonator's magnetic field. One way to achieve this is to add a separate or secondary winding to the magnetic core of the inductor. The loading of this winding can directly effect the core's magnetic field and, consequently, the primary inductance. The loading of the secondary can be accomplished using a switch or a transistor as an active load. In an ideal transformer, when the secondary is open circuited, the primary is no more than an inductor of X value. When the secondary is short



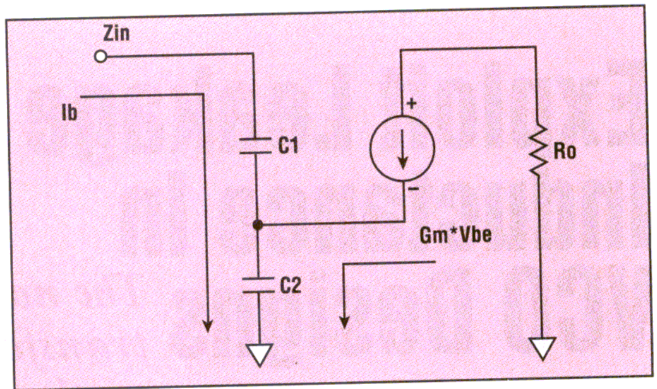
1. A positive-feedback topology using a common-collector amplifier is the basis for a Colpitts oscillator used in the VCO design.



2. The textbook version of the hybrid-π model of a bipolar transistor shows the equivalent resistances and capacitances of the base and collector regions and the transconductance current generator (G_m).



3. This schematic represents the hybrid-π transistor model of Fig. 2 substituted for transistor Q1 in Fig. 1.



4. The schematic of Fig. 3 can be simplified to that shown here because the input resistance (R_i) and base capacitance (C_b) of the transistor model are much smaller than capacitances C1 and C2.

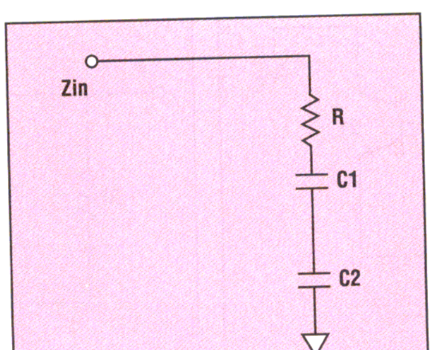
circuited, the inductance of the primary should ideally go to zero. This is not the case due to parasitic inductance and coupling losses. Thus, the measured primary inductance is equivalent to the transformer's leakage inductance. Exploiting this characteristic in a VCO application is the motivation for this design.

The active device used in this design is the Motorola MRFIC0915, a monolithic cascode amplifier that has the high gain, isolation, and low current essential for VCO designs. An RF transformer is configured as the inductive resonator and the secondary load transistor can be any inexpensive RF transistor such as the MMBR941 or MRF947.

NEGATIVE RESISTANCE

To better understand the design of oscillators, it is essential to review the concept of negative resistance. In analyzing oscillators, it is much simpler to think in terms of a one-port system. An oscillator system consists of two "one-port" black boxes—one containing the LC resonator tank, and the other containing the negative-resistance generator. Looking into the resonator port in terms of S-parameters, there is an amplitude loss, and a 180-deg. phase shift at the tank's resonant frequency. The negative-R port will show a positive return loss or gain with an arbitrary phase shift. Positive return loss can be viewed as a port that returns a larger reflected wave from an incident wave, thus adding energy to the system. With the two ports connected together, oscillation will occur when the phases sum to zero and the net amplitude is positive. If there are more resistive losses in the resonator than the negative-R generator can compensate for, the system will cease to oscillate.

Negative resistance is derived from the substitution of the small-signal Hybrid-π bipolar transistor model into a capacitive feedback network. Figure 1 reveals the positive feedback topology for a common-collector amplifier. This is the Colpitts oscillator topology. Capacitors C1 and C2 provide the necessary phase shifting for positive feedback. Figure 2 shows the textbook Hybrid-π Model for a bipolar transistor where $I_c = G_m \times V_{be}$. Figure 3 highlights the substitution of the Hybrid-π transistor model (Fig. 2), replacing Q1 in Fig. 1. A few assumptions can be made to simplify the calculations.



5. Negative resistance is essential for oscillation to occur and this network represents the equivalent negative-resistance input port of the circuit in Fig. 4.

Figure 4 shows the simplified Fig. 3 using the assumption that $C_b << C1$ (base capacitance of transistor is much less than the value of C1) and $R_i << XC2$ (input impedance of the transistor is much less than the capacitive reactance of C2). With these assumptions, the effects of R_i and C_b can be ignored. The derivation of Z_{in} is as follows:

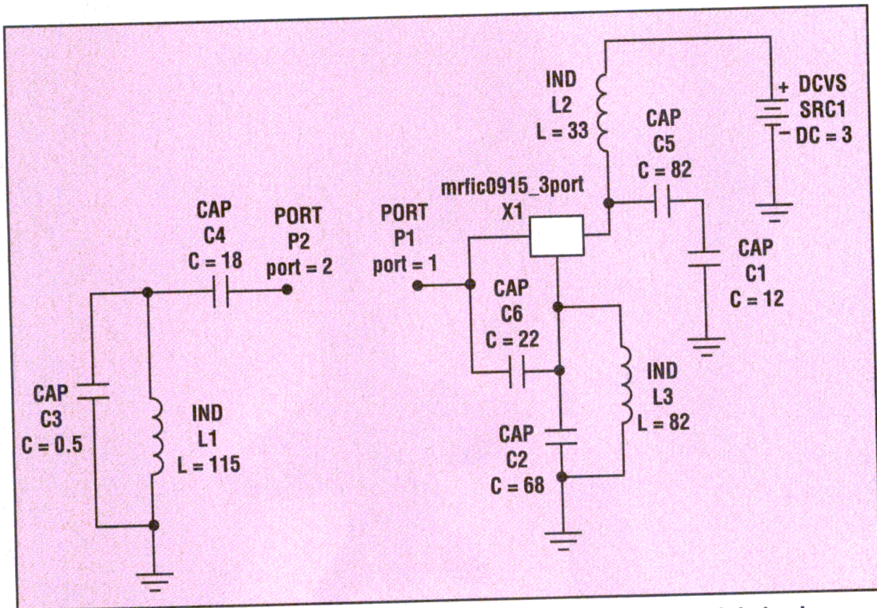
$$V_{in} = I_b \times Xc1 + (I_b + V_{be} \times G_m) \times Xc2 \qquad (1)$$

$$Z_{in} = \frac{V_{in}}{I_b} = Xc1 + Xc2 + \frac{V_{be} \times G_m \times Xc2}{I_b} \qquad (2)$$

$$Z_{in} = Xc1 + Xc2 + G_m \times Xc2 \times Xc1 \quad where \frac{V_{be}}{I_b} = Xc1 \qquad (3)$$

$$Z_{in} = \frac{G_m}{j\omega C1 \times j\omega C2} + \frac{1}{j\omega C1} + \frac{1}{j\omega C2} \qquad (4)$$

$$Z_{in} = \frac{-G_m}{\omega^2 \times C1 \times C2} + \frac{1}{j\omega(\frac{C1 \times C2}{C1 + C2})} \qquad (5)$$



6. To simulate the VCO design for a computer program, the circuit is broken down into two single-port systems, the negative-R generator (Port P1), and the resonator tank circuit (Port P2).

Equation 1 shows the voltage addition across capacitors C1 and C2. The voltage across C1 is I_b (or I_{in}, input current) times the capacitive reactance of C1. But for the voltage across C2, I_b must be summed with the current gain from the collector ($G_m \times V_{be}$) before it can be multiplied by the reactance of C2 to provide the voltage across C2. Thus, the sum of voltages across C1 and C2 is equal to the input voltage, V_{in}. Dividing V_{in} by I_b (input current) defines the input impedance of the network (Eq. 2). Equation 3 substitutes XC1 for V_{be}/I_b and recall that the emitter of the transistor is the node between C1 and C2, so V_{be} is the voltage across C1. Equation 4 substitutes all of the complex terms. Collecting real and imaginary terms, Equation 5 shows the real term with negative resistance and the imaginary phase term. Notice the dominance of G_m in the real term. This derivation proves that it takes gain (G_m, transconductance) to generate negative resistance.

The imaginary term resembles the form of two series capacitors, so the equivalent negative resistance port is modeled as Fig. 5, where:

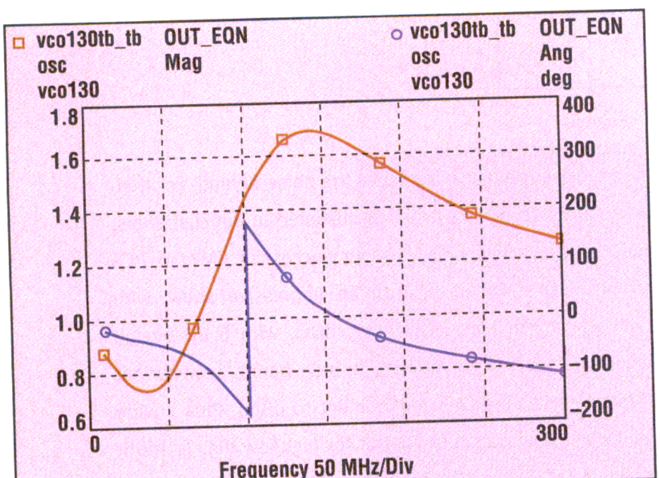
$$R = \frac{-G_m}{\omega^2 \times C1 \times C2} \qquad (6)$$

To maintain oscillation, the resistive loss of the resonating tank network must be less than the magnitude of the negative resistance.

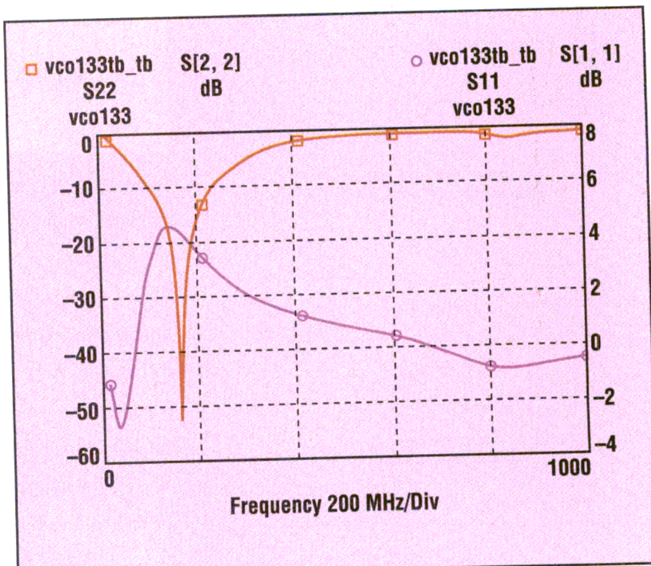
DESIGN SIMULATION

Using a simulation program, such as Libra (from HP EESof), it is possible to estimate and predict the oscillation frequency and gain margin of the oscillator. The first step is to break down the oscillator design into two single-port systems, the Negative-R generator and the resonance tank (Fig. 6). Port-P1 represents the negative-R port and Port-P2 represents the resonator tank. Next, estimate the initial component values then simulate and tune for desired results.

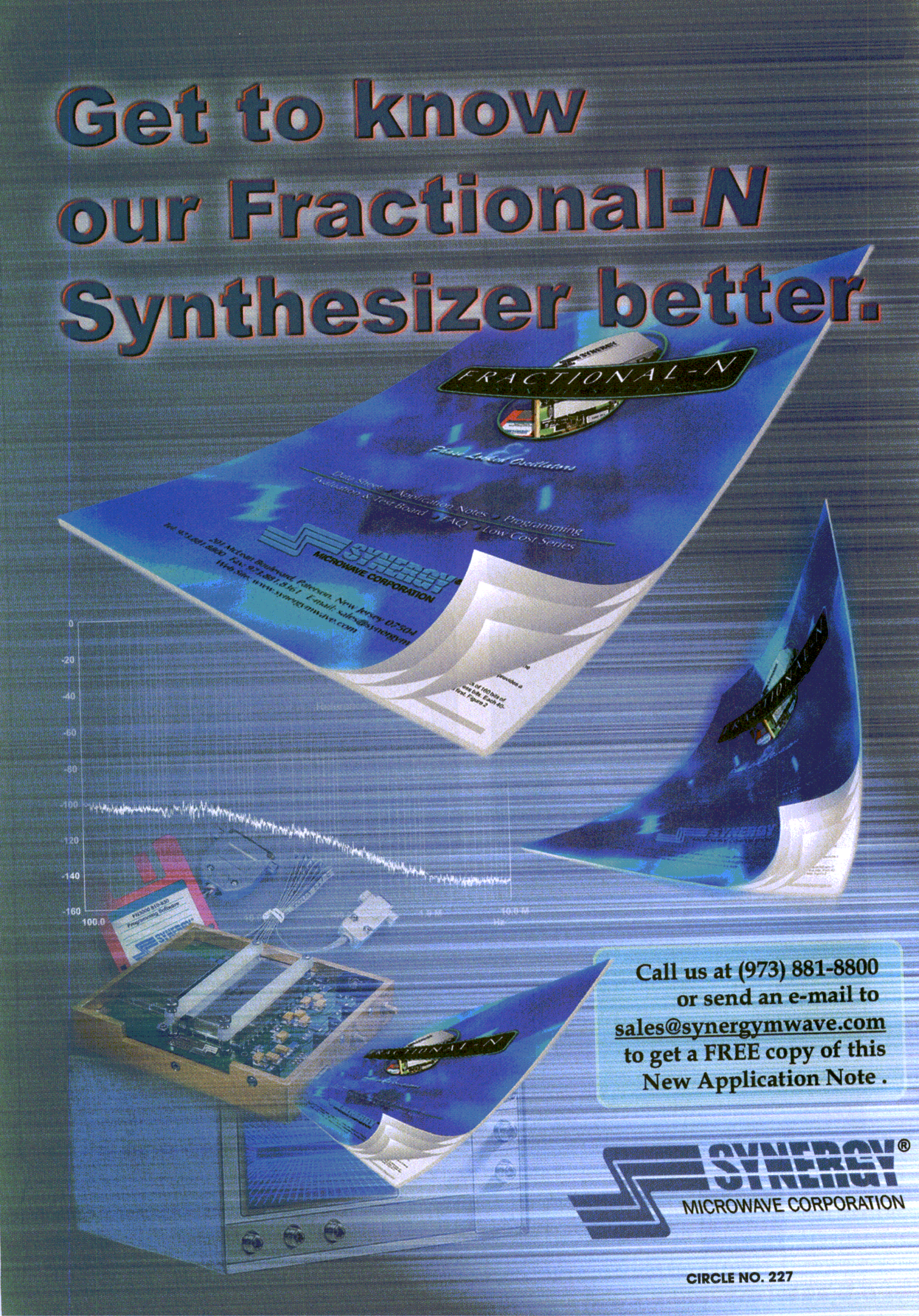
For the resonant port, an LC structure will suffice for simulation purposes as opposed to modeling the transformer. For accurate results, measure the value of the primary inductance of the transformer on a network analyzer and then use this



7. These curves of the VCO simulation of the output equation illustrate the amplitude (in dB) and phase (in degrees) of the combined ports in Fig. 6. The oscillation frequency occurs at 0-deg. phase shift (right axis) and positive gain (about 1.7 dB on the left axis). The oscillation frequency as measured on the horizontal axis is 157 MHz.



8. These are S-parameter curves of the output return loss (S22, left axis) and input or negative-R response (S11, right axis) of the oscillator.



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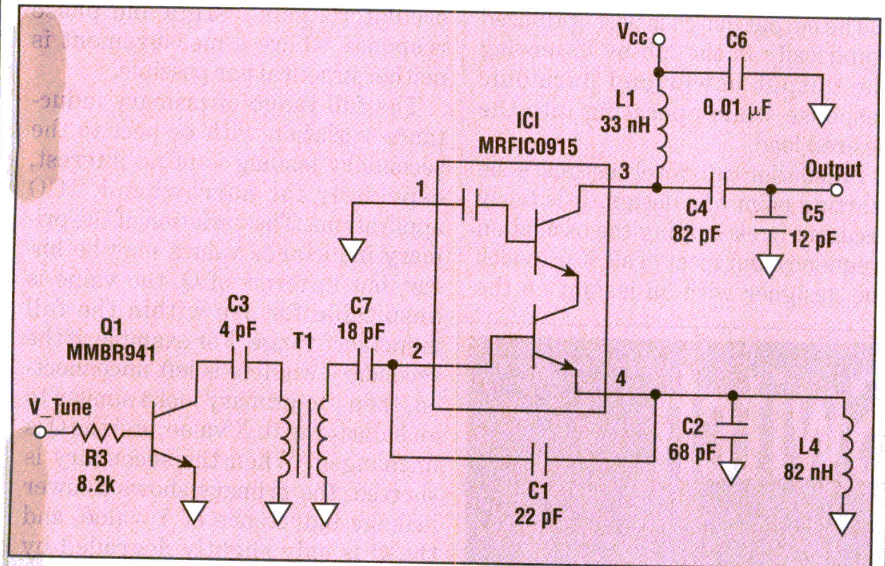
without degrading Q. One technique is to isolate the main inductive tank from any resistive losses. Inserting a small-value capacitor to the secondary (C3) [Fig. 9] minimizes the resistive loading, resulting in a narrower-band VCO while improving Q. This approach does not completely solve the problem of low mid-frequency Qs. It reduces the low-Q band to a narrow usable range. The phase noise is best at the highest and lowest frequency range (10), −121 dBc/Hz and −122.5 dBc/Hz at 100 kHz. This is where the secondary load is open or fully saturated. In the center tuning range, the secondary switch provides a finite resistive loss resulting in lower resonator Q. In this period, the fo/2Q corner frequency extends beyond the active device's fc (flicker-noise) corner frequency and the lowered inductor Q becomes the limiting component in phase-noise response, −111 dBc/Hz at 100 kHz.

The modulation input for this design is very unsophisticated. The load transistor is uncompensated and the bias point is not centered. This circuit has been designed as more of a proof of concept rather than as a refined design. Thus, K_{VCO} is very nonlinear, representing the turn-on knee of the transistor as well as the saturation point of the transistor. V-tune ranging from 0 to +1.5 VDC results in frequency deviations of 152 to 157 MHz. Using a common emitter switch without emitter degeneration, temperature variation drastically varies the load point of the secondary and, consequently, the tuning frequency. In testing K_{VCO}, remember to heavily filter the input voltage with large RC values. Otherwise, spurious power-supply signals can be modulated on to the output. Similarly, the V_{CC} supply voltage must be kept very clean.

The output match was optimized only through simulation. In this particular topology, the output power is inter-related to the feedback capacitor C2 (Fig. 10). The cascode amplifier is designed to have its emitter grounded for maximum gain and output. Although C2 is required for negative-R generation, it also has a secondary effect on the gain of the cascode amplifier. Increasing C2 increases the gain for the common-base buffer amplifier and inversely decreases negative-R. By selecting the value for C2, output power may also be varied. In this design, the output power approximately measured +3.4 dBm at a V_{cc} of +3 VDC and I_{cc} of 5.8 mA. Harmonics were only 8 dBc since the output stage is running practically at compression. This was an attempt to eliminate local-oscillator (LO) amplifiers. A higher-compression device, such as the MRFIC0916, may be used for even higher power output.

VCO pulling of 2:1 VSWR resulted in a frequency deviation of approximately 48 kHz for an fo of 157 MHz.

(continued on page 187)



9. The complete VCO design uses the MRFIC0915 cascode amplifier as the active device and transformer T1, a wirewound, 1:1 ratio, RF type whose inductance is varied with a control voltage.

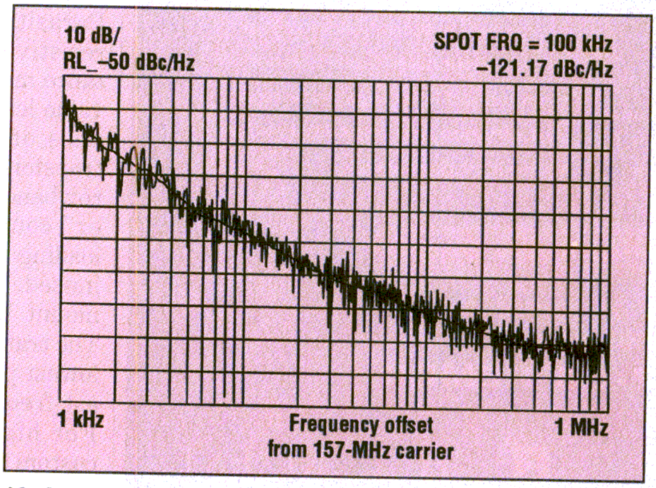
value to start the design. Modeling nonlinear magnetic characteristics may be sufficient at lower frequencies in power electronic designs, but at RF frequencies, it is difficult without math-intensive E&M simulators. For the design of this IF VCO, only a small portion of the transformer's inductance range is required. Thus, it is not necessary to simulate the full dynamic characteristic of the transformer with respect to its secondary loading.

As for the negative resistance port, the active device may be critical to meet close-in phase-noise and oscillation requirements. For VCO applications, silicon (Si)-bipolar devices are preferred due to their inherent low 1/f noise. The MRFIC0915 is an Si monolithic cascode amplifier with high reverse isolation to improve VCO-pulling performance. With on-chip bias circuitry, lower component counts can be achieved. The gain is high enough to provide the necessary negative resistance. The internal active bias improves VCO pushing and temperature performance. The current supply is very low (<2.5 mA at +2.7 VDC) in lower output-power design. If higher power output is desired, the MRFIC0916 is a higher bias/compression replacement.

When simulating the design, the heart of the simulation is defined by the output equation. This equation mathematically connects the resonator port to the negative-R resulting in an output of phase/gain response for the oscillator. When entering the equation, be sure to use the Output Equation Menu and not Output Variable Menu of the program. Define the OUT_EQN of the oscillator to be "OSC = S11 * S22." To display the phase and amplitude response of the combined ports (Fig. 7), plot the magnitude (dB) and the phase (degrees) of the output variable "OSC." Oscillation frequency occurs when the sum of the phase shifts cross 0 deg. and there is positive return loss or gain (dB) in the amplitude response. The tuning of C1 and C2 (negative-R network) can vary the bandwidth (shape) and operating frequency of the positive return loss. For optimal performance, values should be chosen in order to shape the gain curve into as narrow a band as possible while encompassing the tuning range of the VCO. By doing this, spurious unwanted oscillations may be prevented. The emitter inductor (L3) [Fig. 6] is an RF choke optimized at the oscillation frequency. A low-value resistor can be used here, but is not recommended since the internal temperature-compensating network for the active bias is referenced to ground.

In terms of tuning the LC tank, the desired response is to have the steepest phase shift of "OSC" cross the 0-deg. axis. It can be shown through simulation that higher Q resonators will produce steeper 0-deg. phase crossings. The slope of the phase shift is proportional to the oscillator's phase-noise performance of the VCO if device noise is not a limiting factor. Figure 7 shows the simulated result with the 0-deg. phase crossing at approximately 156 MHz and a positive resultant gain of 1.7 dB. The actual measured value for oscillation was surprisingly accurate at 157 MHz.

Due to the high-isolation (>35-dB) feature of the MRFIC0915, the output match values do not affect the oscillator tuning. The output match can be ignored during the time of oscillator tuning. Once all of the oscillator tuning values are derived, the output match can then be determined. Here, a low-pass matching structure is recommended for attenuating harmonic frequencies. To design the output match, terminate Port-P1 (neg-R) and create an output Port-P2. Deacti-



10. A phase-noise plot taken at 100-kHz offset from the 157-MHz oscillation frequency shows the reading to be −121.17 dBc/Hz.

vate all resonator components. The output match can be tuned by varying the series and shunt capacitor combination at the desired oscillation frequency. Tune these values for the lowest output return loss. The S-parameters for the design, S22, which shows the output return loss, and S11, which shows the negative-R port response, are illustrated in Fig. 8. The output match is best optimized empirically in the lab by observing the output power and harmonic response while operating into the desired load.

Simulation can closely estimate the starting point of a design. It is fairly accurate in estimating the oscillation frequency, but most of all, it provides the designer with an insight on the oscillator's gain margin and phase response where a measurement is neither practical nor possible.

The full range of primary inductance variation with respect to the secondary loading is of no interest, especially for narrowband VCO applications. The variation of the primary inductance values may be linear, but in terms of Q, the value is unsuitable for use within the full inductance range. For example, if the secondary winding is left unconnected, then the primary looks similar to an inductor with X value, and the Q is unchanged. When the secondary is shorted, the primary shows a lower leakage inductance of Y value, and the Q is only slightly degraded by coupling and resistive losses. The loading variation on the secondary will proportionally vary the primary inductance from X to Y value. However, in the midst of this transition where the secondary goes through the phase of finite resistive load, the Q of the entire inductor is severely degraded. The resistive loss of the secondary load de-Qs the inductor. Therefore, the usable range is at either end of the X or Y values.

RF TRANSFORMER

The transformer used in this design is a Coilcraft 1812WBT-5, 1:1 ratio, wirewound RF transformer. The primary inductance is measured to be approximately 110 nH at 200 MHz. With the secondary shorted, the leakage inductance value is approximately 23 nH at 200 MHz. Parasitic losses of coupling, core, resistive, and interwinding capacitance may all contribute to a larger-value leakage inductance. The tightness of the coupling of an ideal transformer is of no interest in a narrowband VCO design. In fact, a "looser" coupling is preferred so that loading of the resonator tank is minimized. The availability of surface-mount RF transformers is limited. The transformer chosen is Coilcraft's lowest primary inductance and highest-frequency transformer offered. For higher-frequency designs, a custom transformer with a different turn ratio would be required.

In the completed design (Fig. 9), the goal is to vary the inductance without degrading Q. One technique is to isolate the main inductive tank from any resistive losses. Inserting a small-value capacitor to the secondary (C3) [Fig. 9] minimizes the resistive loading, resulting in a narrower-band VCO while improving Q. This approach does not completely solve the problem of low mid-frequency Qs. It reduces the low-Q band to a narrow usable range. The phase noise is best at the highest and lowest frequency range (10), −121 dBc/Hz and −122.5 dBc/Hz at 100 kHz. This is where the secondary load is open or fully saturated. In the center tuning range, the secondary switch provides a finite resistive loss resulting in lower resonator Q. In this period, the fo/2Q corner frequency extends beyond the active device's fc (flicker-noise) corner frequency and the lowered inductor Q becomes the limiting component in phase-noise response, −111 dBc/Hz at 100 kHz.

The modulation input for this design is very unsophisticated. The load transistor is uncompensated and the bias point is not centered. This circuit has been designed as more of a proof of concept rather than as a refined design. Thus, K_{VCO} is very nonlinear, representing the turn-on knee of the transistor as well as the saturation point of the transistor. V-tune ranging from 0 to +1.5 VDC results in frequency deviations of 152 to 157 MHz. Using a common emitter switch without emitter degeneration, temperature variation drastically varies the load point of the secondary and, consequently, the tuning frequency. In testing K_{VCO}, remember to heavily filter the input voltage with large RC values. Otherwise, spurious power-supply signals can be modulated on to the output. Similarly, the V_{CC} supply voltage must be kept very clean.

The output match was optimized only through simulation. In this particular topology, the output power is inter-related to the feedback capacitor C2 (Fig. 10). The cascode amplifier is designed to have its emitter grounded for maximum gain and output. Although C2 is required for negative-R generation, it also has a secondary effect on the gain of the cascode amplifier. Increasing C2 increases the gain for the common-base buffer amplifier and inversely decreases negative-R. By selecting the value for C2, output power may also be varied. In this design, the output power approximately measured +3.4 dBm at a V_{cc} of +3 VDC and I_{cc} of 5.8 mA. Harmonics were only 8 dBc since the output stage is running practically at compression. This was an attempt to eliminate local-oscillator (LO) amplifiers. A higher-compression device, such as the MRFIC0916, may be used for even higher power output.

VCO pulling of 2:1 VSWR resulted in a frequency deviation of approximately 48 kHz for an fo of 157 MHz.

(continued on page 187)

Model PLL Dynamics And Phase-Noise Performance

Model PLL Dynamics, Part 1

A popular mathematical modeling tool and SPICE software can simplify the analysis of phase-locked loops.

Eric Drucker

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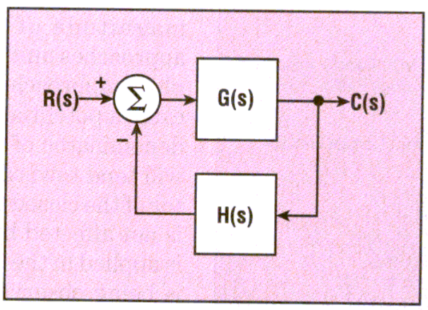
PHASE-LOCKED loops (PLLs) have become a mainstay in modern electronics. Until recently, due to their high cost, their use has been confined to military and high-end commercial hardware and high-performance RF test equipment. With the advent of the "wireless revolution" of the last decade, however, PLLs are now widely used in consumer applications, notably cellular telephones and communications systems where good phase noise is critical. This first installment of a three-part article series will review the fundamentals of PLLs. The calculation of loop dynamics, which affects noise performance, will also be covered. In the next installment, the basics of phase-noise concepts will be reviewed.

Before it is possible to predict the phase noise of a PLL, it is necessary to understand the dynamics of the PLL system. A PLL is basically a control system, where phase is the variable of interest. It can be analyzed using classical linear Laplace transform techniques. Recall that the Laplace transform is a shorthand method for representing a linear differential equation with constant coefficients, with variable s representing the differentiation operator. This linear model is really all that is needed to analyze the noise, modulation, and small-signal switching performance of a PLL (Fig. 1).

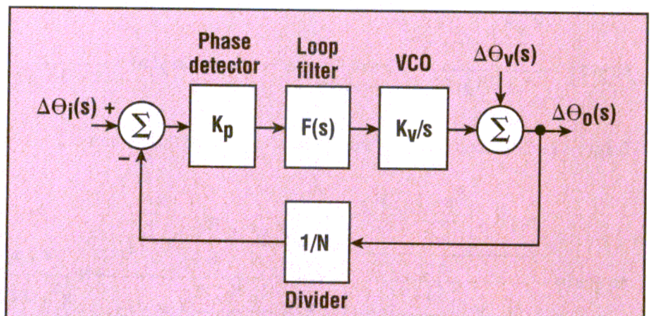
In its simplest form the system consists of a forward-gain block G(s) and a feedback block H(s). The open-loop gain is G(s)H(s) and the system transfer function or closed-loop gain is:

$$C(s) / R(s) = (Forward\_Gain) / (1 + Loop\_Gain) = G(s) / [1 + G(s)H(s)] \quad (1)$$

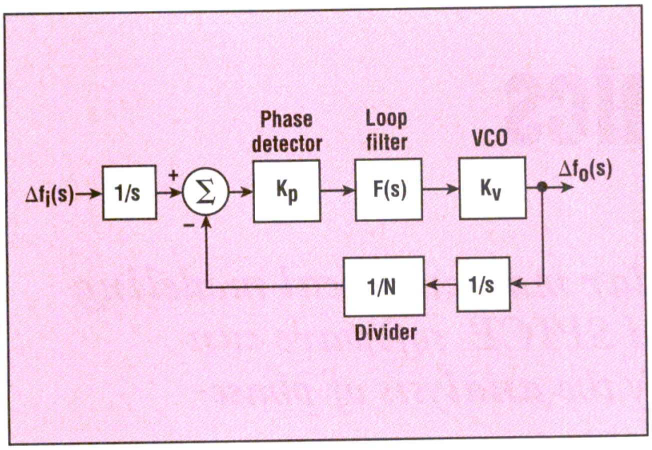
By using this simple rule, it is possible to easily write transfer functions for loops with multiple forward and feedback blocks to obtain the



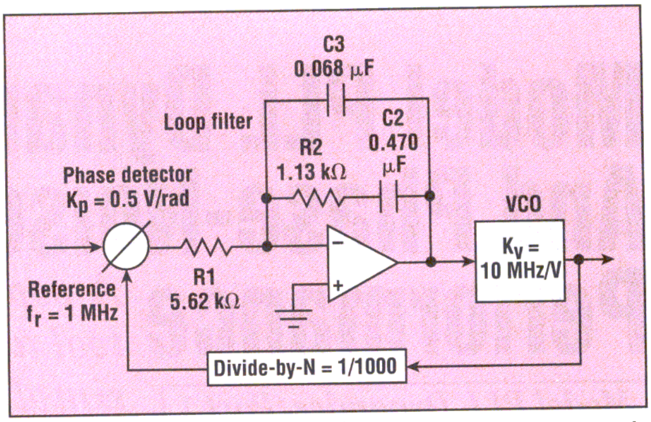
1. This simple control system can be used to emulate the operation of a PLL.



2. A simple PLL model can be constructed with a phase detector, loop filter, VCO, and divider.



3. This alternative model for a PLL rearranges the ideal integrator (1/s) in its transfer function.



4. For the purpose of analysis, this example PLL was used. It consists of a voltage-output phase detector, an active integrator, a VCO, and divider.

transfer function from virtually any input to output. Using signal-graph theory, one can also analyze loops within loops, although this is not necessary for most PLL applications.

By taking the inverse Laplace transform, the small-signal time-domain performance can be predicted, such as the PLL's small-signal frequency and phase-settling time as well as the final phase error. It is possible to apply a step (1/s) or other forcing function at the input, R(s), to see how the system behaves. Even without taking the inverse Laplace transform, only using the transfer function by itself, the initial and final value theorem gives insight into limits of time-domain performance at t = 0 and t = ∞ when excited by step, ramp, etc.

To view the response of the system in the frequency domain, or the small-signal sinusoidal steady state, the Laplace transform variable s need only be replaced by jω to produce Bode plots. These Bode plots lend considerable insight into the performance of a control system. One can analyze the open-loop gain and phase response and be able to predict the performance and stability of the loop when it is closed, which will ultimately determine the noise performance. The stability is important as it affects the amount of peaking in the closed-loop response and in the extreme can lead to loop oscillations. The poles are in the denominator of the transfer function, while the zeros are in the numerator. Each pole yields a –6-dB/octave or –20-dB/decade slope on a Bode plot. A zero results in a similar positive slope.

Only the poles in the denominator of the closed-loop transfer function impact stability. The denominator of the closed-loop transfer function is 1+ G(s)H(s) or 1 + open-loop gain. If the magnitude of the open-loop gain approaches unity at the same time the phase approaches 180 deg., this indicates a potential for instability, as the denominator of the transfer function will tend toward zero. The denominator of the closed-loop transfer function is not affected by where the stimulus is applied in the loop and which output is being observed. Taking these control-theory concepts and applying them to a PLL yields the linearized control system model for a PLL, con-

MATHCAD ANALYSIS FOR EXAMPLE PLL

Component Values and Loop Constants

$R_2 := 1130 \quad R_1 := 5620 \quad C_2 := 0.47\cdot10^{-6} \quad C_3 := 0.068\cdot10^{-6} \quad N := 1000 \quad K_v := 10\cdot10^{6} \quad K_p := 0.5$

Calculate Time Constants of Active Integrator

$T_z := R_2 \cdot C_2 \qquad f_z := \frac{1}{2\cdot\pi\cdot T_z} \qquad f_z = 299.67$ Zero Frequency

$T_p := R_2 \cdot \frac{C_2 \cdot C_3}{C_2 + C_3} \qquad f_p := \frac{1}{2\cdot\pi\cdot T_p} \qquad f_p = 2.371\cdot10^{3}$ Pole Frequency (Only for 3rd Order)

$F_2(s) := \frac{R_2}{R_1}\cdot\frac{(s+f_z)}{s} \qquad F_3(s) := \frac{R_2}{R_1}\left(\frac{C_2}{C_2+C_3}\right)\cdot\frac{(s+f_z)}{s}\cdot\frac{f_p}{s+f_p}$ Loop Filter (Active Integrator 2nd and 3rd Order)

$GH_2(s) := \frac{K_p\cdot K_v \cdot F_2(s)}{s\cdot N}$ Open Loop Transfer Function

$\Theta o_2(s) := \frac{\frac{K_v \cdot K_p \cdot F_2(s)}{s}}{1 + GH_2(s)}$ Output Transfer Function (Low Pass) $\quad \Theta v_2(s) := \frac{1}{1+GH_2(s)}$ VCO Transfer Function (High Pass)

Substitue for Open Loop and Loop Filter Transfer Function and Put in Terms of 2nd Order Transfer Function

$$\Theta o_2(s) = \frac{\dfrac{K_v\cdot K_p\left[\dfrac{(s+f_2)}{s}\cdot\dfrac{R_2}{R_1}\right]}{s}}{1+\dfrac{K_p\cdot K_v\left[\dfrac{(s+f_2)}{s}\cdot\dfrac{R_2}{R_1}\right]}{s\cdot N}} = \frac{N\cdot\dfrac{K_v\cdot K_p}{N}\cdot\dfrac{R_2}{R_1}\cdot(s+f_2)}{s^2+\dfrac{K_p\cdot K_v}{N}\cdot\dfrac{R_2}{R_1}\cdot(s+f_2)} = N\cdot\frac{2\cdot\xi\cdot\omega_n\cdot s+\omega_n^2}{s^2+2\cdot\xi\cdot\omega_n\cdot s+\omega_n^2}$$

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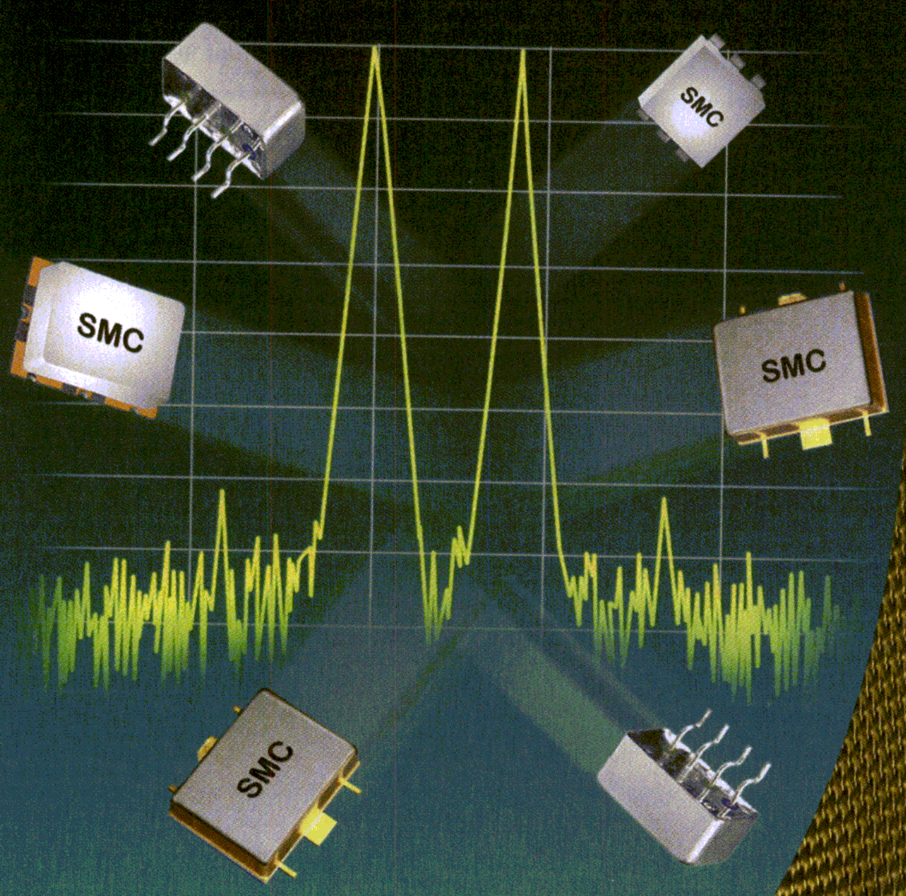

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sisting of a phase detector, loop-filter voltage-controlled oscillator (VCO), and divider (Fig. 2).

Referring to Fig. 2, the forward gain, G(s), is equal to $K_PF(s)(K_V/s)$. The feedback gain, H(s), is equal to 1/N. The loop gain, G(s)H(s), is equal to:

$$G(s)H(s) = K_pF(s)(K_v/s)/(1/N) \quad (2)$$

Therefore, the closed-loop transfer function with respect to the input phase is:

$$\frac{\Delta\theta_o(s)}{\Delta\theta_i(s)} = K_pF(s)\frac{K_v}{s} / 1 + K_pF(s)\frac{K_v}{s}\frac{1}{N} = N\left[\frac{K_pF(s)K_v}{N} / s + \frac{K_pF(s)K_v}{N}\right] \quad (3)$$

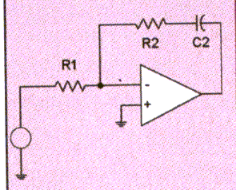
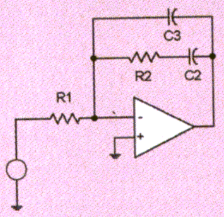
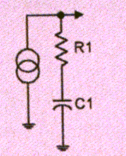
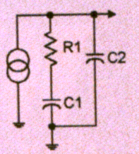
The closed-loop transfer function with respect to phase perturbations introduced at the VCO's output is:

$$\frac{\Delta\theta_o(s)}{\Delta\theta_v(s)} = 1/1 + K_pF(s)\left(\frac{K_v}{s}\right)\left(\frac{1}{N}\right) = s/s + \frac{K_pF(s)K_v}{N} \quad (4)$$

It should be noted that this is a baseband model of a PLL. The carrier, or RF frequency, does not enter into the analysis. What this transfer function represents what happens to the phase of the output signal from the VCO if one "wiggles," or modulates, the phase of the reference signal into the phase detector. This lowpass transfer function also predicts how the loop acts on noise from the reference, phase detector, and divider. Note that at "DC" that gain is N. The second transfer function represents what happens to the phase of the output of the loop if a phase perturbation at the VCO output is introduced. The 1 in the numerator is the forward-path gain. This highpass transfer function predicts how the loop will act on VCO noise.

The VCO has a transfer function of K_v/s. In other words, a VCO acts as a "pure" integrator in a PLL. This comes about because a VCO is a voltage-to-frequency converter. The VCO tuning coefficient (K_v) is typically expressed in MHz/V. To convert the frequency output of the VCO to the phase variable, one applies the relationship that dθ/dt = ω. In other words, phase is the integral of frequency with respect to

Table 1: Comparing various loop filters

Active integrator	Active integrator with pole	Charge-pump integrator	Charge-pump integrator with pole
			
$F(s) = \frac{s\tau_2 + 1}{s\tau_1}$ $\tau_1 = R_1C_2$ $\tau_2 = R_2C_2$	$F(s) = \frac{s\tau_2 + 1}{s\tau_1(s\tau_3 + 1)}$ $\tau_1 = R_1(C_2 + C_3)$ $\tau_2 = R_2C_2$ $\tau_3 = R_2(C_3 \parallel C_2)$	$F(s) = R\frac{s\tau_1 + 1}{s}$ $\tau_1 = R_1C_1$	$F(s) = R\frac{s\tau_1 + 1}{s\tau_1(s\tau_2 + 1)}$ $\tau_1 = R_1C_1$ $\tau_2 = R_2(\frac{C_1C_2}{C_1 + C_2})$
Type2, 2nd Order	Type2, 3rd Order	Type 2, 2nd Order	Type 2, 3rd Order

MATHCAD ANALYSIS (cont.)

Define Gain Crossover in Terms of "DC" gains

$f_x := K_p \cdot \frac{K_v}{N} \cdot \frac{R_2}{R_1}$ $\quad f_x = 1.005 \cdot 10^3$

Solve for Natural Frequency, in Hertz and Damping Factor

$\omega_n := \sqrt{\frac{K_p \cdot K_v}{N} \cdot \frac{R_2}{R_1} \cdot f_z}$ $\quad \omega_n := \sqrt{f_x \cdot f_z}$ $\quad \omega_n = 548.881$

$\xi := \frac{1}{2} \cdot \sqrt{\frac{K_p \cdot \frac{K_v}{N} \cdot \frac{R_2}{R_1}}{f_z}}$ $\quad \xi := \frac{1}{2} \cdot \sqrt{\frac{f_x}{f_z}}$ $\quad \xi = 0.916$

Set Up for Frequency Sweep and Bode Plots of Open and Closed Loop Gain

$f_{start} := 10$ $\quad f_{stop} := 10^5$ $\quad npd := 100$ $\quad i := 0..\left(\log\left(\frac{f_{stop}}{f_{start}}\right)\right) \cdot npd + 0.5$ $\quad f_i := 10^{\frac{i}{npd}} \cdot f_{start}$ $\quad s_i := j \cdot f_i$

$dB_{F2_i} := 20 \cdot \log(|F_2(s_i)|)$ $\quad \phi_{F2_i} := \arg(F_2(s_i)) \cdot \frac{180}{\pi}$ Loop Filter Magnitude and Phase

$dB_{GH2_i} := 20 \cdot \log(|GH_2(s_i)|)$ $\quad \phi_{GH2_i} := \arg(GH_2(s_i)) \cdot \frac{180}{\pi}$ Open Loop Gain Magnitude and Phase

$dB\Theta o2_i := 200 \cdot \log\left(\left|\frac{\Theta o_2(s_i)}{N}\right|\right)$ $\quad dB\Theta v2_i := 200 \cdot \log(|\Theta v_2(s_i)|)$ Magnitude Closed Loop Gains (2 dB/div)

Solve for Gain Crossover, Phase Margin, High Pass and Low Pass -3dB Frequency $\quad f_s := 500$

$f_{c2} := \text{root}(|GH_2(j \cdot f_s)| - 1, f_s)$ $\quad f_{c2} = 1.045 \cdot 10^3$ Loop Gain Crossover 2nd Order

$\phi_{m2} := -180 - \frac{180}{\pi} \cdot \arg(GH_2(j \cdot f_{c2}))$ $\quad \phi_{m2} = -73.998$ Phase Margin 2nd Order

$fv_{3dB\_2} := \text{root}(|\Theta v_2(j \cdot f_s)| - 0.707, f_s)$ $\quad fv_{3dB\_2} = 752.22$ High Pass -3dB Frequency 2nd Order

$fo_{3dB\_2} := \text{root}\left(\left|\frac{\Theta o_2(j \cdot f_s)}{N}\right| - 0.707, f_s\right)$ $\quad fo_{3dB\_2} = 1.292 \cdot 10^3$ Low Pass -3dB Frequency 2nd Order

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time. This accounts for the 1/s, the ideal integrator, in the VCO's transfer function.

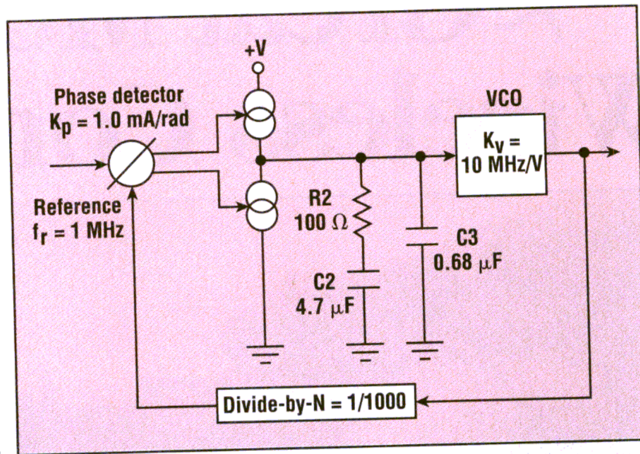
Taking this frequency to phase relationship one step further, it is possible to redraw the block diagram is terms of frequency deviation. The 1/s ideal integration of the VCO is moved to the feedback block, G(s), and the input frequency is transformed to phase by the addition of an ideal integrator before the phase detector (Fig. 3). By applying the control-system rule, the transfer function is:

$$\frac{\Delta f_o(s)}{\Delta f_i(s)} = \frac{1}{s}(K_pF(s)K_v) / 1 + (K_pF(s)K_v)\frac{1}{s}\frac{1}{N}$$

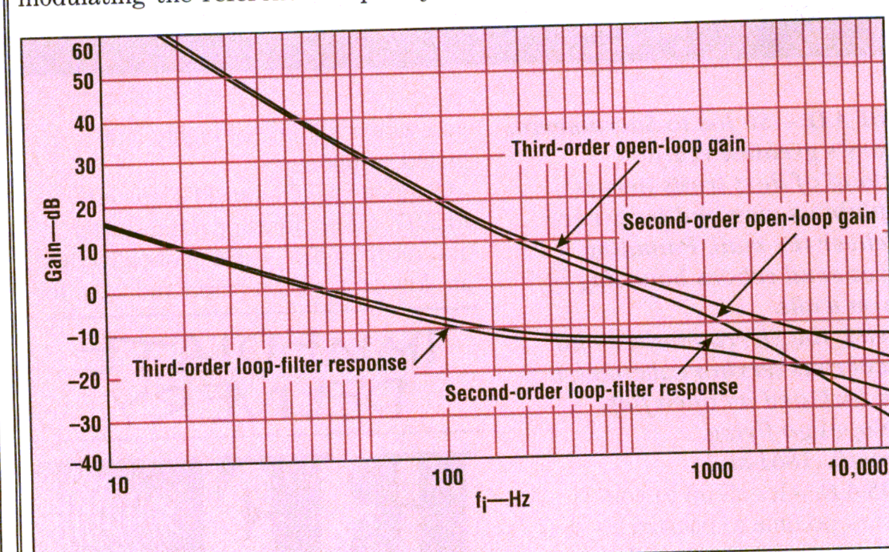
$$= N\left[\frac{\frac{K_pF(s)K_v}{N} / s +}{\frac{K_pF(s)K_v}{N}}\right] \quad (5)$$

This transfer function is the same as before. The only difference is the placement of the 1/s integration blocks. In other words, frequency modulating the reference frequency and observing the frequency deviation at the VCO has the same transfer function as phase modulating the reference frequency and observing the phase deviation at the VCO.

In both models, the phase detector is broken up into two blocks—an ideal subtractor and a phase to voltage converter. There are many types of phase detectors (mixer, multiplier, sample and hold, digital exclusive OR, and digital phase/frequency), but the most common is a digital phase/frequency detector. The phase-detector range is approximately $\pm 2\pi$ with a gain of $K_p = V_p/2\pi$ for a voltage output configuration and $K_p = I_p/2\pi$ for a current output configuration. This type of phase detector has the advantage in that it acts similar to a frequency steering



5. The PLL can also be modeled with a current-output phase detector.



6. The loop-filter and open-loop gain responses are plotted for the second- and third-order cases of the example.

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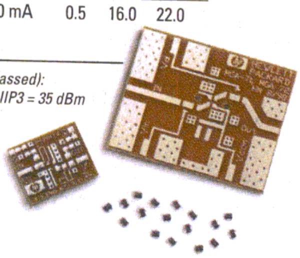
ATF-34143 (output)	4V, 60 mA	0.5	17.5	31.5
ATF-35143 (output)	2V, 15 mA	0.4	18.0	21.0
ATF-38143 (output) *coming soon*	2V, 10 mA	0.5	16.0	22.0

** as a switch (amp bypassed): insertion loss = 2.5 dB, IIP3 = 35 dBm*



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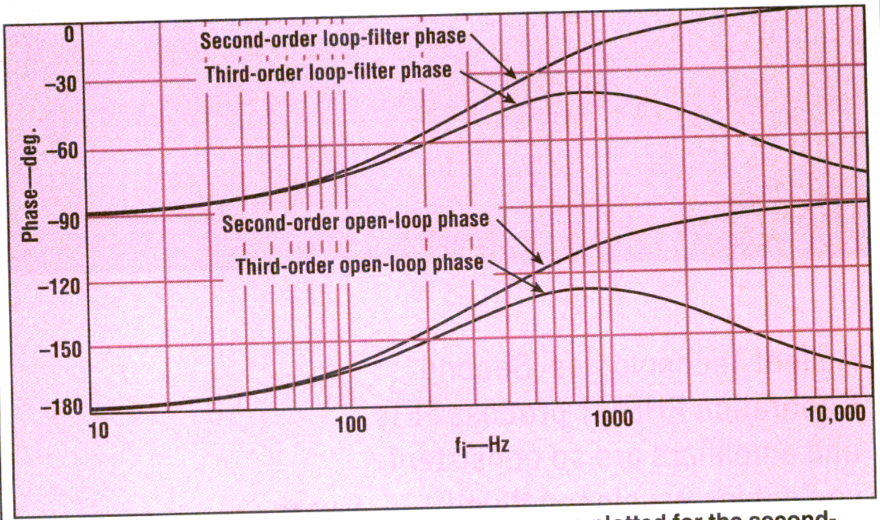
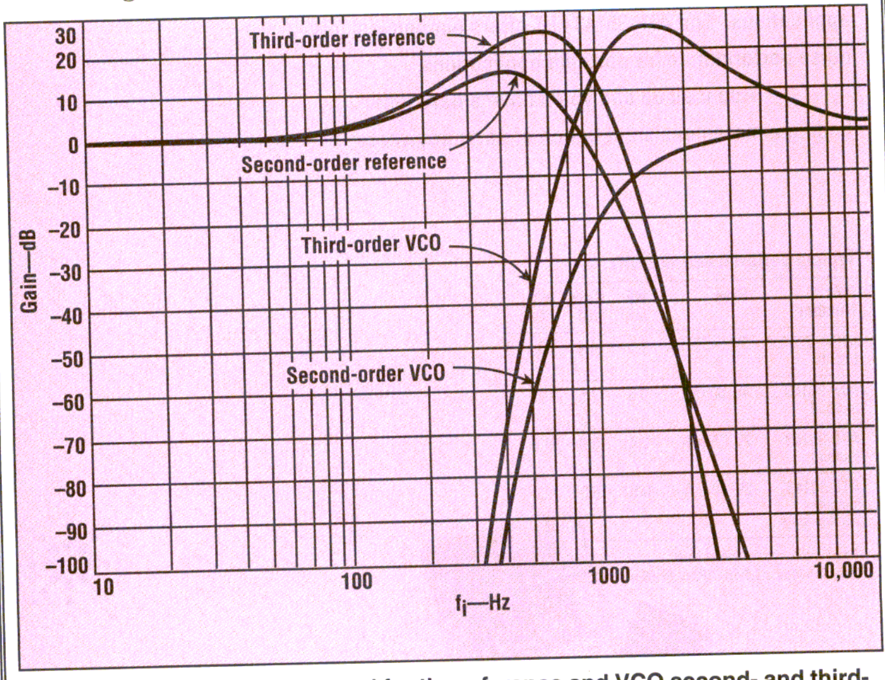


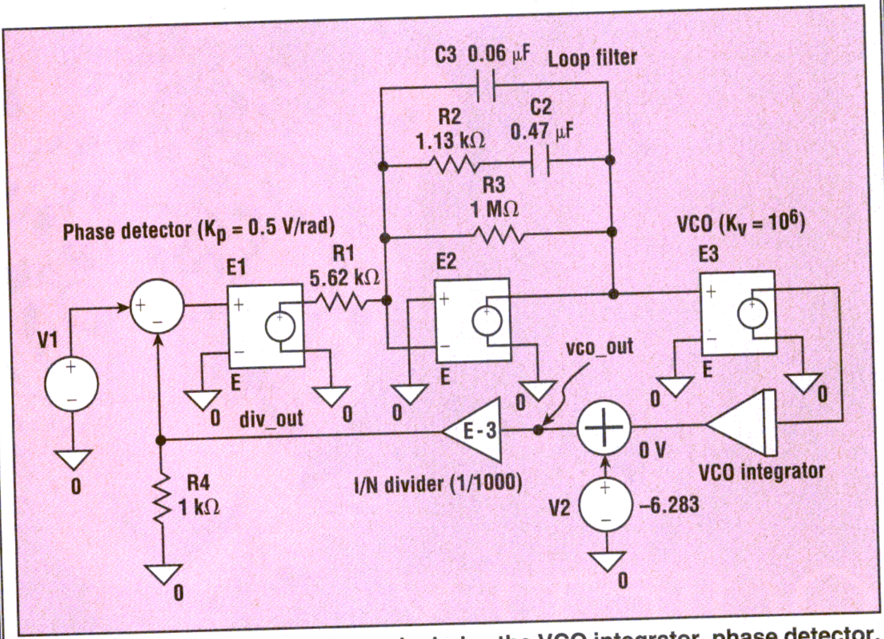
7. The loop filter and open-loop phase responses are plotted for the second- and third-order example cases.

device when the loop is not locked. It can "tune" the VCO close enough to the frequency required for locking. Pure phase detectors, such as a mixer, require additional circuitry in the PLL to steer to VCO close to the correct frequency. The divider in the feedback path has a gain of 1/N.

The loop filter or F(s) block ultimately determines the dynamics of the PLL. In the simplest PLL, the phase detector is connected directly to the VCO, where F(s) = 1, but almost all PLLs use some form of an active integrator as a loop filter. An integrator allows the correct VCO voltage with almost zero phase error at the phase detector, which minimizes the reference energy and hence lowers the reference spurious. The integration response (–20 dB/decade) does not extend indefinitely out in frequency. There is a break, or zero, in the transfer function caused by the addition of an R in series with the integrator capacitor. This break is necessary for loop stability. The form is different depending on whether the phase detector has a voltage or current output.



8. The closed-loop gain is plotted for the reference and VCO second- and third-order cases.



9. This PSPICE schematic diagram includes the VCO integrator, phase detector, and loop filter.

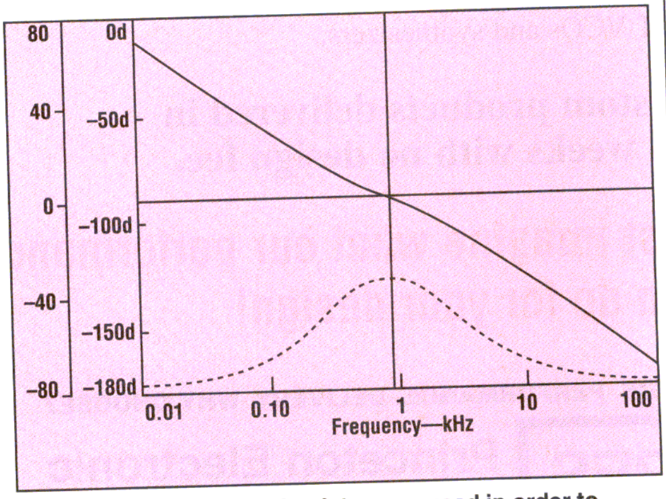
The operational amplifier (opamp) circuitry is for use with a voltage-output phase detector. Most commercial single-chip PLL synthesizers have a charge pump, or current output. The equivalent loop-filter block does not need an active element to perform the integration. Some of the various types of loop filters are shown in Table 1.

The F(s) block can be made quite elaborate by the addition of active or inductor-capacitor (LC) filtering following the integrator. These blocks are useful for filtering of noise or spurious signals. PLLs are often specified in terms of the type and order. The type indicates the number of integrators or poles at DC. It should be pointed out that the virtual pole due to the VCO's frequency-to-phase integration counts for 1. The order is the total number of poles. The simplest PLL without a F(s) block is a Type I, first-order loop.

Including an additional integrator in the F(s) block yields a Type II, second-order loop. Placing an additional pole with the integrator in the F(s) block gives a Type II, third-order loop. These are the most-common loops.

SETTING AN EXAMPLE

Some of these basic PLL concepts and some additional new ideas can be demonstrated with an example. The example of Fig. 4 consists of a voltage-output phase detector with a reference frequency of 1 MHz, an active integrator, a VCO with K_v of 10 MHz/V, and a feedback division ratio



10. The PSPICE circuit simulator was used in order to predict the open-loop gain and phase responses of the example PLL.

of 1000. Therefore, the output frequency is 1 GHz. Usually, it is desired to change the output frequency, so that N is not constant but, in this case, a nominal value of 1000 is assumed. An equivalent version using a current-output phase detector is shown in Fig. 5, although the voltage source version will serve as an example.

MATHCAD ANALYSIS(cont.)

Repeat for 3rd Order Case (Equations Not Shown)

$f_{c3} = 871.621$ $\quad \phi_{m3} = -50.842 \cdot deg$ Loop Gain Crossover and Phase Margin 3rd Order

$fv_{3dB\_3} = 525.688$ High Pass -3dB Frequency 3rd Order

$fo_{3dB\_3} = -1.45 \cdot 10^{3}$ Low Pass -3dB Frequency 3rd Order

The derivation of the loop equations using MathCAD are shown in the sidebar. The time constants are first calculated for the active integrator. Two cases are presented—a second-order case (where C3 is set to 0) and a third-order case. The open-loop and closed-loop transfer functions are shown in terms of the Laplace variable s. The loop filter can be expressed in terms of time constants, as shown in Table 1, or pole/zero frequencies, as shown in the sidebar. The gain-crossover frequency is the frequency at the point the magnitude of the open-loop gain equals 1 or 0 dB $[|GH(j\omega)| = 1]$. The first-order gain crossover frequency is a useful quantity. This is the gain as if this were a first-order loop with the same loop parameters (K_v, K_p, and N), but F(s) is equal to the gain of the loop filter.

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This is arrived at by setting the open loop zero(s) = 0 (DC) and the open-loop pole(s) = ∞. The gain crossover is equal to approximately 1 kHz for this example.

For the second-order case, it is possible to express the closed-loop transfer function in terms of the natural frequency (ω_n) and damping factor (xi). This is a holdover from classical control theory. It should be stressed that this approach is not

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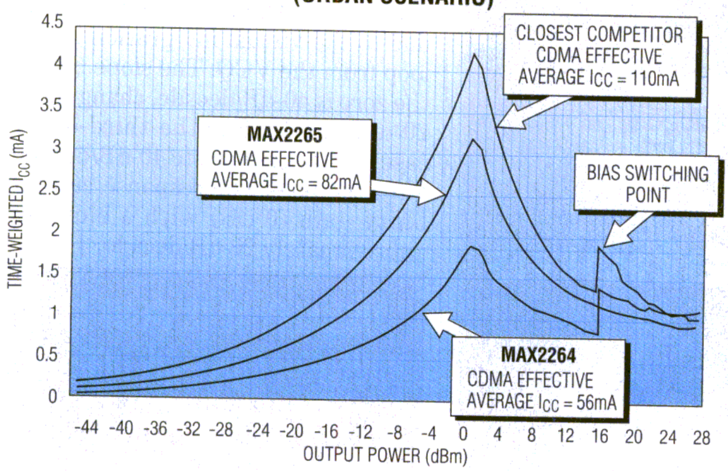

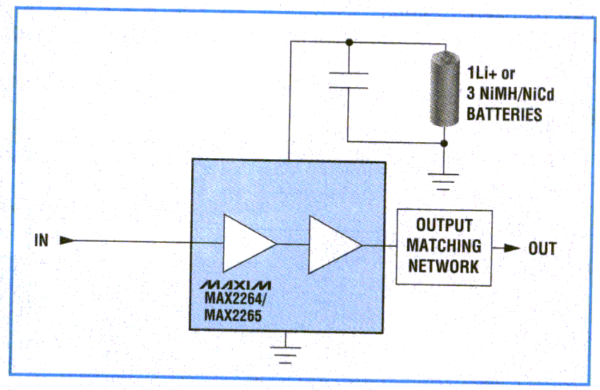

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very useful for higher-order loops.

Creating Bode plots with MathCAD is very straightforward. A log frequency sweep is generated and s is set to jω. Since MathCAD performs all the algebraic and complex number housekeeping, most of drudgery is eliminated.

Figure 6 shows the filter response and the PLL open-loop gain for the second- and third-order cases. The filter response shows the 20-dB/decade slope from the active integrator, flattening out at the zero frequency of 300 Hz. For the third-order case, the response once again drops at 20-dB/decade starting at the pole frequency of 2.3 kHz. The PLL open-loop gain is "tilted" by 20-dB/decade due to the virtual integration in the loop from the VCO. The slope before the zero is 40-dB/decade, changing to 20-dB/decade. For the third-order case, it changes back to 40-dB/decade after the pole. The response crosses unity gain (0 dB) with a slope of approximately 20-dB/decade.

Table 2: Computer loop parameters

	Second-order case	Third-order case
Gain crossover frequency	1045 Hz	872 Hz
Phase margin	74 deg.	51 deg.
Lowpass closed-loop –3-dB frequency	1292 Hz	1450 Hz
Highpass closed-loop –3-dB frequency	752 Hz	526 Hz

USUALLY IT IS BEST TO HAVE AT LEAST 45 DEG. OF PHASE MARGIN TO MINIMIZE THE PEAKING IN THE FREQUENCY DOMAIN AND OVERSHOOT IN THE TIME DOMAIN.

The phase response is shown in Fig. 7. For the filter, the phase shift that is close to DC is –90 deg. After the zero, the phase approaches 0 deg. and, for the third-order case, climbs back up to –90 deg. after the pole. The PLL's open-loop phase differs from the filter by –90 deg. and starts at –180 deg. and approaches –90 deg. for the second-order case. It then goes back to –180 deg. for the third-order case.

The phase margin is probably the best indication of loop stability. It is defined as the phase shift, with respect to –180 deg. at the gain crossover frequency. Using the root-finding function in MathCAD, it is possible to set the magnitude of the open-loop transfer function equal to unity, [|GH(jω)| = 1], then allow MathCAD to find the frequency. The computed values are summarized in

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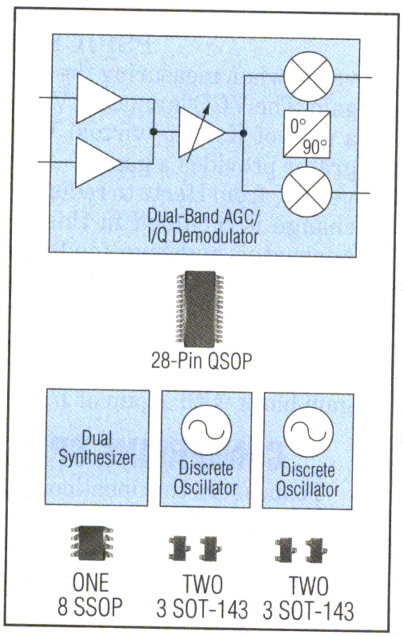

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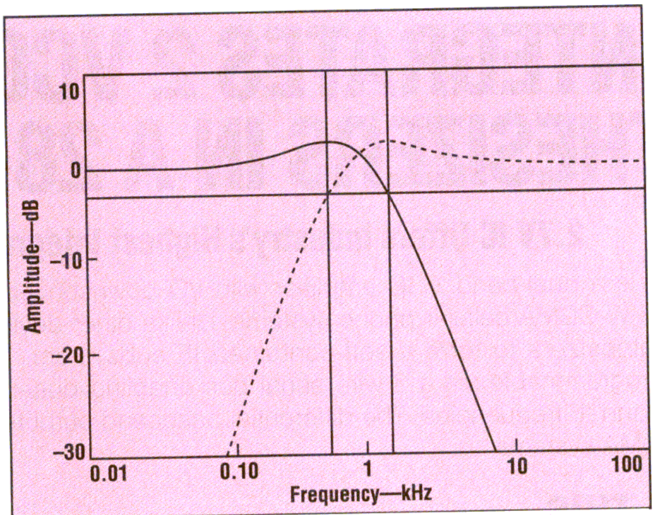

11. The PSPICE circuit simulator was used to predict the closed-loop response of the example PLL.

Table 2. The phase margin is computed from this gain crossover by determining the argument of the open-loop phase and subtracting it from 180 deg. A true first-order loop will provide 90 deg. of phase margin.

The addition of the zero and pole decreases the phase margin from 90 deg. The closer the pole or zero is to the gain-crossover frequency, the worse that the phase margin becomes. The zero is typically placed at approximately one-third of the gain-crossover frequency and a pole should be placed greater than two times the gain-crossover frequency. Usually, it is best to have at least 45 deg. of phase margin in order to minimize the peaking in the frequency domain and overshoot in the time domain.

Figure 8 shows the closed-loop response. For the lowpass case, the DC gain of M is normalized to 1. The third-order case shows more peaking in the highpass and lowpass responses consistent with the reduced phase margin. Once again, MathCAD can be used in order to calculate the 3-dB frequencies by setting the magnitude of the appropriate closed-loop transfer function that is equal to 0.701 (–3 dB).

Using circuit-simulation programs, such as PSPICE, similar results can be obtained as those calculated with MathCAD. As a check, it is useful to model the PLL both ways to see if the results are consistent. The PSPICE model is shown in Fig. 9.

The PLL elements, phase detector, loop filter, VCO, and divider are modeled as voltage-controlled voltage sources (VCVS). The phase detector is broken up into a subtractor and a K_p gain block. The opamp is idealized using a high-gain (10^5) VCVS.

The 1 MΩ resistor in the model of Fig. 9 enables PSPICE to converge when measuring the open-loop gain. The VCO is another VCVS with a gain of K_v. The virtual VCO integrator provides a gain of -2π to convert K_v from Hertz to radians. A sign change is included in this block to guarantee negative feedback. In a real PLL, one would interchange the variable as well as reference inputs to the phase detector to obtain the proper phase. Finally, the divider is a gain block with a gain of 1/N.

CONVERGING SPICE

To measure the open-loop gain and phase, the loop would be broken at R4 and the stimulus applied at V1 and measured at div_out. To measure the lowpass closed-loop gain, the stimulus is applied at V1 and measured at vco_out. The highpass response is obtained by stimulating at V2 and measuring at vco_out (Figs. 10 and 11).

The next installment in this article series on PLLs will review the sources of phase noise, and extend the concepts of loop modeling to predicting the phase-noise performance of the loop. MathCAD and a SPICE simulator will be used in the modeling process. ••

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Comparing Round And Rectangular Crystals

Consider the pros and cons of rectangular crystals carefully when designing a crystal oscillator.

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Technical Support Engineer
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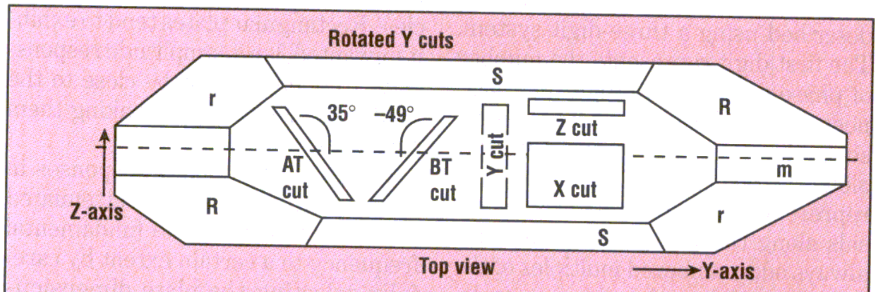
QUARTZ crystals are at the heart of practically every frequency and time-keeping oscillator. Crystals for these sources can be divided into two broad categories—round and rectangular. Within each category, there are several varieties, or "cuts," of crystal. Each category and cut has its own particular set of capabilities and limitations, which engineers must consider carefully when they design a crystal oscillator. This article discusses round and rectangular crystals, and the significant differences in their motional-parameter values. It also discusses the severe limitations of rectangular crystals imposed by their tendency to support unwanted frequency responses and coupled modes.

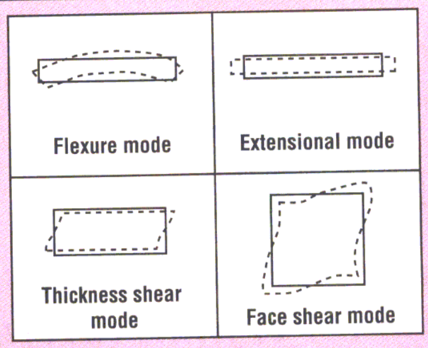
In 1880, Pierre and Jacques Curie demonstrated the existence of piezoelectricity in experiments conducted using rectangular (square and oblong) plates cut from various types of crystals. In 1920, the discovery that quartz piezoelectric resonators could control the frequency of an oscillator created a market for crystals. At first, this market was composed primarily of amateur radio operators. But as the benefits of crystal control became more widely appreciated, commercial radio stations converted their equipment, and the market expanded rapidly. In the first years of crystal manufacture, nearly all commercial units were fabricated using rectangular plates due to the relative ease of shaping these plates.



1. This is the top view of a man-made quartz stone from which crystal-resonator plates are cut.

With the adoption of crystal control by the military, the use of rectangular plates continued well into the middle of World War II. During the war years, the increase in demand for crystal units made quartz an increasingly valuable commodity. And after the war, there was an increasing demand for crystals that could operate at higher frequencies. Many of the plates in military and commercial use were large—one inch per side or larger. But the increasing value of quartz and the need for higher-frequency operation had a great deal to do with spurring the development of smaller plate designs, including round plates.

The operating frequency of a particular type of resonator, called a thickness-shear resonator, is primarily determined by the thickness of the crystal plate—the thinner the plate, the higher the frequency of operation. But a thin rectangular plate with large lateral dimensions is subject to breakage. It was found that round plates could better withstand the stresses of high-frequency operation, so round plates became the industry standard. Still, the use of rectangular plates for some applications, particularly "ham" radio, continued until the early 1960s. Some attempts were made to improve the designs and manufacturing processes for rectangular plates, but the processing equipment of the time did not lend itself to producing very-small rectangular plates with any precision or repeatability. Consequently, round plates almost entirely supplanted the rectangular design.



2. These drawings show the main types of vibrational modes that can be induced in a crystal-resonator plate.

Today, it seems that the crystal industry has come full circle. Driven by improvements in manufacturing technology and the ever-expanding demand for smaller-size packages in surface-mount devices, rectangular plates have returned to the market. But they still present troublesome characteristics that challenge today's designers just as they challenged those of yesteryear.

The terms "strip resonator," "AT-strip resonator," and "BT-strip resonator" are commonly used to describe the low-profile, surface-mount, quartz crystals used in oscillator circuits. Although the word "strip" implies a non-square rectangular shape, many surface-mount crystal packages house a square resonator plate. The word "resonator" simply refers to a crystal plate sandwiched between two electrodes. The terms "AT" and "BT" refer to the way that the plate is cut from the quartz stone. Most of today's demand is for these AT and BT crystals because they can resonate at high frequencies.

Figure 1 shows a cultured (man-made) quartz stone from which crystal-resonator plates are cut. The Y-axis is the mechanical axis, extending from end to end as shown. Y-cut plates are cut from the stone in a way so that the thickness dimension is parallel to the Y-axis. The resonant frequency of a Y-cut plate is primarily determined by its thickness. However, Y-cut plates exhibit some undesirable characteristics that make them unsuitable for commercial use. So most plates used today are cut at a slightly rotated angle, resulting in plates with more desirable, reproducible attributes (the most important of these being frequency stability versus temperature). The two most-common singly rotated Y-cuts are the AT and BT cuts, which, as shown in the figure, are nearly opposite one another in orientation. This difference in orientation results in substantial differences in their operating characteristics.

Figure 2 illustrates the various vibration modes that can be induced in a quartz plate. AT and BT plates are made to vibrate primarily in the thickness-shear mode. However, it is important to understand that any quartz plate can be made to vibrate in any one or combination of the illustrated modes. The vibration modes can be induced electrically, mechanically, acoustically, thermally, or by some combination of these factors. Modes that are induced unintentionally are usually referred to as "coupled" or "unwanted" modes. As a further complication, any singly rotated thickness-shear resonator will also vibrate in the face-shear mode whenever the thickness-shear mode is energized.

The thickness-shear frequency response of an AT plate can be described using a three-digit system. The first digit represents the number of phase reversals through the thickness of the plate, the second represents the number of phase reversals along the plate's X-axis, and the third represents the number of phase reversals along the Z-axis. Overtones are always odd-numbered multiples of the fundamental, so using this nomenclature, the modes 1,1,1; 3,1,1; 5,1,1; etc., represent the fundamental frequency, the third harmonic overtone, and the fifth harmonic overtone, respectively.

Unfortunately, a resonator plate with straight sides and square edges is ideally shaped to reflect waves and facilitate the generation of standing waves. For thickness-shear plates, unwanted frequency responses and coupled modes are particularly troublesome.

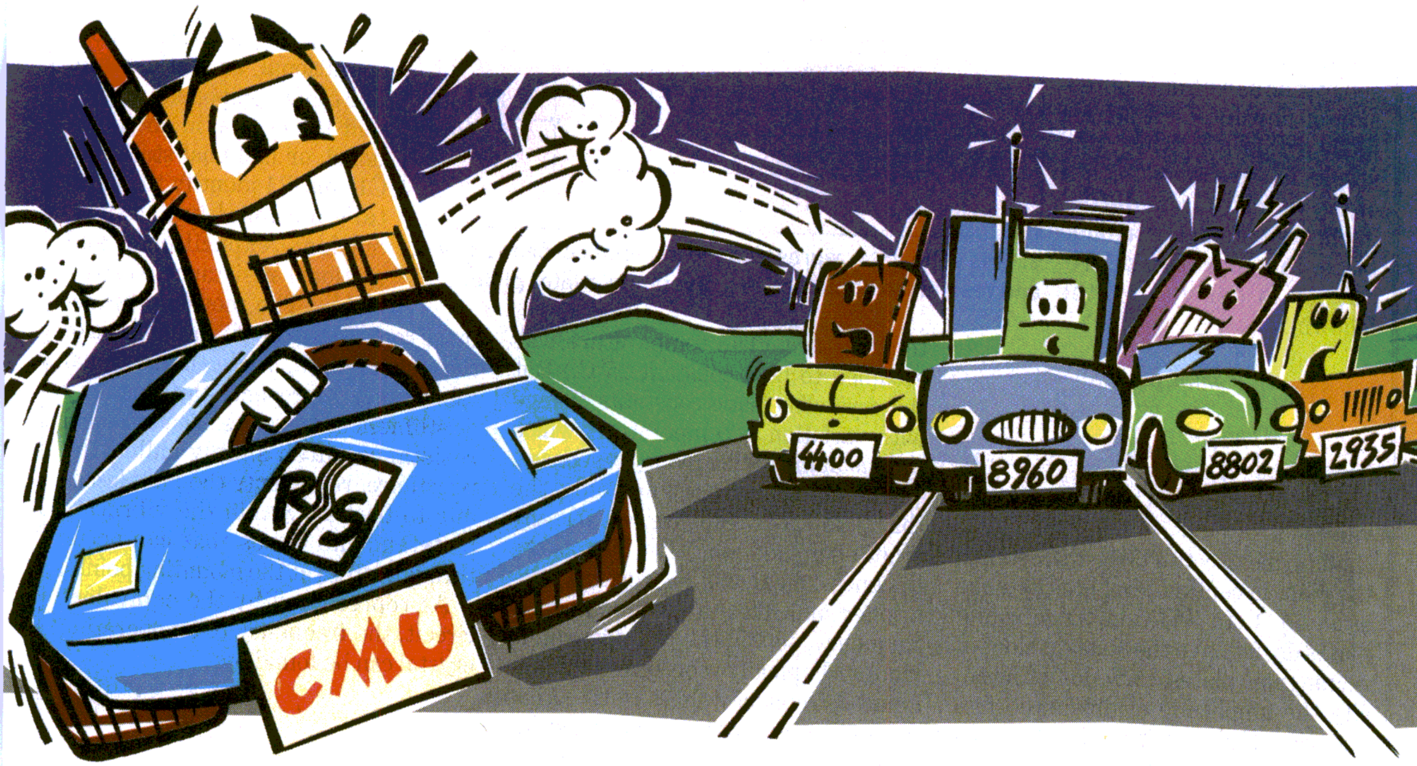
For a rectangular AT-cut plate, the equation for calculating the approximate frequency is:

$$fm,n,p = 0.5\sqrt{\frac{1}{\rho}}\sqrt{\frac{C_{66}m^2}{T^2}+\frac{C_{11}n^2}{L^2}+\frac{C_{55}p^2}{W^2}} \quad (1)$$

where:
m, n, and p = integers,
ρ = the density of quartz (2.65),
T = the thickness,
L = the length,
W = the width of the plate in centimeters, and C_{66}, C_{11}, and C_{55} = the elastic constants of the quartz in the X, Y, and Z directions, respectively.

In the above equation, if m = n = p = 1, the frequency that is noted (f 1,1,1) is the fundamental frequency, or the lowest frequency where the plate would vibrate in the thickness-shear mode. In theory, this plate, with the dimensions provided, would be free of unwanted responses. However, it is extraordinarily difficult to achieve this condition when using rectangular plates. They typically display a range of frequencies, described as f 1,3,1 or f 1,3,3 or some other combination of integers. Thus, the plate vibrates not only at the fundamental frequency, but also at several unwanted frequencies. Rectangular plates tend to exhibit unwanted, large-amplitude responses at frequencies that lie close to the fundamental frequency, making them particularly problematic.

Unwanted frequency responses in rectangular plates can be attenuated and separated from the fundamental frequency to a certain extent by carefully selecting the plate dimensions and/or by beveling the plate edges. But using a round quartz plate with



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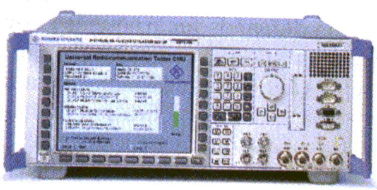

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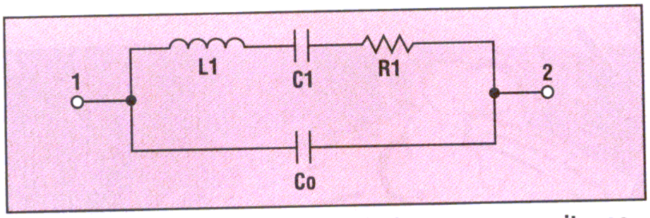
round electrodes makes the separation as well as suppression of unwanted responses more straightforward, and results in the elimination one of the variables from the frequency equation. For a round plate, the approximate frequency is derived by the following:



3. This schematic represents the inductance, capacitance, and resistance contained in a crystal-resonator plate.

$$fm,n,p = 0.5\sqrt{\frac{1}{\rho}}\sqrt{\frac{C_{66}m^2}{T^2} + \frac{(C_{11}n^2 + C_{55}p^2)}{D^2}} \quad (2)$$

where:

all terms except D (the diameter of the plate in centimeters) are the same as in eq. 1. In addition, since round plates do not have the straight sides of rectangular plates, they do not intensify the amplitude of unwanted frequencies. The use of round plates does not eliminate unwanted responses entirely, but it attenuates them so that they are not as troublesome.

It should be noted that both equations yield only approximate frequencies, in part because the plates are not infinite in size. Nonetheless, the equations make it possible to estimate the frequency of unwanted responses and, more important, their distance from the fundamental frequency. For round crystal plates, careful selection of the diameter of the electrodes and the amount of metal used in them enables the designer to control and suppress unwanted responses to some extent.

Rectangular plates, in addition to having unwanted frequency responses, are also likely to have other vibration modes, called "coupled" modes, energized at frequencies near or at the desired frequency. The frequencies of these coupled modes are functions of the lateral plate dimensions. Thus, the designer must carefully select the dimensions of the plate to minimize or eliminate coupled modes. Often, changes of only a few kilohertz require significant changes in dimensions. During World War II, elaborate tables of "safe" dimensions versus frequency were developed and remained in common use for years thereafter.

Up to this point, the performance of rectangular versus circular plates has been considered without regard to temperature. (The temperature was assumed to be a constant 25°C.) But the crystal's elastic constants change with variation in temperature, which can result in new frequency responses. These changes affect not only the thickness-shear response, but also any other energized vibration. Just as the thickness shear will energize at odd-integer multiples of its fundamental frequency, so will the other vibration modes. Typically, the temperature-induced frequency shifts in the other modes are rather large—on the order of hundreds of parts per million per degree Celsius. Thus, a coupled mode interfering with the main-mode response may be the n^{th} overtone of the face shear, or some other response.

As noted previously, coupled modes are easily induced in rectangular plates. Although the amplitude of these responses is normally suppressed enough to avoid gross perturbations, the presence of any coupled mode will perturb the fundamental response, if only slightly. In addition, certain demands for frequency deviation over specific temperature ranges simply cannot be met using rectangular plates. If the application demands purity of frequency or precise frequency deviation over a specific temperature range, the designer must carefully evaluate the use of a rectangular plate.

The operation of a quartz crystal is frequently explained using the familiar "equivalent circuit," illustrated in Fig. 3.

The crystal in question is assumed to be vibrating at a specific frequency and order of overtone, and free of coupled modes. The capacitance labeled "C0" is a real capacitance, comprising the capacitance between the electrodes and the stray capacitance associated with the mounting structure. It is also known as the "shunt" or "static" capacitance, and represents the capacitance of the crystal in a non-operational, or static, state. The other components represent the crystal in an operational, or motional state. L1, C1, and R1 identify the crystal's motional inductance, motional capacitance, and motional resistance, respectively. The motional inductance represents the vibrating mass of the quartz plate, while the motional capacitance represents the elasticity or stiffness of the plate. The motional resistance, often simply called the resistance, represents the bulk losses due to friction within the vibrating plate and the losses that can occur through stress at the mounting points.

As represented by the equivalent circuit, the frequency of an operating crystal can be found by:

$$f = \frac{1}{2\pi\sqrt{L_1C_1}} \quad (3)$$

where:

L1 = the motional inductance in mH,
C1 = the motional capacitance in pF, and
f = the frequency in MHz.

The motional inductance and motional capacitance depend on one another—a change in the value of one results in a change in the value of the other, provided the frequency remains constant. Changes in either of the two nearly always result in a change in the resistance, though this is not a hard and fast rule.

The motional capacitance and inductance of a flat (plano-plano) plate can be varied by changing the area of the electrodes. If the electrode area is increased, the static and motional capacitances increase, the motional inductance decreases, and typically, the resistance decreases. An increase in the motional capacitance results in a change in the natural resonant frequency of the crystal (increased "pullability"), and a less-stable crystal. Conversely, if the electrode area is decreased, the static and motional capacitances decrease, the motional inductance increases, and (usually) the resistance increases, if only slightly. An increase in motional inductance results in decreased pullability, and, thus, there is a more-stable crystal.

Conventional crystal units (such as

those packaged in the HC-49/U holder) typically use a round quartz resonator plate equipped with round electrodes. The electrodes are applied to the surface of the quartz plate using metal deposition under vacuum. Thus, a wide variety of electrode sizes can be applied to a resonator plate that has a specific diameter. If the electrode required by the application is the same size as, or larger than, the resonator plate, one can often use a slightly larger plate in the specified holder.

While it is theoretically possible to apply the same design and manufacturing techniques to strip resonators, it is much less practical to do so. Rectangular resonators are manufactured in extremely large quantities to meet the high demand, and standardization is critical to efficient productivity. The rectangular masks used in the deposition of rectangular electrodes are difficult to fabricate, so it is unlikely that manufacturers will be willing to customize them to any great extent. Moreover, the degree of customization is sharply limited by the limitations of rectangular plates, namely, the limitations placed on the dimensions of the plate by the holder/package, and those necessitated by avoiding coupled modes. The limitations on the dimensions of the electrodes and electrode area, in turn, limit the ranges of values for the shunt and motional capacitances and the motional inductance, and ultimately impact the resistance value.

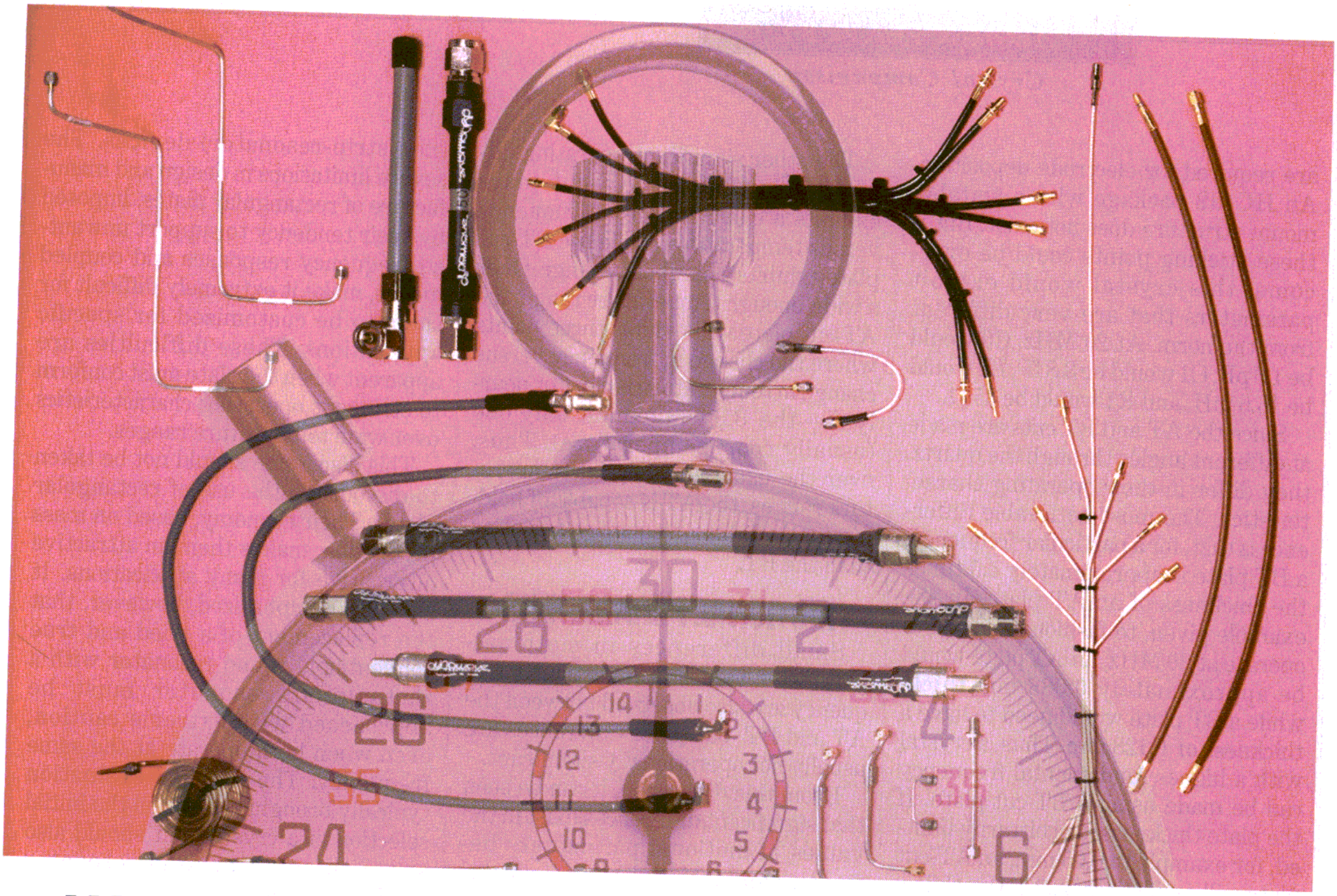
Depending on the application, these limitations may not be significant. In many cases, the values of motional parameters for rectangular plates compare quite favorably with those for conventional circular crystal units. The table compares the parameters at a frequency of 20 MHz for a circular resonator housed in the familiar HC49U holder from Fox Electronics with the parameters of a strip resonator housed in the company's HC49S holder.

Parameters of round and rectangular crystals at 20 MHz

Parameter	HC49U	HC49S
C0	5.5 pF	3.7 pF
C1	20.8 fF	14.2 fF
L1	3.1 mH	4.5 mH
R1	6.1 Ω	8.7 Ω
Q	65.6 K	66.2 K

Both parts are mass produced and intended for mass-market applications, but they exhibit some significant differences. In particular, the increased motional inductance observed in the HC49S (strip resonator) is more than enough to offset the increased resistance, resulting in a higher "Q" value than that of the HC49U.

As a point of interest, assuming the holder of choice is the HC49S, a circular plate would be limited to a diameter of approximately 0.12 in. (3 mm). This plate would use electrodes of approximately 0.06 in. (1.5 mm) in diameter and would be difficult to manufacture, as would the masks that



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are required for electrode deposition. An HC49S package with a suitable mount structure does not exist. But if these sticking points could be overcome, this crystal would exhibit parameters that are very different from the norm. At 20 MHz, C0 would be 1.6 pF, C1 would be 3.8 fF, L1 would be 16.5 mH, and R1 would be 35 Ω.

Since the AT and BT cuts are made at different angles through the quartz, they differ in their operating characteristics. The most noticeable difference is that, for a particular frequency, a BT plate is approximately 1.5 times the thickness of an AT plate. In the example given, to fashion a crystal to operate at 20 MHz, an AT plate would be approximately 0.083 mm thick, while a BT plate would need to have a thickness of 0.128 mm. Thus, a crystal with a higher fundamental frequency can be made using a BT-cut plate. If the plate thickness is arbitrarily limited, for example to 0.05 mm, an AT-cut plate will oscillate at 33.2 MHz while a BT-cut plate will oscillate at 51.2 MHz.

The other significant operating difference is that the AT-cut plate exhibits a cubic change in frequency versus temperature, while the BT-cut plate exhibits a parabolic change. Over a wide-enough temperature range, the AT-cut plate will exhibit three points where the change in frequency versus change in temperature is zero, or nearly so—the BT will exhibit only one (usually room temperature). Thus, over the usual commercial temperature ranges, the AT is capable of holding much tighter frequency deviation than the BT.

MOTIONAL PARAMETERS

Small differences in motional-parameter values at a particular frequency are also observed between the AT and BT, but these differences are usually not operationally significant.

From this discussion, it can be seen that significant differences exist in the values of motional parameters between conventional round crystal units and rectangular surface-mount (i.e., strip-resonator) devices. The severe limitations in design and manufacture of rectangular plates, imposed by their tendency to support unwanted frequency responses and coupled modes, make it extremely difficult for them to be customized for specific applications. These difficulties are apparent when the plate must conform to stringent operating characteristics over wide temperature ranges.

This discussion should not be taken to discourage the use of rectangular plates. Their economy, based on mass production, makes them an attractive alternative for many applications. It should be emphasized, however, that the replacement of a tried and true conventional round resonator with a rectangular resonator must be approached with extreme caution, even when both operate at the same frequency. The detailed evaluation typically brought to bear on the initial selection of a crystal unit should also apply to any change in resonator configuration.••

Measure Residual Noise In Quartz Crystals

Good low-noise crystal-oscillator performance is highly dependent on being able to characterize the residual noise of a quartz-crystal resonator.

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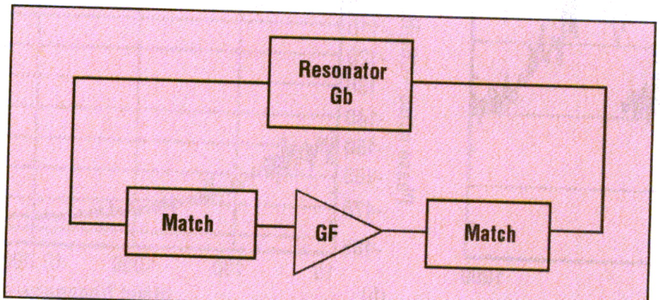
REPEATABLE low-noise crystal-oscillator performance requires a quartz-crystal resonator with low residual noise. Measurements of this residual noise are key to attain this type of repeatable performance. What follows are practical insights into crystal-oscillator design, an examination of the role of the quartz-crystal resonator, and approaches for measuring the phase noise of the crystal oscillator and the quartz-crystal resonator. Hopefully, these insights can help inform crystal-oscillator designers and quartz-crystal manufacturers concerning the issues of reliably predicting oscillator noise performance.

Very-low-noise crystal-oscillator performance is dominated by the noise of each component within the oscillator circuit. Repeatable noise performance from a low-noise crystal oscillator is also desirable. Repeatable noise performance, without having to select components within the oscillator, is desirable as well. An oscillator consists of three distinct components—an amplifier, a resonator, and matching circuits (Fig. 1). The amplifier operates in a nonlinear state of gain compression, which can make modeling the oscillator's phase noise somewhat unpredictable.

For the purpose of this article, a 100-MHz quartz-crystal resonator will be used as an example to demonstrate some key points. In a crystal oscillator, the quality factor (Q) of the quartz crystal dominates the oscillator's noise signature within 1-kHz offset from the carrier frequency. The amplifier dominates the noise floor beyond an offset of 50 kHz. The noise between 1 and 50 kHz is a combination of the quartz-crystal noise and the noise of the amplifier. To understand the problems of predictable phase-noise performance, several important issues must be understood. The condition for oscillation is defined simply as:

$$G_f G_b = 1 \text{ and}$$
$$\phi_f + \phi_b = 360 \text{ deg} \quad (1)$$

where:
G_f = the gain of the amplifier,
G_b = the gain of the resonator,
ϕ_f = the phase angle of the amplifi-



1. An oscillator consists of three distinct components—an amplifier, resonator, and matching circuits.

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er, and

ϕ_b = the phase angle of the resonator.

The loaded Q (Q_L) of the resonator dominates the phase noise close to the carrier. Typically, only 50 percent of the crystal Q can be realized in a low-noise oscillator. This equates to Q/2 = Q_L. Loading of the oscillator's output can decrease Q_L further. Accurate matching of the quartz-crystal resonator and the amplifier is important to achieve optimum noise performance from the oscillator. The output of a crystal oscillator requires a buffer amplifier to ensure that any additional loading to the output of the crystal oscillator has little effect on the resonator Q_L. The following model can provide insight as to the effect of Q_L on oscillator phase noise:

$$L_{C(fm)} = -SNR - 3\ dB + 10\log\left(\frac{f_c}{2f_mQ_L}\right) + 10\log\left(1+\left(\frac{f_c}{2f_mQ_L}\right)^2\right) \quad (2)$$

where:

$L_C(fm)$ = the residual FM of the carrier,

f_c = the flicker frequency,

f_m = the frequency offset,

SNR = the apparent noise floor, given by P_o − NF − 174 dBc,

P_o = the carrier output-power level (in dBm), and

NR = the amplifier residual noise level (zero slope noise).

The amplifier's noise and power output (SNR) contribute greatly to the overall oscillator noise performance. The loaded Q of the resonator dominates the close to the carrier oscillator-gain bandwidth. The residual noise of the amplifier within the gain bandwidth is dictated by the resonator and adds to the resonator residual noise. The SNR of the amplifier in Eq. 2 has a zero noise slope (flat line). Most electronic components have a 1/f or first-order noise slope. This is computed by the second section of Eq. 2 and is added to the 1/f section. The last section of Eq. 2 is a second-order term which represents the noise contributed by the closed-loop gain of the oscillator. Figure 2 shows the residual phase noise of a typical 100-MHz quartz resonator and amplifier.

A simplified variation of the evaluation requires resonator Q and amplifier residual noise information:

$$L_{C(fm)} = L_{R(fm)} + 20\log\left(\frac{BW}{2f_m}\right)$$

$$Where\ Q = \frac{F_c}{\Delta F}\ and$$

$$BW = \Delta F\ \text{(3-dB points)} \quad (3)$$

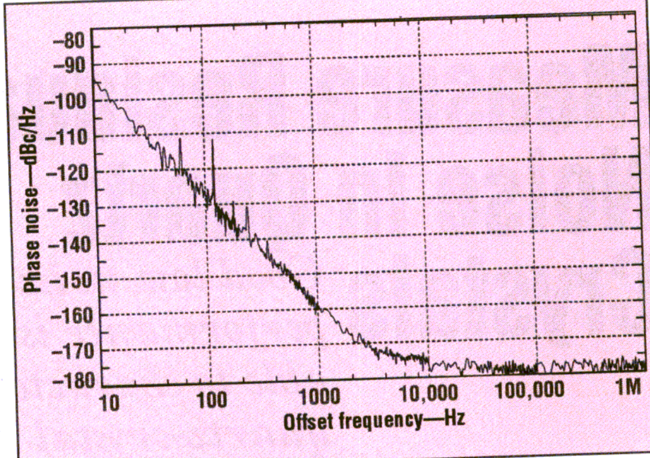
where:

Q = $F_c/\Delta F$, and

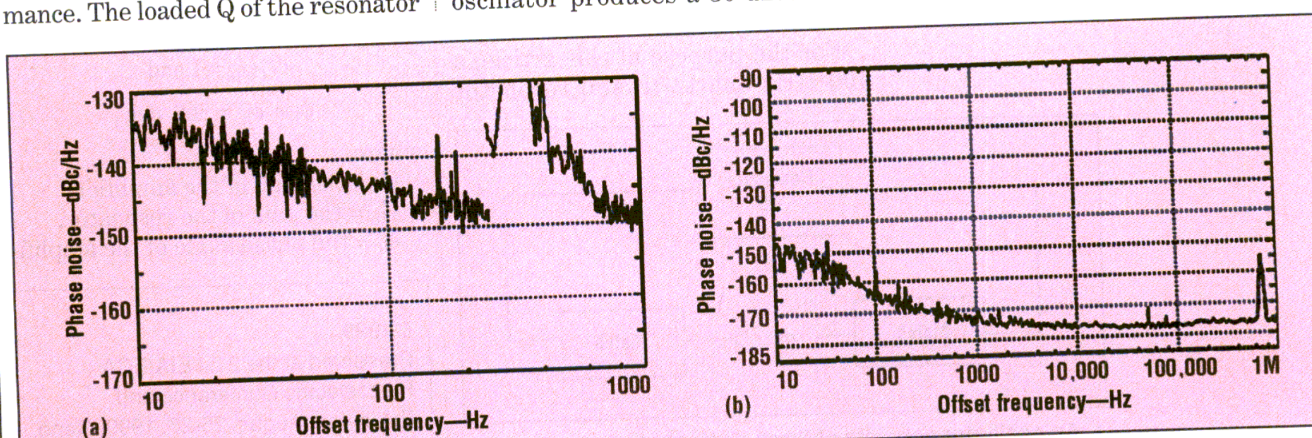
BW = ΔF (the 3-dB points).

Figure 3 represents the actual phase noise from a test oscillator. The oscillator produces a 30-dB/decade slope (a relationship of $1/fm^3$) close to the carrier phase-noise slope which is dominated by the crystal's Q_L. The noise floor of the oscillator is controlled by the performance of the amplifier itself. An important thing to remember is that the oscillator phase-modulation (PM) noise can be no better than the residual noise of either the crystal or the amplifier, or other components within the oscillator. Since the amplifier is a gain element, and the crystal is a loss element, the residual noise of the crystal, which is related to the loaded Q of the crystal resonator, is inherently more difficult to measure because it is at a lower energy level.

It should be noted that the residual phase noise of the oscillator, compared to the crystal and amplifier residual noise at a 100-Hz offset, has a significant amplitude separation. As the measurement offset is reduced, the noise becomes higher. An offset of 100 Hz is a convenient offset point to

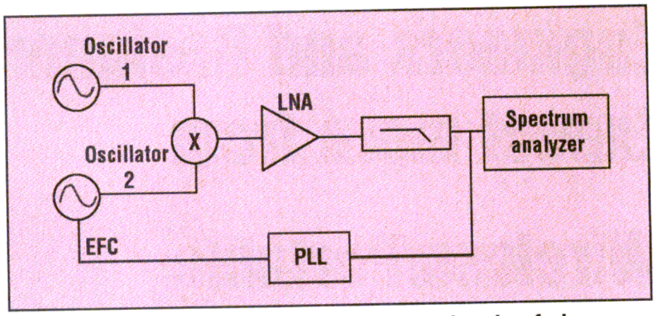


3. This shows the phase noise from a test oscillator.



2. These measurements show the residual phase noise of a typical 100-MHz quartz resonator and amplifier.

evaluate residual component noise and resultant oscillator noise. This offset also reduces measurement sensitivity slightly. Oscillator phase noise is easier to measure at a 100-Hz offset compared to the residual noise of the resonator or amplifier. The measurement of 1/f slope (residual noise) and $1/f^3$ slope (absolute noise) tends to separate the noise-measurement method. This is also one of the several differences which tends to separate the component manufacturer and the oscillator designer.



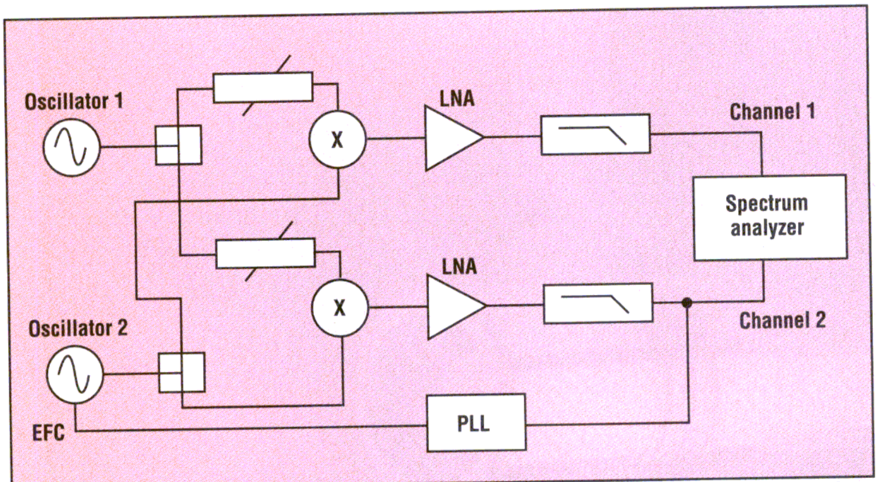
4. This classic approach to measure low levels of phase noise requires two identical oscillators with very-good phase-noise characteristics.

Figure 4 shows a block diagram of a classical low-noise technique for measuring the phase noise of very-low-noise crystal oscillators. Two oscillators of the same design are required and one must be electrically tunable to allow the two sources to be phase locked together. A close mathematical approximation of the phase noise of each oscillator can be achieved if three oscillators are measured (in pairs). The two-unit measurement technique offers very good measurement sensitivity for PM noise. However, the noise floor of the measurement system is typically exceeded by state-of-the-art crystal oscillators.

The noise floor for the noise measurement is dominated by the carrier-frequency power level at the phase discriminator. The two-unit phase-noise measurement technique incorporates carrier cancellation which removes the carrier with baseband noise over an offset range of 1 Hz to 10 MHz, relative to the carrier.

Figure 5 shows an adaptation to the measurement technique which can improve the noise floor of the measurement system by better than 10 dB. This technique uses a cross-correlation method of achieving cancellation of phase noise associated with the noise-measurement instrument itself. Basically, the adaptation uses two of the two-unit measurement technique systems previously discussed. This measurement technique does, however, require a cross-correlation spectrum analyzer.

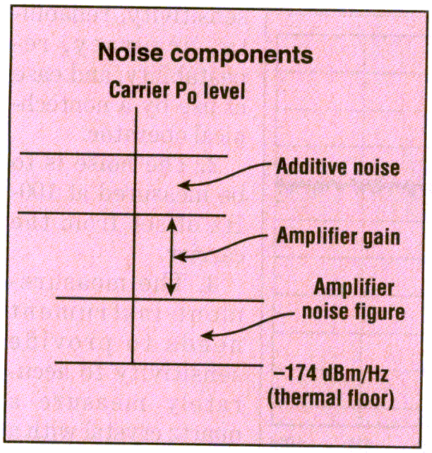
The cross-correlation measurement technique is very expensive and complex. It is not particularly practical as a manufacturing tool. As previously mentioned, the oscillator PM noise can be no better than the residual noise of the crystal, amplifier, or other components used in the oscillator design. A simpler and less-



5. The measurement technique of Fig. 4 can be adapted for an improvement in noise floor of better than 10 dB.

expensive measurement technique would be preferred as a useful manufacturing tool. At this point, the oscillator designer and the crystal manufacturer take different paths in noise-measurement needs. The oscillator designer is looking for close-to-the-carrier noise performance with a noise slope of 30 dB/decade while the crystal manufacturer is measuring a noise slope of only 10 dB/decade.

The carrier amplitude, both with regard to the design of the oscillator and the noise-measurement technique, is important. An oscillator creates a carrier frequency along with its unique noise signature. To achieve adequate measurement sensitivity, a power level of the carrier frequency is used as a reference, whereby the noise is measured in a decibels-below-the-carrier (dBc) relationship. In addition, PM noise is normalized to a 1-Hz bandwidth. After initial measurement sensitivity, calibration is conducted, usually by the beat-note method (beating the same frequencies of two oscillators together to achieve a 0-Hz difference). A subsequent increase in carrier power level of 1 dB will produce a 1-dB increase in dBc noise with regard to the noise-graph data. This assumes linear performance of the measurement instrument or device being measured. The measurement instrument and device that are measured are also assumed not to be sensitive to drive levels. The optimum carrier level for most PM noise measurements is +20 dBm. This power level provides good noise-measurement sensitivity without complicating the measurement



6. Noise components include additive noise, noise due to amplifier gain and noise figure, and noise at the thermal noise floor (−174 dBm/Hz).

technique.

The oscillator example uses a 100-MHz SC-cut crystal which has a drive level of 3 mW. The closed-loop gain is 15 dB. The resulting output-power level from the oscillator would be approximately +6 dBm, including a loss of 11 dB through the crystal. A buffer amplifier that has a gain of 14 dB would be required to achieve a carrier level of +20 dBm. If the buffer is not chosen wisely, it can add additional noise to the oscillator noise signature.

AT-CUT CRYSTAL

Crystal oscillators that use an AT-cut crystal can only be driven by no more than 0.5 mW. An AT-cut crystal oscillator can, therefore, not provide the same noise performance as can an SC-cut crystal, assuming 11-dB loss through the crystal in both cases. Although the difference in apparent carrier power level makes measuring the AT-cut crystal oscillator noise easier (because it is higher), it makes the residual noise measurement of the crystal more difficult due to the lower crystal-drive level.

In the simplest terms, noise is the thermal agitation of atomic structure. Theoretically, 0 K = atomic quiescence (zero energy output). Room temperature is approximately 270 K. Noise is a random process with regard to frequency and amplitude. If the energy level of random noise is measured in a very-short time interval, one measurement at a time, extreme changes in random quantity are observed. By increasing the measurement periods and the number of samples, an accurate statistical average of the noise energy can be derived. The noise-energy output of a resistive device is predictable relative to its temperature as well as resistance:

$$e_n^2 = 4kTRB \text{ (RMS voltage,}$$

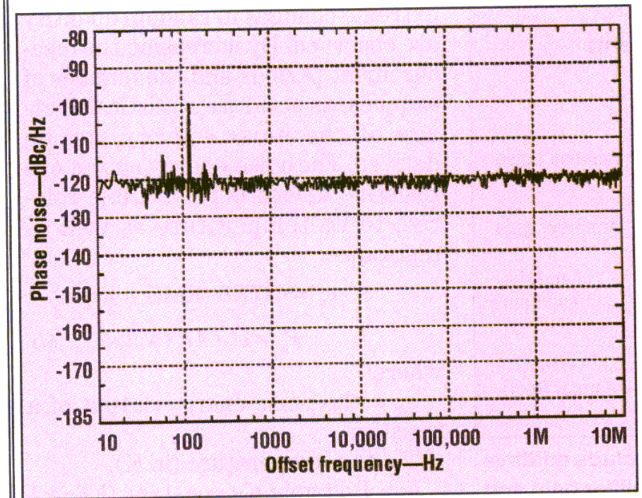
$$P_a = e^2 / 4R \text{ (watts)} \qquad (4)$$

where:

e_n = the noise-energy output of a resistor,
T = the temperature (in K),
k = Boltzmann's constant (kT=4.1 $\times 10^{-21}$ at 300 K),
P_a = the average output power,
B = the noise bandwidth, and
R = the resistance of the resistor (in Ω).

At room temperature, a 50-Ω resistor has a noise output of −174 dBm (Fig. 6). The thermal energy is theoretically presented as random amplitude that is distributed over an infinite frequency interval. The average energy amplitude across the infinite frequency distribution is very flat. In real-world terms, the noise distribution is frequency (band) restricted to counter nonpure resistance issues. Gaussian thermal noise has an average energy slope of zero for amplitude and phase [where amplitude modulation (AM) is equal to PM] over a particular frequency distribution. The −174-dBm kBT noise is, therefore, comprised of equal parts (Ω = 2:1 = 3 dB) of AM and PM noise with their respective levels being −177 dBc for AM and −177 dBc for PM noise.

A thermal noise source can be carefully amplified to a higher output level. As previously mentioned, residual noise typically has a 1/f slope or 10-dB/decade noise slope close to the carrier. The oscillator has a $1/f^3$ or 30-dB/decade noise slope. Thermal noise itself has a zero noise slope. Amplified zero-slope thermal noise is very useful as a quantitative reference for the measurement of noise phenomena. It can be used for rapid calibration of a high-sensitivity noise-measurement instrument. This could be useful in measuring additive and or residual AM and PM noise in



7. This is the typical output from a calibrated Gaussian noise standard (GNS).

electronic devices. With careful evaluation, an amplified thermal noise source can be calibrated as a Gaussian noise standard (GNS). The GNS is calibrated over a particular energy-distribution bandwidth and creates a reference noise level which has a flat, zero-slope noise level for PM and AM noise. The GNS can provide an accurate quantitative noise level, typically −120 dBm, which has an accuracy of ±1 dB over a particular frequency interval. It provides a very-accurate AM and PM noise level of high accuracy. It also provides a known orthogonal relationship of AM and PM noise. In addition, a GNS provides a good 50-Ω source of noise. Figure 7 shows a typical output from a calibrated GNS. The GNS will be used to provide very-rapid measurement calibration and improved accuracy of measurement when incorporated in a comparative noise-measurement instrument.

The goals for measuring residual noise of quartz crystals with regard to this paper are:

1. The PM noise-measurement technique and instrument need to have good sensitivity, reliability, accuracy, repeatability, and ease of use by a nontechnical operator.

2. The noise is to be measured at 100-Hz offset from the carrier.

3. The measurement instrument needs to provide sensitivity to accurately measure a quartz crystal with a residual noise equivalent to a crystal Q of 120 K at 100 MHz.

4. A low-noise frequency synthesizer is used as the carrier source.

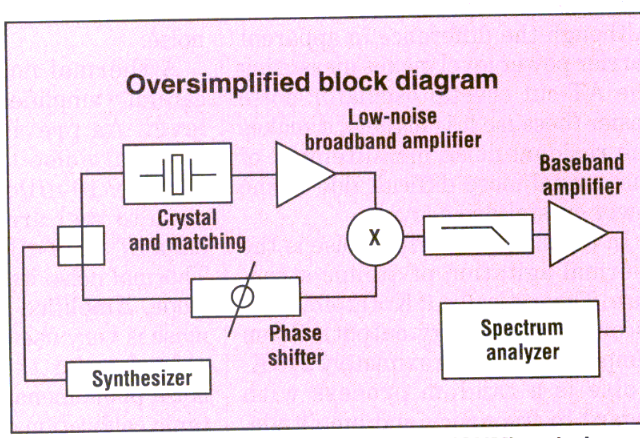
5. The measurement must be very rapid, less than 15 s for each device.

6. Measurement setup time must be rapid, less than 3 min. for each frequency.

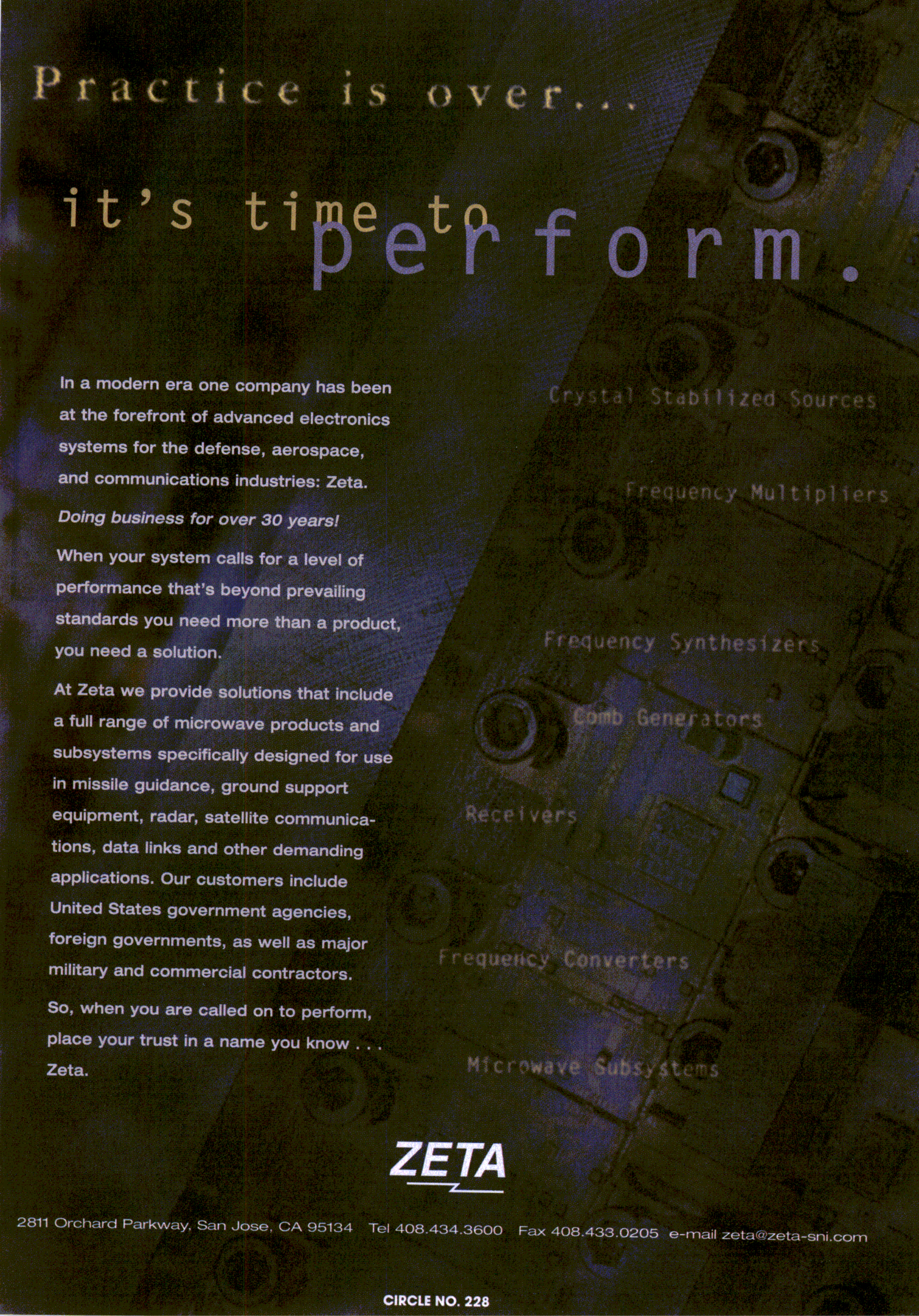
7. The noise-measurement instrument should be automated to reduce operator involvement.

The method developed for measuring quartz-crystal residual noise is a comparative-noise-measurement (CNM) technique (Fig. 8). This technique provides the same inherent noise-measurement sensitivity as does the two-unit method described previously, but it uses only one carrier source.

The CNM technique is inherently a noise bridge that can be simply and rapidly calibrated. The single-carrier source provides two correlated carri-



8. The comparative-noise-measurement (CNM) technique provides good inherent noise-measurement sensitivity, but with only one carrier source.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ers that will cancel each other during the PM noise measurement, leaving the noise of the device being measured. The short-term stability of the carrier source will have an impact on PM discriminator sensitivity. To achieve good measurement accuracy and sensitivity, the carrier source must be chosen wisely. For the purpose of measuring quartz-crystal residual noise, this example will focus on measuring noise at an offset of 100 Hz from the carrier. The expected residual noise level of the crystal can be found as follows:

$$L_{C(fm)} = -177 \text{ dBm} + 13 \text{ dBm} + 10 \log\left(\frac{f_c}{2f_m Q}\right) \quad (5)$$

where:

−177 dBm = the PM noise floor at room temperature, and

+13 dBm = the carrier power level for the measurement.

For a 100-MHz crystal with a Q of 100,000, the expected noise would be −157 dBc.

An amplifier is used to boost the signal level from the crystal to a measurable level.

The residual noise of this amplifier, the residual noise of the measurement instrument, and the residual noise of the crystal residual noise are all in close proximity. Additive noise due to noise proximity can result, but can easily be calculated. The amplifier residual noise will become part of the measuring instrument's noise floor during calibration. This enables noise measurements to be accomplished to the noise floor of the instrument.

To allow these mathematical relationships to be useful, only one of several variables can be unknown. This means that all of the noise variables, and their interaction, except for the quartz crystal must be accurately known. The CNR will calibrate itself for all noise variables. It will then accurately measure the noise of the crystal. A measurement accuracy of ±1.5 dB can be achieved.

The drive level to the crystal resonator is first chosen and set. The correct drive level to the phase discriminator is then adjusted. The noise floor of the CNM instrument is

then measured by bridging across the resonator and inserting the appropriate attenuation equal to that of the crystal. The phase shifter is adjusted in order to achieve phase-discriminator quadrature. The Gaussian noise source is then used to calibrate the measurement sensitivity and to provide an accurately known measurement reference point. The accuracy of the noise reference point is ±1 dB. After this calibration, the carrier levels to both sides of the phase discriminator must remain the same for the rest of the measurements.

The Gaussian noise is then turned "off." With the phase discriminator still set to quadrature, the residual noise floor of the CNR instrument is measured. This represents the limit of noise-measurement sensitivity. The only unknown noise is now the noise of the device that is being measured.

QUARTZ-CRYSTAL NOISE

The crystal resonator is now inserted into the measurement arm of the noise bridge. The noise of the quartz crystal is then measured. The measurement data are manipulated in order to produce the correct residual noise of the quartz crystal that is being tested. Another crystal, which has the same frequency, can then be placed into the crystal fixture and quickly measured. Prototype instruments have shown that this method of residual noise measurement can support repeated measurements in seconds.

Although the issues pertaining to the residual noise measurement of a quartz-crystal resonator are complex, a method, which uses a comparative noise-measurement technique, can be devised in order to simplify and greatly reduce the time it takes to make accurate residual-noise measurements. ••

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Offset PLL Analysis Can Cut Spurious Levels

By analyzing a high-frequency offset PLL design, the frequency and amplitude of its spurious products can be predicted.

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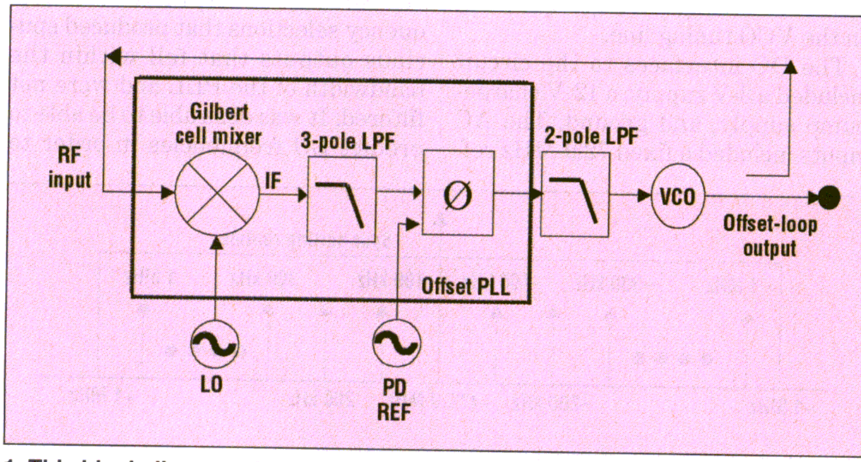
OFFSET phase-locked loops (PLLs) are useful for creating secondary signals that differ from a receiver or transmitter's local oscillator (LO). Using a 0.5-μm bipolar-complementary-metal-oxide-semiconductor (BiCMOS) process, an offset PLL was fabricated with an operating range of 450 to 520 MHz and offset frequency of 72.9 MHz. By analyzing the design, it is possible to estimate the frequency and amplitude of the PLL's spurious outputs as a function of input frequency. In what follows, measured results will be compared with those estimations.

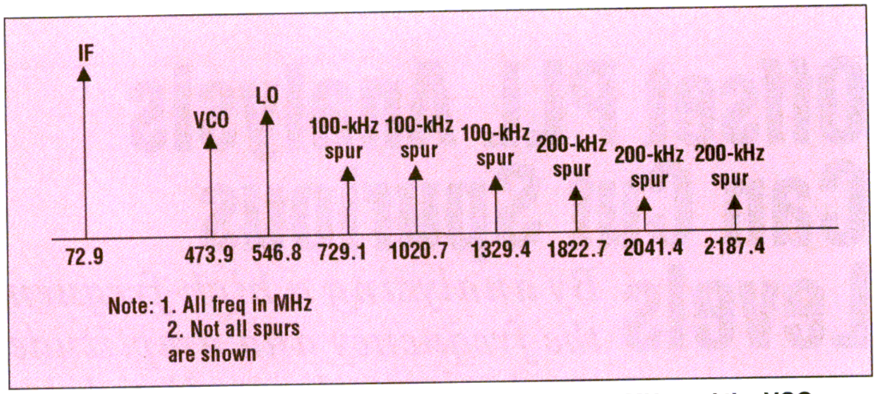
PLLs employing a mixer in the feedback path have long been recognized for their ability to produce an output signal that is shifted in frequency by an amount equal to the frequency of a reference frequency applied at the PLL reference input.[1] This technique is used in cellular phones to produce transmit frequencies that are offset from the main LO synthesizer frequency.[2] The technique is attractive in this application because a signal with fine frequency resolution (on the order of 25 kHz) can be shifted in frequency by a fixed amount while maintaining the frequency resolution of the original signal. This allows the same signal-generation hardware to be used for receive (Rx) and transmit (Tx) functions.

While the PLL-offset technique has proven useful, it can suffer from unwanted spurious content on the spectral output of the offset loop. This spurious content can limit the usefulness of the technique, especially in applications where the range of input frequencies is wide. Due to the high ratio of operating frequency to



1. This block diagram shows the architecture of the 500-MHz offset PLL.

frequency resolution and because the solution is frequency dependent, the problem cannot easily be addressed by circuit-simulation techniques. To date, no analysis has been published that addresses the amplitude and frequency of the spectral components of the output of an offset PLL. Therefore, to improve on the usefulness of an offset PLL design, an analysis on a 500-MHz device was undertaken.



3. In this simulation, the LO frequency chosen was 546.8 MHz and the VCO frequency was 473.9 MHz, with a reference frequency of 72.9 MHz. The highest spurious levels occurred at –100 kHz from the VCO frequency.

PLL DESIGN

The 500-MHz offset PLL was implemented on a single 0.5-μm BiCMOS integrated circuit (IC) with discrete support circuitry. As shown in the block diagram of Fig. 1, the circuit is comprised of a Gilbert-cell mixer, an exclusive-OR phase detector with a charge-pump output, a discrete loop filter, and a discrete voltage-controlled oscillator (VCO). RF and LO inputs to the mixer are buffered via on-chip linear differential-amp based buffers. The mixer output is buffered with a two-stage integrated differential-amp combined with a three-pole integrated lowpass RC filter. Two filter poles are at 150 MHz and one pole is at 30 MHz. All portions of the IC except inputs and outputs are fully differential.

The ability to adjust the design is incorporated into the discrete circuits. The loop filter is a type-2, two-pole filter designed for a loop unity-gain frequency of 100 kHz.[3] The VCO has a range of 450 to 520 MHz with a tuning characteristic on the order of 5 MHz/V. A discrete p-channel current mirror at the charge-pump output facilitates high-voltage operation on the VCO tuning line.

The DC interfaces to the circuit included a 3-V supply, a 12-V charge-pump supply, and ground. The AC inputs included a fixed 72.9-MHz reference signal and a variable-frequency 520-to-590-MHz LO signal. In operation, the VCO output tracks the frequency of the LO signal with a frequency offset equal to the frequency of the reference signal.

The philosophy behind the design was to operate the mixer in a linear mode in order to minimize spurious outputs. Within this constraint, input signal amplitudes were maximized to ensure maximum signal-to-noise on the VCO output signal. The phase detector, with a bandwidth greater than 2 GHz, operated as an ideal sampler of the mixer output. The integrated lowpass filter at the mixer output reduced the amplitude of high frequency mixing products in order to minimize aliasing of these signals into the baseband output of the phase detector. The loop filter reduced the signal amplitude aliased to the baseband output.

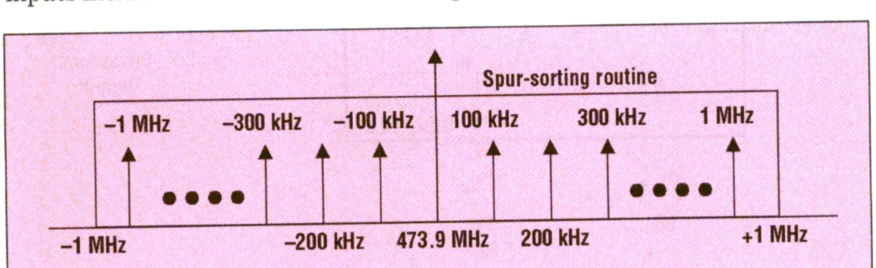
For most LO frequencies, the scheme reduced spurious to –80 dBc or below. However, there were frequency selections that produced spurious outputs that fell within the bandwidth of the PLL and were not filtered. It was desirable to be able to predict LO frequencies in order to estimate spurious frequencies and amplitudes so that for these cases avoidance techniques or other measures could be applied.

ANALYZING THE PLL

In a typical application, the PLL might operate with a VCO frequency in the range 450 to 520 MHz with frequency resolution of 25 kHz or less. For each operating frequency, the interaction of the VCO output, the offset signal, and the PLL reference signal in the presence of circuit nonlinearities produced a unique set of spurious output signals. The analysis of each of the several thousand cases using circuit simulation would be difficult so we developed a three-step process to reduce the calculations to a workable level. The approach was:

1. To screen the input frequencies to identify those which had a potential for spurious near the carrier.
2. To analyze these cases using a frequency-independent circuit-analysis tool, such as a harmonic-balance simulator.
3. To add frequency-dependent effects.

In Step 1, a numerical simulation (MATLAB was used) was conducted to identify operating frequencies where spurs may occur close to the carrier. In this analysis, the mixer and the phase detector were treated as ideal multipliers. Filters were ignored. Input signals were assumed to be unmodulated and periodic. Input signals for the VCO [$S_{VCO}(t)$], LO input [$S_{LO}(t)$], and reference input [$S_{ref}(t)$] were treated as periodic, unmodulated signals that can be



2. The spurious outputs of the PLL's offset loop.

described in the frequency domain as Fourier expansion of the form:

$$S(f) = F(s(t)) = \sum_{i=0}^{n} a_i \delta(f - if_s). \qquad (1)$$

The Fourier signals S_{VCO}, S_{offset}, and $S_{ref}(f)$ were convolved to produce an output signal $S_{out}(f)$:

$$S_{out}(f) = \left(S_{VCO}(f) * S_{off}(f)\right) * S_{ref}(f). \quad (2)$$

The purpose of this initial step in the analysis was to identify those LO frequencies that resulted in baseband spurious signals at the phase-detector output. Thus, the analysis was simplified by setting to unity all amplitude terms. The convolution in eq. 2 was then reduced to an exercise in finding sum and difference frequencies for each pair of terms in the waveform expressions. The calculation was further simplified by limiting the number of terms in the waveforms and by discarding output frequency terms above a pre-determined limit. For this analysis, we chose to limit input signals to a bandwidth of 2 GHz. The VCO and LO signals were represented by the DC term plus the first five harmonics. The DC term plus the first 14 harmonics represent the reference signal. The baseband frequency limit was set at 1 MHz with the assumption that the loop filter and the lowpass action of the PLL attenuated frequencies above that level.

The output of this step was a listing of all spurs below 1 MHz for each LO frequency analyzed. In addition, the harmonic number of the LO (A), VCO (B), and reference (C) signals and the frequency of the signal produced by the combination of the LO and VCO (AB) signals were listed for each spurious signal. This was combined with the circuit analysis of Step 2 to estimate the spurious signals in the VCO output.

In Step 2, the nonlinearities of the mixer and input buffers were analyzed using a harmonic-balance circuit simulator. Selection of the input frequencies for this step was somewhat arbitrary. The case where the LO frequency was a multiple of the difference between the LO and RF frequencies was to be avoided. Input signals were ideal sinusoids. The levels of the input signals were adjusted iteratively as part of the analysis. For this analysis, levels at 80 percent of the 1-dB compression point of the input amplifiers were chosen. Process mismatch was approximated by adding DC sources (1-mV sources were chosen) to one side of each differential-amp in the IC netlist. The output was measured at the mixer output nodes.

The result of Step 2 was a listing of spurious amplitudes for each combination of LO and RF harmonics. Because the result was captured prior to the mixer lowpass filter, the signal was frequency independent and may be used for any LO frequency.

In Step 3, the results of Steps 1 and 2 are combined. For each spurious product identified in Step 1, the harmonic numbers are compared to the results in the previous step to produce an unfiltered amplitude value. The effect of the mixer lowpass filter is added by applying the filter-transfer function to the AB signal. Applying the PLL transfer function to the baseband spurious frequency, identified in Step 1, captures the effect of the PLL lowpass action. Thus, for a particular LO frequency, f_{LO}, a spurious product produced by harmonics A, B, and C was:

$$spur(f_{LO})_{ABC} = ampl_{AB} + mix\_atten(f_{AB}) + PLL\_atten(f_{ABC}), \qquad (3)$$

where:

$ampl_{AB}$ = the value from the previous step for harmonic signals A and B,

$atten(f_{AB})$ = the attenuation due to the mixer lowpass filter, and

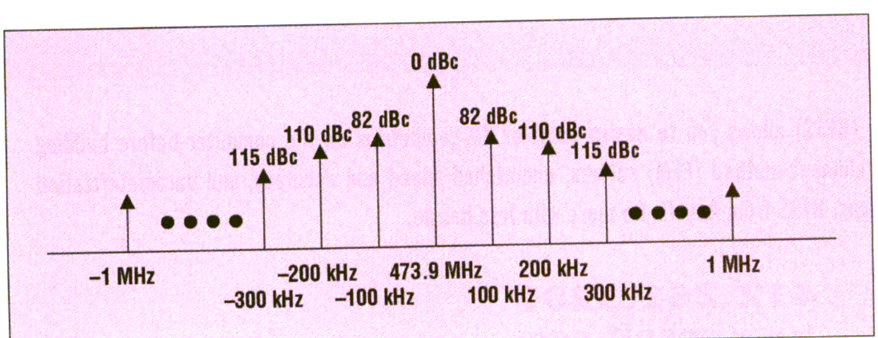
$PLL\_atten(f_{AB})$ = the attenuation on the baseband spurious due to the lowpass action of the PLL.

As an example of this methodology, consider the case where f_{LO} is 546.8 MHz, f_{VCO} is 473.9 MHz. Execution of Step 1 showed spurious products at 100-kHz integer multiples of 100 kHz from the carrier. For this case, the mixer output spurious locations are shown in Fig. 2 with harmonic numbers noted in (A, B) notation for each spurious product. Combining this result with Steps 2 and 3, the 100-kHz spur resulting from harmonics (a, b, c) is estimated as –82 dBc. Spurious products lying 200 kHz and more from the carrier were attenuated to greater than –100 dBc. The spectral output is shown in Fig. 3.

As a second example, consider the case where f_{LO} is 546.7 MHz and f_{VCO} is 473.8 MHz. Again, the dominant spurious is located 100 kHz from the carrier and is –81 dBc.

As a third example, consider the case where f_{LO} is 500.1 MHz and f_{VCO} is 427.2 MHz. For this particular case, no spurious products appeared within the 1-MHz bandwidth specified in Step 1.

Finally, consider the case where f_{LO} is 510.1 and 437.2 MHz. Execution of Step 1 showed that this was a special case where the feedthrough spurious products, (0, 1) and (1, 0) produced spurious in the baseband output of the system. Completion of the calculation showed spurious at a level 60 dBc with separation from the



4. The spurious output levels of the offset PLL were simulated with an LO frequency of 546.7 MHz and VCO frequency of 473.9 MHz, with dominant spurious products at an offset of ±100 kHz from the VCO frequency.

carrier of 100 kHz.

To verify the analysis, measured data was taken on a test board consisting of a mixer/phase detector IC, a discrete VCO, and a discrete filter, as shown in Fig. 1. Two external signal generators provided the LO and phase-detector reference frequencies. As in the first simulation example, f_{LO} was 546.8 MHz, f_{VCO} was 473.9 MHz, and f_{REF} was 72.9 MHz. From the analysis, it was noted that the highest spurious levels were offset ±100 kHz from the VCO frequency (Fig. 3). The measured level of these spurious products was –80 dBc, which was very close to the simulated value of –82 dBc. All other spurious products were greater than –100 dBc, below the measurement capability of the system.

In order to verify the second case, the LO and VCO were shifted to 546.7 MHz and 473.9 MHz, respectively. Once again, the dominant spurs were offset ±100 kHz from the VCO frequency. The measured level of these spurious products was –82 dBc while the simulated value was –81 dBc (Fig. 4).

A third case was also verified where no spurious products were present at the output. With the LO set to 500.1 MHz and the VCO set to 427.2 MHz, the simulation did not show any spurious frequencies. The measured data verified this condition.

The fourth example was verified with f_{LO} at 510.1 MHz and f_{VCO} at 437.2 MHz. The measured level of the 100-kHz spurs in this special case was –55 dBc. This spurious product was generated due to carrier feedthrough of the LO and RF signals.

In general, this technique can be applied across the frequency band of interest and the simulation will accurately predict the frequency and amplitude of the spurious outputs. In this way, the use of computer simulation can clearly improve the cycle time in designing nonlinear circuits and systems.●●

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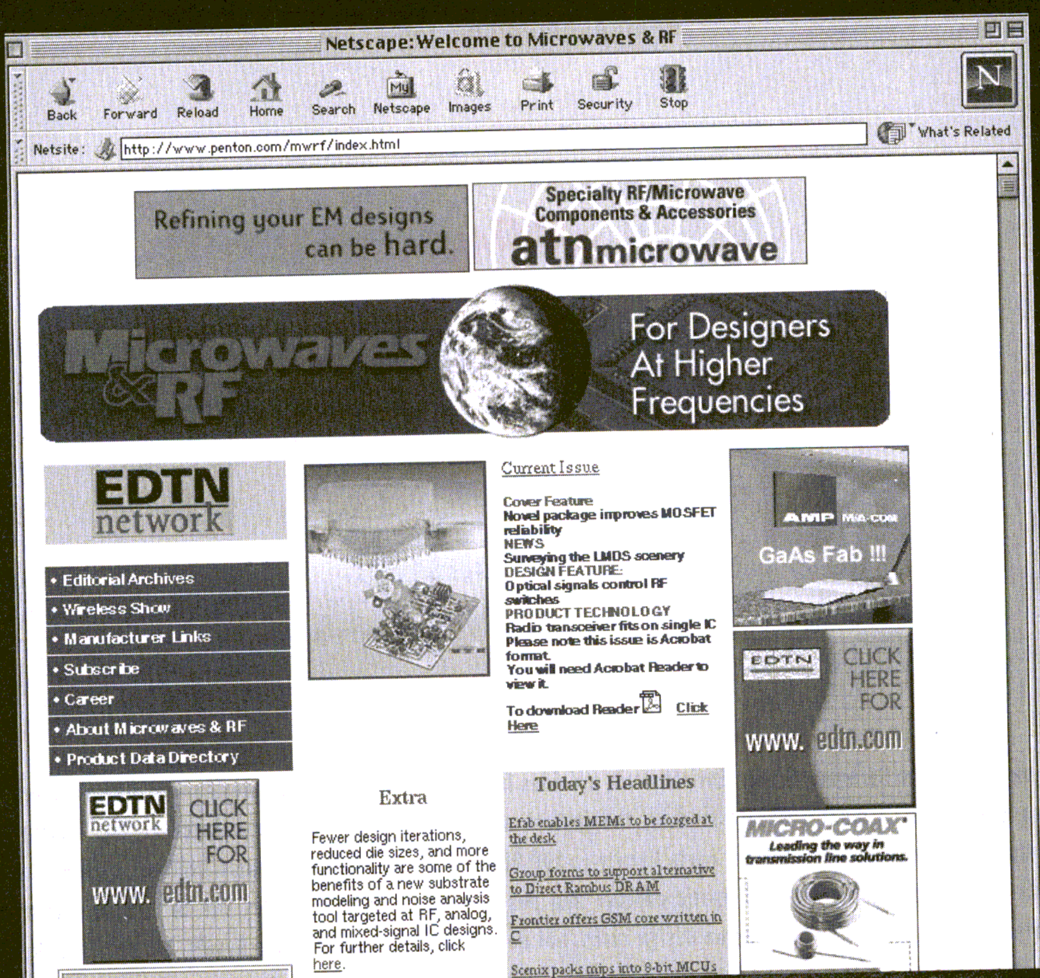

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A new simulation software package provides the tools for analyzing nonlinear oscillator characteristics.

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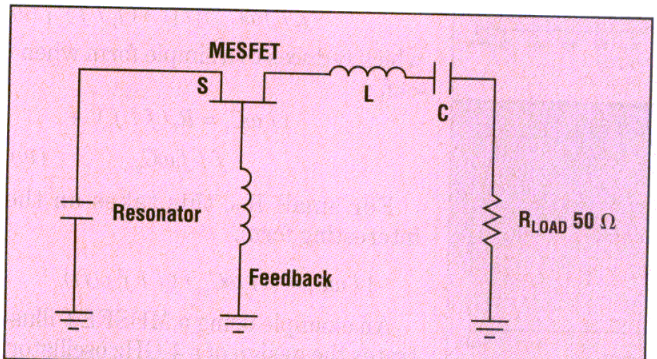
WHEN designing an oscillator, the simplest and most common procedure is to use a small-signal approach where the device is described by small-signal S-parameters at the desired DC bias point. Bipolar junction transistors (BJTs) and field-effect transistors (FETs) can be modeled by a hybrid-pi small-signal linear equivalent circuit, or by a nonlinear model such as Gummel-Poon (for BJTs) or Curtice Cubic (for FETs). This article describes a procedure for designing a typical metal-semiconductor-FET (MESFET) oscillator, using the Curtice Cubic model to generate the S-parameters. In addition, the hybrid-pi equivalent circuit is used to show the source of the negative resistance present in any oscillator circuit. A lumped-element design is first completed at the fundamental frequency of oscillation (although transmission-line elements could also be used). Next, the nonlinear performance is calculated using a new nonlinear simulator from Xpedion Design Systems, Inc. (Santa Clara, CA). This software contains all of the linear, harmonic-balance, and envelope-simulation tools needed to analyze all types of oscillators, mixers, frequency multipliers, and amplifiers.

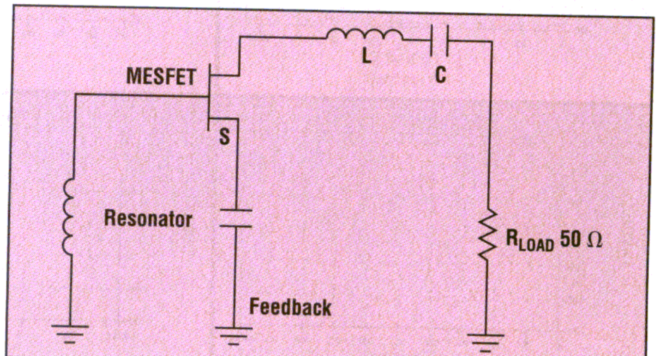
In a typical oscillator design, if $k < 1$, the resonator can be placed at either port to resonate the S_{11} or S_{22}, where the lossless resonator is given a reflection-coefficient magnitude of unity and an angle approximately the conjugate of the angle of S_{11} or S_{22}. After calculating the S_{11}' or S_{22}' at the other port, the load-reflection coefficient is simply the reciprocal of this complex number.

TWO-PORT ANALYSIS

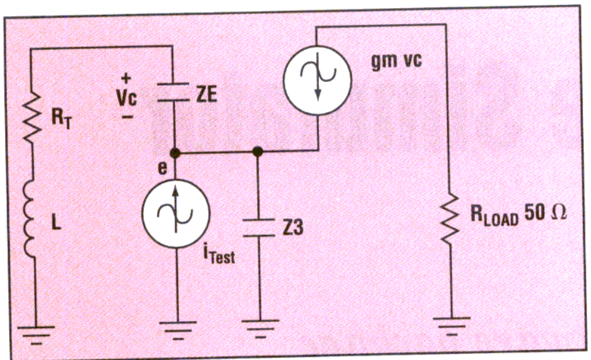
The most-common oscillator design is a common-base or common-gate configuration with inductance in the common lead. The RF portion of the



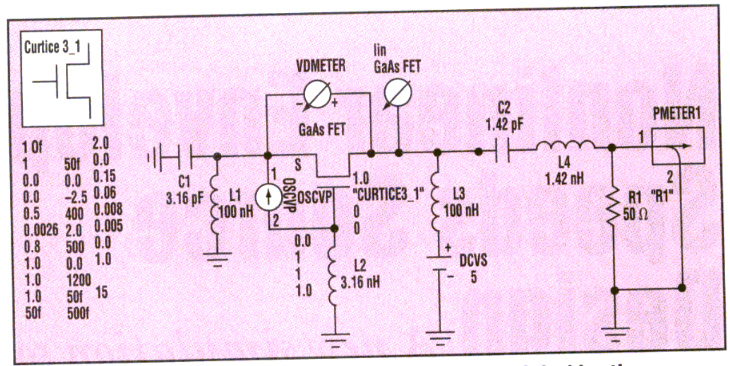
1. This schematic shows the common-gate oscillator configuration.



2. In this schematic, the FET is connected in a common-source oscillator configuration.



3. This schematic shows a simplified hybrid-pi model of a Colpitts oscillator.



4. This oscillator circuit shows the MESFET modeled by the Curtice Cubic simulation.

oscillator design is shown in Fig. 1. The feedback inductor in the common lead has been designed for a high reflection coefficient at the emitter or source (input port). Then the input port is resonated with a lossless element found by calculating S_{11}. After calculating S_{22}', the load circuit is designed by making the load impedance, Γ′, equal to $1/S_{22}'$. The DC-bias circuit is designed for the bias point where S-parameters are known, or for the bias point that will deliver the required power.

An equivalent oscillator design approach is to use a common-emitter or common-source configuration having a capacitor as the feedback element. Figure 2 shows that the circuit is basically the same, but the design approach is different. For the purposes of analysis, the common-emitter (common-source) configuration is used, since the hybrid-pi equivalent circuit applies to this configuration. A transistor can have any one of its three electrodes as the common point, but since the hybrid-pi is a common-emitter or common-source configuration, the present analysis uses this configuration.

HYBRID-PI ANALYSIS

Figure 3 shows a typical MESFET used in a common-source Colpitts oscillator designed to operate at 4 GHz with low phase noise. The first step in this design is to analyze the impedance at node "e," with Z_3 temporarily set to infinity. The next step is to find the value of L_1 by requiring Re $(Z_E) < 0$. Then, the value of C_1 is given by the resonance requirement:

$$I_m(Z_E) + I_m(Z_3) = 0 \qquad (1)$$

The derivation follows:

$$v_c = (-Z_2)/(Z_1 + Z_2)e \qquad (2)$$

$$e = (Z_1 + Z_2)\,(i_{test} + g_m v_c) \qquad (3)$$

$$e + Z_2\, g_m\, e = (Z_1 + Z_2)\, i_{test} \qquad (4)$$

$$Z_E = (e / i_{test}) = (Z_1 + Z_2)/(1 + g_m Z_2) = (R_T + j\omega L_1 + 1/j\omega C_{gs}) / [1 - j(g_m/\omega C_{gs})] \qquad (5)$$

$$Z_E = [R_T + j(\omega L1 - 1/\omega C_{gs})] / [1 - j(f_t / f)] \qquad (6)$$

$$Z_E = [-(\omega L_1 - 1/\omega C_{gs})\,(f_t / f) + R_T + j(\omega L_1 - 1/\omega C_{gs} + f_t / f\omega C_{gs})] / [1 + (f_t / f)^2] \qquad (7)$$

which means the value of L_1 will be given (for f <<ft) by:

$$\omega L_1 = R_T(f / f_t) + 1/\omega C_{gs} = 1/\omega C_{gs} \qquad (8)$$

This simple result intuitively seems correct.

The resonance condition gives C_1 (see Eq. 1)

$$1/\omega C_1 = [(R_T f / f_t + f_t / f\omega C_{gs})] / [1 + (f_t / f)^2] \qquad (9)$$

which reduces to a simple form when f <<f_t:

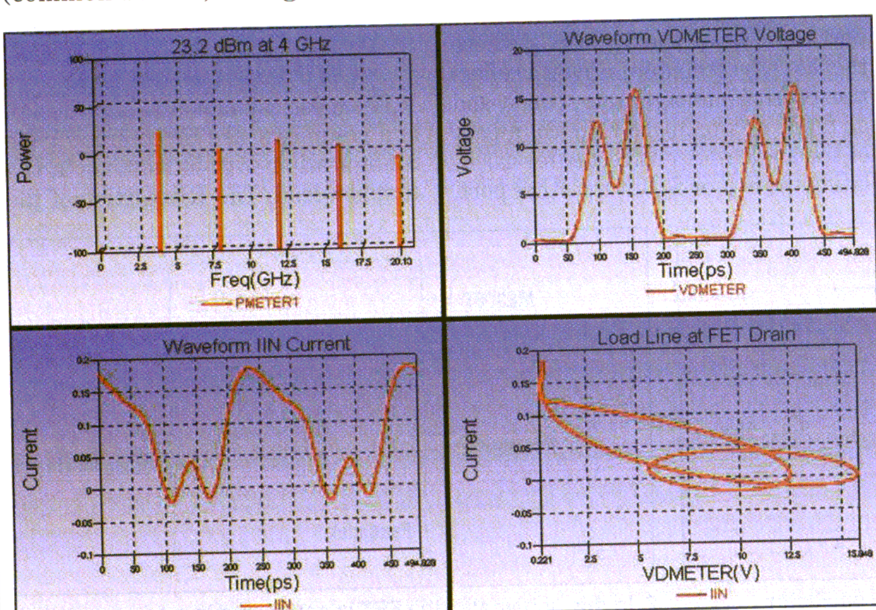
$$1/\omega C_1 = R_T(f / f_t)^3 + f / f_t\omega C_{gs} \qquad (10)$$

For small R_T, this takes on the interesting form:

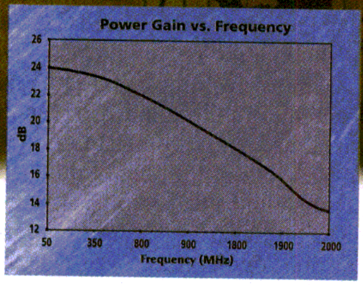
$$1/\omega C_1 = (1/\omega C_{gs})\,(f / f_t) \qquad (11)$$

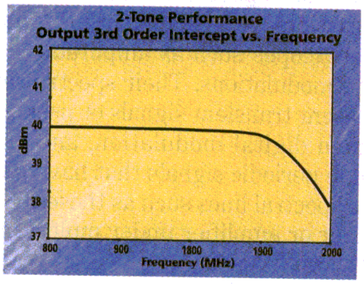
An example using a MESFET illustrates the design of a 4-GHz oscillator, where:

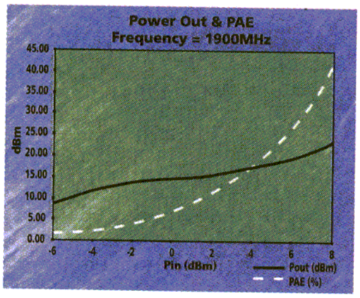
g_m = 60 mS, C_{gs} = 0.5 pF, f_t = 19 GHz,



5. These graphs show the results of the harmonic-balance simulation.







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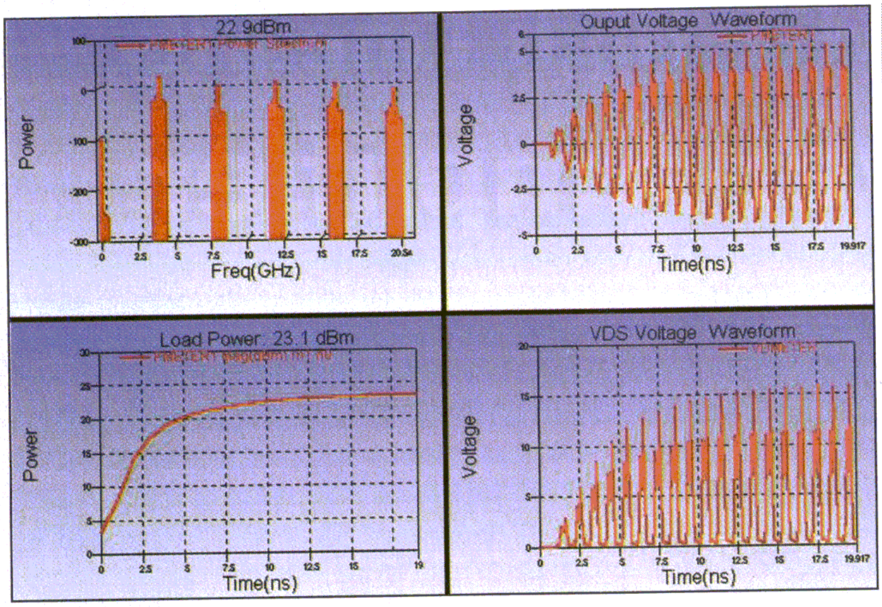

6. These graphs show the results of the envelope simulation.

$R_T = 3\ \Omega$ is:

$$L_1 = 3.16\ nH$$
$$C_1 = 2.47\ pF \qquad (12)$$

The actual 4-GHz design and the calculated values using the previous equations are compared in the table. The adjustment is needed to obtain the desired resonant frequency of 4 GHz.

The series resonant LC filter in the load circuit serves to filter only the fundamental signal
where:

$$F_0 = 1/2\pi(LC)^{0.5} =$$
$$1/2\pi[(1.42)\ (1.42)\ (10)^{-21}]^{0.5} =$$
$$3.54\ GHz \qquad (13)$$

This ignores the tuning effect of the device output capacitance.

The loaded Q is found from the oscillator startup time, which is found by using the envelope-simulation tool on Fig. 4 (see Fig. 6), which provides a start-up time of 4 ns. Therefore:

$$Q_L = \omega\tau/2 = 16\pi = 50 \qquad (14)$$

Using Leeson's oscillator-noise theory, one can estimate the phase noise, $L(f_m)$, of this oscillator by assuming f_c = 100 MHz and F = 3 dB:

$$L(f_m) = (FkTB)/(2\ P_{avs})$$
$$\{[1/(4Q_L)^2](f_0^2 f_c / f_m^3 + f_0^2 / f_m^2) +$$
$$f_c / f_m + 1\} \qquad (15)$$

Inserting the appropriate numbers:

$$L(100\ kHz) =$$
$$[2(-174\ dBm/Hz)]/$$
$$2(+23\ dBm)$$
$$0.25 \times 10^{-4}$$
$$\{[(16 \times 10^{18})10^8]/10^{15}\}$$
$$+\ 0.25 \times 10^{-4}[(16 \times 10^{18})10^{10} +$$
$$(10^8/10^5) + 1 =$$
$$-121\ dBc/Hz \qquad (16)$$

This is a very good state-of-the-art result for a low-phase-noise oscillator. Usually, the resonator losses will degrade this performance somewhat. To complete this design, a buffer amplifier should be designed to reduce the load-pulling effects on the resonant frequency. Most of today's commonly available RF-simulation tools that employ harmonic-balance and time-domain Spice-type techniques do not work well for mixed designs that include nonlinear devices, lossy, distributed transmission lines, and discontinuities [such as mixers, oscillators, and phase-locked loops (PLLs)]. Harmonic-balance techniques can handle mild nonlinearity and lossy distributed transmission lines, but they only perform steady-state analysis by computing the Fourier coefficients of the output solution. Examples include analysis of amplifiers and mixers simulated with a one- or two-tone sinusoidal source. These techniques are efficient when the periodic solution can be represented by the sum of relatively few sinusoids or tones, but they cannot adequately represent the continuous spectrum of transient signals or non-periodic, digitally modulated signals specified by commercial wireless communication standards.

On the other hand, Spice derivatives can perform transient and steady-state analyses, but they are far too slow for any practical analysis of circuits with lossy, distributed transmission lines or signals where the carrier is modulated by RF signals.

The envelope-transient technique, used with harmonic-balance and linear RF simulation, is the best-suited technique—and the only practical one—for all present and future wireless communication designs. Using envelope simulation, one can analyze circuits where the inputs are stimulated by RF carriers with complex, time-varying envelopes such as amplitude and phase modulations. Their spectra can represent transient signals or pseudorandom digital modulation, and can include periodic signals that have discrete spectral lines such as those from a mixer or amplifier under multi-tone excitation.

Using Xpedion software, several oscillator characteristics were measured, including the power spectrum, the dynamic load line, and the waveforms at the output of the transistor. These curves enable the designer to ensure that the device is not in danger of burn out—a very serious design consideration.

There are two methods to analyze the oscillator using Xpedion Software. One is the harmonic-balance method, which applies to any steady-state circuit. The other is the envelope simulation, which enables time-varying analysis of the transient oscillator build up, and, thus, supports the calculation of the loaded Q.

Figures 5 and 6 illustrate the out-

Oscillator design values

	Calculated	Adjusted
L_1	3.16 nH	3.16 nH
C_1	2.47 pF	3.16 pF

puts for this oscillator using these two methods of analysis. In Figs. 4 to 6, the DC bias is V_{ds} = +5 VDC and V_{gs}= 0 VDC for high output power, which is +23 dBm at approximately 4 GHz. The load line operates at +15.9 VDC and 180 mA. In Fig. 6, the envelope simulation predicts an output power of +22.9 dBm and a start-up time of 4 ns. These calculations enable an estimation of the phase-noise performance.

A closer examination of the load line in Fig. 5 shows that the rotation is counter-clockwise, which indicates an inductive load. In other words, the drain current into the transistor and the V_{DS} across the transistor behave as a time-varying inductive load to the rest of the oscillator load circuit. The very-high drain voltage (+15.9 VDC) with only a +5-VDC supply is a result of the high loaded Q of 50. The harmonics of this oscillator could be further improved by working on the load line to make it appear similar to a resistive load line. The transistor used in this study is a typical GaAs MESFET with a gate width of 300 μm and a gate length of 0.3 μm. The RF-to-DC efficiency approaches 50 percent.

Using a new nonlinear design package from Xpedion, which uses ORCAD Capture, this oscillator circuit was analyzed in the harmonic-balance mode and the envelope-simulation mode. Both analyses yielded +23-dBm fundamental power at approximately 4 GHz. The transient result (from envelope simulation) was used to calculate the loaded Q and, therefore, $L(f_m)$ from Leeson's theory for oscillator phase noise.[1]

This article has shown that the procedure for designing a common-source and a common-gate Colpitts oscillator is virtually identical, so the designer is free to select either method. When the simplified hybrid-pi model is analyzed in the common-source mode, the values of the reactive elements of the circuit can be calculated as shown. ••

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Spurious Couplings Degrade Bandpass Filter Performance

Spurious Couplings, Part 2

Combline and interdigital-filter implementations are presented in this second of two articles on bandpass filters.

Richard M. Kurzrok

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IN part 1 of this article (*Microwaves & RF*, October 1999, p. 109) the theory underlying spurious couplings in bandpass filters was described. Part 2 presents the physical implementation of a combline and an interdigital filter whose dimensions and characteristics are designed to minimize spurious couplings.

The new ceramic filters are designed primarily for small-percentage bandwidths. Furthermore, most of the ceramic resonators are shielded by electroplated metal. The combination of narrow bandwidth and resonator shielding has significantly reduced the vulnerability of ceramic filters to spurious couplings. The following discussion on degradation of combline filters will be limited to filters of moderate bandwidths using slabline construction.

As an illustration, a nominal 1-GHz bandpass filter that will be examined in detail is realized. A similar filter has been used for many years in satellite earth-station equipment. Filter specifications are as follows:

- Center frequency: 1.1 GHz.
- 3-dB bandwidth: 90 MHz with usable passband of 54 MHz.
- Number of poles: 11.
- Response shape: 0.01-dB Tchebychev.
- Input/output (I/O) impedance: 50 Ω.

The filter is designed for nominal 60-deg. resonator lengths.

Filter mechanical details shown in Fig. 5 are summarized here:

- Ground-plane spacing: 0.625 in. (1.59 cm).

Table 5: Comparative amplitude and VSWR for 11-pole combline filter at 1.1 GHz

	$k_{13} = 0$		$k_{13} = 0.041$	
x = normalized frequency variable	Insertion loss (dB)	VSWR	Insertion loss (dB)	VSWR
-1.0	3.011	5.828	2.620	5.116
-0.8	0.010	1.100	0.116	1.388
-0.6	0.009	1.096	0.007	1.086
-0.4	0.010	1.100	0.016	1.127
-0.2	0.005	1.071	0.003	1.052
0	0.000	1.000	0.049	1.237
0.2	0.005	1.071	0.005	1.069
0.4	0.010	1.100	0.100	1.356
0.6	0.009	1.096	0.014	1.121
0.8	0.010	1.100	0.016	1.127
1.0	3.011	5.828	3.517	6.843

Table 6: Comparative amplitude and VSWR for 11-pole interdigital filter at 1.1 GHz

	$k_{13} = 0$		$k_{13} = 0.0195$	
x = normalized frequency variable	Insertion loss (dB)	VSWR	Insertion loss (dB)	VSWR
-1.0	3.011	5.828	2.809	5.453
-0.8	0.010	1.100	0.045	1.226
-0.6	0.009	1.096	0.008	1.090
-0.4	0.010	1.100	0.000	1.006
-0.2	0.005	1.071	0.004	1.065
0	0.000	1.000	0.011	1.107
0.2	0.005	1.071	0.005	1.073
0.4	0.010	1.100	0.042	1.216
0.6	0.009	1.096	0.011	1.106
0.8	0.010	1.100	0.000	1.009
1.0	3.011	5.828	3.238	6.271

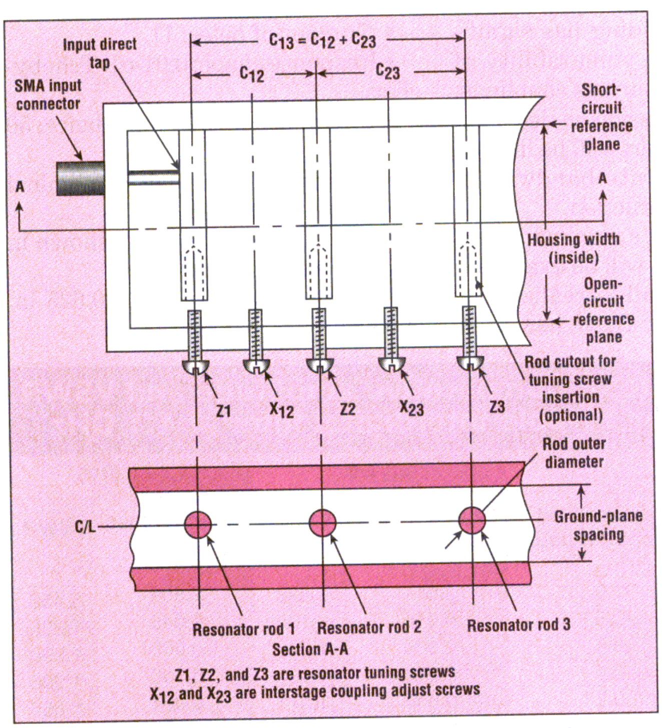
Table 7: Comparative amplitude and VSWR for 11-pole interdigital filter at 3.8 GHz

x = normalized frequency variable	$k_{13} = 0$ Insertion loss (dB)	$k_{13} = 0$ VSWR	$k_{13} = 0.055$ Insertion loss (dB)	$k_{13} = 0.055$ VSWR
-1.0	3.011	5.828	2.518	4.940
-0.8	0.010	1.100	0.183	1.509
-0.6	0.009	1.096	0.007	1.086
-0.4	0.010	1.100	0.041	1.214
-0.2	0.005	1.071	0.002	1.040
0	0.000	1.000	0.088	1.329
0.2	0.005	1.071	0.004	1.063
0.4	0.010	1.100	0.151	1.454
0.6	0.009	1.096	0.017	1.133
0.8	0.010	1.100	0.039	1.209
1.0	3.011	5.828	3.712	7.265

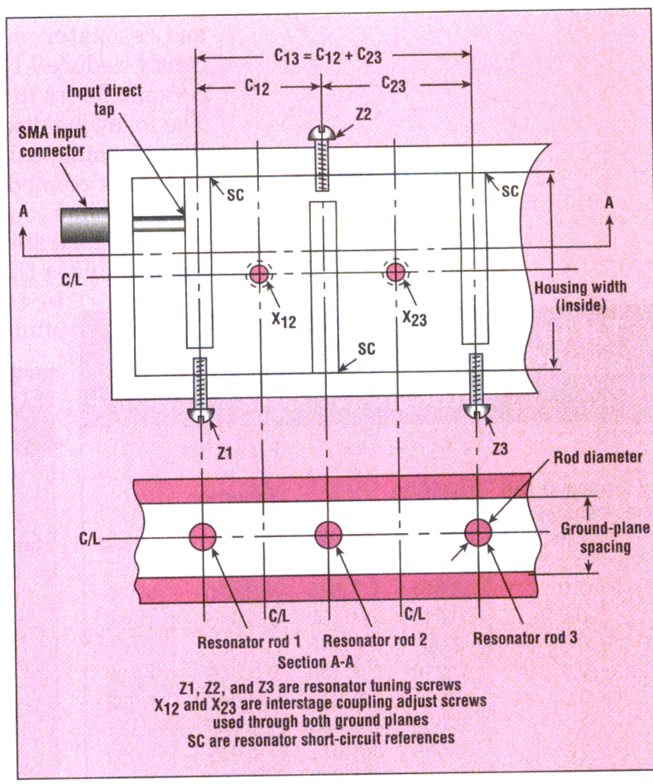
- Rod outer diameter: 0.250 in. (0.64 cm).
- Rod length: 1.75 in. (4.45 cm).
- Rod inner diameter (for tuning screws): 0.171 × 0.750 in. (0.434 × 1.905 cm).
- Resonator tuning screws: number 6-32 (brass).
- Housing width (Inside): 1.875 in. (4.76 cm).
- Housing length (inside): 6.776 in. (17.21 cm).
- Housing-wall thickness: 0.250 in. (0.635 cm) at filter sides and ends.
- I/O coupling: direct tap to I/O resonators.
- I/O connectors: type SMA male.

The physical centerline (C/L) to C/L spacing between the first and second resonators is 0.554 in. (1.407 cm). The physical C/L to C/L spacing between the second and third resonators is 0.622 in. (1.58 cm). This results in a C/L to C/L spacing of 1.176 in. (2.99 cm) between the first and third resonators, which can result in spurious coupling between non-adjacent resonators. This spacing also exists between the ninth and 11th resonators. The C/L to C/L spacing corresponds to a normalized coefficient of coupling k_{13} equal to 0.041.

Amplitude and VSWR responses of the lossless 11-pole combline bandpass filter versus normalized frequency are listed in Table 5. Also shown are amplitude and VSWR responses when $k_{13} = 0.041$. Notice that modest degradation in responses is incurred when the bridging couplings are included. These theoretical results are somewhat pessimistic. Real-world bridging couplings are also affected by electromagnetic (EM) distortions from the adjacent resonators, tuning screws, and interstage-coupling adjust screws located midway between resonator rods and



5. A combline filter built with slabline construction is designed for nominal 60-deg. resonator lengths. C/L spacing between resonators is critical toward reducing spurious coupling between non-adjacent resonators. Each resonator has a tuning screw and resonator rod for adjustments.



6. This mechanical detail of an interdigital bandpass filter is similar to that of the combline filter of Fig. 5. This type of filter is less susceptible to spurious coupling than a similarly constructed combline filter.

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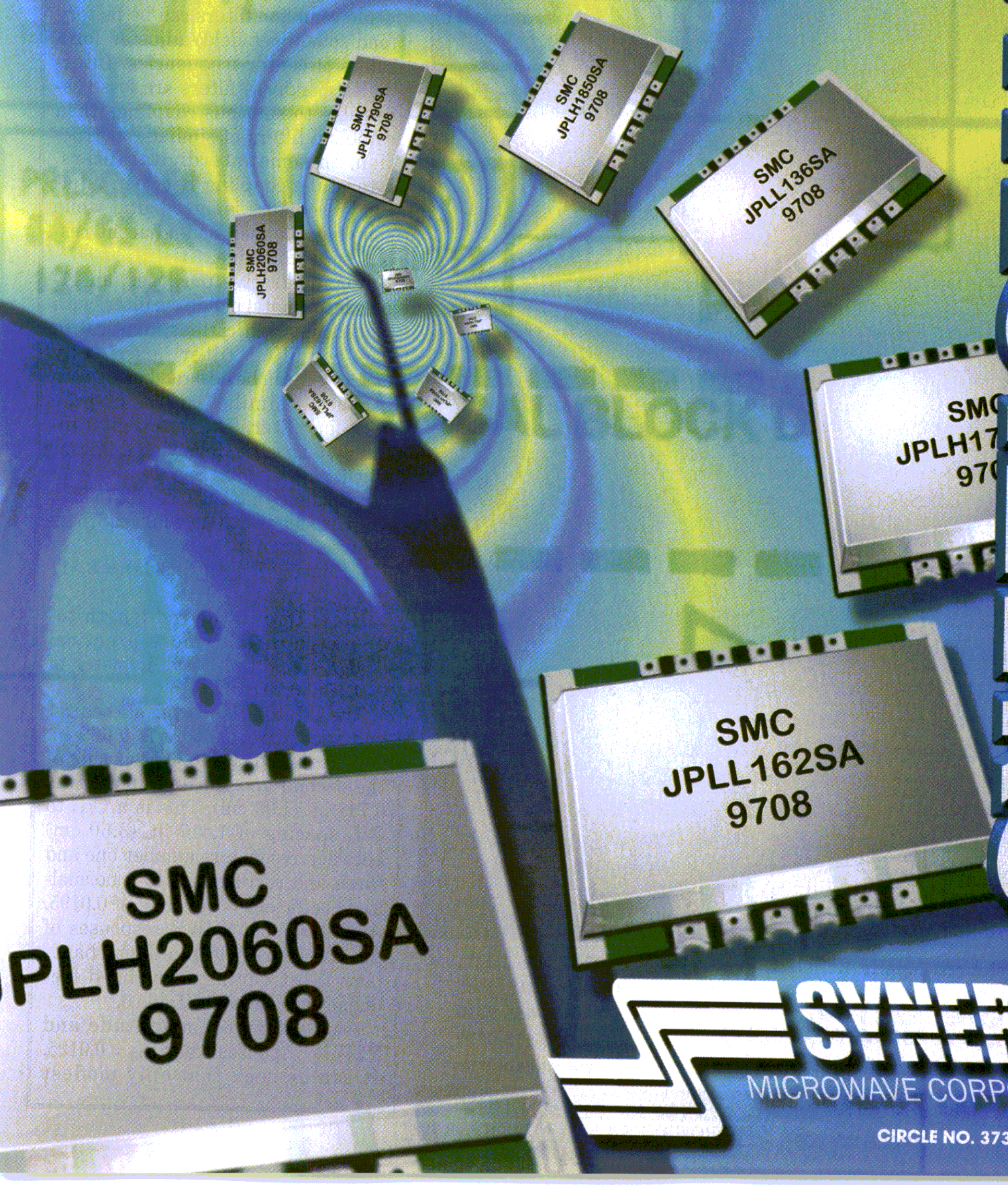

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parallel to resonator rods. These aberrations yielded quite satisfactory combline filters. A nine-pole combline filter, of similar construction, centered at 1.2 GHz with a 3-dB bandwidth of 130 MHz also provided satisfactory results when the design ripple was increased to 0.05 dB.

Interdigital bandpass filters are similar to combline filters with certain important differences:

1. Interdigital filters employ adjacent resonators that alternate the resonator open- and short-circuit reference planes.

2. Interdigital filters have magnetic and electric fields in phase while combline filters have magnetic and electric fields in phase opposition. Consequently, interdigital filters will achieve larger coefficients of coupling than combline filters when filter geometry is similar and filter-rod spacing is identical. Interdigital filters are capable of somewhat larger-percent bandwidths than their combline counterparts.

3. Interdigital filters use nominal 90-deg. resonators with incidental foreshortening in order to tune the desired design-center frequency and take open-end fringing capacitance into account.

4. Interdigital filters are usually designed for fixed center frequencies while combline filters can be factory (and sometimes field) adjusted for a range of center frequencies. Interdigital bandpass filters are less susceptible to spurious couplings than combline filters of similar construction. In some interdigital filters, interstage coupling between adjacent resonators is interdigital while coupling between non-adjacent resonators is combline.

For illustrative purposes, an 11-pole interdigital bandpass filter, with electrical specifications identical to the combline filter previously described, can be designed using construction similar to the 11-pole combline filter. The interdigital filters will have the following different mechanical details (Fig. 6):

- Rod length = 2.250 in. (5.175 cm).
- Housing width (inside) = 2.875 in. (7.303 cm).
- Housing length (inside) = 8.511 in. (21.62 cm).

Note: Due to the rod-length-to-diameter ratio, a more-practical design would use a rod diameter of 0.312 in. (0.79 cm).

The C/L to C/L spacing of the first and second resonators is 0.669 in. (1.70 cm). The C/L to C/L spacing of the second and third resonators is 0.748 in. (1.90 cm). This is a C/L to C/L spacing of 1.417 in. (3.60 cm) between resonators number one and three and corresponds to a normalized coefficient of coupling of 0.0195. Amplitude and VSWR responses of the lossless 11-pole interdigital bandpass filter versus normalized frequency are shown in Table 6.

Also shown are amplitude and VSWR responses when k_{13} = 0.0195. It can be seen that only modest

degradation in responses is incurred when the bridging couplings are included. As another illustrative example, a 3.8-GHz interdigital bandpass filter will be examined in detail. The filter is realized using slabline construction. A similar filter has been used for many years in satellite earth-station equipment. Filter specifications are as follows:

- Center frequency: 3.8 GHz.
- 3-dB bandwidth: 1.1 GHz with usable passband of 800 MHz.
- Number of poles: 11.
- Response shape: 0.01-dB Tchebychev.
- I/O impedance: 50 Ω.

The filter is designed for nominal 90-deg. resonator lengths.

Filter mechanical details are summarized as follows:

- Ground-plane spacing: 0.312 in. (0.79 cm).
- Rod outer diameter: 0.148 in. (0.38 cm).
- Rod length: 0.700 in. (1.778 cm) typical.
- Resonator tuning screws: number 4-40 (stainless-steel set screws).
- Housing width (inside): 0.777 in. (1.97 cm).
- Housing length (inside): 2.896 in. (7.36 cm).
- Housing-wall thickness: 0.250 in. (0.635 cm) at filter sides and ends.
- I/O coupling: direct tap to I/O resonators.
- I/O connectors: type SMA male.

The physical centerline (C/L) to C/L spacing between the first and second resonators is 0.223 in. (0.57 cm). The physical C/L to C/L spacing between the second and third resonators is 0.264 in. (0.67 cm). This results in C/L to C/L spacing of 0.497 in. between the first and third resonators. It can result in spurious coupling between non-adjacent resonators. This spacing also exists between the ninth and 11th resonators. Resonator C/L to C/L spacing corresponds to a normalized coefficient of coupling k_{13} equal to 0.055.

Amplitude and VSWR responses of the lossless 11-pole combline bandpass filter versus normalized frequency are shown in Table 7. Substantial degradation in responses is incurred when the bridging couplings are included. With appreciable coupling screw penetrations, the spurious bridging coupling k_{13} was beneficially reduced. With skilled alignment, the filter was usable at the RF input to C-band downconverters for satellite earth stations.

The 3.8-GHz interdigital filter has a percentage bandwidth approaching 30 percent. For larger-percent bandwidths, interdigital bandpass filters with uniform slabline construction (i.e., all resonator rods of the same diameter) will incur larger spurious couplings and response-shape deterioration that might not be acceptable for some applications. ●●

Acknowledgements

In the interest of brevity, all applicable references have been omitted. During the past four decades, a large number of engineers have made numerous important technical contributions in the area of general filters as herein described.

RF Power Amplifiers For Wireless Communications

Steve C. Cripps

Power amplifiers (PAs) are key components in modern wireless communications systems. Successful amplifier designs (with high efficiency and low distortion) can extend the range and capacity of a cellular network. Unsuccessful designs (with low efficiency and high distortion) can limit the range of analog cellular systems and increase the number of bit errors in a digital cellular system, causing dropped calls and dissatisfied subscribers. In the text *RF Power Amplifiers for Wireless Communications*, Steve Cripps provides the formulas for success, sharing his many years of practical design experience in the areas of high-power transistors and amplifiers.

Author Steve Cripps has been actively involved in the Microwave Theory & Techniques portion of the IEEE, and has worked as a design and applications engineer for numerous high-frequency firms. Most recently, he has served as a course instructor for Besser & Associates specializing in classes on high-efficiency-amplifier design. He presents his information in an easy-to-follow, straightforward manner with a moderate dose of graphic illustrations (typically every two pages).

The book's 10 chapters open with an introduction of linear RF amplifier theory. Chapter 1 also covers weak nonlinear effects in amplifiers, including effects that can be analyzed through power and Volterra series, and strongly nonlinear effects. Nonlinear device models for computer-aided design (CAD) are reviewed and conjugate-matching techniques are briefly discussed.

Chapter 2 jumps right into linear PA design, defining the meanings of the terms linear and Class A and how they pertain to PA performance. This chapter discusses gain and power matching, and introduces the load-pull equipment and instrumentation that can be used to achieve good gain and power-matching conditions. Cripps also introduces loadline theory, along with some refinements related to the effects of packages on device and amplifier performance. He gives an example of a Class A amplifier design, how to establish the target specifications, how to set up the schematic diagram for the amplifier, and how to design and input- and output-matching networks.

Chapter 3 details conventional high-efficiency amplifier modes, and how to use the power-utilization factor (PUF) to compare different amplifier configurations. The PUF is the ratio of RF power delivered by a device in a particular mode under consideration to the power it would deliver as a simple Class A amplifier. The PUF can be used to compare amplifiers on the basis of watts per dollar. Chapter 3 covers Class A, Class AB, Class B, and Class C configurations.

Chapter 4 covers matching network design, transforming the theoretical and idealized results and equations of Chapter 3 into practical designs. The focus of the chapter is on the derivation and analysis of matching-circuit networks and configurations that include the proper harmonic terminations. After presenting readers with the proper topologies and network element values, the designs are evaluated through nonlinear computer simulation techniques.

Chapter 5 details overdrive and limiting effects in RF PAs, considering the behavior of Class A, AB, and B amplifiers in overdriven conditions. The saturation of device current when heavily driven at the input of an amplifier can result in higher RF output power but with little improvement in efficiency, although the use of voltage clipping can result in significant improvement in efficiency, although there is a trade-off in third-order distortion effects. This chapter reviews the advantages and disadvantages of overdriving an amplifier and the possible side-effects of distortion.

Chapter 6 features switching-mode amplifiers for RF applications, borrowing from the techniques used for years in power-supply designs to achieve high levels of efficiency. The chapter begins with a simple switching device with a broadband resistive load and considers the effects of tuning the load. The chapter also considers Class D amplifier designs and how they can be applied to high-efficiency RF amplifiers.

Chapter 7 reviews nonlinear effects in RF PAs, including bias modulation effects and amplitude-modulation-to-phase-modulation (AM-to-PM) effects, and explains how to apply two-tone power-series analysis and two-tone envelope analysis to the design of high-efficiency amplifiers. Chapter 8, which should be of particular interest to RF engineers, highlights a series of techniques for enhancing the efficiency of a PA, including the concept of the Doherty amplifier for power conservation.

Chapter 9 discusses PA linearization techniques, while Chapter 10 unveils a number of different PA architectures, including push-pull designs and balanced-amplifier designs. Chapter 10 also discusses the importance of power-combining structures, and details the design of interstage matching networks and how they are critical to attaining optimum efficiency for the overall PA.

RF Power Amplifiers for Wireless Communications includes several "bonus" sections, including an Appendix with SPICE circuit file listings that permit the evaluation of RF power and efficiency. The circuit files are related to material presented in Chapters 5 and 6 of the text. Bonus sections include a short glossary and a list of books for recommended reading, including the text by Steve Maas, *Nonlilnear Microwave Circuits*, and the excellent book, *Microwave Circuits Design Using Linear and Nonlinear Techniques* by George Vendelin, Tony Pavio, and Ulrich Rohde.

RF Power Amplifiers for Wireless Communications is a well-organized and written text that provides a great deal of fundamental information essential to designers of high-efficiency amplifiers. It should be on the shelf or desk of any design engineer who is faced with creating high-power architectures. (1999, 337 pp., hardcover, ISBN: 0-89006-989-1, $85.00). **Artech House, Inc., 685 Canton St., Norwood, MA 02062; (800) 225-9977, (781) 769-9750, FAX: (781) 769-6334, e-mail: artech@artech-house.com, Internet: http://www.artech-house.com.**

Compact RF Module Fits CDMA Base Stations

This front-end module, which is ideal for miniature CDMA base stations, can fit on a single printed-circuit board.

Xiaowei Zhu, Jianyi Zhou, Wei Hong, and Xiangyang Wang
State Key Laboratory of Millimeter Waves, Department of Radio Engineering
Southeast University, Nanjing (210096), People's Republic of China.

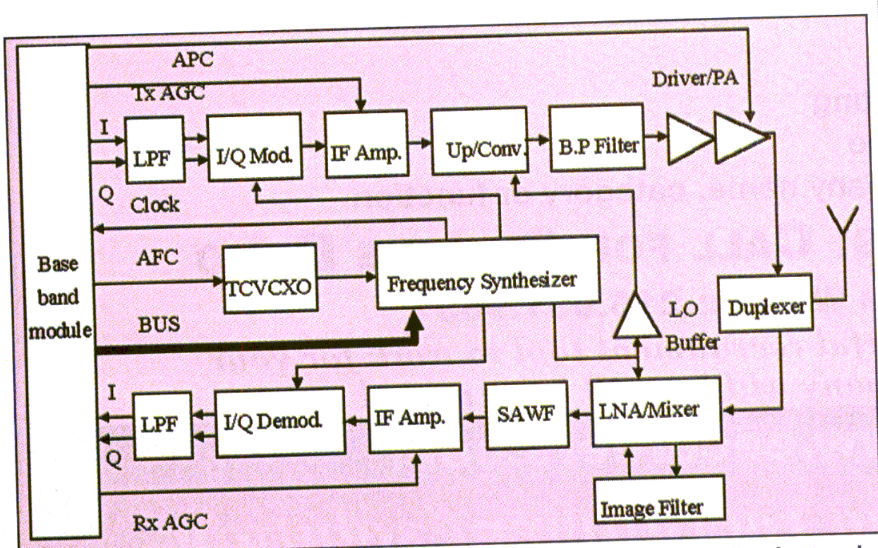
CELLULAR coverage increasingly requires the placement of compact base stations in areas with difficult shadowing and multipath effects. In what follows, the design and simulation of a compact front-end circuit for code-division-multiple-access (CDMA) base stations is presented. The design employs monolithic-microwave-integrated-circuit (MMIC) technology where practical and is well-modeled through the use of commercial personal-computer (PC) design software.

CDMA cellular mobile communication systems based on IS-95 have inspired much attention recently for their attractive features compared with other systems,[1] including larger capacity, more-efficient bandwidth utilization, and effective soft-handoff characteristics. Miniature cellular base stations based on CDMA can be used to extend the capacity of local communication networks. The mini-cellular base station must be small, light in weight, have low power consumption, and low cost. The authors have selected commercial MMICs for this RF front-end module design. The commercial ICs are low cost, operate with low voltage and current, and are small, originally developed for mobile handsets. The complete RF module is designed and manufactured on a single printed-circuit board (PCB).

This paper focuses mainly on the simulations and designs of the gain and noise figure response, the impedance match between the two ICs, and the crosstalk problems based on using the PCB board. Finally, the experimental results of the RF front-end module will be shown.

SYSTEM DESIGN

Since ICs developed for CDMA mobile handset have been used in this design, the functional diagram of the RF front-end module is the same as in a CDMA vehicle-mounted cellular mobile station as shown in Fig. 1.[2] The intermediate frequencies (IFs) for receiving and transmitting are also 85.38 and 130.38 MHz, respectively. The difference between this design and the mobile station is the local-oscillator (LO) frequency of the



1. The RF front-end module includes frequency conversion, amplification, and filtering, using commercial MMICs.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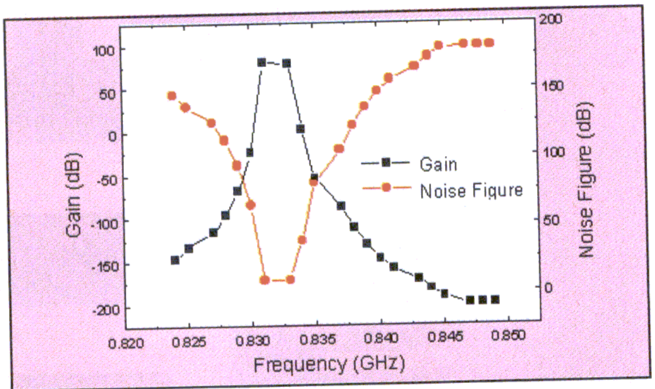
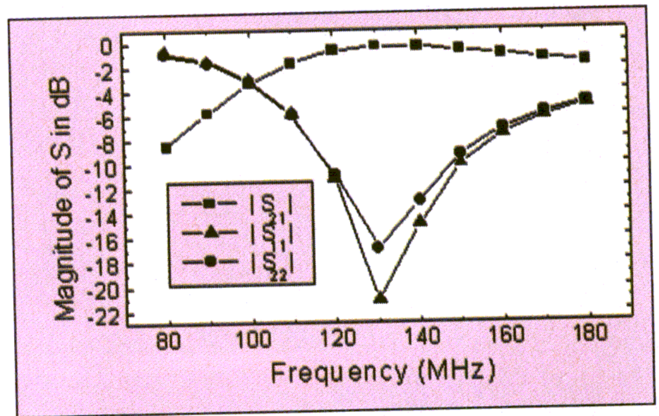
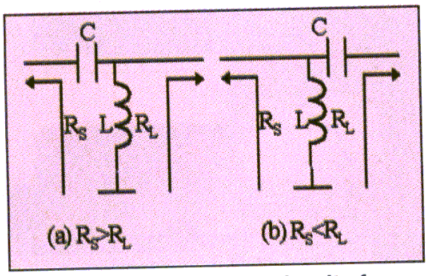


2. The gain and noise figure of the module's receive path were simulated with commercial nonlinear simulation program.



4. Exact matching-network design was needed to achieve stable performance of the IF amplifiers.



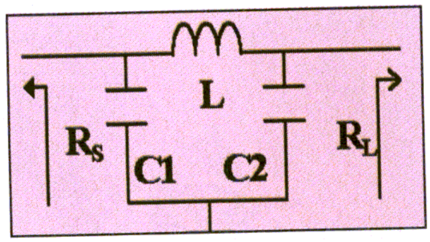
3. Two typical matching circuits for the modulator IC and the AGC IF amplifier are shown.

upconverter and mixer. The LO frequency of the minicellular RF module is 738 to 763 MHz. The control signals from the baseband module to the RF front-end module include receive/transmit (Rx/Tx), automatic gain control (AGC), automatic frequency control (AFC), automatic power control (APC), and a digital bus that is used to transfer proper data to the frequency synthesizers.

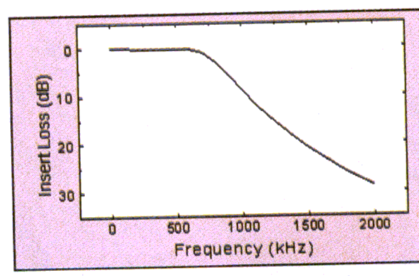
The phase-locked-loop (PLL) LOs supply four LO frequencies for the mixer/up-converter, the in-phase/quadrature (I/Q) modulator/ the demodulator, and the baseband processor, respectively.[3] The 39.3216-MHz LO output for the baseband module serves as the central-processing-unit (CPU) clock and the reference frequency for code modulation with a spreading sequence and for recovery in correlation. This frequency is 36 times the chip rate (1.2288 MHz).

The RF front-end module includes an I/Q modulator/demodulator, intermediate-frequency (IF) AGC amplifiers, an upconverter, low-noise amplifier (LNA)/mixers, a driver amplifier, power amplifier (PA), filters, and PLL LOs. The RF99xx series of chips from RF Micro Devices (Greensboro, NC) is employed for the Tx and Rx paths. Two synthesizers, model LMX2332A from National Semiconductor (Santa Clara, CA), are used for the PLL LOs in order to generate four frequencies for upconverter and mixer, I/Q modulator/demodulator, and baseband clock. A surface-acoustic-wave (SAW) filter for a receiver IF filter, ceramic filters for image rejection, and a duplexer were chosen. The BGY118A or RF2108 can be used as PAs, respectively. The RF2703 is used as an I/Q quadrature demodulator and HPMX2005 is used as an I/Q quadrature modulator.

In the design of the RF module, a computer-aided-engineering (CAE) program, Microwave Success,[4] [available from Ansoft (Pittsburgh, PA)] is used to predict the system response. Simulation shows that the gain is better than 80 dB and the noise figure is approximately 8 dB in each channel from 824 to 849 MHz.

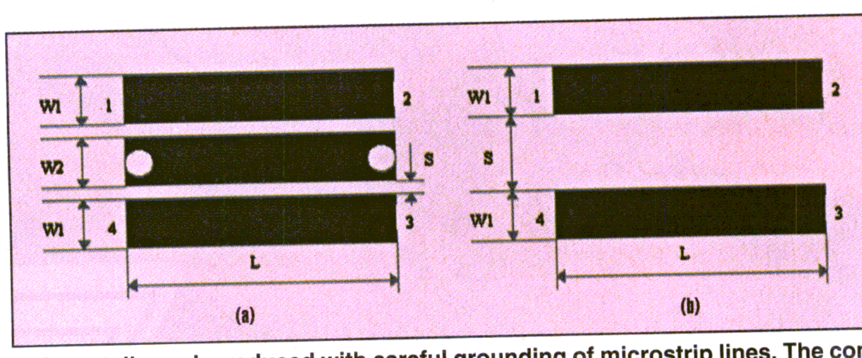


5. This lowpass filter was developed for use in the RF front-end module.



6. This is the response of the filter circuit in Fig. 5.

Figure 2 shows an example of gain and noise character at channel 832.11 ±0.625 MHz. The gain drops and the noise figure increases quickly outside this band. The out-band noise rejection is well-suited for the minicellular



7. Crosstalk can be reduced with careful grounding of microstrip lines. The configuration (a) reduces coupling by approximately 10 dB over (b).

base-station application.

As previously mentioned, there are many ICs made by different companies that are employed in the design. Therefore, the impedance match problem between stages is of great importance for the RF front-end module. The matching circuits in this design also serve as filters. With the aid of the Microwave Harmonica nonlinear simulation software,[5] suitable impedance matching and filter circuits are obtained without much difficulty. Figure 3 shows two typical matching circuits for the modulator IC [model HPMX2005 from Agilent Technologies (San Jose, CA)] and the AGC IF amplifier (model RF9909 IC). The output impedance of the HPMX2005 is 50 Ω and the input impedance of the RF9909 is up to 1 kΩ. If the impedance between the two elements is not matched, it will cause self-excitation of the IF amplifier. The matching circuitry is designed to operate the IF amplifier under stable conditions. The analytical performance of the match network between the I/Q modulator and IF AGC is shown in Fig. 4.

In the receive path, an inductor-capacitor (LC) lowpass filter and an operational amplifier are employed to reject spurious in out band and increase the level of the I/Q signals. The lowpass filter also serves as impedance-match circuits to match the impedance between the quadrature demodulator and operational amplifier. The schematic diagram and the analytical performance of the filter are shown in Figs. 5 and 6.

ANALYZING PCB CROSSTALK

Since the whole module is designed to fit on a single PCB and the devices are arranged closely with each other on PCB, the isolation problem of each circuit unit is very important. Poor isolation will lead to large crosstalk and leakage which will deteriorate the specification of system greatly. In this paper, an example to reduce the crosstalk between two microstrip lines is given which is shown in Fig. 7 (a) [denoted as configuration (a)] and with the original configuration which is shown in Fig. 7b [denoted as configuration (b)]. In configuration (a), the central strip is grounded by two via holes at its two ends. Four different cases are analyzed with Microwave Harmonica. Two different dimensions are used for (a) and (b). For (a), where w1 = 1 mm, w2 = 0.3 mm, s = 0.3 mm, L = 20 mm and w1 = 1 mm, w2 = 1 mm, s = 0.3 mm, L = 20 mm, respectively. For (b), where w1 = 1 mm, s = 0.9 mm, L = 20 mm and w1 = 1 mm, s = 1.6 mm, L = 20 mm, respectively.

Although the response curves are not shown, the coupling between lines drops approximately 10 dB when configuration (a) is used. As a result, the crosstalk is reduced greatly and the specification of the system is improved significantly. From the experimental results, one can find that the carrier leakage is sup-

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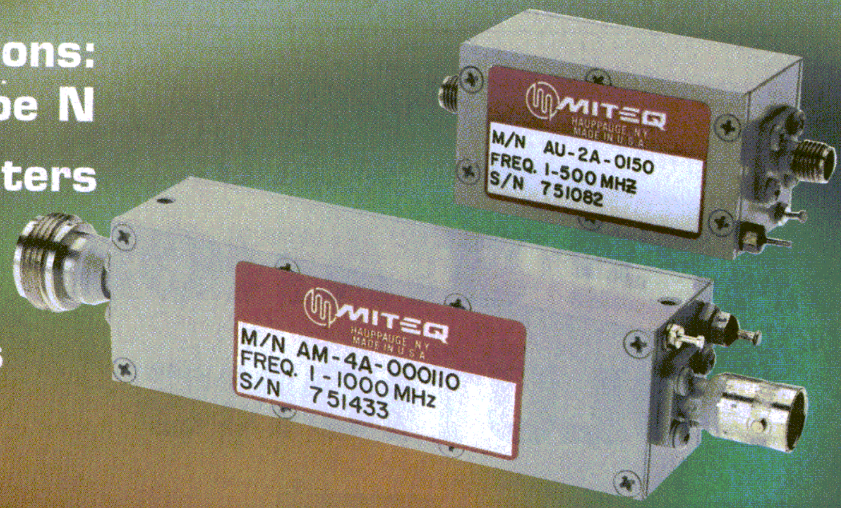

FREQUENCY (MHz)	MODEL NUMBER	GAIN (dB, Min.)	GAIN FLATNESS (±dB, Max.)	VSWR IN/OUT	NOISE FIGURE (dB, Max.) F_1	$F_ø$	F_2	OUTPUT POWER (dBm, Min.)	DOMESTIC PRICE (1-9 PCS)
0.01 – 200	AU-1442	35	0.5	2.0:1	1.2	1.2	1.2	5	$300
0.01 – 200	AU-1447	56	0.5	2.0:1	1.2	1.2	1.2	12	$325
0.01 – 500	AU-1310	30	0.5	2.0:1	1.3	1.4	1.5	8	$300
0.01 – 500	AU-1332	45	0.5	2.0:1	1.3	1.4	1.5	10	$325
0.01 – 1000	AM-1300	27	0.75	2.0:1	1.4	1.6	1.8	8	$325
0.01 – 1000	AM-1431	35	0.75	2.0:1	1.4	1.6	1.8	10	$350
0.02 – 1000	AM-1551	38	1.0	2.0:1	1.4	1.6	1.8	15	$350
1 – 100	AU-3A-0110	55	0.5	2.0:1	1.2	1.2	1.2	12	$300
1 – 200	AU-1464	35	0.5	2.0:1	1.2	1.2	1.2	6	$275
1 – 200	AU-1494	56	0.5	2.0:1	1.2	1.2	1.2	11	$300
1 – 500	AU-2A-0150	30	0.5	2.0:1	1.3	1.4	1.5	8	$275
1 – 500	AU-3A-0150	45	0.5	2.0:1	1.3	1.4	1.5	10	$300
1 – 500	AU-4A-0150	60	0.5	2.0:1	1.3	1.4	1.5	10	$325
1 – 1000	AM-2A-000110	26	0.75	2.0:1	1.4	1.6	1.8	8	$300
1 – 1000	AM-3A-000110	35	0.75	2.0:1	1.4	1.6	1.8	8	$325
1 – 1000	AM-4A-000110	51	1.0	2.0:1	1.4	1.6	1.8	9	$350
5 – 300	AU-1021	24	0.5	2.0:1	2.4	2.5	2.7	20	$275
5 – 300	AU-1525	61	0.5	2.0:1	1.2	1.2	1.3	20	$350
100 – 1000	AM-1412	35	0.75	2.0:1	1.4	1.6	1.8	15	$350
100 – 2000	AM-1526	9	1.0	2.0:1	8	5.5	5.5	20	$350
200 – 2000	AMMIC-1427	20	1.5	2.2:1	4.2	4.3	4.6	14	$375
500 – 1000	AM-2A-0510	24	0.5	2.0:1	1.4	1.5	1.6	0	$300
500 – 1000	AM-3A-0510	38	0.5	2.0:1	1.4	1.5	1.6	9	$325
500 – 2000	AM-3A-0520	29	0.75	2.0:1	1.4	1.9	2.4	3	$350
1000 – 2000	AM-3A-1020	29	0.5	2.0:1	1.8	2.1	2.4	10	$325
1000 – 2000	AM-1477	39	1.0	2.0:1	1.8	2.1	2.4	15	$350
1000 – 2000	AM-4A-1020	40	0.75	2.0:1	1.8	2.1	2.4	10	$350

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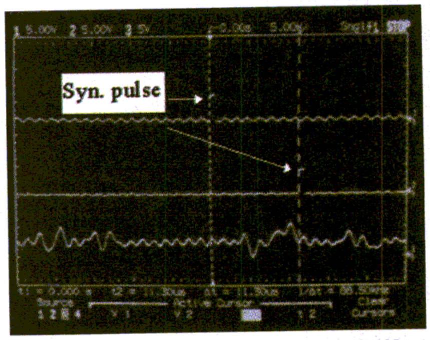
pressed more greatly than the original configuration. Meanwhile, the area of the PCB is not enlarged at all.

EXPERIMENTAL RESULTS

The RF front-end module was measured in the laboratory and at the National Mobile Communication Research Lab of Southeast University. The AGC range in receiving and transmitting path is approximately 90 and 84 dB, respectively. The output power can reach +23 or +30 dBm at the antenna port by using different PAs. The minimum receive threshold level reaches approximately –100 dBm and the noise figure of the system is about 8.3 dB.

To evaluate the receiving path, an RF signal at 832.11 MHz was fed to the antenna port of the RF module under test. The waveform and spectrum of the baseband I/Q signal were measured using a model 492BP spectrum analyzer from Tektronix and a model HP 54601A oscilloscope from Agilent Technologies (Fig. 8). The signal level reaches 2 V peak-to-peak and the SNR was more than 35 dB at approximately 800-kHz offset from the center frequency.



8. The waveform of the baseband I/Q signal was measured using a model HP 54601A oscilloscope from Agilent Technologies (Santa Rosa, CA).

In order to evaluate the transmission path, a model 436 power meter from Agilent Technologies (Santa Rosa, CA) was used to measure the RF output power at the antenna port. The measured transmission frequency of the minicellular base station was at 877.11 MHz and output power was +20 dBm. When the maximum output power was obtained, the signal-to-noise ratio (SNR) was better than 35 dB at 850-kHz offset from center frequency. The spectrum of spurious signal was less than –39 dBc in the full band. The data illustrate that the PCB crosstalk was reduced greatly. ●●

Acknowledgments

The authors would like to acknowledge Professors Chunming Chao and Xiao-Hu You for their valuable ideas and suggestions on I/Q quadrature modulation and demodulation. This work is supported by the China Natural Science Foundation under Grant 69625102.

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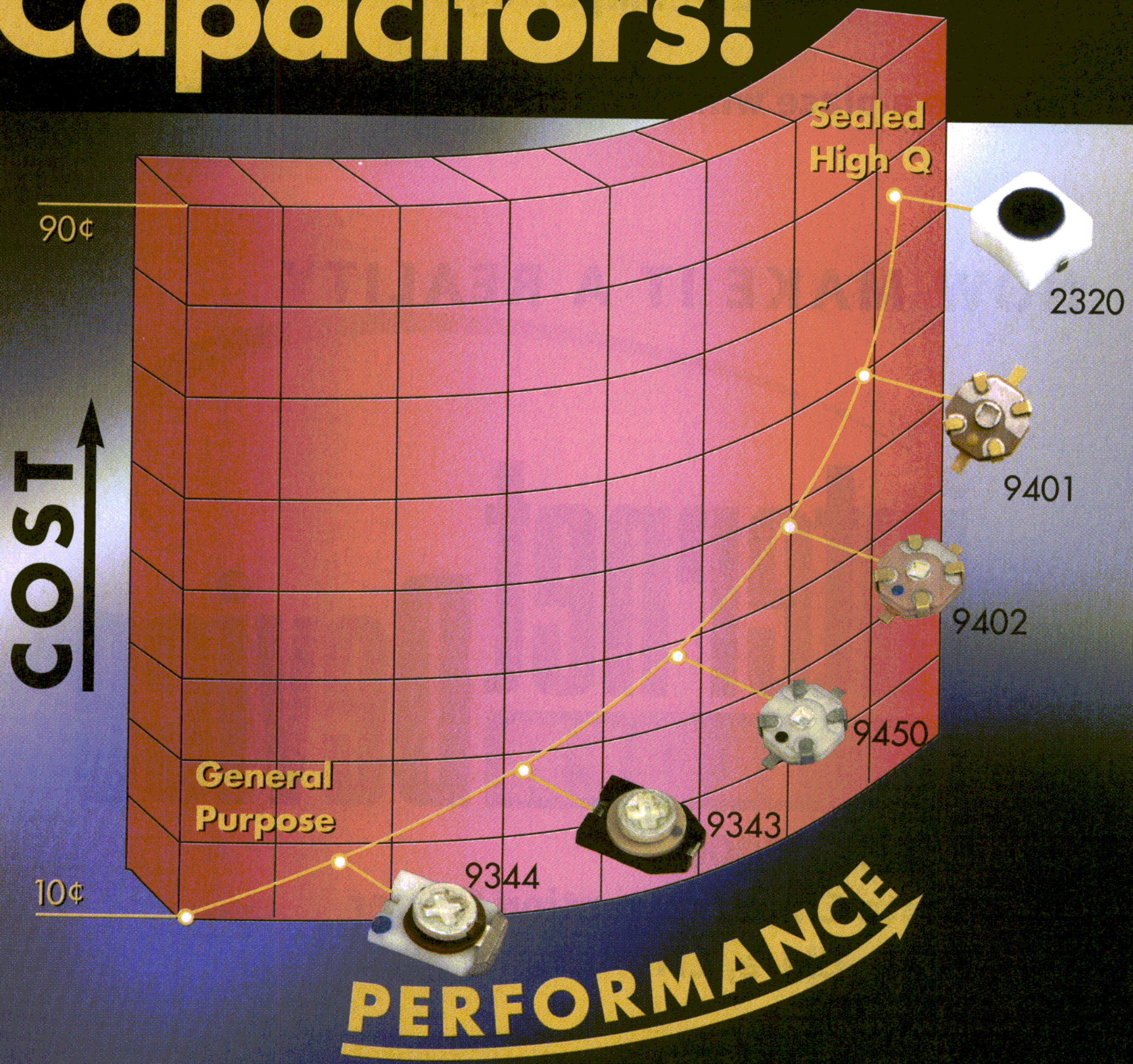

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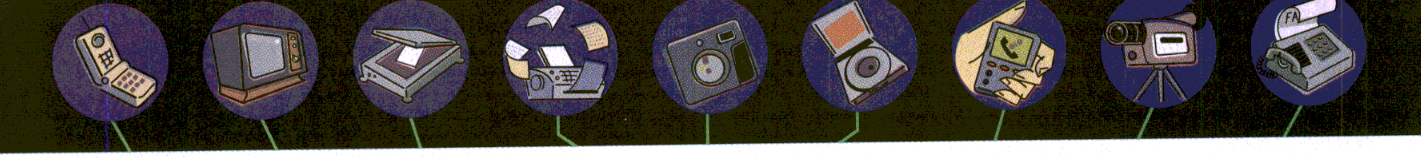

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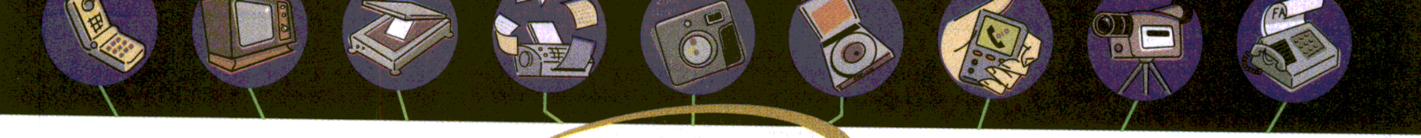

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Techniques Yield Tiny Hairpin-Line Resonator Filters

Some straightforward design techniques and a custom software program can help shrink the size of hairpin-line resonator filters.

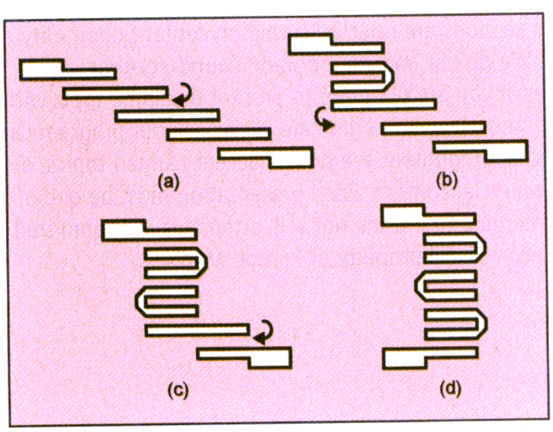
Rodrigo Neves Martins
Graduate Student
Humberto Abdalla Jr.
Associate Professor
Universidade de Brasília, Departamento de Engenharia Elétrica, P.O. Box 04386, 70.710-900-Brasília-D.F., Brazil, e-mail: abdalla@ene.unb.br.

HAIRPIN-LINE resonator filters are relatively simple to design and build, although they are generally too large for mobile radio applications. Fortunately, design methodology and supporting software have been developed that support the creation of narrowband filters with miniature hairpin resonators that are compact and low in cost.

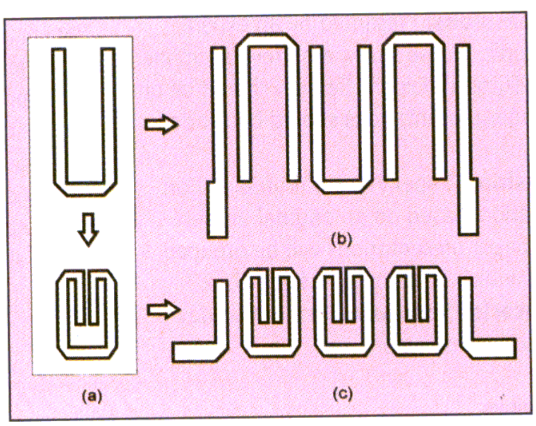
Traditionally, microstrip bandpass filters are widely used at microwave frequencies with special attention at X-band. In this band, with an appropriate dielectric substrate, it is possible to perform an analysis based on quasi-transverse-electromagnetic (TEM) modes of propagation. Among the innumerous structures that can be used, edge-coupled microstrip filters are very popular because they do not require short circuits and are easy to design and build. The main disadvantage is their large size. In order to solve this problem, hairpin-line filters are used. Conceptually, hairpin-line filters can be obtained by folding the resonators of edge-coupled filters.[1] Figure 1 shows the construction of a hairpin-line filter, where each half-wave resonator is folded into a hairpin. While the configuration is suitable for compact microwave bandpass filters, the size of the hairpin is still too large to design a filter for mobile radio communications.

To reduce the size of hairpin resonators and create an attractive topology for applications in the A-band of mobile radio communications, the arms of the resonator are reactively loaded with parallel coupled lines.[2] Figure 2 shows the difference between the conventional hairpin resonator and the miniaturized hairpin resonator loaded with coupled lines. Filters using these miniaturized resonators are 50 percent more compact than filters that use conventional hairpin resonators.

When it is necessary to design a



1. This four-step folding procedure can be used to obtain a hairpin-line filter. Each half-wave resonator is folded into a hairpin. The configuration is suitable for compact microwave bandpass filters.



2. By applying some straightforward design procedures, it is possible to transform (a) a conventional hairpin resonator and (b) a miniaturized hairpin resonator hairpin-line filter into a (c) miniature hairpin-line filter.

bandpass filter with narrow bandwidth and high selectivity, a conventional lowpass-to-bandpass transformation, although theoretically correct, does not achieve the desired performance. Filters with these characteristics are achieved by coupling similar-type resonators together. In this case, the resonators consist of reactive parallel circuits which are tuned to the desired center frequency and coupled by a simple lumped capacitance. The design of multiresonator filters is based on the lowpass prototype aided by the concept of coupling coefficients, k_{ij}, and quality factors, q_I.[3]

The coupling coefficient k_{ij} is defined for a lowpass prototype circuit as the ratio of the resonant frequency of two adjacent elements to the 3-dB cutoff frequency [Fig. 3(a)]:

$$k_{ij} = w_{ij} / w_{3dB} \qquad (1)$$

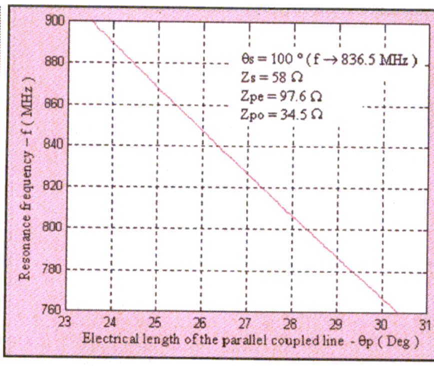
where:

$w_{ij} = 1/(g_I g_j)^{0.5}$, and

$w_{3\,dB}$ = the normalized cutoff frequency (= 1).

Therefore:

$$k_{ij} = (g_i g_j)^{-0.5} \qquad (2)$$



5. Fine resonance frequency tuning of the hairpin-line filter can be achieved by adjusting θ_p.

The quality factor, q_I, is defined as the quality of the reactive element influenced by the source and load resistance, if present, and it is in series or parallel. For symmetrical and lossless networks, the quality factor of each element evaluated at $w = w_{3\,dB} = 1$ is infinity except for the end terminations:

$$q_i = g_i R_i, \text{ for } i = 1, n \qquad (3)$$

where:

R_1 = the source termination, and

R_n = the load termination.

From the bandwidth, Δf, and the center frequency, f_m, the unnormalized coupling coefficients, k_{ij}, and the unnormalized quality factor, Q_i, for the end resonators can be obtained[3]:

$$K_{i,j} = k_{i,j}\, \Delta f / f_m \qquad (4)$$

$$Q_i = q_i f_m / \Delta f, \text{ for } i = 1, n \qquad (5)$$

These quantities are directly related to the bandpass circuit elements (Fig. 3b). The coupling capacitances between the ith and jth nodes are provided for:

$$C_{i,j} = K_{i,j}\, C_{node} \qquad (6)$$

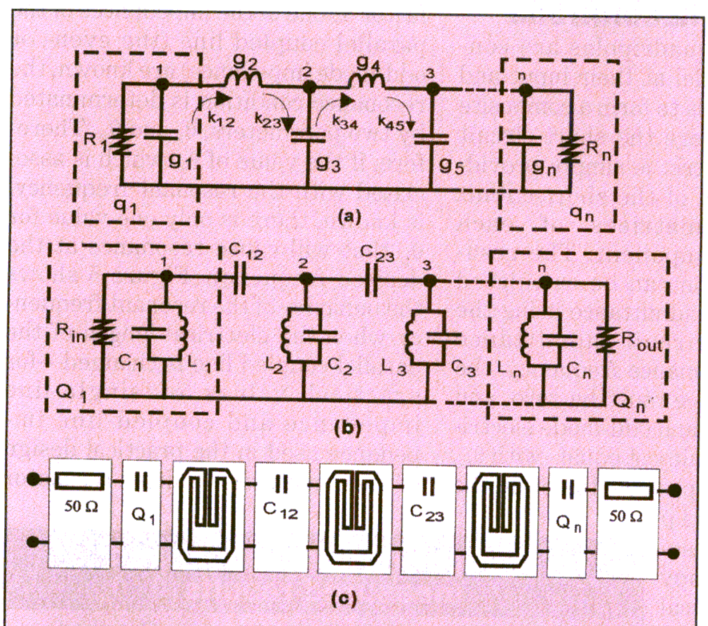
where:

C_{node} = the total shunt capacitance of each node when all other nodes are shorted to ground.

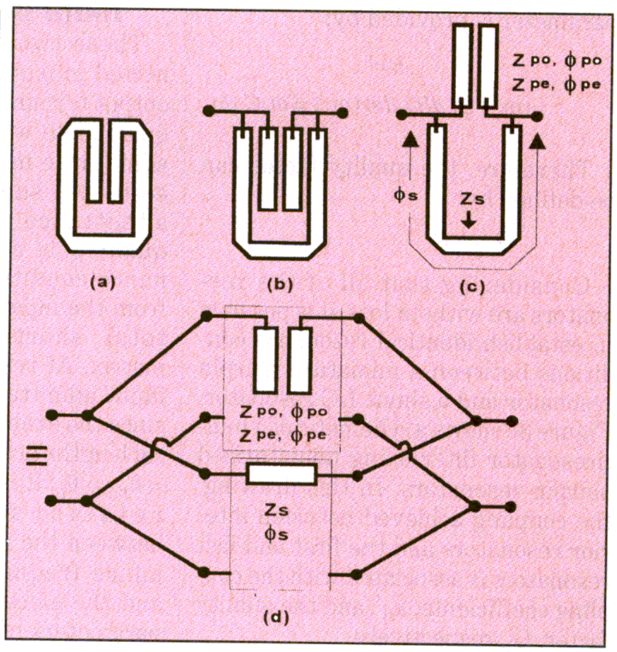
Therefore, the shunt capacitors of the parallel tuned circuits are equal to the total nodal capacitance without the values of the coupling capacitors connected to that node[4]:

$$C_i = C_{node} - C_{i-1,i} - C_{i,i+1} \qquad (7)$$

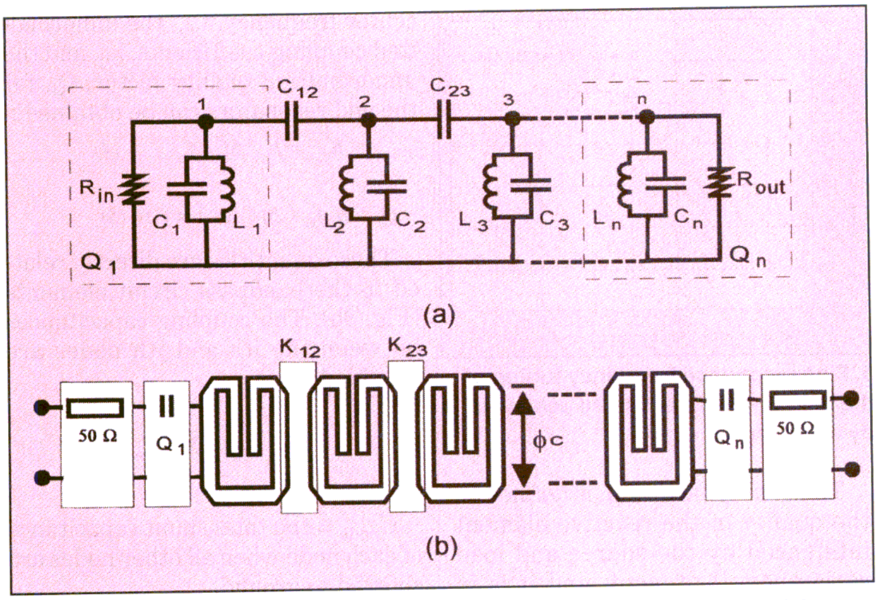
When all of the nodes are shorted except for the ith node, the nodal inductor, L_I, and the nodal capacitor,



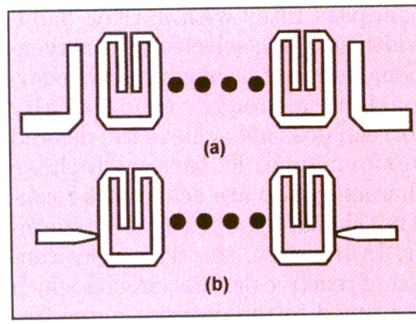
3. The schematic diagrams for these three structures show (a) a lowpass filter used for defining k values, (b) a bandpass filter derived from the lowpass filter, and (c) a miniature hairpin resonator filter with 50-Ω input and output ports. The coupling acheived is associated with coupling coefficients, k_{ij}, and the quality factor, Q_{ij}.



4. Two quadripoles in a parallel connection can be used to form an equivalent circuit of a hairpin resonator (d), by modifying the basic hairpin resonator (a) through input and output electrical connectors (b) while maintaining the even- and odd-mode electrical lengths and impedances (c).



6. The equivalent circuit (a) shows the circuit-element representation of the coupling effects. The interstage coupling between resonators (b) is achieved by parallel coupling of lines.



7. This tapped bandpass filter can be simplified by using taps (b) instead of coupled sections (b) for the end resonators.

C_I, resonate at f_m.

If the circuit is built in distributed form, the equivalent resonance properties of the resonators, regardless of their form, are obtained through the resonant frequency and the slope parameter.[5] For shunt LC resonators, the susceptance slope parameter is provided by:

$$b = (\omega_0 / 2)\, dB / d\omega (\omega_0) = \omega_0 C \quad (8)$$

Therefore, the quality factor can be defined by:

$$Q = b R \quad (9)$$

Considering that all of the resonators are without loss, it is possible to establish identical resonance conditions between a miniature hairpin resonator and a shunt LC resonator. Figure 3c shows a schematic of a multiresonator filter using miniaturized hairpin resonators. In this drawing, the coupling achieved between interior resonators and the first and last resonators is associated with the coupling coefficients, k_{ij}, and the quality factor, Q_i, respectively.

A hairpin resonator can be considered as two quadripoles represented by a transmission line and a parallel coupled line, respectively (Fig. 4), with the following parameters: Z_s is the characteristic impedance of the transmission line, θ_s is the electrical length of the transmission line, Z_{pe} and Z_{po} are the even- and odd-mode impedances, respectively, of the parallel coupled lines, and θ_{pe} and θ_{po} are the even- and odd-mode electrical lengths of the parallel coupled lines.

HAIRPIN RESONATORS

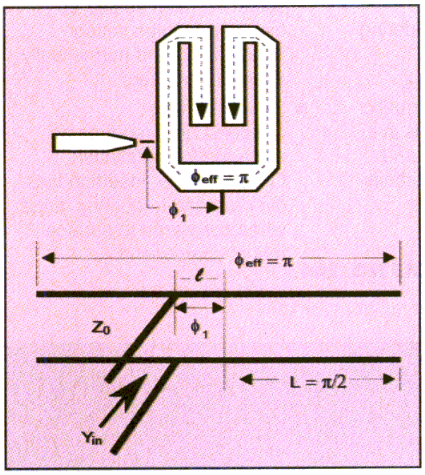
These two quadripoles are connected in parallel at their input and output terminals to form a composite quadripole where the short-circuit admittance matrix is simply provided by the sum of the short-circuit admittance matrices of each quadripole component. The resonance condition can be calculated from the input admittance using the total short-circuit admittance matrix. At resonance frequency, the input admittance must be zero, and since the even- and odd-mode electrical lengths are almost equal, with $\theta_{pe} = \theta_{po} = \theta_p$, it is possible to obtain the relationship between the resonance frequency and the electrical parameters of the transmission line and coupled line.[2] The result of these calculations is the resonance equation shown here:

$$(Z_{pe} Z_{po} \cot\theta_p - Z_s^2 \tan\theta_p)\sin\theta_s + Z_s(Z_{pe} + Z_{po})\cos\theta_s - Z_s(Z_{pe} - Z_{po}) = 0 \quad (10)$$

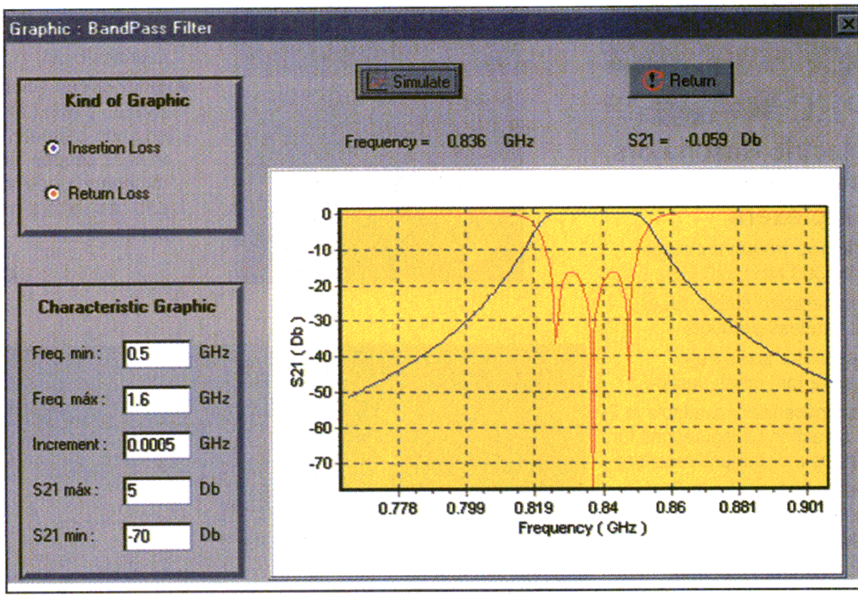
An analysis of the resonance equation (eq. 10) shows that some parameters can be adjusted by the designer while other parameters are intrinsically linked to each other. The line impedances are design parameters, and it is evident that the resonance frequency is directly proportional to the electrical length of the resonator. Hence, if the impedance of the single transmission line and the coupling factor or one of the impedances of the parallel coupled line (the even- or odd-mode impedance) are known, the resonance condition is determinated by two parameters, θ_s and θ_p. Therefore, if the value of θ_s, which is associated with the resonant frequency, is known, there is only one value for θ_p that will cause resonance at the desired frequency. Figure 5 shows the behavior of the resonant frequency when the electrical length of the parallel coupled line is changed—for practical values of single-line impedance and coupled-line impedance used in the practical design of the miniaturized hairpin resonator

Comparing theoretical and measured results

Specification	Theoretical	Measured
Center frequency	836.5 MHz	830 MHz
Bandwidth	25MHz–3 percent	27MHz–3.25 percent
Insertion loss		1.5dB



8. This equivalent circuit can be used to represent a tapped miniature hairpin resonator.



9. The software program was used to predict and plot the frequency response of the hairpin-line resonator filter.

filter. Consequently, the variation of the electrical length of the parallel-coupled line causes a fine frequency tuning, which supports greater design flexibility.

The non-normalized coupling coefficients represent the interstage coupling between resonators, that is achieved by parallel lines coupling with electrical length of ϕ_c (Fig. 6):

$$K_{i,j} = C_{i,j} / C_{node} = k \sin\phi_c / \{2[(1-k^2)\cos^2\phi_c + \sin^2\phi_c]^{0.5}\} \quad (11)$$

where:

$k = (Z_{oe} - Z_{oo})/(Z_{oe} + Z_{oo})$,

and

$(Z_{oo} - Z_{oe}) = ZS^2$

These equations enable the even and odd impedances to be obtained for the coupled line as a function of the coupling coefficients between the resonators, coupled electrical length, and characteristic impedance of the single transmission line of the resonator:

$$z_{oe} = [(Z_s)^2[2K_{ij} + \{\sin^2\phi_c + (2K_{ij})^2\cos^2\phi_c]\}^{0.5}]^{0.5} \times ([\sin^2\phi_c + (2K_{ij})^2\cos^2\phi_c]^{0.5} - 2K_{ij})^{-0.5} \quad (12)$$

If the even and odd impedances are known by using the classic synthesis process, the line width and the spacing between the resonators are easily obtained.[6] The quality factor of the first and last resonators will be used to calculate the coupling of the filter to the source and to the load.

Bandpass filters are designed for maximum power transfer, accomplished by using low-loss networks and a good matching network between the input and output impedances in the desired frequency band. In the topology analyzed here, the source-power transfer to the load is obtained by coupling to the resonator-transmission line. This kind of coupling has problems in production due to a significant reduction in the coupled section length, and for this reason, the spacing of the external coupling sections is very critical. To avoid this, the end resonators may be externally coupled by tapping instead of using a coupled section (Fig. 7).

The schematic of the tapped miniaturized hairpin resonator is shown in Fig. 8, where the effective electrical length of resonance is defined.[7]. Using this effective electrical length, the equivalent circuit of the tapped miniaturized hairpin resonator is established. The tapping location, ϕ_1, is provided by:

$$\phi_1 = \beta_{eff}\,\lambda = 2\pi\lambda / \lambda_{eff} = \pi\lambda / 2L \quad (13)$$

In the vicinity of the resonant frequency, the input admitance at the tap point is:

$$Y_{in}(\omega) = G_0 + jB(\omega) = G_0 + jb\,(\omega / \omega_0 - \omega_0 / \omega) \quad (14)$$

where :

G_0 = the input conductance of the filter,

b = the slope parameter of the equivalent circuit of the tapped miniaturized hairpin resonator, and

ω_0 = the angular resonant frequency.

The susceptance slope parameter b of the tapped miniaturized hairpin resonator is:[8]

$$b = (\omega_0 / 2)\, dB / d\omega\,(\omega_0) = \pi Y_a / 2\sin^2\phi_1 \quad (15)$$

The condition of resonance and maximum power transfer is established when the input admittance of the structure is purely real and equals the source conductance:

$$Y_{in}(\omega) = G_0 = 1/R = b/Q \quad (16)$$

Considering that the structure is symmetrical, these equations enable the calculation of the tap point of the input and output resonators:

$$\lambda = (\lambda_{eff} / \pi) \arcsin [(\pi R / 2Z_0 Q)^{0.5}] \quad (17)$$

On the basis of the derived formula, software was developed for the design of tapped miniaturized hair-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pin-line filters. The software is composed of three independent modules that execute the following functions:

• Construction of the filter-transfer function with Chebyschev or Butterworth frequency response. This module also contains a dedicated graphic interface that permits the visualization of the frequency response before the filter synthesis.

• Graphics visualization and analysis module of the poles and zeros of filters in the complex variable plane (the S plane).

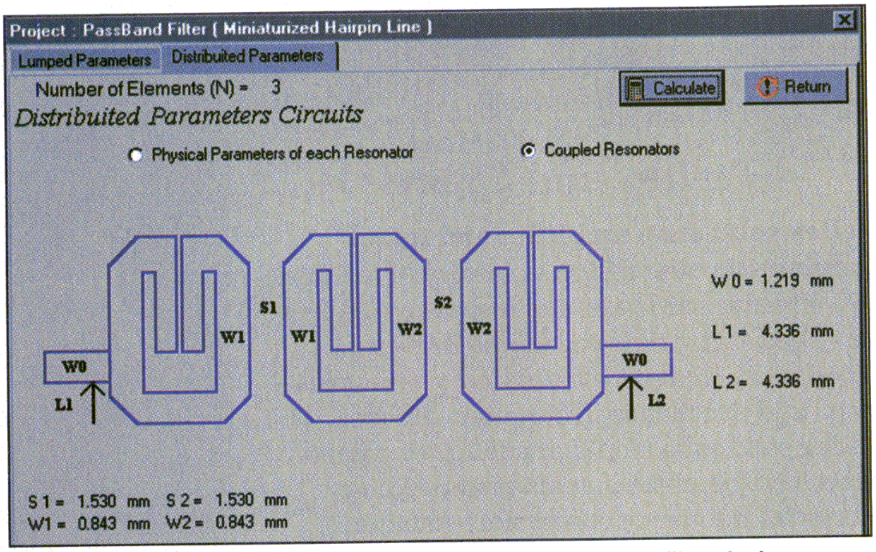
• Synthesis of the filter in lumped and distributed parameters. The synthesis software module provides the layout of the filter, including all of the calculated dimensions, taking the chosen fabrication technology into account.

A step-by-step design procedure that uses the developed software is outlined:

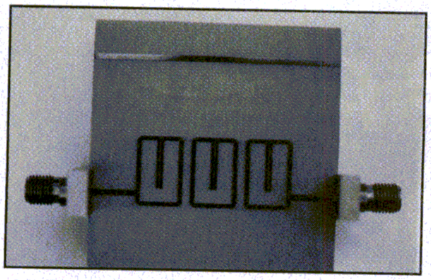
1. The type of frequency response and the transmission structure is first selected. The filter specifications and the basic parameters of the transmission structure based on Fig. 9 are then completed.

2. With the specifications selected, it is possible to access the analysis and synthesis modules of the computer program.

These software modules support the realization of the hairpin circuit using all necessary data. Figure 9 shows a typical output of the frequency response module, where it is possible to see the insertion and return losses. In the synthesis mod-



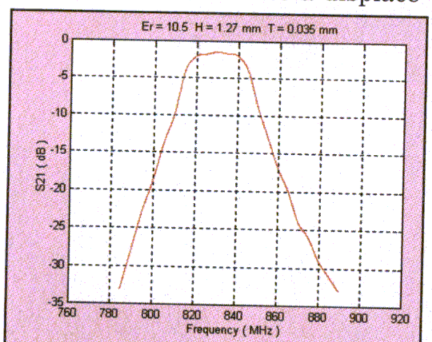
10. The program shows the miniature hairpin-line resonator filter design.



11. This photograph shows the miniature hairpin-line resonator filter fabricated with the help of the custom computer program.

ule, it is possible to obtain the design in lumped and distributed parameters. In the program, a design using distributed parameters initiates calculation of the miniature hairpin resonator and the calculation of coupling the resonators and the end-tapped resonators. A screen with the layout of the tapped miniaturized hairpin-line resonator filter is shown in Fig. 10.

Using this software, a miniature hairpin-line filter was designed and tested for the following specifications: a center frequency of 836.5 MHz, a fractional bandwidth of 3 percent, ripple of 0.1 dB, and three resonators. A microstrip transmission structure was chosen for the filter, using a substrate with a dielectric constant ϵ_r of 10.5 and thickness of 1.27 mm. To tune the filter and obtain the adjustment of the tap point, a computer-aided optimization process was used. A photograph of the filter is shown in Fig. 11 and its measured frequency response is shown in Fig. 12. The passband insertion loss was found to be approximately 1.5 dB. Measurements indicate a displacement of 1 percent at the center frequency in addition to a bandwidth that is close to the specified value. ••



12. The frequency response of the miniature hairpin-line resonator filter agrees well with simulated data from the computer program.

Acknowledgments

This work was supported in part by Conselho Nacional de Desenvolvimento Científico e Tecnológico, CNPq.

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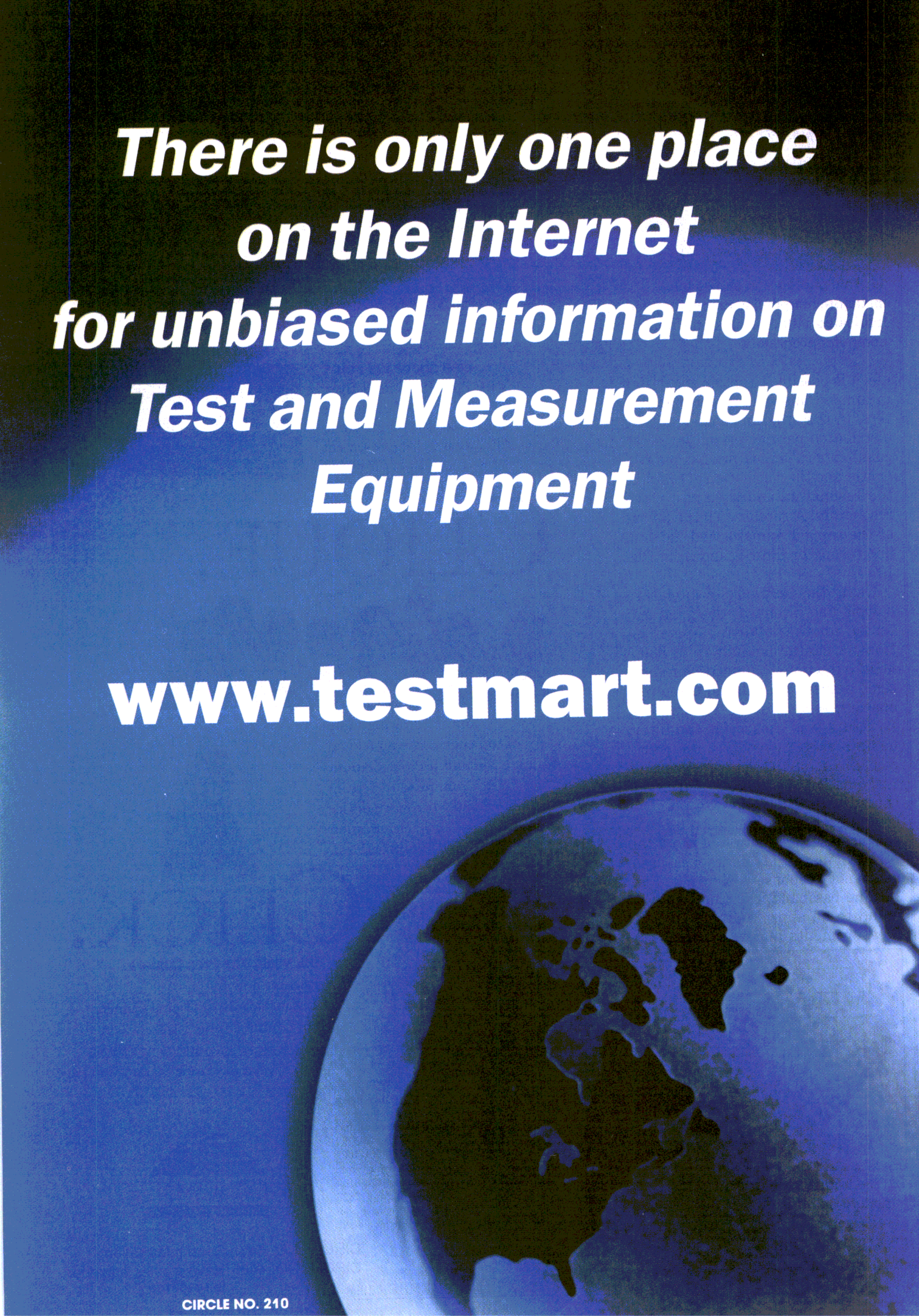
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This new company's website provides the data bases and search engines to link users and specifiers with the new and used test equipment they seek.

JACK BROWNE
Publisher/Editor

Internet-based commerce often suggests sales of books, software, or even airline tickets. But the Internet can also connect buyers and sellers of test and measurement equipment at TestMartE (San Bruno, CA) at http://www.testmart.com. This global on-line marketplace represents an independent third-party source of test and measurement equipment in the form of a Web Community of test-equipment manufacturers and customers. The site is constantly adding new data and features and expanding new membership to meet its objective of everything test and measurement on the Internet.

TestMart is owned and operated by Technical Communities, Inc., a private company formed in 1998 to create Internet-based business-to-business electronic commerce for technical equipment marketplaces. The company secured a major round of capitalization from leading venture capitalists Crosspoint Venture Partners (Woodside, CA) and New Enterprise Associates (Menlo Park, CA) in the spring of 1999.

Managed as a neutral third party, TestMart provides reliable, unbiased information and a safe, affordable trading environment for new and used test equipment. The firm's independent data bases contain high-quality, proprietary, and licensed content previously unavailable to users of test equipment. Information is available on products from all manufacturers, whether or not they have chosen to affiliate with TestMart.

Summary of product search and compare fields

Search by	Retrieve
Product category	Normalized unbiased specification information
Model number	Side-by-side comparisons
Manufacturer/multiple manufacturers	Detailed product information
Broad product category	Initial summary specifications
Keyword/phrase	Complete detailed specifications
Like/similar product	

Product-support information fields include electrical specifications, power-supply characteristics, calibration intervals, physical specifications, reliability information, warranty information, programming languages, life-cycle data, and options. Data fields for manufacturers and service providers include company names, locations, predecessor companies, contact information, and website addresses.

The TestMart website includes powerful search engines for access to all information in the data bases, quickly locating those products that meet a customer's specified characteristics. Detailed specifications are presented in a normalized format for clear side-by-side comparisons of equipment from different manufacturers. Data are contained within the site, eliminating the gathering and piecing together of incomplete information in dissimilar formats from multiple manufacturer's catalogs or websites.

SEARCH AND COMPARE

TestMart gives all manufacturers equal access to an efficient neutral electronic-commerce marketplace for their products and services, saving them the cost and complexity of more narrowly focused sites. The TestMart website is actually modeled after the trading floors of stock exchanges, a universal format


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that has proven safe and reliable for use by individuals and companies.

The TestMart website currently features a number of capabilities to speed and simplify the selection of new and used test equipment, including the search-and-compare function *(see table)*. Users find products by model, manufacturer, or as many as eight characteristics for side-by-side product comparisons with unbiased data in a normalized format. Searches can be performed according to any number of the available parameters. The site's e-store offers on-line shopping at storefronts for new equipment, refurbished second-hand equipment, and special offers from manufacturers. Custom sourcing locates vendors of hard-to-find products on request.

The TestMart website includes two additional storefronts—Refurbished Instruments and Manufacturers Special Offers. The Refurbished Instruments storefront offers fully reconditioned and calibrated equipment. Each instrument carries a standard six-month warranty. TestMart offers a tightly controlled 21-point process for the refurbishment of an instrument from receipt to final shipment. Among the 21 points are verification of free title, replacement of damaged or missing elements, replacement of expendables (such as filters), testing of all functions, latest revisions and service alerts, full calibration to manufacturer's specifications, and the provisioning of all standard manuals and accessories. Extended warranties and "before and after" calibration data are available as extra cost options. The Manufacturers Special Offers storefront includes reconditioned "low-mileage" demonstration equipment and surplus new products, most of which carry the manufacturer's standard new product warranty.

A featured product at the time of this review was the model 4531 power meter from Boonton Electronics Corp. (Parsippany, NJ). The TestMart Homepage offered a brief description of the 110-GHz power meter, with a link to fairly extensive details and specifications, such as the use of the power meter's 20-MHz video bandwidth for measuring the peak and average power levels of modulated signals. This particular product summary offered information on associated sensors, statistical-analysis capabilities, sampling capabilities, and remote-control connections.

The TestMart site offers many opportunities for electronic commerce (e-commerce), based on both reconditioned and new equipment. In the secondhand area, the site's Manufacturer's Mart provided product samplings from more than 100 test-and-measurement manufacturers, including B+K Precision, Fluke, and Kenwood, with products ranging from probes and power supplies to dual-channel oscilloscopes.

In the New Instrument Store, the "Search and Buy" page, for example, offered more than 30 models of signal generators and synthesizers and more than 40 models of spectrum/signal analyzers. In the network-analyzer section, a variety of instruments were on sale from IFR Systems (formerly Marconi Instruments). Under RF power meters, more than 20 products were available, including instruments from Boonton Electronics Corp. and Giga-tronics (San Ramon, CA). A quick check of "Microwave Components" revealed numerous precision adapters, a DC-to-18-GHz power splitter with 3.5-mm connectors, and a power divider with a range of DC to 26.5 GHz, several precision fixed coaxial attenuators for DC to 18 GHz, scalar-network-analyzer (SNA) detectors, and even a few precision coaxial-cable assemblies. Prices were clearly listed for each item. Additional items on the "Search and Buy" e-commerce page include audio test instruments, cable testers, digital oscilloscopes, electronic loads, function generators, optical meters, video signal generators, and power monitors. Searches can also be performed by individual manufacturer and product type or by specific model numbers.

An electronic library (eLibrary) features independent, up-to-date information on more than 10,000 test and measurement products, data bases of support information, such as calibration intervals, year-2000 (Y2K) status, and out-of-support dates, a crosslinked directory of industry names and categories, a directory of calibration laboratories, a wide range of application articles and white papers, a glossary of terms, and market reports from respected analyst firm Frost & Sullivan (New York, NY). A sampling of white papers includes "New Rules for Buying and Selling Test Equipment" and "Test & Measurement and The Internet."

The TestMart site offers great value for its additional editorial content alone. In the Frost & Sullivan section of the site, for example, browsers could find articles on "Computer-based virtual instrumentation," "Renting and leasing of test and measurement equipment," "Strategic reorganizations," "Test & Measurement and the Internet: An analysis of the convergence of these industries and the road ahead," and "Agilent Technologies: The new identity for Hewlett-Packard's spin-off tells a tale." This last article, written by Frost & Sullivan consultant Shekar Gopalan, provides several screens worth of comment on the rebirth of Hewlett-Packard's test, medical, and component groups as they embark on their own business identity, away from the computer and printer businesses.

"We currently have detailed specifications of over 9500 products from 140 manufacturers," according to TestMart's CEO Peter Ostrow. "We fully expect to reach our goal of 12,000 products, 200 manufacturers, and 600 service providers by the end of this year. Members can search and compare products in these data bases, specifying up to eight parameters within an ever-growing number of key product categories."

TestMart membership is free of charge. Test-equipment sellers support the site. Members register with very basic information and are then given full access to data bases, reference data, and e-commerce, while being able to request literature, quotations, and support through direct links to the manufacturers.

For more information, contact: TestMart, 851 Traeger Ave., San Bruno, CA 94066; (650) 624-0525, FAX (650) 624-0535, e-mail: info@testmart.com.
Internet: http://www.testmart.com

Website Focuses On Millimeter-Wave Antennas

This site offers a wide selection of microwave antennas, antenna positioners, and a supporting family of waveguide and coaxial components.

ALAN "PETE" CONRAD

Special Projects Editor

Millimeter-wave antennas are the area of interest to be found at a useful website maintained by Q-par Angus (Herefordshore, England) at http://www.q-par.co.uk. For more than 25 years, the firm has been a leader in the design and manufacture of components and systems operating through submillimeter-wave bands. Although the company specializes in microwave antennas and antenna positioners, the firm also offers an extensive range of coaxial and waveguide components, including standard and custom horn antennas.

The company manufactures horn antennas operating from 300 MHz to 100 GHz in a variety of styles including plane rectangular, conical, multimode, double and quadruple ridged, as well as corrugated antenna types. Typical products include an 18-to-40-GHz broadband reflector antenna, an 18-to-40-GHz broadband Cassegrain antenna with a motorized subreflector, broadband steerable surveillance antennas, and millimeter-wave cornucopia (hog-horn-type) antennas. The firm also offers center-feed parabolic reflector antennas with diameters ranging from 0.3 to 2.0 m and larger. They are ideal for applications ranging from narrowband communications to wideband surveillance.

Split reflector antennas are available with four quadrant splits for ease of transport and storage. The antennas are supplied with dowels and quick-release fasteners to ensure rapid and accurate assembly. A selection of feeds for parabolic reflector antennas is also available, covering the 1-to-26-GHz frequency range and higher.

Browsers to the website can view precision antenna positioners with single or multiple axes or translational rotations in X, Y, and Z coordinates for field-probe positioning. Analog and digital servoloops can be implemented. Q-par Angus positioners are especially suited to measurements on millimeter-wave antennas and radomes where very-high positional accuracy is required.

Other positioners include a modular (one-, two-, or three-axis) system for antennas to 3.7 m in diameter. Each controller module operates one axis on the positioner. The positioner can provide "whole-sky" coverage and is Peltier cooled for demanding environments. Q-par Angus has supplied up to six-axis positioners of this type that are used to eliminate multi-

New to the Q-par Angus website is a 1.5-to-18-GHz broadband horn antenna.

path effects in communications systems. An embedded controller unit is used for each axis. A computer terminal that sends single commands for each axis can control the positioner through a single RS-232 connection. Options include a positioner controller through a Windows 95/98/NT environment.

New to the site is a 1.5-to-18-GHz broadband horn antenna *(see figure)*. This compact high-performance unit is ideal for testing of electromagnetic interference (EMI) and radio-frequency interference (RFI) as well as measurements of electromagnetic compatibility (EMC) and wideband spectrum surveillance. The design can also be used as a receiving antenna or as a radiator for transmitting moderate power levels. Special techniques have been incorporated to prevent higher-order waveguide modes. The horn can be mounted in a parabolic reflector to increase directional resolution and gain. It is constructed with a metal/glass composite.

A measured calibration chart of gain versus frequency is supplied with each horn along with integral type-N or SMA coaxial-to-waveguide transitions. The antennas can also be provided with standard waveguide flange connections. Mounting brackets and protective aperture windows can be provided as options.

In addition to its extensive lines of antennas, the firm also manufactures a variety of microwave and millimeter-wave components, including waveguide polarizers and transitions, variable and fixed attenuators, filters, phase shifters, and rotary joints. For example, filters include a tunable bandpass model that can be delivered to custom requirements. One of these filters covers 2.0 to 2.7 GHz with a nominal passband of 25 MHz and a typical insertion loss of 2 dB.

The site contains numerous links to other useful websites, including http://www.open.gov.uk/radiocom, the United Kingdom's Radio Communications Agency. The agency is responsible for the allocation, maintenance, and supervision of the UK Radio Spectrum. Another link, http://www.ukspace.com, the website for the UK's Space Industry, promotes the UK space industry in the global space market. The http://www.open.gov.uk link is the UK government's index of websites, with virtually everything listed. Finally, http://www.mrf.co.uk provides a link to the UK Microwave and RF show, which is usually held annually in September. ●

For access to many different informative links related to antennas, or for more information on the company's line of antennas and related products, please visit the site at:

Q-par Angus Ltd., Barons Cross Lodge, Leominster, Herefordshire HR6 8RS, England; (44) (0)1568 612138, FAX: (44) (0)1568 616373.
Internet: http://www.q-par.co.uk.

Site Spotlights Signal-Processing Tutorials And Application Notes

This invaluable reference source contains information on digital signal processing, (DSP) data acquisition and display, and LabVIEW instrument drivers.

ALAN "PETE" CONRAD

Special Projects Editor

LabVIEW is a software package almost synonymous with automatic-test-equipment (ATE) applications. Developed by National Instruments (Austin, TX), the software provides a wide range of signal analysis and processing capabilities when used with companion instrument drivers. As LabVIEW has grown in popularity, so has the proliferation of instrument drivers, the software modules designed to control programmable instruments. To aid the development of these drivers, National Instruments has created standards for instrument-driver structure, device management, instrument input/output (I/O) functions, and error reporting, and a powerful website (at http://www.ni.com) to support them. Complementing LabVIEW is a series of tutorials reviewing integration and applications of LabVIEW add-ons. Available free of charge at the company's website, these tutorial articles are an excellent source of reference material for browsers searching for signal and data-processing applications *(see figure)*.

For example, the site offers a note on a digital filter-design tool set. The article introduces a new digital filter design and analysis tool implemented in LabVIEW. The software tool enables developers to graphically design classical infinite-impulse-response (IIR) and finite-impulse-response (FIR) filters. Once designed, operators can use the software to interactively review filter responses and save filter coefficients. Also, real-world filter testing can be performed within the digital filter-design application using a plug-in data-acquisition (DAQ) board.

With the digital filter-design stand-alone application, an operator can quickly and easily design digital filters for signal conditioning and control systems without being an expert in DSP technology. The powerful graphical user interface (GUI) can be used to interactively design classical filters such as lowpass, highpass, bandstop, and bandpass digital FIR and IIR filters without programming. In addition, the digital filter-design application includes the ability to create arbitrary re-

The National Instruments' website at http://www.ni.com provides a host of publications and application notes in addition to extensive product literature.

sponse filters by interactively modifying the magnitude response plot. The digital filter-design application also includes the ability to use National Instruments' DAQ hardware to filter and analyze real-world signals.

The website also provides information on the firm's signal-processing toolset, which provides users with a wide range of ready-to-run stand-alone signal-processing capabilities. The toolset includes components for digital filter design, third-octave analysis, joint time/frequency analysis (JTFA), wavelet and filter-bank design, super-resolution spectral analysis, and the Virtual Bench dynamic signal analyzer (DSA) for dynamic signal acquisition, display, and analysis.

Reference materials on the website include the Fourier transform and its applications, introduction to wavelets and wavelet transforms, a practical guide to LabVIEW's analysis capabilities, and time frequency analysis. Also available are tutorials on time-frequency analysis, understanding digital signal processing (DSP), practical DSP modeling, techniques, and programming in C, discrete-time signal processing, and DSP principles, algorithms, and applications. Other notes include a tutorial on adaptive signal processing, and understanding the Fast Fourier transform (FFT).

In particular, application note AN041, "The fundamentals of FFT-based signal analysis and measurement in LabVIEW and LabWindows," is a 20-page document that steps a reader through analysis of stationary and transient signals. The note explains how to make conversions from a two-sideband power spectrum to a single-sideband (SSB) power spectrum, how to adjust the frequency resolution even when working in the time domain, basic computations using an FFT, anti-aliasing and aquisition front ends for FFT-based signal analysis, and limitations on the use of the acquisition front end. The literature also covers how to calculate the measurement bandwidth for a particular sampling frequency and the significance of spectral leakage.

Other notes include techniques for creating an interface between a Hewlett-Packard controller computer and a personal computer (PC), four practical applications for joint time/frequency analysis, strain gauge measurements, and a glossary of DAQ specifications. Browsers can also review technical manuals for any of National Instruments' standard products. Each of the manuals, in turn, is loaded with tutorial articles, design examples, and additional information that can be printed out for future reference. ●

For more information, contact: National Instruments Corp., 6504 Bridge Point Pkwy., Austin, TX 78730-5039; (800) 258-7019, (512) 338-9145, FAX: (512) 683-5794. **Internet: http://www.ni.com.**

Practical Application Notes Abound At Site

Visitors to the site at http://www.kditriangle.com will discover a broad spectrum of active and passive RF and microwave components along with a supporting line of application notes.

JACK BROWNE
Publisher/Editor

More than 30 years ago, KDI/triangle (under a different name) began to offer quality RF and microwave components for military and commercial applications. The firm has made dramatic advances in packaging over the years and is now a leader in miniature RF and microwave components as well as many surface-mount designs. More information on the firm's product lines, along with a generous collection of technical articles and application notes, can be found at the company's website at http://www.kditriangle.com *(see figure)*.

Thirty years later, the company is now highly regarded as a supplier of components and subsystems for wireless communications applications. With a continuing product improvement program, KDI has replaced nearly all of their hybrid-packaging components with Surfpac surface-mount technology.

Surfpac incorporates a single piece of alumina substrate material for the circuit board and hybrid package header, eliminating expensive Kovar, gold (Au)-plating, and glass-firing processes (for glass-to-metal seals). By eliminating the more-expensive materials and additional processing steps, quality and reliability are improved and size and cost are reduced. The use of Surfpac technology results in an almost immediate order-of-magnitude reduction in size for many component designs.

By adopting the Surfpac process, multiple circuits are fabricated on a single substrate, improving unit-to-unit performance consistency. This is especially critical for those designs that must achieve consistency in amplitude and phase performance from unit to unit.

In addition, Surfpac input and output contacts are an integral part of the substrate, package, and process. Lead frames for input and output can be provided when needed for larger packages. This process replaces the tedious bonds and lead attachment required in traditional hybrids. Surfpac technology has reduced the size and cost of KDI/triangle's components such as switches, phase shifters, and attenuators by an ☞

KDI/triangle's site at http://www.kditriangle.com offers more than just product data sheets, with a variety of technical notes on active and passive components.

order of magnitude. For example, manufactured with traditional RF/microwave processes, a 60-deg. phase-shifter hybrid for operation at personal-communications-services (PCS) frequencies from 1.9 to 2.1 GHz costs approximately $800. A comparable Surfpac phase shifter costs about $50, and delivers the same level of performance. The Surfpac phase shifter measures only 1.5 × 1.0 × 0.375 in. (3.81 × 2.54 × 0.9525 cm) versus 3.0 × 2.0 × 1.5 in. (1.62 × 5.08 × 3.81 cm) for the hybrid counterpart. The weight of the Surfpac phase shifter is also reduced, from 11 oz. for the hybrid to less than 2 oz. for the Surfpac model.

KDI/triangle's passive products include attenuators [including fixed, chip, programmable and voltage variable attenuators (VVAs)], bias tees, couplers, power combiners/dividers, and detectors. Other products include filters, duplexers, limiters, phase shifters, resistors, terminations, switches, ferrite circulators, and isolators. Active components include upconverters, downconverters, modulators, and small-signal amplifiers. The company also manufactures subsystems. They consist of combinations of active and passive components configured as receiver front ends, embedded cellular base-station diagnostic switch-divider-coupler matrices with microprocessor functions, and divider-amplifier-filter subsystems for cellular base stations. Other subsystems include upconverters and downconverters, and linearized VVAs with amplifiers, switches, and phase shifters.

The KDI/triangle site offers a series of practical application notes. They include a thermal-resistivity table to simplify temperature calculations, information on a 50-Ω chip-resistor termination for narrowband impedance matching, and a review of power terminations for microstrip and stripline applications. Other application notes cover soldering surface-mount packages and installation details, as well as a review of resistor technology assessed at microwave frequencies. Technical overviews include analog and digital attenuators, resistors, and their use as terminations, couplers, and power dividers.

For example, clicking on the application note entitled "Resistor technology assessed at microwave frequencies" yields three pages of literature with useful details on analyzing and specifying resistive films and systems. Equations are included for calculating the resistance of a film and the resistivity of a material. Background information is provided on different high-frequency resistor types, including carbon (C)-film resistors, nickel (Ni)-chrome resistors deposited by vacuum evaporation or sputtering, and tantalum (Ta) resistors formed by sputtering. ●

For more information on the company's product lines or application notes, please contact:

KDI/triangle Corp., 60 South Jefferson Rd., Whippany, NJ 07981; (973) 887-5700, (973) 887-8100, FAX: (973) 884-0445, e-mail: sales@kditriangle.com.

Internet:
http://www.kditriangle.com.

Website Offers Free Tutorial On DSP

For those interested in an outstanding introduction to digital-signal-processing (DSP) techniques, this site provides several excellent teaching tools.

ALAN "PETE" CONRAD
Special Projects Editor

Digital-signal-processing (DSP) microcontrollers continue to gain in speed and drop in price. Thus, DSP techniques are increasingly used in modern electronic systems, especially in communications. While DSP concepts can be daunting, a superb site run by BORES Signal Processing (Fordwater, Pond Road, Woking, Surrey GU22 0JZ, England) offers an easy-to-follow training course on DSP and its application in modern systems.

BORES Signal Processing specializes in a variety of bus-based products, including support for personal-computer (PC), PCI, PCMCIA, PC/104, Sbus, VME, and SCSI buses. The firm's products are suitable for speech, audio, and telecommunications applications.

Through their website at http://www.bores.com, the company also offers a series of application and product-specific on-line training courses for nominal fees. The courses consist of practical how-to techniques that include substantial real-world hardware applications of their products. The United Kingdom's engineering society, The Institute of Electrical Engineers (IEE), approves the training courses under their program guidelines for continuing professional development.

In addition to their line of hardware products, the company offers and supports a digital filter-design and analysis software package called QWDesign. The software is available for PCs operating under DOS or Windows environments as well as for Macintosh computers and workstations running the Xwindows/Motif operating system.

The QEDesign package helps a user design all popular types of digital filter in finite-impulse-response (FIR) and infinite-impulse-response (IIR) implementations. QEDesign uses special mathematical methods to arrive at the best solution, taking into account the finite precision of DSP data formats and arithmetic. A companion program, DSPworks, enables an operator to test a filter design against real or simulated signals while working with the actual hardware (if available). The software programs produce ASCII files of filter coefficients. Advanced versions are available with optional code generators that produce complete DSP assembly-language programs. The QEDesign software is manufactured by Momentum Data Systems (Costa Mesa, CA).

Perhaps the highlight of the BORES website is a powerful DSP tutorial course available for on-line viewing and study. Topics include a basic explanation of DSP, the basics of sampling, aliasing, reconstruction and quantization, time-domain processing, as well as correlation and convolution. Other topics include frequency analysis, Fourier transforms, frequency resolution, as well as spectral leakage and windowing. Also included are tutorials reviewing FIR and IIR filters, including design, realization, and quantization effects. A separate module covers correlation techniques, autocorrelation techniques (for extracting a signal from noise), cross-correlation techniques (for identifying unknown signals or locating a known signal), and convolution methods. Also covered are Fourier transforms, convolution in the frequency domain, short-time Fourier transforms, frequency leakage, and other transforms.

The site includes a module that reviews IIR filter equations, frequency response, the Z transform, the meaning of Z, and filter poles and zeroes. Also included are IIR filter design by impulse invariance, IIR filter design by the bilinear transform, direct form I and II filters, quantization in IIR filters, and IIR filter implementation and structures.

For more information on the DSP educational courses, or data on the company's line of bus products, please contact: BORES Signal Processing, Fordwater, Pond Rd., Woking, Surrey GU22 0JZ, England; (44) (0)1483 740138, FAX: (44) (0)1483 740136.
Internet: http://www.bores.com.

Testing mixers for group delay

Vector network analyzers (VNAs) are often used to analyze the group-delay performance of linear networks. Group-delay testing is an effective means of checking a device's phase linearity. While it can be difficult to evaluate the group delay of a nonlinear component where frequency translation takes place, such as a mixer, the VNA is still the measurement tool of choice. An application note from Hewlett-Packard Co., "Use the time domain option of the HP 8510C and HP 8720ES vector network analyzers," explains how.

The time-domain option on a VNA can be used to measure the group delay through a mixer. The technique involves an additional mixer. The test method uses the measured reflection coefficient from a single mixer that is terminated in a 50-Ω airline and a short circuit. The measured frequency response of the mixer is transformed into an impulse response using the time-domain option. By knowing the absolute delay of the airline, the absolute delay through the mixer can be calculated by examining the two-way reflection from the short in the time domain. In addition, the delay linearity of the mixer as a function of frequency can be measured using the vector analyzer's time-domain gating functions. Gating can be used to filter the effects of reflections internal to the mixer, isolating only the transmitted signal through the mixer. The gated signal contains the delay distortion introduced by the frequency-translation process.

The application note provides the example of the intermediate-frequency (IF) port of a broadband mixer measured with a VNA as a function of frequency. The mixer's RF port is terminated with an airline and a short. In this case, the 50-Ω airline is placed between the mixer and the short to electrically separate the reflections and improve the measurement resolution in the time domain.

The application note is included in the October 1999 (Vol. 10, No. 2) edition of the company newsletter, *HP 8510/8720 News*, which also includes notes on using computer-aided-engineering (CAE) software with a VNA to de-embed the electrical parameters of a test fixture, and how a great deal of measurement flexibility is possible with a mixer-based test set for a VNA. Copies of the newsletter are free upon request from: **Hewlett-Packard Co., Test and Measurement Call Center, P.O. Box 4026, Englewood, CO 80155-4026; (800) 452-4844, Internet: http://www.hp.com/go/8510-8720news.**

CIRCLE NO. 194 or visit www.mwrf.com

Understanding the operation of low-distortion amplifiers

Low-distortion, DC-coupled amplifiers can serve a variety of RF applications, including as cable drivers, in automatic-test-equipment (ATE) systems, in arbitrary waveform generators, and as surface-acoustic-wave (SAW) resonator drivers. An example of such an amplifier is the KH561 driver amplifier from KOTA Microcircuits (Loveland, CO). The amplifier, which features a 150-MHz 3-dB bandwidth with +24-dBm output power, achieves second- and third-order distortion of only –59 and –62 dBc, respectively. The internal-current-limiting design provides good stability even when driving capacitive loads. The company's combination data sheet and application note, "KH561 Wideband, Low Distortion Driver Amplifiers," offers a wealth of information on the amplifier and its theory of operation.

The application note explains that the KH561 has the appearance of a classic operational amplifier, with several key differences. For one, the error signal is a current into the amplifier's inverting input (current feedback) and the forward gain from this current to the output is relatively low but well-controlled. The amplifier is designed for low internal gain and current-mode output in order that an equivalent output impedance can be achieved without a series-matching resistor.

The application note provides design equations for determining the various components needed with the KH561. It also explains the use of an external compensation capacitor for maintaining optimum gain at different settings and load conditions. The note also details how to calculate the performance accuracy for the KH561 under different voltage and load conditions, along with guidelines for thermal analysis and protection. Copies of the application note are free from: **KOTA Microcircuits, Inc., 1215 South Grant Ave., Loveland, CO 80537; (877) 667-7373, (970) 667-7373, Internet: http://www.kotamicro.com.**

CIRCLE NO. 195 or visit www.mwrf.com

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COVER FEATURE

Company's Rebirth Includes Major EDA Software Release

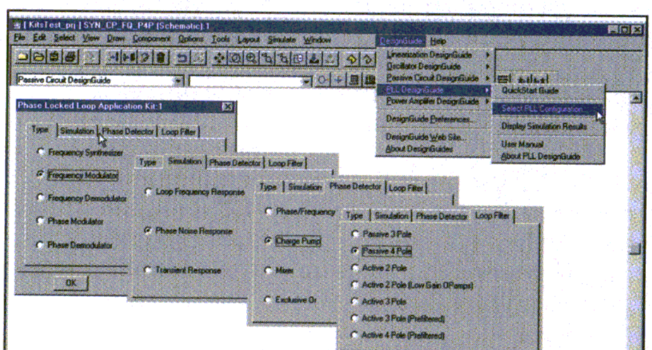
A series of applications-based personalities has been developed to simplify the use of a comprehensive suite of EDA software tools.

Daren McClearnon
Technical Consultant
Agilent Technologies, 1400 Fountaingrove Pkwy., M/S 2US-P, Santa Rosa, CA 95403; (404) 891-6461, FAX: (707) 577-5260, Internet: http://www.agilent.com/eesof-eda.

RENAISSANCE might be the most-fitting name to describe the new Agilent Technologies (Santa Clara, CA) and the company's first product launch, Version 1.3 of the Advanced Design System (ADS) software suite. Born of Hewlett-Packard's test and measurement, medical, and component groups, Agilent Technologies is a subsidiary of Hewlett-Packard with a focus on electronic solutions for emerging technologies, such as wireless communications. From a key part of the new company, the Agilent EEsof Electronic Design Automation (EDA) organization, comes an easier-to-use version of the powerful ADS software.

On November 1, 1999, the original core business of Hewlett-Packard that centers on test and measurement was separated from the computers and imaging businesses to become a new subsidiary called Agilent Technologies. Agilent EEsof EDA, formerly the HP EEsof Division of Hewlett-Packard, is rolling out a significant new wave of software and knowledge products based on its Advanced Design System product platform. Agilent has begun to target designers in specific applications, putting focused capability on their desktops to move beyond limitations of older generation design products of all vendors—HP EEsof included. In some cases, these represent new categories of products. The goal of the new software products is accelerated design cycle times using smarter tools that are easier to use.

Agilent EEsof EDA has continually invested in improved simulators, libraries, platforms, etc. for many years. As new software technologies have been added to meet the demands of today's applications, methods for dealing with the corresponding complexity have arisen as well. Application personalities and design libraries, automation features, and application training are all ways to deal with a number of trends taking place in the high-frequency industry. These trends include the use of the software for a wider range of applications, the complexity of designs ever increasing, and entry of many new engineers to the field of high-frequency design.



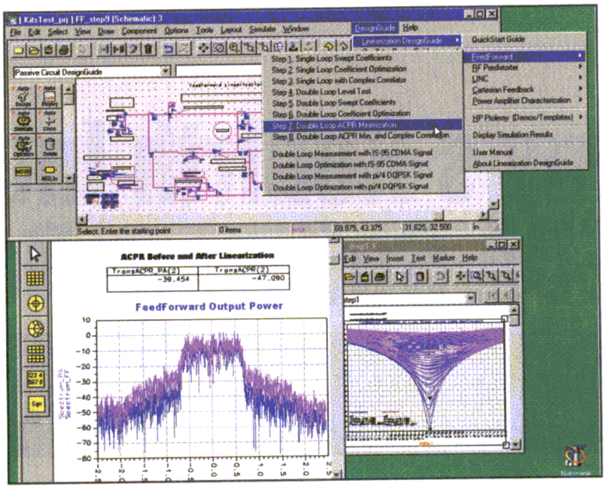
1. The PLL DesignGuide has preconfigured schematic diagrams, simulations, and plot types for several PLL topologies and analysis techniques.

To note the changing face of high-frequency design, one need look no further than the instruments used to measure performance in the research and development (R&D) environment. Although a vector network analyzer (VNA) is a valuable piece of any RF/wireless design laboratory, most laboratories equipped for evaluating modern high-speed, digitally-modulated electronics also use a complex-modulation signal generator, vector signal analyzer (VSA), an oscilloscope or logic analyzer, a modulation-domain analyzer, and a host of peripheral devices.

Design software has evolved as well. Years ago, S-parameter simulators were the primary design tools. Today, the ADS suite offers software equivalents to VSAs, signal generators, logic analyzers, and much more. The irony is that design software enables one to access the equivalent of approximately two dozen instruments, a bookshelf of paper manuals and application notes, an environmental chamber, corporate parts libraries, etc.—all through a single interface. While this level of sophistication is unexpected from a single test instrument, it is possible with a single suite of software tools, such as ADS.

Most designers explore a distinct "path" through the software's features in early use, then stay within that path for future design tasks. Agilent Technologies is working hard to make that path through the ADS suite of tools fast and effective, even when the software may only be used sporadically. Some of the steps being taken to make the ADS easier to use include:

• An application layer is being developed on top of the basic ADS platform to help designers do certain tasks quickly. This application layer is being created largely by third-party partners and consultants with specialized areas of expertise. These partners embed their design knowledge into a wizard-like interface and preconfigured templates in ADS, effectively delivering their experience and intellectual property (IP) using the ADS platform. Each modular bundle of IP is called a "DesignGuide."



2. Experience and knowledge can help accelerate the design of a linearizer. The latest version of ADS enables operators to experiment with potential designs.

SIZING UP THE IMPROVEMENTS IN ADS

New features for Version 1.3 include:

•Real-timing tuning of circuit elements in Tune Mode.

• Quick calculation of transmission-line parameters with LineCalc.

• The availability of TrueType fonts for professional report appearance and readability.

• New printing and metafile capabilities.

• Advanced synthesis capabilities with E-Syn.

• Numerous data-display enhancements, such as zooming the scale on a plot with a mouse, and dual Y-axis scales.

• A new navigational utility for documentation and continually updated manuals available on the Internet.

• The capability to generate phase-noise for all harmonic-balance modes, not only for the oscillator design mode.

• The capability to perform noise analyses at multiple frequencies and multiple nodes in a single harmonic-balance simulation.

•The inclusion of analog BER for QPSK and $\pi/4$ DQPSK, along with contour plots and capability for performing third-order-intercept budget analysis.

• Three-dimensional visualization capability for the planar electromagnetic (EM) simulator Momentum.

• The capability to export Momentum layout and substrate information to the three-dimensional EM simulator HP HFSS.

• Robust SPICE import capability specifically for RF IC processes (many enhancements relative to Version 1.1 of ADS).

• The inclusion of yield-sensitivity histograms.

• Capability for platform-independent HPIB instrument control through a local-area-network (LAN gateway).

• The inclusion of parameterized, silk-screenable fonts in the layout mode.

• An enhanced bill of materials for surface-mount-technology (SMT) designs.

• Digital Filter Tool extensions for synthesizing wireless and user-defined digital-signal-processing (DSP) filter types.

• New DSP HDL synthesis libraries in support of Xylinx, Altera, and other device suppliers.

In addition, optional capabilities based on ADS 1.3 platform are:

• DesignGuides.

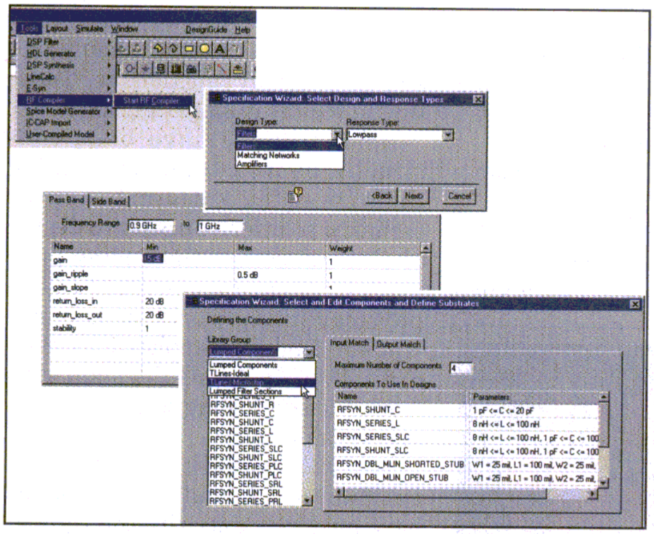
•DesignLibraries for wideband code-division multiple access (WCDMA), IS-95, Global System for Mobile Communications (GSM), and cdma2000.

• RF Compiler synthesis.

• DesignSeminars.

•Optimization capability for Momentum.

• The Circuit Encoder provides encryption capability for integrated-circuit (IC) vendors to supply detailed physical models to end-users for accurate simulation, but without revealing the IC vendor's intellectual property (IP).

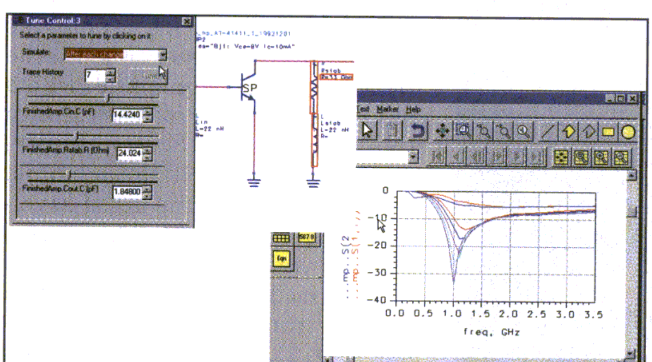


3. RF Compiler adapts circuit topologies within constraints to meet performance specifications.

• Some of ADS's classic analysis and synthesis capabilities, such as Esyn, LineCalc, and Tune Mode, have been ported and extended. These are woven into the design environment so that the result of using one of these tools is an operational schematic, ready to use (see sidebar).

• The RF Compiler within ADS offers new capabilities to speed the design of certain circuits. The RF Compiler can be used to synthesize new amplifier designs and matching networks using (effectively) constrained topology optimization. Whereas traditional synthesis tools are direct implementations of specific network theory and algorithms, the RF Compiler can deal with real-world trade-offs, such as return loss versus stability versus gain for a particular commercial transistor.

• Custom design libraries have been developed for wireless standards, for use in system/RF analog cosimulations. These libraries add new component primitives (models and functions) for generating signals, measuring results, and implementing various architectures in wideband code-division-multiple-access (WCDMA), Global System for Mobile Communications (GSM), IS-95, and cdma2000 interfaces, with more to come.



4. Tune mode gives designers a real-time understanding of complex sensitivities and interactions that is difficult to learn from hardware prototypes.

• In order to support the need for greater education, a curriculum of application-oriented short courses is being organized on a worldwide basis to improve customers' design skills. These "DesignSeminars" are being delivered by experts from industry as well as academia on such topics as amplifier linearization and mixer design.

In more detail, the DesignGuides are add-on personalities to the standard ADS environment that enable an operator perform one of three main categories of tasks:

• Guide the user visually through a complex, multistep design flow.

• Automate the synthesis/implementation of a circuit, based on key physical as well as performance specifications.

• Automate the setup, simulation, and data-display functions to visualize the results in single keystrokes.

DesignGuides have been constructed by industry experts, using the ADS as the platform to deliver technical solutions directly to design engineers, rather than using pure math engines unconnected to the physical/analog world, or in hand-crafted standalone applications. Several of the DesignGuides authors work outside the Agilent Technologies organization.

To date, approximately 20 different individuals and organizations have been working with the Agilent EEsof EDA applications group to deliver intellectual property on ADS in the form of a DesignGuide. The first five DesignGuides are complete and are currently available, with new DesignGuides available throughout the coming year. DesignGuides include the model E5610A passive circuit DesignGuide (for such circuits as filters and couplers), the model E5611A power-amplifier (PA) DesignGuide, the model E5612A oscillator DesignGuide, the model E5613A phase-locked-loop (PLL) DesignGuide, and the model E5614A linearization DesignGuide. Each DesignGuide leverages the knowledge of industry experts to save ADS users time in developing their own designs. This is of compelling importance to workgroups with new designers and infrequent users of design software.

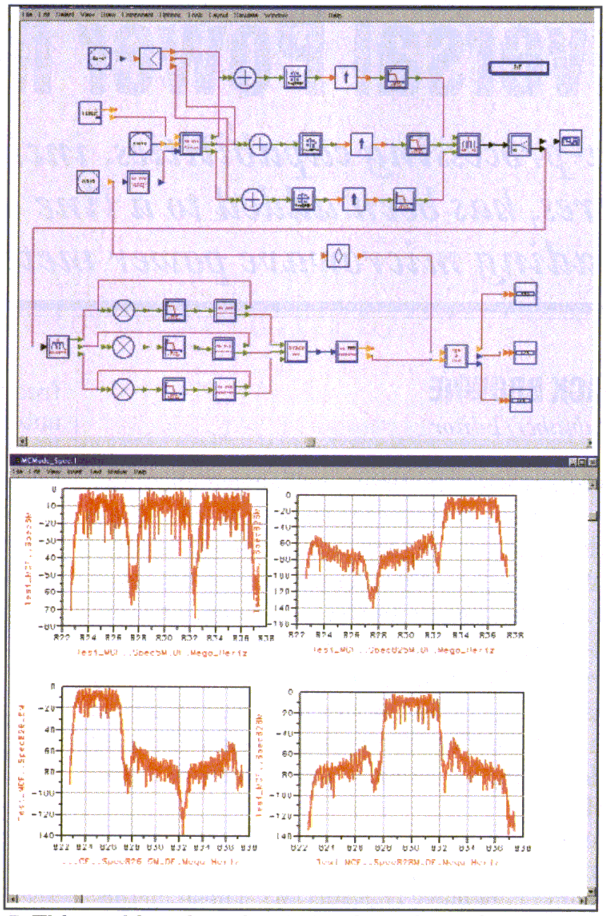
As an example, the PLL DesignGuide has preconfigured schematic diagrams, simulations, and plot types for several PLL topologies and analysis techniques (Fig. 1). The linearization DesignGuide, which was developed by Professor Shawn Stapleton of Simon Fraser University Vancouver, British Columbia, Canada), can save time in the development of a feedforward linearizer. The software enables examination of potential design approaches, even if a final transistor is not yet available (Fig. 2). (Detailed information on each of Agilent EEsof EDA's DesignGuides can be found on the Agilent Technologies website at http://www.agilent.com/find/eesofeda.)

Each DesignGuide includes a certain amount of synthesis capability, but from an application perspective. There are also more direct-synthesis tools that create working designs and back-annotate the results into the ADS schematic environment.

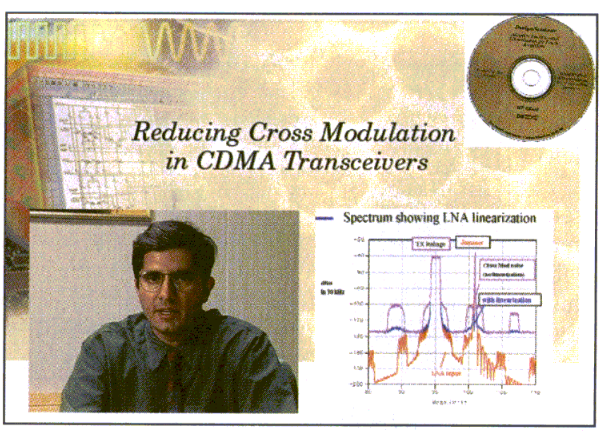
One of the most exciting new technologies contained within Version 1.3 of the ADS suite is the RF Compiler (revealed publicly at the Microwave Theories & Techniques Conference, Anaheim, CA, June 1999). RF Compiler (Fig. 3) targets linear-amplifier design in its first release. The designer enters key performance specifications such as match, gain, stability, and so on. A topological category (e.g., a two-stage amplifier) is selected, then a vocabulary of components (resistors, inductors, capacitors, microstrip lines, stubs, etc., within settable ranges) is specified. The RF Compiler then experiments with different shunt and series arrangements of the components using a genetic optimization algorithm, eventually finding a topology and a set of component values that best matches the performance criteria. The design is based on the designer's transistor and guarantees that the component values can be implemented in the real world (i.e., not based on unrealistic values of capacitance or inductance, such as femtofarads or picohenries, respectively). Future enhancements to RF Compiler will add application breadth and depth.

Esyn is a more traditional synthesis program for filter and matching network synthesis, using canonical topologies such as Butterworth and Bessel-Thomson configurations. Designers can specify frequency-response characteristics, then they can choose from a variety of synthesized alternatives for suitability to an application. Esyn back-annotates ADS schematics with ready-to-use synthesized networks. The software, which should be familiar to users of Series IV software suite tools, is oriented toward lumped matching networks and filters, but it does have some transmission-line capability.

Also familiar to Series IV users will be the contour plots, third-order-intercept-budget capability, yield histograms, Momentum visualization, LineCalc, and tune mode features of Version 1.3 of the ADS software. Tune mode (Fig. 4) benefits from the fact that ADS simulators remain in a computer's random-access memory (RAM) after the end of a simulation. This enables the user to move slider bars to update component values and watch the response traces moving in real-time. Any numeric parameter can be tuned, and any plot can be updated, even complex contour maps and high-level results such as adjacent-channel power ratio (ACPR) and error vector magnitude (EVM).



5. This multicarrier cdma2000 signal in ADS can be sent to an arbitrary signal generator to stimulate a real device. Conversely, such signals can be captured on a VSA for use as stimuli in the ADS software.



6. DesignSeminars are focused, practical application training to help designers improve their engineering skills. Pictured is Rishi Mohindra delivering a DesignSeminar on cross modulation.

DESIGN LIBRARIES

Given Agilent Technologies' activities as a leader in wireless test equipment, the company is keenly aware of emerging standards and design architectures. The firm has leveraged this application knowledge for users of ADS to gain early access to the wireless standards for system partitioning and design using the ADS suite of software tools. "Design Libraries" include new custom functional blocks, simulation setups and measurements, signal sources, and much more to customize the basic ADS system/RF simulation engines for WCDMA, IS-95, GSM, and cdma2000 (Fig. 5).

Because ADS is unique in its ability to cosimulate in real time between the DSP and analog hardware and impairments, it is possible to simulate the "bits-to-bits" response with actual, nonlinear error-correction schemes recovering data that has passed through analog amplifiers,

(continued on page 188)

Analysis Power Added To Universal Power Meters

A variety of data-processing capabilities, including histogram and CDF features, has been added to a line of peak/average-reading microwave power meters.

JACK BROWNE
Publisher/Editor

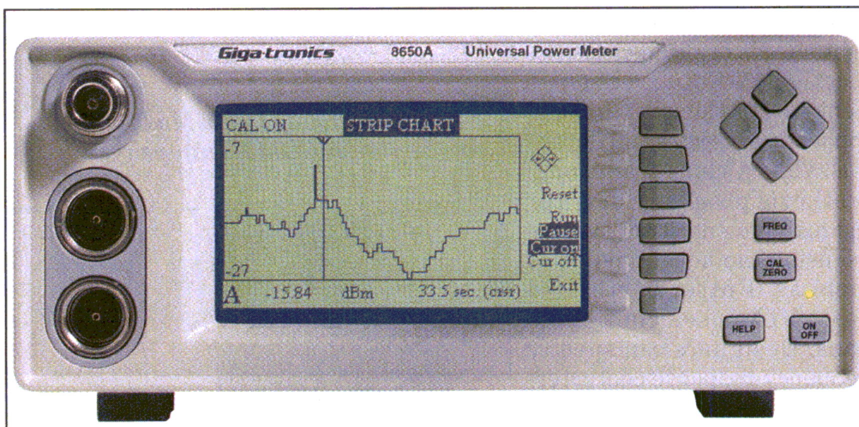
MEASUREMENT tools adapt with the times, or become obsolete. The 8650A series universal power meters from Giga-tronics (San Ramon, CA) are in the former category, adding powerful new analysis capabilities that significantly enhance the usefulness of these microwave peak- and average-reading power meters. Functional enhancements include histogram analysis, cumulative-distribution-function (CDF) analysis, complementary-cumulative-distribution-function (CCDF) analysis, and strip-chart functions. The 8650A series of power meters is available in single- and dual-channel versions for measurements of power levels from −70 to +47 dBm (depending on choice of power sensor) at frequencies from 10 MHz to 40 GHz.

The 8650A series of power meters (Fig. 1) is already widely used in the amplitude characterization of complex modulated signals, such as the time-division-multiple-access (TDMA) and code-division-multiple-access (CDMA) formats commonly used in second-generation (2G) digital-cellular communications systems. They already contain a host of features that aid in the measurement of peak and average power levels for the changing-amplitude signals of cellular and personal-communications-services (PCS) networks.

Numerous diode-based power sensors are available for the 8650A meters, including a line of sensors with 10-MHz video bandwidth for evaluation of next-generation wideband cellular signals. The sensors incorporate a patented power-sweep calibration system to overcome the accuracy limitations of diode sensors operating outside of their predictable square-law region. Each sensor relies on calibration factors stored in its own electronically erasable programmable read-only memory (EEPROM). These factors are transferred to the power meter when the sensor is connected, and the meter automatically reads a new set of calibration factors when a sensor is changed. When a measurement frequency is keyed into the meter, it automatically calls up the precise calibration factor for the frequency or, for an entered frequency that falls between calibration frequencies, interpolates a value appropriate to that frequency.

Using a burst-average-power (BAP) mode, the meters can automatically measure the average power of pulsed signals that are amplitude modulated during the pulse on period (as in TDMA bursts). The average power reading of a burst pulse is measured between 3-dB points. Even if the duty cycle changes in time, it does not affect the accuracy of the meter reading, and eliminates the need to manually set time gating for burst measurements.

A time-gating feature in the 8650A meters enables users to program specific start and stop times for a

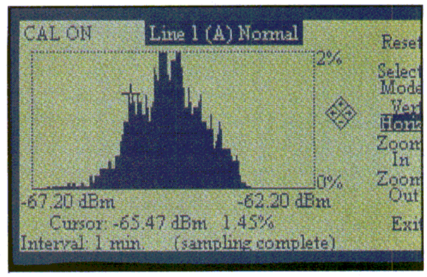


1. The 8650A series of universal power meters provides peak- and average-power measurements from 10 MHz to 40 GHz with a number of new analysis capabilities.

measurement, to measure average power during specific time periods of a burst signal. In addition, a built-in delay line makes it possible to trigger measurements on a pulse a few nanoseconds ahead of the pulse's leading edge. A built-in timebase provides delays to 100 ms.

A peak-hold function displays the highest instantaneous power level measured during the time period that the function is activated. The display value tracks the measured value only when it is rising to a new maximum, but holds at the established maximum value when the measured value is falling.

The histogram function (Fig. 2) is one of several new capabilities for the 8650A power meters. It enables an operator to examine a power-range distribution over a specified time period. The minimum to maximum power levels measured during the time period are shown in the x-axis, while the percent of time each power level is measured is shown in the y-axis. Resolution can be improved by using a zoom function. The histogram function can be used together with measurements of crest factor and average mean power to determine optimum design criteria for key wireless components.



2. This screen shot shows a typical histogram display. The cursor can provide precise information about a particular data point.

The CDF enables an operator to display the percentage of time that a signal falls below a specified power level. The x-axis shows the amount of power at the selected level while the y-axis shows the percentage of time that the power is at or below the threshold level. A cursor can be moved along the CDF curve to show the power and corresponding percentage of time for a particular data point. The CCDF feature reorients a CDF curve in accordance with the relationship CCDF = 1 − CDF in order to show a descending slope.

The new strip-chart capability enables an operator to view a signal's varying power levels over a period of time. The x-axis displays time from the start of a measurement to a selected period of 1 to 200 minutes, while the y-axis shows the minimum to maximum power levels measured during the selected period. P&A: $3310 (single-channel model) and $4870 (dual-channel model); 30 days. **Giga-tronics, Inc., 4650 Norris Canyon Rd., San Ramon, CA 94583; (925) 328-4650, FAX: (925) 328-4700, Internet: http://www.gigatronics.com.**

CIRCLE NO. 52 or visit www.mwrf.com

Switched Filter Channelizer Enhances Receiver Performance

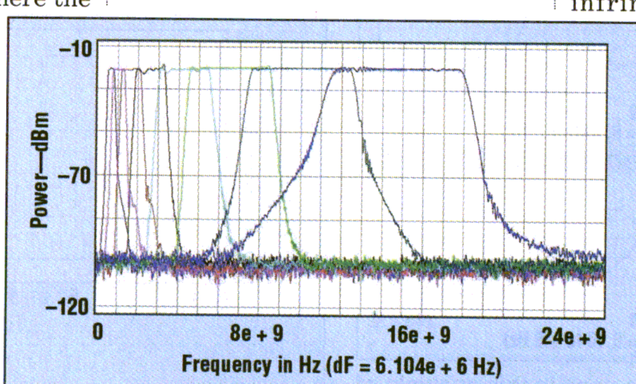
This eight-channel subsystem offers overlapping passbands to reduce harmonics and mixer spurious responses while maintaining pulsed signal fidelity.

Floyd Parin
President
Microwave & Video Systems, Inc., 87B Sandpit Rd., Danbury, CT 06810; (203) 792-7474, FAX: (203) 792-7475, Internet: http://mvsmicro@worldnet.att.net.

ALAN "PETE" CONRAD
Special Projects Editor

SWITCHED filter channelizers (SFC) are used in most broadband superheterodyne receivers. They divide the RF signal bandwidth of interest into a single channel of less than one octave. The bandwidth reduction reduces the probability of unwanted spurious and harmonic responses from appearing at the frequency-converter output. In addition, SFC systems designed with overlapping adjacent-filter bandwidths can eliminate the processing of signals distorted by the band-edge response of filters. The MFA 5005 eight-channel switched filter bank from Microwave & Video Systems, Inc. (MVS) [Danbury, CT] is an example of this type of subsystem. It operates from 0.5 to 18 GHz in eight bands with an input/output (I/O) VSWR of less than 2.0:1 and minimum switching speed of 200 ns.

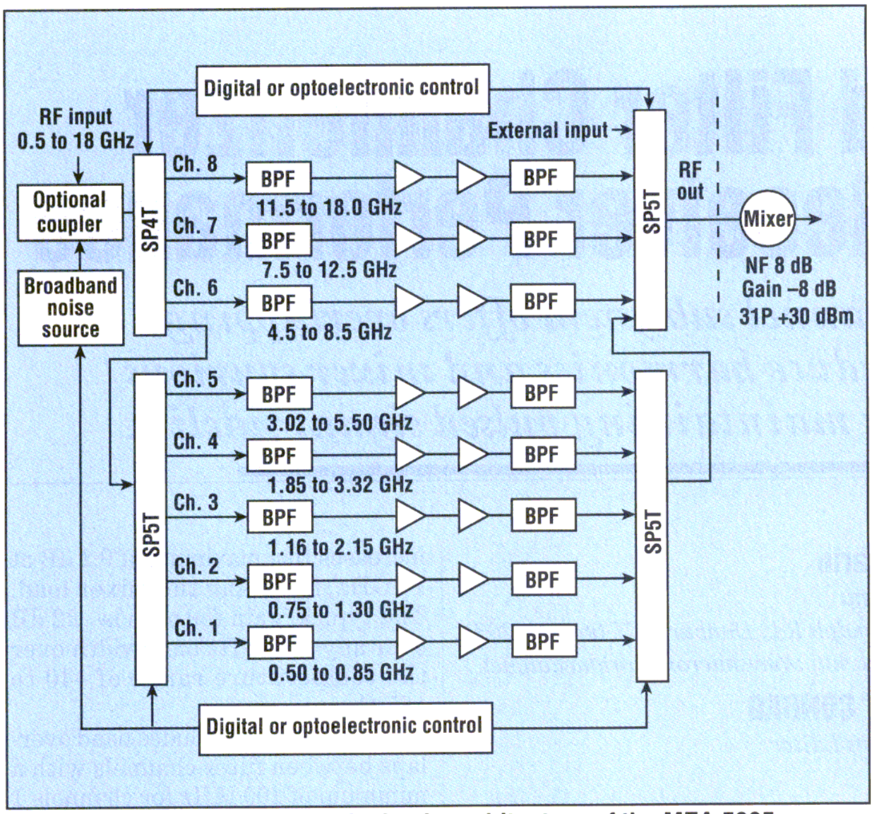
The MFA 5005's custom architecture (Fig. 1) uses five of the eight channels to partition the frequency range from 0.5 to 5.0 GHz where the signal density is greatest. The remaining three channels partition the frequency range from 4.5 to 18 GHz into three bands. Each channel is filtered at the input and output to reduce ambient harmonic-related signals and amplifier-generated second-harmonic responses to a minimum level of –45 dBc measured at the load output. The MFA 5005 incorporates low-noise monolithic-microwave-integrated-circuit (MMIC) amplifiers to achieve a typical noise figure of 7 dB at 2 GHz. The noise figure of these low-noise amplifiers (LNAs) increases to a maximum of 9.2 dB at 18 GHz, including the mixer load. The typical gain flatness is ±2 dB over any 350-MHz bandwidth over the temperature range of –40 to +85°C.



1. The eight-channel spectral response of the MFA 5005 reveals the frequency overlap of adjacent bands and individual channel bandwidths.

The MFA 5005 includes band overlaps between filter channels with a minimum of 100 MHz for channels 1 and 2, increasing to a maximum of 1 GHz for channels 6, 7, and 8. This important feature eliminates the distortion that occurs due to pulsed signals infringing on the skirts of bandpass filters typically found in SFC designs that specify 1-to-3-dB filter crossover frequencies. Filter overlap can be customized to meet specific requirements (Fig. 2).

While the MFA 5005 SFC is typically used to attenuate unwanted spurious and harmonic signals, care should be taken with pulsed signals to avoid distortion. Pulsed-signal distortion is typically caused by signals infringing on the crossover frequency bands of adjacent SFC channels. Fortunately, system-level computer-aided-engineering (CAE) software tools such as SystemView from Elanix, Inc. (Westlake Village, CA) can be used to model SFCs, such as the MFA 5005, in order to minimize pulsed-signal distortion. The software was used to analyze a pair of bandpass filters with 1-dB crossover overlap at 12 GHz. The filters were designed for passbands of 8 to 12 GHz and



2. This block diagram shows the basic architecture of the MFA 5005 switched filter channelizer. It can be equipped with digital or optical control.

12 to 18 GHz, respectively (Fig. 3). The software was also used to model the MFA 5005's channel 7, at 7.5 to 12.5 GHz and channel 8, at 11.6 to 18.0 GHz (Fig. 4). The simulation illustrates the ±500-MHz frequency overlap between bands at 12 GHz. The band overlap prevents the effects of signal distortion by adjacent filters from simultaneously occurring in two channels. The MFA 5005 simulation shows the normalized detected pulse responses of the filter pairs with and without frequency overlap. The two red traces from left to right are the detected signal responses of the MFA 5005's filter bands seven and eight with a 1-GHz frequency overlap.

Traces three and four from the left is the detected pulse response of the filter channels without frequency overlap. The third trace is the distorted response of a filter being excited 6 dB down the edge of the filter response. Sharp transitions at the leading and trailing edge of the detected signal is often mistaken as a valid signal. The fourth trace is the response of the second filter close to its crossover frequency. It also shows signs of distortion at the trailing-band edge.

Options for the MFA 5005 include an internal noise source coupled to the input. The noise source, which is manufactured by Micronetics, Inc. (Hudson, NH), supplies built-in-test (BIT) signals for each channel and can also be used as a source of calibration signals. Additional options include optoelectronic (OE) band switching, which is especially useful when the MFA 5005 is operating in environments with high electromagnetic interference (EMI). The OE control eliminates control signal corruption that could be encountered with twisted-pair shielded-wire control lines.

In addition to the MFA 5005 switched filter channelizer, the firm offers several additional switched filter assemblies, with 6- and 10-channel configurations, as well as single-pole, double-throw (SPDT) switches; single-pole, four-throw (SP4T) switches; and single-pole, eight-throw (SP8T) switches. **Microwave & Video Systems, Inc., 87B Sandpit Rd., Danbury, CT 06810; (203) 792-7474, FAX: (203) 792-7475, e-mail: mvsmicro @worldnet.att.net, Internet: http://www.micronetics.com.**

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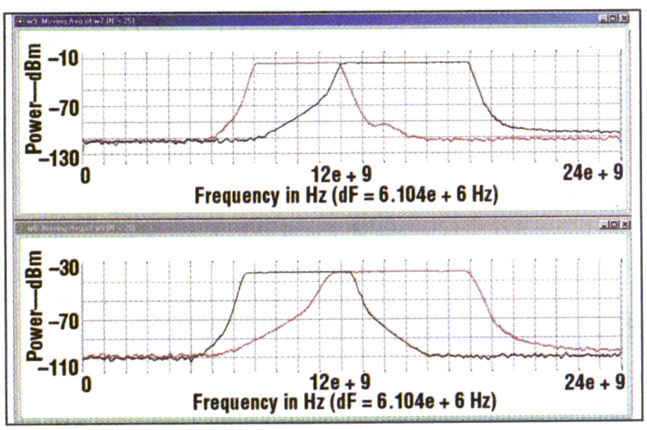
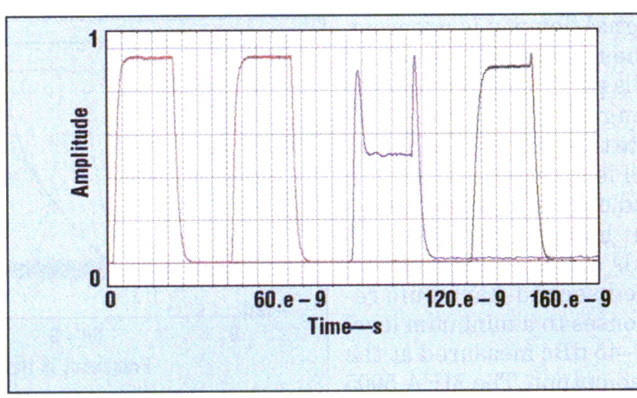


3. The SystemView software was used in this analysis of two bandpass filters covering the frequency bands of 8 to 12 GHz and 12 to 18 GHz with 1-dB crossovers at 12 GHz.



4. The software was used to simulate the MFA 5005's channel 7, at 7.5 to 12.5 GHz and channel 8, at 11.6 to 18.0 GHz.

Optical Transceivers Transport Multiple Carriers

This pair of transceivers multiplexes four RF channels onto one fiber-optic cable between base station and antenna.

DON KELLER
Senior Editor

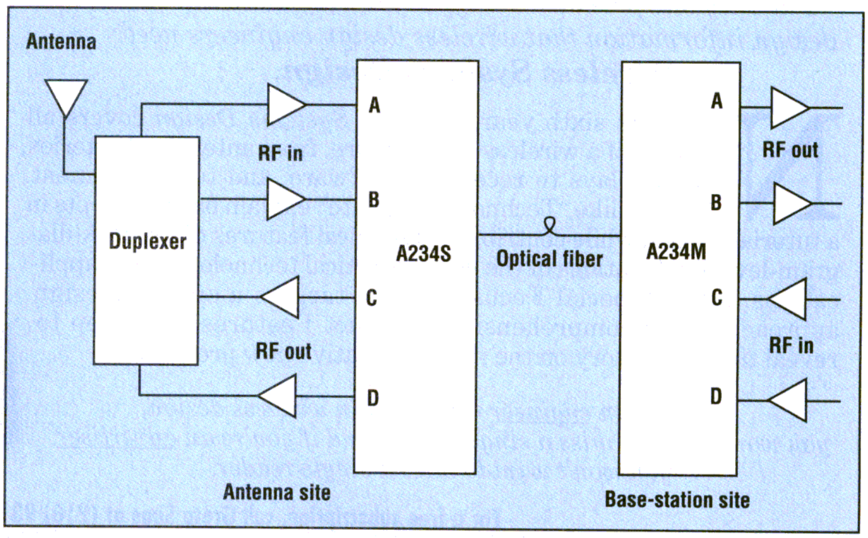
FIBER optics has grown to become a significant factor in the wireless revolution. This is mainly because fiber-optic cable is lighter, cheaper, and imposes much less signal loss than copper (Cu) coaxial cable. In a typical application, fiber-optic cables are used instead of coaxial cables to carry RF signals between a base station and its remote antenna. At each end of the fiber-optic cables, a transceiver converts the signals from RF to optical, and vice versa. For a bidirectional channel, this normally requires two cables. Two bidirectional channels would require four cables. But in some locations, fiber-optic cables are in short supply. In other locations, the base-station operator must lease the cables on a monthly basis. For these situations, Anacom Systems Corp. (New Brunswick, NJ) has developed a set of transceivers that multiplexes multiple RF signals so that they can be carried on a single optical cable.

The AC234 series transceivers multiplex four RF channels—two bidirectional channels—over one optical cable. The series consists of a set of two essentially identical transceivers, one for the base-station site (labeled M for "master") and one for its remote-antenna site (labeled S for "slave"). Each transceiver has two SMA RF-input connectors, two SMA RF-output connectors, and one FC/APC optical connector (Fig. 1). The M transceiver's RF-output connectors, and the corresponding RF-input connectors on the S transceiver, are labeled "A" and "B." The M transceiver's RF-input connectors and the S transceiver's RF-output connectors are labeled "C" and "D." To multiplex these four RF signals onto the optical cable, the transceivers use a variation of a method called wavelength-division multiplexing (WDM).

Conventional WDM enables two RF signals—call them "A" and "B"—to be multiplexed onto a single fiber-optic cable by modulating them onto different optical wavelengths. For example, the "A" RF signal going from the base station to the antenna would modulate a laser diode having a fixed wavelength of 1300 nm, while the "B" RF signal ranging from the antenna to the base station would modulate a laser diode that has a different fixed wavelength, perhaps 1500 nm. Anacom Systems has expanded on this concept and developed a proprietary variation of WDM that enables the AC234 transceivers to double the channel capacity from two RF channels to four.

DYNAMIC RANGE

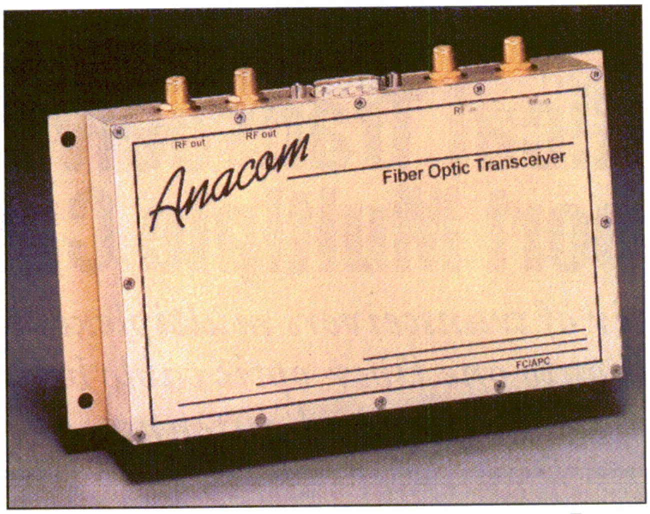
In each transceiver's transmitter section, each of the two RF downlink signals directly modulates the bias current of a separate laser diode. Internal optical feedback monitors the diode's bias quiescent point for maximum dynamic range. The transmit-



1. This block diagram shows the A234 in a typical base-station application.

ter can accept RF-input signals at power levels to +10 dBm. In the receiver section, a high-speed, indium-gallium-arsenide (InGaAs), positive-intrinsic-negative (PIN) photodiode detects the uplink signals, and the two RF signals are extracted. The receiver can accept optical power levels to 4 mW.

The system can carry RF signals at frequencies between 50 and 2200 MHz. Flatness over any 150-MHz band is >1.5 dB. Isolation between local RF ports is typically 50 dB, and separation (lack of crosstalk) between parallel channels is typically 40 dB. The minimum spurious-free dynamic range with 3-dB optical loss is 95 dB. Maximum output noise floor is −130 dBm/Hz. At personal-communications-services (PCS) frequencies between 1700 and 2200 MHz, the system offers a gain of 0 dB at an optical fiber length of 1 km, an output noise of −132 dBm/Hz, and a third-harmonic input intercept point (IIP3) of +25 dBm at 5 dBo. (Note that a decibel of optical loss, or dBo, is equal to two decibels of RF loss.)



2. This photo shows the transceiver's four SMA RF connectors and 9-pin D connector.

In addition to telecommunication-signal connectors, each transceiver has a 9-pin D connector (Fig. 2) and four light-emitting-diode (LED) indicators. The D connector is used to supply power to the transceiver, and to output system monitoring and alarm signals. The LEDs indicate the status of each RF channel. The transceivers require +12 VDC of power and can operate at temperatures from −30 to +75°C. Each transceiver measures 5.75 × 3.0 × 1.13 in. (146 × 76.2 × 28.6 mm) and weighs 0.6 lb. (0.27 kg). **Anacom Systems Corp., 100 Jersey Ave., Bldg. A, New Brunswick, NJ 08901; (732) 846-2680, FAX: (732) 846-2626, e-mail: techinfo@anacomsystems.com, Internet: http://www.anacomsystem.com.**

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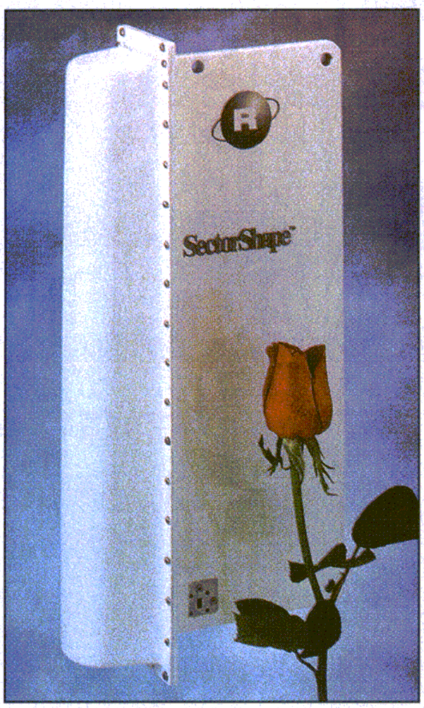
Electronically Shaped Antennas Link LMDS

Through extensive computer analysis and precise mechanical design, these antennas provide uniform radiation patterns for line-of-sight links from 24.5 to 32 GHz.

JACK BROWNE
Publisher/Editor

MILLIMETER-WAVE frequencies have long been attractive for communications applications. While millimeter-wave frequencies offer generous information bandwidths, the technologies to design and produce components at these frequencies have been expensive. But thanks to advances at REMEC Magnum (San Jose, CA), millimeter-wave frequencies are becoming more accessible for practical communications applications. The firm's SectorShape line of shaped-beam hub antennas is targeted at local-multipoint-distribution-system (LMDS) applications from 24.5 to 32 GHz.

The SectorShape LMDS antennas employ electronically controlled downtilt characteristics to simplify alignment. The antennas can be mounted straight up, without the need to mechanically achieve the proper downtilt angle. This simplifies integration with the LMDS hub electronics, and ensures uniform sector coverage since installers no longer must rely on precise mechanical mounting and adjustments.



The SectorShape hub-mounted LMDS antennas provide uniform coverage through a unique mechanical design and optimized electrical beam shaping.

SHAPED PATTERNS

The SectorShape antennas feature a unique mechanical design to achieve uniform dispersion of the antenna beam patterns. The vertical patterns are electronically shaped to remove nulls and provide uniform coverage as a function of range. The shaped azimuth patterns also ensure uniform sector coverage, with reduced spillover into adjacent cells. Through painstaking electromagnetic (EM)-field analysis, the engineering team at REMEC Magnum has developed what appears to be almost randomly shaped ridged reflectors for the antennas, in order to maintain precise symmetric antenna patterns over broad frequency ranges. The mathematical analysis was performed with the help of a method-of-moments (MOM) planar EM-field solver working in conjunction with the MATLAB mathematical-analysis software.

FLEXIBLE OPTIONS

In actual use, the beautifully intricate details of these antennas are covered by an ASA plastic radome (see figure). The antennas, which mate readily to telecommunications poles or to the electronics packages of LMDS outdoor units (ODUs), can be weather sealed and ultraviolet (UV) hardened. Models are available with horizontal or vertical polarization for various frequency bands within the 24.5-to-32-GHz range. Models can also be specified with azimuth beamwidths of 45 or 90 deg.

For example, model ALHH02285 is a SectorShape antenna designed for use from 27.5 to 29.5 GHz. Using linear horizontal polarization, the antenna achieves a 3-dB horizontal azimuth beamwidth of 45 deg. while controlling the 3-dB vertical beamwidth to only 2.4 deg. This model, which is also available with vertical polarization as the ALH02285, achieves 23-dBi gain with maximum VSWR of 1.50:1. Additional models cover frequency ranges of 24.5 to 26.5 GHz and 30 to 32 GHz (see table).

When a wider beam is needed, the same three basic frequency ranges are also available in models with vertical and horizontal polarization and 3-dB beamwidths of 90 deg. For example, model ALHH04285 uses linear horizontal polarization to achieve a 3-dB horizontal beamwidth of 90 deg. and 3-dB vertical beamwidth of 3.5 deg. The antenna, which is also available with vertical polarization as model ALHV04285, delivers 20.5-dB gain with a maximum VSWR of 1.50:1.

A sampling of 45-deg. azimuth-beam SectorShape LMDS antennas

Model	ALHH02310 (hort.) ALHV02310 (vert.)	ALHH02285 (hort.) ALHV02285 (vert.)	ALHH02255 (hort.) ALHV02255 (vert.)
Frequency range (GHz)	30 to 32	27.5 to 29.5	24.5 to 26.5
Polarization	Linear	Linear	Linear
Gain (dBi)	23.5	23	22.5
Vertical 3-dB beamwidth (deg.)	2.2	2.4	2.6
Horizontal 3-dB beamwidth (deg.)	45	45	45
VSWR	1.50:1 (max.)	1.50:1 (max.)	1.50:1 (max.)
Maximum input power (W)	60	60	60
Standard WG	WR-28	WR-28	WR-28

The SectorShape antennas are well-suited for use with millimeter-wave point-to-multipoint radios. The compact antennas measure 18 × 9.0 × 3.5 in. (457.2 × 228.6 × 88.9 mm) and weigh 5.5 lbs. (2.5 kg). All of the antennas are fitted with WR-28 waveguide flanges—all are rated for maximum input power of 60 W. The antennas feature an operating temperature range of −40 to +75°C, and are built to operate effectively in wind loads to 125 mph (200 km/h). **REMEC Magnum, 1990 Concourse Dr., San Jose, CA 95131; (408) 432-9898, FAX: (408) 432-1551, e-mail: sales@remecmagnum.com, Internet: http://www.remecmagnum.com.**

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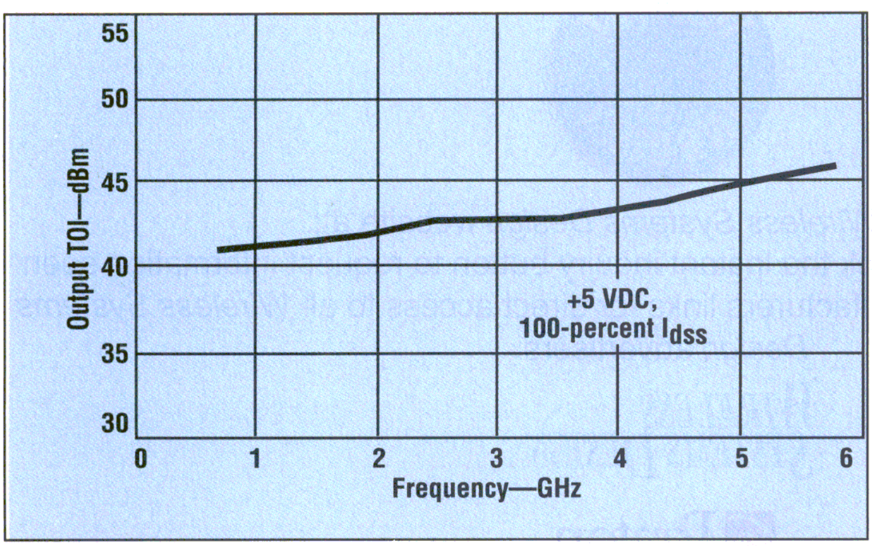
Linear Amps Drive Multichannel Systems

Based on a reliable GaAs MESFET process, these amplifiers offer high intercept points for low-distortion multichannel applications.

JACK BROWNE
Publisher/Editor

AMPLIFIERS are often accused of being a weak link in a wireless communications system. Without adequate dynamic range, an amplifier can compress and distort a carrier, especially when the signal employs complete digital modulation. One solution to the need for wireless system dynamic range is the AH4 and AH11 linear amplifiers from Watkins-Johnson Co. (Palo Alto, CA). The amplifiers provide linear medium-power performance through 6 GHz in tiny surface-mount packages.

The amplifiers are manufactured at the company's ISO9000-certified gallium-arsenide (GaAs) and thin-film facility (Milpitas, CA), leveraging a mature GaAs metal-semiconductor-field-effect-transistor (MESFET) process that delivers discrete and monolithic devices with long mean time to failure (MTTF). The AH11 builds on the company's earlier AH1 amplifier, with higher output power and greater dynamic range. The amplifier features 12-dB gain from 600 to 2100 MHz. Ideal for base-station receivers and broadband wireless distribution systems, the AH11 is designed for balanced and push-pull configurations. It achieves a third-order intercept point (IP3) of +44 dBm when used in a balanced configuration along with an IP3 of +47 dBm in a push-pull configuration.



1. The AH4 offers high-output third-order-intercept performance across its full operating band.

The AH11, which works with a single +5-VDC supply, delivers +26-dBm output power at 1-dB compression in either configuration. It provides 11.4-dB typical gain in a balanced configuration and 12-dB typical gain in a push-pull configuration, with 3.7-dB noise figure in a push-pull configuration and 4.2-dB noise figure in a balanced configuration. The amplifier has an operating temperature range of –40 to +85°C and typically draws 300-mA current in a balanced configuration and 600-mA current in a push-pull configuration, both at +5 VDC. Supplied in a low-cost thermally enhanced SOIC-8 surface-mount package, the AH11 amplifiers are 100-percent tested for RF performance.

The AH4 amplifier has a wider frequency range than the AH11, with a bandwidth of 0.1 to 6.0 GHz and typical gain of 13.5 dB (minimum of 12.4 dB) across that range. Suitable for wireless-local-loop (WLL) and other communications applications requiring high linearity, the amplifier achieves output IP3 performance of typically +38 dBm and better than +36 dBm at 800 MHz (Fig. 1). The noise figure at 800 MHz is typically 2.7 dB (Fig. 2), while the output power at 1-dB compression (at 800 MHz) is +21 dBm. The small-signal gain is typically 13.5 dB at 800 MHz, with minimum gain of 12.4 dB at that frequency. Similar to the AH11, the AH4 is designed for use with a single

+5-VDC supply. It draws 150-mA typical current and a minimum of 120-mA current. Supplied in a high-frequency land-grid-array (LGA) package, the AH4 is rated for operating temperatures from –40 to +85°C.

For those who wish to design their own amplifiers, the company recently introduced the model AP3 wide-dynamic-range field-effect transistor (FET). The GaAs FET features 10-dB gain at 3.5 GHz with 2-dB noise figure and +21-dBm output power at 1-dB compression. Useful over the frequency range from 0.1 to 6.0 GHz, the FET is supplied in an LGA surface-mount package. It achieves typical output IP3 of +39 dBm at 800 MHz and is rated for an MMTF of more than 100 years. It is designed for use with +8-VDC supplies.

Earlier in the year, the firm had introduced the FH1 and FHF1 GaAs FET transistors for high-dynamic-range applications. The FH1 operates on power supplies of +2.7 to +5.0 VDC and delivers 18-dB gain, 1.2-dB noise figure, and +42-dBm output third-order intercept point at 3 GHz. The FHF1 is designed for higher-frequency use. It operates from the same power-supply range, but provides 12-dB gain and 2.4-dB noise figure. **Watkins-Johnson Co., 3333 Hillview Ave., Palo Alto, CA 94304; (650) 493-4141, Internet: http://www.wj.com.**

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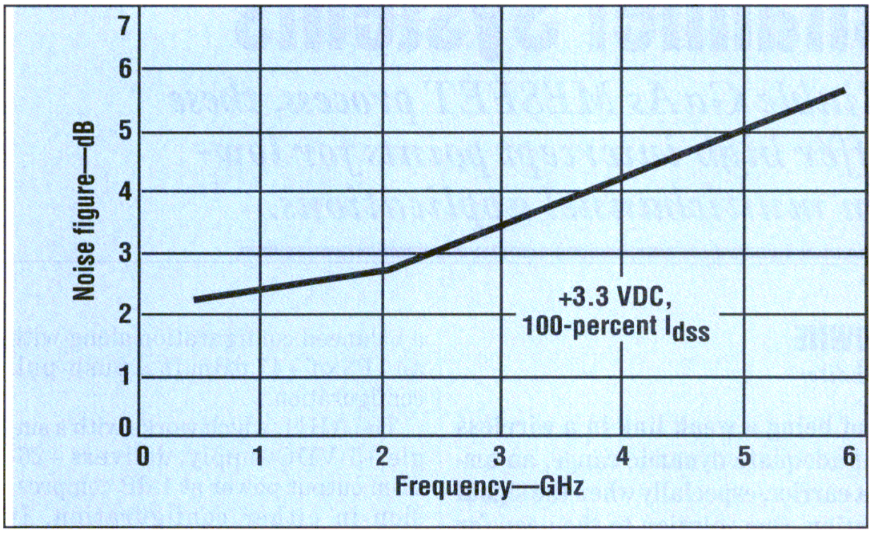


2. Even for a medium-power amplifier, the AH4 maintains relatively low noise figure across its full operating frequency range.

Linear Simulator Tracks Circuit Performance

This full-featured linear simulator has all of the design and analysis functions of high-end applications without being difficult to use.

ALAN "PETE" CONRAD
Special Projects Editor

LINEAR simulation software is still one of the most widely used computer-aided-engineering (CAE) tools for small-signal and passive linear designs. The Eclipse CAE software suite from Arden Technologies (Forest, VA) represents one of the better values in linear simulators, offering powerful linear modeling capabilities for less than $1000. The latest version of Eclipse, Version 5.0, has been optimized for multi-tasking use on the 32-b Windows NT and 95 operating systems. Working with the Windows operating system provides engineers quick access to the different functions needed to design and analyze active linear and passive high-frequency circuits.

This latest version of Eclipse offers a wide range of new features, including Monte Carlo yield analysis, constant gain circles, the capability to use VSWR as an output parameter, and unlimited netlist nodes. The software also has increased the number of possible sweep points to 2000, and included a series of new manual tuning tools. Using netlist data entry, an operator can create new designs, monitor tuning variables, and check optimization criteria from the same screen (see figure).

The program is equipped with a comprehensive element model library. The library contains resistors, inductors, capacitors (ideal/lossy, self-resonant), reactance, complex impedances, and dependent sources. Also included are ideal transformers, multiport blackbox devices (with definable S-, Y-, and Z-parameters), port terminations (impedance, gamma, or blackbox), transmission lines, and coupled lines. Other models include attenuators, transformers, control blocks (summing, integrator, differentiation, pole-zero, and gain blocks), along with a host of stripline structures, microstrip structures, bipolar transistor, field-effect-transistor (FET), and diode models. Circuit elements can be easily edited with clearly labeled pop-up fields showing all element parameters. Each field can display context-sensitive help with full on-line documentation only a mouse click away.

User-defined variables provide powerful input- and output-processing capabilities. This feature enables an operator to combine constants, program variables (such as Y-, Z-, or S-parameters, gain, current, frequency, etc.). Program functions and other user variables can be interrelated complex mathematical expressions. Once defined, programmable user-defined variables can be graphed or used as element parameter inputs.

Users have complete control over circuit stimulus and output processing through Eclipse's project notebook. Each Eclipse project can store up to 10 versions of a design. This allows an operator to keep the history of progression from one conceptual design to another in a single file. Each version contains all project parameters, including netlist, variables, optimization goals, and graph sheets. Each page contains its own definition regarding how the circuit is to be swept.

Eclipse can sweep a circuit by changing frequency, element parameters, or user-defined variables. Element sweeping makes it possible to directly vary any single parameter of any element over a chosen range of values at a single frequency. By sweeping a user-defined variable (which can also be assigned to a circuit element), an operator can indirectly vary numerous circuit elements as well.

Eclipse's manual-tune function enables operators to see the effects of changing, for example, the value of a capacitor sing 0.01- or 0.1-percent increments, or by using standard Electronic Industries Association (EIA) values of 1, 5, and 10 percent. Independent save and recall registers are available for intermediate storage of tuning values.

Optimization features allow a user to minimize the difference between desired and actual circuit performance. Performance goals are formulated in terms of mathematical expressions comprised either of program and user-defined variables. Relative as well as absolute specifications can be mixed when defining goals. Eclipse includes a summary box that displays the contribution of

(continued on page 186)

Chip Antenna Reduces Cell-Phone Dimensions

Miniature in size and light in weight, a chip antenna makes portable phones smaller, more rugged, and less expensive.

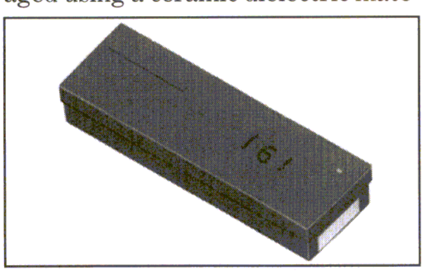
GENE HEFTMAN
Senior Editor

IN many handheld products such as cellular and digital telephones, personal digital assistants (PDAs), and pagers, the antennas currently used for transmitting and receiving radio signals are a weak link. They make the unit larger, more difficult to operate, more prone to break, and higher in cost. To combat these drawbacks, manufacturers such as Murata Electronics North America (Smyrna, GA) are developing a class of miniature, lightweight antennas that can be mounted on a printed-circuit board (PCB) within the unit, and do not protrude outside where they can be broken off or interfere with operation.

The company's contribution to the PCB-antenna market is the LDA82 chip multilayer antenna, an improved version of a device first brought out in 1996. The new antenna is aimed at replacing conventional external types with a small, surface-mountable, monolithic design that fits entirely within the product (see figure). The LDA82 is specifically targeted at licensed and unlicensed applications in the frequency spectrum from 900 to 2600 MHz. Specific end-product types include portable phones, PDAs, pagers, wireless local-area-network (WLAN) cards, and industrial-scientific-medical (ISM)-band equipment.

Because of its monolithic construction, the LDA82 measures only 9.5 × 2.0 × 2.0 mm (0.374 × 0.079 × 0.079 in.) and weighs less than 0.3 g. In portable wireless devices, it saves PCB space and makes the product more robust mechanically while maintaining performance comparable to existing solutions. In high volumes, the cost of the LDA82 is $1.00, making it attractive in the extremely cost-sensitive arena for manufacturing portable communications and data-processing products. The antenna can be surface mounted with pick-and-place machinery, an important consideration toward reducing manufacturing cost and increasing productivity.

Once mounted on a PCB, the LDA82 chip needs no adjustment—its center frequency is laser trimmed for precision. This frequency is specific to the user's design. It is packaged using a ceramic dielectric material that offers excellent temperature and mechanical stability. This is due to the company's use of low-temperature-co-fired-ceramic (LTCC) technology, which also enables a high level of integration with individual components.



Small, light, and PCB mountable, the LDA82 chip multilayer antenna fits entirely within a portable wireless product and performs as well as conventional antennas that are mounted externally.

Originally developed for military systems, LTCC is a multilayer technology that enables RF engineers to create passive components—capacitors, inductors, and resistors—in the LTCC substrate. Silver (Ag) and gold (Au) metal alloys are printed onto selected layers of the substrate. The low-temperature process enables these highly conductive metals to be used. Each layer is a ceramic composite with very-stable dielectric properties.

As a three-dimensional (multilayer) technology, PCB space can be conserved by packaging active and passive components within a single LTCC device. Since a number of RF structures can be embedded in a ceramic substrate, system size, cost, and weight are reduced.

The process is compatible with silicon (Si) and gallium-arsenide (GaAs) integration. Use of the high-conductivity metals enables the high-Q characteristics needed in RF designs. LTCC also has low thermal expansion characteristics that make it suitable for flip-chip or wirebond manufacturing processes. **Murata Electronics North America, 2200 Lake Park Dr., Smyrna, GA 30080-7604; (770) 436-1300, FAX: (770) 436-3030.**

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(continued from page 181)
each goal to the overall error.

Monte Carlo yield analysis can be used to predict manufacturing repeatability. While an ideal circuit with precise design values might appear to provide acceptable performance, the cumulative effect of component tolerances may make the design unusable due to excessive failures during manufacturing. Eclipse helps to determine the repeatability of a design by providing mixed graphical and tabular views of the sampling results. Using the results of the analysis, a user can choose to increase or decrease component tolerances and performance specifications and repeat the simulation until design goals are achieved.

Output parameters can consist of S-, Y-, and Z-parameters (for one to four ports), maximum available gain, group delay, and three types of voltage gain. Other parameter definitions consist of series or parallel impedances with reactance displayed as ohms, inductance or capacitance, stability criteria, and gain circles. Output data can be viewed in graphical or tabular formats. The program provides four independent markers for each graph. Each marker's X and Y values are automatically tracked and displayed during simulation, tuning, and optimization.

A graph properties dialog box enables an operator to create custom graphs and plots. An autoline feature allows a user to define additional boundary lines on each graph. Traces can be saved in memory for comparison with "live" data. Eclipse's history feature can dynamically retain and display as many as five of the most-recent traces. The software, which can be downloaded for a free 30-day evaluation from the company's website, is supplied with excellent documentation. The literature includes several examples that help a first-time user learn the many features of this program quickly and easily. P&A: $695.00, Upgrades $199.00. **Arden Technologies, Inc., P.O. Box 286, Forest, VA 24551; (804) 525-6837, FAX: (804) 525-5376, e-mail: sales@ardentech.com, Internet: http://www.ardentech.com.**

CIRCLE NO. 58 or visit www.mwrf.com

Antenna system monitors satellite EIRP

The model 9848-800 transportable antenna system has a parabolic antenna and two omnidirectional, bifilar helical antennas to monitor the effective isotropic radiated power (EIRP) of communication satellites operating from 1.44 to 1.51 GHz. The system has a nominal gain of 19.5 dBic, dual-circular polarization, and a nominal half-power beamwidth (HPBW) of 15 deg. Return loss is 22 dB and axial ratio is 2 dB maximum on axis. The system includes an adjustable tripod, an AZ/EL gear head, a parabolic antenna, two bifilar helical antennas, as well as a carrying case for each major piece of equipment. **Seavey Engineering Associates, Inc., 28 Riverside Dr., Pembroke, MA 02359; (781) 829-4740, FAX: (781) 829-4590, Internet: http://www.seaveyantenna.com.**

CIRCLE NO. 64 or visit www.mwrf.com

Low-noise GaAs FETs span DC to 6 GHz

Two gallium-arsenide field-effect transistors (GaAs FETs) exhibit low noise and span frequencies from DC to 6 GHz. Model FH1 covers frequencies from DC to 3 GHz and is ideal for cellular and personal-communications-services (PCS) applications such as code-division multiple access (CDMA), time-division multiple access (TDMA), Advanced Mobile Phone Service (AMPS), and Global System for Mobile Communications (GSM). It features a noise figure of 1.2 dB, a gain of 18 dB, and an output third-order intercept point (IP3) of +42 dBm. Model FHF1 covers frequencies from 3 to 6 GHz and is ideal for applications such as wireless local loop (WLL), wireless local-area network (WLAN), and universal-national-information infrastructure (UNII). It provides a noise figure of 2.4 dB, a gain of 12 dB, and an ouput IP3 of +39 dBm. Both transistors operate on a power supply of +2.7 to +5.0 VDC and are housed in an industry-standard SOT-89 package. **Watkins-Johnson Co., 3333 Hillview Ave., Palo Alto, CA 94304; (650) 493-4141, Internet: http://www.wj.com.**

CIRCLE NO. 65 or visit www.mwrf.com

Monolithic amps serve dual-band TDMA phones

The model MRIFC1856 integrates two three-stage gallium-aresenide field-effect-transistor (GaAs FET) amplifiers on a single monolithic chip for dual-band, dual-mode, time-division-multiple-access (TDMA) cellular phones. One amplifier covers 824 to 849 MHz for Advanced Mobile Phone Service (AMPS) while the other covers 1850 to 1910 MHz for personal communications services (PCS). The amplifiers have an adjacent-channel power of −29 dBc. **Motorola Semiconductor Products Sector, P.O. Box 52073, Phoenix, AZ 85072-2073; (602) 413-4991, FAX: (602) 413-7986, Internet: http://www.motorola.com/sps.**

CIRCLE NO. 66 or visit www.mwrf.com

Female F connectors feature low VSWR

A new line of female F connectors for microwave applications operates at frequencies to 3 GHz with a VSWR of 1.2:1 and a return loss of 25 dB. The connectors are available in several configurations including standard printed-circuit board (PCB), chassis mount, and splice. They can also be made to customer specifications. **Holland Electronics LLC, 4219 Transport St., Ventura, CA 93003; (805) 339-9134 ext. 120, FAX: (805) 339-9064, Internet: http://www.hollandelectronics.com.**

CIRCLE NO. 67 or visit www.mwrf.com

Serializer conserves power

The MAX3890 2.5-Gb/s, 16:1 serializer offers 495-mW power consumption. It converts 16-b-wide, 155-Mb/s parallel data to 2.5-Gb/s serial data in applications including synchronous digital hierarchy (SDH)/ synchronous optical network (SONET) and asynchronous transfer mode (ATM). Operating from a single +3.3-VDC supply, it accepts low-voltage differential-signal (LVDS) clock and data inputs. **Maxim Integrated Products, 120 San Gabriel Dr., Sunnyvale, CA 94086; (408) 737-7600, Internet: http://www.maxim-ic.com.**

CIRCLE NO. 68 or visit www.mwrf.com

continued from page 67

This is a very good result due to the high-isolation property of the MRFIC0915. In terms of VCO pushing, the results were better at the higher V_{cc} voltages. A V_{cc} of +2.5 to +3.5 VDC resulted in a frequency deviation of 210 kHz. However, the variation from +3.0 to +3.5 VDC was very minimal, 45 kHz (fo = 157 MHz). This device is designed for +2.7 to +5.0 VDC, so at lower voltages, the biasing network may reach its limits for active compensation.

Even with unusable Q's in the mid inductance values, a designer can still take advantage of the large dynamic ratio of inductance values for a variety of other applications. A simple frequency-shift keying (FSK) would be ideal using this technique. The deviation frequency can be set by the transformer turn ratio and minor tuning can be adjusted by the secondary coupling capacitor. An "on/off" switch on the secondary can then be used for FSK. Without a varactor, temperature variation would not pose much of a problem due the magnetic core's inherent tighter temperature tolerance compared to a semiconductor's temperature variation.

In applications where minute variations of the resonance tank are required, inductive perturbation may be advantageous to varactor tuning. Automatic frequency control (AFC) for a temperature-compensated crystal oscillator (TCXO) may be feasible. For narrowband adjustment, smaller turn ratio (i.e., less turn on the secondary) is desired for minimal coupling. Temperature variation from the varactor can be removed.

The performance of this oscillator is moderate due to the unavailability of higher Q RF transformers. However, it serves to prove the concept of using the transformer's non-ideal characteristics in a unique and different application. The RF transformer used is an open-core type where the fields are highly susceptible to proximity perturbation and, consequently, de-tuning. A closed core or shielded transformer is preferred, but Q may be an issue. In the application where size is not an issue, hand-wound RF transformers on ferrite cores (beads/toroids) can be very effective. The simplicity of the VCO design was credited to the monolithic cascode RF amplifier, MRFIC0915. Only the minimal and essential components were required to create a working oscillator. ●●

Acknowledgments

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NEW PRODUCTS

Fail-safe switches offer 5-M operations

The 601 series magnetic coaxial failsafe switches can handle RF power levels to 100-W continuous wave (CW) at frequencies from DC to 75 GHz and offer as many as five million operations without performance degradation. The miniature, electro-mechanical switches are available with an actuation voltage of +12 or +28 VDC and are intended for test-equipment applications. Maximum insertion loss is 0.5 dB, maximum VSWR is 1.5:1, and isolation is at least 60 dB. **Dow-Key Microwave Corp., 4822 McGrath St., Ventura, CA 93003-7718; (805) 650-0260, FAX: (805) 650-1734, Internet: http://www.dowkey.com.**

CIRCLE NO. 69 or visit www.mwrf.com

IF filter provides flat response

The model 8490 70-MHz intermediate-frequency (IF) filter has a bandwidth of ±18 MHz and maintains a flatness of 1.5 dB. It has a 40-dB stopband ±38 MHz wide. The filter has a 50-Ω impedance and is housed in a hermetic package that measures 1.0 × 0.5 × 0.35 in. (2.54 × 1.27 × 0.889 cm). **Piezo Technology, Inc., 2525 Shader Rd., Orlando, FL 32804; (407) 298-2000, (407) 293-2979, Internet: http://www.piezo tech.com.**

CIRCLE NO. 70 or visit www.mwrf.com

Spectrum analyzer spans 100 kHz to 1600 MHz

The model 9052 spectrum analyzer mounts inside a personal computer (PC) and performs measurements across the 100-kHz-to-1600-MHz frequency range. Every point in a sweep is synthesized, with frequency accuracy of 0.5 parts per million (PPM). Absolute level accuracy is ±0.5 dB. The analyzer includes a graphical user interface (GUI) for displaying set-up information as well as collected data on the PC monitor. **Morrow Technologies Corp., 2300 Tall Pines Dr., Largo, FL 33771; (727) 531-4000, FAX: (727) 531-3531, Internet: http://www.morrowcorp.com.**

CIRCLE NO. 71 or visit www.mwrf.com

Transmitters are frequency agile

The FATT4044 family of telemetry transmitters has transmitting frequencies that span the 400-to-440-MHz frequency band that are programmable through a micro-D-type connector. This enables the transmitters' operating frequency to be preset by the user or controlled digitally for frequency-hopping applications. The channel width of these transmitters spans a frequency range from 10 Hz to 15 kHz and the transmitters' deviation sensitivity is 20 kHz/V. **Frequency Products Ltd., Rose Mills, Hort Bridge, Ilminster, Somerset TA19 9QA, United Kingdom; 01460 57166, FAX: 01460 57777, Internet: http://www.frequencyproducts.com.**

CIRCLE NO. 72 or visit www.mwrf.com

(continued from page 169)
modulators, and channel models. The result is that a system architect can easily partition a design and predict the frame error rate (FER) very early in the process, for example, due to the ability to integrate the actual algorithmic and analog designs, either at a behavioral or physical (transistor) level.

It is also possible to link the ADS software to an arbitrary signal generator or a VSA to create and capture modulated waveforms from real hardware, thus mixing and matching hard and soft prototypes. Version 1.3 of ADS can therefore successfully integrate high-level components such as rake receivers and adaptive antenna arrays from the Design Libraries with user-developed routines in Matlab, C, and VHDL/Verilog, true RF analog transistor-level circuits, and measured data in one real-time cosimulation.

USING THE INTERNET AND A TELEPHONE BRIDGE FOR THE AUDIO, DESIGNERS CAN OBTAIN JUST THE APPLICATION KNOWLEDGE THAT THEY WANT WITHOUT TRAVEL, LONG WAITING PERIODS, OR HIGH COST.

Many organizations are expanding into new application areas and find their people could benefit from additional education or refresher courses. An expanding number of academic and industry experts are creating "DesignSeminars," one-to-two-hour concentrated application training sessions, to provide this application assistance on demand (Fig. 6). Such sessions are convenient because they can be delivered live via the Internet to an engineer at his desk, by compact-disc-read-only memory (CD-ROM), or, in person to workgroups by special arrangement.

Using the Internet and a telephone bridge for the audio, designers can obtain just the application knowledge they want without travel, long waiting periods, or high cost. Designers interact directly with the author, and keep a CD-ROM with the presentation files, the author's media files, ADS examples, and related materials. Designers today have their choice of many fine programs offered by various industry consultants and university for continuing education. Agilent EEsof EDA DesignSeminars are intended to supplement these programs with practical insights that include ADS design examples that they can apply after the session is over.

At present, seven such seminars are available off-the-shelf, with several dozen more actively being planned for Year 2000. Titles currently include Adaptive FeedForward Linearization (model N3500A), Adaptive RF Predistortion (model N3501A), Power Amplifier (PA) Design, Small Signal Approach (model N3502A), Gilbert Cell Mixer—CMOS (model N3503A), Reducing Cross Modulation in CDMA Transceivers (model N3504A), RF IC MOS Mixer Design Basics (model N3505A), and Bit Error Rate (BER) and Importance Sampling (model N3506A). [For more information on DesignSeminars or to purchase one online, visit http://www.agilent.com/find/eesofeda.]

Version 1.3 of the ADS software suite incorporates several advances that enable designers to accomplish their goals in fewer keystrokes than ever before. Some of these new technologies, such as Tune Mode and LineCalc, are familiar. They help a designer develop an intuitive feel for a design. Other technologies, such as DesignGuides, Esyn, RF Compiler, and the Design Libraries, help the designer achieve first-pass success quickly. Finally, the DesignSeminars are aimed at increasing and improving the designer's knowledge and skills. Taken together, these features assure that ADS users will continue to be the most-effective high-frequency designers in the world. **Agilent Technologies, Inc. (subsidiary of Hewlett-Packard Co.), Test and Measurement Organization, 5301 Stevens Creek Blvd., MS 54LAK, Santa Clara, CA 95052.**

CIRCLE NO. 51 or visit www.mwrf.com

Software tests RF components

The GPTS Windows-compatible software package measures de-embedded RF and DC parameters of RF transistors and other components under constant or swept input power, frequency, and DC bias. It includes through-reflect-line (TRL) characterization of test fixtures and wafer probes. The program processes continuous wave (CW) as well as pulsed signals and modulated signals such as Global System for Mobile Communications (GSM), code-division multiple access (CDMA), and wideband CDMA (WCDMA). The test data can be sent to Cartesian plots and spreadsheets, and transferred to optimization software. An adapter/ removal module enables measurement of S-parameters of mixed-connector type structures, such as matching networks of amplifiers. **Focus Microwaves, 970 Montee-de-Liesse, Suite 308, Ville St. Laurent, Quebec H4T 1W7, Canada; (514) 335-6227, FAX: (514) 335-6287, Internet: http:// www.focus-microwaves.com.**

CIRCLE NO. 73 or visit www.mwrf.com

Logamp features ±0.75-dB linearity

The model MCWL-4-4538 miniature matched logarithmic amplifier pair features a log linearity of ±0.75 dB at a standard center frequency of 200 MHz. Its operating bandwidth is at least 20 MHz. The log video slope is 25 ±1.5 mV/dB as defined by the best-fit straight line of the video output voltage, measured over the typical signal input range of −67 to +3 dBm. It provides a VSWR of less than 2.0:1 with a limited intermediate-frequency (IF) output power of 0 dBm. Channel-to-channel isolation between the pairs is better than −50 dB. The pair consume approximately 2 W from a ±5- or 6-VDC power supply. It is housed in a dual flat pack with an area of approximately 1.2 in.^{2} **Signal Technology Corp., Olektron Operation, 28 Tozer Rd., Beverly, MA 01915; (978) 524-7444, FAX: (978) 927-9328, Internet: http://www.sigtech. com.**

CIRCLE NO. 74 or visit www.mwrf.com

Isolators/circulators reach 28 GHz

Models 2L9N (flange-mount) and 2H9N (square) drop-in isolators/circulators are available at operational frequencies of 18, 23, 24, 27, and 28 GHz and have a typical insertion loss of 0.7 dB. They are designed for local-multipoint-distribution-system (LMDS) applications such as satellite-based systems, plain old telephone service (POTS) with Internet access, wireless local loop (WLL), or video conferencing. Minimum isolation is 16 dB, maximum insertion loss is 1 dB and maximum VSWR is 1.4:1. The devices can handle loads to 0.4 W and operate from −40 to +70{DEG}C. Model 2L9N's flange-mount package measures 0.5 − 0.25 × 0.15 in. (1.27 − 0.635 × 0.381 cm). **Renaissance Electronics Corp., 1300 Massachusetts Ave, Boxborough, MA 01719: (978) 263-4994, FAX: (978) 263-4944, Internet: http://www.rec-usa.com.**

CIRCLE NO. 75 or visit www.mwrf.com

SAW filters target CDR

The TFH2448 series of surface-acoustic-wave (SAW) filters operate in the 2.488-GHz region and are designed specifically for clock and data-recovery (CDR) applications. Center frequencies range from a minimum of 2847.92 MHz to a maximum of 2488.72 MHz, with 2488.32 MHz being nominal. Insertion loss at nominal center frequency ranges from 15.5 to 22 dB, and input/output (I/O) return loss is 3 dB. The filters operate at temperatures from 0 to +70°C and are packaged in a hermetically sealed, surface-mount, leadless chip carrier. **Vectron, Intl., 166 Glover Ave., Norwalk, CT 06856-5160; (203) 853-4433, FAX: (203) 849-1423, Internet: http://www.vectron.com.**

CIRCLE NO. 76 or visit www.mwrf.com

RF modules serve cellular and GSM networks

Four new RF modules are designed specifically for use as code-division-multiple-access (CDMA) and time-division-multiple-access (TDMA) repeaters for cellular and Global System for Mobile Communications (GSM) bands. Model MRM-02-1202A operates on the forward cellular channel from 864 to 894 MHz, while model MRM-0201203A operates on the reverse cellular channel from 824 to 849 MHz. Model MRM-05-2222A operates on the forward GSM channel from 935 to 960 MHz, while model MRM-05-2223A operates on the reverse GSM channel from 890 to 915 MHz. The modules offer a typical gain of 80 dB and a 1-dB compression point of +20 dBm. At a gain of 60 dB, the gain flatness is ±1.0 dB over the operating frequencies and the noise figure is 2.5 dB. Each module draws 1.3 A from a +9-to-+12-VDC power supply and is housed in an enclosure measuring 209.7 × 102.4 × 19.5 mm. **Microwave Communications & Components, Inc., 14F Prime Center, #546-4, Guui-dong, Kwangjin-Gu, Seoul, Korea; 82-2-3424-0800, FAX: 82-2-3424-0808, Internet: http://www.mcck.com.**

CIRCLE NO. 77 or visit www.mwrf.com

Surveillance receiver is software configurable

The model WJ-8629A surveillance receiver can be software configured to perform multiple functions. The receiver's digital-signal-processing

(DSP) section has an industry-standard interface that provides access to the receiver's analog-to-digital converter (ADC), digital downconverter (DDC), and DSP. Using this access, system designers can use software algorithms to retune the receiver and demodulate, demultiplex, decrypt, and decode signals. Applications include spectral display, single-channel direction finding (DF), voice recognition, language recognition, voice/data discrimination, modulation detection, RF signal identification/qualification, as well as multiple geo-location DF. A standard library of algorithms is supplied with the receiver. The receiver's manufacturer offers a library of algorithms that are written by other DSP suppliers, and also offers a developer's kit to help users design proprietary algorithms and applications. **Watkins-Johnson Corp., 700 Quince Orchard Rd., Gaithersburg, MD (301) 948-7550, FAX: (301) 921-9479, Internet: http://www.wj.com.**

CIRCLE NO. 78 or visit www.mwrf.com

YIG oscillator boasts low FM noise

Model YOM3022 miniature yttrium-iron-garnet (YIG)-tuned oscillator covers a triple-octave frequency range of 3.5 to 15 GHz while suppressing frequency-modulation (FM) noise to −120 dBc measured at 100-kHz offset from the carrier. Typical RF output power is +13 dBm, which remains linear to ±8 MHz over the unit's frequency range. **Omniyig, Inc., 3350 Scott Blvd., Suite 66, Santa Clara, CA 95054; (408) 988-0843, FAX: (408) 727-1373, Internet: http://www.omniyig.com.**

CIRCLE NO. 79 or visit www.mwrf.com

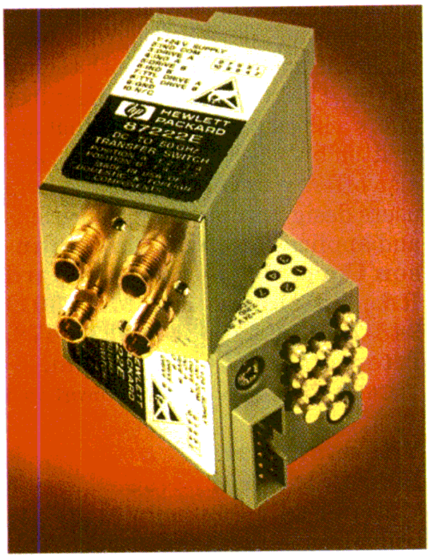
Low-cost terminators used as "50-Ω dustcaps"

The 3200 series 50-Ω terminators are designed for high-volume, low-cost applications where they are sometimes called "throwaway terminators" or "50-Ω dustcaps." The terminators are available with SMA, BNC, TNC, and type-N connectors. Operating frequency range is DC to 4 GHz for BNC, TNC, and type-N models and DC to 8 GHz for SMA models. **Inmet Corp., 300 Dino Dr., Ann Arbor, MI 48103; (888) 244-6638, (734) 426-5553, FAX: (734) 426-5557, Internet: http://www.inmetcorp.com.**

CIRCLE NO. 80 or visit www.mwrf.com

Coaxial transfer switch routes 50-GHz signals

The model HP87222E four-port coaxial transfer switch routes DC-to-50-GHz signals between ports. It can be used for drop-out switching, signal reversal, bypassing an active device, switching signals between two



inputs and two outputs, and as a single-pole, double-throw (SPDT) switch for product-test systems, satellite- and antenna-monitoring systems, and test instrumentation. Isolation between ports is greater than 100 dB from DC to 12 GHz, greater than 90 dB to 26.5 GHz, and greater than 60 dB to 50 GHz. The switch is designed to operate for more than 10 million cycles. Insertion-loss repeatability is less than 0.03 dB for five million cycles at 25 7C. It features opto-electronic indicators and interrupts, magnetic latching, and TTL/5-V complementary-metal-oxide-semiconductor (CMOS) compatibility. The switch operates from 125 to +75°C and measures 0.95 × 0.35 × 2.7 in. (2.413 × 0.889 × 6.858 cm). **Hewlett-Packard Co., 3000 Hanover St., Palo Alto, CA 94304; (800) 452-4844, Internet: http://www.hp.com.**

CIRCLE NO. 81 or visit www.mwrf.com

PIN-diode switch spans 0.3 to 18 GHz

The model SWN-2181-2A positive-intrinsic-negative (PIN) diode switch covers 0.3 to 18 GHz with a maximum switching speed of 50 ns. The single-pole, double-throw (SPDT) switch has an integral transistor-transistor-logic (TTL) driver and employs solid-state chip diode and microstrip construction. Minimum isolation is 55 dB, maximum insertion loss is 3.0 dB, and maximum VSWR is 2.0:1. The switch operates on a ±5-VDC power supply and features reverse-voltage and over-voltage protection. It can handle a maximum continuous-wave (CW) power of +23 dBm and operates at temperatures from −65 to +8 °C. The switch is intended for use in both commercial and military applications. **American Microwave Corp., 7311G Grove Rd., Frederick, MD 21701; (301) 662-4700.**

CIRCLE NO. 82 or visit www.mwrf.com

Miniature attenuators cover 0.5 to 3.0 GHz

Two compact, gallium-arsenide (GaAs), integrated-circuit (IC), field-effect-transistor (FET) digital attenuators cover 0.5 to 3 GHz for the wireless communications industry. Model AA105-85 is a 4-b, single positive control attenuator that attenuates to 15 dB in 1-dB steps, and has a typical insertion-loss range of 1.3 to 2 dB. Model AA106-86 is a 5-b, single positive control attenuator that attenuates to 15.5 dB in 0.5-dB steps and has a typical insertion-loss range of 1.7 to 2.6 dB. Both devices have a third-order intercept point (IP3) of +45 dBm. The attenuators feature low DC power consumption and are housed in a miniature MSOP-10 plastic package. Typical applications include cellular radio, wireless data, and wireless-local-loop (WLL) gain-level control circuits. **Alpha Industries, 20 Sylvan Rd., Woburn, MA 01801; (508) 894-1904, FAX: (617) 824-4579, Internet: http://www.alphaind.com.**

CIRCLE NO. 83 or visit www.mwrf.com

Single-card demodulator performs three functions

The model 1800 FQD Flexi-QAM universal demodulator combines three independent functional elements—tuner, resampler, and demodulator—on a single double-wide 6U VersaModule-Europe (VME) card. The front end is a digital tuner that accepts as many as 160 MSamples/s, tunes through an 80-MHz Nyquist bandwidth and decimates the incoming data rate by as much as 20,000. The resampler upsamples by 64 and downsamples by 20,000 while dedopplerizing asynchronously over one percent of the input data rate. Resampling ratios can be fixed or adaptive. The tuner and resampler are integrated with an applications engine and bit slicer to perform complex demodulation. Tuning, resampling, and demodulation functions may be invoked simultaneously. Applications include time-division multiplexing (TDM), frequency-division multiplexing (FDM), and canceling doppler. **Apcom, Inc., 8-4 Metropolitan Court, Gaithersburg, MD 20878; (301) 948-5900, FAX: (301) 948-1631, Internet: http://www.apcominc.com.**

CIRCLE NO. 84 or visit www.mwrf.com

MMIC amp powers 37-to-40-GHz applications

The model SPGA-07006-CC gallium-arsenide (GaAs), monolithic-microwave-integrated-circuit (MMIC) amplifier puts out 1.5 W of power at 1-dB compression from 37 to 40 GHz. The two-stage linear amp has a typical power gain of 9 dB and a typical power-added efficiency (PAE) of 12 percent. **Sanders Co., Lockheed Martin, 65 Spit Brook Rd., Nashua, NH 03061; (603) 885-2817, FAX: (603) 885-2813, Internet: http://www.sanders.com-/gaas.**

CIRCLE NO. 85 or visit www.mwrf.com

SP16T PIN-diode switch targets 2 to 18 GHz

The model 1744 single-pole, 16-throw (SP16T) positive-intrinsic-negative (PIN)-diode switch covers the 2-to-18-GHz frequency range. It exhibits a maximum witching speed of 500 ns and a maximum insertion loss of 6.0 dB. Isolation between throws is 60 dB from 2 to 14 GHz and 50 dB from 14 to 18 GHz. The switch measures 4.5 × 4.0 × 0.75 in. (11.43 × 10.16 × 1.905 cm). **General Microwave Corp., 5500 New Horizons Blvd., Amityville, NY 11701; (516) 226-8900, Internet: http://www.gmcwave.com.**

CIRCLE NO. 86 or visit www.mwrf.com

Frequency standard provides 13 outputs

The model A10-B rubidium frequency standard bench instrument

has three sine-wave outputs, four squarewave outputs, and a distribution amplifier with six outputs. The three sine-wave output frequencies are 1, 5, and 10 MHz, while the four squarewave output frequencies are 1 Hz and 1, 5, and 10 MHz. The frequency standard is one-third the size of previous units and has a 1 pps synchronizing input. It also has Global Positioning System (GPS) synchronizing/locking inputs to enable a cesium beating performance upgrade. An external +24-VDC battery input allows uninterrupted operation in the event of a power failure. **Quartzlock, Ltd., Gothic Plymouth Rd., Totnes, Devon TQ9 5LH, England; +44 (0)1803 862062, FAX: +44 (0)1803 867962, Internet: http://www.quartzlock.com.**

CIRCLE NO. 87 or visit www.mwrf.com

VCO serves satcom market

The model V674ME01 voltage-controlled oscillator (VCO) covers 1820 to 2480 MHz and is designed specifically to serve applications such as satellite communications, earth stations, and digital radios. The VCO has a tuning-voltage range of 0.5 to 9.5 VDC and an average tuning sensitivity of 115 MHz/V. At 10-kHz offset and a typical bandwidth of 1 Hz, the phase noise for this VCO is −96 dBc/Hz. Output power is +6 dBm ±3 dBm. Nominal power-supply voltage is 10 VDC and typical current draw is 13 mA. The VCO operates at temperatures from −40 to +85°C, and is housed in a MINI-14H style package. **Z-Communications, Inc., 9939 Via Pasar, San Diego, CA 92126; (619) 621-2700, FAX: (619) 621-2722, Internet: http://www.zcomm.com.**

CIRCLE NO. 88 or visit www.mwrf.com

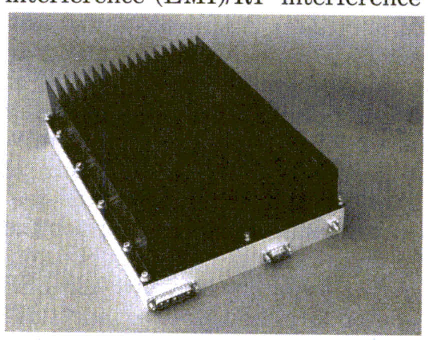
Drop-in isolators/circulators boast low insertion loss

Four new drop-in isolators boast an insertion loss of 0.5 dB or less. The model 0160CAD covers 1.30 to 1.85 GHz and provides 17 dB of isolation, 0.5-dB insertion loss, and a VSWR of 1.3:1. The model 0470IED S-band isolator covers 4.4 to 5.0 GHz and provides 20 dB of isolation, 0.4-dB insertion loss, and a VSWR of 1.25:1. Model 0615IED covers 5.8 to 6.5 GHz and provides 22 dB of isolation, 0.35-dB insertion loss, and a VSWR of 1.25:1. Model 1425IED covers 14.0 to 14.5 GHz and provides 23 dB of isolation, 0.4-dB insertion loss, and a VSWR of 1.3:1. **Nova Microwave Corp., 380 Tennant Ave., Unit 3, Morgan Hill, CA 95037; (408) 778-2746, FAX: (408) 779-5967, Internet: http://www.novamicro.com.**

CIRCLE NO. 89 or visit www.mwrf.com

Horn antenna produces 250V/m fields

The model AT4002A microwave horn antenna is capable of generating fields to 250V/m with a minimum gain of 11 dBi. The antenna accepts 250 W of input power from 0.8 to 5 GHz and supplies the high-intensity fields necessary for electromagnetic interference (EMI)/RF interference



(RFI) testing in shielded rooms. Its specifically designed septums are installed to focus beamwidth and ensure field intensity at three meters. The antenna measures 46.3 × 46.3 × 69.2 cm, weighs 6 kg, and mounts easily on a tripod or backplate. **Amplifier Research Corp., 160 School House Rd., Souderton, PA 18964; (215) 723-8181, Internet: http://www.ar-amps.com.**

CIRCLE NO. 90 or visit www.mwrf.com

HFF crystals reach 200 MHz

Improvements in inverted-mesa processing technology are credited for extending the maximum frequency of the CC1F series of high-frequency fundamental (HFF), thickness-shear-mode, AT quartz-crystal resonators that span across the 160-MHz-to-200-MHz frequency range. The resonators are now available at frequencies from 30 to 200 MHz and are suitable for use in high-speed communications systems that require high-frequency references, including fiber-optic telecommunications, gigabit Ethernet, 10 base T, and frame-relay applications. The resonators' nominal load capacitance is 10 pF while their nominal frequency tolerance is ±50 PPM, but other load capacitances and tighter and wider frequency tolerances are available. Typical series resistance is 25 Ω, maximum is 50 Ω. The motional capacitance of the resonators ranges from 3 to 9 fF and the static capacitance ranges from 1.5 to 4 pF. The resonators have a maximum drive level of 100 ωW. They are housed in a 0.32 × 0.15 × 0.07-in. (8.1 × 3.8 × 1.8-mm) package and are available with a variety of environmental ratings. **Micro Crystal Div. of SMH (US), Inc., 601 Campus Dr., Ste. B4, Arlington Heights, IL 60004; (847) 818-9825, FAX: (847) 818-9915, Internet: http://www.microcrystal.com.**

CIRCLE NO. 91 or visit www.mwrf.com

Modeling software handles large signals

Large- and small-signal modeling software eases the development of large-signal transistor models by simplifying the procedures for extracting metal-semiconductor-field-effect-transistor (MESFET) along with high-electron-mobility-transistor (HEMT) model parameters. The LASIMO software offers a set of proven transistor models. **Optotek Ltd., 62 Steacie Dr., Kanata, Ontario K2K 2A9, Canada; (613) 591-0336, FAX: (613) 591-0584, e-mail: optotek@optotek.com, Internet: http://www.optotek. com.**

CIRCLE NO. 92 or visit www.mwrf.com

Directional couplers suited for cable TV

A family of 50-Ω directional couplers is designed for cable TV (CATV) and other communications applications.

The ADC-10-1R series offer a nominal 10.5±0.5-dB coupling value and ±0.2-dB (typical) coupling flatness over the frequency range of 5 to 900 MHz. Package size is just 3 mm in height. **Mini-Circuits, P.O. Box 350166, Brooklyn, NY 11235-0003; (718) 934-4500, FAX: (718) 332-4661, e-mail: sales@mini circuits.com.**

CIRCLE NO. 93 or visit www.mwrf.com

Frequency translator boasts low jitter

The model FX070 low-noise, narrowband frequency translator generates a 2488.32-MHz output derived from an external 12.96 MHz clock and maintains a typical output jitter of less than 5 ps rms. The device offers a drop-in solution for clock-frequency translation and clock distribution in Synchronous Optical Network (SONET)/synchronous digital hierarchy (SDH), asynchronous transfer mode (ATM), and other telecommunication applications. The translator has a minimum output signal of 0 dBm into 50 Ω and operates at a supply voltage of +5 VDC±5 percent. It is housed in a 16-pin, surface-mountable, gull-wing flatpack package measuring 1 × 1 × 0.28 in. (2.54 × 2.54 × 0.7112 cm). **Vectron International, 166 Glover Ave., Norwalk, CT 06856-5160; (203) 853-4433, FAX: (203) 849-1423, Internet: http://www.vectron.com.**

CIRCLE NO. 94 or visit www.mwrf.com

VCOs generate high frequencies

The eight members of the VCO690 series of high-frequency, voltage-controlled oscillators (VCOs) generate signals in the 3000-to-5900-MHz range. The last four numbers in the VCO's model number identify the center of its frequency range. For example, model VCO690-5250T generates frequencies from 5150 to 5350 MHz, model VCO690-5500T generates frequencies from 5400 to 5600 MHz, and model VCO690-5800T generates frequencies from 5700 to 5900 MHz. The VCOs draw less than 10 mA from a +5-VDC supply, and the control voltage for most of the models in the series ranges from +0.5 to +5 VDC. Typical output power is −1 dBm, and typical phase noise at 100-kHz offset is approximately −105 dBc/Hz. The VCOs are housed in a pick-and-place, reflow-compatible, surface-mount package measuring 0.5 × 0.5 × 0.25 in. (1.27 ×1.27× 0.635 cm). **Vari-L Co., Inc., 4895 Peoria St., Denver CO 80239 (303) 371-1560, FAX: (303) 371-0845, Internet: http://www.vari-l.com.**

CIRCLE NO. 95 or visit www.mwrf.com

ADC supports high speed

The model AD9203 10-b analog-to-digital converter (ADC) operates from a +3.3-VDC power supply and dissipates 74 mW at full speed (40 MSamples/s). Additional power savings can be achieved by using an external resistor when operating at lower sampling rates. In standby mode, the ADC dissipates 0.65 mW. It supports an input voltage range of 1 to 2 VDC peak-to-peak and features a data-format-select option and an internal clamp circuit. The converter has a linearity of±0.25 LSB and an intermediate-frequency (IF) undersampling capability to 130 MSamples/s. The designer can use the on-chip, programmable reference or an external reference to suit the DC-accuracy and temperature-drift requirements of a particular system. The ADC operates over a temperature range of −40 to +85°C and is available in a 28-pin, thin-shrink, small-outline package (28 TSSOP). **Analog Devices, Inc., 804 Woburn St., Wilmington, MA 01887; (800) 262-5643, FAX: (781) 937-1021, Internet: http://www.analog.com.**

CIRCLE NO. 96 or visit www.mwrf.com

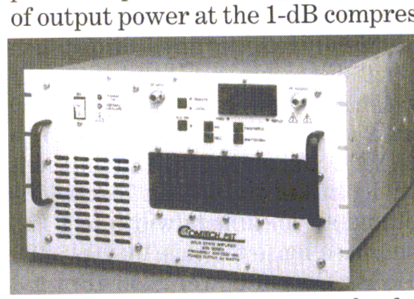
Monolithic log amp replaces hybrids

The AD8306 is a monolithic logarithmic amplifier designed to replace expensive hybrids or discrete amplifiers in avionics and radar applications that measure and amplify intermediate-frequency (IF) signals and detect phase-modulated signals. It provides accuracy of ±0.4 dB over the center 80 dB of its 100-dB input range. The amplifier's output produces the logarithm of the input signal- input range of 0.4 to 2.4 V and a stable, limited output of ±2-deg. phase error at a maximum input frequency of 400 MHz. The device runs from a single 2.7-to-6.5-V supply and draws a typical current of 16 mA. The AD8306 is supplied in a 16-lead, narrow-body plastic small-outline (SO) package or a military qualified 16-lead ceramic dual-in-line (DIP) package. P&A: $14.50 (1000 qty.). **Analog Devices, Inc., Ray Stata Technology Center, Wilmington, MA 01887; (800) 262-5643, FAX: (781) 937-1021, Internet: http://www.analog.com.**

CIRCLE NO. 97 or visit www.mwrf.com

PA delivers 50-W output

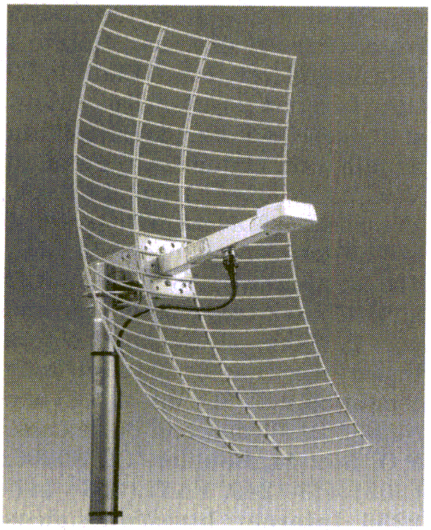
The model ARD88258-50 is a rack-mountable gallium-arsenide (GaAs) power amplifier (PA) capable of 50 W of output power at the 1-dB compression point. It operates over the frequency band of 800 to 2500 MHz, and provides a minimum gain of 47 dB and a typical noise figure of 10 dB. An integral IEEE-488 interface permits full monitor and control of all amplifier functions for test applications. **Comtech PST, 105 Baylis Rd., Melville, NY 11747; (516) 777-8900, FAX: (516) 777-8877.**



CIRCLE NO. 98 or visit www.mwrf.com

Antenna package meets ISM-band requirements

An antenna system comprising a parabolic-grid reflector antenna with a 50-Ω passive-feed dipole and integrated type-N female connector is a complete directional-antenna package for 2.4-GHz point-to-point wire-



less communications. The complete antenna and feed assembly (PMANT-19) weighs less than 4 lbs. (1.8 kg) and measures 16.7 × 9.4 × 23.6 in. (42.4 × 23.9 × 60 cm). The antenna is fabricated using zinc (Zn)-plated welded-wire construction with powder-coat paint and a Quik-clamp adjustable bracket that fits up to a 1.5-in. (3.8-cm) diameter pole or an adjustable heavy-duty bracket that fits a pole of up to 2.4 in. (6 cm) in diameter. The passive feed comes in a waterproof sealed-plastic housing with an integrated type-N female connector. P&A: $38.00 (single qty.). **Pacific Wireless, 2844 Mar Vista Dr., Suite 101, Aptos, CA 95003; (831) 419-5119, FAX: (831) 684-2494, Internet: http://www.pacwireless.com.**

CIRCLE NO. 99 or visit www.mwrf.com

Test system measures differential devices

The characteristics of balanced circuits such as differential amplifiers can be accurately and comprehensively characterized with the ATN-4000 Series Test Systems. Single-ended and mixed-mode s-parameter data can be measured on devices used in RF, analog, and data-communication applications. The system can be fully turnkey, and includes the ATN hardware and system software, a Hewlett-Packard Vector Analyzer, and a Pentium™-based personal computer (PC) with a general-purpose-interface-bus (GPIB) interface. **ATN Microwave, Inc., 101 Billerica Ave., North Billerica, MA 01862-1256; (978) 667-4200 ext. 8040, FAX: (978) 667-8548, e-mail: jnorton@atnmicrowave.com, Internet: http://www.atnmicrowave.com.**

CIRCLE NO. 100 or visit www.mwrf.com

Dual-mode upconverters designed for wireless

A pair of RF integrated circuits (RF ICs) are dual-mode upconverters designed for both cellular and code-division-multiple-access (CDMA) applications. The RF2638 has a 13-dBm output at the third-order intercept point (IP3) with a conversion gain of 0 dB. The RF2641 has a 5.5-dBm output at IP3 and a conversion gain of 7 dB. Both ICs operate from a 3-V supply voltage, and both can be used as binary-phase-shift-keying (BPSK) modulators. The devices cover the frequency range of 500 to 2500 MHz. They are housed in miniature small-outline (MSOP) 8-pin packages. **P&A: $1.20 (10,000 qty). RF Micro Devices, 7625 Thorndike Rd., Greensboro, NC 27409-9421; (336) 664-1233, Internet: http://www.rfmd.com.**

CIRCLE NO. 101 or visit www.mwrf.com

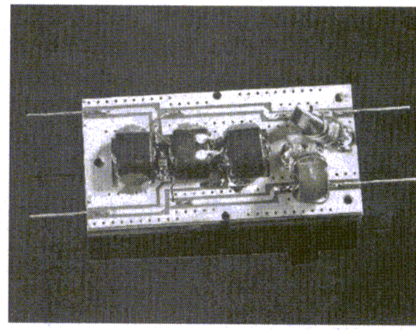
Software aids in wireless deployment

A new version of a software package for in-building and microcell wireless system deployment upgrades the functionality of the original package. SitePlanner™ 4.0 combines computer-aided-design (CAD) software, inventory and cost-tracking databases, and RF propagation modeling and measurement capabilities in a single, transportable design environment for use on a personal computer (PC). The improvements include point-and-click capabilities for interactively determining antenna placements for desired RF or interference contours, new measurement capabilities, and others. **Wireless Valley Communications, Inc., 104 Hubbard St., Blacksburg, VA 24060; (540) 552-8300, FAX: (540) 552-8234, e-mail: info@wvcomm.com, Internet: http://www.wvcomm.com.**

CIRCLE NO. 102 or visit www.mwrf.com

Surface-mount hybrid handles 200 W

The model SM-J4-4093 is a high-performance surface-mount hybrid circuit rated for continuous-wave (CW) power levels up to 200 W. Cov-



ering a frequency range of 30 to 175 MHz, the device has insertion loss of 1 dB maximum, amplitude balance of ±0.5 dB (1.0 dB peak-to-peak) and 90-deg. phase balance of ±4 deg. The hybrid offers quadrature isolation of 18 dB minimum. VSWR characteristics are 1.5:1 from 30 to 150 MHZ and 1.7:1 from 150 to 175 MHZ. P&A: $250 (5-9 qty.) **Signal Technology Corp., Olektron Operation, 28 Tozer Rd., Beverly, MA 01915; (978) 524-7444, FAX: (978) 927-9328, e-mail: mailbox@strandmarketing.com, Internet: http://www.sigtech.com.**

CIRCLE NO. 103 or visit www.mwrf.com

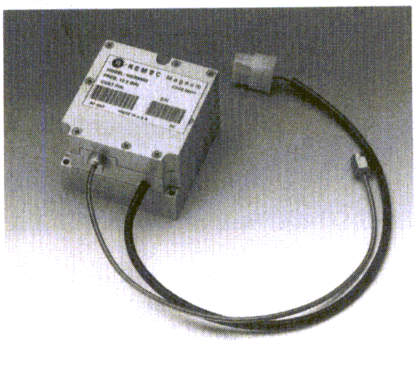
High-power RF parts targeted at wireless

A family of high-power (greater than 100 W typically) surface-mount couplers, quadrature hybrids, and baluns are intended specifically for the cellular and personal-communications-systems (PCS) markets. Any surface-mount package can be cross-referenced, even those that are not standard. **Raditek, 1702H Meridian Ave., San Jose, CA 95125; (408) 266-7404, FAX: (408) 266-4483, e-mail: sales@raditak.com, Internet: http://www.raditek.com.**

CIRCLE NO. 104 or visit www.mwrf.com

Stable oscillators used In LMDS and radio links

A series of phase-locked sources which are internally referenced, phase-locked, dielectric-resonator oscillators are intended for high-volume applications in systems that use second- or third-harmonic mixing or multipliers to achieve frequencies from 23 to 38 GHz for up- and down-converter local oscillators (LOs). Such systems can be local multipoint distribution systems (LMDS) and millimeter-wave radio links. The series MDR5530 Phase-Locked Sources are available at frequencies

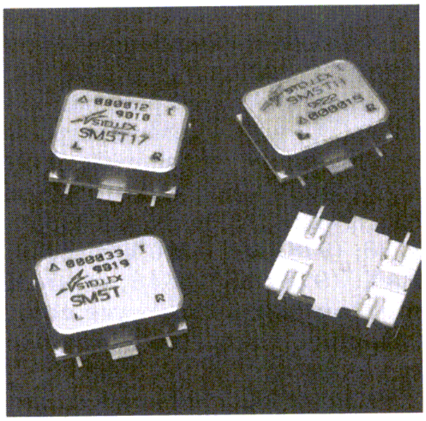


from 9 to 13 GHz. They have an internal ovenized crystal oscillator that maintains stability at ± 2 PPM, with all spurious signals maintained at levels lower than −85 dBc. Power output is 17 ±2 dBm and maximum phase noise at 1 kHz offset from the carrier is −95 dBc. **REMEC Magnum, Inc., 1990 Concourse Dr., San Jose, CA 95131; (408) 432-9898, FAX: (408) 432-1551, e-mail: arosenzweig@remecmagnum.com.**

CIRCLE NO. 105 or visit www.mwrf.com

Wideband mixers are load insensitive

The models SM5T/SM5T17-/SM5TH are wideband, load-insensitive mixers that are available in hermetic, surface-mount packages for high-reliability applications. Frequency coverage ranges from 50-to-5000-MHz local oscillator (LO) and RF, 50-to-3000-MHz intermediate frequency (IF). Three LO drive levels are offered—10, 17, and 23 dBm. Typical performance includes 7.2-dB conversion loss as well as 35-dB isolation. **Stellex Electronics, Inc., Stanford Industrial Park, 3333



Hillview Ave., Palo Alto, CA 94304-1204; (800) 321-8075, e-mail: sales@stellexms.com.**

CIRCLE NO. 106 or visit www.mwrf.com

BGA packages run at fiber-optic speeds

The VIA/BGA is a leadless, thin film, ceramic ball-grid-array (BGA) package for devices that are used in broadband data links such as fiber-optic OC-192 (Synchronous Optical Network (SONET)/synchronous-digital-hierarchy (SDH) systems. The package can support data rates of 10 to 20 Gb/s, with a possible extension to over 20 Gb/s. It can also serve for packaging Ka-band gallium-arsenide (GaAs) monolithic microwave integrated circuits (MMICs) used in wireless broadband system such as local multipoint distribution systems (LMDS). Conventional leaded packages cannot be used at data rates of 10 Gb/s and above. VIA/PLANE, a single-layer ceramic interconnect substrate with tungsten (W)-copper (Cu) sold vias forms the package base. **Micro Substrates Corp., 2400 South Roosevelt St., Tempe, AZ 85282; (480) 731-6230, FAX: (480) 731-6229, Internet: http://www.microsubstrates.com.**

CIRCLE NO. 107 or visit www.mwrf.com

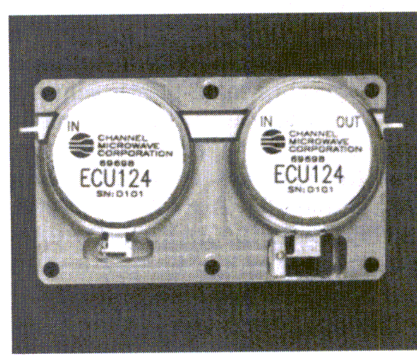
Insertion tee passes frequencies to 40 GHz

The model 5542-LL dual-inductor bias insertion tee with DC blocking capacitor passes frequencies that span 12 kHz to 40 GHz. The bias insertion tee offers two DC inputs in order to apply independent DC bias to each RF port. The model 5542-LL is ideal for systems that carry data rates covering the 10-to-40-Gb/s frequency range such as synchronous digital hierarchy (SDH) as well as synchronous optical network (SONET). Its risetime is 7 ps. Insertion loss is less than −0.8 dB from the 100-kHz-to-8-GHz frequency range, increasing to −2 dB at 32 GHz, reaching −3 dB at 40 GHz. Return loss is better than −20 dB from 1 MHz to 4 GHz, and better than −13 dB to 20 GHz. Isolation is better than −50 dB at frequencies above 100 MHz. It can handle a maximum voltage of 16 VDC, a maximum current of 100 mA, and a maximum average RF power of 5 W at frequencies below 10 GHz. The tee measures 1.75 × 0.45 × 0.37 in. (4.445 × 1.143 × 0.9398 cm) and uses 2.92-mm, 40-GHz connectors that are mechanically and electrically compatible with K, SMA, and 3.5-mm connectors. **Picosecond Pulse Labs, P.O. Box 44, Boulder, CO 80306; (303) 443-1249, FAX: (303) 447-2236, Internet: http://www.picosecond.com.**

CIRCLE NO. 108 or visit www.mwrf.com

Low-loss isolator can dissipate 80 W

The ECU124 is an 80-W ultra-high-frequency (UHF) drop-in isolator that offers 50-dB isolation (minimum) over the frequency range of 850 to 870 MHz. Insertion loss

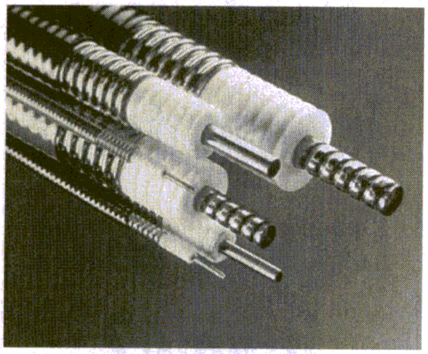


through both of the junctions is 0.35 dB maximum while VSWR is a maximum of 1.15:1. The device is housed in a package where the footprint measures 2.170 × 1.250 in. (5.51 × 3.18 cm) while being 0.23 in. (0.58 cm) high. **Channel Microwave Corp., 480 Constitution Ave., Camarillo, CA 93012; (805) 482-7280, FAX: (805) 987-8794.**

CIRCLE NO. 109 or visit www.mwrf.com

Transmission-line attenuation is reduced

Improvements in closed-cell foam dielectric design and manufacturing enhance the performance of the



HELIAX cable transmission-lines in sizes from 0.5- through 2.25-in. (0.64- through 5.72-cm) diameter. For example, at 894 MHz, the enhanced HELIAX LDF7-50A cable (1 5/8-in. diameter) [4.13 cm] has an attenuation of 0.71 dB/100 ft., an improvement of 0.06 dB over the older version. Guaranteed VSWR is 1.13:1 making the cables suitable for all wireless communication systems. **Andrew Corp., 10500 West 153rd St., Orland Park, IL 60462; (800) 225-1479, Internet: http://www.andrew.com.**

CIRCLE NO. 110 or visit www.mwrf.com

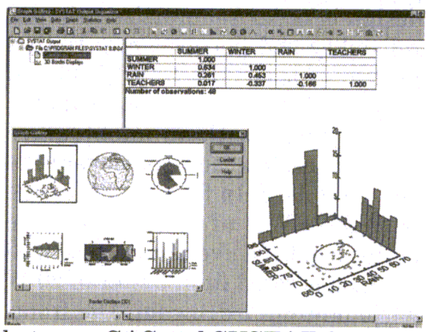
Broadband amp boasts high IP3

A 180-W, class-A, broadband linear amplifier covers any 200-MHz band from 2.4 to 2.7 GHz and boasts a third-order intercept point (IP3) of +66.5 dBm. The gallium-arsenide field-effect-transistor (GaAs FET) amplifier has a minimum gain of 40 dB that remains flat to ±1.0 dB over its frequency range. Maximum noise figure is 10 dB and VSWR in and out are 1.5:1. Features include protection from overvoltage, reverse polarity, and overtemperature, and output isolation from open or short circuits. The amplifier draws 75 A from a +12-VDC power supply and operates at case temperatures ranging from 0 to +50°C. It measures 9 × 13 × 1.5 in. (22.86 × 33.02 × 3.81 cm) **Chesapeake Microwave Technologies, Inc., 281 Industrial Rd., Glen Rock, PA 17327; (717) 235-1655, FAX: (717) 235-2501.**

CIRCLE NO. 111 or visit www.mwrf.com

Statistical software update offers more graphics

The newest version of the SYSTAT statistical-research software program, SYSTAT 9, offers expanded data-management options, automated graph creation, and new statistics procedures, enhancing its capabilities as a tool for scientific research. The program adds several new features, including SAS, ODBC, and HTML file options, Graph Gallery, Command Templates, Missing Values Analysis, Smooth Module, Advanced DOE Wizard, and Customizable Toolbars. The SAS, ODBC, and HTML file options enable users to convert data files

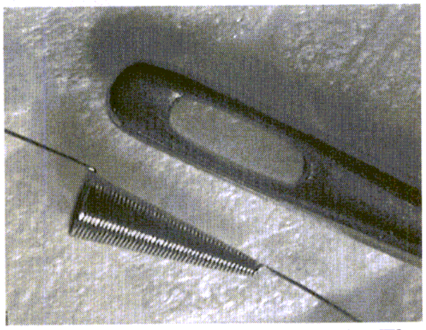


between SAS and SYSTAT formats, access ODBC data-base files, and save their output to HTML. The Graph Gallery feature creates graphs automatically. The feature enables users to choose an item from an extensive display of graphs and substitute their data into the graph. Users can also add their own graphs to the gallery for automated graph creation. The Command Templates feature enables users to quickly substitute their data and variables into automation routines. Missing Values Analysis imputes missing values when data are missing from a data set. The Smooth Module helps users visualize patterns in noisy data using 126 non-parametric smoothers. The Advanced DOE Wizard applies the exact experimental design using a question-and-answer dialog and two new design types. And the Customizable Toolbars feature saves time by displaying the statistics and graphic tools used most often. **SPSS, Inc., 233 S. Wacker Dr., 11th fl., Chicago, IL 60606; (312) 651-3000, FAX: (312) 651-3668, Internet: http://www.spss.com.**

CIRCLE NO. 112 or visit www.mwrf.com

Miniature conical inductor covers 10 MHz to 40 GHz

A conical inductor only slightly larger than the eye of a needle operates with no resonance over a bandwidth of 10 MHz to 40 GHz when con-



nected across a 50-Ω microstrip. The broadband response of the coil is attributed to precision winding, gold (Au) plating, and powdered-iron filling. The inductor is available in values of 0.84, 6.5, and 8 μH and are capable of handling 250 mA of current. Typical insertion loss across the frequency band is −0.3 dB. Due to its wide bandwidth, the inductor can be employed in numerous RF and microwave applications. **Piconics, Inc., 26 Cummings Rd., Tyngsboro, MA 01879-1406; (978) 649-7501, FAX: (978) 649-9643, Internet: http://www.piconics.com.**

CIRCLE NO. 113 or visit www.mwrf.com

Software upgrade improves CDMA-handset testing

Version 3.1 of the TASKIT/CDMA software is the most recent upgrade to this measurement package for evaluating code-division-multiple-access (CDMA) handsets. This particular version enables carriers to compare handsets and choose the model that will provide the best service to their subscribers. The upgraded software doubles test throughput while adding a feature that enables simultaneous comparison of competing handset-performance results. It supports the latest published industry standards, as defined in EIA/TIA-98B for cellular phones and in ARIB T53 v1.1 for Japanese handsets. TASKIT/CDMA v3.0 stores test conditions and results in an industry-standard Microsoft Access data base for post-processing in MS Excel, MS Word, Crystal Reports, along with other applications. The software can also capture spectrum-analyzer-based test results in graphical format. **Telecom Analysis Systems, Inc., 34 Industrial Way East, Eatontown, NJ 07724-3319; (732) 544-8700, FAX: (732) 544-8347; Internet: http://www.taskit.com.**

CIRCLE NO. 114 or visit www.mwrf.com

Small antenna has multiple uses

Capable of being used either in the indoors or outdoors and for voice or data, the model ASPPA2988 fixed-station Discreet™ planar antenna is designed for 800-MHz applications. The planar antenna incorporates a precision-engineered microstrip design in order to optimize network reliability and performance. With a profile of less than 2-in. (5.08-cm) deep, it blends into the surrounding environment with an unobtrusive appearance. The antenna covers the 806-to-869-MHz frequency range with a VSWR of 1.5:1 across the entire band. The vertically polarized antenna is rated for a power of 20 W while offering 7-dBi gain. The front-to-back ratio is 12 dB. Dimensions are 8.5 × 8.4 × 1.9 in. (21.6 × 21.3 × 4.8 cm.). P&A: $120. **Antenna Specialists, 30500 Bruce Industrial Pkwy., Cleveland, OH; (440) 349-8643, FAX: (440) 349-7430.**

CIRCLE NO. 115 or visit www.mwrf.com

Fixed inductors suit DC-to-DC converters

Miniature fixed inductors are surface-mount types for use as DC choke coils in DC-to-DC converters. The D62CB and D63LCB series inductors are low-profile and shielded, and are available in values ranging from 1.0 to 82 μH, ±20 percent. They are rated for a frequency range of 10 kHz to 1 MHz. The maximum footprint is 0.25 ×0.24 × 0.12 in. (6.3 ×6.0 × 3.0 mm). Portable applications such as cellular phones and personal digital assistants (PDAs) can make use of the miniature parts. **Toko America, Inc., 1250 Feehanville Dr., Mount Prospect, IL 60056; (847) 297-0070, FAX: (847) 699-7864, e-mail: info@tokoam.com, Internet: http://www.tokoam.com.**

CIRCLE NO. 116 or visit www.mwrf.com

DDS ICs synthesize sine waves to 120 MHz

Models AD9852 and AD9854 direct-digital-synthesizer (DDS) integrated circuits (ICs) synthesize sinewaves at frequencies from DC to 120 MHz in response to digital commands. The AD9852 contains a 12-b, 300-MHz digital-to-analog converter (DAC), while the AD9854 features dual 12-b, 300-MHz DACs for quadrature outputs. Both devices have a 48-b tuning word that yields a tuning resolution of 1.066 μHz. When referenced to an accurate clock source, these chips generate a stable frequency-, phase-, and amplitude-programmable sine-wave output. They can be digitally tuned at a rate of 100 million new frequencies per second. The sine-wave output can be externally filtered and converted to a square wave by the internal comparator for agile clock-generator applications. The chips provide 14 b of digitally controlled phase modulation and single-pin, phase-shift keying (PSK). When configured with the on-board comparator, the 12-b control DAC facilitates pulse-width modulation (PWM) and static duty-cycle control in a high-speed clock-generator application. The 12-b digital multiplier(s) permit(s) programmable amplitude modulation, shaped on-off keying, and precise amplitude control of the DDS DAC output(s). A programmable 4 × to 20 × REFCLK multiplier circuit can generate clock signals to 300 MHz from a lower-frequency external clock. The chips operate at +3.3 VDC from −40 to +85°C. **Analog Devices, Inc., 814 Woburn St., Wilmington, MA 01887; (800) 262-5643, FAX: (781) 937-1021, Internet: http://www.analog.com.**

CIRCLE NO. 117 or visit www.mwrf.com

Power FET spans 10.11 to 10.7 GHz

The model EIA1011-4M power field-effect transistor (FET) can output RF power levels to 4 W from 10.7 and 10.11 GHz. At the 1-dB compression point, typical output power is +36.5 dBm, typical gain is +10.5 dB, and typical power-added efficiency (PAE) is 30 percent. The transistor's output third-order intercept point (IP3) is 43 dBm, and its input and output are internally matched to 50 Ω. It can dissipate a maximum continuous power of 25 W and operate at a maximum continuous channel temperature of 150°C. The FET is housed in a package measuring 0.65 × 0.382 × 0.0073 in. (1.651 × 0.97028 × 0.018542 cm). **Excelics Semiconductor, Inc., 2908 Scott Blvd., Santa Clara, CA 95054; (408) 970-8664, FAX: (408) 970-8998, Internet: http://www.excelics.com.**

CIRCLE NO. 118 or visit www.mwrf.com

GPS-based time/frequency standards challenge cesium

The model-8 series portable time/frequency-standard receivers are said to have high immunity to propagation and ground-wave effects, and claim to be longer-lived, much less expensive, and at least as accurate as cesium (Cs)-tube-based standards. The receivers use microwave signals from the Global Positioning System (GPS) to control the frequency of a crystal oscillator, an oven-controlled crystal oscillator (OCXO), or a rubidium (Rb) atomic standard. The receivers use high-res-

olution carrier-phase measurement in addition to traditional coarse-acquisition (C/A) code tracking and boast an accuracy 10,000 times better than that attainable with C/A code alone. They have built-in software that averages the signals from all received satellite signals, but can operate properly with only one GPS satellite signal. Stability with OXCO option is better than 1 10ᴵOR − 12. The receivers are available with a standard output frequency of 0.1, 1, 5, or 10 MHz, or an optional output frequency of 2048 kHz or 13 MHz. They have sinewave and transistor-transistor-logic (TTL)-compatible outputs, and are available in bench-top, rack-mount, Euro-cassette, and other forms. Applications include standards laboratories, telecom synchronization, time transfer, and personal-communications-network (PCN)/Global System for Mobile Communications (GSM)/code-division-multiple-access (CDMA) base-station commissioning. **Quartzlock (UK) Ltd., Gothic, Plymouth Rd., Totnes, Devon TQ9 5LH, England; +44 (0)1803 862062, FAX: +44 (0)1803 867962**

CIRCLE NO. 119 or visit www.mwrf.com

DSP supports packet switching

The model MSC8101 digital-signal-processor (DSP) chip is optimized for the telecommunication industry's transition from circuit-switched networks to packet-switched networks. Employing the company's Star*Core technology, the chip is aimed at developers of next-generation communication and networking infrastructure. It includes a 300-MHz DSP core, four arithmetic logic units (ALUs) that provide 1200 DSP million instructions per second (MIPS)—or 3000 reduced-instruction-set-computer (RISC) MIPS, a 150-MHz communications-processor-module (CPM) programmable network-protocol engine, 512 kB (256 k 16-b words) of on-chip static RAM (SRAM), a 100-MHz 64- or 32-b Power-PC-bus interface, and a programmable memory controller, a 300-MHz enhanced-filter coprocessor (EFCOP), and a centralized, direct-memory-access (DMA) engine. The chip is manufactured using the company's 1.3-μm copper (Cu)-interconnect-process technology. It operates with a +1.5-VDC core and an independent +3.3-VDC input/output (I/O) power supply, and dissipates approximately 0.5 W of power. Applications include asynchronous transfer mode (ATM), Fast Ethernet, and time-division multiplexing (TDM). **Motorola Semiconductor Products Sector, P.O. Box 52073, Phoenix, AZ 85072-2073; (602) 413-4991, FAX: (602) 413-7986, Internet: http://www.motorola.com/sps.**

CIRCLE NO. 120 or visit www.mwrf.com

Switches and filters

An 88-page catalog covers switches, filters, attenuators, terminations, couplers, dividers/combiners, and detectors. Coastal switches, lowpass filters, bandpass filters, and power dividers are described. Complete specifications are included. **RLC Electronics, Inc.;** *(914) 241-1334, FAX: (914) 241-1753.*

CIRCLE NO. 121 or visit www.mwrf.com

Voltmeters

An eight-page brochure on high-performance RF power meters and voltmeters focuses on how these instruments conduct automatic-test-equipment (ATE) production tests. Features and benefits of the company's instruments are discussed. **Boonton Electronics Corp.;** *(973) 386-9696, FAX: (973) 386-9191, Internet: http://www.boonton.com.*

CIRCLE NO. 122 or visit www.mwrf.com

Satellite broadcasting

A series of data sheets contains information on satellite broadcasting. Information on video-transmission services, data-transmission services, video applications, audio applications, and data applications is included. A corporate profile is provided. **Microspace Communications Corp.;** *(919) 850-4500, Internet: http://www.microspace.com.*

CIRCLE NO. 123 or visit www.mwrf.com

Interconnect adapter

A 212-page catalog enables engineers to locate adapters and accessories for their device under test (DUT), and can be used as a source book for a range of integrated-circuit (IC) packages and chip types. Emulator tools, logic analyzer/scope adapters, programming adapters, production/test adapters, debugging accessories, prototyping adapters, field-configurable adapters, and custom adapters are covered. **Emulation Technology, Inc.;** *(408) 982-0660, FAX: (408) 982-0664, e-mail: catalog@emulation.com, Internet: http://www.emulation.com.*

CIRCLE NO. 124 or visit www.mwrf.com

Wireless components

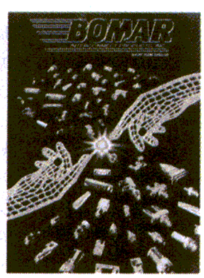
Wireless components, networks, and instruments are covered in a 256-page catalog. Attenuators, VSWR/power monitors, power/ VSWR monitors, circulators, custom assemblies/low-noise amplifiers (LNAs), directional couplers, duplexers, electromechanical switches, filters, and isolators are featured. Personal monitors, power combiners/dividers, receiver couplers, receiver multicouplers, reflectometer couplers, survey meters, switchable combiners, terminations, tower-top amplifiers, and tunable combiners are also offered. **Narda Microwave-West;** *(916) 351-4500, FAX: (916) 351-4550, e-mail: nardawest@L-3COM.com, Internet: http://www.L-3COM.com/narda.*

CIRCLE NO. 125 or visit www.mwrf.com

RF connectors

A line of RF connectors is discussed in a 52-page, short-form catalog. The RF connectors consist of encompassing BNC, twin BNC, miniature TNC, twinax N, ultra-high-frequency (UHF) [mini and multi], F, SMA, and D-subminiature styles. Specialty broadcast connectors, 7/16 DIN, and printed-circuit-board (PCB)-mountable jacks in edge-mount, right-angle, and vertical-mount configurations are also presented. **Bomar Interconnect Products, Inc.;** *(201) 347-4040, FAX: (201) 347-2111, Internet: http://www.bomarinterconnect.com.*

CIRCLE NO. 126 or visit www.mwrf.com



Modems and receivers

Video/audio modulators and demodulators, switching systems, and receivers are featured in a 40-page catalog. Electrical characteristics include frequency range, intermediate frequency (IF), output level, phase noise, and input/output (I/O) impedance. **MITEQ, Inc.;** *(516) 436-7400, FAX: (516) 436-9219, (516) 436-7430, Internet: http://www.miteq.com.*

CIRCLE NO. 127 or visit www.mwrf.com

Epoxy systems

A four-page application-selector guide discusses two-component epoxy systems. Adhesives, sealants, coatings, encapsulants, and potting compounds are covered. Viscosities, mix ratios, setup times, cure schedules, service operating-temperature ranges, color codes, and application recommendations are listed. **Master Bond, Inc.;** *(201) 343-8983, FAX: (201) 343-2132.*

CIRCLE NO. 128 or visit www.mwrf.com

Antenna products

A 24-page brochure offers a range of antenna products and accessories for wireless mobile and land-based communications to automotive applications. The brochure covers wireless telephone hands-free kits and glass-mount, tri-band, concealed bumper, and rooftop antennas for cellular personal-communications-services (PCS) applications. **Hirschmann, Inc.;** *(800) 225-0524, (973) 830-2000, FAX: (973) 830-1470, e-mail: marcomm@hirschmannusa.com, Internet: http://www.hirschmannusa.com.*

CIRCLE NO. 129 or visit www.mwrf.com

Coaxial accessories

A catalog features sections on cable-installation accessories, lightning-protection products, and value-added services. Installation aids and new services for installers are also covered. Product descriptions are included. **Andrew Corp.;** *(800) 255-1479, (708) 349-3300, Internet: http://www.andrew. com.*

CIRCLE NO. 130 or visit www.mwrf.com

Mobile radio

An application note offers different ways to optimize mobile radio networks. The fundamentals of mobile-radio network optimization are discussed. Global System for Mobile Communications (GSM) specifications and a list of abbreviations are provided. **Wandel & Goltermann, Inc.;** *(919) 941-5730, FAX: (919) 941-5751, e-mail: info@ wago.de, Internet: http://www.wg.com.*

CIRCLE NO. 131 or visit www.mwrf.com

MMIC die

A catalog features more than 75 monolithic-microwave-integrated-circuit (MMIC) die, ceramic packaged die, along with plastic packaged die covering DC to 40 GHz. Five millimeter-wave MMIC up/downconverter and amplifier die, as well as attenuators, mixers, and modulators that are suitable for wireless applications are covered. **Hittite Microwave Corp.;** *(781) 933-7267, FAX: (781) 932-8902, e-mail: hmcsales@hittite.com, Internet: http://www.hittite.com.*

CIRCLE NO. 132 or visit www.mwrf.com

Receivers and tuners

Microwave receivers and tuners, up/downconverters, along with VXI and VME products are covered in a catalog. Descriptions are included for each product. **Communication Solutions, Inc.;** *(410) 574-4557, FAX: (410) 574-4559, e-mail: sales@comsol-inc.com, Internet: http://www.comsol-inc.com.*

CIRCLE NO. 133 or visit www.mwrf.com

Test instruments

A 52-page catalog offers instruments for test, measurement, control, and calibration. Sound-level meters, data-acquisition (DAQ) software, temperature indicators, temperature sensors, multifunction calibrators, and multimeters are specified. Power meters, phase indicators, frequency counters, voltage indicators, transmitters, temperature meters, and refractometers are featured. **Davis Instruments;** *(800) 272-6196.*

CIRCLE NO. 134 or visit www.mwrf.com

Adapters and analyzers

A 296-page catalog covers adapters, analyzers, fiber-optic products, oscilloscopes, surface-mount-device (SMD) products, and test instruments. Cabling and conductivity equipment, wire wrap, gauges, as well as soldering and desoldering equipment are presented. An index is provided. **Techni-Tool;** *(800) 832-4866, (610) 941-2400, FAX: (610) 828-5623, e-mail: sales@techni-tool.com, Internet: http://www.techni-tool.com.*

CIRCLE NO. 135 or visit www.mwrf.com

Test and measurement

Benchtop test and measurement information as well as case studies are presented in a 60-page catalog. Descriptions, data sheets and application notes are offered. Oscilloscopes, probes, logic analyzers, multimeters, and data-acquisition (DAQ) systems are also detailed. Four case studies focus on a specific product measurement application. **Hewlett-Packard Co.;** *(800) 452-4844, e-mail: hptm_CustomerCare@hp.com, Internet: http://www.hp.com/go/bi.*

CIRCLE NO. 136 or visit www.mwrf.com

DAQ recorder

A 12-page brochure describes a four-channel data-acquisition (DAQ) field recorder. The brochure contains complete specifications of the unit as well as chart samples. Features are included. **Astro-Med, Inc.;** *(800) 343-4039, e-mail: MTGroup@astro-med.com.*

CIRCLE NO. 137 or visit www.mwrf.com

Communications cabling

A guide on the technology as well as the installation of communications cabling focuses on the significance of a good cabling training course. A list of training resources is also provided. **Fotec, Inc.;** *(800) 537-8254, FAX: (781) 396-6395, e-mail: info@cableu.net, Internet: http://www.cableu.net.*

CIRCLE NO. 138 or visit www.mwrf.com

Power meters

A 16-page brochure details modern and traditional applications of power meters. Specifications are included. **Anritsu Co., Microwave Measurement Div.;** *(408) 778-2000, FAX: (408) 778-0239, Internet: http://www.global.anritsu.com.*

CIRCLE NO. 139 or visit www.mwrf.com

Microwave connectors

A line of custom and standard adapters, receptacles, interface gages, and cable connectors is described in a four-page brochure. Information on the company's capabilities is included. **SRI Connector Gage Co.;** *(407) 259-9688, FAX: (407) 259-9681, e-mail: info@sriconnectorgage.com.*

CIRCLE NO. 140 or visit www.mwrf.com

Trimmer capacitors

A catalog offers ceramic chip-trimmer capacitors. Data on self-resonant frequency, Q, voltage ratings, and temperature co-efficient are shown for each part. Complete specifications are provided. **Voltronics Corp.;** *(973) 586-8585, FAX: (973) 586-3404, e-mail: info@voltronicscorp.com, Internet: http://www.voltronicscorp.com.*

CIRCLE NO. 141 or visit www.mwrf.com

Test equipment

Digital phosphor oscilloscopes and universal cable testers are highlighted in a 308-page catalog. Programmable power supplies, digital multimeters (DMMs), oscilloscopes, spectrum analyzers, frequency counters, erasable-programmable-read-only-memory (EPROM) programmers, function generators, and electronic enclosures are featured. Surface-mount-technology (SMT) products and electrostatic-discharge (ESD) protection products are also presented. **Contact East, Inc.;** *(978) 682-2000, FAX: (978) 688-7829, Internet: http://www.contacteast.com.*

CIRCLE NO. 142 or visit www.mwrf.com

Power supplies

A series of brochures describes a family of rack-mounted, high-density, switch-mode power supplies and related equipment for telecommunications plants. The brochures provide product descriptions, product data, specifications, and schematics, along with ordering information. **Lambda Electronics, Inc.;** *(516) 694-4200, FAX: (516) 293-0519, e-mail: energysys@lambda.com, Internet: http://www.lambdaenergy.com.*

CIRCLE NO. 143 or visit www.mwrf.com

Data loggers

A catalog contains information about a line of single-channel data loggers. Four different loggers are described. Specifications include resolution, sample rate, data storage, and power. **AEMC Instruments;** *(617) 451-0227, FAX: (617) 423-2952, e-mail: sales@aemc.com, Internet: http://www.aemc.com.*

CIRCLE NO. 144 or visit www.mwrf.com

RF components

A 20-page catalog and applications guide describes a line of RF loads and attenuators. New instruments for digital broadcast, high-power forced-air loads, and selection switches are offered. Specifications include power rating, frequency range, connector type, and connector options. A product and application index is included. Outline drawings are presented. **Bird Electronic Corp.;** *(440) 248-1200 ext. 2207, FAX: (440) 248-5426, e-mail: sales@bird-electronic.com, Internet: http://www.bird-electroni c.com.*

CIRCLE NO. 145 or visit www.mwrf.com

VCXOs and CXOs

A catalog features technical information, specifications, and mechanical information for a line of CXOs, PXOs, voltage-controlled crystal oscillators (VCXOs), voltage-controlled-temperature-compensated crystal oscillators (VC-TCXOs), TCXOs, oven-controlled crystal oscillators (OCXOs), and crystals. Oscillators for tight-stability applications and frequency ranges that span 1 to 821 MHz are offered. Surface-mount-device (SMD) oscillator VCXOs, wide-pulling VCXOs and SMD OCXOs are presented.**Fordahl USA;** *(770) 888-0104, FAX: (770) 888-4451, e-mail: mnewco me@fordahl.com.*

CIRCLE NO. 146 or visit www.mwrf.com

Coaxial connectors

Adapters, attenuators, coaxial-cable assemblies, coaxial connectors, and coaxial switches are listed in a 138-page catalog. DC blocks, detectors, directional couplers, limiters, patch cords, phase trimmers, power dividers, terminations, and twinax cable assemblies are covered. A connector identifier and coaxial-cable assembly selection list are included, along with an index. **Pasternack Enterprises;** *(949) 261-1920, FAX: (949) 261-7451.*

CIRCLE NO. 147 or visit www.mwrf.com

Surface-mount devices

A catalog covers surface-mount devices, including Zeners, Schottky, switching, and ultra-high-frequency (UHF) diodes. Bridges, transistors, and junction field-effect transistors (FETs) are provided. Schematic drawings are also offered. **Electronic Devices, Inc.;** *(800) 678-0828, (914) 965-4400, FAX: (914) 965-5531, e-mail: edi-sales@cwix.com, Internet: http://www.edidiodes.com.*

CIRCLE NO. 148 or visit www.mwrf.com

Test equipment

An 18-page catalog focuses on obsolete, hard-to-find test equipment. Amplifiers, logic analyzers, meters, network analyzers, oscilloscopes, power supplies, and pulse generators are presented. Recorders, signal generators, spectrum analyzers, standards, sweep generators, telecommunications gear, and video equipment are also included. **Test Equipment Connection Corp.;** *(800) 615-8378, (407) 804-1299, FAX: (800) 819-8378, (407) 804-1277, Internet: http://www.4test equipment. com.*

CIRCLE NO. 149 or visit www.mwrf.com

Power meters

A 312-page catalog covers test and measurement equipment. The catalog includes specifications for commercial and wireless test sets, signal sources and analyzers, counters and power meters, avionics, along with spectrum analyzers. Microwave, telecommunications, automatic test equipment (ATE), as well as systems and service solutions are also presented. **IFR Americas, Inc.;** *(316) 522-4981, FAX: (316) 522-2328, e-mail: info@ifrinternational.com, Internet: http://www.ifrinternationa l.com.*

CIRCLE NO. 150 or visit www.mwrf.com

Microwave components

Cascadable amplifiers, detectors, intermediate-frequency (IF/RF) attenuators, voltage-controlled limiters, IF/RF limiting amplifiers, and low-temperature co-fired ceramic (LTCC) broadband amplifiers are offered in a 34-page catalog. A section on high-reliability products, value-added services, and cables is included. Specifications as well as outline drawings are provided. **Avnet;** *(800) 332-8638, (408) 360-4000, Internet: http://www.em.avnet. com/rfm/mts.*

CIRCLE NO. 151 or visit www.mwrf.com

DAQ boards

A 32-page catalog covers instrument and data-acquisition (DAQ) solutions. Systems multimeters, sensitive meters, test and measurement software, DAQ boards, and real-time control boards are covered. Features and specifications are included. **Keithley Instruments, Inc.;** (888) KEITHLEY, *(440) 248-0400, FAX: (440) 248-6168, Internet: http://www. keithley.com.*

CIRCLE NO. 152 or visit www.mwrf.com

Frequency control

A 64-page sourcebook features a line of frequency-control devices. A product-selection guide and specifications are offered. Approximately 40 surface-mount and through-hole quartz crystals, crystal oscillators, temperature-compensated crystal oscillators (TCXOs), and voltage-controlled crystal oscillators (VCXOs) are highlighted. Details on environmental specifications are provided, **ECLIPTEK Corp.;** *(800) ECLIPTEK, (714) 433-1200, FAX: (714) 433-1234, e-mail: sales@ eclip tek.com, Internet: http://www.eclip tek.com.*

CIRCLE NO. 153 or visit www.mwrf.com

Test system

A 42-page brochure offers news on test sets and software. A TV test transmitter, TETRA mobile radios, a digital radio-communication tester, and a test platform for multicarrier applications is discussed. A section of application notes is included. **Rohde & Schwarz;** *+4989/4129-2232, FAX: +4989/4129-3208, Internet: http:// www.rsd.de.*

CIRCLE NO. 154 or visit www.mwrf.com

Potting/encapsulation

A two-page application selector guide discusses potting and encapsulation systems. Viscosity, set-up times, cure schedules, service temperature ranges, volume resistivity, and application recommendations are listed for more than 30 grades. **Master Bond, Inc.;** *(201) 343-8983, FAX: (201) 343-2132, Internet: http:// www.masterbond.com.*

CIRCLE NO. 155 or visit www.mwrf.com

Meters/instruments

Multimeters and accessories, clamp-on probes and meters, electrical test instruments, oscilloscopes and accessories, and temperature-measurement instruments are covered in a 64-page catalog. Descriptions and features are also presented. **Meters and Instruments.com;** *(800) 773-0370, FAX: (800) 773-0371, Internet: http://www.metersandins trumen ts.com.*

CIRCLE NO. 156 or visit www.mwrf.com

Grade bridges

Silicon (Si) bridge rectifiers are the focus of a short-form catalog. Specifications include average current, voltage, and surge. Outline drawings are provided. **Electronic Devices, Inc.;** *(914) 965-4400, FAX: (914) 965-5531, e-mail: edi-sales@cwix.com, Internet: http://www.edidiodes.com.*

CIRCLE NO. 157 or visit www.mwrf.com

Low-noise amplifiers

Information concerning offshore solutions for RF and microwave manufacturing requirements is contained in a brochure. A partial list of products manufactured and tested is provided. The company's capabilities and systems are also presented. **Pacific Microwave Corp.;** *(632) 696-9960, FAX: (408) 986-8823, e-mail: pmc@pacific-microwave.com, Internet: http://www.pacific-micro wave.com.*

CIRCLE NO. 158 or visit www.mwrf.com

Data conversion

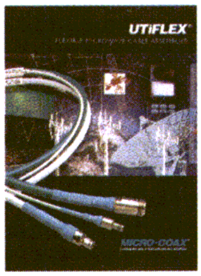
Information on data-conversion and signal-processing integrated circuits (ICs) is included in a product selection guide. Analog-to-digital converters (ADCs), digital-to-analog converters (DACs), video DACs, comparators, and track-and-hold amplifiers are overviewed. Video-line drivers and a video chip set are also highlighted. **Signal Processing Technologies, Inc.;** *(800) 643-3SPT, (719) 528-2300, FAX: (719) 528-2370, Internet: http://www. spt.com.*

CIRCLE NO. 159 or visit www.mwrf.com

Cable assemblies

A 24-page catalog describes flexible microwave cable assemblies that are constructed using a low or ultra-low-density polytetrafluoroethylene (PTFE) dielectric. A selection guide for cables, connectors, and armors, as well as a description of a typical cable construction is included. Complete specifications are included. Sections on part-number designation, cable-assembly care and handling, as well as formulas are provided. **MICRO-COAX;** *(800) 223-2629.*

CIRCLE NO. 160 or visit www.mwrf.com



Tool kits

A 308-page catalog contains a line of handheld meters and tool kits. Test equipment, power and specialty tools, wire and cable, as well as equipment for soldering and telecommunications are included. **Jensen Tools, Inc.;** *(800) 426-1194, (602) 968-6231, FAX: (800) 366-9662, (602) 438-1690, e-mail: jensen@stanleyworks.com, Internet: http://www.jensentools. com.*

CIRCLE NO. 161 or visit www.mwrf.com

Frequency multipliers

Crystal-stabilized sources, frequency multipliers, frequency synthesizers, comb generators, receivers, frequency converters, and microwave subsystems are presented in a 12-page brochure. Specifications include frequency range, voltage, and power output. **Zeta;** *(408) 434-3600, FAX: (408) 433-0205, e-mail: zeta@zeta-sni.com, Internet: http://www.zeta-sni.com.*

CIRCLE NO. 162 or visit www.mwrf.com

Tantalum capacitors

A military and aerospace tantalum products catalog features a series of MIL-qualified tantalum capacitors. Specifications and a part-number chart are included. **AVX Corp.;** *(843) 946-0414, FAX: (843) 448-1943, Internet: http://www.avxcorp.com.*

CIRCLE NO. 163 or visit www.mwrf.com

Tunable filters

A series of data sheets offers information on tunable bandpass and bandreject filters. Specifications include frequency, insertion loss, length, and VSWR. Application information is included. **K&L Microwave, Inc.;** *(410) 749-2424, FAX: (410) 749-5725, e-mail: klsales@klmicrowave. com, Internet: http://www.klmicrowave. com.*

CIRCLE NO. 164 or visit www.mwrf.com

Phase noise

A guide discusses the problem of phase noise when selecting oscillator designs for timing circuits. A technical explanation of phase noise is offered. Random processes in electronic systems that contribute to phase-noise occurrence are presented. Mechanical specifications are also included. **Connor-Winfield Corp.;** *(630) 851-4722, FAX: (630) 851-5040, e-mail: info@con win.com, Internet: http://www.conw in.com.*

CIRCLE NO. 165 or visit www.mwrf.com

Driver amplifiers

A brochure focuses on a pulse pattern generator for evaluating high-bit-rate digital components and systems. Specifications include operating frequency, data output, clock output, and operating temperature range. Descriptions are provided. **LA Techniques Ltd.;** *+44 1522 791244, FAX: +44 1522 793718, e-mail: la@clara.net, Internet: http://ww w.la.clara.net.*

CIRCLE NO. 166 or visit www.mwrf.com

IC sockets

A 280-page catalog describes connectors, cable assemblies, integrated-circuit (IC) sockets, semiconductors, ICs, transistors, diodes, rectifiers, crystals, oscillators, inductors, coils, filters, and capacitors. Resistors, potentiometers, thermistors, optoelectronics, light-emitting diodes (LEDs), and liquid-crystal displays (LCDs) are also specified. Outline drawings are included. Pricing information, descriptions, and an index are provided. **Digi-Key;** *(800) 344-4539, (218) 681-6674, FAX: (218) 681-3380, Internet: http://www.digi key.com.*

CIRCLE NO. 167 or visit www.mwrf.com

Microwave mixers

Microwave and millimeter-wave mixers are covered in a 126-page catalog. Double-balanced mixers, a double-tuned filter mixer, a downconverter mixer, a triple-balanced mixer, a quad mixer, and a power mixer are featured. Electrical specifications and outline drawings are provided. **MITEQ, Inc.;** *(516) 436-7400, FAX: (516) 436-7430, Internet: http://www.miteq.com.*

CIRCLE NO. 168 or visit www.mwrf.com

Ferrite cores

Soft ferrite cores are listed in a selection guide. Electromagnetic-interference (EMI) suppression components for filtering and broadband transformer applications are offered along with E, U, and I cores; toroids; and RM core ferrite components for switch-mode power supplies and high-power applications. Ferrite product offerings in E core and UR core configurations for consumer television and computer monitor flyback transformers, are provided, along with E cores and toroids for electronic ballast applications. **AVX Corp.;** *(843) 946-0414, FAX: (843) 448-1943, Internet: http://www.avxcorp.com.*

CIRCLE NO. 169 or visit www.mwrf.com

Digital oscilloscopes

A 384-page catalog offers an assortment of electronic test equipment. Component testers, digital multimeters (DMMs), cable analyzers, frequency counters, function generators, digital oscilloscopes, and power supplies are featured. The computer testing selection includes benchtop test equipment, erasable-programmable-read-only-memory (EPROM) testers and SIMM testers. Local-area-network (LAN) test-equipment choices include analyzers, category 5 testers, continuity testers, and fiber-optic test equipment. Bit-error-rate (BER) testers as well as transmission test sets are covered in the telecommunications selection. Fiber-optic test equipment is included. **Specialized Products Co.;** *(800) 866-5353, FAX: (800) 234-8286, Internet: http://www.specialized.net.*

CIRCLE NO. 170 or visit www.mwrf.com

PCB connectors

A line of self-aligning printed-circuit-board (PCB) connectors is described in an eight-page brochure. Design possibilities and complete specifications are included. Application notes and outline drawings are provided. **Applied Engineering Products;** *(203) 776-2813, FAX: (203) 776-8294, e-mail: aepsales@aepconnectors.com, Internet: http://www.aepconnectors.com.*

CIRCLE NO. 171 or visit www.mwrf.com

Photodetectors

A catalog highlights indium-gallium-arsenide (InGaAs) photodetectors, receivers, along with monitors. Avalanche Photodiode (APD) and positive-intrinsic-negative (PIN)-based receivers, optical monitors for instrumentation, and photodiodes in inductive-capacitive (LC) receptacles are offered. The products in the catalog are suitable for high-speed receiver applications, Gigabit Ethernet, as well as Optical Monitor Networking. **EPITAXX, Inc.;** *(609) 538-1800, Internet: http://www.epitaxx.com.*

CIRCLE NO. 172 or visit www.mwrf.com

Test equipment

An 18-page brochure covers test equipment. Modeling and pricing information are included. **Test Equipment Connection Corp.;** *(800) 615-8378, (407) 804-1780, FAX: (800) 819-TEST, (407) 804-1277, Internet: http://www.4testequipment.com.*

CIRCLE NO. 173 or visit www.mwrf.com

Pulse generators

Amplifiers, bias tees, lowpass rise-time filters, DC blocks, resistive power-divider tees, emitter-coupled-logic (ECL) and positive-ECL (PECL) terminators, along with attenuators are presented in a 10-page short-form catalog. Specifications include bandwidth, rise time, and insertion loss. Oscilloscope delay lines, transformers, and pulse generators are also featured. **Picosecond Pulse Labs;** *(303) 443-1249, FAX: (303) 447-2236, e-mail: info@picosecond.com, Internet: http://www.picosecond.com.*

CIRCLE NO. 174 or visit www.mwrf.com

Test and measurement

An eight-page catalog features test and measurement cables for phase and amplitude stable measurements to 40 GHz. Low-loss system cables for wireless, space, and high-power RF/microwave applications are presented. Performance charts are included. **MegaPhase;** *(877) MEGAPHASE, (570) 424-8400, FAX: (877) MEGAFAX, (570) 424-6031, e-mail: sales@megaphase.com, Internet: http: //www.mega-phase.com.*

CIRCLE NO. 175 or visit www.mwrf.com

Cermet resistors

A line of surface-mount chip resistors and chip-resistor arrays, surface-mount leaded and leadless resistor networks, through-hole resistor networks, surge/power resistor networks, and strain-gage pointing devices is covered in a 56-page cermet resistor products catalog. Electrical, mechanical, and environmental specifications are listed. Packaging information is provided. **CTS Corp.;** *(219) 589-3111, FAX: (219) 589-3243, e-mail: resistors@rb.ctscorp.com, Internet: http://www.ctscorp.com.*

CIRCLE NO. 176 or visit www.mwrf.com

Cable assemblies

A six-page brochure focuses on a line of microwave cable assemblies. Benefits of the ARACON fiber are also discussed. Specifications include maximum insertion loss, phase stability versus temperature, along with power-handling characteristics. **MICRO-COAX;** *(800) 223-2629.*

CIRCLE NO. 177 or visit www.mwrf.com

SOC solution

A fold-out brochure describes an architecture that combines product-term logic, look-up table logic, and memory into a single device. This family offers content-addressable memory (CAM), extended high-bandwidth input/output (I/O) support [including low-voltage differential signaling (LVDS)], and support for multiple phase-locked loops (PLLs). **Altera Corp.;** *(408) 544-7000, Internet: http://www.altera.com.*

CIRCLE NO. 178 or visit www.mwrf.com

Ceramic capacitors

Information on high-capacitance multilayer ceramic chip capacitors is contained in a brochure. Performance charts are included. A replacement guide for tantalum (Ta) and aluminum (Al) electrolytic capacitors is provided. **Taiyo Yuden, Inc.;** *(800) 348-2496, FAX: (408) 573-4159.*

CIRCLE NO. 179 or visit www.mwrf.com

Isolators and circulators

A 14-page catalog highlights R-class, S-class, and M-class drop-ins. Isoadapters, waveguides, isolators, and circulators are covered. Outline drawings are provided. **Alcatel;** *(408) 229-8171, FAX: (408) 229-8506, Internet: http://www.ferrocom.com.*

CIRCLE NO. 180 or visit www.mwrf.com

Filters and oscillators

Crystal oscillators (XOs), voltage-controlled XOs (VCXOs), temperature-compensated XOs (TCXOs), VCTCXOs, voltage-controlled oscillators (VCOs), oven-controlled XOs (OCXOs), and filters are specified in a 60-page catalog. An appendix is included, along with outline drawings. **Piezo Technik GmbH;** *+49 7264 9145-0, FAX: +49 7264 7557, e-mail: info@foq.de, Internet: http://www.foq.de.*

CIRCLE NO. 181 or visit www.mwrf.com

Antenna feeds

A catalog presents standard antenna products which are available from stock or for near-term delivery. Antennas, antenna feeds, specialized microwave components, microwave subsystems, and testing services are examined. **Seavey Engineering Associates, Inc.;** *(781) 829-4740, FAX: (781) 829-4590, e-mail: info@seaveyantenna.com, Internet: http://www.seaveyantenna.com.*

CIRCLE NO. 182 or visit www.mwrf.com

Wireless cable

Copper (Cu) combiners, Cu accessories, aluminum (Al) combiners, Al accessories, interference filters for wireless cable, video/audio combiners, and multipoint distribution systems (MDS)/multichannel MDS (MMDS) combiners are covered in a 38-page catalog. Radar-interference filters, MMDS relay antennas, filters for 28-GHz local-multipoint-distribution-system (LMDS) band, lowpass harmonic-suppression filters, transmission-line accessories, and tunable notch filters are also featured. Specifications are provided. **Microwave Filter Co.;** *(800) 448-1666, (315) 438-4700, FAX: (888) 411-8860, (315) 463-1467, e-mail: mfcsales@microwavefilter.com, Internet: http://www.microwavefilter.com.*

CIRCLE NO. 183 or visit www.mwrf.com

Pulsed EMI

A handbook on pulsed electromagnetic interference (EMI) provides a reference for understanding threats, test requirements, and requirements of the European Union's electromagnetic-compatibility (EMC) directive for compliance testing. Electrostatic discharge (ESD), electrical fast transients (EFT), surges resulting from lightning or switching in the power grid, and power-quality failure (PQF) are examined. **KeyTek;** *(978) 275-0800, FAX: (978) 275-0850, e-mail: sales@keytek.com, Internet: http:// www.keytek.com.*

CIRCLE NO. 184 or visit www.mwrf.com

Epoxy preforms

A brochure contains an overview of standard and custom epoxy preform applications. Advantages of epoxy preforms compared to traditional liquid-dispensing systems are discussed. An introduction to automatic, semi-automatic, and manual loading systems is included. Product specifications are provided. **Multi-Seals, Inc.;** *(860) 643-7188, FAX: (860) 643-5669.*

CIRCLE NO. 185 or visit www.mwrf.com

Microwave components

A 15-page product guide presents custom RF and microwave power transistors, monolithic microwave integrated circuits (MMICs), and power amplifiers (PAs). General-purpose amplifiers, frequency-modulation (FM) broadcast amplifiers, high-frequency (HF) and very-high-frequency (VHF) amplifier pallets and modules, and low-noise amplifiers (LNAs) are specified. **Richardson Electronics;** *(800) 737-6937, (630) 208-2200, FAX: (630) 208-2550, e-mail: ssc@rell.com, Internet: http: //www.rell.com.*

CIRCLE NO. 186 or visit www.mwrf.com

Long-life switches

A line of long-life magnetic switches is covered in a six-page brochure. A single-pole, double-throw (SPDT) fail-safe switch, a double-pole, double-throw (DPDT) transfer switch, and a single-pole, six-throw (SP6T) multiposition switch are included. **Dow-Key Microwave Corp.;** *(805) 650-0260, FAX: (805) 650-1734, Internet: http://www.dowkey.com.*

CIRCLE NO. 187 or visit www.mwrf.com

DAQ solutions

Transient recorders, data acquisition (DAQ) and recorders, oscilloscopes, power and isolation products, telemetry products, and software products are featured in a 20-page short-form catalog. Specifications are provided, along with descriptions. **Nicolet Instrument Technologies;** *(608) 276-5600, FAX: (608) 273-5061, Internet: http://www.niti.com.*

CIRCLE NO. 188 or visit www.mwrf.com

Telecom tools

Cable locators, cable testers, digital multimeters (DMMs), fiber-optic test equipment and tools, oscilloscopes, power-analysis equipment, and telecom test equipment are described in a 128-page catalog. **Specialized Products Co.;** *(800) 866-5353, FAX: (800) 234-8286, Internet: http://www.specialized.net.*

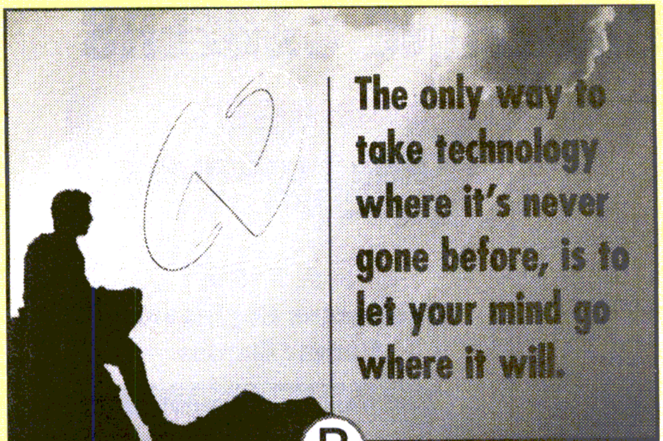
CIRCLE NO. 189 or visit www.mwrf.com

Test equipment

A 100-page catalog highlights new and reconditioned test equipment, including coaxial connectors and accessories, component test instruments, electromagnetic-interference (EMI) tools and accessories, frequency counters, function/sweep generators, lightwave instruments and cable testers, as well as oscilloscopes and accessories. Power supplies, recorders and data acquisition (DAQ), and spectrum analyzers are also specified. **Tucker Electronics;** *(800) 527-4642, (214) 348-8800, FAX: (214) 348-0367, Internet: http://www.planettest.com.*

CIRCLE NO. 190 or visit www.mwrf.com

In most cases, advertisements contained in Microwaves & RF employment section indicate that the companies are equal opportunity employers. The Federal Civil Rights Act of 1964, and other laws, prohibit discrimination in employment based on race, color, religion, national origin, sex or for any reason other than lack of professional qualification for the position being offered. It should be noted that employment advertisements in Microwaves & RF are published for the readers convenience and in no way, to the best of our knowledge, promote unlawful discrimination.



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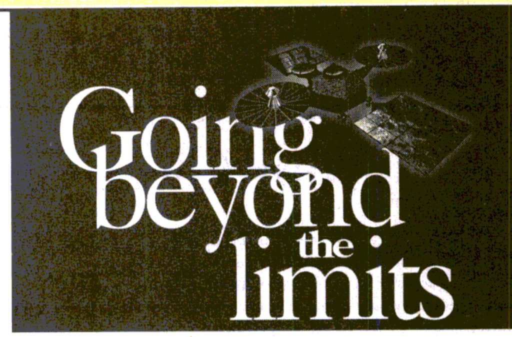

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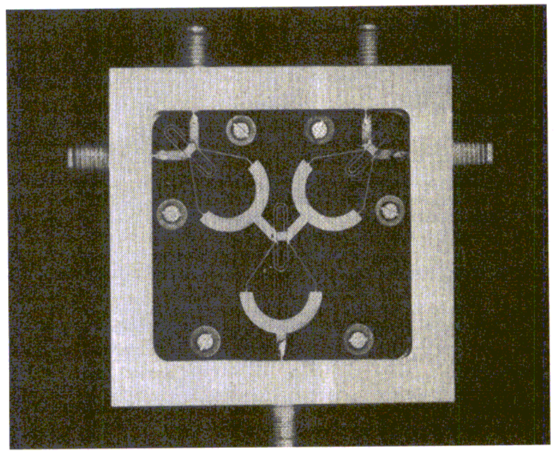

Eighteen years ago, Richard Webb of Magnavox Government and Industrial Electronics Co. (Fort Wayne, IN) reported on a new class of stepped-impedance power dividers and combiners that offered Wilkinson-like performance at a fraction of the size. A four-way, 2-GHz design was fabricated on Duroid 5880.

Microwaves & RF December Editorial Preview

Issue Theme: Wireless Show Preview

News

December marks not only the end of a year, but the end of a decade. It has been a decade of change for the high-frequency industry, one in which military applications lost their stranglehold over many manufacturers as wireless systems brought the long-awaited promise of commercial applications. A Special Report will look back at the year and the decade that was, in a review of some of the changes that took place among companies, people, and technologies in the high-frequency industry.

Design Features

Design Features in December equip wireless designers with practical techniques for active and passive circuits. For example, an author from Motorola will discuss the design of a low-noise amplifier (LNA) for cellular and personal-communications-services (PCS) applications. Two authors from Canada will explain the effects of radiation from cellular telephones on human brains, and how electromagnetic (EM) simulation tools can be used to optimize the performance of a millimeter-wave klystron.

Product Technology

December's Product Technology section will feature one of the more advanced automatic test systems ever developed for wireless amplifier testing. This system arms amplifier designers with a great deal of information on the linearity of their products.

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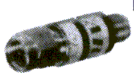
FIXED ATTENUATORS DC-18 GHz $40.

- Models to 55 dB
- SMA or Type N conn.
- 50 W average models

Freq. Range (GHz)	Average Power (W)	Model No. N Conn.	Model No. SMA Conn.
DC-18.0	1	N9412-*	9412-*
DC- 5.0	1	N4402-*	4401-*
DC- 4.0	5	N4405-*	4405-*
DC- 4.0	10	N4410-*	4410-*
DC- 4.0	25	N4425-*	4425-*
DC- 4.0	50	N4450-*	4450-*

*Value of attenuation

4425 Types



9412 & 4401 Types (1.14")

N9412 Types (2.42")

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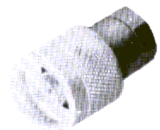

- DC-18 GHz model
- 50 W model
- SMA or Type N conn.

Freq. Range (GHz)	Average Power (W)	Model No. N Conn.	Model No. SMA Conn.
DC-18.0	1		9512
DC-12.4	2	N9512	
DC-12.4	5	N9505	9505
DC-12.4	10	N9510	9510
DC- 8.0	25	N9525	9525
DC- 8.0	50	N9550	

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Freq. Range (GHz)	Medium Power Average (W)	Medium Power Model No.	High Power Average (W)	High Power Model No.
2.60- 3.95	1200	284-925	4500	284-920
3.30- 4.90	1000	229-925	3000	229-920
3.95- 5.85	750	187-925	2000	187-920
4.90- 7.05	625	159-925	1500	159-920
5.85- 8.20	500	137-925	1000	137-920
7.05-10.0	425	112-925	600	112-920
7.00-11.0	325	102-925	500	102-920
8.20-12.4	225	90-925	500	90-920
12.4 -18.0	200	62-925	250	62-920

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