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FOR DESIGNERS AT HIGHER FREQUENCIES

Microwaves & RF

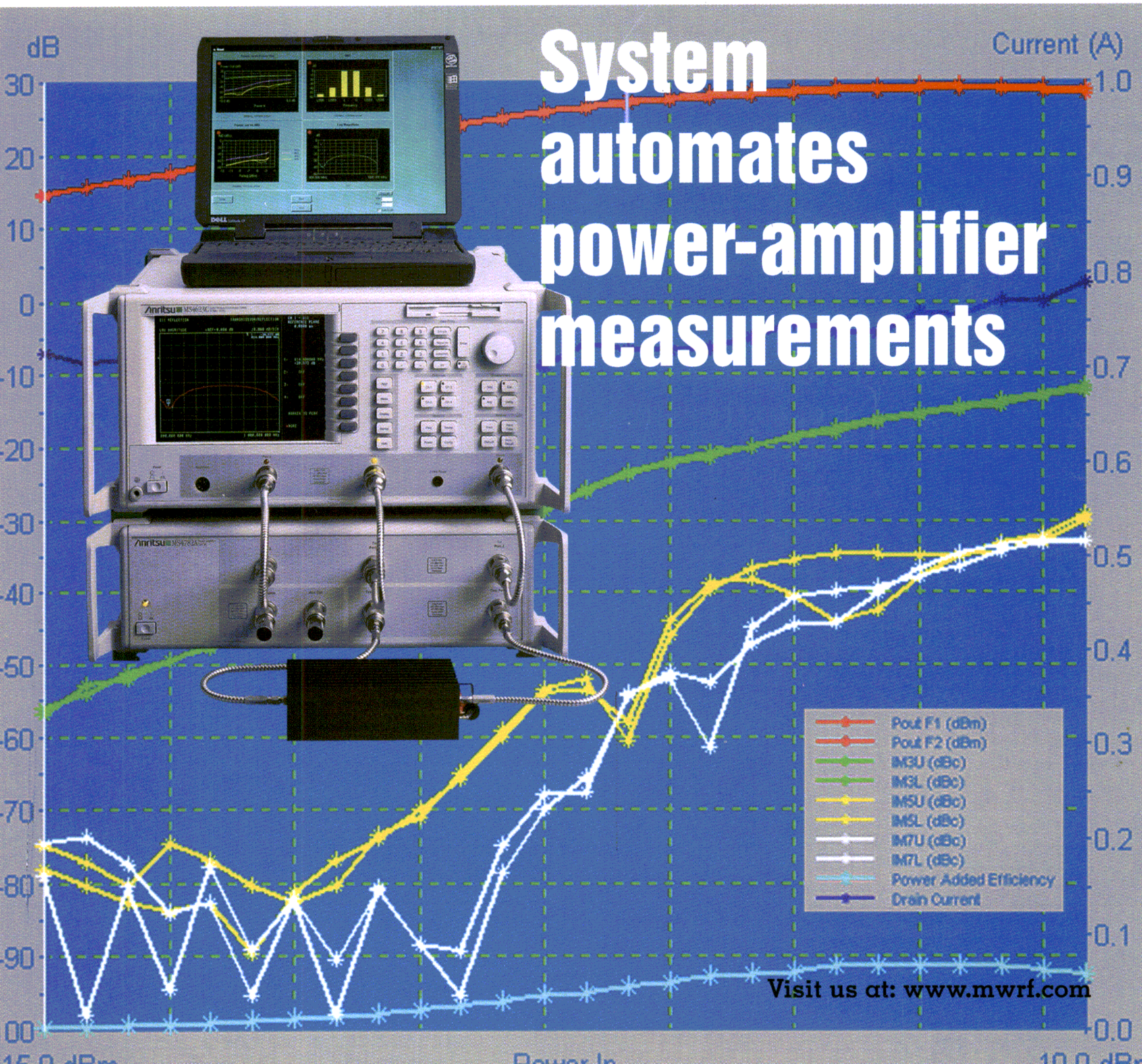
Wireless Show Issue

NEWS
Reviewing a decade of change

DESIGN FEATURE
Designing low-noise amps

PRODUCT TECHNOLOGY
Top Products of 1999

System automates power-amplifier measurements



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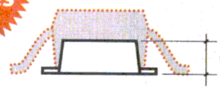
New NEC Bipolar Transistors

Higher f_Ts, Lower 1/f

New, Smaller Packages

Visit us at BOOTH 417 WIRELESS SYMPOSIUM

NEW Packages



- **Flat Lead** design reduces parasitics and improves electrical performance
- **Low Profile** package is ideal for PCMCIA and other space-constrained designs

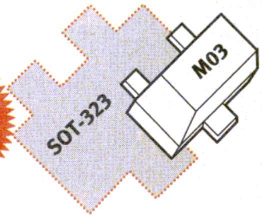
Oscillators & Buffer Amps

With the best *1/f* performance available, these devices help you achieve the phase noise your design demands. They're also available in Twin Transistors.

Part Number	Corner Freq*	V_{CE}	I_C	Package
NE856M03	3 KHz	3 V	30 mA	M03
NE685M03	5 KHz	3 V	5 mA	M03

**Review Application Note AN1026 on our website for more information on 1/f noise characteristics and corner frequency calculation.*

HALF SIZE



New M03

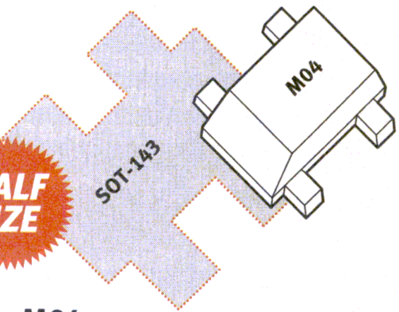
Half the footprint area of a SOT-323

LNAs

Need low noise and high gain in an ultraminiature package for your hand-held wireless products? These new high frequency NPN transistors deliver!

Part Number	Description	NF	Gain	Freq	Package
NE687M03	11 GHz f_T LNA	1.2 dB	13 dB	1 GHz	M03
NE661M04	25 GHz f_T LNA	1.2 dB	22 dB	2 GHz	M04
NE662M04	23 GHz f_T LNA	1.1 dB	20 dB	2 GHz	M04

HALF SIZE

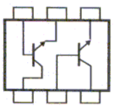


New M04

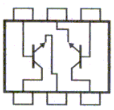
Half the footprint area of a SOT-143

Twin Transistor Devices

Cascode LNAs, cascade LNAs and oscillator/buffer combinations are just three possible uses of these versatile devices. *Matched Die* versions pair two adjacent die from the wafer to help simplify your design, while *Mixed Die* versions — an NEC exclusive — let you optimize oscillator performance while achieving the buffer amp output power you need. 40 different combinations available.

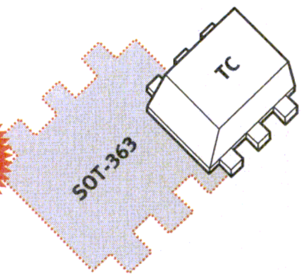


Part Number	Description	Q1 Spec	Q2 Spec
UPA810TC	Matched Die/Cascade LNA	NE856	NE856
UPA814TC	Matched Die/Cascade LNA	NE688	NE688



Part Number	Description	Q1 Spec	Q2 Spec
UPA826TC	Matched Die/Osc-Buffer Amp	NE685	NE685
UPA840TC	Mixed Die/Osc-Buffer Amp	NE685	NE681

HALF SIZE



New TC Twin Transistors

Half the footprint area of a SOT-363

Data Sheets and Application Notes are available at **www.cel.com**

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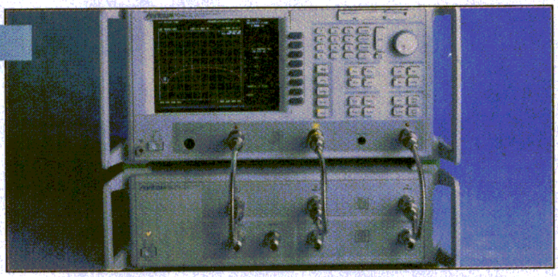

DEPARTMENTS

NEWS

WIRELESS SYMPOSIUM & EXHIBITION

BLUETOOTH SECTION

HIGH-SPEED DESIGN

SOFTWARE SOLUTIONS

DESIGN FEATURES

PRODUCT TECHNOLOGY

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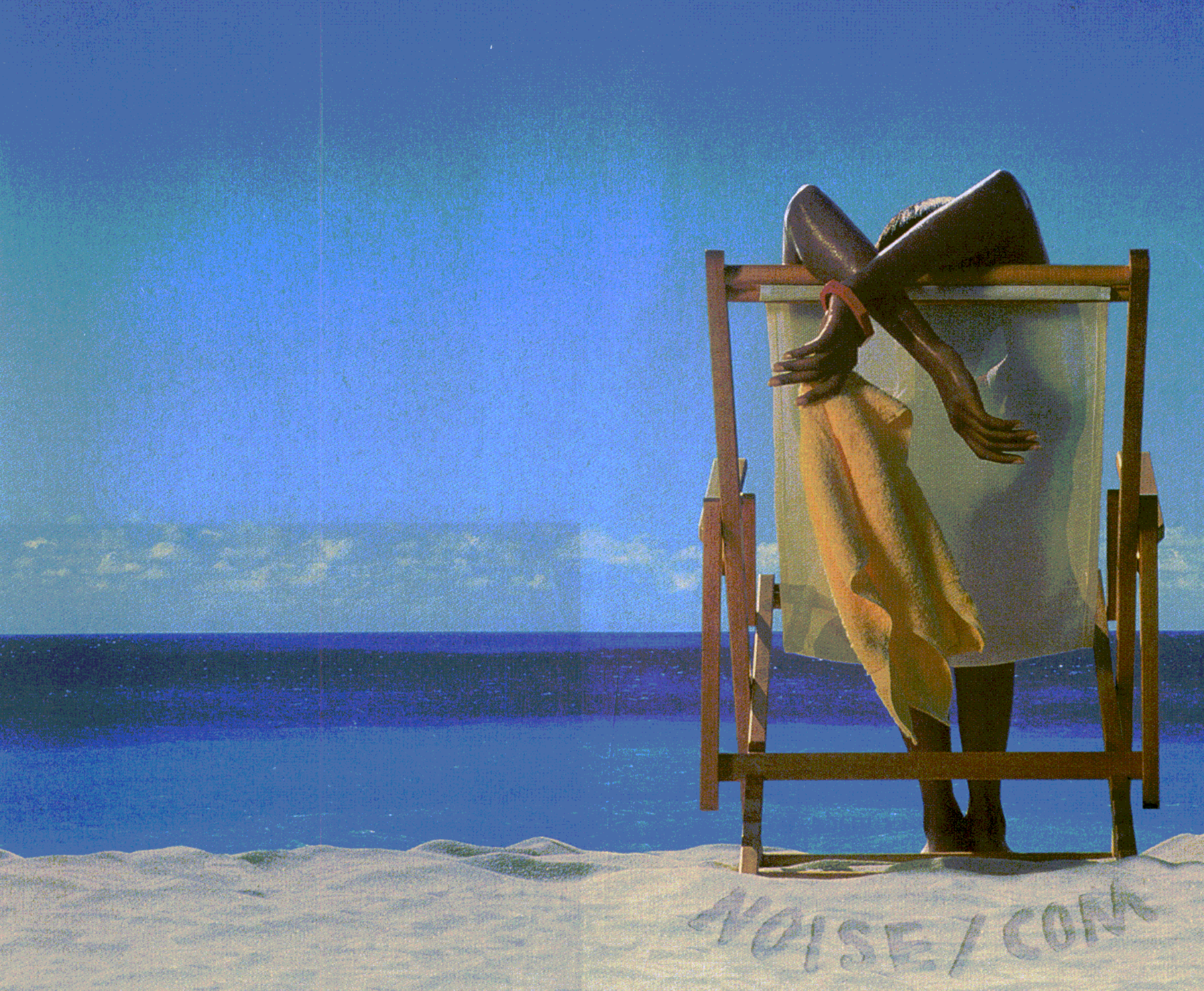
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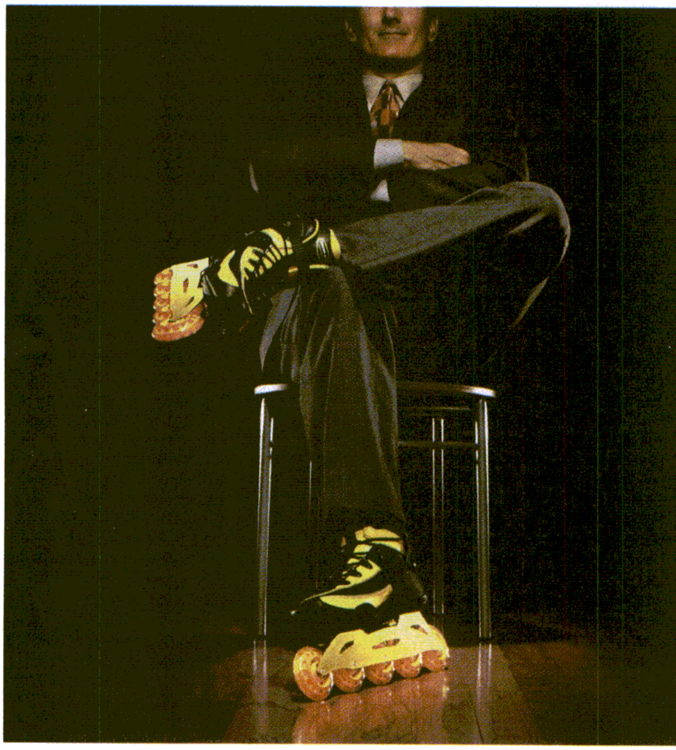

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As part of an ongoing focus to meet customer needs, two stars in the RF arena — Richardson and Motorola — have joined forces to provide you the best in RF technology. Richardson Electronics is now authorized worldwide to sell Motorola wireless RF and IF components.

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CIRCLE NO. 235

TABLE FLAW

To the editor:

I am sure you or your staff have noticed the flaw in the table that appeared at the top of page 139 in your October 1999 issue. In the bottom row of the table, the listings should be 10^7 rather than 107.

Also, it should be noted that all semiconductor devices, including electron tubes, operate on the basis of the DIODE equation, although their transconductance efficiency will be low. The transconductance can be defined in terms of the device output current and Kappa (K), q, k, and T, where q, k, and T have the usual meanings in solid-state physics:

$$g_m = KqI/kT$$

where:
K = the transconductance efficiency,
I = the device current, and
q and kT = are the usual parameters that have the usual definitions in solid-state physics.

The value of Kappa may be defined by reading the input-voltage change that is required to make a 2:1 change in output current and divide it into 0.018, namely:

$$K = 0.018/\Delta V$$

Using these equations or a curve of Kappa versus current and the first equation will improve design effectiveness.

Keats Pullen Jr.
Kingsville, MD

ELECTRON TUBES

To the editor:

I found November's editorial (p. 17) on electron tubes and the decreasing amount of technology developments in this area to be interesting. I am a clinical engineer for the Department of Radiation Oncology at St. Luke's Hospital in Missouri. I have maintained and repaired Varian linear accelerators for the last 12 years and have attended several courses taught by Varian in Palo Alto, CA. At the last course, they mentioned that they were developing magnetrons that can put out as much power as some of the much bulkier klystrons using an electromagnet on the magnetron versus using a fixed magnet.

I think they will never be able to replace the klystron or magnetron for putting out serious RF power. But since we are in the computer age, they continue to update and miniaturize electronic circuits and modules to the point that they cannot be repaired, but only replaced by complete board replacements. But if you loose a magnetron or a klystron, that is where you need someone who is knowledgeable about these tubes to make the decision on whether to replace it or find the source of the problem. Thank you for your article on this subject. I enjoyed it.

Rick Guthrie
Clinical Engineer
Missouri

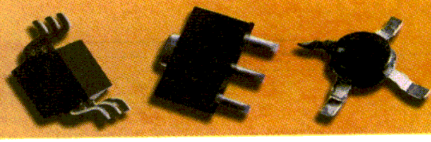
Silicon Germanium (SiGe), Stanford Microdevices' latest RF semiconductor process, offers benefits not attainable by conventional silicon-bipolar technologies: lower noise figures, lower power consumption, high output power at high efficiency, and high integration level.

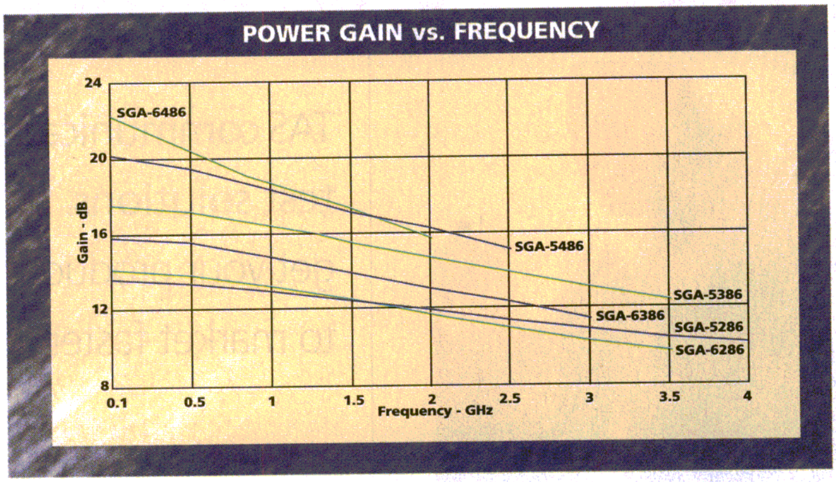
As part of a series of Stanford Microdevices' initiatives to apply silicon germanium technology to a broad spectrum of communications applications, we are now offering the wireless market devices built using a patented silicon germanium manufacturing process. As these devices enter the marketplace, consumers 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.

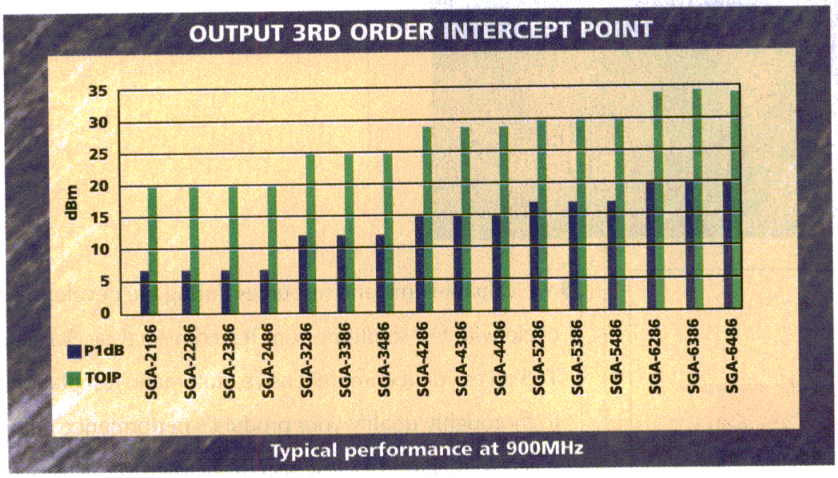
PRODUCT SELECTION GUIDE
General Purpose Amplifiers

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. 223

THE LAST ISSUE OF THE CENTURY

Millennium madness is upon us (although the true millennium is still a year away). Newscasts, magazines, and newspapers are alive with stories on the millennium—celebrations to bring in the new one and tales of individuals and events from the old one. This millennium "fever" has many people believing that some magic barrier will be passed on that midnight of December 31st when, in fact, it is just another New Year. Amid all this madness, it is easy to overlook the energy and excitement of this past year, as well as the changes that have transpired.

If anything, 1999 could be called "The Year of the Internet" given the amount of attention lavished on the World Wide Web. On the stock market, any Initial Public Offering (IPO) with a ".com" at the end of the name was almost guaranteed to double in price during the first day of trading. In the world of commerce, companies are now judged by their website. And even the high-frequency industry felt the effects of the Internet in 1999. Exhibitors at PCS '99 (New Orleans, LA) could not make the letters WAP (for Wireless Access Protocol) at their booths big enough to convey their excitement about the business potential for wireless Internet services.

The past year was a time when the words "millimeter wave" no longer signified a technology that was "just around the corner." Growing interest in the use of line-of-sight links at 28 and 38 GHz for cellular backhaul, data transmissions, and local multipoint distribution systems (LMDS) finally convinced millimeter-wave equipment manufacturers to seek cost-effective ways to produce these once-exotic parts.

It was a year when companies in military and space-based electronics found stability (and often growth). It was also a year when IRIDIUM—that 10-years-in-the-making, satellite-based, cellular system—finally flew, and then crashed (for lack of subscribers). It was a year in which the sales of traditional terrestrial cellular telephones continued to climb (thanks to the widespread acceptance of one-rate billing plans by service providers), and a year in which telephone companies sought to buy cable-television (CATV) companies with a vision toward providing all-in-one (voice, data, video, and Internet) service.

It was a year for products based on new technologies, such as silicon-carbide (SiC) transistors from Cree Research (Durham, NC) and Si-germanium (SiGe) integrated circuits (ICs) from Maxim Integrated Products (Sunnyvale, CA). And it was a year of great change, notably the transformation of part of one of the industry's greatest companies, Hewlett-Packard Co., to Agilent Technologies. The fanfare surrounding the change has been reminiscent of the spinout of Lucent Technologies from AT&T.

Finally, it was a year of great sadness and loss. It was a time when this magazine lost one of its finest editors, Victor Perrote, as well as one of its noblest contributors, David Sprague. With this last issue of the century, we remember these friends. And we urge you to remember not just the millennium but, fully, the year 1999, for it was a year for the ages.

Jack Browne

Publisher/Editor

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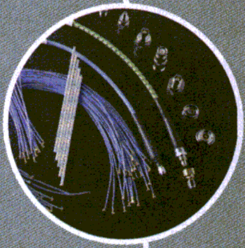
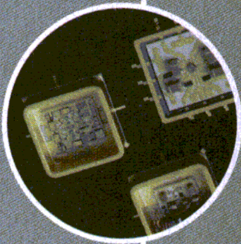
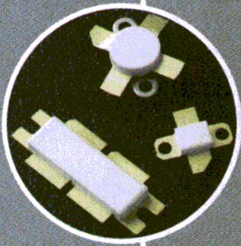
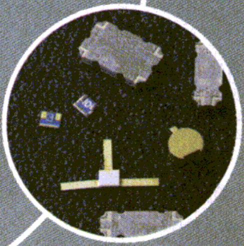
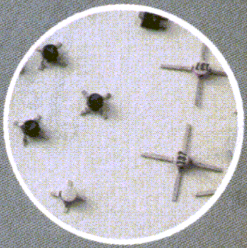

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PRODUCTS

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SUPPLIER	RF INTERCONNECT: CONNECTOR/ADAPTERS	RF INTERCONNECT: CABLE ASSEMBLY/ANTENNAS	RF INTERCONNECT: TEST&MEASURE COMPONENTS	RF POWER: TRANSISTOR	RF POWER: MODULES	RF POWER: AMPLIFIER	RF POWER: COUPLER/COMBINER/LOADS	RF SEMI'S & COMPONENTS: TRANSISTOR	RF SEMI'S & COMPONENTS: DIODE	RF SEMI'S & COMPONENTS: RFIC/MMIC	RF SEMI'S & COMPONENTS: LNA	RF SEMI'S & COMPONENTS: SWITCH	RF SEMI'S & COMPONENTS: HYBRIDS	RF PASSIVES: CAPS	RF PASSIVES: INDUCTORS	RF PASSIVES: CIR/ISOLATOR	RF PASSIVES: FILTERS/DUPLEXER	FREQ CONTROL/CONVERSION: MIXERS/MOD/DEMOD	FREQ CONTROL/CONVERSION: PLL/SYNTHESIZERS	FREQ CONTROL/CONVERSION: VCO/CRYSTALS
AEP (APPLIED ENGINEERING PRODUCTS)	●	●																		
AGILENT TECHNOLOGIES (HP)			●					●	●	●	●	●						●		●
AMP	●	●																		
AMPHENOL	●	●																		
ANALOG DEVICES										●	●							●	●	
ANAREN MICROWAVE							●													
ANRITSU	●	●	●																	
AVANTEK					●	●					●		●							
AVNET MTS		●			●	●					●		●							
AVX														●	●		●			●
BC COMPONENTS (PHILIPS COMPONENTS)														●						
BERG/FCI (SPECIALTY)	●																			
BOURNS															●					
CONEXANT SYSTEMS INC.(ROCKWELL)						●				●	●							●		
CTS CORPORATION																				●
CTS WIRELESS (MOTOROLA CPD)																	●			●
DALE															●					
ECLIPTEK																				●
EIC CORPORATION						●		●		●	●									
EMC TECHNOLOGY							●													
EPCOS (SIEMENS)															●		●			
ERICSSON				●	●	●														
FDK FUJI ELECTROMECHANICAL CO, LTD															●	●				●
FOX																				●
FUJITSU										●	●						●	●	●	●
HITACHI				●	●	●		●	●	●	●						●	●		
INFINEON (SIEMENS)								●	●	●	●	●						●		
INTERSIL (HARRIS)								●		●	●	●						●	●	
ITT INDUSTRIES CANNON (SEALECTRO)																				
JOHANSON TECHNOLOGY														●			●			
JOHANSON MANUFACTURING														●						
JOHNSON COMPONENTS	●	●																		
M/A-COM	●	●	●	●	●	●		●	●	●	●	●	●			●		●		●
MAXIM						●				●	●							●		●
MICROSEMI				●				●	●											
MOLEX	●																			
MOTOROLA				●	●	●		●	●	●	●		●					●	●	●
M-PULSE								●	●	●	●									
M-TRON																				●
MURATA	●	●		●				●						●	●	●	●	●		●
NATIONAL SEMICONDUCTOR										●								●		
OKI				●				●		●	●							●		
PANASONIC															●					
PHILIPS SEMICONDUCTORS				●	●	●		●	●	●	●					●		●		
PRECISION TUBE		●																		
PULSE/VALOR															●					
RAYTHEON					●	●				●	●									
ROHM								●												
SARONIX																				●
SAWTEK																	●			
SPRAGUE/VISHAY														●			●			
STANFORD MICRODEVICES				●		●		●		●	●	●								
ST-MICROELECTRONICS (SGS)				●	●	●														
SYNERGY										●			●					●		
TDK														●	●		●			●
TEMIC DIV OF ATMEL								●	●	●	●									
TEXAS INSTRUMENTS						●				●	●							●	●	
TOKO															●		●			
TOSHIBA				●	●	●		●	●	●										●
TUSONIX														●			●			

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CIRCLE NO. 224

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Advanced Electronic-Packaging Market Is Soaring

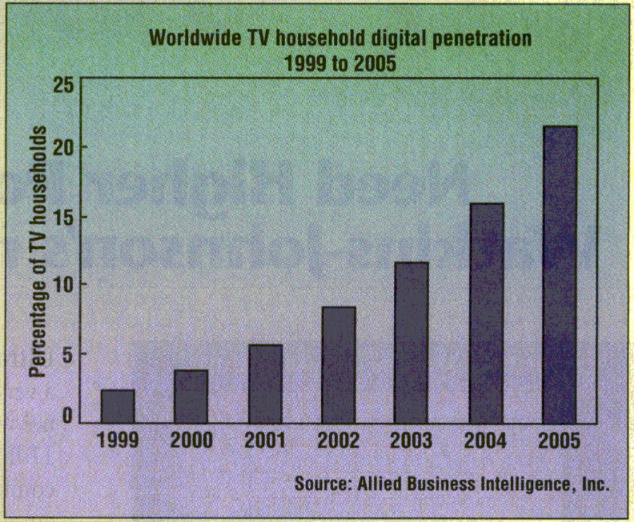
NORWALK, CT—According to a Business Communications Co., Inc. study, *GB-235 Advanced Electronic Packaging*, the market for advanced electronic packages is estimated at approximately 3 billion units in 1999. This market for ball-grid-array (BGA), chip-scale-packaging (CSP), and flip-chip integrated-circuit (IC) packaging technologies is expected to grow at an average annual growth rate (AAGR) of 35.7 percent to reach 16 billion units by 2004. These units are components sold in the IC markets that are packaged in one of the advanced packages.

To a large extent, however, the 35.7-percent AAGR is the projected result of the increasing use of newer CSP technologies in wider application markets. From 1999 to 2004, an AAGR of between 40 and 50 percent is forecast for unit growth as production ramps up for the CSP group of standard and emerging advanced-packaging technologies. Furthermore, a large portion of the total market's unit increase is the expected result of continual market penetration into the traditional packaging-applications markets. Those advanced packages will enable the IC manufacturer's higher-performance applications and original equipment manufacturer's (OEM's) size-constrained products with component requirements that can no longer be met by the traditional electronic packages.

The market for advanced electronic packages is estimated at $5 billion for 1999. Growing at an AAGR of 34.7 percent from 1999 to 2004, this market is expected to total $23 billion by 2004. These revenues represent only the part of the price of the IC in the IC market that is the cost of the package. An application in the high end of the contract-engineering markets may have more custom prototyping and non-recoverable engineering costs associated with it as part of the package price.

Worldwide Digital Broadcasting To Show Substantial Growth

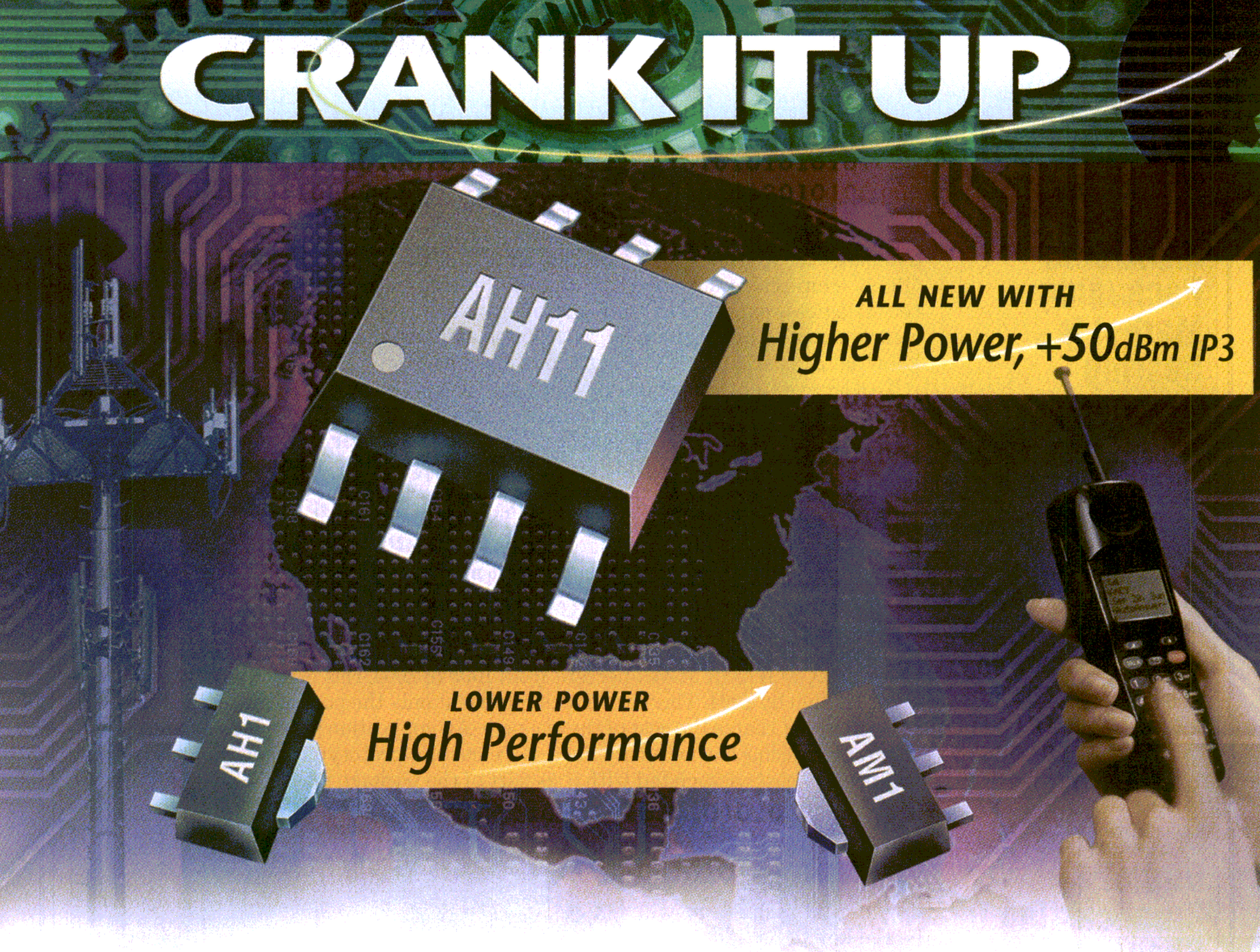
OYSTER BAY, NY—Similar to nearly all communications technologies today, digital technology will be the key to broadcast services, including the new age of television, according to a report from Allied Business Intelligence, Inc. (ABI). The report, "Digital Broadcast 99—Worldwide Market for Digital Broadcast Systems and Equipment," states that worldwide digital broadcasting, including satellite, cable, and terrestrial services will have a 43-percent compound annual growth rate (CAGR) from 1999 to 2005. Growth is being driven by the convergence of computers with televisions, spawning an ever-widening audience for new services. Entertainment will attract the majority of subscribers, and real video-on-demand—when it arrives—will be a major source of income for broadcasters.



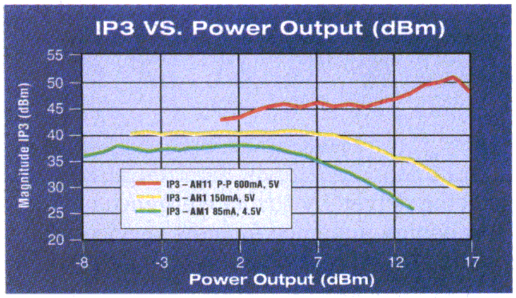
By year-end 1999 there will be a 2.5-percent worldwide penetration of digital TVs per household for all digital-broadcasting services. This penetration rate will rise to 21 percent by year-end 2005 (see figure).

Global digital TV and set-top box sales will rise in 2003, igniting a sharp annual growth rate of 121 percent for digital terrestrial services and a penetration of 5.2 percent of all TV households over the next five years. Digital satellite will have the largest number of worldwide digital subscribers in 2005 with 94.7 million.

In the US, the current penetration rate of 16 percent for digital services for all TV households primarily stems from digital-broadcasting-services subscribers. ABI forecasts that the total US digital-services penetration rate will increase to 60 percent by 2005. The most active digital broadcast regions are North America and Europe, with 92 percent of all digital subscribers.



Need Higher Power? You need Watkins-Johnson's new AH11 amplifier.



WJ High Dynamic Range Amplifiers

Product	Frequency (MHz)	IP3 (dBm, typ.)	P1dB (dBm, typ.)	NF (dB, typ.)	Bias current (mA, typ.)
AH11	250-3000	47	27	3.7	600
AH1	250-3000	41	21	2.9	150
AM1	250-3000	36	18	2.6	75

Ultra high IP3 is what our new **AH11** is all about. Combined with a very low noise figure, it's the perfect choice for today's multichannel wireless systems. Drawing only 600mA, the AH11 delivers 17dBm of linear output power with an IP3 of 50dBm. A great price combined with the outstanding linear efficiency makes this versatile amplifier perfect for multiple sockets, reducing overall part count.

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CIRCLE NO. 270

Search For Extraterrestrial Intelligence Is Extended

WESTLAKE VILLAGE, CA—Elanix, Inc. recently announced that it has donated several licenses of SystemView by Elanix to help the SETI Institute develop next-generation signal-processing systems to seek out evidence of extraterrestrial intelligence. The donated licenses have an approximate value of $163,000.

SystemView by Elanix is a Windows simulation and analysis software for communications, digital-signal-processing (DSP), and RF/analog applications. SystemView enables software designers to determine the optimal design parameters and shortens development time by enabling thorough debugging and testing early in the software-design cycle.

The SETI Institute's Project Phoenix searches the microwave spectrum for pulsed and narrowband continuous-wave (CW) signals that might indicate extraterrestrial communication technology, focusing on the regions around individual stars similar to the sun. The system looks for extremely weak signals in a radio environment that is rich with strong RF interference (RFI), so system artifacts must be kept to an absolute minimum. SETI engineers are designing a new generation of receivers and signal detectors to replace the current Phoenix system, which was built nearly a decade ago. The new system, which has been in development since late last fall, will become operational in the fall of 2000.

"SystemView was already our top contender for this work on our new SETI system, and the fact that Elanix has generously contributed these licenses for SystemView makes this a particularly positive situation for us," says Dr. Kent Cullers, developer of the SETI signal-processing algorithms, whose work with SETI was portrayed through the character of Kent Clark in the film *Contact*.

First Nationwide Wireless Customer Internet Survey Is Conducted

NEW ORLEANS, LA—Telephia™ announced the first findings from Wireless E~Trac, the largest Internet survey of wireless subscribers ever conducted. In the largest and most comprehensive survey of its kind, Telephia, in partnership with Harris Interactive, an Internet market-research company, has surveyed wireless subscribers to better understand wireless brand awareness, buying and usage habits, customer satisfaction, interest in new product offerings, and factors affecting switching and loyalty.

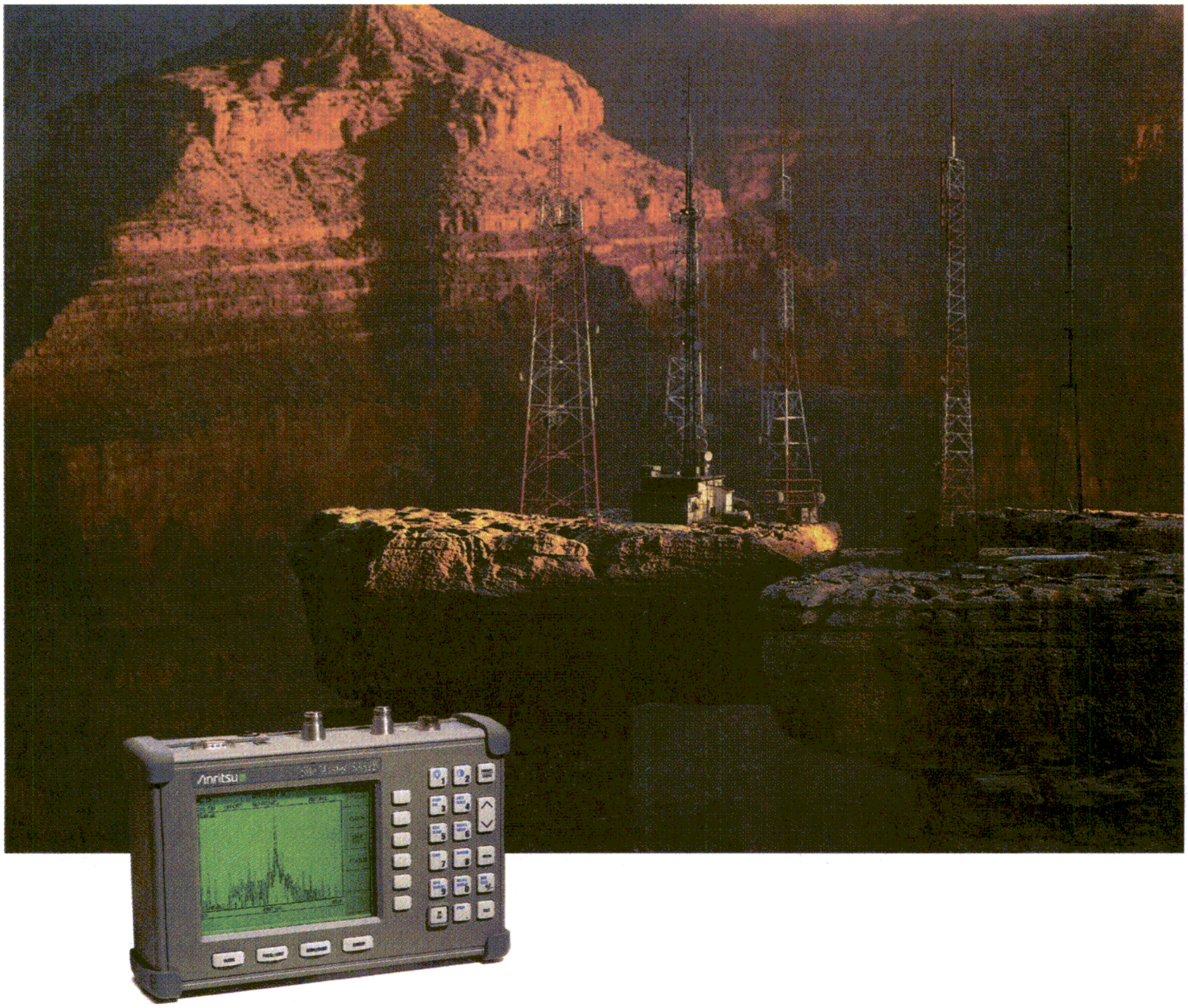
Telephia, a provider of integrated marketing and network-quality competitive analysis, is helping wireless carriers change the way they compete—by providing them with the necessary information to truly understand the marketplace. By tapping the power of Harris Interactive's Internet data base, Telephia has launched Wireless E~Trac, a nationwide survey of up to 50,000 subscribers. The findings cover the following markets: New York, Los Angeles, Chicago, Philadelphia, Detroit, Dallas, Boston, Houston, San Francisco/San Jose, Baltimore/Washington, DC, Miami, and Portland, OR.

As an example of the types of data available, Telephia is releasing top-line results from the Los Angeles survey:

- More than four out of five respondents surveyed said that they would be willing to provide demographic information and receive promotions and advertising information in exchange for a discount of $15 on their monthly service.
- Twice as many women as men expressed interest in pre-paid service plans.
- The same carriers who have the highest customer-satisfaction ratings among business subscribers fall behind their competition in the personal subscriber market segment.
- Approximately half of the respondents indicated that price promotions or service pricing was the primary purchase driver. Service-area and voice-quality concerns ranked far behind.

Wireless E~Trac offers five topic surveys within each market: customer satisfaction, brand awareness, purchasing decision, product development, as well as switching and loyalty dynamics. Each survey includes market-level information on user and usage profiles, market share and telecommunications expenditures, calling patterns, and perceptions regarding delivered performance on network-quality metrics. "As a syndicated product, Wireless E~Trac brings carriers far-reaching and complete wireless market intelligence quickly," says Telephia's Bill BonDurant.

Out Here, Field-Proven Takes On A Certain Significance.



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CIRCLE NO. 202

Services Offered For Two Phone Numbers On One Wireless Headset

WEST POINT, GA—Powertel, Inc., a wireless personal-communications-services (PCS) provider serving the southeastern US, is introducing services that enable the use of two telephone numbers on one wireless handset.

The first, called Appear Local℠, enables a customer to have two local phone numbers in two different area codes—one a hometown number and another in different Powertel service area. "This will appeal to business users who want a local presence in two markets, even though they are in different area codes," explains Mike Bashaw, vice president of marketing and product development for Powertel. "Likewise, Appear Local is great for families with relatives—especially college students—in another Powertel service area." The calling party incurs no long-distance charges and both numbers draw from the customer's primary-rate plan. The cost for Appear Local is $4 per month.

The second new service, known as Call Tracker℠, provides the customers with two numbers that will be separated call by call on customers' billing statements and the service enables customers to easily separate their business calls from personal ones. "The itemized bill listing for each number simplifies business-call record keeping," Barshaw says. "Also, a distinctive ring or separate display indicator for each number makes it easy to know when a call is for business purposes." Both numbers draw from the customer's primary-rate plan. The cost for Call Tracker is $6 per month.

Contract For Public-Safety Communications System Is Finalized

LOWELL, MA—M/A COM, Inc. and AMP, Inc. recently announced that a contract has been signed and finalized to deploy M/A COM's OPENSKY™ wireless Internet-protocol (IP) network. OPENSKY will be used for the Commonwealth of Pennsylvania's Statewide Public Safety Digital Radio Communications System.

Pennsylvania's intent is to deploy a state-of-the-art digital radio system. "No other state has a comprehensive statewide public-safety radio system to rival this new network," says Thomas G. Paese, Pennsylvania's Secretary of Administration. "The digital technology employed in this radio network offers improved public-safety communications, and we think it represents a new model that other states will want to copy."

The contract, with a funded value of $95 million over the next 18 months, involves MA-COM supplying infrastructure equipment for a new, digital voice and data radio-communications network for the Commonwealth of Pennsylvania. The statewide radio system, which will employ OpenSky wireless IP network technology, will be a thoroughly modern system. The network infrastructure will be comprised of several hundred base stations along with regional control centers and network control centers. The statewide system is slated for final completion in 2001.

Wireless Connectivity To Internet Infrastructure Is Demonstrated

PALM BAY, FL—Intersil Corp., a developer of silicon (Si) technology for wireless local-area networks (WLANs), announced that it has demonstrated the use and interoperability of various wireless networking products at the 1999 Intel Developer Forum. Products used in Intersil's demonstration incorporate Intersil's advanced PRISM® WLAN chip-set technology.

The Intel Developer Forum, held earlier this year in Palm Springs, CA, brought leading software, hardware, and chip developers together to share technical insight on personal-computer (PC) technologies, tools, and training. This year's conference, "Advancing the Internet," focused on converting the challenges of the Internet into opportunities for growth through next-generation computing designs.

At its booth, Intersil demonstrated a wireless network for a small-office/home-office (SOHO) environment. The setup featured a Nokia wireless Access Point (AP) which bridges to the Internet through a modem and phone line.

"Networks will increasingly offer wireless on-ramps to the Internet's Information Superhighway as people demand fast, mobile connections wherever they roam," says Chris Henningsen, vice president of PRISM Wireless Products at Intersil. "We're thrilled with the opportunity to demonstrate the role of wireless networking in the Internet revolution to many of the leading developers in the IT and computing industry. We're confident that PRISM will be one of the most significant silicon building blocks for the Internet infrastructure in the years to come." To date, over 40 companies have fielded PRISM-based wireless systems.

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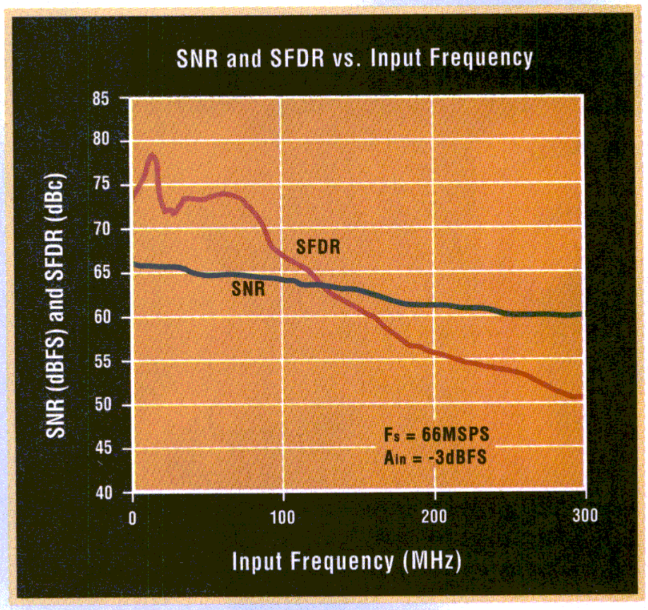

DEVICE	RESOLUTION	SAMPLE RATE	SNR	SFDR	MAXIMUM SPECIFIED f_{in}
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CLC5958	14bit	52MSPS	71dBFS	90dBc	70MHz

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CIRCLE NO. 376

Electronics Century

At the historic confluence of the decade, century, and millennium, the last hundred years show that the impact of electronics technology dwarfs all other areas.

Looking Back At The Electronics Century

GENE HEFTMAN
Senior Editor

BY the time this story appears in print, the end of the decade, the century, and the millennium (unofficially) should be days or hours away. Since relatively few humans can be eyewitness to this once-in-a-thousand years phenomenon, the temptation is great to write some words that will convey the sum and substance of life in this time should they be discovered by whoever inhabits planet Earth at the next millennium. It is of little use trying to find a core idea that embraces a span of years as great as a millennium. And doing the same for a decade will give insignificant perspective to future readers digging into human existence over the final hundred years of the second millennium. But a century is approximately the right time frame to identify a dominant theme that best characterizes a significant advance in human achievement. Some may object, but the last 100 years of the second millennium should fittingly be called the Electronics Century.

When one thinks about it, most of the life-changing inventions of the 20th century outside of transportation—automobiles and airplanes—are based on electronics or electricity. Who can argue that the telephone, radio, radar, television, and computer are less vital to modern life than any means of transportation? Take it one step further and it's clear that all vehicles—in the air, on land, or at sea—are heavily dependent on electronics and computers for their correct and safe operation.

In 1969, the engineering feat of the century—or of any century for that matter—the landing of a man on the moon was made possible as much by advances in electronics as any other technological development up to that time. The interesting thing is that when extraordinary space events such as moon landings occur and we talk to humans on another planet, our electronics skills are revered as the marvels of the age. But when we fail, as in the recent loss of two very expensive spacecraft designed to explore the Martian surface and atmosphere, electronics is usually the culprit. The very fact that the success or failure of our most ambitious quests hangs on electronics is testament to the pre-eminence of this science in modern life.

Every avenue of critical human endeavor from agriculture to business to communications to medicine relies so heavily on electronics and computers that governments worldwide are imploring their citizens not to panic when the clock strikes midnight on December 31, 1999, and computers not outfitted with the Y2K fix will think it is the beginning of the 20th century and not the end. Nothing outside of an asteroid striking the earth could be more disastrous to modern society than a massive computer failure of those systems that control our power, water, public safety, and economic life. If the potential failure of computers in the waning hours of the century can strike fear into the hearts of millions worldwide, who can doubt that the electronics revolution begun early in this century truly defines the very essence of our civilization as the third millennium dawns.

One of the peculiarities of the latter part of the 20th century is the notion that developments in virtually every human sphere—scientific, political, economic, and social—are moving at a more accelerated rate than ever in history. What normally took decades in other eras now seems crammed into years and even months, something that is particularly evident to everyone engaged in science and engineering. To better understand the warp speed at which electronics moves these days, I perused the December 1989 edition of *Microwaves & RF* to gauge the magnitude of the changes that have taken place during the past 10 years. The issue looked back at the microwave industry during the 1980s and looked ahead to forecast some trends that would be important in the 1990s. Most interesting is not what the stories predicted, but what was left unsaid.

Reporting on the wireless communications industry was not even on the magazine's radar screen. It is not that the industry was non-existent—it had almost 2.7 million subscribers and revenues of $2.5 billion—but the technology was still in its toddling analog stage (see table). A glance at the table reveals what can only be described as staggering growth over the next 10 years. By 1999, there were 76 million users (actually 81.8 million projected by the CTIA at year-end 1999 in the US alone) and annual revenues were slightly above $37 billion, an almost 15-fold increase over 1989. The industry now employs approximately 142,000 people compared with the 1989 total of just fewer than 14,000. Interestingly, the average length of a wireless call is almost the same (2.4 minutes now, 2.35 minutes then) but the price to the consumer for phone service has been cut more than half from $85.52 to $40.24. Try thinking of some non-electronic product or service that costs less now than it did 10 years ago.

There is good reason why the wireless industry was in a fledgling state in 1989. The answer comes from our sister publication *Electronic Design's* December 28, 1989 issue. In it, the magazine covered the top products of the year in areas such as integrated circuits (ICs), test and measurement, computers and peripherals, and of course, communications. The top communications product of 1989 was a cellular chip set from Signetics that consisted of six devices, claimed to cut component count by 60 percent more than then-current solutions and sold for the bargain price of $60 (more than some phones cost today). The article claimed that the chip set replaced eight printed-circuit boards (PCBs) in cellular systems and was suitable for pocketsize, battery-powered handsets as well as most traditional mobile applications.

By contrast, today's wireless designers think in terms of system-on-a-chip (SOC) technology with the goal of integrating an entire radio—RF, baseband, and logic functions on a single chip. Although its not quite ready, at the present pace of semiconductor advances, single-chip radio technology will probably be a reality in the first few years of the new millennium.

From a few brief references in the media of 1989, wireless technology came a long way in the 1990s. For example, the data aspects of wireless communications are becoming even more important than the voice aspects. The wireless local-area network (WLAN) is a system that permits computers and peripherals to communicate with each other using radio signals to transmit digital information. The great advantage of a WLAN is that it offers all of the capabilities of its wired counterpart but without the physical limitations of the wire itself. The Holy Grail of WLAN technology—yet to be acheived—is connectivity at LAN speeds (in tens of Mb/s) among computers located anywhere in the world. This is a difficult goal technically, but one that will probably be acheived in the next century.

A NET GAIN

Another subject that drew scant attention in the electronics trade press of 1989 is that little eight-letter word—Internet. Together with the wireless revolution, what better typifies the decade of the 1990s than the Internet, which, in 10 short years, has become the world's greatest information and communications medium? It is not as if the Internet did not exist ten years ago, but as with wireless communications it had not yet reached the point of critical mass, which is what the 1990s technologies are all about.

The packet-switching concept used to transfer data on the Net was developed during the mid 1960s, and the Internet was actually born in approximately 1970 when the Department of Defense (DoD) commissioned the Advanced Research Projects Agency (ARPA) to investigate networking among computers. The idea was to create a system that could withstand the mass destruction of a nuclear attack by distributing critical data and allowing it to travel among many locations along different paths. So the Internet came to life as the ARPANET, and in fact, e-mail was invented in 1971 to enable the sending of messages over ARPANET across a distributed network. It is not even debatable that e-mail is now one of the top two benefits of the Internet and probably will be until some kind of 21st century mental telepathy comes along that eliminates typing words on a computer screen.

By 1989, the Net had already grown to approximately 100,000 hosts, had close to 1000 news groups, and was on the verge of a big breakout. That came in 1991 with the release of the World Wide Web (WWW) which gave computer users easy access to any kind of information from any place in the world. Initially, sites were non-graphic but it is difficult to remember when the Web was that primitive.

Multimedia—pictures, sound, and text—is what changed the Net from a high-tech toy to one that appealed to virtually all levels of society. It began to draw in millions of computer users who wanted to explore the huge data banks available to them using a technique coined in 1992 known as "Surfing the Internet."

In 1993, there were just 600 WWW sites. Four years later there were a million, and at the close of 1999, millions more. By the way, in 1990, ARPANET passed into history at the tender age of 20 years.

Combining the technologies of wireless and the Web will produce a sea change in virtually every aspect of life in the next millennium. In the first five to 10 years, Bluetooth technology will enable communications not only between computers/peripherals and wireless phones, but between phones and various kinds of household appliances. Imagine checking the refrigerator while driving home from work to see if milk is needed, and then going on the Web to order it from the supermarket so it is ready when the customer arrives at the store and is charged to their account. Of course, that is just the tip of the iceberg. The point is, the dizzying pace of scientific and technical developments over the last 10 or 20 years puts even wild predictions within the realm of possibility.

Granted that mankind has invented a huge and remarkable array of technological toys just within this

century, it should be easy to trace how it all got started. One can go back before the turn of the century to find some significant sequence of discoveries that had to be in place to get us here, but the seminal event of the modern electronics era—post 1950—was the transformation of electronics technology from one of vacuum tubes to semiconductors.

FROM ONE TO A BILLION

The activities that took place on December 23, 1947 at Bell Telephone Laboratories (Murray Hill, NJ) are generally regarded as the beginning of the so-called "Information Age" that spawned the computer revolution, the Internet, and wireless communications. On that day, John Bardeen, Walter Brattain, and William Shockley demonstrated a single semiconductor device that could amplify a voice signal over a loudspeaker. It was called a point-contact transistor and it laid the foundation for every advance in electronics technology from that day to this. There is a direct heritage from that first transistor to the IC to the microprocessor to the desktop computer to wireless communications to the Internet to anything that is foreseeable on the technological horizon. In 1954, the IBM Corp. announced that henceforth vacuum tubes would no longer be used in its digital computers. The first transistorized computer used 2000 devices.

On the 50th anniversary of the transistor's introduction, the manufacturing technology for "transistors" allowed five million of them to be packed on a single chip and 200 chips to be placed on a single 8-in. (20.32-cm) silicon (Si) wafer, making a grand total of 1 billion devices.

In the realm of high-frequency systems, Si bipolar transistors have been around since the early 1950s, and processing improvements have allowed them to serve in many microwave and RF applications to this day. A milestone in high-frequency semiconductors occurred in 1966 with the announcement of a gallium-arsenide (GaAs) metal-semiconductor field-effect transistor (MESFET) that became the workhorse solid-state device for microwave applications at frequencies in the tens of gigahertz. This was followed approximately 10 years later by the aluminum GaAs (AlGaAs/GaAs) heterojunction process, which has led to high-speed semiconductors, called high-electron mobility transistors (HEMTs) and heterojunction FETs (HFETs). A device conceived in 1957 called the heterojunction bipolar transistor (HBT) lay dormant for many years, but recently emerged as a higher-frequency replacement for Si bipolar transistors.

GaAs and Si bipolar ruled the high-

The CTIA's annualized wireless industry data-survey results June 1985 to June 1999 Reflecting domestic US commercially operational cellular, ESMR, and PCS providers

Date	Estimated total subscribers	Annual total service revenues (thousands)	Annual roamer revenues (thousands)	Cell sites	Direct service provider employees	Cumulative capital investment (thousands)	Average local monthly bill	Average local call length
1985	203,600	354,316	N/A	599	1697	588,751	N/A	N/A
1986	500,000	666,782	N/A	1194	3556	1,140,163	N/A	N/A
1987	883,778	941,981	N/A	1732	5656	1,724,348	N/A	N/A
1988	1,608,697	1,558,080	N/A	2789	9154	2,589,589	$95.00	2.25
1989	2,691,793	2,479,936	210,699	3577	13,719	3,675,473	$85.52	2.35
1990	4,368,686	4,060,494	365,549	4768	18,973	5,211,765	$83.94	2.32
1991	6,380,053	5,075,963	565,989	6685	25,545	7,429,739	$74.56	2.20
1992	8,892,535	6,688,302	838,077	8901	30,595	9,276,139	$68.51	2.38
1993	13,067,318	9,008,700	1,124,493	11,551	36,501	12,775,967	$67.31	2.38
1994	19,283,306	12,591,947	1,552,382	14,740	45,606	16,107,921	$58.65	2.36
1995	28,154,415	16,460,516	2,173,003	19,844	60,624	21,721,711	$52.45	2.27
1996	38,195,466	21,525,861	2,737,177	24,802	73,365	26,707,046	$48.84	2.24
1997	48,705,553	25,575,275	2,858,432	38,650	97,039	37,454,294	$43.86	2.25
1998	60,831,431	29,637,742	3,166,656	57,674	113,111	50,178,812	$39.88	2.34
1999	76,284,735	37,214,819	3,837,994	74,157	141,929	66,782,827	$40.24	2.40

frequency roost at the beginning of the decade, but by the end, both were under pressure from competitive processes. This is a result of the revolution in the demand for portable wireless-communication products which impose a unique set of requirements on equipment designers. A wireless portable phone, for example, must consume low power to minimize battery drain and optimize talk time, be small in size for user convenience, and be inexpensive due to extreme competition among service providers. Semiconductor technologies other than GaAs and bipolar offer superior characteristics to meet these needs, and thus have been on the ascendancy over the past two or three years.

The metal-oxide-semiconductor (MOS) process invented in the 1960s is gaining favor for signal-handling and power-amplification purposes. Complementary MOS (CMOS) will probably become the primary process for digital logic, analog small-signal, and mixed-signal circuitry as designers attempt to integrate as much of a phone's functions into as few ICs as possible. The characteristics of CMOS make it preferable to GaAs and bipolar for the high-density, low-power ICs needed in 21st century battery-powered, handheld electronic products.

For higher-power applications such as in the wireless-communications infrastructure, another form of MOS, laterally-diffused MOS (LDMOS), is encroaching on GaAs and bipolar territory in applications that require very linear performance at power levels at 100 W and greater. Just as LDMOS prepares to unseat GaAs, a pretender to the throne is waiting in the wings in the form of Si carbide (SiC), a technology that offers superior high-frequency, high-power capability. SiC is a fledgling technology whose impact will continue to be felt over the years.

What has happened to GaAs and bipolar is representative of the rise and fall of many technologies within electronics technology. The difference between today's changes and those of 50 years ago is ability of present-day scientists and engineers to turn ideas into realities with much greater speed and success.

MAN OF THE CENTURY

Since this article has tried to hit some of the high points of electronic achievement over the century, it seems natural to single out one individual whose contribution rose above all others and pushed the science to a point that almost everything else followed. That pioneer could properly be crowned as the Man of the Century. While there are a number of individuals with good credentials, the field can be narrowed to two.

The runners up, men who come up just short of the mark, are the aforementioned Bardeen, Brattain, and Shockley of transistor fame. Also second-rankers are Robert Noyce and

Gordon Moore, both associated with the early development of the IC and, of course, microprocessors. Harold Black made a significant discovery in the 1930s with his invention of negative-feedback theory and amplifiers that employed it. The one thing holding these great men from immortality goes back to something Albert Einstein once said. Einstein remarked that the reason he had been able to advance scientific thought as profoundly as he did was because he was able to stand on the shoulders of giants who came before him. So too did those men just mentioned who had the research of great scientists and engineers who came earlier.

So who is the Man of the Century? There are really two, but one gets the nod here. He was born in Council Bluffs, IA in 1873 and educated at Yale University. In 1906, Lee De Forest invented something called the Audion amid the criticism and disbelief of everyone around him. Electronic engineers educated before 1960 know it as the triode vacuum tube. And what an invention it was. It became the foundation component of all radio, radar, television, and computer systems until transistors began replacing vacuum tubes in the early 1950s. A prolific inventor, De Forest also designed the earliest wireless radio and telegraph transmitters, and in 1910 presented the first live opera broadcast. De Forest reigns supreme because he faced obstacles the others did not and also he did not have access to the deep pockets of a Bell Labs, Fairchild Semiconductor, and Intel Corp. to carry out his work.

Running second to De Forest—but very closely—is Guglielmo Marconi, often called the "Father of Radio." Interestingly, De Forest's 1950 autobiography is entitled *Father of Radio*. Who the real "father" is does not matter since both rank among the greatest inventors of this or any other century. Marconi invented a true wireless radio, and even before the 20th century, in 1895, built a system that could send and receive a signal at a distance of approximately two miles. In 1901, he received the Morse code signal for the letter "s" sent across the Atlantic Ocean to Canada. Marconi is generally credited with turning the radio from a laboratory curiosity into a practical communications medium.

Several years ago, at the Wireless Symposium/Portable by Design technical conference in California, this publication distributed promotional tee shirts with the name of the conference on the front and a promotional picture on the back. That particular year, the picture was of Marconi, looking at a wireless set sometime in the mid 1930s. There was a printed quote over his picture that stated, "It is dangerous to put limits on wireless." Now that is a prediction that might hold up until the next millennium. ••

A successful military supplier looks to the commercial digital microwave radio market for continual growth in the year 2000.

One Company's Quest For Balance

JACK BROWNE
Publisher/Editor

CHANGE is the one constant in the microwave industry, especially for a company fortunate to experience strong growth, such as Stellex Microwave Systems, Inc. (Palo Alto, CA). In a span of only two years, Stellex was born of part of Watkins-Johnson company, learned how to survive as a separate company, and enjoyed growth as a solid supplier of components and subsystems for military and commercial customers. If that was not enough, in the last year the company also acquired Phoenix Microwave Corp. (Telford, PA), a leading supplier of high-frequency amplifiers, and began construction on a new 160,000-sq.-ft. facility in San Jose, CA.

Stellex still shares real estate with its "former self," Watkins-Johnson, on a large business campus in Palo Alto, CA, but plans to relocate to a modern facility on Hellyer Ave. by the fourth quarter of 2000. The new facility will consist of two buildings with 100,000 sq. ft. of manufacturing floor space and 60,000 sq. ft. of engineering and administrative floor space. According to Dean Merkley, the firm's vice president of sales and marketing, "the new facility will allow us to quickly respond to market opportunities and leverage our core strengths for growth in our traditional markets as well as the dynamic telecommunications broadband wireless sector."

The new facility is necessary in part due to growth at Stellex, and in part due to the acquisition of Phoenix Microwave Corp. earlier this year. According to Stellex CEO Keith Gilbert, "the acquisition of Phoenix Microwave was a big push for us in the component area. We've experienced some modest growth during the year in that area, but we wanted to make a more aggressive move, and also help support our growing subsystems businesses." While Gilbert oversees Stellex, and is intimately involved with the company's subsystems business, Gus Kamnitsis, the founder and president of the former Phoenix Microwave Corp., will run Stellex's combined microwave-component operations, with facilities in California and Pennsylvania.

Gilbert notes that Stellex was initially associated almost entirely with military markets, particularly in missile-based electronics. But during 1999, the business mix has changed with the addition of growth in commercial communications markets. "Our commercial business has gone from essentially nothing last year to several million dollars worth of business in 1999," he says.

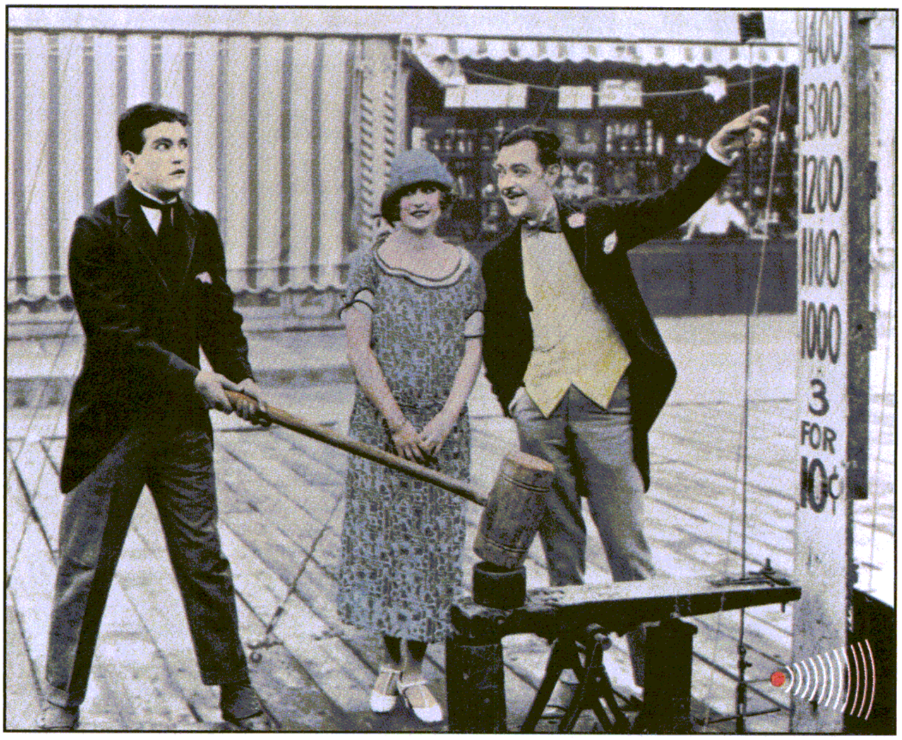
Gilbert explains that the company has already had the tools in place to compete in commercial markets: "Many of the products that we are selling into the commercial communications markets are based on our core technologies, such as YIG oscillators. Combining the YIG technology with our metal-injection-molding (MIM) packaging technology has given us some distinct advantages in terms of cost and performance."

Merkley points to the digital microwave radio market as an area of particular success: "We've addressed the point-to-point radio market with practical hardware modules. Customers in that market need hardware at volumes from just a few pieces to more than 200 units per week, and we have the manufacturing flexibility to meet their needs. In fact, we recently received a large order from a major radio supplier for a microphonics-free, phase-hit-free frequency synthesizer."

The firm has actively sought new markets in commercial and military areas, and is currently delivering a 28-GHz outdoor unit (ODU) for local-multipoint-distribution-system (LMDS) applications. The ODU is actually a full 28-GHz transceiver with RF and digital circuitry. Originally designed as two circuit boards, it has been reduced to a single cost-effective circuit board.

For more information, please contact: **Sellex Microwave Systems, Inc., 3333 Hillview Ave., Palo Alto, CA 94304-1233; (800) 321-8075 FAX: (650) 813-2328, e-mail: stellexms. com, Internet: http://www. stellexms.comm.** ••

POWER



AMPLIFIERS

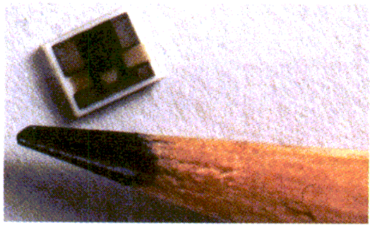
Digital crosspoint switch delivers 1.5 Gb/s per port

The model AD8150 X-stream digital crosspoint switch integrated circuit (IC) performs data routing at rates from 270 Mb/s to 1.5 Gb/s per port for applications such as standard-definition television (SDTV), high-definition television (HDTV), and fiber-optic network routing. It offers a switch array of 33 input by 17 output. The IC uses bipolar-complementary-metal-oxide-semiconductor (BiCMOS) technology and dissipates less than 1.5 W. **Analog Devices, Inc., Ray Stata Technology Center, 804 Woburn St., Wilmington, MA 01887; (800) 262-5643, FAX: (781) 973-1021, Internet: http://www.analog.com.**

CIRCLE NO. 64 or visit www.mwrf.com

Passive attenuators span DC to 2 GHz

A new family of passive, temperature-compensating attenuators maintains a constant attenuation versus temperature-change slope from DC to 2 GHz. The attenuators are completely passive, single-chip, thick-film components that provide the same temperature-compensating action as an active circuit with lower cost, higher reliability, less circuit-board real estate, and no distortion. The attenuators can also be used as temperature sensors, and can be supplied for application-specific requirements. They are fabricated on surface-mountable ceramic substrates that range in length from 0.075 to 0.145 in. (1.91 to 3.68 mm), and in width from 0.06 to 0.123 in. (1.52 to 3.12 mm). Maximum rated power dissipation is 0.2 W at 25°C. They are particularly suited to military systems or any system subject to harsh environments. **Methode Electronics, Inc., 7447 West Wilson Ave., Chicago, IL 60706; (800) 232-6858, FAX: (708) 867-3149, Internet: http://www.methode.com.**



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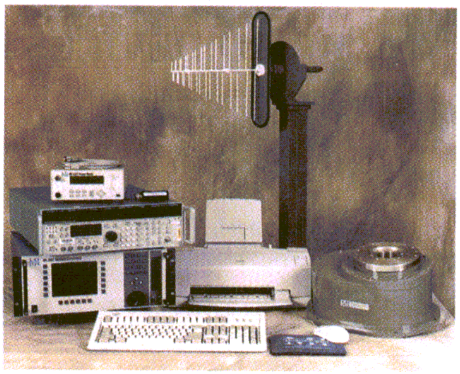
Antenna-measurement system performs far-field evaluations

The model MI-3610 test system performs far-field antenna measurements from 100 MHz to 8 GHz, and can acquire multiple frequency characteristics in a single scan. The system measures side-lobe levels to –40 dB with a noise-floor level of approximately –70 dBm, and includes analysis software to simplify pattern evaluation. The software supports antenna-pattern analysis, data presentation, and data output. Data files can be plotted in polar or rectangular formats for single or multiple traces. **Microwave Instrumentation Technologies, LCC, 4500 River Green Pkwy., Suite 200, Duluth, GA 30096-2580; (800) 848-7921, FAX: (678) 475-8391, Internet: http://www.mi-technologies.com.**



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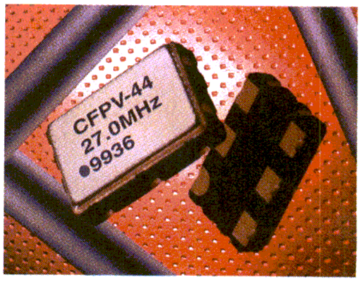
VCXOs serve SONET/SDH

The CFPV-41/42/43/44 series of miniature, surface-mount voltage-controlled crystal oscillators (VCXOs) is designed for Synchronous Optical Network (SONET)/synchronous-digital-hierarchy (SDH) transmission systems in local-telephone exchanges, local-area networks (LANs), or wide-area networks (WANs). The oscillators offer a high degree of "frequency pulling"—control of the output frequency by an applied voltage—allowing degraded incoming signals to be corrected by a phase-locked



loop (PLL). Models CFPV-41 and -42 are capable of frequency pulling to at least ±50 PPM. They operate from a +5-VDC power supply and require a +2.5 ±2-VDC frequency-control voltage at pin 1. Models CFPV-43 and -44 are capable of frequency pulling to at least ±100 PPM. They operate from a +3.3-VDC power supply and require a +1.65 ±1.5-VDC frequency-control voltage. All four of the models are available at any output frequency between 1 and 52 MHz and are stable to ±25 PPM. The VCXOs operate from –10 to +70°C. **C-MAC MicroTechnology, Frequency Products Division, 4222 Emperor Blvd., Suite 300, Durham, NC 27703-8466; (919) 941-0430, FAX: (919) 941-0530, Internet: http://cfpwww.com.**

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SMA Connectors: cable types, microstripline, bulkhead, panel mount, field replaceables, hermetic, stripline and radius right angles.

SMP and new SSMP Connectors: subminiature and sub subminiature push-on connectors for up to 40 GHz and beyond.

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2.92mm "K" Connectors and Adapters: cable types, field replaceables, radius right angles and in-series adapters.

Adapters: in and between series; SMA, TNC, Type "N", 7mm, 3.5mm. 2.4mm and "K"™.

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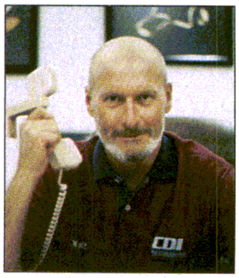
Cable Assemblies: custom semi-rigid and flexible plus Handi-Form™ reformable cable assemblies.

"K" is a registered trademark of the Wiltron Company

...but if you need something special, let's talk."



Walt Carpenter
CDI Sales Manager

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Feds Curb Microsoft's Power

In a decision that reverberated around the world, the antitrust case of the US government against Microsoft Corp. concluded on Friday, November 5 with the verdict that the world's most powerful software maker is a monopoly. In his decision, US District Judge Thomas Penfield Jackson said in part that the company "demonstrated that it will use its prodigious market power and immense profits to harm any firm that insists on pursuing initiatives that could intensify competition against one of Microsoft's core products." With sales this year of $19.7 billion, Microsoft's Windows operating system runs most of the world's desktop and laptop computers—approximately 90 percent—which makes it the equivalent of the 800-lb. gorilla of the computer universe.

The crux of the decision is not to wound Microsoft financially or break it up, but to spur more innovation, promote competition in the software industry, and benefit consumers with more product choices at lower cost. In fact, the Department of Justice is hoping that it can reach a settlement with Microsoft before punishment is handed down. A negotiated settlement is highly preferable because the government does not want to cast a pall on one of the world's most successful companies, one that is helping to drive the booming economy lead by the high technology sector. At the same time, the strongly worded decision indicates that some serious and far-reaching concessions are expected from Microsoft. In the extreme, which many software-industry pundits consider unlikely, Judge Jackson could order the company to split into smaller units that would compete against each other by selling different versions of software.

A key element of the case against Microsoft began in late 1997 when Judge Jackson ordered Microsoft to stop bundling its Internet browser with the Windows 95 operating system. At that time, many worried that Microsoft's clout could allow it to conquer the Internet with a closed standard, putting a damper on the Net's creativity, diversity, and openness. Installing its Internet Explorer software in with the operating system had a significant effect on Netscape which held 90 percent of the browser market when it started in business but steadily lost share to Microsoft. Today, however, major players such as America Online, Sun Microsystems, and Compaq Computer have shifted the balance of power and companies are learning ways to sidestep Microsoft on the Internet.

Although Microsoft was severely rebuked, the justice system grinds exceedingly slow and the penalty phase of the case will not take place until next year. If the case eventually winds up in the Supreme Court, no decision is likely until about 2003. ●●

Contracts

Harris Corp.—Has signed a contract with Brazil's Telemig Cellular for the supply of 49 digital microwave radio links. The contract, valued at $2.8 million, positions Harris as Telemig Cellular's largest supplier of microwave radios.

Berkeley Varitronics Systems—Was awarded a contract by Hughes Network Systems of India to deliver five receiver systems comprised of Champ Ultra-Lites and Champ receivers for expansion of the fixed wireless network in India.

Hewlett-Packard Co.—Has signed an equipment purchase agreement (EPA) with Motorola's Austin, TX-based Semiconductor Products Sector (SPS). This agreement covers semiconductor test solutions, including system-on-a-chip (SOC) test, RF integrated-circuit (RF IC) test, memory test, semiconductor parametric test, and services.

LCC International, Inc.—Has been chosen by Dutchtone NV of The Netherlands to conduct Dutchtone's Quality of Service (QOS) measurement and reporting process. The agreement is already in effect and is valid until the end of 2000. The QOS contract requires LCC to measure the overall network quality for Dutchtone's GSM-1800 network in The Netherlands. LCC's ability to collect, measure, and analyze data as it is perceived by users will be fundamental to Dutchtone's ability to adjust its network to enhance user service.

G.T. Microwave, Inc.—Completed a $750,000 contract for the design, development, and qualification of an integrated RF subassembly. Concurrent with the fulfillment of this research-and-development (R&D) contract, G.T. Microwave has been awarded the initial production phase worth an approximate $1.5 million to be completed by the end of 2001.

Watkins-Johnson Co.—Announced that its Wireless Products Group (WPG) and Sprint have signed a multiyear Master Purchase Agreement for Watkins-Johnson repeaters to be used in the Sprint PCS all-digital nationwide network.

Scientific-Atlanta, Inc.—Signed a contract with Telespazio SpA, a Telecom Italia Group company, to develop, manufacture, and install the satellite ground terminals that form a major portion of the ground infrastructure network for a new global satellite system, Astrolink (http://www.astrolink.com).

Spire Corp.—Received a $750,000 contract from the US Air Force Research Laboratory at Wright-Patterson Air Force Base to continue its development of advanced high-frequency transistors for future commercial and military communications systems.

Teradyne, Inc.—Announced that Texas Instruments (TI) has placed a major order for Teradyne's VX test-simulation software, including multiple seats of VX for Saber for system-on-a-chip (SOC) and mixed-signal device development and DigitalVX for digital-only device development.

Motorola, Inc.—Was awarded a $29.9 million contract by Kuwait Mobile Telecommunication Co. (MTC) for the expansion of MTC's Global System for Mobile Communications (GSM) communications digital cellular network.

Fresh Starts

Gabriel Electronics, Inc. and Endgate Corp.—Have entered an agreement to jointly introduce a new generation of smaller and more-attractive antennas for the broadband wireless market.

DSP Communications, Inc.—Signed a licensing agreement with Cadence for code-division-multiple-access (CDMA) data software. This agreement allows Cadence to integrate the CDMA IS707A protocol software, enabling higher-rate data services and support for Internet browsers, circuit data, and packet data in next-generation CDMA mobile phones.

Tellabs—Announced that it has completed its acquisition of NetCore Systems, Inc.

Stellex Industries—Has completed the acquisition of the privately held RF and microwave component supplier, Phoenix Microwave Corp. The acquisition was financed through Stellex Industries' existing acquisition facility.

California Eastern Laboratories (CEL)—Announced that NEC Electronics, Inc. will transfer all marketing, sales, technical support, and distribution responsibilities in North America for NEC fiber-optic components to CEL. The transfer became effective on October 1, 1999.

Noise Com, Inc.—Announced the execution of a definitive agreement to merge Boonton Electronics Corp. into a wholly owned subsidiary of Noise Com.

Richardson Electronics Ltd.—Signed a global distribution agreement with SDP Components, Inc., a manufacturer of RF and microwave coaxial connectors.

Sensys Technologies, Inc.—Has changed its name to Sensytech, Inc. The company's headquarters and ticker symbol will remain unchanged. The company's new Internet website is http://www.sensytech.com.

Pulse and AMP—Have signed an agreement to collaborate on a line of stacked modular jacks, RJ-45 connectors integrating wirewound magnetics, hubs, switches, routers, and other networking devices.

Quadrant Technologies—Announced that it will acquire ARCOM, a New Hamphire-based millimeter-wave transceiver company.

WinStar Communications—Disclosed its plans for the commercial rollout of its point-to-multipoint (PMP) service. As part of what WinStar called an accelerated deployment plan, the company will integrate PMP technology into its network in key US markets during the fourth quarter, including Washington, DC, Phoenix, Oakland, San Jose, Seattle, and Salt Lake City.

SignalSoft Corp.—Announced that it is partnering with Siemens to offer an enhanced wireless application protocol (WAP)-based solution that uses the location of the mobile customer to personalize data services. This will allow users on Siemens' WAP infrastructures to access and interact with a variety of Internet content that is tailored to their location.

Ranoda Electronics, Inc.—Danny Feng to national sales manager; formerly western regional sales manager with Oak Frequency Control Group.

Stellex Electronics, Inc.—Louis M. Seieroe to vice president of West Coast component operations; formerly director of component engineering and manufacturing operations. Also, Mark Fournier to director of sales and marketing; formerly sales and marketing manager for the aerospace and defense segment at M/A-COM.

SEIEROE

FOURNIER

Signal Processing Technologies, Inc. (SPT)—Arthur Ryder to international sales manager; formerly responsible for local-area-network (LAN) and communications customers in New England for National Semiconductor Corp.

Intertek Testing Services (ITS)—Charles Fisher to site manager of the Richardson, TX testing laboratory; formerly site manager of the Cortland, NY laboratory.

CTS Corp.—Philip G. Semprevio to executive vice president; formerly group vice president for the CTS wireless components operations. Also, Francis Loo to managing director of CTS Singapore Pte. Ltd.; formerly customer/product support engineering manager and sales/marketing manager; In addition, John W. Cline to director of engineering for CTS Reeves Frequency Products; formerly president of Oak Frequency Control, Inc.

Gel-Pak Corp.—Darby Davis to international sales manager; formerly product sales manager for Asia at OnTrak Systems.

Motorola's Semiconductor Products Sector (SPS)—Daniel Artusi to vice president and general manager of the Networking and Computer Systems Group (NCSG); formerly general manager of the Wireless Infrastructure Systems Division (WISD).

SatCom Systems, Inc.—James E. Bunting to chief financial officer; formerly executive vice president and chief financial and operating officer for Intellicell Corp.

Inmarsat—Michael Storey to president and chief executive officer; formerly executive vice president of MCI Worldcom in Europe.

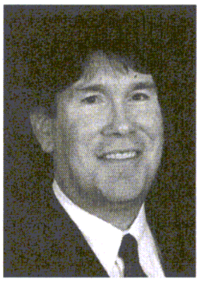
Prodelin Corp.—Tom Bell to product-line director for specialty antennas; formerly product marketing manager at EMS Technologies.

Metawave Communications Corp.—Andy Merrill to vice president of customer operations; formerly field-engineering manager for Motorola's Western region.

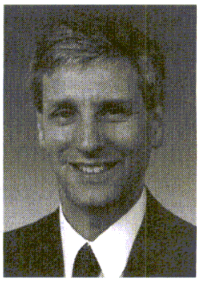
Lockwood Greene—Dana Hicks to telecommunications industry director; formerly worked in the corporate marketing department for J.A. Jones, Inc.

Electronic Industries Alliance (EIA)—David Isaacs to vice president of public policy; formerly employed as director of environmental affairs in the government-relations department.

ANADIGICS—Glenn Fraser to vice president of RF standard products; formerly director of the wireless business unit for Fujitsu Microelectronics, Inc.



FRASER



DOLLIVE

ITT Industries, Avionics Division—Louis Dollive to vice president; formerly director of project engineering with the Aerospace/Communications Division.

Electronic Industries Alliance (EIA)—Lesley Ahmuty to vice president of human resources.

Short Courses

Introduction to Software Radio and Wireless Networks
January 24-26, 2000 (Los Angeles, CA)
UCLA Extension, Department of Engineering
10995 Le Conte Ave., Suite 542
Los Angeles, CA 90024
(310) 824-3344, FAX: (310) 206-2815
e-mail: mhenness@unex.ucla.edu
Internet: http://www.ucla.edu/shortcourses

Telecom Trends: Markets & Technologies
January 27-28, 2000 (Portofino Hotel and Yacht Club, Redondo Beach, CA)
Technology Futures, Inc.
13740 Research Blvd., Suite C-1
Austin, TX 78750-1859
Kirsten Palumbo (800) TEK-FUTR, FAX: (512) 258-0087
e-mail: seminars@tfi.com

Infrared Imaging Systems and Applications
February 9-11, 2000 (Los Angeles, CA)
UCLA Extension, Department of Engineering, Information Systems and Technical Management, Short Courses
10995 Le Conte Ave., Suite 542
Los Angeles, CA 90024
(310) 824-3344, FAX: (310) 206-2815
e-mail: mhenness@unex.ucla.edu
Internet: http://www.ucla.edu/shortcourses

Fiber-Optic Communication Systems
February 14-16, 2000 (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) 263-3160
e-mail: Custserv@epd.engr.wisc.edu
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DP3T MMIC switch designed for cellular phones

Dual-band phones that are vehicle mounted and handheld need a switch to connect between an external and an attached antenna, and to connect one of these antennas to a transmitting power amplifier (PA) or a receiving circuit. This requires a high-power, dual-pole, triple-throw (DP3T) switch with low insertion loss. This device, realized as a heterojunction-field-effect-transistor (HFET) monolithic microwave integrated circuit (MMIC), has been developed by Akira Nagayama, Masatoyo Nishibe, Takayuki Inaoka, and Nobuhiro Mineshima of Japan Radio Co. (Saitama, Japan). Some gallium-arsenide (GaAs) MMIC switches are available, but all are single pole, double throw (SPDT) or double pole, double throw (DPDT) and none can be operated above +33 dBm. The GaAs device implemented by the authors exhibits a mean gate-leakage current of 50 nA/mm at +33 dBm of additional RF power, and an insertion loss of 0.4 dB (at +34 dBm) at a frequency of 950 MHz. See "Low-Insertion-Loss D3PT Switch for Dual-Band Cellular Phones," *IEEE Journal of Solid-State Circuits*, Vol. 34, No. 8, August 1999, p. 1051.

Variable capacitors built with MEMs processing

Voltage-controlled variable capacitors (varactors) are important elements in the filters and oscillators of high-frequency radio transmitters and receivers. Key parameters are high quality factor (Q) and wide tuning range. Advances in RF microelectromechanical systems (MEMs) fabrication techniques support the construction of high-quality tuning capacitors according to Charles L. Goldsmith, Andrew Malczewski, Zhimin J. Yao, Shea Chen, John Ehmke, and David H. Hinzel of Raytheon Systems Corp. (Dallas, TX). They built RF MEMs capacitors on a high-resistivity silicon (Si) substrate with a 1-μm-thick layer of Si dioxide (SiO_2) as a buffer layer using surface micromachining techniques. The resulting devices operate at up to 40 GHz with tuning ratios in the range of 70:1 to 100:1. Control voltages are in the +30-to- +50-VDC range and switching times are less than 10 μs. A 6-b variable capacitor with a tuning range of 1.5 to 33.2 pF was fabricated. This capacitor will be used eventually to build a high-performance tunable filter using only capacitor tuning. See "RF MEMs Variable Capacitors for Tunable Filters," *International Journal of RF and Microwave Computer-Aided Engineering*, Vol. 9, No. 4, July 1999, P. 362.

MAP and AMP methods improve GMSK synchronization

An improved method of closed-loop synchronization of a radio receiver with the phase of a carrier signal modulated by Gaussian minimum-shift keying (GMSK) can improve the performance of digital wireless communications systems, particularly in Europe. The method proposed by Marvin K. Simon of the California Institute of Technology (Pasadena, CA) is based on a combination of maximum a posteriori (MAP) estimation of digital modulation containing intersymbol interference (ISI) and the Laurent amplitude-modulation-pulse (AMP) representation of continuous phase modulation (PM) conveying digital data. In older GMSK carrier-synchronization schemes, ISI is not taken into account, leading to subpar performance of the systems. The present method takes ISI into account, allowing systems to approach optimal performance. See "MAP- and Laurent-AMP-based Carrier Synchronization in GMSK," *NASA Tech Briefs*, Vol. 23, No. 9, September 1999, p. 38.

Ray-tracing method predicts cellular propagation

With growing cell-phone traffic in densely populated areas, system providers must reduce cell size to build a larger network of microcells and additional base stations. The problem with a denser architecture is to understand exactly how signals will propagate through it, and how it will be affected by path loss, delay spread, and other anomalies. The answer, according to Hae-Won Son and Noh-Hoon Myung of the Department of Electrical Engineering, Korea Advanced Institute of Science and Technology (Taejon, Korea), is a very fast ray-tracing method called a ray-tube tree. A ray-tube tree is based on the uniform geometrical theory of diffraction (UTD) and can operate in a quasi three-dimensional (3D) environment such as a complex propagation area composed of arbitrary buildings and streets. The ray-tube tree is described as a point-to-point tracing technique, which provides greater accuracy than other ray-tracing methods. The authors used their method in the downtown area of Ottawa, Canada and generated results that were in close agreement with published measurements. See "A Deterministic Ray Tube Method for Microcellular Wave Propagation Prediction Model," *IEEE Transactions on Antennas and Propagation*, Vol. 47, No. 8, August 1999, p. 1344.

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HI5767/4	10	40
HI5740*	2x10	60
HI5767/6	10	60
HI5762	2x10	60

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HI5628/6	2x8	60
HI5660	8	125
HI5628	2x8	125
HI5760/6*	10	60
HI5728/6	2x10	60
HI5760	10	125
HI5728	2x10	125
HI5860	12	125
HI5828	2x12	125
HI5960	14	125

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HSP50215	Programmable Up Converter (PUC)
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HSP50217‡	Multi-channel PUC
HSP50016	Digital Down Converter
HSP50110	Digital Quadrature Tuner
HSP50210	Costas Loop Demodulator
HSP50414‡	Wideband Tuner
HSP50415*	Wideband Programmable Modulator
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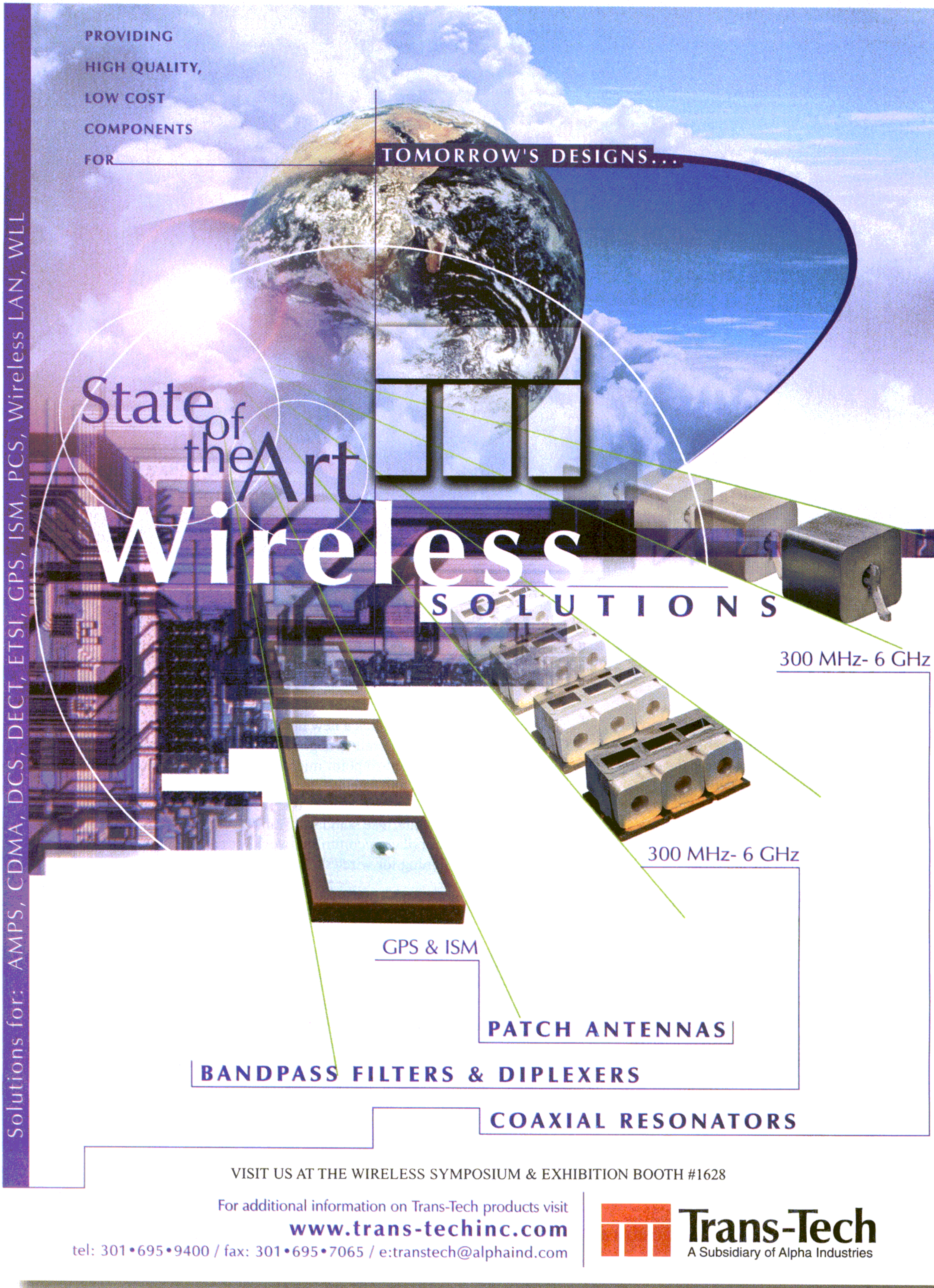

CIRCLE NO. 215

Design A Low-Noise Communications Amplifier

This article on low-noise-amplifier design illustrates challenges and offers some helpful hints.

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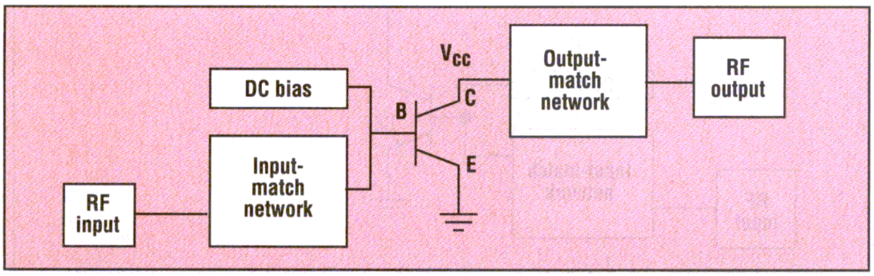
LOW-NOISE amplifiers (LNAs) represent one of the basic building blocks of a communications system. In real-world situations, such as cellular-phone systems, the received signal is very low in power and must be amplified before the information it contains can be properly demodulated. But all amplifiers add noise to the signals they boost, and when amplifying a very low-level signal, the amplifier's own noise can swamp the signal. The purpose of an LNA is to amplify the received signal to acceptable levels while minimizing the noise it adds. This article describes the design of an LNA that achieves these two important criteria.

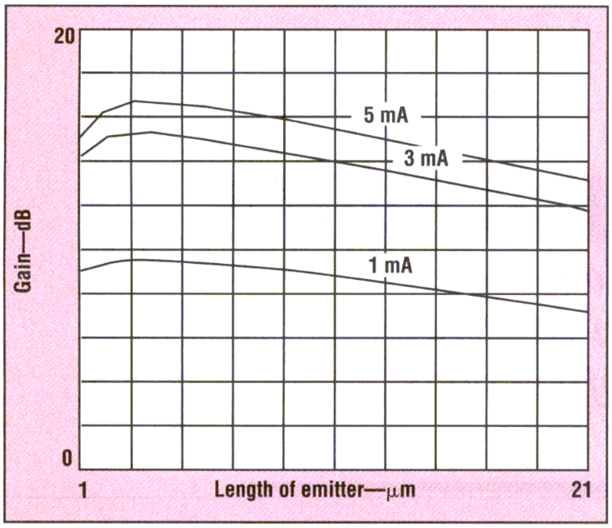
The first step in the design is selecting the active device and circuit configuration. The simplest amplifier configuration is a bipolar-junction transistor (BJT) in a common-emitter (CE) configuration. Figure 1 shows the complete CE amplifier configuration, which consists of the transistor, DC-biasing circuitry, and impedance-matching networks.

Once the device configuration is chosen, the next step is to find the DC-bias voltage and current. Usually, the power-supply voltage is known or is supplied by the customer. Sometimes, however, the circuit is designed to work over a range of supply voltages. There are two advantages to this approach—versatility and reliability. This circuit is more versatile because it can be used in multiple applications. Second, if the DC power supply is a battery, the circuit is more reliable because it can better tolerate the battery's changing voltage as power is consumed. A related design concern is power consumption. In a handheld mobile application, the circuit's power must be supplied by a battery, and the designer must consider the constraints of such an application. First, there is a trade-off of available power versus the weight of the handheld phone. Customers want small, lightweight cell phones, so market pressure forces cell-phone manufacturers to use small batteries with limited current capacity. Thus, the LNA circuit's current flow must be kept to a minimum to conserve power. Another reason to minimize the circuit's current is to increase battery life. Cell-phone customers want increased talk time, so market pressure favors cell phones that have long battery life.

The main design goals of an LNA are to achieve high gain and low noise, but the circuit must also be



1. This block diagram shows the BJT in a common-emitter configuration, along with the DC bias and impedance-matching networks.



2. This graph shows the change in performance of the single-transistor, common-emitter LNA as the emitter length varies.

unconditionally stable over a wide bandwidth. Stability is a critical factor in any design, especially at higher frequencies. If an amplifier is unstable in its operating range, it will oscillate. Even instabilities outside the operating range can be detrimental due to feedback and adjacent-channel requirements. One way to predict stability is to calculate the factor MU. MU is derived from the scattering parameters (S-parameters) of the circuit, as shown in equation 1.

$$MU = \frac{\left|1 - S_{11}^2\right|}{\left(1 - S_{11}^2\right) / \left[S_{22} - \det(S)S_{11}{}^*\right] + \left(S_{21}S_{12}\right)} \quad (1)$$

where:

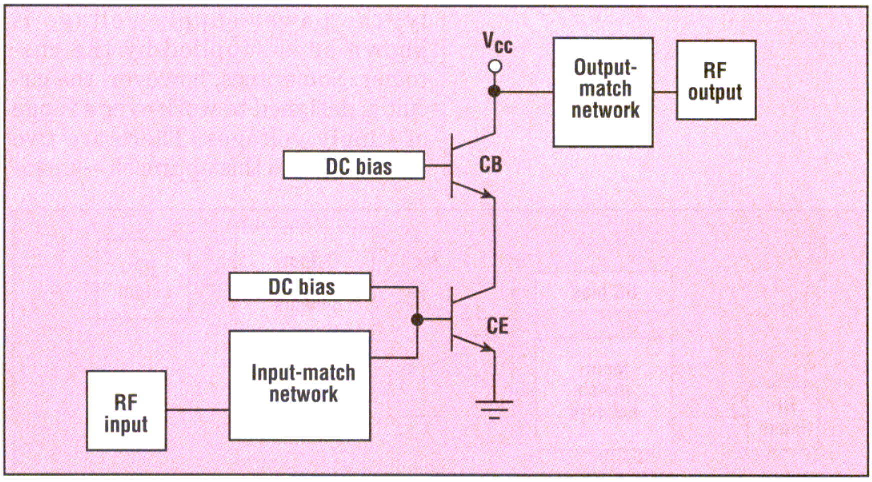
$*$ = the conjugate operation, and
$\det S = S_{11}S_{22} - S_{21}S_{12}$

The stability factor MU must be greater than 1 in the operating frequency range to guarantee unconditional stability. Other factors to be accounted for are the input return loss (IRL) and the output return loss (ORL). Since the CE configuration is a single-gain-stage amplifier, IRL and ORL are the S-parameters S_{11} and S_{22}, respectively. For simplicity's sake, nonlinear RF parameters such as intermodulation distortion (IMD) and the 1-dB compression point are neglected.

In this design, the desired minimum gain is +15 dB and the maximum allowable noise figure is 2 dB. The circuit must also exhibit an acceptable return loss of 15 dB and be unconditionally stable. Factors that affect the gain and noise of the LNA include the DC bias current and the dimensions of the active device. In modern fabricated transistors, each terminal of the device has an associated length, width, and number of fingers. The base and collector dimensions are fixed, but because of the fact that the emitter has the most impact on the device's performance, its dimensions are varied. The results of varying the emitter length are shown in Fig. 2. It is apparent from this graph that the simplest LNA configuration—that of a single transistor configured as a CE—will not meet the desired design goals. Therefore, a more complex circuit is required.

The natural thing to do is add another active device to the circuit. There are several methods of combining two transistors, including cascade, cascode, and differential pair. The cascode configuration, shown in Fig. 3, consists of a CE followed by a common base (CB). This configuration is similar to the existing single common-emitter configuration, but has some advantages over it. In the CE configuration, there is a capacitance between the collector and base, and it is magnified by the Miller effect. Therefore, the input and output are not fully isolated. This leads to performance degradation at higher frequencies. In the cascode configuration, the RF input is applied to the base of the CE transistor and the RF output is taken from the collector of the CB transistor. This configuration yields better isolation than the single-transistor, CE configuration. The trade-off is circuit complexity. Now there are twice as many transistors and, therefore, twice as many variable device dimensions. To optimize performance, the designer must vary the CE dimensions, the CB dimensions, the DC operating point, and the impedance match.

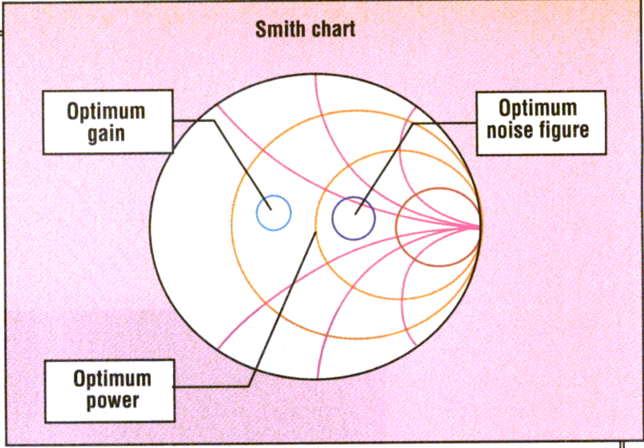
In RF design, the matching of the circuit plays a critical role in obtaining optimum performance. Traditionally, the input and output are matched to the impedance for maximum power transfer. However, the goal of the LNA design is not to optimize power, but noise figure and gain. Unfortunately, calculating impedance to optimize gain, noise, and power often yields three different values. Modern simulation software can compute the impedance for the optimum values of gain and noise. Figure 4 shows the three impedances. The impedance for maximum gain is at the center of the circle



3. This block diagram illustrates the two-transistor cascode configuration, along with the DC bias and impedance-matching networks.

on the left of the chart, while the center of the circle on the right of the chart is the impedance that yields minimum noise figure. The optimum impedance for power is at the very center of the chart. Clearly, optimizing the impedance for one factor simultaneously guarantees non-optimal values for the other factors. This is another example of a trade-off that the designer must face.

At this point, the designer must replace the ideal sources in the bias circuit and ideal values in the matching circuit with equivalent real components. This often presents the designer with a new set of problems. First, the bias network must be robust enough to function properly over a range of power-supply voltages and temperatures. This introduces additional complexity into the bias network. The real components in the bias network—the resistors and large capacitors—operate at DC voltages, so frequency effects are not a problem. The matching network, however, contains real capacitors and inductors that operate at RF frequencies. Real components differ from ideal ones in several respects. First, real components have a price associated with them. There is a trade-off between price and performance of these parts. The competitiveness of today's markets often forces designers to use inexpensive components in their designs. Real discrete components have a finite resistance called series-equivalent resistance (SER). The SER introduces losses that result in lower gain and noise figure. Although typically only a few tenths of an ohm in value, SER will affect the matching networks. Discrete components also have a Q value, measured at a particular frequency, that can contribute to unwanted resonance. A component's series-resonant frequency (SRF) is the frequency where it will behave erratically. For example, if an inductor is operated at or above its SRF, it might behave as a capacitor. To avoid this, select components where the SRF is much higher than the operating frequency. Also, leaded through-hole parts have leads that add series inductance to a design, and surface-mount parts have pads that add shunt capacitance to a circuit. All of these factors can degrade the cir-



4. The optimal-load impedances for three different characteristics lie at different points on the Smith chart.

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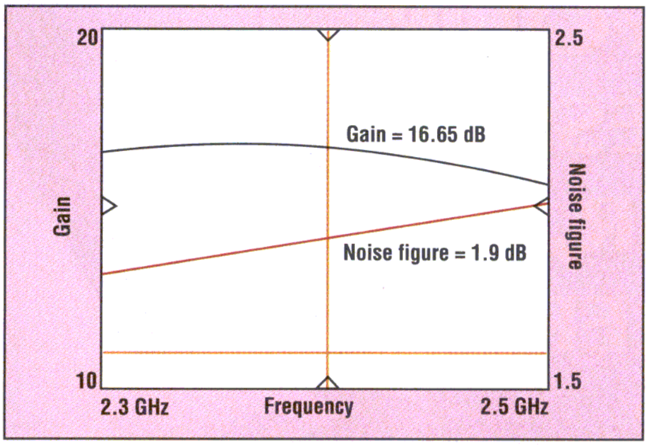
CIRCLE NO. 242

cuit's performance from the ideal, and the designer must carefully take them into account.

Another issue is that of packaging a completed design. If the circuit is to be integrated and sold as an integrated circuit (IC), it must be packaged. The package introduces several negative effects. In an IC, the bond wires add unwanted inductance (L) and the bond pads add unwanted capacitance (C). Isolation between pins in the package is also important. Lack of pin-to-pin isolation in a feedback circuit can lead to major reliability problems and stability concerns. The additional inductance in the emitter of the collector-emitter section can severely degrade the noise figure of the circuit. Additionally, several grounds are usually needed to improve the performance of RF circuits, but the package has a limited number of pins. After using the input, output, and power-supply pins, there may not be enough ground pins to accommodate an adequate design.

Finally, the designer relies heavily on the accuracy of the device models. The models often have difficulty measuring accurately the RF capabilities of a circuit. In some cases, such as the nonlinear RF effect, two-tone IMD products, the models cannot predict behavior at all. The designer must face the trade-offs, take into account manufacturing variability and model inaccuracy while still exceeding all of the design specifications. Typically, the designer "pads" the design with some headroom to compensate for these problems. Once the circuit is built, the designer usually adjusts the bias circuitry and matching networks to optimize performance. For the LNA design in question, Fig. 5 shows the final simulation results. ●●



5. This graph shows the performance characteristics of the final cascode LNA design.

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Construct A Millimeter-Wave E-Plane Integrated Power Combiner

This novel device combines the power of two Gunn diodes to generate robust millimeter-wave signals.

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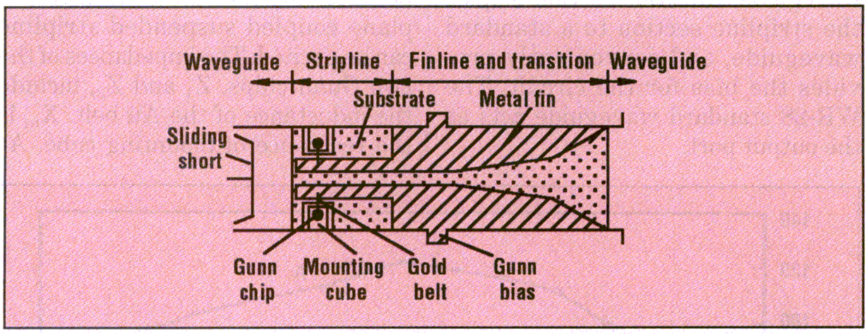
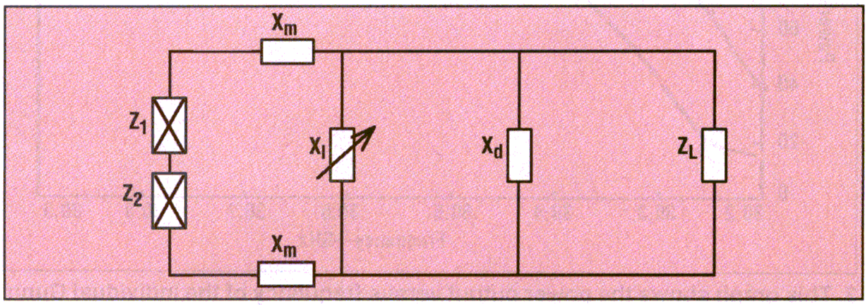
GUNN diodes are widely used as microwave and millimeter-wave low-noise oscillators. But the output power from a single Gunn device is relatively low and, therefore, is not suited for medium-power applications. One approach to achieve higher output power is to combine the power of two Gunn diodes. This article presents the design of a novel, millimeter-wave power combiner for that purpose. The combiner circuit adds the contributions of two Gunn chips through an E-plane coupled, suspended stripline and finline structure, which is housed in a WR-28 waveguide. At the Ka-band, this power combiner can handle output-power levels from 200 to 305 mW over a bandwidth of more than 550 MHz.

Millimeter-wave power combiners can be segregated into four main categories—chip-level combiners, circuit-level combiners, spatial combiners, and hybrids of these three categories.[1] The circuit-level category includes an approach called the resonant-combining approach, which usu-



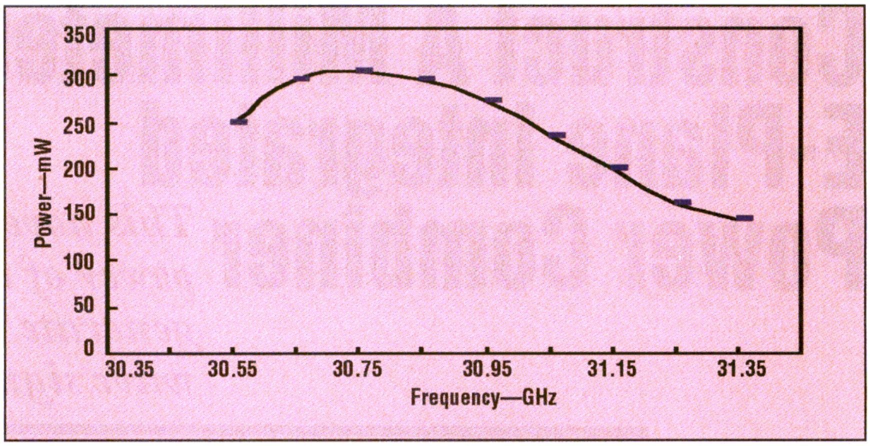
1. This diagram shows the physical structure of the power combiner and its constituent components.



2. This schematic diagram shows the power combiner's equivalent circuit.

ally applies rectangular- or cylindrical-waveguide-resonant-cavity combining techniques.[2] While the millimeter-wave integrated circuit (IC) is superior to other transmission lines, the resonant E-plane integrated power combiner presented in this article is even better. To achieve good repeatability in manufacturing, this combiner uses Gunn chips instead of packaged Gunn devices. By optimizing the dimension of the E-plane-coupled suspended stripline, finline, and mounting cube, the combiner can generate substantial output power over a particular portion of the Ka-band.

Figure 1 shows the physical configuration of the combiner, which consists of four main sections. The sliding short in the waveguide serves to mechanically tune the combiner's frequency. The resonant-cavity section consists of an E-plane-coupled suspended stripline. The Gunn chips are affixed to the mounting cubes by hot-pressure welding. The mounting cubes are situated beside the coupled stripline, and each diode chip connects to the circuit through a gold (Au) belt, which is ultrasonically bonded to the chip. A finline-to-waveguide transition section couples the stripline section to a standard waveguide, and conveniently provides the bias for the circuit. The WR-28 standard waveguide acts as the output port.



4. This graph shows the combined power output versus frequency of both Gunn diodes operating simultaneously.

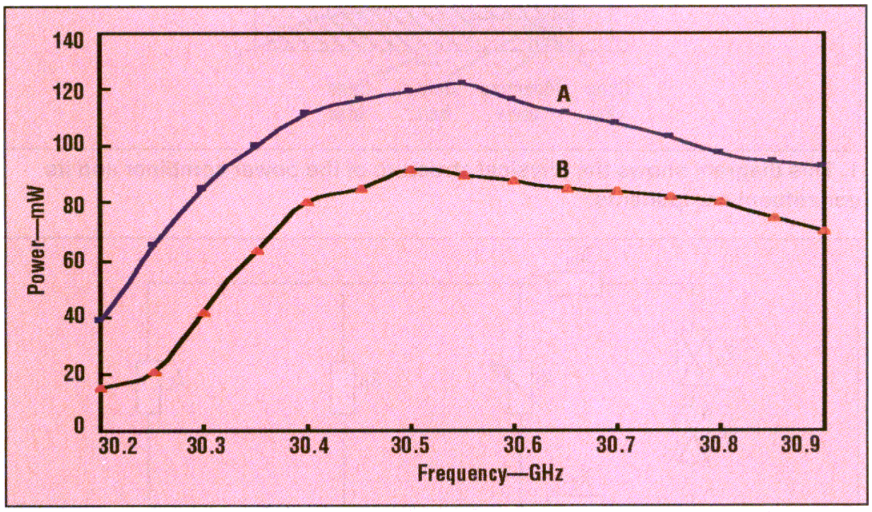
The interaction between the Gunn devices and the circuit converts some of the applied DC energy into millimeter-wave power, but most of the DC energy is converted into heat. It is therefore important to consider the chip's heat-sinking capability to prevent overheating and subsequent destruction of the device during operation. The method used to mount the Gunn chip is the same as in ref. 3.

Figure 2 shows the equivalent circuit of the power combiner. The two Gunn chips are connected in series because only the odd mode of the E-plane coupled suspended stripline can be excited. The impedances of the two Gunn chips, Z_1 and Z_2, include the inductance of the Au belt. X_m is the reactance of mounting cube. At the plane where the Gunn chips are located, X_l is the reactance of the sliding short and X_d is the diminishing reactance between the coupled suspended stripline and finline. Z_L is the equivalent impedance of the load.

To obtain high output power, the Gunn devices must be well-matched to the circuit. To optimize power, the designer must carefully consider the equivalent circuit shown in Fig. 2, the steady-state oscillation condition of the combiner, and the parameters of Gunn chips. By optimizing structural parameters such as the slot width, coupled-stripline width and length, and the dimensions of the mounting cube as well as the finline-to-waveguide transition section, the designer can achieve excellent circuit performance.

In constructing the power combiner, the authors housed the E-plane circuit of the power combiner in a WR-28 waveguide for Ka-band operation. The circuit pattern was etched on a 10-mil (0.254-mm)-thick Duroid 5880 substrate with a dielectric constant of 2.22. The GaAs Gunn chips were manufactured by Nanjing Electronic Devices Institute of China. To reduce the influence of parasitic inductance, the length of Au belt between the chip and circuit was kept as short as possible.

When testing the combiner's performance, the authors first operated it with only one chip active at a time, and then with both chips active. Figure 3 shows the test results of the

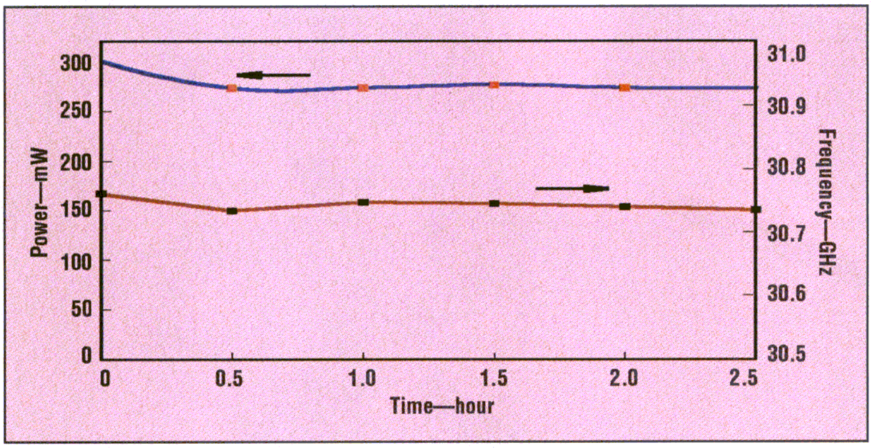


3. This graph shows the power output versus frequency of the individual Gunn diodes when activated separately.

power combiner operating with only one chip active at a time. Curve A indicates the output power when only chip number 1 was activated with a bias of +4.8 VDC and 0.88 A. With only chip number 1 active, the circuit achieved more than 40-mW output power from 30.16 to 30.85 GHz, and reached a maximum output power of 122 mW at 30.49 GHz. Curve B shows the output power when only chip number 2 was activated with a bias of +4.9 VDC and 0.7 A. With only chip number 2 active, the circuit achieved more than 15-mW output power from 30.15 to 30.80 GHz, and reached a maximum output power of 92 mW at 30.45 GHz.

To operate the combiner with both chips active, their respective bias conditions remained the same as for single-chip operation. Figure 4 shows the combiner's output power versus frequency. With both chips active, the combiner achieved more than 200-mW output power from 30.61 to 31.16 GHz, and reached a maximum combined output power of 305 mW at 30.74 GHz.

Figure 5 shows the power output and frequency of the combiner over two 2.5-h periods. During the first period, the combiner was tuned to a frequency of 30.74 GHz. Then the combiner was tuned to 30.93 GHz and ran for another two and a half hours. Over both periods, the combiner demonstrated very good stability. ••



5. This graph of the power output and frequency of the combiner demonstrates its stability over two 2.5-h periods.

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EM Software Helps Refine EIA Klystron Design

The use of a powerful but easy-to-use computer-aided-engineering software program made possible rapid improvements in the design of a millimeter-wave klystron.

David Carpenter
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Peter Horoyski and Mark Hyttinen
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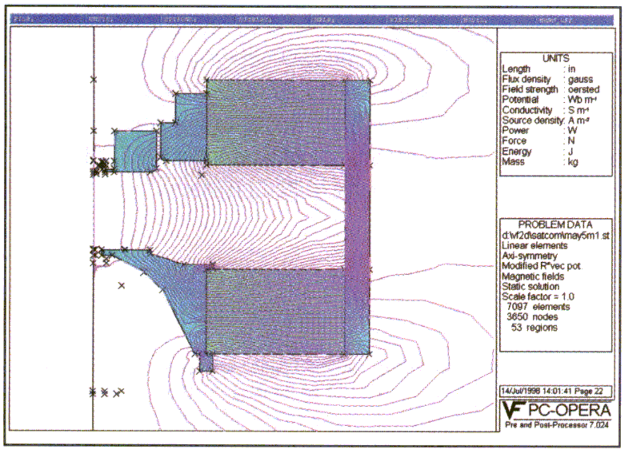
ELECTROMAGNETIC (EM) simulation software can be a powerful computer-aided-engineering (CAE) tool. In one case, this software helped to solve a difficult problem in the design of a millimeter-wave extended-interaction (EIA) klystron. Similar to all amplifiers based on vacuum electron devices, excellent beam transmission is of paramount importance. A recent Ka-band (approximately 30-GHz) amplifier prototype had suffered from less-than-optimum electron-beam focusing. Simulating the klystron using EM software showed the designers where the beam was hitting the cavity of the klystron and helped guide the redesign of the magnet pole piece that solved the problem.

Klystron RF amplifiers are recognized globally as rugged and reliable sources of RF power and, as such, are used in large numbers in communications and radar applications. The conversion mechanism is the familiar space-charge wave process where velocity modulation in an electron beam transforms to current or density modulation with distance. An electron gun produces a narrow beam of electrons, which is maintained at a required diameter by a magnetic field while it passes through the tube's RF section.



1. This axisymmetric model of the EIA klystron's magnetic circuit shows the lines of magnetic flux.

As the use of the lower-frequency microwave spectrum for satellite and terrestrial communications grows to saturation, the need for millimeter-wave devices becomes apparent. However, extrapolating microwave vacuum electron devices into the millimeter-wave range presents designers with the challenges of fabricating miniature precision parts and controlling high-current-density electron beams.

Conventional klystrons do not scale well to the millimeter-wave region. If a conventional microwave klystron were simply scaled to smaller dimensions to produce higher frequencies, increased skin-effect losses would drastically reduce amplifier gain. In addition, the magnetic-field requirement would quickly increase to a range that exceeds the saturation limit of the magnetic pole pieces. The current density at the cathode surface would similarly increase to levels well beyond what is acceptable for long operational life.

The EIA klystron was developed some years ago to overcome the problems of high-frequency operation. An EIA klystron contains a ladder-like structure that forms a series of cavities where the electron beam passes. When the beam enters an RF-excited cavity with approximately synchronous velocity, it receives cumulative velocity modulation at each gap. The resonated slow-wave structure provides high RF interaction

impedance compared to a single-gap klystron.

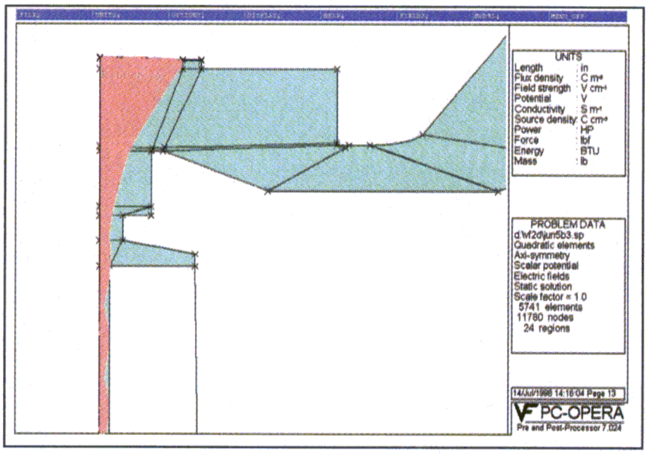
A particular challenge in the design of a millimeter-wave klystron is a well-focused and confined electron beam. This is achieved with the use of highly refined computer modeling, precision assembly techniques, and high-performance cathodes and magnetic structures. The goal is to produce an electron-beam diameter with minimum ripple and cause the beam to pass as closely as possible to the beam tunnel without collision. This makes it possible for the circuit to be heated mainly by the inevitable RF losses, enabling the thermal capacity of the copper (Cu) circuit to be used for maximum RF power.

In an early prototype of a recent Ka-band (approximately 30-GHz) device developed by CPI Canada (Georgetown, Ontario, Canada), the electron beam, which is focused by two sets of permanent magnets, was partially intercepted by the RF circuit. The quality of the focus could easily be measured by measuring the current transmitted by the device. But with the device assembled, there was no way to probe the internal electron dynamics to determine where the problem was.

This problem would have been time-consuming and expensive to resolve by traditional experimental methods. Without a method to measure the electron trajectories inside the device, designers would have had to infer the beam dynamics based on probes external to the vacuum envelope. Building a prototype vacuum electron device is costly and requires a considerable lead time. Once the device was built, designers could easily determine how well it worked, but would be limited in their in situ diagnostic capability.

Fortunately, personal-computer (PC) software that is easy to use and relatively inexpensive is now available to model EM devices, including space-charge effects. CPI Canada engineers selected OPERA-2D software from Vector Fields, Inc. (Aurora, IL) to perform a two-dimensional (2D) analysis of the klystron. This software package was selected due to its outstanding technical functionality and a graphical user interface (GUI) that greatly reduces the time required to complete the analysis. Before purchasing the software, scientists from CPI Canada analyzed a series of cases where the software did an excellent job of predicting the results of several experiments involving the company's products.

CPI engineers graphically generated a model of the klystron by defining a 2D cross-section using the software's advanced computer-aided-design (CAD) facilities. The program then automatically divided the model into finite elements. The material properties of the components were specified from the library of material data contained in the system.



2. This axisymmetric model of the EIA klystron's gun optics includes electron trajectories from the cathode, through the gun region, and into the tunnel in the RF circuitry.

The analysis provided graphical output including graphs and histograms of the solution and contour plots that showed the magnetic-field values superimposed on the surfaces of the model (Fig. 1). The program also produced particle trajectory plots that showed the predicted path of the electron beam. The results of the initial iteration matched the experimental results. The output of the analysis indicated that the nonthermal electron beam, instead of passing smoothly through the gaps of each cavity, was partially intercepting the cavity structure. If not corrected, this problem would have reduced the RF performance of the device and could potentially have produced reliability problems by generating heat that might have caused the interaction circuit to fail.

By showing exactly how the beam was being focused in the prototype, the analysis output helped designers to gain a clear understanding of the problem (Fig. 2). CPI Canada's scientists used the software to evaluate alternate designs for the magnetic circuitry. The software helped to improve each design iteration by providing more understanding of how the changes made in the magnetic field affected the nonthermal trajectory of the electron beam. Within a few iterations, each of which took only an hour to two to develop, the scientists had created an alternate magnetic pole piece design that, according to the software, directed the beam through the gaps without intercepting any of the cavities.

Following the simulations, the next step involved building a prototype of the new design. Once this prototype was built and characterized, measurements revealed that it met the objective of focusing the beam smoothly through the gaps in the cavities without interception. After additional testing, the design has been deemed a success and is currently in production for use in commercial satellite-communications systems.

This project clearly demonstrates the advantages of EM simulation in the design of millimeter-wave devices. Engineers can determine the values of EM fields at every point in the problem domain and can determine the precise trajectory of a particle stream. With many devices, this information cannot be obtained experimentally, forcing engineers to rely in part on trial and error. The ability of analysis to provide values over the entire problem domain allows engineers to have a better understanding of their design and often, as in this case, helps them to improve its performance. ••

Manufacturing Practical 28-GHz Multichip Modules

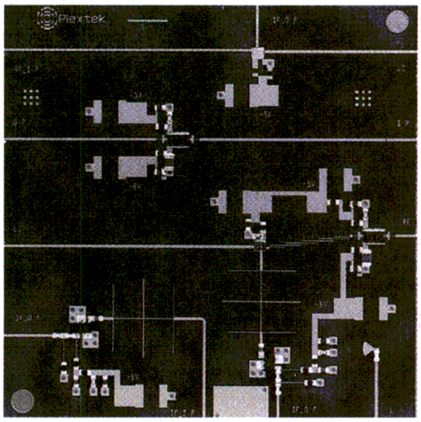
These frequency upconverter and downconverter modules are designed for high-volume applications in broadband wireless-access systems using readily available technologies.

Liam M. Devlin, G.A. Pearson, A.W. Dearn, and S. Williamson

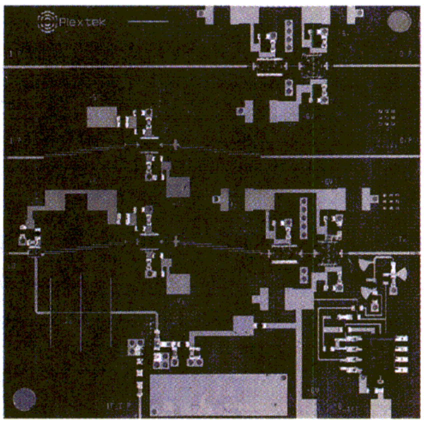
Plextek Ltd., London Rd., Great Chesterford, Essex CB10 1NY, England; 01799 533 200, FAX: 01799 533 201, Internet: http://www.plextek.co.uk.

BROADBAND wireless-access systems, such as local multipoint distribution services (LMDS) and multipoint video-distribution systems (MVDS), tend to operate at millimeter-wave frequencies where spectrum is available. These frequencies were formerly occupied by low-volume applications, including radio astronomy and military systems, and the high cost of the equipment reflected the low volumes of the applications. But as broadband wireless-access applications blossom, new techniques are being developed to produce higher volumes of millimeter-wave equipment at lower prices. The report that follows details the design and development of frequency upconverter and downconverter multichip modules (MCMs) for LMDS use at 28 GHz. The MCMs are suitable for high-volume, low-cost manufacturing using printed filters, GaAs monolithic microwave integrated circuits (MMICs), discrete surface-mount-technology (SMT) components, and a polytetrafluoroethylene (PTFE) composite software substrate.

The heritage of millimeter-wave electronics has been one of radio astronomy and military systems, with hardware that was produced very expensively and in small volumes. But with the growing use of millimeter-wave systems for commercial applications, particularly in LMDS and MMDS, manufacturers must scramble to find new ways to design and manufacture millimeter-wave equipment cost-effectively.



1. This photograph shows the millimeter-wave downconverter MCM. All decoupling was realized through 0402-size SMT components.



2. This photograph shows the millimeter-wave upconverter MCM, which includes some diagnostic subcircuits.

GaAs MMIC technology offers a way to fabricate large volumes of repeatable, reproducible millimeter-wave circuits at low cost. However, module assembly techniques, suitable for circuits operating at millimeter-wave frequencies, can be complex and costly. These techniques also tend to be incompatible with low-cost manufacturing methods, which could be adopted for the biasing, control, and intermediate-frequency (IF) circuitry. Still, low-cost approaches have been successfully implemented in Europe for producing low-cost millimeter-wave subassemblies for LMDS. The basis for one approach involves the use of PTFE substrates rather than ceram-

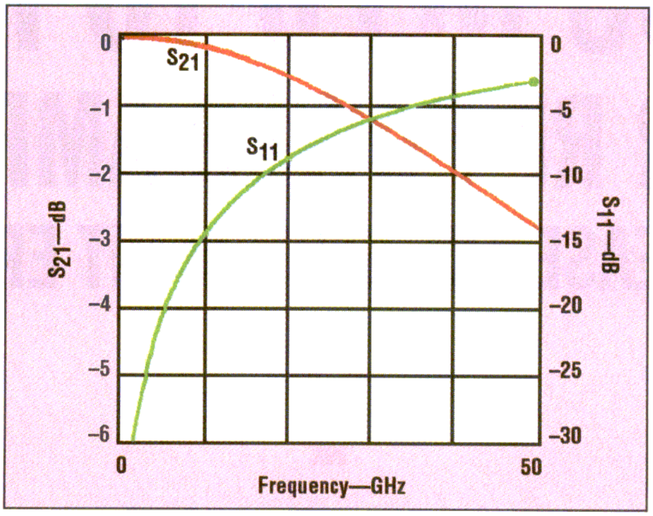
ic boards, with the attachment of bare semiconductor die and SMT components in a single process step. The following details the design, fabrication, and measurement of a 27.5-to-29.5-GHz frequency upconverter and a 27.5-to-29.5-GHz frequency downconverter.

Careful choice of substrate is vital. In addition to being low cost, the substrate should possess the following properties for optimum use at millimeter-wave frequencies:

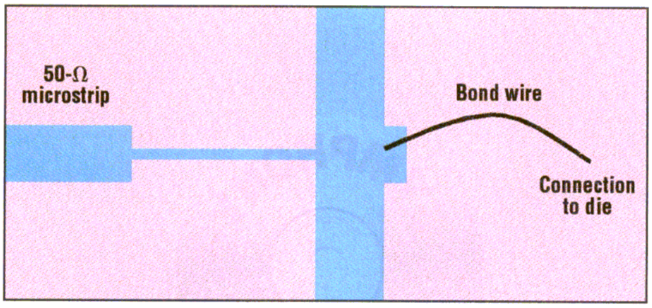
- Thin substrate height (to reduce dispersion and radiation losses).
- Low dielectric constant (which helps to reduce the effects of tolerance variations and avoid impractical dimensions for distributed structures).
- Well-controlled dielectric constant (reduces performance variation).
- Low dissipation factor (low loss).

With these factors in mind, the material chosen was Rogers RT Duroid® 5880, a glass-microfiber-reinforced PTFE composite with a dissipation factor (tan δ) of 0.0009 and a relative dielectric constant (ϵ_r) of 2.2 (with a standard dielectric-constant tolerance of ±0.02). The substrate material is available in thin heights and a height of 0.005 in. (0.0127 cm) was selected for the millimeter-wave designs at 28 GHz. The material is also available with brass backing. In addition to providing mechanical rigidity, the brass backing allows bare MMIC die to be mounted within pockets cut into the substrate. The result is the surface of the die being practically level with the surface of the substrate, minimizing the lengths of bond wires (and the resulting parasitic capacitances and inductances) used for interconnections.

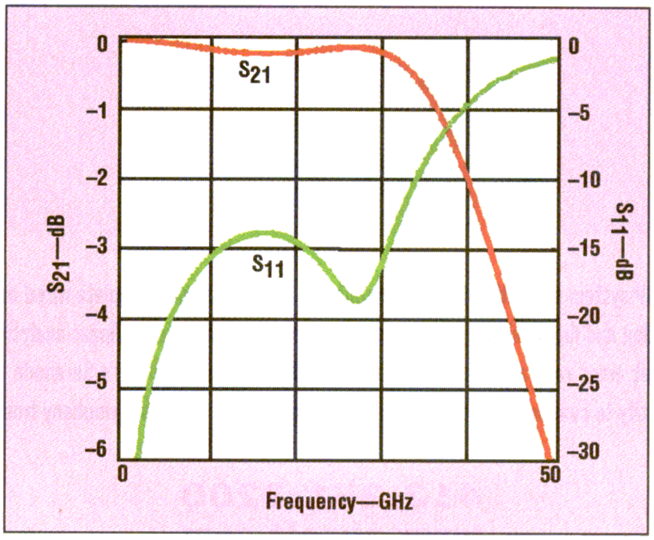
The first stage of processing the substrate is the drilling of via holes and mounting holes. Selective plating of the through-substrate via holes, to make contact between the substrate's front-side metallization and its backside metallization, then occurs. Next, the chip-mounting pockets are cut into the substrate, revealing the brass backing. Selective nickel-gold (NiAu) plating of the copper (Cu) tracking and the brass of the pocket bases provides protection from contamination and a surface suitable for Au wire bonding.



3. The insertion loss and impedance matching were evaluated as functions of frequency for a 0.3-nH bond wire in a 50-Ω system.



4. Provided that the residual inductance of a bond wire is low enough, it can be incorporated into a lowpass-filter structure.



5. This simulated performance is based on the model of a lowpass filter structure incorporating the 0.3-nH inductance of a typical Au bond wire.

ASSEMBLY PROCESS

The first stage in the assembly process is to dispense conducting epoxy to the pocket bases for die attachment and onto the placement pads for the attachment of any SMT components. For development work, dispensing is carried out manually. When high-volume manufacturing is implemented, automated dispensing methods are applied. The bare die and the SMT components are then placed on the substrate. Again, this is performed by hand during the developmental stage, but is automated with pick-and-place machinery during high-volume production. The epoxy is then cured and all components are fixed in place, including bare die and SMT, in one step.

After curing, the dice are bonded to tracks or pads on the Duroid using 0.001-in.-diameter Au wire, using wedge-wedge thermosonic bonding. Figure 1 shows the completed assembly of the 27.5-to-29.5-GHz downconverter MCM. Some diagnostic subcircuits have also been fabricated on the same tile. No discrete microwave capacitors were used. All decoupling is realized

through 0402 SMT components. This reduces component cost and assembly complexity.

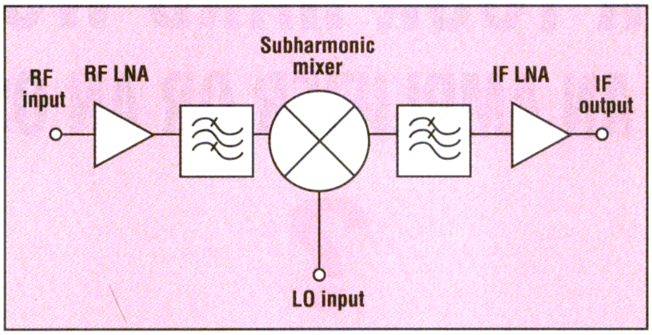
A photograph of an upconverter MCM (which also includes some diagnostic subcircuits) is shown in Fig. 2. The 4-GHz IF amplifier and the RF power-detection circuit have been realized entirely with SMT components and can be seen at the bottom left-hand side and bottom right-hand side of the photograph, respectively.

Although this fabrication procedure results in the shortest practical bond-wire lengths, there is still an associated inductance of approximately 0.3 nH per bond for 0.001-in.-diameter Au bond wire. At lower frequencies, the reactance that this represents is very low and can be ignored. At millimeter-wave frequencies, however, even this low inductance can cause significant performance degradation. Figure 3 shows a plot of the simulated insertion loss and match of a 0.3-nH bond wire versus frequency in a 50-Ω system. By 18 GHz, the return loss of the bond wire has fallen to below 10 dB. By 28 GHz, the return loss is below 7 dB, with an associated insertion loss of more than 1 dB.

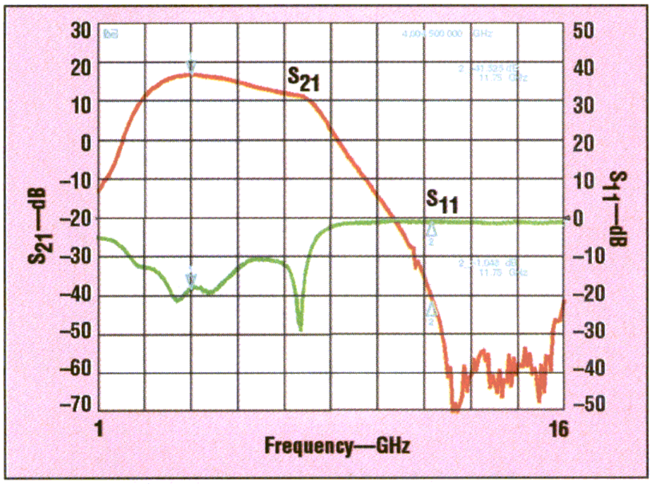
It is clear that simply accepting the performance degradation caused by a 0.3-nH bond wire at millimeter-wave frequencies is not acceptable. There are three options for resolving the problem:

1. Reduce the inductance by using multiple parallel bond wires or Au tape.
2. Use ICs which have been designed to accommodate a 0.3-nH inductor at all RF ports.
3. Incorporate the inductance into a lowpass-filter structure.

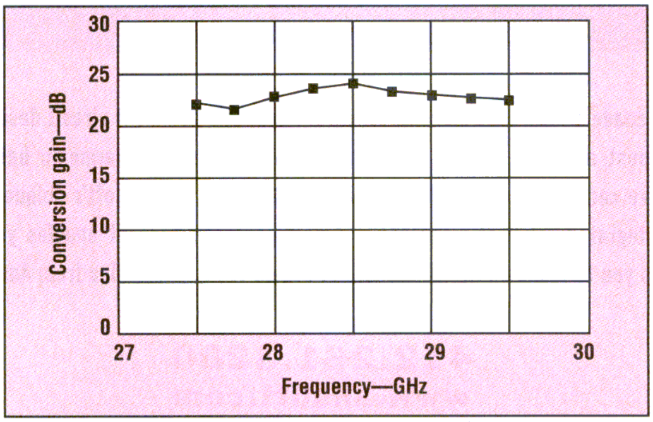
Option 1 is not the best approach for low-cost, high-volume use. Multiple bonds increase assembly time and require a larger, nonstandard bond pad (with more parasitic shunt capacitance); tape bonding also has a significant cost penalty. Option 2 is viable but requires all ICs to be designed for a specific assembly process. Also, the RF on-wafer (RFOW) measured performance of the ICs will differ significantly from the in-circuit performance as the RF port bond wire inductance, which the circuit"s performance has been optimized to include, would be missing. Option 3 allows ICs designed for best RFOW performance to be used. So long as the bond wire inductance is low enough, it can be absorbed into a practical, lowpass-filter structure, such as that shown in Figure 4. The printed open-circuit stubs act as a shunt capacitance and the narrow (high-impedance) series microstrip line serves as an inductance to complete the third-order lowpass-filter structure.



6. The millimeter-wave frequency downconverter module is designed to handle input frequencies from 27.5 to 29.5 GHz and provide an IF of 4 GHz.



7. The performance of the downconverter's lowpass-filter/IF-amplifier subcircuit was evaluated through measurements.



8. The conversion gain of the frequency downconverter was measured around 23 dB as a function of frequency.

Figure 5 shows the simulated performance of a lowpass-filter design, which uses this technique to incorporate a 0.3-nH bond wire inductance. It has been optimized for use to 30 GHz. Improved return loss and insertion loss, compared to the simple series bond wire case, is evident above 10 GHz.

A downconverter MCM was designed and fabricated using the methods described above. It operates over an RF frequency range of 27.5 to 29.5 GHz, with an IF range of 4 GHz. The local-oscillator (LO) input is in the range 11.75 to 12.75 GHz, as the downconverter uses a sub-harmonic mixer which accepts a half-frequency LO. All components used are commercially available. A block diagram of the complete downconverter is shown in Fig. 6.

The low-noise amplifier (LNA) and the mixer are 0.25-μm gate-length pseudomorphic-high-electron-mobility-transistor (PHEMT) GaAs MMICs, which are used in bare die form. Image filtering is realized using a five-element,

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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	

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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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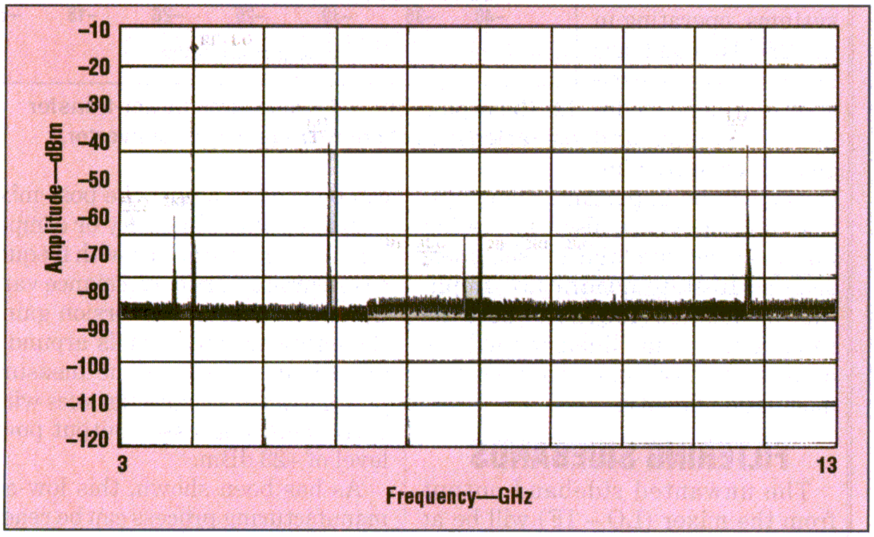
printed coupled-line filter,[1] while the lowpass IF filter is a printed stub design. It is strictly a bandstop filter, which rejects the one-half LO frequency output of the mixer (which can be particularly high for subharmonic mixers). An inexpensive SMT component is used to realize the IF amplifier, with a network of 0402 passive components and printed stubs to provide flat gain-versus-frequency response.

TEST CIRCUITS

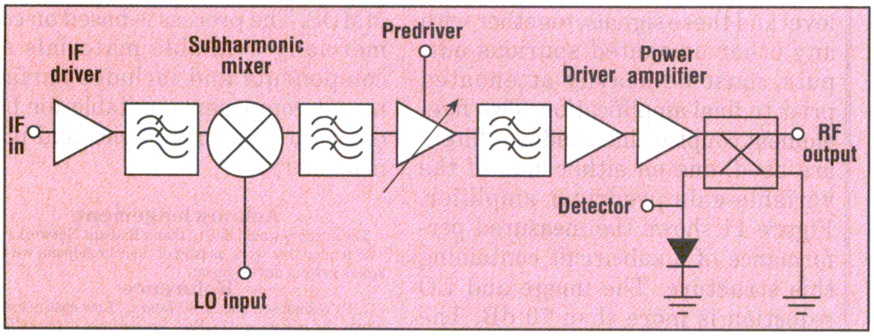
In addition to the complete downconverter, a number of subcircuits were fabricated on the same tile for diagnostic purposes. Figure 7 shows the measured performance from 1 to 16 GHz of a subcircuit comprising the IF lowpass filter and IF amplifier. It exhibits a gain of 16 dB at 4 GHz and a rejection of more than 55 dB for the 11.75-to-12.75-GHz one-half LO frequency range. The conversion gain versus frequency of the complete downconverter is around 23 dB (Fig. 8). The image rejection is more than 35 dB across the band.

A plot of the IF port output spectrum for an RF input of –40 dBm is shown in Figure 9. The subharmonic mixer contains a one-half-LO amplifier. The level of unfiltered one-half LO at the IF output of the mixer is approximately +4 dBm. This is quite significant and is the reason for the bandstop nature of the IF filter. The one-half-LO level at the output of the entire downconverter is –39 dBm, having been substantially attenuated by the IF filter. The one-quarter-LO products are a result of the one-quarter-LO output from the signal source used to drive the LO. If this frequency component is present in the end system, a simple highpass filter on the LO port of the mixer can be used to attenuate it.

Similar to the downconverter, the



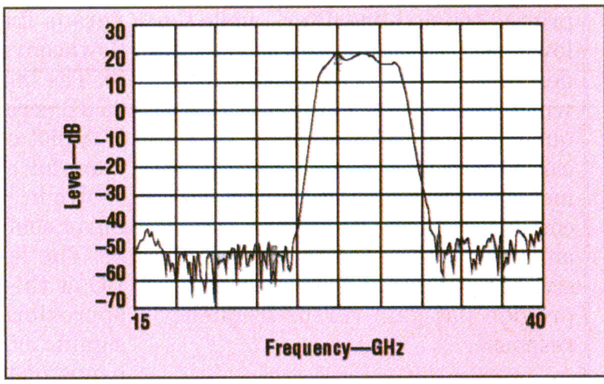
9. These measured results show the output spectrum of the downconverter's IF port, using an RF input signal at –40 dBm.



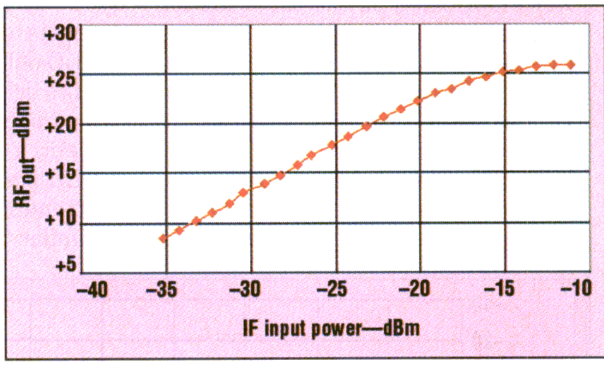
10. The frequency upconverter is based on a heterodyne architecture using commercially available components.

upconverter adopts a heterodyne architecture and uses only commercially available parts. As can be seen from its block diagram (Fig. 10), the upconverter uses the same subharmonic mixer as the downconverter. All of the transmit-chain RF amplifiers are 0.25-μm-gate-length PHEMT MMICs, used in bare die form.

The IF amplifier and lowpass filter are similar to those in the receiver (downconverter), although an amplifier with higher intermodulation performance is used in the upconverter. Upconverters for LMDS systems, operating in the 28-GHz band, are likely to use non-constant-envelope modulation schemes and good transmitter linearity will be important. Some system developers are also considering higher-order modulation schemes, such as 16-state quadrature amplitude modulation (16QAM), where the requirements for linearity will be even more stringent to preserve modulation fidelity.



11. These plots show the measured nominal gain of an upconverter subcircuit containing the predriver amplifier and two printed coupled-line bandpass filters.



12. These plots show the measured power-transfer characteristics of entire frequency upconverter.

FILTERING SIDEBANDS

The unwanted sideband output from the mixer (LO – IF) will be at around the same level as the wanted RF signal (RF = LO + IF). The LO output will also be at a significant level and these signals, together with any other unwanted spurious outputs, must be heavily attenuated prior to final amplification. Two five-element coupled-line bandpass filters are used, one on either side of the variable-gain predriver amplifier. Figure 11 shows the measured performance of a subcircuit containing this structure. The image and LO rejection is more than 70 dB. The variable-gain amplifier has a gain-control range of more than 15 dB and can be used to adjust the post-mixer gain to optimize linearity or compensate for gain variations with frequency or part-to-part performance variations. The overall conversion gain of the entire upconverter is around 43 dB. Figure 12 shows the measured power-transfer characteristics with a 1-dB gain-compressed output power level of +23 dBm.

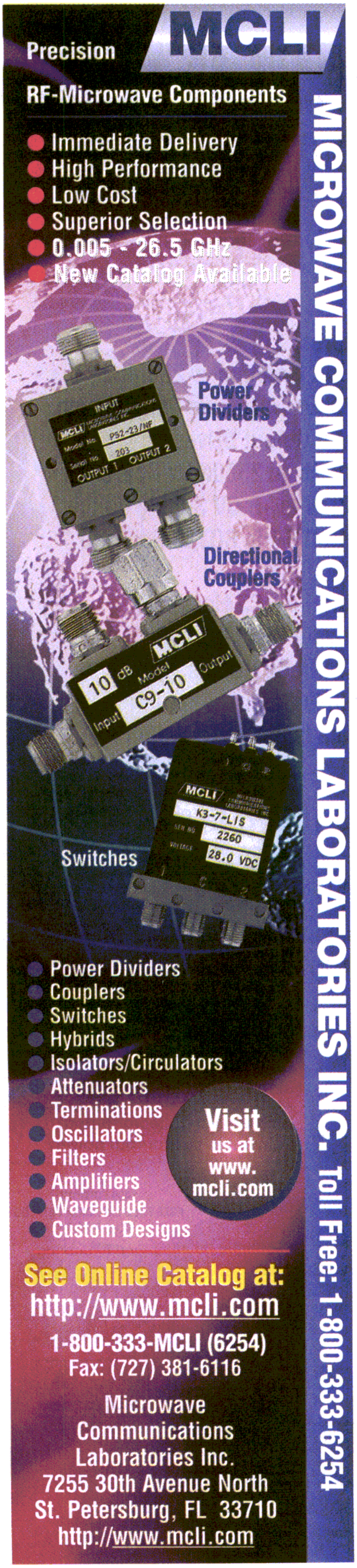
As has been shown, this low-cost manufacturing process can be readily applied to the high-volume production of millimeter-wave modules for such growing markets at LMDS and MMDS. The process is based on commercially available materials and components and includes surface-mount components suitable for handling with automated pick-and-place machinery.

Acknowledgement

The authors would like to thank Radiant Networks Ltd. who funded this work as part of their broadband wireless access system development.

Reference

1. S. Williamson and A.W. Dearn, "Low cost microstrip filters and mixers at 43 GHz," *Proceedings of the IEE Colloquium on Millimeter-wave Circuits and Technology for Commercial Applications*, Wednesday, 24th March 1999, pp. 3/1-3/8.



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DESIGN FEATURE

Radiation Effects

Gauging The Effects Of Cell-Phone Radiation On The Brain

What are the possible adverse effects that cellular phones might have on human brains, and can these effects be minimized by alternative antenna configurations?

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DISCUSSIONS have been many but studies have been few about the effect of the close proximity of handheld cellular and cordless phones on human brains. The discussions have been inconclusive thus far, but opinions about these effects range from no effect to short-term memory loss to brain tumors. This article identifies four direct effects possible from exposure to electromagnetic (EM) radiation from cellular phones that are of major concern. They are the interference caused by an external signal acting on the normal neurological signals, the unwanted excess currents flowing through the neurological networks, induced current exceeding the current-handling limitation of the neurological networks, and dissipation of heat into the brain tissues. To investigate cell-phone radiation, it is helpful to borrow methods that are used to analyze a similar situation—the EM interference (EMI) associated with RF transmitters and other electronic equipment.

During operation, a handheld cellular phone is placed very close to the brain and, thus, an analysis of its effects must involve near-field situations where, in the immediate vicinity of a radiating antenna, the EM fields are predominantly induction fields. For a vertically polarized, quarter-wave monopole located on a large ground plane, the electric field E and the magnetic field H along the ground plane at a short distance d from the monopole are given by:

$$H = I_o \lambda / (2\pi d)^2$$

$$E = I_o \lambda \eta / (2\pi d)^2 \qquad (1)$$

where:

I_o = the peak base current of the monopole,

λ = the wavelength of the frequency of operation, and

η = 120 π = the impedance of free space.

If P_R is the power radiated by the monopole having a radiation resistance R_R, then:

$$I_o = (2P_R / R_R)^{1/2} \qquad (2)$$

For a cellular phone with P_R = 1.6 W, R_R = 36.5 Ω, and an operating frequency of 1.9 GHz:

$$I_o = 0.296$$

$$\lambda = 0.158 \qquad (3)$$

Therefore:

$$H = 1.185 \times 10^{-3} / d^2 \ (A/m), \text{ and}$$

$$E = 0.447 / d^2 \ (V/m) \qquad (4)$$

where:

d = meters.

During the operation of a cellular phone, the nearest part of the brain is approximately 5 cm from the base of the antenna and the medium of propagation is almost entirely free space. Hence, the value of H is approximately 0.5 A/m and E is about 179 V/m. Although some modifications to these results are expected due to the smaller size of the ground plane associated with the monopole mounted on

a cellular phone, the magnitude of these fields is, nevertheless, quite large. In comparison, a 100-kW broadcast transmitter, located typically 10 km away and operating at 100 MHz, produces an electric field of approximately 0.15 V/m. With these estimates, it is possible to investigate the effect of the electric and magnetic fields on human brains.

To facilitate calculations, an analytical model of the brain is used. The neurological network carrying the nerve signals is assumed to contain a large number of closed loops and open-ended probes. These loops couple to the magnetic field so that the coupling is maximum when the loop planes are perpendicular to the magnetic field. Similarly, the probes couple to the electric field so the coupling is maximum when the probes are parallel to the electric field.

First, consider a loop of area S (m^2) with its plane perpendicular to the magnetic field. The coupled magnetic field appears as an induced EMF, V_{iL}, across a gap in the loop, given by:

$$V_{iL} = \omega\mu SH \qquad (5)$$

where:

ω = the angular frequency of operation, and

μ = the magnetic permeability of the medium.

The brain is assumed to be a nonmagnetic medium, so $\mu = \mu_o = 4\pi \times 10^{-7}$ H/m. Then, V_{iL} will be approximately 7500S V. Let R_{IL} be the internal resistance of the voltage source V_{iL}. Then, for a particular load R_{LL} (which includes the ohmic resistance of the loop and any resistance due to other coupled loops), the current I_{LO} through the loop is given by:

$$I_{LO} = 7500S / (R_{IL} + R_{LL}) \qquad (6)$$

In addition, currents from the other coupled loops, I_{LC}, will also flow through this loop so that the total induced current flowing through the loop is:

$$I_L = I_{LO} + I_{LC} \qquad (7)$$

Next, consider a probe of length l (m) located parallel to the electric field. The coupled electric field will develop an induced voltage V_{iP} across the probe, which for a short probe of length l is given by:

$$V_{iP} = El \qquad (8)$$

Then for E = 179 V/m, V_{iP} will be (179l) V. Therefore, if R_{IP} is the internal resistance of the voltage source V_{iP}, then for a particular load R_{LP} (which will include the ohmic resistance of the probe and those due to any other coupled probes), the resulting probe current I_{PO} is given by:

$$I_{PO} = 179l / (R_{IP} + R_{LP}) \qquad (9)$$

In addition, currents from other coupled probes, I_{PC}, will also flow through this probe so that the total induced current flowing through the probe is:

$$I_P = I_{PO} + I_{PC} \qquad (10)$$

Therefore, a cellular phone in operation creates an induced current I_L in a loop and I_P in a probe, modeling the neurological network of the brain. These currents might interfere with the normal brain signals already present in the loop and in the probe. Also, if the magnitudes of these currents exceed the current carrying capabilities of the neurological network, the network itself could become susceptible to damage. Finally, the neurological network is not designed to carry these externally induced currents and so the currents are ultimately dissipated into the surrounding tissues in the form of heat. This may not be harmful for relatively weak currents acting for a short period of time. However, the possibility of harm due to long-term dissipation into these tissues does exist. Thus, theoretically, a cellular phone is capable of affecting the human brain in various ways, including the disruption of brain functions and possibly inflicting some damage on the tissues in several areas of the brain.

REASON FOR CONCERN

Evidently, any type of EM field, from near or far, strong or weak, high frequency or low frequency, will couple to the neurological network of the brain to produce an induced current. Assuming that the magnitude of this current does not exceed the specified limit of the neurological network, no damage to the network itself is anticipated. However, there is still the possibility of interference with the normal brain signals and the as-yet-unknown effect of dissipation. If this induced current is quite small, the effect of its dissipation into the surrounding tissues for a short period of time may not be particularly harmful. However, the consequence of exposure of these tissues to low-level dissipations for a long period of time is not clear. This chronic, low-level exposure is probably already occurring in the form of exposure to high-frequency radiation fields from broadcast transmitters and low-frequency induction fields from power lines. These EM fields have been present in the environment for many years, but so far have eluded direct linkage to any neurological disorders. By comparison, the use of handheld cellular phones results in levels of exposure that are on the order of 60 dB higher than those due to broadcast transmitters. The possibility of damage is therefore significantly higher.

As mentioned earlier, the four areas of major concern are the interference caused by an external signal acting upon the normal neurological signals, the unwanted excess currents flowing through the neurological networks, induced current exceeding the current-handling limitation of the neurological networks, and dissipation of heat into the brain tissues. The consequences of all of these four effects are physically measurable, including the specification of the maximum neurological current limit. Moreover, the evaluation of the induced currents that were previously derived requires the electrical resistance per unit length of the neurological conductors. Also, an approximate diagram of the neurological network to estimate the loop and probe dimensions as well as the parameters for the mutual couplings are needed. But to carry out these measurements, access to a human brain is necessary, and those who have that access are mostly in the medical profession. The techniques involved in the measurements are relatively straightforward and could easily be conducted in a hospital laboratory. Once the measured data are available, they could be referenced

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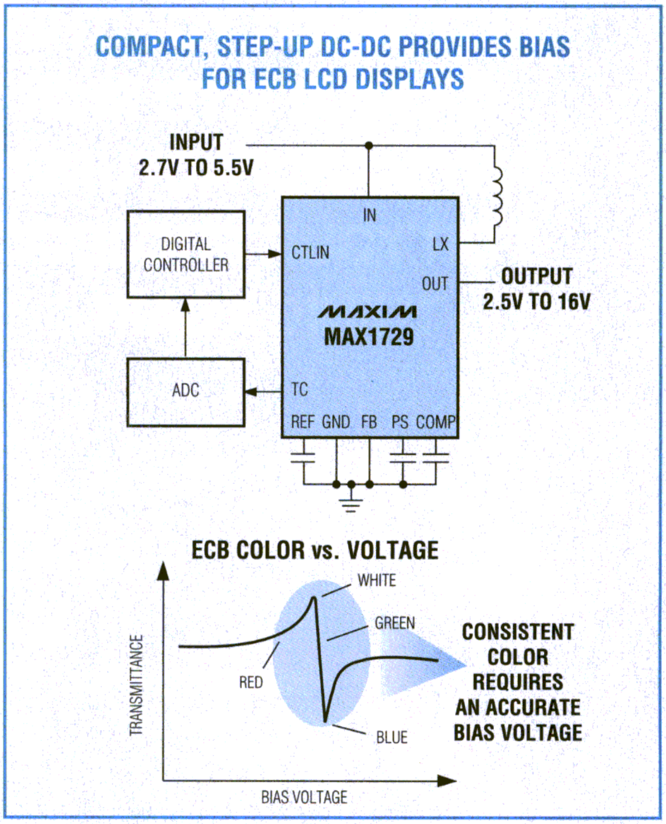

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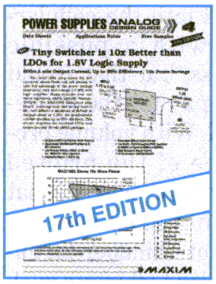

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with the computed engineering data to draw an overall picture of the magnitude of the problem. It thus appears that the involvement of the medical-research community is essential to make any meaningful progress toward the achievement of the desired results.

So far, some possible effects of radiation from a cellular phone on human brains have been discussed in general terms without any definite conclusions. However, as previously mentioned, more tests are still to be conducted and a definite answer may not be available for quite some time. In the mean time, efforts should be directed toward the development of ways to reduce the level of the offending radiation. There are two ways to reduce the magnitudes of the electric and magnetic fields at a particular location produced by a given radiator. One is by increasing the distance between the location and the radiator, and the other is by blocking the radiation in that particular direction.

In the case of a cellular phone, the distance between the phone and the brain could be increased if the phone is fitted with an audio-output jack to be connected to a headphone-microphone set. With a connecting cable of one meter, even for a line-of-sight scenario, the electric field could be reduced from 179 V/m to approximately 17.7 V/m. The extra advantage of this arrangement is that both hands remain free during conversation.

Alternatively, the monopole antenna on a cellular phone could be replaced by a printed antenna, such as a dipole, patch, or spiral antenna. These types of antennas operate with a ground plane behind them to prevent back radiation. Proper design could produce a cardioid (heart-shaped) type of radiation pattern with a deep small-angle null in the back direction. This would yield a radiation pattern that looks as if it were omnidirectional, with an angular section blocked by the head of the operator. Note that the width of the null should approximately correspond to the angle projected by the brain. The gain of this type of antenna is expected to be higher than that of the monopole, so that the performance of the cellular phone might not be compromised, even along the beam edges. The width of the antenna could be the same as that of the cell phone, but the length should be smaller to avoid blockage by the holding hand of the operator. This antenna could be integrated into the cellular-phone circuitry with a possible increase in thickness, but that would be a small price to pay for the subsequent peace of mind. With volume productions, the price of the printed antenna will probably be close to that of the monopole. In a fixed wireless system, a wall-mounted indoor terminal could use a similar technique such as a built-in directional antenna that is pointed outward to reduce the indoor radiation. ●●

Acknowledgement
The author wishes to thank Tami Morris for her help in editing the manuscript.

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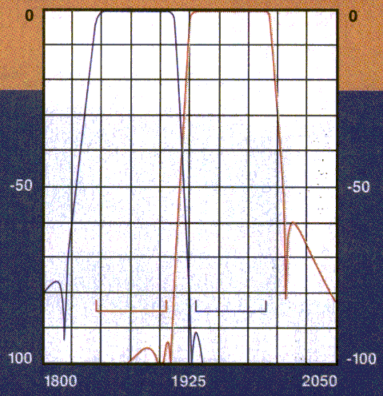

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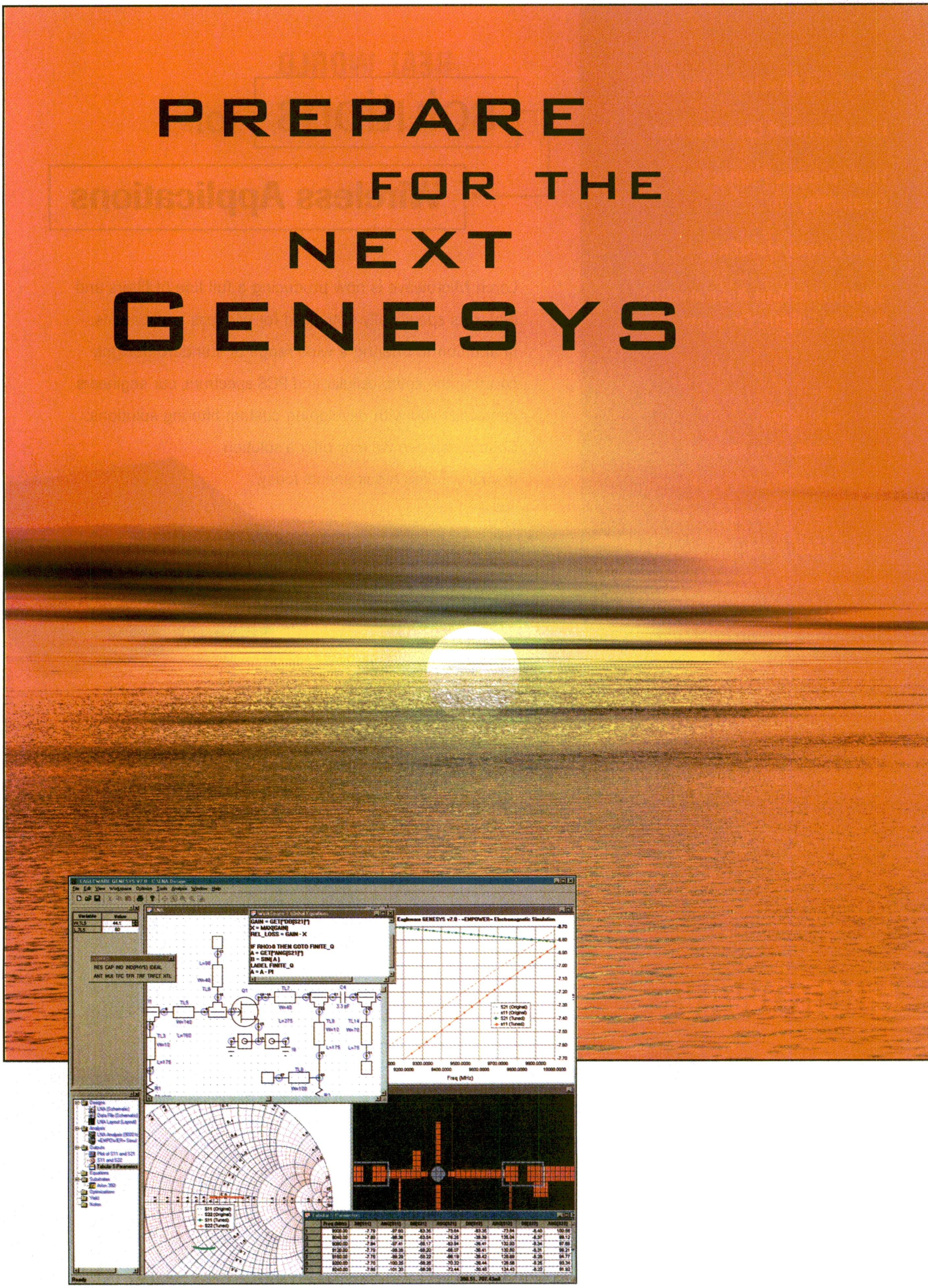
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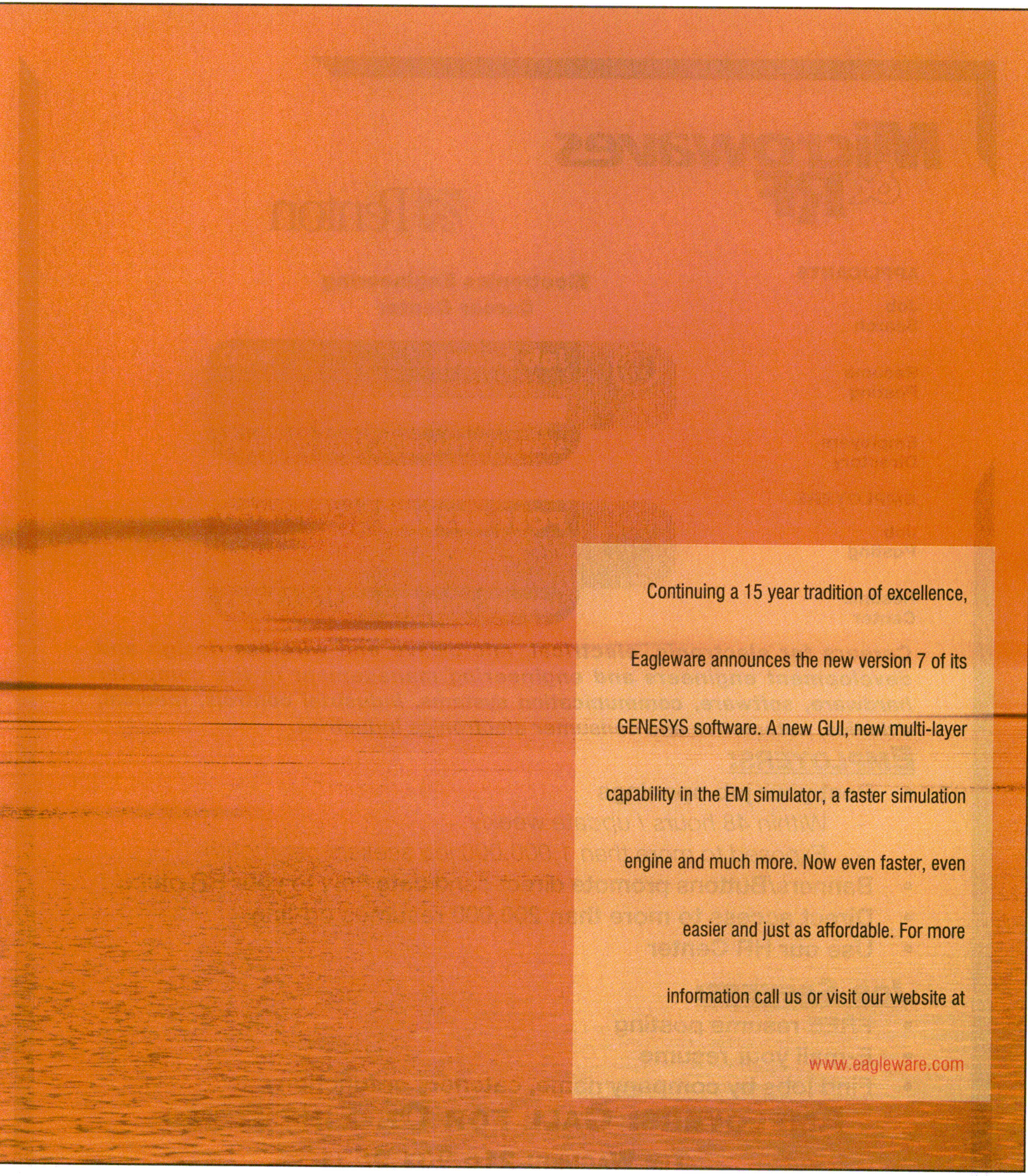
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Calculate Power In Gaussian-Modulated Wireless Systems

Understanding how Gaussian amplitude modulation affects power and wave shaping is important in improving the performance of wireless data systems.

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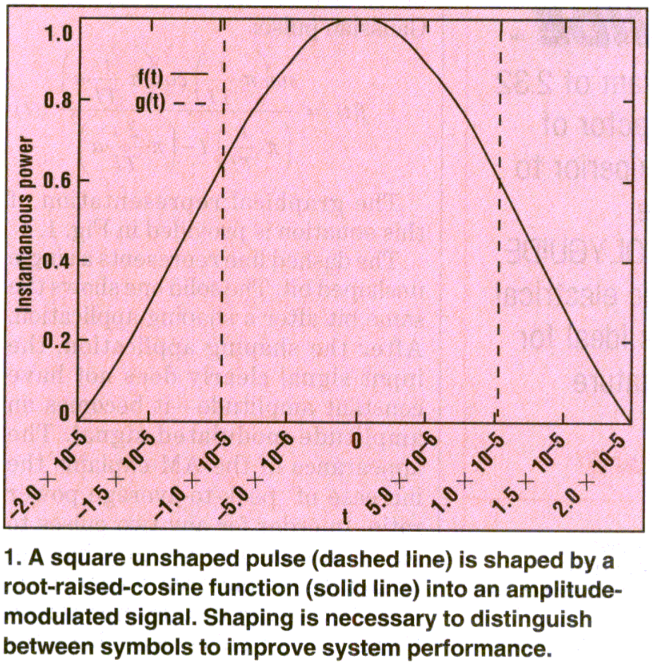
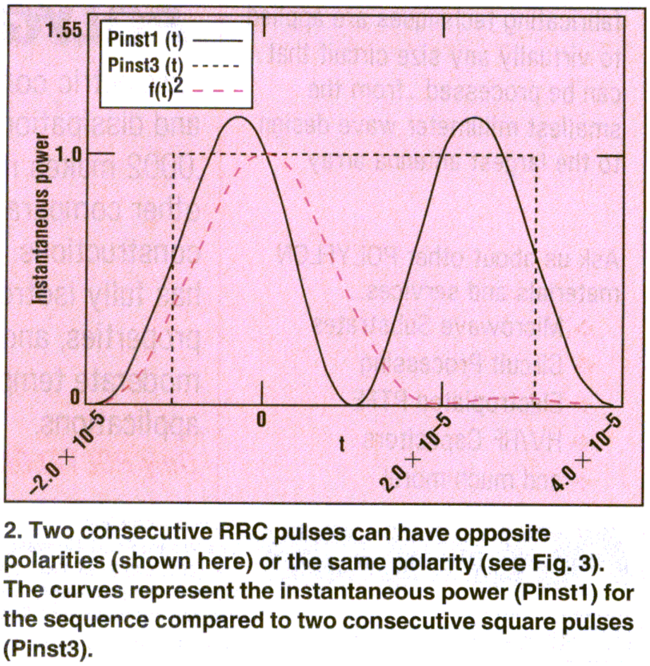
PHASE-SHIFT keying (PSK), a special case of phase modulation,[1] is the modulation scheme used for digital wireless data communications. This modulation should not create any spectrum spreading into adjacent channels, but spreading does occur. The reason is the application of shaping to a phase-modulated signal which is used to reduce intersymbol interference (ISI). The shaping is required to distinguish between symbols and, thus, to improve the performance of a wireless digital data system.

Applying shaping to a phase-modulated signal causes a problem, however, because it creates the appearance of Gaussian-type amplitude modulation (AM) on the phase modulation (PM). The term "Gaussian type" includes all types of pulses where the time-domain representation is similar to their frequency-domain representation. AM does not detract from the advantages of PM, but it does impose constraints on system linearity. That is, shaping increases the peak-to-average power ratio, and the appearance of higher-than-expected peaks—compared to unshaped PM signals—causes unwanted nonlinearity effects.

The goal of this article is to show the appearance of AM on the phase-modulated scheme and to predict the



1. A square unshaped pulse (dashed line) is shaped by a root-raised-cosine function (solid line) into an amplitude-modulated signal. Shaping is necessary to distinguish between symbols to improve system performance.



2. Two consecutive RRC pulses can have opposite polarities (shown here) or the same polarity (see Fig. 3). The curves represent the instantaneous power (Pinst1) for the sequence compared to two consecutive square pulses (Pinst3).

value of the peak-to-average power ratio increase caused by the Gaussian-type AM. To figure out the actual value of the peak-to-average power ratio, the graphs of the single Gaussian-type pulse and the combination of two consecutive pulses were created. The combination of more than two pulses should not contribute noticeably to the ratio of peak-to-average power since the spread of each of the shaped pulses is constrained to the adjacent slots. However, to confirm this, the combination of three consecutive pulses was evaluated. Then the peak power of the sequence was found from the graphs. A value of average power was found from calculations. It was determined that the resulting peak-to-average power ratio exceeds the similar ratio for an unshaped signal (equal to 1) by approximately 3 to 4 dB. This result coincides with the one obtained from statistical calculations.[2]

Statistical calculations are avoided in this article, but their results are well-known.[2] Rather, the idea is to visualize AM to eliminate the mystery associated with it.

GRAPHICAL INTERPRETATION

The software used in the demonstration is MathCAD, which can create graphs according to formulas developed in the analysis. Then the results are evaluated within the framework of the software package.

From the graph, the following information is found:

- The graphical justification of the appearance of the AM in the PM scheme.
- The length of the shaped pulse at a particular length of the corresponding square pulse.
- The actual peak power value of the pulse sequence.

The value of the average power and, consequently, the value of the peak-to-average power ratio, are found from calculations.

The name of the MathCAD file is paper_2.mcd, which is available from the author on request.

The formula describing root-raised-cosine (RRC) pulses is derived from the formula for the Gaussian pulse:

$$f(t) := \frac{\sin\left(\pi\cdot\frac{t}{T1}\right)\cos\left(\pi\cdot\frac{t}{T1}\cdot a\right)}{\left(\pi\cdot\frac{t}{T1}\right)\left[1-\left(\pi\cdot\frac{2\cdot t}{T1}\cdot a\right)^2\right]} \quad (1)$$

The graphical representation of this equation is provided in Fig. 1.

The dashed line represents a single unshaped bit. The solid one shows the same bit after a shaping application. After the shaping application, the input signal clearly does not have constant amplitude—it becomes an amplitude-modulated signal. The appearance of the AM explains the increase of peak-to-average power ratio. In order for any two pulses to have the same energy, they have to occupy the same area.[1] Therefore, the shaped amplitude-modulated Gaussian-type pulse has to have the

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CMM0330	824 - 849 MHz	Multi-Mode	3.6 V	40 dB	30.0 dBm	40%	27.0 dBm	30%	31.0 dBm	60%
CMM0331	824 - 849 MHz	Analog	3.6 V	29 dB*	—	—	—	—	31.0 dBm	60%
CMM0333	824 - 849 MHz	Multi-Mode	4.8 V	42 dB	31.0 dBm	40%	28.0 dBm	30%	32.0 dBm	55%
CMM0530-LC	**824 - 849 MHz**	**Multi-Mode**	**3.0 V**	**30 dB**	**30.0 dBm**	**45%**	**28.5 dBm**	**40%**	**31.0 dBm**	**60%**
CMM0335	870 - 925 MHz	GSM	5.8 V	31 dB*	35.0 dBm	55%	—	—	—	—
CMM1630	**1710 - 1785 MHz**	**GSM**	**3.0 V**	**31 dB***	**33.5 dBm**	**60%**	—	—	—	—
CMM1530-LC	**1.85 - 1.91 GHz**	**PCS/PCN**	**3.0 V**	**30 dB**	**30.0 dBm**	**40%**	**28.5 dBm**	**35%**	—	—
CMM1330	1.85 - 1.91 GHz	PCS	3.6 V	30 dB	29.0 dBm	35%	—	—	—	—
CMM1333†	1.85 - 1.91 GHz	PCS	4.8 V	32 dB	30.5 dBm	35%	28.0 dBm	30%	—	—
CMM1335†	1.85 - 1.91 GHz	PCS	5.8 V	33 dB	31.0 dBm	35%	28.5 dBm	30%	—	—

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CPM1530-PM	1.9 GHz	28.5 (CDMA)	30	35	3.0

MMIC Amplifiers

Model	Frequency Range	Application	Power Output (+dBm) Typ	Power Added Efficiency (%) Typ	Small Signal Gain (dB) Typ	Drain Voltage (V) Typ	Drain Current (mA) Typ	Package Type
CMM2305	800 - 2700 MHz	Driver	17.0	—	20.0	+5	150	MSOP-8
CMM2306	800 - 2700 MHz	Driver	17.0	—	20.0	+5	150	SOIC-8
CMM2308	800 - 2700 MHz	High Dynamic Range	17.0	—	19.0	+5	150	SOIC-8
CMM1321	1.85 - 2.0 GHz	PCS	30.0	50	—	+5	700	SO-8
CMM2321	2.4 - 2.5 GHz	ISM	30.0	30 - 52	—	+5	700	SO-8
CMM3554	**3.45 - 3.50 GHz**	**W-CDMA**	**24.0**	—	—	**+7.75**	**600**	**SO-8**

Power GaAs FETs

Model	Frequency Range	Application	Operation (Volts)	Current (mA)	Gain (dB)	P1dB (dBm)	Noise Figure (dB)	3rd Order Products (dBc)	Package Type
CFK2162-P1	800 - 900 MHz	Base Station/Handset	8	800	20	33	—	30 (@ 29 dBm)	SO-8
CFH2162-P1	800 - 900 MHz	Base Station	10	1100	20	36	—	30 (@ 33 dBm)	Power Flange
CFB0301	**0.8 - 2.0 GHz**	**Base Station/Pole Top/LNA Duplexers**	**5**	**70**	**16**	**22**	**0.8**	**58 (@ 5 dBm)**	**Micro-X**
CFK0301	**0.8 - 2.0 GHz**	**Dual Phase/Gain Matched LNA**	**5**	**70**	**16**	**22**	**0.8**	**58 (@ 5 dBm)**	**SO-8**
CFK2162-P3	1.8 - 2.0 GHz	Base Station/Handset	8	800	14	33	—	30 (@ 29 dBm)	SO-8
CFH2162-P3	1.8 - 2.0 GHz	Base Station	10	1100	14	36	—	30 (@ 33 dBm)	Power Flange
CFK2162-P5	2.3 - 2.5 GHz	Base Station/Handset	8	800	12	33	—	30 (@ 29 dBm)	SO-8
CFH2162-P5	2.3 - 2.5 GHz	Base Station	10	1100	12	36	—	30 (@ 33 dBm)	Power Flange

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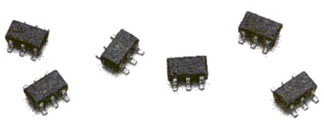

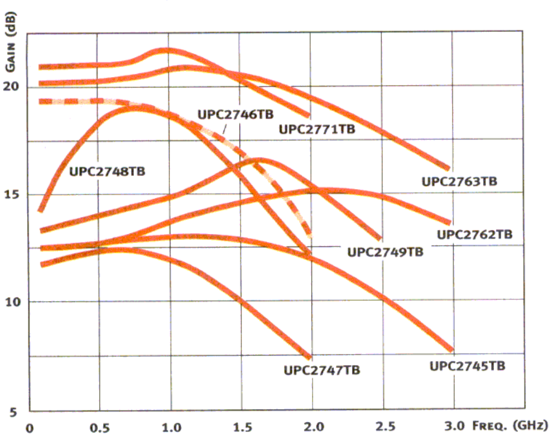

GAIN VS. FREQUENCY

5V WIDEBAND RFIC AMPS — FROM 25¢

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

3V WIDEBAND RFIC AMPS — FROM 35¢

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UPC2745TB	50MHz–2.7GHz	12	6	-3.0	7.5	500MHz
UPC2746TB	50MHz–1.5GHz	19	4	-3.7	7.5	500MHz
UPC2747TB	100MHz–1.8GHz	12	3.3	-11	5	900MHz
UPC2748TB	200MHz–1.5GHz	19	2.8	-8.5	6	900MHz
UPC2749TB	100MHz–2.9GHz	16	4	-12.5	6	1.9GHz
UPC2762TB	100MHz–2.9GHz	14.5	7	7	27	1.9GHz
UPC2763TB	100MHz–2.4GHz	20	5.5	6.5	27	1.9GHz
UPC2771TB	100MHz–2.1GHz	21	6	11.5	36	900MHz

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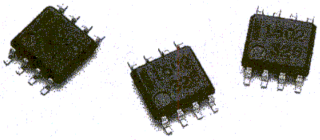

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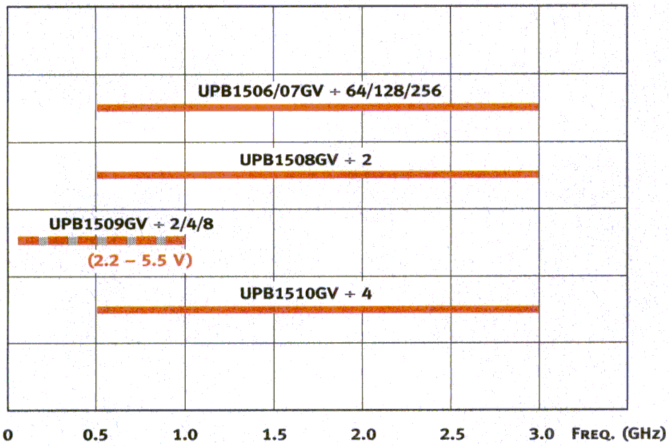
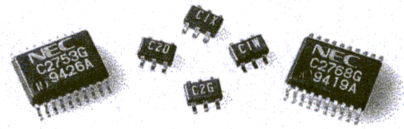


Frequency Range



3V Frequency Converters—from 60¢

PART	RF Frequency (MHz)	ICC (mA)	Conversion Gain (dB)	Output IP3 (dBm)
UPC2756TB[1]	100 - 2000	5.9	14	0
UPC2757TB[1]	100 - 2000	5.6	13	0
UPC2758TB[1]	100 - 2000	11	17	+6
UPC2768GR[1]	10 - 450	7	80	-17
UPC8106TB[2]	100 - 2000	9	9	+1
UPC8112TB[1]	800 - 2000	8.5	13	-10
UPC8116GR[3]	100 - 500	4.1	6.5	—

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

UPC8104GR
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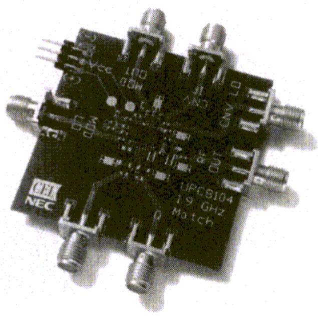

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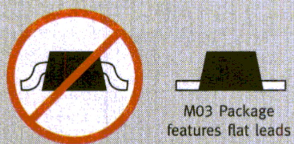

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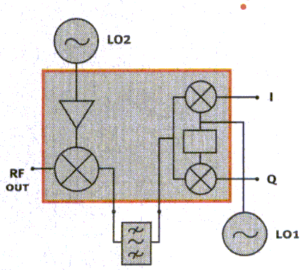

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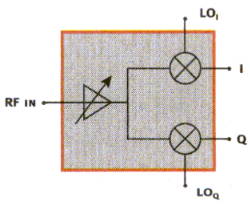
- 1.9GHz RF Output



UPC2766GR
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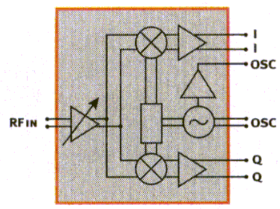
- 30dBc typ distortion



UPC3205GR
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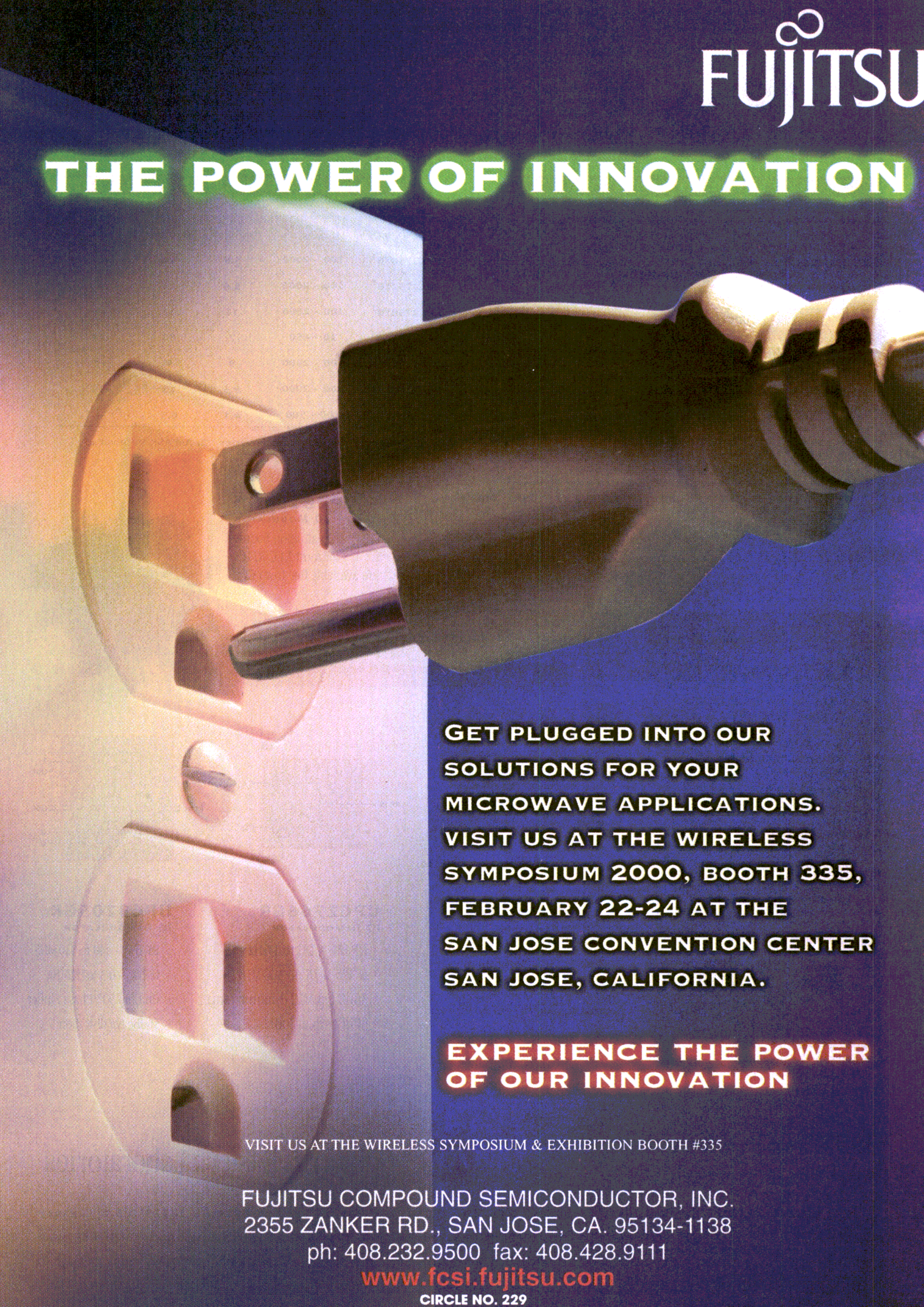
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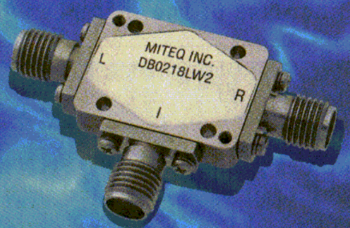
DB0130LA2	1 to 30	DC to .5	8.5
DB0218LW2	2 to 18	DC to .75	6.5
DB0218LA1	2 to 18	DC to .75	6.5
DB0226LA1	2 to 26	DC to .5	6.5
DB0426LW1	4 to 26	DC to 2	7.5
DB0440LW1	4 to 40	DC to 2	9
TB0218LW2	2 to 18	0.5 to 8	7.5
TB0218LA1	2 to 18	0.5 to 8	7.5
TB0226LW2	2 to 26	0.5 to 8	10
TB0440LW1	4 to 40	0.5 to 20	10

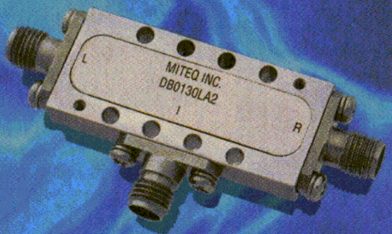
HIGH ISOLATION MIXERS

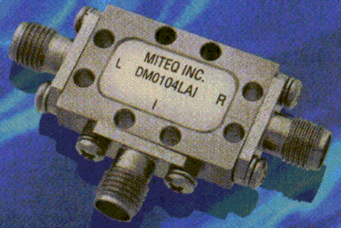
MODEL NUMBER	FREQUENCY RANGE RF/LO (GHz)	IF (GHz)	LO-RF ISOLATION (dB, Typ.)
DM0052LA2	0.5 to 2	DC to 0.5	40
DM0104LA1	1 to 4	DC to 1	40
DM0208LW2	2 to 8	DC to 2	40
DM0408LW2	4 to 8	DC to 2	40
DM0412LW2	4 to 12	DC to 4	40
DM0812LW2	8 to 12	DC to 4	35
DM0520LW1	5 to 20	DC to 8	35

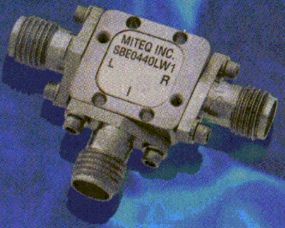
SUB-HARMONIC MIXER

MODEL NUMBER	FREQUENCY RANGE RF (GHz)	LO (GHz)	IF (GHz)
SBE0440LW1	4 to 40	2 to 20	DC to 1.5









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same area as the original square one. To accomplish this, the pulse spreads out into areas assigned to the adjacent pulses. The overall length of the Gaussian-type pulse is approximately two times larger that the corresponding square pulse length. This change in the pulse length makes adjacent pulses overlap. It leads to the increase of the instantaneous amplitude of the resulting pulse, which, in turn, leads to the change of peak-to-average power ratio.

Two consecutive pulses can be either of the same polarity (Fig. 3) or of opposite polarities (Fig. 2). Depending on the sequence, the peak-to-average power ratio will differ. To determine the peak power value from the figures and the average power value, use the following equations:

For pulses of the same polarity,

$$g2(t) = f(t) + f(t - T1) \tag{2}$$

$$Pinst2(t) = [g2(t)]^2 \tag{3}$$

And for pulses of opposite polarity,

$$g1(t) = f(t) - f(t - T1) \tag{4}$$

$$Pinst1(t) = [g1(t)]^2 \tag{5}$$

Figures 2 and 3 represent the instantaneous power values for the sequence of two RRC pulses. The resulting power distribution for the sequence of two pulses with opposite polarities is shown in Fig. 2. The similar distribution for the sequence with the same pulse polarities is shown in Fig. 3. For comparison purposes, the instantaneous power distribution of a single RRC pulse as well as two consecutive square pulses is shown on the same graphs.

According to the definition, peak power is a maximum value of instantaneous power. From the graphs, get the value of the peak power for the sequences of two pulses. It is 1.53.

The value of average power is found from calculations—average power is defined as the instantaneous power averaged over a specified time interval:

$$Pav = \lim_{T \to \infty} \frac{1}{2 \cdot T} \cdot \int_{-T}^{T} g(t)^2 \, dt \tag{6}$$

This formula requires a knowledge of the value of instantaneous power in the time interval of $-\infty$, ∞. The only way to obtain that value is through statistical calculations, which are omitted in this presentation. The purpose of this technique is to help develop a visual understanding of the affects of AM on digitally modulated signals. If the statistical calculations were allowed, it would obscure the visualization process.

It would help if the signal under consideration were a periodic one. In that case, it would be sufficient to know only the small portion of the whole signal somewhere in the interval of $-T_0/2$, $T_0/2$. The rest of the signal is known, since it repeats itself over the period T_0.

The formula for defining a periodic

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signal is:[1]

$$g(t) = g(t - T_0) \quad (7)$$

Equation 6 applied to the periodic signal with the period T_0 is simplified:

$$Pav_{per} = \frac{1}{T_0} \cdot \int_{-\frac{T_0}{2}}^{\frac{T_0}{2}} g(t)^2 dt \quad (8)$$

Clearly, digitally modulated signals used in wireless communications are not periodic ones. However, for a better understanding of the nature of the digital-modulation effects, assume a certain periodic pattern in the signals under consideration. Statistically speaking, there is an equal probability of the sequence of two pulses with the same polarity as the sequence of two pulses with opposite polarities.

It follows from eq. 7 that the value of average power is not dependent on the periodic properties of the signal. So imagine the signal under consideration to be a pseudo-periodic one, consisting of an equal number of each of the pulses' sequences.

This provides a method of calculation of average power. Specifically, at first, calculate the average power of the sequence of two pulses with the same polarity. The sequence is of a periodic nature. Assume that the whole data stream consists only of this sequence, with a period of 2T1—the period of this sequence. Then, since this sequence is only 50 percent of the assumed pattern, divide the resulting value of average power by 2. Conduct the same operation on the sequence of two pulses with the opposite polarities. Adding both results provides the average power of the imagined data stream. This supports finding the peak-to-average power ratio of the data stream.

CALCULATING POWER

Using the suggested method and eqs. 3 and 5 substituted in 8, the following results are obtained for the values of average power for each of the bit sequences:

$$Pav1 := \left(\frac{1}{2 \cdot T1} \cdot \int_{-T1}^{T1} Pinst1(t)\, dt \right) \quad (9)$$

$$Pav2 := \left(\frac{1}{2 \cdot T1} \cdot \int_{-T1}^{T1} Pinst2(t)\, dt \right) \quad (10)$$

Pav1 represents an average power of the sequence of two RRC pulses with opposite polarities. Pav2 represents the power of the same sequence but of the pulses with the same polarity. According to the method's guidelines, the period of the sequence, T_0, is equal to 2T1. The values of an average power for RF-modulated data streams are:

Pav1 = 0.478

for a data stream consisting only of the periodic sequence of two RRC pulses with opposite polarities, and

Pav2 = 0.8

for a data stream consisting only of the periodic sequence of two RRC pulses with the same polarities.

According to the method's guidelines, each sequence is accountable

only for 50 percent of the assumed pattern. It means that the average power of the whole-assumed sequence is:

Pav = 1/2(Pav1) + 1/2(Pav2) = 0.63

This comprises all of the data necessary for calculations of peak-to-average power ratio. The peak power (from Fig. 3) is equal to 1.53. The average power, Pav, is equal to 0.639. Usually, the value of peak-to-average power ratio is expressed in decibels by the equation:

$$R = 10 \cdot log\left(\frac{P}{Pav}\right) \qquad (11)$$

Substituting into eq. 11, R comes out to 3.8 dB, the value exactly obtained by statistical methods for QPSK modulation scheme.[2]

Clearly, this method is not intended to substitute for statistical calculations. Only statistical calculations can predict the real content of the data stream. However, the correlation shows that a good guess was made for the content for at least one data-stream scheme. It confirms that the generic approach was correct.

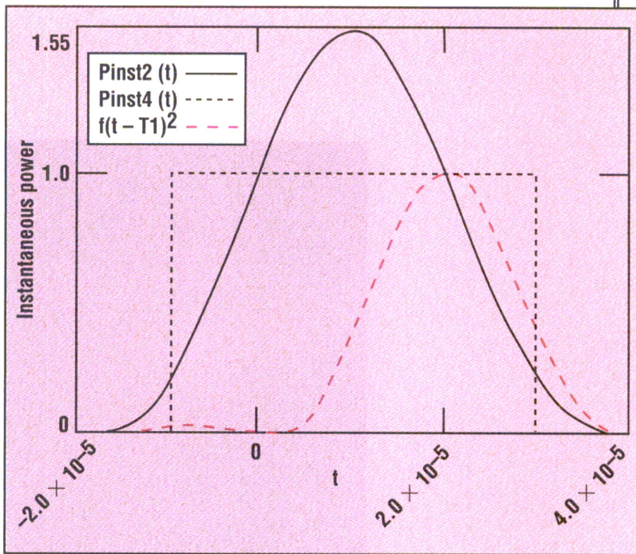
There is another interesting observation confirming the validity of this approach. It is known from the statistical calculations that if the modulation scheme does not support the constellation diagram's coordinate crossing, the peak-to-average power ratio is reduced. It follows that for a QPSK modulation scheme, the peak-to-average power ratio is 3.8 dB, while for OQPSK modulation scheme it is only 2.4 dB.[2] Both schemes use the same constellation diagram. The only difference between them is that OQPSK prohibits an abrupt change of phase of the signal vector. This method explains the reason for the change of the peak-to-average power ratio in those two modulation schemes.

The abrupt change of the vector's position reverses polarity of the I and Q bit streams. It makes the appearance of the sequence certain with two bits of opposite polarities in each bit stream (I or Q). The value of the peak power for the periodic sequence of two pulses with opposite polarities is 1.14 (Fig. 2). The value of the average power for that bit sequence (assuming that the sequence consists only of a string of pulses with opposite polarities) is 0.478. So the peak-to-average power ratio is ≈3.8 dB.

The value of the peak power for the periodic sequence of two pulses with the same polarity is 1.53 (Fig. 3). The value of the average power for that sequence (assuming that the sequence consists only from a string of pulses with the same polarities) is 0.8, from eq. 9. So the peak-to-average power ratio is ≈2.8 dB—smaller than in the case with abrupt phase changes. In reality, the content of QPSK and OQPSK data streams is going to differ drastically from the 2-b models considered earlier. However this example permits visualizing the advantages of the refined change in the position of the signal vector versus the abrupt

position change. The result coincides with the trend given by statistical predictions.

The combination of more than two consecutive pulses should not contribute noticeably to the ratio of peak-to-average power. The reason is that the spread of each of the shaped pulses is contained to the adjacent slots. In order to confirm this, evaluate the sequences of three consecutive pulses, determine the maximum peak value of these sequences, determine the average value of the sequence producing the maximum peak, and find the resulting peak-to-average power ratio.



3. Two RRC pulses of the same polarity produce the instantaneous power Pinst2. The peak power for pulses of the same polarity is much larger than that for pulses of opposite polarity (see Fig. 2). Thus, the type of sequence determines the peak-to-average power ratio. The increase of the ratio over an unmodulated signal is due to Gaussian-type AM.

Possible combinations of three consecutive pulses are as follows:

$$g4(t) = g2(t) - f(t + T1) \quad (12)$$

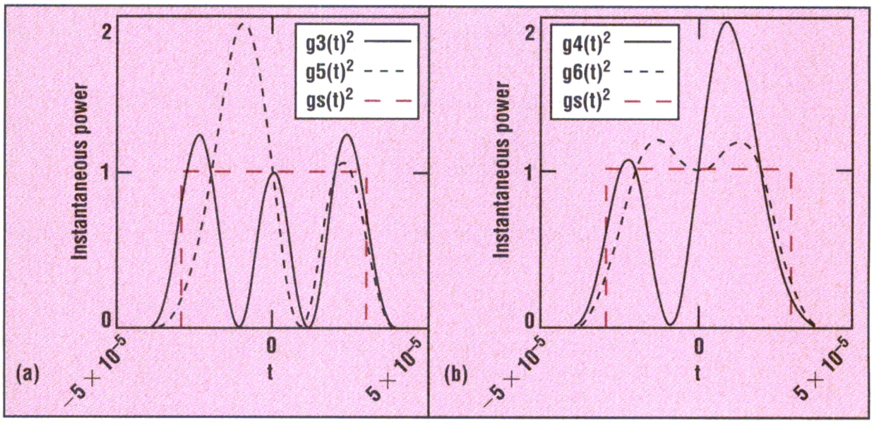
$$g6(t) = g2(t) + f(t + T1) \quad (13)$$

$$g3(t) = g1(t) - f(t + T1) \quad (14)$$

$$g5(t) = g1(t) + f(t + T1) \quad (15)$$

The graphs represent the instantaneous power values for the sequence of three RRC pulses. For the comparison, the instantaneous power distribution of three consecutive square pulses is shown on the same graphs.

From Fig. 4 it follows that there are two combinations creating the same value of peak power, 1.97. It is the sequences, g5(t) and g6(t). Assuming that the whole pattern consists of sequence g5(t), calculate its average power using the method described previously. The period of the assumed periodic signal T_0 is going to be equal to 3T1 (since the sequence consists of three pulses with period T1). The formula for the



4. The peak-to-average power ratio is not increased for different combinations of three consecutive RRC pulses. Two combinations, g5(t) in (a) and g6(t) in (b), produce the same peak value. Calculating the average value for each sequence provides almost equal results. The resulting peak-to-average ratio is very close for both sequences.

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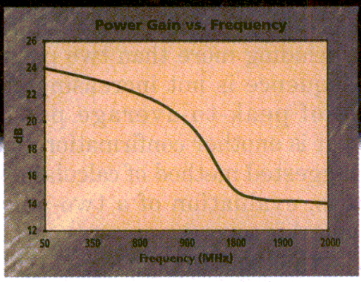

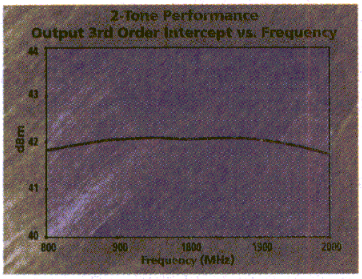

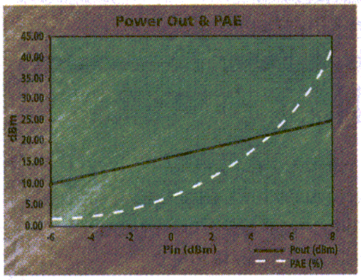

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800-900	20.0	1.5:1	2.0:1	24.0	40.5	5.0	115
1800-2000	14.5	1.5:1	2.0:1	24.0	42.0	5.0	115

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calculation of average power (eq. 8) is modified to include an adjustment for the RF-modulated data stream:

$$Pav5 := \left[\frac{1}{3 \cdot T1} \cdot \int_{-\left(\frac{3}{2} \cdot T1\right)}^{\frac{3}{2} \cdot T1} g5(t)^2 \, dt \right] \quad (16)$$

The result of the calculations is:
Pav5 = 0.89

Substituting this value and the peak value into formula (11), the following is the value of peak-to-average power:
$R5_3 \approx 3.5$ dB

Conducting the same operation on the sequence g6(t), the result is:
Pav6 = 0.927

Substituting this value and the peak value to eq. 11, the value of peak-to-average power is:
$R6_3 \approx 3.3$ dB

The results ($R5_3$ and $R6_3$) confirm that including more than two pulses per sequence is not increasing the value of peak-to-average power ratio. It is another confirmation that the suggested method of calculations (that is, evaluation of a two-pulse sequence) is correct.

It is important to keep in mind that the preceding presentation was related to alleged baseband signals. That is, signals applied to the input of an RF modulator. RF modulation is performed according to the formula:

$$V_{mod}(t) =$$
$$A[I(t) \cos(\omega_c t) - Q(t) \sin(\omega_c t)] \quad (17)$$

Here, the symbols Q and I represent data streams. The symbol V is an RF-modulated signal. The I and Q are orthogonal to each other, so they are mutually independent. It means that in order to obtain an average power of an RF-modulated signal simply multiply each pulse of the data stream by a sin ($\omega_c t$) [or cos ($\omega_c t$)] and perform calculations of integrals (eq. 8). Since this multiplication should reduce the result by half, the peak-to-average power ratio for the RF-modulated data stream would be increased by 3 dB.

Acknowledgment
This paper was inspired by questions and helpful discussions with my colleague G. Belinkiy.

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2. D.W. Bennett, *et al.* "The Effect of Modulation on the Power Rating of Multi-Channel Linear Amplifiers," *Proceedings of International Zurich Seminar on Digital Communications*, March 8-11, 1994.

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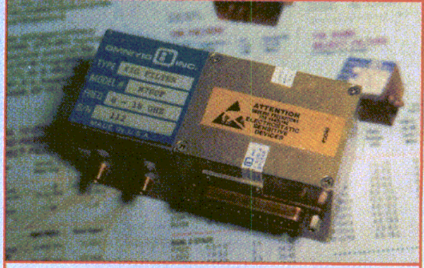
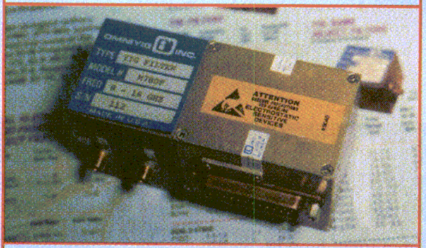


YIG BAND REJECT FILTERS

Omniyig Model No.	Freq. Range (GHz)	Ins. Loss (max.) (dB)	Bandwidth @ 40 dB (min.) (MHz)
6-, 8- and 12-STAGES			
P106RX	0.5 – 1.0	1.5	10
L106RX	1.0 – 2.0	1.5	10
C105RX	2.0 – 8.0	1.5	10
X106RX	8.0 – 12.4	1.5	20
Ku106RX	12.0 – 18.0	1.8	20
M102RX	4.0 – 12.4	1.5	8
M103RX	4.0 – 12.4	1.5	10
M104RX	4.0 – 18.0	1.5	10–60



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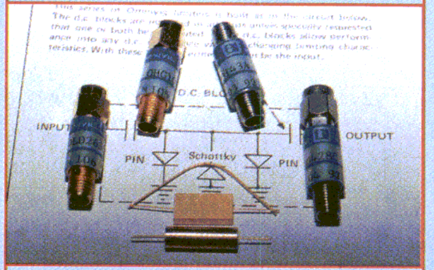
- 4-Stages, Dual 4-Stages
- 6-Stages
- 7-Stages

The filters can be integrated with analog drivers or 12-bit digital drivers built to commercial or military specifications.



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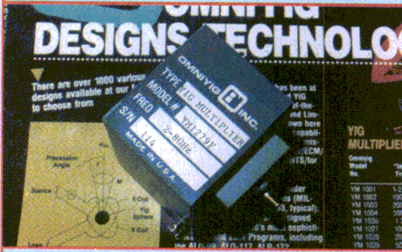
THIN FILM YIG OSCILLATORS

Omniyig Model No.	Freq. Range (GHz)	RF Pwr. Output (mW)	2nd Har. (dBc
YOM1517	0.5 – 2.0	20–60	16
YOM1518	1.0 – 4.0	20–60	16
YOM1514	4.0 – 12.0	10	15
YOM1513	4.0 – 10.0	10	15
YOM83	2.0 – 6.0	20	12
YOM1948	3.5 – 10.5	15	12
YOM1317	2.0 – 8.0	20	12
YOM818	8.0 – 18.0	20	12
YOM1516	6.0 – 18.0	20	10
YOM2320	2.0 – 10.0	13	11
YOM2321	5.0 – 18.0	13	9

We offer other models with 2nd Harmonic –60 dBc. Oscillators integrated with 2-stage filters are available.



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STANDARD UNITS

Output Computer Tested

Omniyig Model No.	Input Freq.	Output (GHz)	Output Pwr. (dBm)
YM 1001	1–2 GHz	2 – 13	6
YM 1002	100 MHz	1 – 12	-33
YM 1003	200 MHz	1 – 12	-28
YM 1004	500 MHz	1 – 12	-10
YM 1026	1–2 GHz	2 – 18	2
YM 1027	100 MHz	1 – 18	-40
YM 1028	200 MHz	1 – 18	-30
YM 1029	500 MHz	1 – 18	-22
YM 1087	.1–.2 GHz	1 – 12	-25

* RF input power on all models 0.5 to 1.0 watts.

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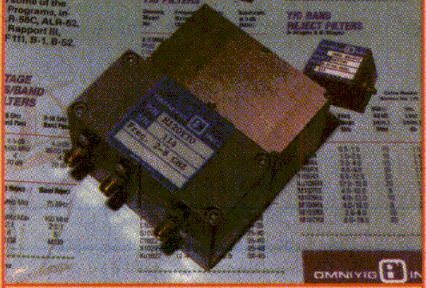

YIG FILTERS

Omniyig Model No.	Freq. Range (GHz)	Ins. Loss (dB)	Bandwidth @ 3 dB (MHz)
6-STAGE			
P106	0.5 – 1.0	6.5	12–30
L106	1.0 – 2.0	5.5	20–35
S106	2.0 – 4.0	5.0	20–40
C106	4.0 – 8.0	4.5	25–40
X106	8.0 – 12.4	4.5	25–40
Ku106	12.4 – 18.0	4.5	28–45
3-STAGE			
P103	0.5 – 1.0	5.0	14–25
L103	1.0 – 2.0	3.5	20–35
S103	2.0 – 4.0	3.0	20–35
C103	4.0 – 8.0	3.0	25–40
X103	8.0 – 12.4	3.0	25–40
Ku103	12.4 – 18.0	3.5	30–45
4-STAGE			
P104	0.5 – 1.0	6.0	12–23
L104	1.0 – 2.0	4.5	20–35
S104	2.0 – 4.0	4.0	20–35
C104	4.0 – 8.0	4.0	25–40
X104	8.0 – 12.4	4.0	25–40
Ku104	12.4 – 18.0	4.0	28–45
DUAL 2-STAGE			
P1022	0.5 – 1.0	3.5	17–30
L1022	1.0 – 2.0	3.0	24–35
S1022	2.0 – 4.0	2.5	25–40
C1022	4.0 – 8.0	2.5	25–40
X1022	8.0 – 12.4	2.5	25–40
Ku1022	12.4 – 18.0	2.5	30–45
MULTIOCTAVE BANDS			
M1611/2	1.0 – 18.0	5.5	25–65
M1612/4	2.0 – 18.0	6.5	25–75
M102/2[5]	1.0 – 12.4	5.0	25–60
M1613/2	1.0 – 12.4	5.5	25–60
M1048/4	4.0 – 18.0	6.0	25–60
M203/4[5]	1.0 – 18.0	6.5	25–70

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Omniyig Model No.	Freq. Range (GHz)	k Factor (mv/mw)	TSS (dBm)
Zero Bias			
ODZ0004A	0.1 – 18	1200	–51
ODZ0510A	0.5 – 4	1750	–53
ODZ0518A	1.0 – 12	1250	–52
ODZ0527A	2.0 – 12	1250	–52
ODZ0328A	2.0 – 18	1250	–52
Tunnel Planar			
ODT0004A	0.1 – 18	750	–50
ODT0510A	0.5 – 4	800	–50
ODT0527A	2.0 – 12	800	–50
ODT0328A	2.0 – 18	700	–50
ODT0240A	6.0 – 18	700	–50

COMB GENERATORS

Omniyig Model No.	Input Freq. (MHz)	Output Freq. Range (GHz)	Output Pwr. (dBm)
OHG10140	100	0.1 – 4	–10
OHG10118	100	0.1 – 18	–40
OHG20218	200	0.2 – 18	–34
OHG30318	250	0.25 – 18	–29
OHG51027	500	0.5 – 18	–20
OHG61027	1000	0.1 – 18	–33
OHG72027	2000	2.0 – 18	–10
OHG61026	1000	1.0 – 26	–35
OHG71026	2000	2.0 – 26	–20

TRACKING YIG FILTERS/ YIG OSCILLATORS

Omniyig Model No.	Freq. Range (GHz)	Filter IL (dB)	Tracking (MHz)
M129YTO	0.5 – 2	5.5	5
M120YTO	2 – 8	5.0	7
M121YTO	8 – 18	5.0	8

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LIMITERS

Omniyig Model No.	Freq. Range (GHz)	Max. Ins. Loss (dB)	Max. Lkg. Pwr. (dBm)*
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OLP2801A	0.1 – 0.5	0.5	+20
OLP2817A	1.0 – 4.0	0.5	+19
OLP2726A	2.0 – 8.0	1.2	+19
OLP2640A	6.0 – 18.0	2.0	+18
OLP2650A	2.0 – 18.0	2.5	+18
Schottky			
OLD2802A	0.1 – 1.0	0.5	+15
OLD2709A	0.5 – 2.0	0.5	+15
OLD2762A	2.0 – 8.0	1.0	+14
OLD2635A	4.0 – 18.0	2.5	+14
OLD2650A	2.0 – 18.0	2.5	+13

*Measured at 1 Watt CW Power

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Omniyig Model No.	Input Freq. (MHz)	Output Freq. Range (GHz)	Output Pwr. (dBm)
CG252A	100–200	0.1 – 12	–24
CG253A	100	1.0 – 18	–38
CG256A	200	1.0 – 18	–35
CG259A	250	1.0 – 18	–30
CG262A	500	1.0 – 18	–18
CG265A	1000	1.0 – 18	–15
CG266A	1000	2.0 – 26	–33
CG268A	2000	2.0 – 18	–20
CG269A	2000	2.0 – 26	–35

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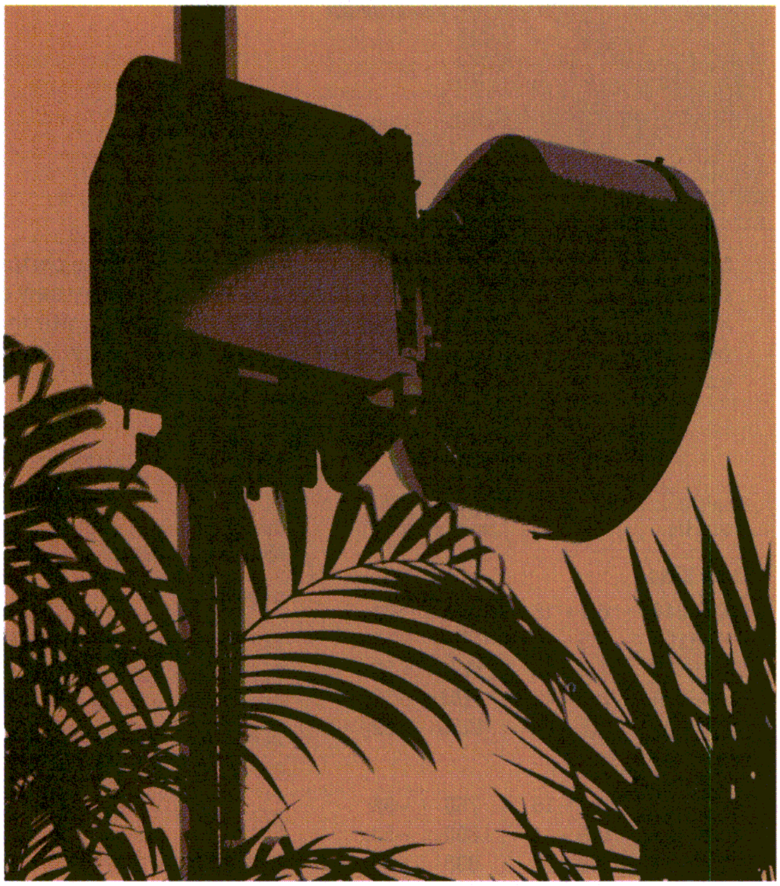

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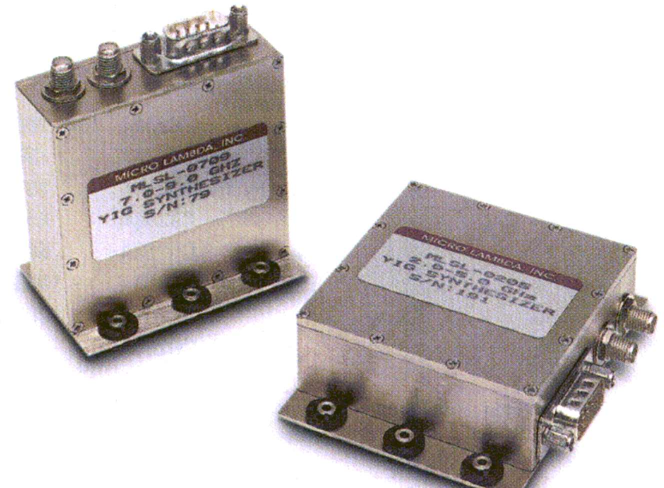

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CIRCLE NO. 216

Wireless Symposium
Portable by Design

Emerging Applications Boost Eighth Wireless Symposium

The growth of the wireless industry depends on the widespread acceptance of new data-based applications, such as Bluetooth, HomeRF, and wireless Internet services.

JACK BROWNE
Publisher/Editor

WIRELESS applications have become such an integral part of this industry that most high-frequency engineers now take them for granted. But the past two years have witnessed the first signs of inconsistent growth in wireless markets, due largely to occasional slumps and inaccurate forecasts in cellular handset sales. Still, the wireless industry is strong, and high-frequency engineers will continue to be challenged by the usual design constraints of better performance and lower cost, with the additional pressure of shorter time to market. And the one place that they can find answers to their design-related questions is at the Wireless Symposium/Portable By Design Conference & Exhibition, scheduled for February 22-24, 2000 in the San Jose Convention Center (San Jose, CA).

Entering its eighth year, the Wireless Symposium has become a meeting place of choice for many engineers involved in wireless systems design. The conference provides many educational opportunities for engineers to enhance their skills in many different areas, including RF, analog, digital, packaging, and power-supply disciplines. The many full-day and two-day workshops (see table), for example, cover everything from antennas and propagation to wireless measurement techniques. Taught by industry experts, these workshops are compact up-to-date courses that can bring novice engineers up to speed on unfamiliar topics and provide a solid review of a specific technological area for more experienced engineers.

The course "Antennas and Propagation for Wireless Communications," for example, is taught by Dr. Steven Best, CEO of Cushcraft Corp. (Manchester, NH). The one-day workshop offers a broad introduction to antenna properties, antenna-design considerations, and propagation issues. It covers basic concepts and definitions used by antenna professionals, key antenna characteristics, such as VSWR, radiation pattern, polarization, axial ratio, directivity, and gain. The course includes an overview of different antenna types, such as wire antennas, microstrip antennas, circular-polarized designs, and aperture antennas. The workshop reviews a variety of RF propagation issues, such as path loss, multipath fading, polarization distortion, noise and interference, and diversity implementation, and details the impact of each parameter on overall wireless system performance. The workshop concludes with some practical examples of the concepts presented and demonstrations of actual antenna design using some

WIRELESS WONDERS AT SHOW

One of the many attractions at the Eight Annual Wireless Symposium & Exhibition will be an awards ceremony hosted by the new Internet e-commerce site, Wireless Wonders (http://www.wireless-wonders.com). The ceremony will unveil the "Seven Wireless Wonders of the World" as voted by visitors to the Wireless Wonders website, a site with the basic theme "Worryless Wireless Shopping." The site provides information on selected commercial wireless products, such as two-way radios, cellular telephones, and Global Positioning System (GPS) receivers, and allows visitors to purchase products electronically. In addition, customers who visit the site before January 1, 2000 can nominate their favorite wireless products of 1999 for an award as a top product of the year. Visitors to the site from January 1 through February 20, 2000 can vote for any of the nominated products, with a chance to win a free Motorola i1000plus smart multifunction telephone (a $299 value). The drawing will be held at the Wireless Symposium & Exhibition/Portable By Design Conference on February 24th.

commercially available antenna-design software.

For wireless engineers delving into digital signal processing (DSP), the two-day workshop "DSP Made Simple" represents a fast-paced but accessible introduction to a complex topic. Taught by Rick Lyons of the respected educational firm, Besser Associates (Mountain View, CA), the workshop tries to keep mathematical content to a minimum. Still, it introduces the basic equations behind DSP and fully explains their implementation according to signal-processing theory. The workshop incorporates just enough mathematics to develop a fundamental understanding of DSP theory. It illustrates the theory with well-chosen examples, and covers many key topics in DSP theory, including lowpass and bandpass sampling, discrete Fourier transforms, and the development of finite-impulse-response (FIR) digital filters.

In addition to traditional favorites such as "RF Fundamentals" (taught by Rick Fornes of Besser Associates) and "Wireless Made Simple" (taught by Al Scott of Besser Associates), the workshop lineup includes proven presenters such as Morris Engelson of JMS (Portland, OR), Darryl Schick of Linear Lightwave (Lafayette Hill, PA), Randy Rhea of Eagleware (Tucker, GA), and Eric Drucker of PLL Consultants (Seattle, WA). Each has presented workshops in years past at the Wireless Symposium, and each has refined and developed their presentation for optimum effectiveness. Morris Engleson's one-day workshop, simply titled "Measuring Wireless," provides comprehensive insights into different types of wireless signals, including digitally modulated signals, electromagnetic interference (EMI), RF interference (RFI), pulsed signals, high-power signals, broadcast signals, television signals, and effective methods for measuring these signals with a spectrum analyzer. Engleson, often referred to as "The Father of the Spectrum Analyzer" for his pioneer work in developing applications for this workhorse RF/microwave instrument, teaches with humor and with his experience, shows attendees how to become more efficient and effective with the instrument. The course explains the many different measurements that are possible on a particular type of signal and how to set up the spectrum analyzer for a particular measurement result.

Darryl Schick, formerly chief engineer at RDL (Conshocken, PA), has spent several years following developments in current and third-generation (3G) cellular and personal-communications-services (PCS) systems and standards. His two one-day workshops address the present and future of cellular access—code-division multiple access (CDMA) and wideband CDMA (WCDMA), respectively. The first course, entitled "Fundamentals of CDMA Technology for PCS," takes an in-depth look at CDMA wireless technology, and how CDMA is implemented in the TIA/EIA/IS-95 wireless communication standard. Topics covered include CDMA performance issues, cyclic-redundancy-check (CRC) and forward-error-correction (FEC) coding, interleaving, orthogonal (Walsh) coding, pseudorandom-noise (PN) coding, in-phase/quadrature (I/Q) modulation, call establishment, signaling, and the ID-95 CDMA standard. This course is recommended as a pre-requisite for the second workshop, called "3G Wideband CDMA Technology Standards." This second course examines 3G Wideband CDMA technology, and how 3G-CDMA is implemented in the TIA cdma2000™ and European Telecommunications Standards Issue (ETSI)/ARIB WCDMA standards. This course builds on the previous day's "Fundamentals of CDMA Technology for PCS" seminar, covering 3G-specific concepts including high-bit-rate data transmission, OVSF coding, turbo coding, embedded pilot symbols, quadrature PN spreading, asynchronous cell-site operation, and detailed overviews of the cdma 2000™ and ETSI/ARIB proposed standards.

One of the longest-running workshops at the Wireless Symposium, Randy Rhea's popular "Oscillator Design" course, teaches a unified ap-

Workshops at a glance

Tuesday, February 22	Wednesday, February 23	Thursday, February 24	Friday, February 25
9:00 AM - 4:30 PM	9:00 AM - 4:30 PM	9:00 AM - 4:30 PM	9:00 AM - 4:30 PM
Wireless Made Simple (I) Al Scott, Besser Associates	Wireless Made Simple (II) Al Scott, Besser Associates	DSP Made Simple (I) Rick Lyons, Besser Associates	DSP Made Simple (II) Rick Lyons, Besser Associates
RF Fundamentals (I) Rick Fornes, Besser Associates	RF Fundamentals (II) Rick Fornes, Besser Associates	Digital Modulation (I) Joe Boccuzzi, Besser Associates	Digital Modulation (II) Joe Boccuzzi, Besser Associates
Topical Issues in RF Power Amplifier Design (I) Steve Cripps, Besser Associates	Topical Issues in RF Amplifier Design (II) Steve Cripps, Besser Associates	Oscillator Design Randy Rhea, Eagleware	Antennas & Propagation for Wireless Communications Steven Best, Cushcraft Corp.
Measuring Wireless Morris Engelson, JMS	Fundamentals in CDMA Technology for PCS Darryl Schick, Linear Lightwave	3G Wideband CDMA Technology Standards Darryl Schick, Linear Lightwave	Phase Locked Loops Eric Drucker, PLL Consultants RF Wireless Systems Fundamentals Rick Fornes, Besser Associates

proach to the design of oscillators with inductor-capacitor (LC), transmission-line, surface-acoustic-wave (SAW), and crystal resonators. The course, which covers fixed-frequency sources and voltage-controlled oscillators (VCOs), provides a full understanding to the design of oscillators that leads to higher performance and lower-cost designs. Topics include starting, nonlinear behavior, phase noise, harmonics, tuning, quality factor (Q), and low and high power, with emphasis in the frequency range of 100 to 2400 MHz.

Eric Drucker, a relative newcomer to the Wireless Symposium's educational team, has nonetheless impressed attendees with his grasp of phase-locked-loop (PLL) concepts. He returns to the Eighth conference with his "Phase Locked Loop" workshop for designers of frequency synthesizers. The course covers the fundamentals of analysis, design, and modeling of PLLs, as well as phase noise and how it affects system-level performance. The course reviews the various components that make up a PLL design, including oscillators, dividers, and phase detectors.

TECHNICAL SESSIONS

The technical sessions at the Wireless Symposium/Portable By Design Conference & Exhibition are indicative of many future-locking applications, such as WCDMA, 3G systems, Bluetooth, and HomeRF. A technology track chaired by Rob McMorrow of Alpha Industries (Woburn, MA), "Cellular, Cordless, PCS, including 3G & WCDMA," includes sessions on spread-spectrum techniques, WCDMA and cdma2000 measurements, a comparison of the enhanced-GSM system Enhanced Data Rates for GSM Evolution (EDGE) and WCDMA, a tutorial session on wireless local-area networks (WLANs), and the feasibility of a single-integrated-circuit (IC) cellular radio. The spread-spectrum session, for example, provides basic information with minimal mathematical formulation. It covers frequency-hopping techniques, direct-sequence PN systems, hybrid systems, as well as processing gain.

Perhaps the most intriguing session in this track deals with the possibility of a one-IC radio. The radios in next-generation cellular telephones will have to address multiple bands as well as multiple modes of operation. To achieve the inconsistent goals of lower cost, smaller size, and higher functionality, designers are turning to higher levels of chip integration. Radio functions that once took five to six ICs to implement have been replaced with as few as one or two highly integrated ICs. Papers in this session will compare ex-

isting highly integrated solutions for cellular and cordless handsets.

In a track on "Advanced Techniques" chaired by Doug Lockie of Endgate Corp. (Sunnyvale, CA), nonlinear analysis, amplifier design (covered from the start to the finish of a specific design), and new simulation techniques are addressed. The amplifier session covers load-pull methods and simulation of adjacent-channel power (ACP) and third-order intercept (IP3) performance, with an examination into the trade-offs in device technology, size, and bias in practical amplifier circuits. The session on new simulation techniques explores how the theory of neural networks can be applied to wireless systems design, and how electromagnetic (EM) simulators are increasingly finding a place among designers of high-frequency wireless components and systems, especially those designed for millimeter-wave applications at 28 GHz and above.

Veteran Wireless Symposium Chairperson Ben Zarlingo returns with a track on test and measurement techniques and advances, including a session on analyzing new signal formats by linking software with instrumentation. In this session, an approach is presented for characterizing new signal and modulation formats where the companion receiver—constructed in a software simulation with standard electronic-design-automation (EDA) tools—can perform full analysis functions on waveforms captured and imported from a vector signal analyzer. Additional sessions in the test and measurement track cover the testing of wideband and Bluetooth systems, including troubleshooting techniques for wide bandwidth and frequency-hopped signals, and techniques for digital demodulation of signals from 20 to 500 MHz, measurement of EDGE signals, and the impact on existing GSM-based measurement systems. A new technique for accelerating ACP measurements; quality measurements on 3G signals, including code-domain power, error-vector magnitude (EVM), rho and complimentary cumulative distribution functions (CDFs); and measurement differences between CDMA2000 and CDMAOne systems are also offered.

Another experienced Wireless Symposium Chairperson, Tom Brinkoetter of Anritsu Co. (Morgan Hill, CA), will be moderating a track of sessions on WLANs, Bluetooth, and HomeRF systems. A session on WLANs, for example, will open with a Federal Communications Commission (FCC) consultant providing an update on FCC policies and interpretations of the rules for WLANs. The session will include a presentation by a Vice-Chairman of the IEEE 802.11

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committee, describing the group's progress on the WLAN standard, with recent recommendations. An additional session on WLANs will describe a newly recommended modulation format "CCK" to reach 11-Mb/s data rates, and wired Ethernet compatibility, and provide a description of a new radio chip set that implements the new 802.11 CCK/direct-sequence, spread spectrum (DSSS) modulation. Additional sessions will detail how the Bluetooth and HomeRF standards can be applied to the development of home multimedia networks. The session will include a report on a low-cost direct-conversion radio IC that supports IEEE 802.11 standards, and will evaluate how a new IEEE 802.11 chip set performs in a reference PCMCIA II card design.

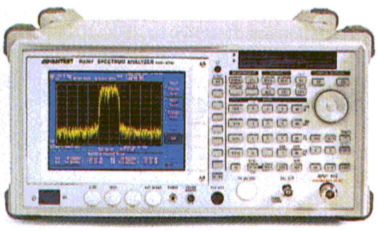
A track on components for wireless systems design chaired by Anthony Wutka of Texas Instruments, Inc. (Dallas, TX) covers the design in addition to the use of a variety of key components, including operational amplifiers and analog-to-digital converters (ADCs). The opamp session will cover the general physics driving the trend toward higher accuracy, lower voltage, and lower-cost opamps. It will show attendees what to look for when choosing opamps for applications in this new and growing market, cover key specs, testing techniques, and trim techniques. It would also include corroborating report information from industry analysts that note which applications show the strongest use of these new op amps and why the overall market growth is expected. The session on high-speed ADCs will review the progression of high-speed ADCs with power consumption of less than 100 mW, and power-saving strategies for off-the-shelf ADCs. The session will also present a new approach to portable-system firmware development called out-in approach, wherein the interface software and the core functionality are developed together. It will show how to detect coding errors and performance errors much earlier than the firmware development methods that are usually used.

Another old friend of the Wireless Symposium, Paul Khanna of Agilent Technologies (San Jose, CA), will chair a session on broadband wireless access. The session will provide an update on fixed wireless access, with a focus on recent developments in the field of wireless access using multiuser multipoint distribution system (MMDS) and license-exempt bands. A second session on broadband wireless-access will examine developments in the field of fixed wireless access solutions using millimeter-wave frequencies, with a focus on local multipoint distribution systems (LMDS) and a European perspective on broadband wireless access. In addition, Dr. Khanna will be in attendance for awards presentations at the Wireless Symposium hosted by a new website for wireless e-commerce, http://www.wireless-wonders.com (see sidebar).

INTEGRATED CIRCUITS

One of the most dedicated members of the Wireless Symposium Technical Committee, Mark McDonald of Linear Technology Corp. (Milpitas, CA), will be chairing a track on wireless IC solutions. His track will include a session on single-mask programmable RF IC technology and how it can be applied for solutions in dual-band cellular telephones. The technology supports straightforward optimization of such parameters as bias, noise figure, and output power from a base wafer.

In contrast to the tiny IC, a track on base-station trends chaired by Peter Rha of San Francisco University (San Francisco, CA) offers presentations on a number of state-of-the-art base stations employed in cellular and PCS systems, providing insights into what is currently possible at this level. Sessions highlight the architecture and signal-processing issues of reconfigurable base stations to support multiple standards of cellular and PCS systems, the design methodology of a single intermediate-frequency (IF) Global System for Mobile Communications (GSM)/EDGE transmitter by modeling the DSP,



digital-to-analog converter (DAC), and IF/RF sections, and architecture issues related to providing a cost-effective software-radio design for base stations.

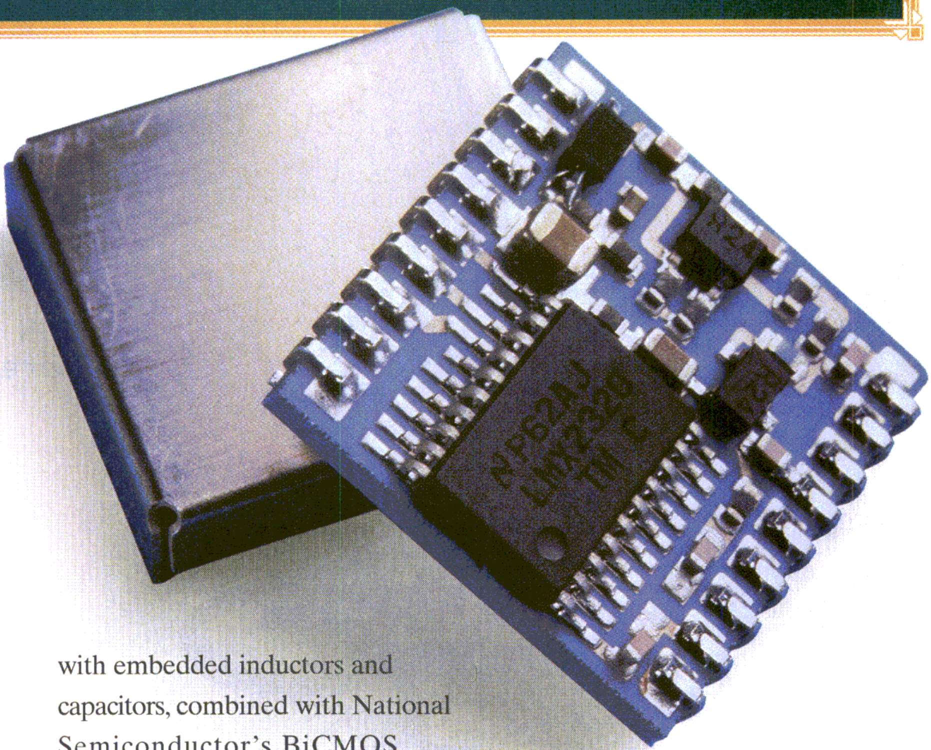
A track on modulation techniques chaired by Earl McCune of Tropian, Inc. (Cupertino, CA) spotlights hybrid-phase-shift-keying (HPSK) spreading, which has been proposed as the spreading technique for the reverse link of 3G technologies, such as WCDMA and cdma2000. In these systems, the mobile phone can transmit multiple coded channels at different power levels. HPSK supports multichannel transmission while minimizing the peak-to-average power ratio of the signal. A presentation on HPSK will explain how the technique works and why it has been selected as the spreading method for 3G direct-sequence, spread-spectrum systems.

ANTENNAS AND RADIOS

The sessions previewed here are only a sampling of the many presentations to be made at the upcoming Wireless Symposium/Portable By Design Conference & Exhibition. For example, a track on high-power design chaired by Dave Osika of ANADIGICS, Inc. (Warren, NJ) reviews the circuit topologies and devices for 3G handsets, while a track on antennas chaired by Peter Slettman, Remec Magnum (San Jose, CA) covers microcellular and in-building antennas, limitations on small antennas, and the latest smart-antenna designs. A session on ultra-wideband radio design chaired by Eric Schmidt of Centerpoint Broadband Technologies (San Jose, CA) will unveil new products and technologies for this time-modulated radio technology, as well as a review of the latest in OC-12 modems for point-to-point LMDS applications. For more information on the Wireless Symposium/Portable By Design Conference & Exhibition, contact Conference Manager, Betsy Tapp, at Wireless/Portable 2000, 611 Route 46 West, Hasbrouck Heights, NJ 07604; FAX: (201) 393-6297, e-mail: btapp@penton.com, Internet: http://www.WirelessPortable.com. ●●

Application Profile

DuPont Green Tape™ Shrinks Wireless Communications Devices.



National Semiconductor chose DuPont Green Tape™ materials to integrate passive components into circuit substrates used in wireless communications devices, improving performance and reducing circuit size and cost.

The Challenge: Small-Size, High-Performance Circuits for Wireless Telecom

In wireless communications devices such as cellular telephones, wireless LANs and satellite global positioning systems (GPSs), the ratio of passive to active components may be more than 100:1, which increases circuit size, weight and cost. National Semiconductor engineers needed to address the problem of integrating the necessary passive components, while still meeting circuit size and cost-reduction goals.

In addition, the new circuit had to meet complex performance requirements. Portable wireless components typically operate in the 900 MHz–2.4 GHz range, and require high efficiency (or high Qs) to meet stringent power and signal integrity requirements.

The Solution: Dupont 951 Green Tape™ System

The new circuit substrates use the DuPont 951 Green Tape™ system with embedded inductors and capacitors, combined with National Semiconductor's BiCMOS frequency synthesizer ICs.

The combined technology was first used on a VCO/synthesizer designed to embed the resonator and several passive circuit elements of a loop filter in a frequency control module. The embedded technology reduced circuit size by a factor of four and cut costs by half. The circuit has eight conductive layers, 200-micron lines and spaces, and 150-micron vias. It contains two buried inductors and four buried capacitors. Each substrate master produces 64 individual circuits.

The embedded functions of the substrate eliminate many interconnections with poorly controlled impedance, which traditionally require additional components to control the effects of parasitics and impedance mismatches. Concurrent design of active RF ICs with substrates containing embedded passives simplifies IC design and improves circuit efficiency to reduce power consumption, improve battery life, or reduce battery size.

For more information, call DuPont at 1-800-284-3382, press 3, or visit the DuPont Microcircuit Materials Web Site (http://www.dupont.com/mcm/).

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New Era Products Check-In At Wireless Symposium

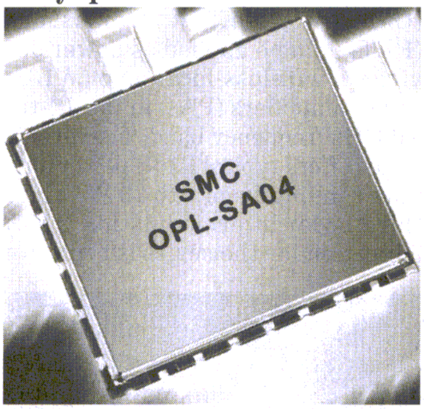
The innovative components needed to sustain the growth of wireless communications in the 21st century will make their debut at the Wireless Symposium.

GENE HEFTMAN
Senior Editor

IT is a new year, a new century, and a new millennium, and another opportunity to ponder and examine the newest products and latest technology available to designers of wireless-communications equipment. The big event takes place at the Eighth Annual Wireless Symposium and Exhibition in San Jose, CA, February 22-24, 2000. Next year, 400 providers of components, test equipment, software, and services will begin the journey into 21st century communications technology. Ahead in this adventure lie the opening stages of third-generation (3G) wireless, the first trials of Bluetooth technology, the mobile Internet, local-area networks (LANs), plus unknown projects still in the embryonic stage. Some of the kinds of products needed to get there appear on the following pages. Thousands more will be on display at the Symposium.

Phase-locked source offers low phase-noise

A new series of fixed-frequency, phase-locked sources that operate over the range of 70 to 300 MHz deliver optimum performance in terms of phase noise and spurious rejection. They use a custom-built phase-detector chip with a noise floor of −160 dBm. This device can handle frequencies up to 50 MHz to enable a phase-locked loop (PLL) to do a comparison at the input-reference frequency (in most cases). This lowers the divide-by number of the voltage-controlled oscillator (VCO) frequency, resulting in lower phase noise, higher spurious rejection, and wider loop bandwidth, if needed, to substantially minimize microphonic effects. The device is housed in a compact surface-mount package



(SMP). The sources are well suited for high dynamic-range applications. **Synergy Microwave Corp., 201 McLean Blvd., Paterson, NJ 07504; (973) 881-8800, FAX: (973) 881-8361, e-mail: sales@synergymwave.com.**

CIRCLE NO. 133 or visit www.mwrf.com

Single-balanced mixer smaller than hybrids

An ultra-miniature single-balanced mixer, the HMC272MS8 comes in an 8-lead plastic surface-mount Mini Small Outline Package (MSOP8). A passive mixer, it is constructed of gallium-arsenide (GaAs) Schottky diodes and a planar transformer balun on a single chip. The RF port is balanced via the monolithic-microwave-integrated-circuit (MMIC) balun while the local-oscillator (LO) port is connected directly to the diodes. The device can be used as an up- or downconverter for personal communications systems (PCS), wideband code-division multiple access (WCDMA), 2.4-GHz industrial-scientific-medical (ISM) band, and other communication systems. No external components are required to operate the device. Measuring 0.118 × 0.190 × 0.040 in. (3.0 × 4.9 × 1 mm), the mixer is the thinnest one on the market. Electrical performance is guaranteed over the temperature range of –40 to 85 C. Samples with evaluation printed-circuit boards (PCBs) and production quantities, including tape-and-reel packaging, are available from stock. P&A: $0.69 (100k qty.). **Hittite Microwave Corp., 12 Elizabeth Dr. Chelmsford, MA 01824; (978) 250-3343, FAX: (978) 250-3373, Internet: http://www.hittite.com.**

CIRCLE NO. 134 or visit www.mwrf.com

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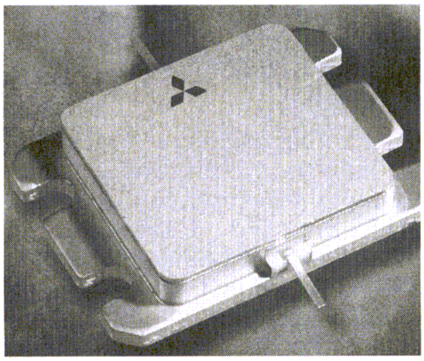
EDA software has more automation

A new release of the Advanced Design System (ADS) electronic-design-automation (EDA) software package from the EEsof group aims at improving designer productivity in the areas of design automation, design education, and usability. Release 1.3 includes new tools called design guides to help less experienced designers achieve first-pass success easier and faster. Enhancements to the ADS core provide real-time interactive tuning of multiple parameters, analysis, and synthesis of transmission lines, filter synthesis, matching network synthesis, improved noise analysis, and faster large-scale circuit-envelope simulations. To make designers more knowledgeable, the company offers a curriculum of application-specific short courses developed by industry and academic experts. **Agilent Technologies, Inc., Test and Measurement Org., 5301 Stevens Creek Blvd., MS 54LAK, Santa Clara, CA 95052; (800) 452-4844 ext. 6850.**

CIRCLE NO. 135 or visit www.mwrf.com

Power GaAs FETs designed for WLL

A family of gallium-arsenide (GaAs) field-effect transistors (FETs) can be applied as power devices in wireless-local-loop (WLL) power amplifiers (PAs) in the 3.4-to-3.6-GHz frequency band. The MGFC series offers typical P1dB power outputs ranging from 4 to 30 W, while third-order intermodulation (IM3) distortion for the series is typically

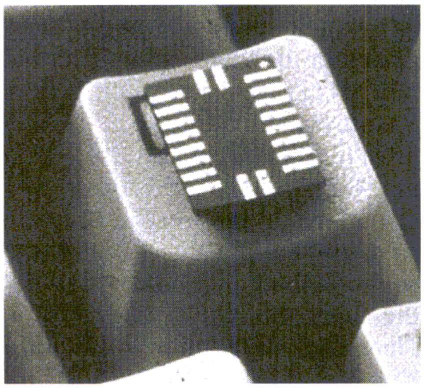


–45 dBc at power outputs from 25 to 34.5 dBm, depending on the specific device. The FETs are matched internally to 50 Ω to simplify system design. They are hermetically sealed in metal/ceramic packages for high reliability. **Mitsubishi Electronics America, Inc., 1050 East Arques Ave., Sunnyvale, CA 94086; (408) 730-5900, Internet: http://www.mitsubishichips.com.**

CIRCLE NO. 136 or visit www.mwrf.com

Datacom transceivers work over short range

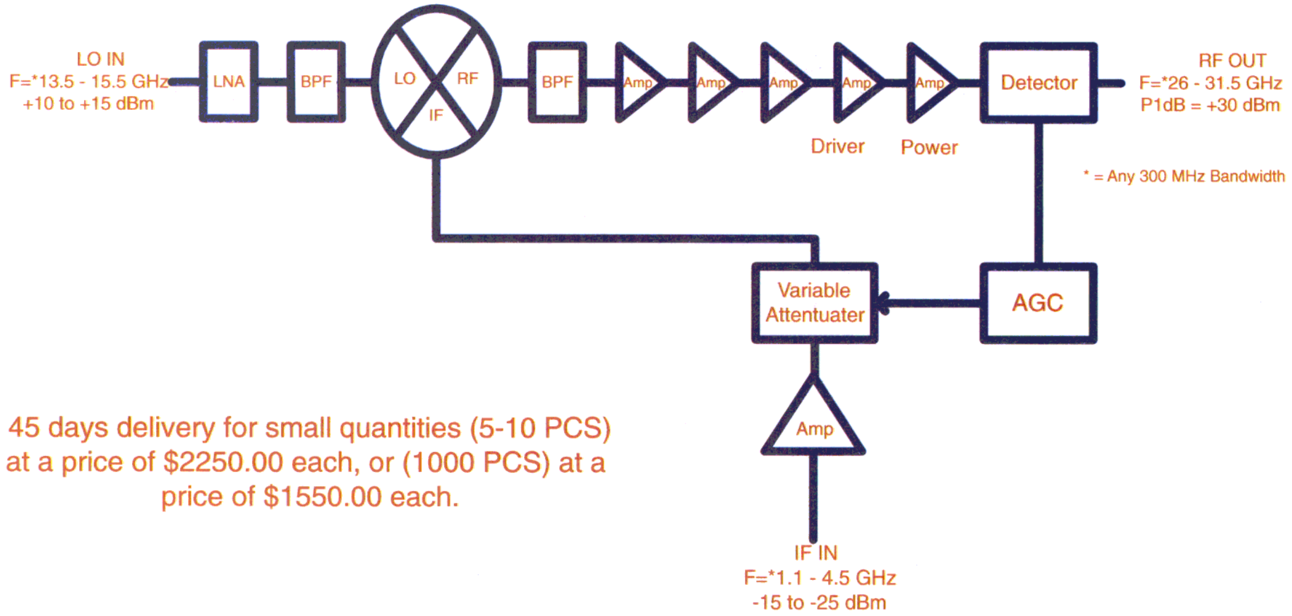
The second-generation (2G) amplifier-sequenced-hybrid (ASH) transceiver family is designed for short-range data-link applications in North America, Europe, and Scandinavia. The TR1000 is the North American version at 916.5 MHz, the



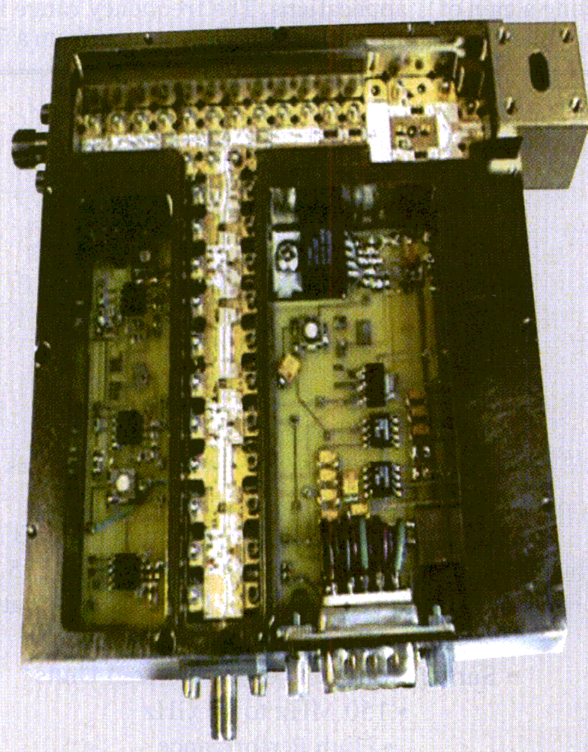
TR1001 is for Europe and Scandinavia at 868.35 MHz, and the TR3000 handles I-ETS 300 220 applications at 433.92 MHz. ASH transceivers are small hybrids that offer a completely integrated solution, with all RF filters and active circuitry contained within the module. The receiver contains a log detector in combination with digital automatic-gain control (AGC) achieves 100-dB dynamic range. On the transmit side, a user can choose on-off-keying (OOK) or amplitude-shift-keying (ASK) modulation. Transmitter power can be adjusted to meet Federal Communications Commission (FCC) limits with a wide range of antennas.

The TR1000 and TR1001 are housed in 0.28 × 0.40 × 0.08-in. (0.71 × 1.02 × 0.20-cm.) metal-ceramic hy-

1 Watt Linear Power LMDS Base Station Transmitter



45 days delivery for small quantities (5-10 PCS) at a price of $2250.00 each, or (1000 PCS) at a price of $1550.00 each.



Narda DBS offers other very LOW cost wireless products using MMICs on SoftBoard

- Power Amplifiers
- Low Noise Amplifiers
- Down-Converters
- UP-Converters
- Full Transceivers
- 12 To 60 GHz Coverage

DBS Microwave Inc.

Narda DBS Microwave
4805 Golden Foothill Parkway
El Dorado Hills, CA 95762
Phone: (916) 939-7545
Fax: (916) 939-7540
email: info@dbsmw.com
http://www.dbsmw.com

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dbs microwave
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brid packages. The TR3000 comes in a 0.35 × 0.42 × 0.08-in. (0.89 × 1.07 × 0.20-cm) package of similar construction. P&A: $17.50 (1000 qty.). **RF Monolithics, Inc., 4347 Sigma Rd., Dallas, TX 75244; (972) 448-3700, FAX: (972) 387-8248, Internet: http://www.rfm.com.**

CIRCLE NO. 137 or visit www.mwrf.com

Solid-state RF amps test CDMA drivers

Three solid-state RF amplifiers are intended for testing the driver amplifiers used in code-division-multiple-access (CDMA) wireless transmission. The "S" series amplifiers are similar to an existing family but deliver more power at narrower bandwidth. All three—the 120S1G3, 60S1G3, and 30S1G3—offer frequency response from 0.8 to 3.0 GHz, and are intended to test narrower frequency responses than the original family. The amplifiers can minimize adjacent-channel power, a key factor in achieving high-quality CDMA transmissions. P&A: 120S1G3, $67,000; 60S1G3, $35,000; 30S1G3, $18,000. **Amplifier Research, Inc., Souderton, PA; (215) 723-8181, Internet: http://www.ar-amps.com.**

CIRCLE NO. 138 or visit www.mwrf.com

Silicon-carbide transistor suits wireless

Silicon-carbide (SiC) metal-semiconductor-field-effect-transistor (MESFET) technology is a new high-power alternative to traditional gallium-arsenide (GaAs) and metal-oxide-semiconductor (MOS) processes. The CRF-20010 is a SiC power transistor for wireless and broadcast applications. It is a 48-V, 10-W high-linearity RF transistor having a gain of 12 dB at 2 GHz. In some applications, the device can eliminate a DC-to-DC converter as may be required with GaAs and MOS devices. The typical application is in a driver stage of wireless base-station amplifiers. It can operate under a number of access methods including time-division multiple access (TDMA), code-division multiple access (CDMA), and frequency modulation (FM). **Cree Research, Inc., 4600 Silicon Dr., Durham, NC 27703; (919) 313-5300, FAX: (919) 313-5452, Internet: http://www.cree.com.**

CIRCLE NO. 139 or visit www.mwrf.com

TCXO/VCXO comes in surface-mount form

Housed in a surface-mount-package, the Model XO3080 is a temperature-compensated/voltage-controlled crystal oscillator for wireless applications. The frequency range is 10 to 100 MHz. Operation is from a 5-

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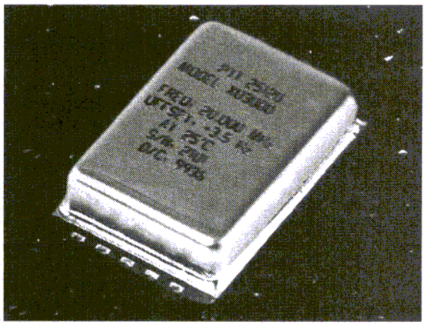


V power supply. The temperature stability is ± 0.75 PPM over the temperature range of –30 to 70°C. Depending on the version, aging per year can be as low as ± 1 PPM maximum. The output signals from the various models are sine waves. Oscillators are housed in a 0.98 × 0.69 × 0.22-in. (2.49 × 1.75 × 0.559-cm) surface-mount reflow package. **Piezo Technology, Inc., 2525 Shader Rd., Orlando, FL 32804; (407) 298-2000, FAX: (407) 293-2979, e-mail: sales@piexotech.com., Internet: http:// www.piezotech.com.**

CIRCLE NO. 140 or visit www.mwrf.com

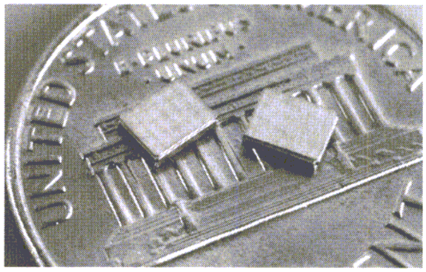
High-frequency duplexer used for wireless modems

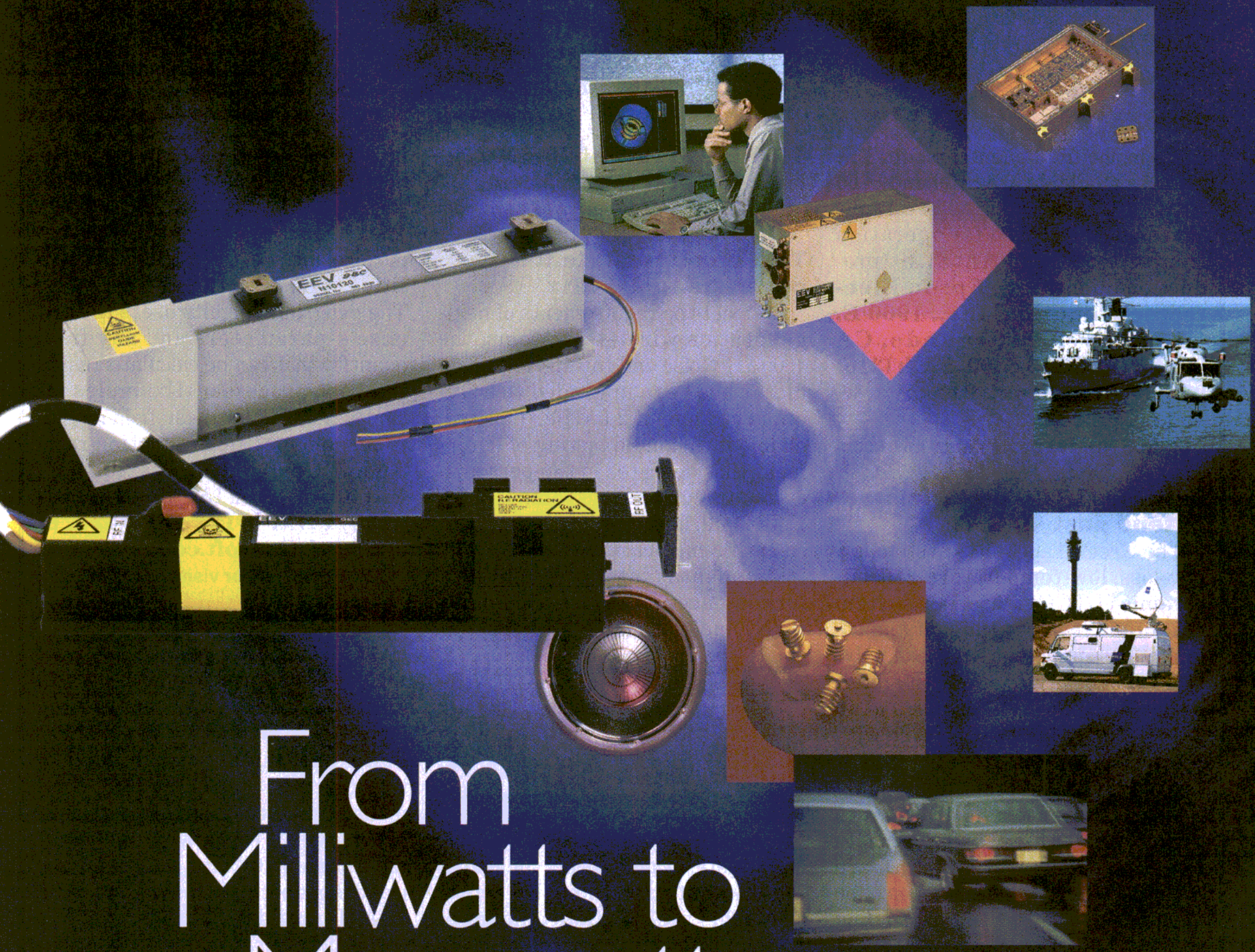
The CCDP-90 is a 2.4-GHz duplexer designed for wireless modem applications. It achieves 100-dB receiver-to-transmitter isolation between channels with less than 2.5-dB loss in the passband. One channel passband is 2400 to 2424 MHz while the second is 2440 to 2463 MHz. The duplexer comes in a package measuring 5.0 × 3.5 × 1.0 in. (12.7 × 8.9 × 2.5 cm) with SMA connectors. Standard as well as custom designs are available. **ClearComm Technologies, Inc., 1918C Northwood Dr., Salisbury, MD 21801; (410) 860-0500, FAX: (410) 860-9005, e-mail: clearcomm@dmv.com, Internet: http://www.clearcommtech.com.**

CIRCLE NO. 141 or visit www.mwrf.com

Subminiature crystal fits portable products

Measuring just 0.125 × 0.01 × 0.03 in. (3.2 × 2.5 × 0.7 mm), the FA238 series of crystals are designed for portable applications requiring miniature surface-mount packages. The crystals are available over a frequency range of 20 to 50 MHz and op-





erate in the fundamental mode. Tolerances available are ±30 and ±50 PPM. They are packaged in ceramic cases and are rated for operation from –20 to 70°C. P&A: $1.40 (production quantities). **Epson Electronics America, Inc., 1960 E. Grand Ave., El Segundo, CA 90245; (310) 955-5300, FAX: (310) 955-5400, Internet: http://www.eea.epson.com.**

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Low-loss LTCC materials extend past 40 GHz

The Green Tape™ 943 system is a low-loss, low-temperature-cofired-ceramic (LTCC) materials system that offers low loss-tangent and attenuation equivalent to that of polytetrafluoroethylene (PTFE) laminates and thin film on alumina at 40 GHz and beyond. It is available with a full line of compatible co-fired silver (Ag) and gold (Au) conductors. Green Tape LTCC materials are used to create high-density interconnects with embedded functions. They are becoming the materials of choice for functions that must meet demanding size and cost requirements. **DuPont Microcircuit Materials, 14 T.W. Alexander Dr., Research Triangle Park, NC 27709; (919) 248-5752, Internet: http://www.dupont.com/mcm.**

CIRCLE NO. 143 or visit www.mwrf.com

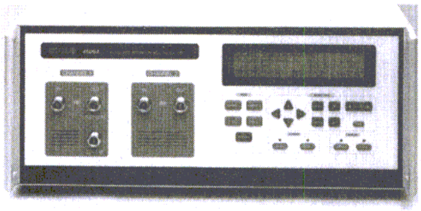
Computer simulation aids in filter designs

A new version of the CST Microwave Studio (ver. 1.1) software is used for filter design and the design of high-speed digital devices. A new feature is the Eigenmode Solver, through which a modal analysis of eigenmodes supports the fast calculation of weak coupled or high resonant structures. The new version also enables better importing of computer-aided-design (CAD) data and the reading of DXF files used with planar structures. A number of other improvements are also incorporated in ver. 1.1. **CST of America, Inc., 124 Mount Auburn, Suite 200N, Cambridge, MA 2138; (617) 576-5857, FAX: (617) 576-5702, e-mail: info@cst-america.com.**

CIRCLE NO. 144 or visit www.mwrf.com

Test emulator extends coverage to 2.5 GHz

To meet the requirements of next-generation wireless systems, the 4600AH Noise and Interference Emulator has been upgraded to a frequency range of 2.5 GHz. This will enable it to handle testing of equipment that operates in the personal-communications-systems (PCS), IMT-2000, and 2.4-GHz industrial-scientific-medical (ISM) bands. The instrument is integrated for performing accurate carrier-to-noise (C/N) and carrier-to-interference



(C/I) tests. It accurately measures the power of an incoming RF signal, then adds the specified amount of noise or interference to obtain a desired C/N or C/I ratio. It is available with TASKIT/4600 for Windows software to facilitate test setup and control. **Telecom Analysis Systems, Inc., 34 Industrial Way East, Eatontown, NJ 07724; (732) 544-8700, FAX: (732) 544-8347, e-mail: sales@taskit.com, Internet: http://www.taskit.com**

CIRCLE NO. 145 or visit www.mwrf.com

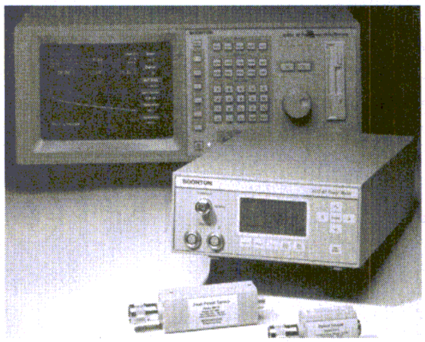
EM simulator designs complex structures

The High-Frequency Structure Simulator (HFSS) version 7.0 enables engineers to design three-dimensional (3D) high-frequency structures such as connectors, integrated-circuit (IC) packages, and antennas found in cellular phones, communications systems and microwave circuits. Version 7.0 integrates an optimization and parametrics module called Optimetrics™, and a faster solver engine. This allows the user to import simulation results directly into the optimizer, allowing engineers to understand device characteristics over a large design space. Then it is easy to identify the highest performance design that is least sensitive to manufacturing tolerances. The program permits users to optimize s-parameters and any field quantity that can be calculated using the post-processor. Examples include far-field gain, near-field magnitude, and specific absorption rate. **Ansoft Corp., Four Station Sq., Pittsburgh, PA 15219; (412) 261-3200, FAX: (412) 471-9427, e-mail: info@ansoft.com.**

CIRCLE NO. 146 or visit www.mwrf.com

Power meters make HDTV measurements

High-definition-television (HDTV) measurements are the key application for the 4530 Series RF Power Meters. Designed for production testing, the instruments can make high-speed peak and continuous-wave (CW) power measurements from 10 kHz to 40 GHz, depending on the sensor, across a 20-MHz modulation bandwidth. The series incorporates statistical analysis features such as histograms and cumulative distribution functions,



enabling them to conduct fast analysis of complex signals such as HDTV. Up to 500,000 samples per second can be captured in single-channel statistical mode. Prices range from $3650 to $5650 with 12-wk. delivery. **Boonton Electronics Corp., 25 Eastmans Rd., Parsippany, NJ 07054; (973) 386-9696, FAX: (973) 386-9191, Internet: http://www.boonton.com.**

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WINTER ISSUE

BLUETOOTH

FOR DESIGNERS OF PERSONAL CONNECTIVITY SOLUTIONS

MARKET UPDATE

Projections Push Product Development

SYSTEM DESIGN

Transceiver Provides System Solution

TEST STRATEGIES

Perform Bluetooth RF Measurements

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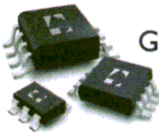

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AWS5504	DC-2.0	17	0.4	38	55	SOT-6
AWS5506	DC-2.5	20	0.45	28	45	SOT-6

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BLUETOOTH

Introduction

How Could So Many Companies Be Wrong?

Bluetooth markets should begin to explode in 2000. At least, that is the hope and thinking of the founding Bluetooth member companies, Ericsson, IBM, Intel, Nokia, and Toshiba Corp., along with more than a thousand other companies in support of the de-facto standard as part of the Bluetooth Special Interest Group (SIG). The predicted market numbers are staggering, with projections in the area of hundreds of millions of electronic devices per year. But the expected costs for these devices are also shocking, in the neighborhood of $10 or less for complete Bluetooth transceiver systems operating at 2.4 GHz.

Combine the aspects of high volume and low cost with the implied critical time to market issues, and Bluetooth represents a wireless market that is not unlike other large wireless markets, such as those for hand pagers and cellular telephones. The difference is that where a family today might own one or two cellular handsets, the potential number of Bluetooth devices within a household is large. Conceivably, any electronic device that can be controlled, or that can contain memory, is a candidate for Bluetooth. The most commonly touted applications revolve around the personal computer (PC), such as using Bluetooth wireless interconnections to link a PC to a printer, or to transfer database files between a PC and a cellular telephone or Personal Digital Assistant (PDA).

A number of companies are already manufacturing Bluetooth solutions (see "Bluetooth Projections Push Product Development"), notably Scandinavian firms such as Digianswer, Ericsson, and Sonera, although companies in the US, such as National Semiconductor, and in Germany, such as TEMIC Semiconductors, have also taken a lead in the market with integrated-circuit (IC) building blocks.

With so many companies taking a vested interest, it is reasonable to assume that Bluetooth will take off. It is a very straightforward standard, largely based on the specifications for the Digital European Cordless Telephone (DECT) system. Since Bluetooth is based on established regulations in Europe, Japan, and North America within the unlicensed industrial-scientific-medical (ISM) frequency range of roughly 2.4 to 2.5 GHz, no frequency-allocation lotteries need be held, as with personal communications services (PCS). It is simply one of those rare applications in which the available ISM bands within each area of the globe happened to coincide, much to the delight of equipment suppliers everywhere. In Europe and the US, for example, the available ISM frequencies at 2.4 GHz span from 2400 to 2483.5 MHz, with the exception of Spain, which uses 2445 to 2475 MHz and France, which uses 2446.5 to 2483.5 MHz. In Japan, the range is 2471 to 2497 MHz.

In all cases, Bluetooth radios employ frequency-hopping, spread-spectrum (FHSS) methods, jumping across 70 1-MHz-wide channels. A basic Bluetooth system consists of a radio transmitter and receiver, a baseband control unit, and link-management software. Frequency-shift-keying (FSK) modulation is used to modulate data on the wireless carriers.

Bluetooth has an almost elegant simplicity to it, where radios can operate as either master or slave units, with as many as seven slaves per master within a piconet. Since the master of one piconet can be a slave within another piconet, there is almost endless flexibility within the Bluetooth format—one of the many reasons for such optimism about the future of Bluetooth.

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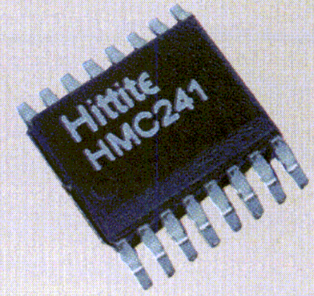

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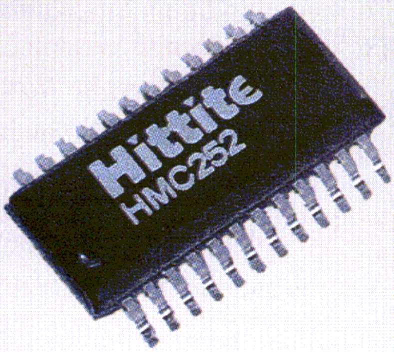

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HMC253QS24 SP8T

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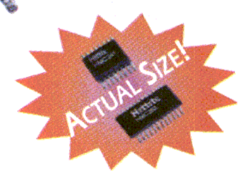

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CIRCLE NO. 186

Ron Schneiderman
Chief Editor, Wireless Systems Design

Bluetooth Projections Push Product Development

Bluetooth stands to become the fastest-growing de-facto standard ever.

If market projections mean anything today in wireless communications, one of the most dramatic is that before the year 2002, Bluetooth technology will be built into hundreds of millions of electronic devices. This would make Bluetooth technology the fastest-growing de-facto standard, and would certainly challenge the Internet as the fastest adaptation of any technology ever.

So much for the hype, where are the products? A few key players demonstrated the potential for Bluetooth at the recent Telecom '99 in Geneva and several more new products will be on display at the Bluetooth Developers Conference this month in Los Angeles.

In Geneva, Motorola used its P1088 "smartphone," expected to be available early next year, to demonstrate Bluetooth's capabilities. Motorola is reportedly working Bluetooth across six of its product groups, including its commercial land-mobile operation, and Telematics, which deals with automotive applications. Motorola has also recently acquired Danish Bluetooth specialist Digianswer from Olicom A/S. Digianswer's current Bluetooth effort is a PC card-based Bluetooth developer's kit that it has been selling for at least seven months. Many of the companies at Telecom '99 were using the Digianswer device to demonstrate their Bluetooth technology.

Motorola will embed Digianswer's Bluetooth technology into its DigitalDNA wireless connectivity, portable computing, and home-networking product lines. The Digianswer product is a Type II PC card with Bluetooth compliant hardware/firmware and software support for Windows 95/98. The card is available in two versions, a 0- and +20-dBm radio, the second of which has additional features such as signal-strength indication and programmable radio amplifier. Ericsson also demonstrated a Bluetooth-based cellular handset, headset, and digital camera at Geneva .

Perhaps the most-interesting application of Bluetooth at Telecom '99 was by Sonera, Finland's leading network operator, which used the technology in a soft-drink vending machine. Using the Bluetooth link, drinks could be ordered using a Wireless Application Protocol (WAP)-based phone.

The application is a natural for Sonera, which supplies public-key-infrastructure (PKI)-based solutions for mobile commerce throughout Finland. Sonera subscribers use pay-by-Global System for Mobile Communications (GSM) phones to buy consumer products and services. The company anticipates a fast-growing and eventually huge mobile e-commerce market and views Bluetooth as an opportunity to create a transaction-based market for mobile-network operators.

1. Less than 1-mm thick, Silicon Wave's Bluetooth integrated circuit (IC) combines radio, modem, and controller functions in a single component.

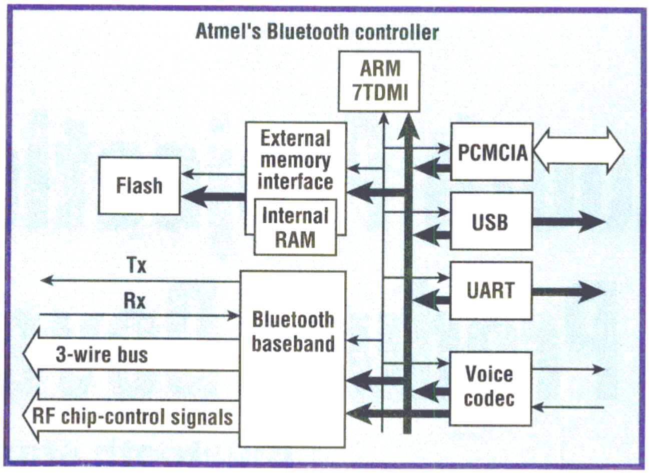
The Gartner Group believes that at least 75 percent of new mobile phones shipped by 2004 will support e-cash payment by Bluetooth links to point-of-sale (POS) terminals and vending machines.

With more than 1100 members in the Bluetooth Special Interest Group (SIG), expectations for Bluetooth technology are high. Shipments of Bluetooth-enabled products are expected to begin to pick up during the first half of 2000 and will then ramp up noticeably in the second half of the year. Growth will continue into 2001 and by 2004, the Converging Markets & Technologies Group of Cahners In-State Group is projecting that Bluetooth devices could exceed 400 million units.

Several semiconductor, test and measurement, antenna, and other vendors are pressing hard to take advantage of those heady numbers.

Bluetooth Projections

Silicon Wave (San Diego, CA) plans to delivery a fully integrated Bluetooth radio, modem, and synthesizer. The radio is designed using a direct-conversion architecture for the 2.4-GHz transceiver. The modem is also fully integrated, including burst timing and control. Synthesizer functions are fully integrated and require no external voltage-controlled oscillator (VCO) or resonator. The chip (Fig. 1) requires no major external discrete components or other devices. Rather, it interfaces to a simple switch and antenna, system-timing crystals, and a small number of low-cost discrete capacitors and resistors.



2. Atmel's AT76C551 Bluetooth controller, available in several options, integrates an ARM7TDMI core and dedicated Bluetooth baseband block.

Dave Lyon, Silicon Wave's CEO, views the device as the first high-volume, low-cost application of a software-define radio, or software radio. The integration of so much functionality on a single chip provides the fastest path to a $5 Bluetooth solution in the marketplace. Lyon believes the price for high volumes of the component will drop to $5 by the end of 2001.

The Silicon Wave chip functions as a radio-peripheral device and connects to a separate complementary-metal-oxide-semiconductor (CMOS) digital controller that implements the high-speed data-control functions of the Bluetooth medium-access-control (MAC) layer. By next year, Silicon Wave plans to provide a single-chip radio-modem-synthesizer with the Bluetooth MAC layer integrated on the chip. Based on customer requirements, Silicon Wave will also facilitate the integration of the controller functions into a separate baseband controller or host processor in the customer's product by making the digital controller for the radio-modem-synthesizer available in four options—standalone, integrated into the radio-modem-synthesizer integrated circuit (IC), incorporated into a separate baseband controller, or incorporated directly into the customer's host processor.

Silicon Wave is currently shipping component prototypes. The device is available in a 68-pin, 10 × 10-mm plastic package and is supported by Bluetooth protocol stack software up through the host-controller-interface (HCI) layer, which can be licensed from Silicon Wave. Production samples will be available in the first quarter of 2000 with full production in the second quarter.

Meanwhile, Silicon Wave has agreed to collaborate on Bluetooth developments with TDK Systems Europe Ltd., Tokyo-based module maker Taiyo Yuden Co. Ltd., Hitachi Semiconductor (America), Inc. (San Jose, CA), and Amkor Technology (Chandler, AZ), and Extended Systems, Inc./Counterpoint Systems Foundry.

The TDK agreement takes advantage of that company's interface and mobile-communications software-stack expertise. The first TDK products to incorporate Silicon Wave RF devices will include PC Cards, Bluetooth kits for GSM phones, Bluetooth Compact Flash adapters, modems, and local-area-network (LAN) access points. Taiyo Yuden will incorporate Silicon Wave RF ICs into modules for use in communications and computer products. Hitachi will use its 16-b H8S microcontroller as the baseband controller and Silicon Wave's radio modem controller (RMC) to provide a complete Bluetooth solution to original equipment manufacturers (OEMs) and module manufacturers. Extended Systems/Counterpoint will focus on developing a portable, embedded-protocol-stack matching Bluetooth specifications. Silicon Wave's RMC will be packaged in Amkor's MicroLeadFrame IC packages.

TEMIC Semiconductors (Heilbronn, Germany), a wholly owned subsidiary of Atmel Corp. (San Jose, CA), has launched its own short-range RF transceiver for Bluetooth. The T2901 complies with all Bluetooth specifications and, along with Atmel's forthcoming Bluetooth single-chip controller (baseband) and standard flash, forms an integrated module with all of the ICs needed for Bluetooth. The new controller (AT76C551) will integrate an ARM7 TDMI core (Fig. 2), dedicated Bluetooth baseband block, voice codec, and standard interfaces, and will interface directly with the T2901 transceiver.

The T2901 adheres to the Bluetooth 0-dBm output power at the antenna, spectrum spreading with 1600 frequency hops per second switching among 79 channels in the 2.4-GHz band, with a gross data rate of 1 Mb/s. Full-duplex transmission is achieved by using a time-division-duplex (TDD) scheme. The phase noise of the VCO of −89-dBc/Hz at a 500-kHz offset as well as transmit/receive (Tx)/(Rx) turn-around-time of 100 µs also meets Bluetooth specifications.

The device has a ramp-signal generator for a smooth increase of the output power and an auxiliary voltage-regulator on-chip. The supply-voltage range is +2.7 to +3.3 VDC (+6 VDC with additional PNP transistor). A proprietary on-chip image rejection mixer converts the frequency down to 111 MHz, reducing power drain. The image-rejection mixer offers up to 35-dB image rejection.

At −80 dBm, the sensitivity exceeds the Bluetooth requirements by 10 dB. "This distinguishes our solution from others by a 10 times higher operating range," says Udo Tillman, marketing manager for Bluetooth RF solutions at TEMIC.

The T2901 also contains a modulation-compensation circuit (MCC) for modulating the VCO. The MCC enables an advanced closed-loop modulation scheme, preventing frequency drifts as usual with conventional open-loop modulation and eliminates the need for in-phase/quadrature (I/Q) modulation used in some competing

RF solutions.

TEMIC is also developing a silicon-germanium (SiGe) front-end IC (T7024) for Bluetooth, which will include a power amplifier (PA) and low-noise amplifier (LNA) as well as the drivers of a positive-intrinsic-negative (PIN) diode switch. This part, in conjunction with T2901, provides a +20-dBm solution that will boost the range of Atmel's Bluetooth system beyond 100 m.

Samples of the T2901 are currently available in TQFP48 packages. TEMIC also is providing a design kit with the reference design, interface, and RF board, as well as evaluation software.

Atmel will also provide all Bluetooth software through the HCI and will develop software through the logical-link-control adapter-protocol (L2CAP) level.

Ericsson is also working with ARM (Cambridge, United Kingdom) to introduce a family of ARM-powered Ericsson Bluetooth cores and firmware for licensing by OEMs and Si vendors.

"We have designed and implemented several ARM7/TDMI core-based controllers which have been successfully incorporated into a variety of products including Ericsson mobile phones," says Orjan Johansson, director and general manager of Ericsson's Bluetooth Product Unit (Stockholm, Sweden).

Ericsson and ARM are also co-developing software support, with full compatibility to electronic-design-automation (EDA) tools through prototyping, interoperability testing, and system-level verification. Prototype Si of the initial Ericsson Bluetooth core is available now.

Ericsson has unveiled a Bluetooth headset for cellular phones. The headset has a radio chip that gives the user a wireless range to 30 ft. (10 m). It can be used with Ericsson's T28, T28 World, and R320 cellular phones.

Ericsson has also signed an agreement with Visa International to develop secure payment solutions for the purchase of goods and services over the Internet via a mobile terminal over open standards that include Bluetooth. One area of cooperation will be developing a payment system for mobile e-commerce using Ericsson's Bluetooth-enabled electronic wallet, which can serve as a conventional wallet for bills and coins, and contains multiple smart-card readers. A smart card inserted into the wallet can communicate with a Bluetooth-based mobile terminal. The mobile phone can be used for Internet shopping using the smart card in the wallet for payment.

Another company, Widcomm, Inc. founded last year in San Diego, CA specifically to design and manufacture wireless products using Bluetooth technology, has demonstrated its Blue-Connect module, which is built on Handspring's Springboard expansion platform. Blue-Connect will enable Handspring's portable Visor organizer to automatically connect with several computing devices.

With this add-on module, Wid-

Bluetooth Projections

comm lets Visor users manage e-mail, update contact information, and download calendar appointments via a fast and secure radio link. Future implementations of the unit will enable users to access the Internet.

Widcomm is also working with Acer NeWeb (San Jose, CA), the Acer Group's advanced communications division, to produce Bluetooth modules produced by Acer, but based on Wicomm technology. Texas Instruments (Dallas, TX) is producing the chip sets for Widcomm's Blue-Connect product.

Widcomm and Acer plan to follow their arrangement on Blue-Connect with an ongoing series of Bluetooth solutions, including Bluetooth-enabled personal-computer (PC), personal-digital-assistant (PDA), and cellular-phone adapters.

The Blue-Connect will be available in the second quarter.

Las Vegas, NV-based Ensure Technologies has come up with a wireless PC security solution for Bluetooth. Called XyLoc, the device is designed to prevent unauthorized access to confidential information, and simultaneously makes access to network services and business applications more convenient for authorized users. At the same time, XyLoc simplifies implementation of public key infrastructure (PKI) by security digital certificates stored on PCs, ensuring that they are protected from unauthorized use.

George Brostoff, president of Ensure, says his company's technology will feature Bluetooth-compatible smart cards that will be interoperable with any Bluetooth-enabled device.

Philips Semiconductors also expects to be a major Bluetooth player. Due to its similarities to the Digital European Cordless Telecommunications (DECT) standard, where Philips is already a factor, Dirk Braune, international product-marketing manager for corded and cordless telephone ICs in Philips Semicon's Telecom Terminals Business Unit, says that the company was "60 to 70 percent there with the Bluetooth design before we even started." Philips' first Bluetooth chip set will be ready to ship by early next year.

"By April next year, we will have an enhanced baseband controller working with the UAA3558 transceiver, with specialized hardware and software for highly integrated Bluetooth solutions," notes Braune. "And soon after that, we will have embedded-system components to meet a wide range of different Bluetooth profiles."

Braune says that the range of Bluetooth solutions depends much on the synergies between Philips Semiconductors and VLSI Technology that prompted their recent merger. On the RF side, Philips contributes low intermediate-frequency (IF) transceiver technology, which it originally developed for DECT. Philips has also incorporated its new UAA3558 Bluetooth transceiver into a thin-film hybrid RF module that measures 10 × 12 mm and consumes 45 mA in the receive mode and 30 mA in transmit mode. VLSI Technology will provide its baseband controller for the Bluetooth product.

National Semiconductor Corp.'s (Santa Clara, CA) Bluetooth entry is the single-chip LMX3162 transceiver, which also comes out of its work with 2.4-GHz DECT phones. The chip can be used in combination with National's SC14402 integrated baseband processor for handset implementation.

The test and measurement community is also onto Bluetooth with Agilent Technologies (formerly Hewlett-Packard) adding Bluetooth capability its ESG-D series of digital generators and 89441A vector signal analyzer for testing Bluetooth designs.

A number of antenna companies are Bluetooth-ready. RangeStar International Corp. (Aptos, CA) has developed a surface-mountable, single- or dual-band antennas that can deliver a 0-dBi gain and is small enough to be embedded into almost any product. It measures 18 × 3.8 × 1.6 mm and weighs 1 g.

Centurian International (Lincoln, NE) is also demonstrating an internal antenna for Bluetooth-enabled portable computing devices. The antennas are available in two designs—a planar inverted F antenna (PIFA) or a patch variation. BT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Developing Measurement Solutions For Bluetooth

Manufacturing test requires the generation of GMSK frequency-hopped signals and the capture and analysis of these signals over a suitably wide instantaneous bandwidth.

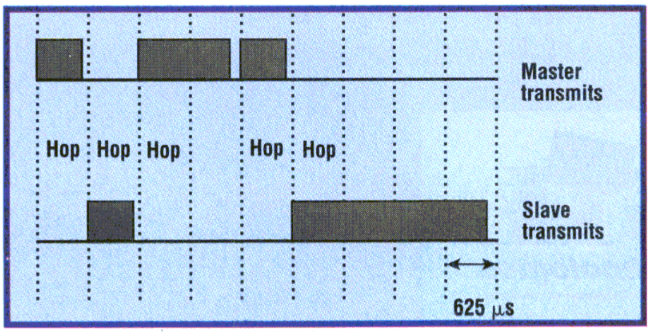
Network connections for computers, peripheral devices, and communications equipment have traditionally taken the form of wire. But with the emerging Bluetooth standard, economical, short-range wireless local-area networks (WLANs) may soon be a reality. Bluetooth employs time-division duplexing (TDD) with slow frequency hopping to communicate over multiple wireless channels. The physical and data links are straightforward, but the relevant test and measurement issues for performance verification may pose some problems.

A Bluetooth network consists of a master device and one or more slave devices.[1] As many as seven slave devices may be active at a particular time, but additional slave devices can be in the idle or packed state. In Bluetooth terminology, a master device and its set of slave devices is referred to as a piconet. The coverage area of a piconet can be extended by permitting a device to be attached to one or more piconets.

Bluetooth operates in the 2.4-GHz industrial-scientific-medical (ISM) band. In the US and Europe, except for France and Spain, Bluetooth employs 79 channels, each with a bandwidth of 1 MHz. In Japan, France, and Spain, the system is based on 23 channels, spaced at 1-MHz intervals. Data are transmitted at a raw bit rate of 1 Mb/s with Gaussian frequency-shift-keying (GFSK) modulation employing a bandwidth-time (BT) product of 0.5. Bluetooth is based on TDD, using 625-ms timeslots. All transmissions from the master device must begin in an even-numbered timeslot. All transmissions from a slave device must begin in an odd-numbered time slot. However, transmissions are allowed to span multiple time slots, up to a maximum of five time slots. As a result, data transmission is not constrained to be symmetrical and the available bandwidth can be divided between uplink and downlink traffic in various ratios. The maximum asymmetric data rate is 721 kb/s and the maximum symmetric data rate is 185.6 kb/s (Fig. 1).

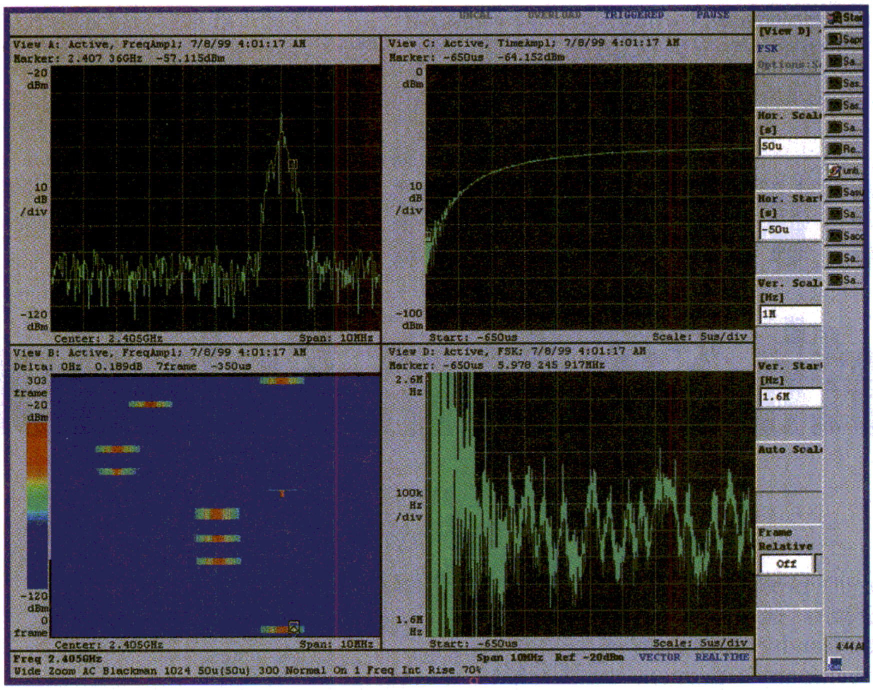
Robust operation is enhanced by frequency hopping. Bluetooth uses slow frequency hopping, at a hop rate of 166 hops/s or one hop per time slot.

The Bluetooth standard specifies two types of physical links—synchronous-connection-oriented (SCO) and asynchronous-connectionless (ACL) links. The SCO links are intended for the transmission of continuous streams of 64-kb/s audio. The standard supports pulse-code-modulation (PCM) encoded audio (using A-law or μm-law weighting) and continuous-variable-slope-delta (CVSD) modulation encoded audio. The ACL links are used for data transmissions.



1. The Bluetooth TDD/frequency-hopping structure is based on 625-μs time slots.

Complete validation of a Bluetooth system offers a number of test challenges, including verification of output-power calibration, spectral-mask verification, frequency-hop control, loopback testing, and protocol validation. However, given pressures to meet market demands at prices as low



2. These four screens show the frequency spectrum, amplitude profile, modulation characteristics, and spectrogram of simulated Bluetooth signals.

as $5 for Bluetooth devices, the scope of manufacturing testing can be assumed to be minimal. However, achieving sufficient design margins to allow minimal manufacturing test will require component designs with wide operating tolerances. As a result of these conflicting requirements, designs should be fully characterized prior to manufacturing.

Characterization of a frequency-hopping TDD design presents the challenge of simultaneously capturing frequency and amplitude transitions. Of particular interest will be the frequency-hopping pattern, oscillator set-on time, as well as the amplitude profile of the Bluetooth signal. The key to acquisition and analysis of these signals is the ability to seamlessly record a signal over a sufficiently long period of time, and then apply post-acquisition signal processing in order to examine the signal with regards to frequency, amplitude, modulation, and transient behavior.

Given the pseudorandom nature of the frequency-hopping pattern, it is difficult to capture any particular burst with a traditional spectrum analyzer or modulation analyzer. A relatively new tool, known as a real-time spectrum analyzer, offers the wide instantaneous bandwidth needed to capture entire frequency-hopping sequences.

The measurements presented here are intended to demonstrate the nature of Bluetooth signals and the measurement challenges presented to component designers. To create a frequency-hopping GFSK-modulated TDD signal, a model SMIQ03B vector-signal generator from Rohde & Schwarz (Munich, Germany) was used. A frequency-hopping list was created and stored in the signal generator and combined with an amplitude-versus-time control list. The signal generator was loaded with a short list of only 15 hops across a 20-MHz frequency span. The signal generator can be used for repetitive sequences having as many as 2000 frequency hops over any desired span.

Signal acquisition and analysis were performed with a model 3086 real-time spectrum analyzer from Sony/Tektronix (Beaverton, OR). The analyzer incorporates a downconverter and is followed by an analog-to-digital converter (ADC) for signal acquisition. This allows the instrument to capture signals in instantaneous bandwidths as wide as 30 MHz for periods that last to 50 ms. Reducing the capture bandwidth (and, therefore, the sampling rate of the ADC) enables extended periods of waveform acquisition. Analysis of the captured waveform is achieved by reprocessing the signal to derive time-versus-amplitude, time-versus, deviations, as well as spectral information. Additional details regarding real-time spectrum-analysis concepts can be found in reference 2 at the bottom of this page.

The complete record of all captured information, known as a spectrogram, can be seen in the lower left-hand quadrant of Fig. 2. The x-axis shows frequency (across a 10-MHz span) while the y-axis shows time, measured over a period of 15 ms. The colors in the spectrogram represent the absolute amplitude of the signal, ranging from blue at –100 dBm to red at 0 dBm. It can be seen that the signal is on during nine bursts in the observation window for this test, with hopping taking place several times. It can also be seen from the three consecutive bursts on the same frequency that there is a slight frequency drift on each hop.

The spectrogram of Fig. 2 consists of several hundred frames of data. Any of these frames can be reprocessed in new domains by using one of the marker functions to select a frame for reprocessing. Figure 2 also shows a classical spectrum-analysis display, along with a time-versus-amplitude display in the upper right-hand frame. The start of the burst was selected for display, showing a rise time of approximately 35 μs. The lower left-hand display was processed to show deviation versus time. The noise at the beginning of the demodulated waveform indicates that no burst is present. As the amplitude of the burst stabilizes halfway through the time period, a deviation of approximately ±200 kHz can be seen.

The Bluetooth standard provides a low-cost method for electronic devices to interact over wireless links. The standard accommodates moderate-rate data transfers (to 721 kb/s assymetric and 185.6 kb/s symmetric).BT

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Editor's Note: This paper was originally presented at the Wireless Symposium/Portable By Design Fall Conference, New Orleans, LA, September 20-22, 1999.

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Transceiver

Vikas Vinayak, William O. Keese, and Christopher Lam
National Semiconductor, Wireless Communications, 2900 Semiconductor Dr., M/S D3-500, Santa Clara, CA 95052-8090; (408) 721-5000, FAX: (408) 721-3575, Internet: http://www.national.com.

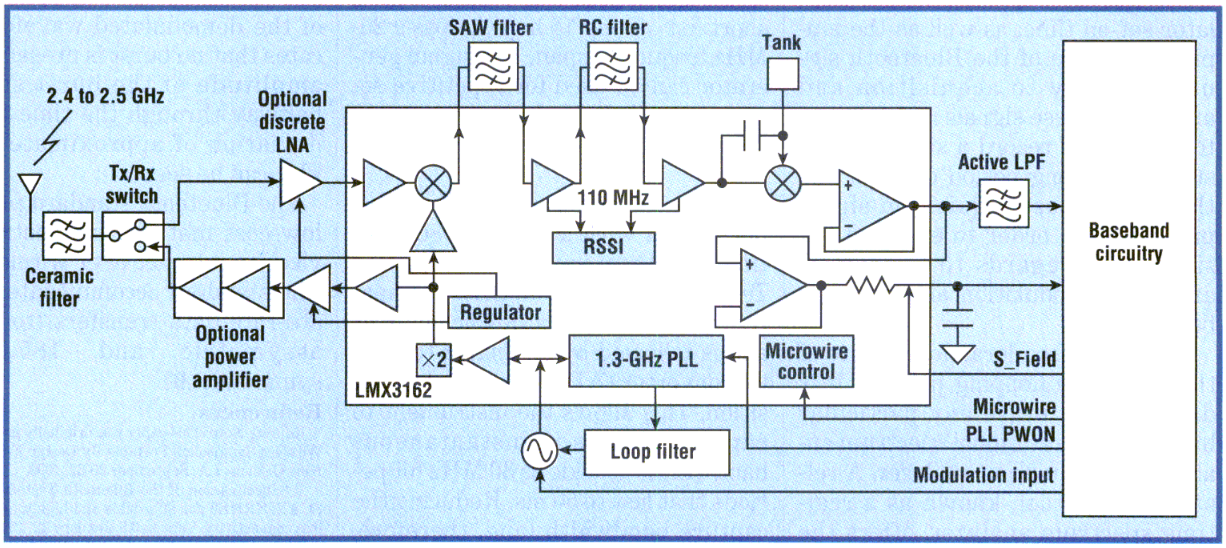
Transceiver Provides Bluetooth System Solution

Based on a multifunction transceiver IC, this receiver and transmitter circuit can meet the needs of Bluetooth and HomeRF designs for the next several years.

Effective radio designs for Bluetooth products begin with transceiver integrated circuits (ICs) such as the LMX3162 from National Semiconductor (Santa Clara, CA). Leveraging the company's proven phase-locked-loop (PLL) technology, the LMX3162 is suitable for low-power Bluetooth and HomeRF applications in the 2.4-GHz band. It was used as the core of an RF transceiver design capable of meeting the basic Bluetooth low-power specifications.

Introduced earlier in 1999 (see *Microwaves & RF*, April 1999, p. 138), the bipolar-complementary-metal-oxide-semiconductor (BiCMOS) LMX3162 radio transceiver was designed for low-cost frequency-modulation (FM) schemes such as Gaussian frequency-shift keying (GFSK).[1] A high tolerance to system nonlinearity supports decreased operating current and lower voltage headroom. In particular, the transmitter side of the radio benefits enormously. There is only a single frequency-modulated carrier which is insensitive to amplifier nonlinearities.[2,3] Noncoherent demodulation meets the bit-error-rate (BER) performance requirements of these protocols and translates to simpler receiver architectures at reduced cost.[4,5]

The full transceiver (Fig. 1) consists of the LMS3162 transceiver IC, a power amplifier (PA), voltage-controlled oscillator (VCO), voltage regulator, transmit/receive (Tx/Rx) switch, ceramic filter, and surface-acoustic-wave (SAW) filter. The LMX3162 BiCMOS IC[6] contains the PLL Tx and Rx functions. The 1.3-GHz PLL is shared between Tx and Rx sections. The transmitter portion of the LMX3162 includes a frequency doubler and high-frequency buffer and employs direct VCO modulation. The receiver portion consists of a 2.5-GHz low-noise down-converting mixer, an intermediate-frequency (IF) amplifier, a high-gain limiting amplifier, a frequency discriminator, a received-signal-strength indicator (RSSI), and an analog DC compensation loop. The receiver



1. This block diagram shows a complete Bluetooth transceiver based on the LMX3162 IC.

section has a single-conversion architecture and the received signal is demodulated by a quadrature discriminator.[7] The IC features an on-chip regulator to allow supply voltages ranging from +3.0 to +5.5 VDC.

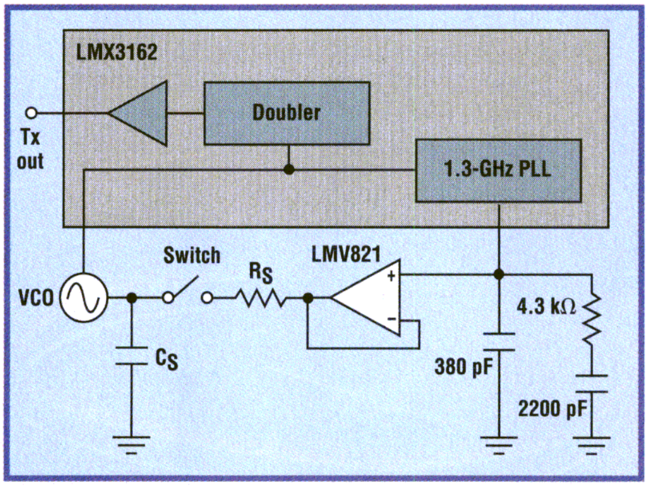
The ceramic filter is shared between the Tx and Rx sections, while the SAW filter provides the necessary IF selectivity. The RSSI output may be used for channel-quality monitoring and regulation of transmitted power, as required by HomeRF and Bluetooth specifications, respectively. The external regulator supplies the VCO and prevents frequency pulling. The Tx/Rx switch provides a path between the antenna and either the Tx or Rx section. The PA is implemented using a discrete bipolar transistor. An external VCO module provides the transceiver's local oscillator (LO) signals.

The transceiver's on-board PLL runs at one-half the frequency of the industrial-scientific-medical (ISM) band (2.4 to 2.5 GHz). An integrated frequency doubler synthesizes the required ISM-band frequencies. This architecture alleviates the disturbance to the LO when the PA is switched on. The radiation is isolated by offsetting the PA output frequency from the LO frequency.

The PLL is shared between the Tx and Rx sections, since HomeRF, Bluetooth, and upbanded DECT are half-duplex time-division-multiple-access (TDMA) systems, with data transmitted and received in different time slots. The length of time is determined by the particular protocol. The PLL must be able to hop to a desired carrier frequency in a particular amount of time (the lock time) before data transmission and reception can begin. The lock time is defined as the time the PLL takes to settle down to an acceptable frequency error.

To improve performance as well as reduce the cost of implementation, the transceiver transmits and receives data in the open-loop mode.[8] The PLL is first locked at the desired carrier frequency and then shut down during data transmission or reception. In this short duration, the VCO is subsequently modulated by the baseband signal in Tx mode or idling in Rx mode. There are two concerns with the open-loop mode of operation.

The first issue is VCO drift as the loop capacitors discharge or charge (due to the leakage currents associated with the PLL's charge pump and the VCO's varactor diode). This implies that the VCO's drift must be negligible compared to the carrier frequency. To achieve low-frequency drift of less than 50 kHz in 25 ns at the upper end of the operating temperature range, a large capacitor is mandated. This modification limits the loop bandwidth and increases the lock time substantially. This situation is particularly demanding for HomeRF applications. The lock time requirement is 134 µs, while the open-loop Tx time is 20 ms. Additional circuitry is required to improve the current leakage without sacrificing the loop bandwidth.



2. This low-drift PLL circuitry maintains the transceiver's frequency-stability performance.

To resolve this issue, a unity-gain opamp, a CMOS sampling switch, and a low-leakage capacitor are employed between the loop filter and the control line of the VCO (Fig. 2). This configuration handles the lock-time and current-leakage requirements by using different values of capacitors. With this implementation, a small capacitor in the loop filter is used to provide loop bandwidth and phase margin to achieve the required lock time while a large capacitor at the control line of the VCO reduced the frequency drift. The unity-gain opamp duplicates the information (voltage) stored to the low-leakage capacitor (the large capacitor) while the PLL is in lock mode. In open-loop mode, the CMOS sampling switch is used to suspend the operation of the opamp with sufficient isolation of the capacitors. Once the PLL is closed, the switch resumes sampling.

The maximum dwell time for Bluetooth is 11.25 ms, in the scan mode during which the transceiver is receiving only. Frequency drift can be avoided without additional circuitry by using the PLL in closed-loop mode while receiving data. This may degrade the BER by a decibel or two, which is acceptable because the transceiver easily meets Bluetooth's minimum sensitivity requirements.

The second issue with open-loop modulation is subtle. The VCO's phase noise can be thought of in the time domain as cycle-to-cycle jitter in the instantaneous frequency. At the instant the loop is opened, the instantaneous frequency of the VCO shows a random fluctuation due to the phase noise, and this must be included in any error-budget calculations of transmitter accuracy. This indicates that the phase noise is an important design criterion for open-loop modulation. The phase noise of the PLL must be minimized, even though the loop is unlocked during transmission and reception. Conventional techniques for noise reduction must be employed, such as low-phase-noise crystal oscillators and good grounding and filtering techniques to reduce the noise spikes coming from the digital part of the radio.

A Tx signal is generated on the radio by simple frequency modulation of the VCO. A shaped baseband is applied directly to the loop filter or the modulation port of the VCO. The VCO module chosen for the Bluetooth radio, the model URAE8X630A from Alps, has a modulation port connected to the VCO's internal varactor diode through a series capacitor separate from the tuning-voltage input port.[9] The amplitude of the signal generated by the baseband processor is adjusted by a resistive divider to obtain the desired frequency deviation.

In the Bluetooth transceiver, the output of the VCO is fed to the LMX3162, where its frequency is doubled and is also used as the PLL input. The frequency-doubled signal is

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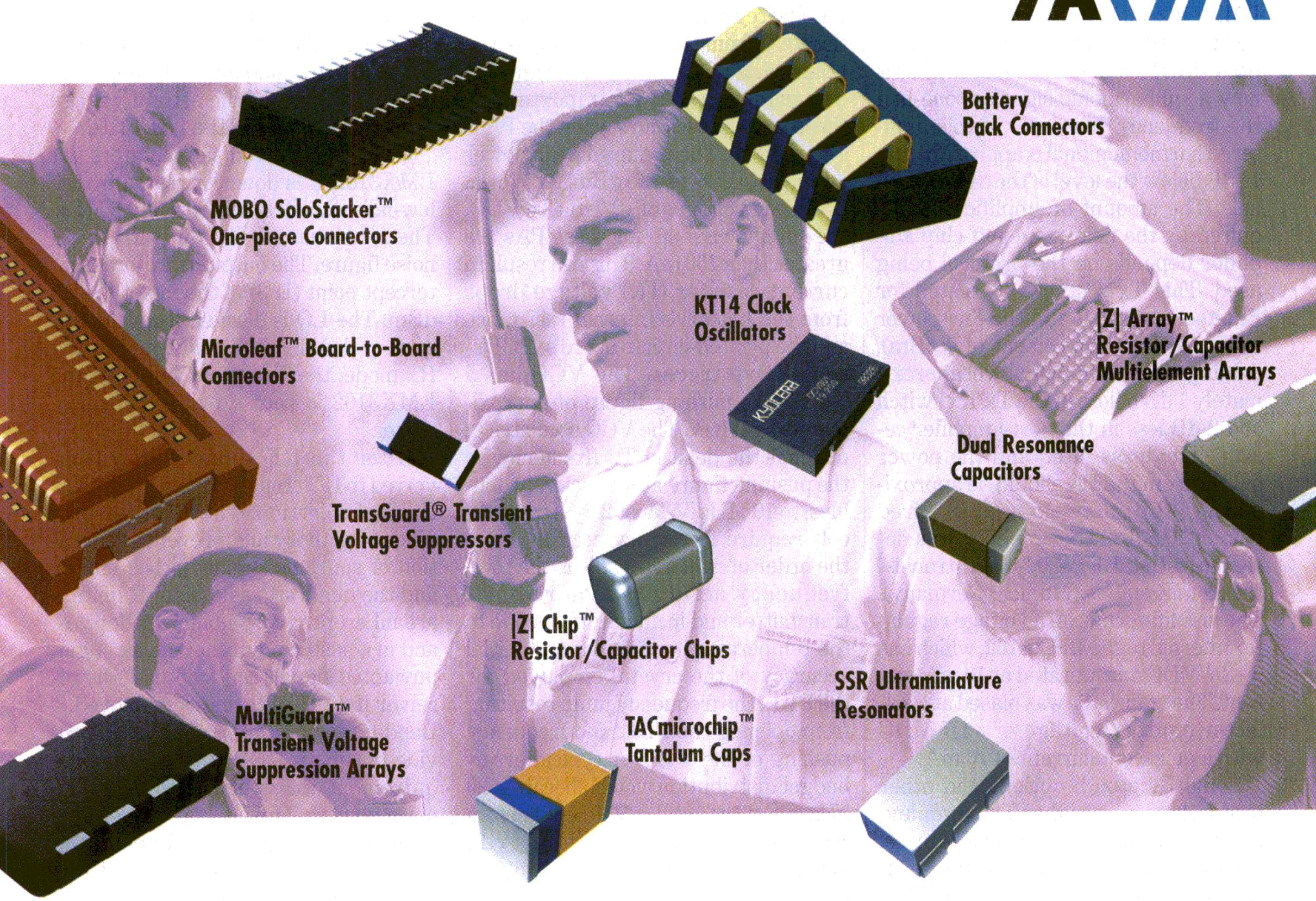

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then buffered and is output from the LMX3162 at −7.5 dBm. This signal needs to be screened through a high-pass filter to reduce the level of what is now a subharmonic signal at one-half the frequency. The level of this unfiltered harmonic signal is approximately 11 dB below the level of the desired signals. The amount of amplification required by the next-stage, off-chip amplifier depends on the protocol being used. This Tx section was tested for Bluetooth operation in the low-power mode (with a requirement of 0 dBm). Adding to this minimum level approximately 1 dB of loss in the Tx/Rx switch and 2-dB loss in the post-amplifier ceramic bandpass filter, and the power output from the PA should be approximately +3 dBm, yielding a required gain of 10.5 dB. The amplifier was designed with a BFP420 bipolar transistor from Siemens (Munich, Germany). The amplifier runs off a voltage regulator internal to the LMX3162, which has a +2.7-VDC output rated at 10 mA current. The transistor was biased at a collector-emitter voltage of +1.7 VDC with a quiescent current of 10 mA.

Some Bluetooth options and other protocols require higher Tx power levels, in the range of +20 dBm and more. This mandates the use of high-efficiency PAs, such as the model ITT2302 from ITT GaAsTEK (Roanoke, VA) for upbanded Digital European Cordless Telecommunications (DECT) and the same company's model ITT2304 for Bluetooth and HomeRF.[10] These amplifiers connect directly to the −7.5-dBm output of the LMX3162, and also offer an on-board Tx/Rx switch, 14-dB gain low-noise amplifier (LNA), and +3.6-VDC operation. The BFP420-based PA is not required when using the ITT2304.

After power amplification, the Tx signal is filtered to remove all harmonics and subharmonic components of the carrier signal, as required by Bluetooth protocol and regulatory organizations, such as the Federal Communications Commission (FCC). The protocol determines the acceptable level of spurious content. A two-stage ceramic filter was chosen for this purpose, a model DFC22R44P084LHA from Murata Electronics (Smyrna, GA). The filter has a 3-dB bandwidth of 84 MHz centered at 2.442 GHz and typical insertion loss of 2 dB.[11]

The VCO gets its power supply from an external low-noise voltage regulator. The regulator isolates the supply to the VCO from the power supply to the other parts of the radio and from various transients. Most important of these transients occurs when the PA is switched on. The required peak power can be in excess of +20 dBm. At typical operating voltages of +2.7 to +3.6 VDC, the supply currents for these PAs are greater than 150 mA. This can result in current-resistor (IR) voltage drops from the battery's internal resistance and the printed-circuit-board's (PCB's) conductive traces. The VCO has a worst-case pushing figure of approximately 5 MHz/V. The VCO oscillates at one-half the desired Tx frequency, so the pushing figure also effectively doubles, to 10 MHz/V. Most 2.4-GHz protocols require frequency accuracies on the order of ±50 kHz. This is the total frequency accuracy required of a transmitter and includes effects due to the temperature coefficient and initial accuracy of the crystal employed for the PLL; the frequency jump resulting from opening the PLL; and frequency pushing of the VCO. A typical error-budget distribution would allocate ±20 kHz out of the total ±50 kHz to errors caused by pushing. Dividing this by 10 MHz/V, the allowed noise on the power-supply pin of the VCO is ±2 mV. Now consider the connection of the battery to the PA and the VCO, and that the two traces have 2 cm in common. Assuming 35-μm-thick copper (Cu) traces that are 12 mils wide, the series resistance of the trace comes to approximately 22 mΩ, assuming resistivity of 20 nΩ/m for Cu. The internal resistance of a typical nickel-metal-hydride (NiMH) battery used in cellular handsets is approximately 0.25 Ω. The total series resistance becomes 0.272 Ω and the IR drop computes to 40.8 mV, which is in excess of what is allowed. The voltage regulator shields the VCO from all such switching events.

A ceramic filter selects the desired frequency band received by the antenna. The LMX3162 processes the received signals at an IF of 110.5 MHz and the LO is chosen to be 110.5 MHz below the RF input signal. The ceramic filter rejects the image frequency 221 MHz below the RF input while also removing or attenuating out-of-band blockers.

While the transceiver meets the BER requirements of Bluetooth and HomeRF, some applications require the use of an external LNA. An LNA built using the BFP420 transistor can achieve 13-dB gain and 2-dB noise figure. It can run off the second voltage regulator internal to the LMX3162.

Once the received signal enters the LMX3162, it is downconverted by the low-noise 2.5-GHz mixer to 110.5 MHz. The mixer has 17-dB gain with 11-dB noise figure. The output third-order intercept point (IP3) of the mixer is +7.5 dBm. The LO is derived from the frequency doubler internally, and in the Rx mode, the Tx output buffer of the LMX3162 is shut down to conserve power.

After the RF signal is downconverted to IF, it must be band limited for channel selection. The IF filter provides selectivity and prevents generation of spurious signals in the limiter and the quadrature detector. Limiters are inherently very nonlinear devices, and in a hostile environment, stronger, unwanted signals can "capture" the receiver if no IF filtering is employed.[12] Band-limiting is also required to provide optimum BER, the primary requirement for which is to limit the noise power as much as possible. This filtering can be performed before the quadrature detector and after it. However, it is a known fact that discriminators have nonlinear performance with respect to the input signal-to-noise ratio (SNR).[13] This is called the threshold effect. The discriminator needs to see an SNR that is above a certain threshold, otherwise its performance degrades rapidly. Thus, the IF signal must be filtered early in the receiver chain.

In the radio, the IF filter is implemented by a low-cost commercial DECT SAW filter, the SAFU110.6MSA40T from Murata Electronics. The filter is centered at 110.6 MHz, with a 3-dB bandwidth of 1.5 MHz. The minimum insertion loss is approximately 3 dB. The SAW filter is matched to the LMX3162 using two inductors and two capacitors. As the market for 2.4-GHz products increases, SAW filters that have been designed specifically for these protocols will be made available by various vendors and improve the performance of these radios. After the initial filtering, the IF signal is amplified by the IF amplifier and fed to the IF limiter. A resistor and two capacitors provide some filtering.

The LMS3162 demodulates the IF signal by quadrature demodulation.[7] The phase-shifting tank consists of a capacitor, an inductor, and a varactor diode. The varactor diode is used to tune the tank circuit, along with its associated parasitic elements, to exactly 110.5 MHz. The voltage at the output of the quadrature discriminator is measured by the baseband controller's ADC and compared to a reference. The generated error signal is amplified and converted back to an analog signal by using a digital-to-analog converter (DAC).

Using elements with different quality factors (Qs) and values can change the Q of the tank. Higher Qs mean a narrower bandwidth and greater sensitivity. This translates to better SNR and greater ISI.[14,15] Conversely, lower Qs result in slightly lower SNR and lesser ISI. The LMX3162 has an internal 1-pF quadrature shift capacitor.

Once the signal has been demodulated, it is passed through an active lowpass filter. This limits the noise bandwidth of the system and provides larger peak-to-peak voltage output.

The LMX3162 provides a feature that eliminates the effect of any initial frequency offset between the transmitter and the receiver. Most RF protocols have an initial synchronization field during which a string of alternating digital 1s and 0s is transmitted. During this time, the demodulated signal is well known and its average represents the nominal center frequency of the transmitter. This average level can be captured by a sample-and-hold circuit and used as a reference level for a data-slicing comparator, which converts the demodulated signal into logic-level 0s and 1s. The LMX3162 features an on-board sample-and-hold circuit for this purpose. An internal resistor of 3 kΩ and external capacitor together provide the averaging time constant. The sample-and-hold action is controlled by the LMX3162's S_Field input.

The transceiver achieves a BER of 10^{-3} for a Bluetooth modulated signal at an input power of −83 dBm, with the received signal being offset by the ±115-kHz frequency offset allowed by Bluetooth. This measurement was performed on the transceiver without an LNA and using the low-cost DECT SAW filter. This performance easily meets the Bluetooth minimum-sensitivity requirement of −70 dBm. With the use of a high-performance LNA and a SAW filter optimized for the application, sensitivity of −96 dBm can be expected.

The Bluetooth and HomeRF specifications require frequency accuracies of ±75 and ±120 kHz, respectively. The transmitter must be within this limit and the receiver must be able to operate with these frequency offsets.

The maximum operating temperature in the Bluetooth specifications is +35°C ambient. Adding to this 10° due to the self-heating of the product, the drift specification must be met at +45°C. This is 20° above room temperature, and quadruples the leakage current to 220 pA. The maximum continuous Tx time for Bluetooth is five slots or 3.125 ms. Bluetooth has a channel spacing of 1 MHz, but the IF of the radio is at 110.5 MHz. This means that the LO must be synthesized with a frequency resolution of 0.5 MHz. The PLL output is doubled in frequency and this halves the resolution requires from the PLL to 0.25 MHz. For 0.25-MHz frequency resolution, the phase-comparison frequency that must be used is 0.25 MHz. The lock-time requirement for Bluetooth is 220 µs, and budgeting for margins and programming time reduces this to 180 µs. To achieve a lock time of less than 180 µs with a phase-comparison frequency of 0.25 MHz requires a total loop-filter capacitance of approximately 5 nF. Using this value, the frequency drift on account of leakage is calculated as:

$$\Delta f = I_{leakage}\,\Delta t K = I_{VCO}/C$$

The drift in 3.125 ms is approximately 20 kHz which meets the Bluetooth requirement of 40 kHz.

The lock and drift requirements of HomeRF are demanding. The Alps VCO employed in the transceiver has a tuning sensitivity, K_{VCO}, of 140 MHz/V at 2.4 GHz. A phase-detector comparison frequency of 250 kHz was used, as well as a second-order loop filter, with a loop bandwidth of 40 kHz and phase margin of 50 deg. The lock time is measured from the falling edge of signal that shuts down the PLL to 1225 MHz (or 2450 MHz at the Tx-output port) within 5 kHz of the final frequency (or 10 kHz at the Tx-output port). The lock time is 111 µs.

The frequency drift due to the current leakage is measured starting from the rising edge of the PLL, PLL_PD. The low drift of 778 Hz/ms at +85°C is much better than what is required for HomeRF.

In a test for co-channel interference (CCI), the radio met a BER of 10^{-3} for a CCI that is 11 dB below a designed input signal at levels as low as −80 dBm. At the specified desired signal level of −60 dBm, the radio even meets the BER for a CCI that is only 6 dB. For Bluetooth's first three years, the CCI requirements are somewhat relaxed, allowing radios to meet a CCI specification of 14 dB, a level at which the LCM3162 performs well to −83-dBm sensitivity.

For adjacent-channel-interference (ACI) requirements, a Bluetooth radio must perform at a BER of 10^{-3} with an undesired signal interfering at a 1-MHz offset. The desired signal must be at the same level as the interference signal, both specified at −60 dBm. The three-year relaxed specification for the 1-MHz test is an ACI that is 4 dB below the desired signal (which the LMX3162 radio meets). The low-cost, off-the-shelf SAW filter selected for the radio has a 3-dB bandwidth of 1.5 MHz and is wider than that required for Bluetooth. The LMX3162-based radio meets the 2-MHz ACI specification for levels from −81 to −30 dBm. When evaluated for a Bluetooth ACI at a 3-MHz offset frequency, the LMX3162-based radio meets the specification from −72 to −35 dBm. BT

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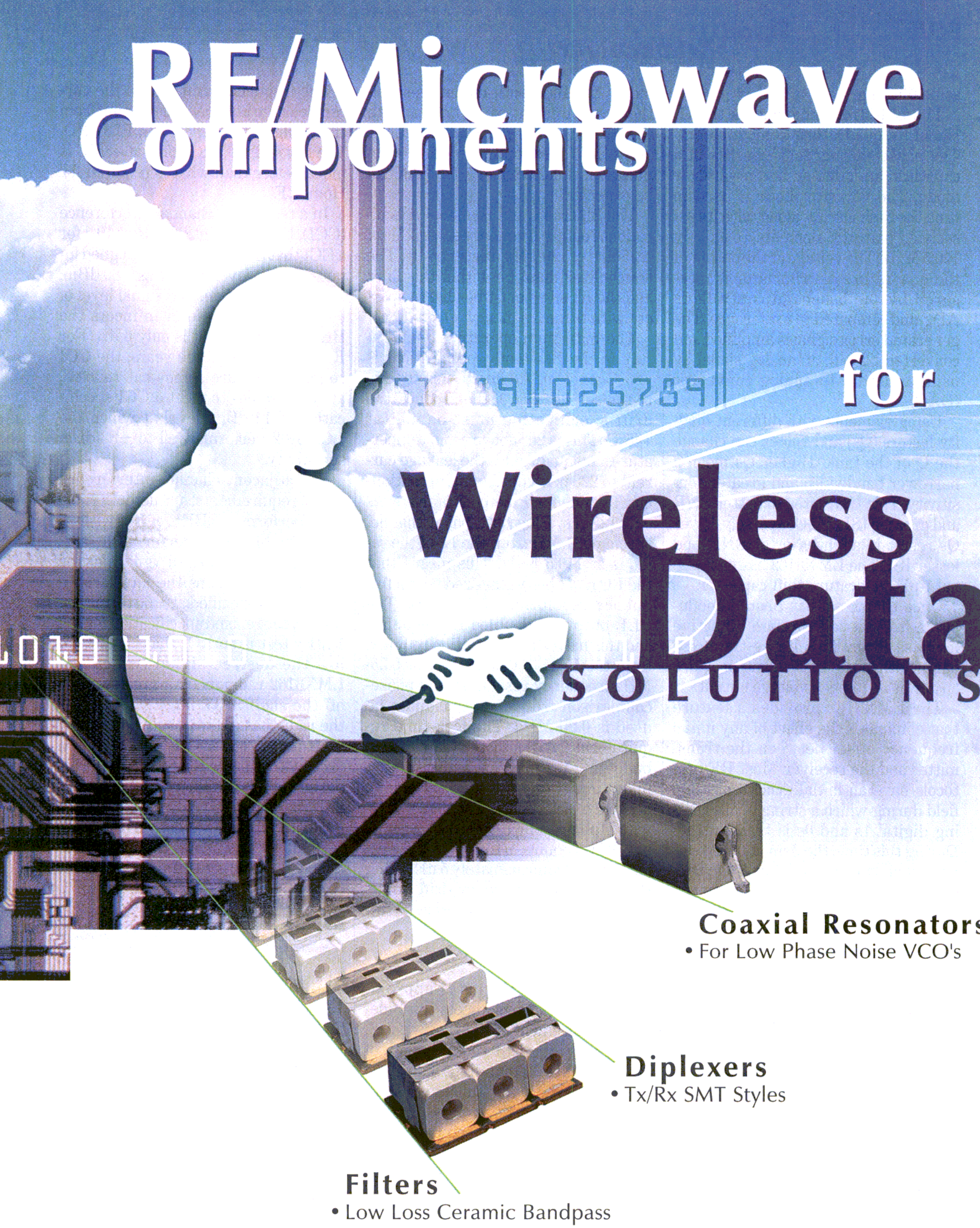
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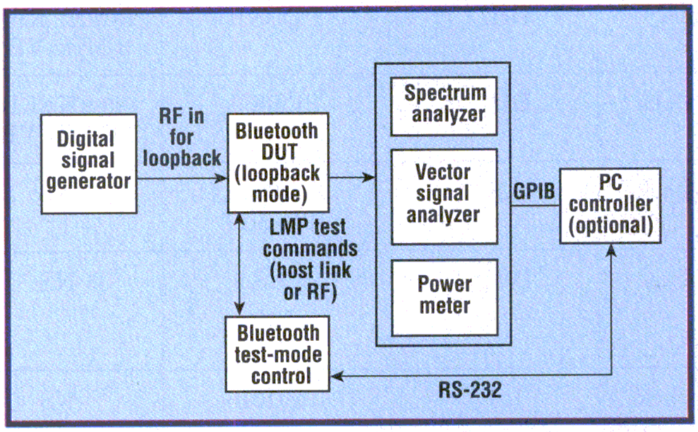
Perform Bluetooth RF Measurements

A good understanding of Bluetooth transmitter and receiver requirements can be converted into useful techniques for measuring designs and prototype devices.

Measurement solutions for Bluetooth must properly exercise the transmitter and receiver sections of a device under test (DUT). These solutions are made more complex by the fact that Bluetooth employs signals that are a sequence of time-division-duplex (TDD) bursts, as well as frequency hopping. But solutions are readily available, based on commercial test equipment and meeting the requirements of established Bluetooth specifications.[1]

Bluetooth systems operate in the 2.4-GHz industrial-scientific-medical (ISM) band using spread-spectrum (frequency-hopping) techniques. Variations in the basic frequency range exist in Japan, Spain, and France, relative to the rest of Europe and the US as different power classes are used for different operating ranges, but many of the principles presented here for Bluetooth measurements can be applied to the different international versions of Bluetooth receivers and transmitters.[2] The reader may note some minor deviations from the test procedures which are a result of the recent churn in the Bluetooth RF test specification as it solidifies to its final version.

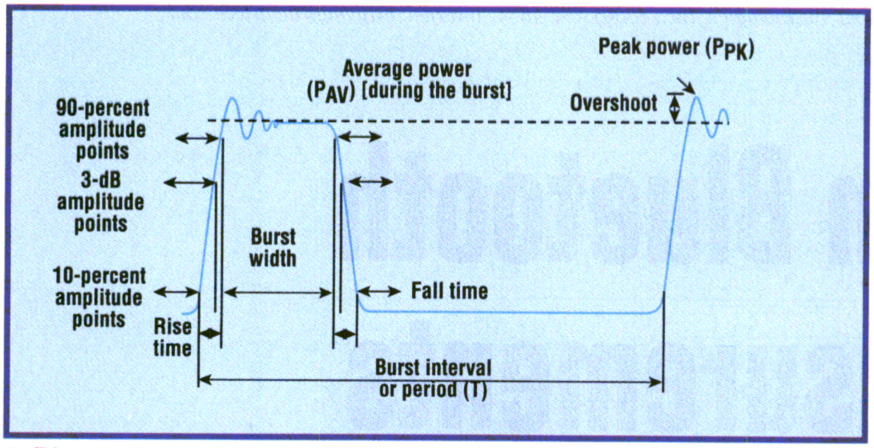
Different measurements are made for Bluetooth transmitter and receiver testing.[3] Figure 1 shows a transmitter measurement setup with a Bluetooth DUT placed in a loopback mode as a slave (rather than a master) unit. As a slave, it must generate its burst timing by receiving poll packets from the test-signal generator. In this way, a signal from the digital-signal generator can be transmitted into the DUT's receiver and looped back through its transmitter for analysis. The Bluetooth DUT's test mode is controlled either by protocol sent over an RF connection or by direct digital control—either method requires a Bluetooth test-mode control. Since cable losses and impedance mismatches within the Bluetooth band can be severe, good-quality interconnections and components should be used as part of the test setup.



1. This measurement setup is suitable for evaluating the performance of Bluetooth transmitters. If a direct cable connection is not available between the Bluetooth DUT and the test equipment, a coupling device (such as an antenna) is needed.

If a direct cable connection is not possible between a Bluetooth DUT and the measurement equipment, a coupling device, such as an antenna, is necessary. The path loss between the antenna and test equipment should be included in the calculations. Table 1 provides a summary of the test parameters required for Bluetooth transmitter tests.

Since Bluetooth signals are a sequence of TDD bursts, triggering is critical. To obtain a viewable signal, triggering should occur on the rising edge of the signal envelope. Frequency hopping adds a further degree of difficulty to Bluetooth transmitter-signal analysis. While frequency hopping is essential to the



2. Bluetooth output-power measurements are performed in the time domain, based on these pulsed-signal characteristics.

operation of a Bluetooth device, it is not necessary for parametric testing. To reduce the number of variables and identify individual performance characteristics, frequency hopping can be turned off for a number of tests. However, the transmit (Tx) and receive (Rx) channels can be set at the extreme ends of the band, forcing the Bluetooth DUT's voltage-controlled oscillator (VCO) to switch frequency.

Three different types of payload data are called out for in different test cases—PRBS9, 10101010, and 11110000 data sequences. Each pattern provides different stress mechanisms and is chosen for each measurement. PRBS9 is a pseudo-random-bit sequence of period $2^9 - 1$ that is intended to simulate live traffic. It produces a modulated signal with a spectral distribution approximating that of a real signal. The 10101010 pattern provides an additional test for the modulation filter. It also changes the spectral shape of the transmitter output. The 11110000 pattern enables a check of Gaussian filtering. After a series of four ones or zeros, the output should have reached a fully settled condition.

Either a spectrum analyzer or a vector signal analyzer (VSA) can be used for many Bluetooth transmitter measurements. VSAs differ from traditional spectrum analyzers in that they can capture the magnitude and phase of a signal. A VSA can be useful for a wide selection of measurements in the time, frequency, and modulation domains (changes of frequency as a function of time).

Transmitter Testing

RF transmitter power measurements include average power in a burst, peak power, power density, and power control. Power level is a critical parameter is a digital communications system. These tests help to ensure that power levels are high enough to maintain links, yet low

Table 1: Bluetooth transmitter test parameters

Transmitter test	Frequency hopping	Test mode	Packet type	Payload data	Measurement bandwidth
Output power (Average peak)	On	Loopback	LS	PRBS 9	3-MHz RBW, 3-MHz VBW
Power density	On	Loopback	LS	PRBS 9	100-kHz RBW, 100-kHz VBW
Power control	Off	Loopback	DH1	PRBS 9	3-MHz RBW, 3-MHz VBW
Transmit output spectrum	Off	Loopback	DH1	PRBS 9	100-kHz RBW, 300-kHz VBW
Modulation characteristics	Off	Loopback	LS	11110000, 10101010	NS
Initial carrier frequency tolerance	On and off	Loopback	DH1	PRBS 9	NS
Carrier frequency drift	On and off	Loopback	LS	10101010	NS
Burst profile	Off	Loopback	NS	NS	

Notes: LS = longest supported; NS = not specified.

enough to minimize interference within the ISM band and to maximize battery life.

Output-power measurements are performed in the time domain using the appropriate signal analyzer. Average power is measured over at least 20 to 80 percent of the duration of a signal burst (Fig. 2). The duration of the burst (the burst width) is the time between the leading and trailing 3-dB points compared to the average power (which is also measured with the signal analyzer). In addition to measuring average power, signal analyzers allow the user to view other meaningful data, such as transient events. Using a swept-tuned spectrum analyzer, the signal envelope of a burst can be viewed in the time domain by setting the frequency span to zero. External triggering can be used to capture a burst-mode signal. The number of periods displayed is controlled by the sweep time. Using the analyzer's peak-detector mode, the peak-power level can be measured by setting the trace to max hold and using the peak-search function. The average power of a burst can also be determined by analyzing the trace data. The test must be repeated for all frequency channels.

Average and peak power are similarly measured with a VSA. VSAs provide a triggering delay feature to support viewing of a burst signal prior to the trigger point. VSAs also provide an average or mean power function to automatically determine the average power (Fig. 3). The sweep time and the trigger delay are adjusted to measure the average power of the burst, while avoiding the rising and falling edges. The results are expressed in equivalent isotropically radiated power (EIRP). Since EIRP is a measure of the radiated power of the system, this measurement includes the effects of the transmitter, cable loss, and antenna gain. When performing tests that use direct port-to-port connections, the gain of the antenna must be added to all measurements to ensure that the overall system will not exceed the DUT's power-output specifications.

The power-density measurement provides the peak power density in a 100-kHz bandwidth. The measurement starts with the signal analyzer in the frequency domain, a center frequency in the middle of the Bluetooth frequency band, and a span that is wide enough to view the complete band. The analyzer's resolution bandwidth is set to 100 kHz. A one-minute signal sweep is performed with the trace in max hold with peak detection. The peak value of the trace is found—this frequency becomes the analyzer's new center frequency (Fig. 4a).

For the second part of the measurement, the analyzer is changed to the time domain (zero span) and a single one-minute sweep is performed (Fig. 4b). The power density is calculated as the average of the trace. This calculation may be performed on a spectrum analyzer by analyzing the trace data and averaging the results. A VSA can also determine the mean power of the trace.

Power-control tests allow testing or calibration to be performed on the level-control circuitry in those Bluetooth devices that support power control. Power control is performed in the same manner as average power measurements, but at three discrete frequency channels. The power-control test verifies power levels and power-control step sizes to ensure that they are within the specified range.

The transmit-output spectrum measurement analyzes the power levels in the frequency domain to ensure that out-of-channel emissions are minimized. This helps reduce overall system interference and ensure regulatory compliance. The three-part measurement checks that the operating frequency range is within limits at the −80-dBm/Hz points. It also checks the bandwidth at the −20-dB points to ensure that it is less than or equal to 1.1 MHz. Lastly, it provides a mask for adjacent-channel power requirements.

Figure 5 shows an output spectrum display of a Bluetooth signal with a +5-dBm carrier in swept mode. The span is set to 10 MHz. A low-noise signal generator was used to produce the spectrum display—

the noise levels from a Bluetooth DUT would typically be higher.

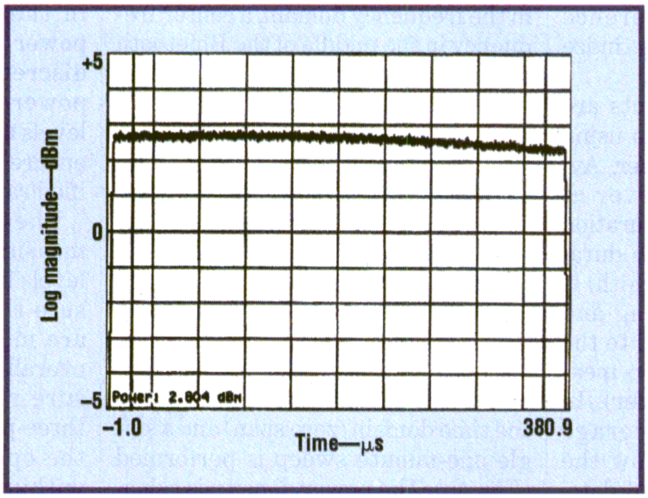
The output spectrum provides a combined view of the effects of modulation and power switching. Overlaps may occur, but failures at offsets greater than 500 kHz from the carrier frequency are likely due to switching transients. This can be confirmed by comparing the output-spectrum plots with the burst profile for a particular Bluetooth DUT.

Unlike some other time-division systems, such as Global System for Mobile Communications (GSM) and Digital European Cordless Telecommunications (DECT), which have gated and non-gated measurements, Bluetooth's output-spectrum measurement is not gated. Spectrum measurements should capture the entire period for a burst, as well as the space between bursts to include modulation and transient effects.

Bluetooth-modulation measurements include evaluations of modulation characteristics, initial carrier-frequency tolerance, and the amount of carrier-frequency drift. Modulation measurements reflect the performance of the modulator circuitry as well as the stability of the local oscillator (LO). The modulator and the VCO may be affected by digital noise on the power supply or by transmit power bursts. Verification of modulation characteristics requires the ability to demodulate the Bluetooth signal so that the frequency of each bit can be determined.

A test of modulation characteristics is actually a frequency-deviation measurement. For modulation characteristics, two sets of a repeating 8-b sequence are used in the payload sequence—00001111 and 01010101. The combination of the two sequences is used to check the modulator performance and the premodulation filtering.

If a VSA is used to demodulate the signal, phase and symbol information are maintained. The frequencies of each bit in the 8-b sequence are measured and averaged together. Then, the maximum deviation from the average for each of the 8-b sequences is computed. The maximum deviations and the average of the maximum deviations are used in the result. This procedure is performed for the 00001111 payload sequence over a period of at least 10 packets. This process is then repeated with the 01010101 payload sequence. Due to the numerous data points, this test lends itself to software control.



3. This display of average and peak power was made with an HP 89441A VSA at 2.402 GHz using a sweep time of 380 µs.

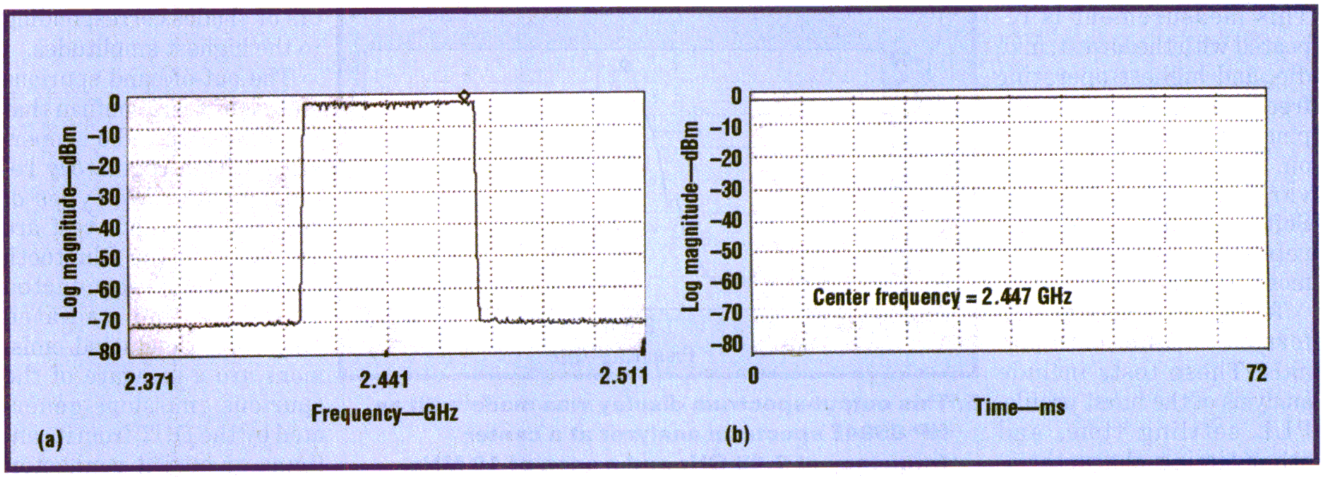
Modulation Quality

Modulation quality can also be evaluated with a VSA. Modulation-quality measurements, such as frequency-shift-keying (FSK) error, magnitude error, and eye diagrams, which are not a direct part of the Bluetooth specifications, can provide invaluable troubleshooting tools.

The initial carrier-frequency tolerance test verifies the accuracy of the transmitter's carrier frequency. A standard DH1 packet with a preamble, and with pseudorandom bit sequence (PRBS) as payload, is used. The initial 4 b of a packet, the preamble bits, are analyzed to determine the extent of the frequency deviation from center frequency. This measurement requires the signal to be

Table 2: Receiver test parameters

Test	Frequency hopping	Test mode	Packet type	Payload data	BER (percentage)
Sensitivity Single slot	Off On (optional)	Loopback	DH1	PRBS 9	0.1
Multislot	Off On (optional)	Loopback	DH5 (DH3)	PRBS 9	0.1
C/I	Off	Loopback	Longest supported	PRBS 9	0.1
Blocking	Off	Loopback	DH1	PRBS 9	0.1
Intermodulation	Off	Loopback	DH1	PRBS 9	0.1
Maximum input	Off	Loopback	DH1	PRBS 9	0.1



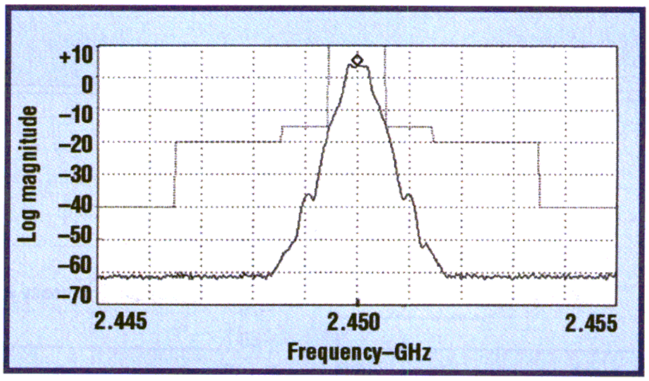
4. These displays of power density were made with an HP 8594E spectrum analyzer at a center frequency of 2.441 GHz and span of 240 MHz (a) and center frequency of 2.477 GHz and span of 0 Hz (b).

demodulated to measure the frequency deviation of each symbol. After demodulation, the frequency offset of each of the preamble bits is measured and averaged. When performing this measurement, the analyzer's frequency span should be wide enough to provide proper demodulation of the wide-bandwidth Bluetooth signal (Fig. 6). Any spectrum-analyzer function that provides autocorrection of the center frequency must also be disabled during this measurement. The Bluetooth specification requires that this measurement be performed with frequency hopping on and off. In either case, the analyzer is set to one frequency channel. When hopping is on, there will be an additional effect of slew as the transmitter quickly jumps from one frequency to the next. The slew may be noticed in the initial carrier-frequency offset as the carrier frequency settles. The additional stress from hopping will help to identify amplifier-response problems.

A more convenient method of measuring the initial carrier-frequency tolerance is available with the HP 89441A VSA in demodulation mode. With its result length set to the minimum number of symbols (10), the analyzer provides the carrier offset in its symbol-error display. Since this minimum number of symbols is greater than 4, the user may notice less variation in the result due to noise. It is important that the 0101 pattern continue.

Carrier-frequency drift is also measured as a demodulated signal using a VSA. The payload data consist of a repeating 4-b 1010 sequence. To perform this measurement, the absolute frequencies of the four preamble bits are measured and integrated to provide the initial carrier frequency. Then, the absolute frequencies of each successive 4-b part in the payload are measured and integrated. The resulting frequency drift is the difference between the average frequency of the four preamble bits and the average frequency of any four bits in the payload field. The maximum drift rate can also be checked, and is defined as the difference between any two adjacent 4-b groups within the payload field.

This measurement is repeated with the lowest, middle, and highest operating frequencies, first with hopping off, then with hopping on. It is also repeated for varying packet lengths. Software control makes this repetitive measurement more straightforward.



5. This output-spectrum display was made with an HP 8594E spectrum analyzer at a center frequency of 2.45 GHz and a span of 10 MHz.

Tuning tests may be performed on Bluetooth signals. These tests include analysis of the burst profile, PLL settling time, and other timing characteristics. While not part of the Bluetooth specifications, these tests can help engineers ensure that their designs meet the criteria of the specifications.

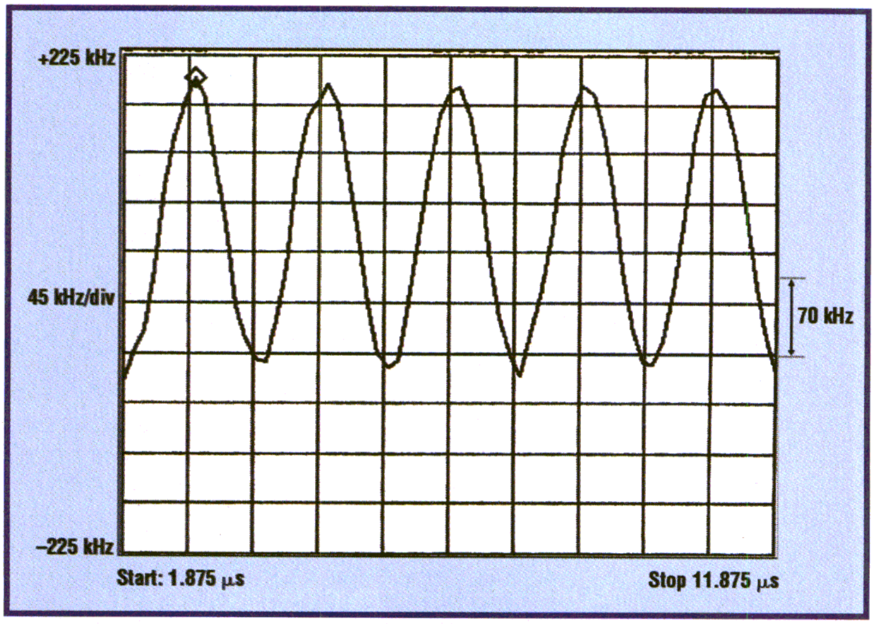
Burst rise and fall times can be measured in the time domain using a signal analyzer. No definitions for rise and fall time have been developed for Bluetooth. The conventional industry definition of rise time is the time required for a pulse signal to rise from its 10-percent amplitude point (−20 dB) to its 90-percent amplitude point (−0.9 dB). The fall time is defined with the same amplitude points, but in reverse. The DECT standard (which is similar to Bluetooth) defines rise and fall times somewhat differently, with the rise time from the −30-to −3-dB amplitude points and the fall time from the −6- to −30-dB amplitude points. Pretriggering allows the rise time to be easily captured and measured. There is no defined mask test for the burst profile. Some devices may exhibit faster transients than these definitions, but excessive fast switching will cause failures in the output spectrum test by creating increased spectrum spreading due to the sharper edges of the burst.

A VSA can be used to create spectrogram displays that illustrate characteristics such as PLL settling time at turn on. The spectrogram displays frequency on the x-axis and time on the y-axis. Amplitude is shown through different colors or shades of gray with the brightest colors or shades corresponding to the highest amplitudes.

The out-of-band spurious emissions tests confirm that the Bluetooth radio is operating within regulatory requirements. Two types of spurious emissions test are identified in the Bluetooth specifications—conducted emissions and radiated emissions. Conducted emissions are a measure of the spurious emissions generated by the DUT from its antenna or output connector. Radiated emissions are a measure of the spurious emissions leakage from the cabinet of the DUT.

Separate standards are specified for these tests in the US and in Europe. The US follows the Federal Communications Commission (FCC) Part 15.247 standard while Europe follows the European Technical Standards Institute (ETSI) ETS 300 328 standard.

Spurious emissions tests are performed using a spectrum analyzer to sweep through frequency ranges looking for spurious signals. Specifications for spurious emissions are provided in the Bluetooth RF Test Specifications.[1] The ETSI standard requires a spectrum-analyzer frequency range to 12.75 GHz while the FCC standard specifies a frequency range to 25 GHz. Tests requiring compliance to the International Special Committee on Radio Interference (CISPR) publication 16 may require EMC spectrum analyzers with quasi-peak detection capability.

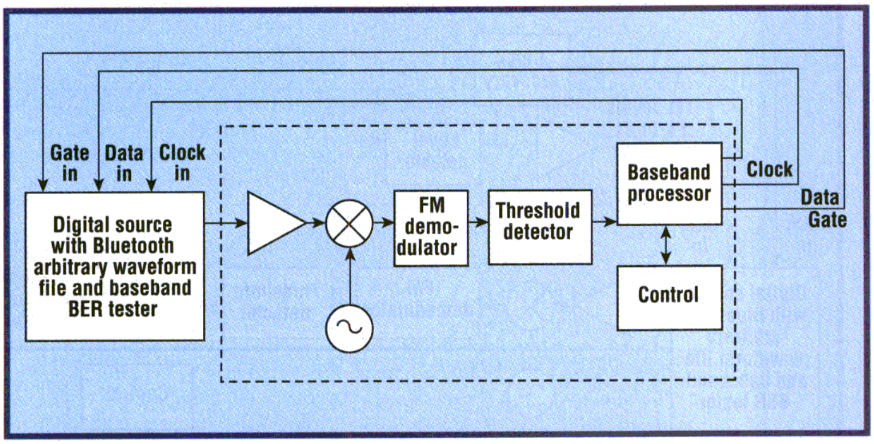


6. An HP 89441A VSA was used to produce this display of initial carrier frequency tolerance for an offset frequency of 70 kHz from a center frequency of 2.45 GHz.

Receiver Measurements

Receiver measurements specified for Bluetooth include the following: sensitivity using single-slot data packets, sensitivity using multiple-slot data packets, carrier-to-interference (C/I) performance, blocking performance, intermodulation (IM) performance, and maximum input level. Bluetooth receiver performance is evaluated in terms of bit-error rate (BER). Table 2 offers a summary of the test parameters for Bluetooth receiver tests.

Sensitivity is tested by sending various impaired signals to the receiver and then measuring the re-



7. This BER test setup employs output signals from the Bluetooth DUT's baseband processor.

ceiver's BER. The transmit power is chosen to that the input the receiver is −70 dBm. The test is performed at the lowest, middle, and highest operating frequencies. The impairments are defined in the test procedure and include variations in the carrier-frequency offset, carrier-frequency drift, modulation index, and symbol-timing drift. The HP ESG-D series of signal generators is ideal for generating these signal impairments. The sensitivity test for multislot packets is similar to that for the single-slot packets, except that DH5 packets are used instead of DH1 packets. If DH5 packets are not supported, DH3 packets can be used.

The C/I performance is measured by sending co-channel or adjacent-channel Bluetooth-modulated signals in parallel with the desired signal and then measuring the receiver's BER. The ratio of the carrier-signal level to the interfering-signal level is specified. The test is performed at the lowest, middle, and highest frequencies, with the interfering signals at all operating frequencies within the band.

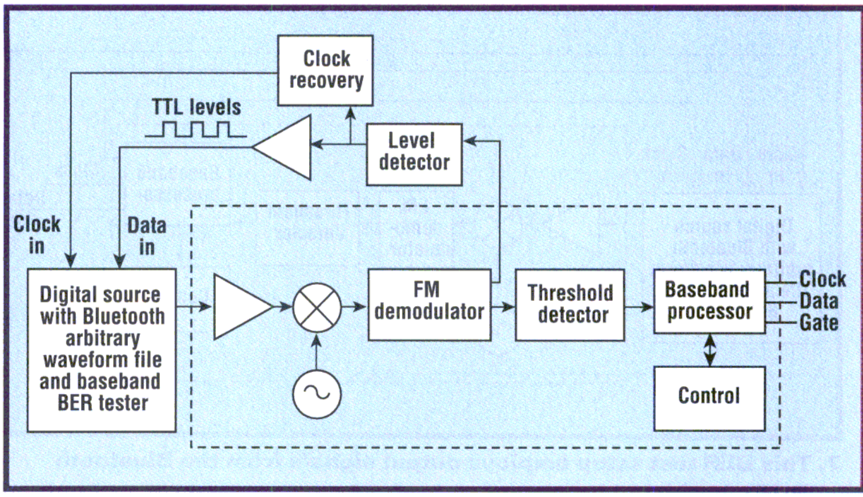
The blocking performance test specifies a Tx and Rx frequency of 2460 MHz. The tester continuously sends a Bluetooth-modulated signal that is 3 dB more than the reference-sensitivity level. Simultaneously, the tester sends a continuous-wave (CW) interfering signal and measures the BER of the receiver. The full compliance test requires the interfering signal to range from 30 MHz to 12.75 GHz in 1-MHz increments. The amplitudes associated with each frequency range are detailed in the Bluetooth specifications.

IM performance measures unwanted frequency components resulting from the interaction of two or more signals passing through a non-linear device. The measurement is performed by the test source continuously sending a Bluetooth-modulated signal that is 6 dB above the reference sensitivity. Simultaneously, the tester sends signals to generate third-, fourth-, and fifth-order IM products. The BER is then measured to determine the performance of the receiver in the presence of IM distortion. Multiple signal generators may be required when performing the C/I, blocking performance, and IM performance tests.

BER Testing

The maximum input-level test measures the BER performance when the input signal is set at a maximum power level, specified at −20 dBm. The test is performed at the lowest, middle, and highest operating frequencies.

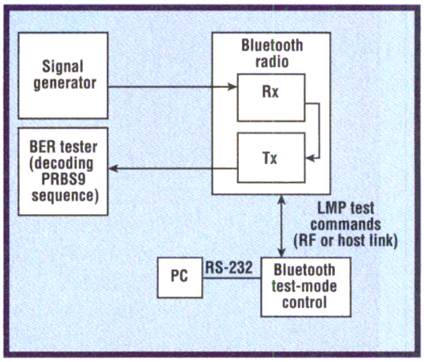
To perform the BER tests, a signal generator can be used to generate a Bluetooth-modulated signal and transmit this signal to the DUT. The signal is then routed through the DUT and demodulated. The data are then returned to a BER tester for analysis. Test setups can either be based on routing the clock, data, and gate outputs of the baseband



8. This modification to the BER test setup uses the output of the Bluetooth receiver's FM demodulator.

processor to the BER tester (Fig. 7) or by taking output signals from the Bluetooth receiver's frequency-modulation (FM) demodulator (Fig. 8). In this latter setup, the output of the DUT's FM demodulator is routed to a signal generator's BER tester inputs after the signal has been digitized and the clock signal has been recovered. Alternatively, the digitized output of the threshold detector may be looped back directly to the BER tester along with a clock signal. Both of these examples are ideal for research-and-development (R&D) work where direct access to the DUT's circuitry is available.

A third method requires a BER tester with the capability of demodulating a Bluetooth signal. In this case, the DUT must be instructed to loopback its receiver signal using test-mode commands. These commands may be sent over the RF link or through direct-digital control of the



9. In this BER test setup, the Bluetooth DUT is placed in loopback mode with the BER tester.

DUT. The output of the DUT's transmitter can then be routed to the BER tester for analysis. Provided with a PRBS 9 payload, the BER tester can determine the BER (Fig. 9).

For non-frequency-hopping applications, there are several ways of creating a Bluetooth signal with a signal generator. The HP ESG-D series of signal generators offers a built-in Bluetooth signal selection (with Option UND). This feature provides the ability to define a Bluetooth signal and offers several user-defined impairments. With option UN8, the same series of signal generators allows the manual creation of pulsed 2FSK signals with Gaussian filtering and customizable payloads to simulate Bluetooth signals.

Furthermore, customized arbitrary-waveform files for the HP ESG-D series of signal generators has been created in order to simulate normal as well as impaired Bluetooth signals. These files require the dual arbitrary-waveform-generation option (option UND). The impaired Bluetooth signals support advanced analysis of Bluetooth receivers by stressing the reception as well as demodulation capabilities of the DUT. The files are available on the Internet, at the Bluetooth portion of the Agilent Technologies' site at http://www.agilent.com/find/ bluetooth_waveforms. BT

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Apply Optical WDM To Wireless Systems

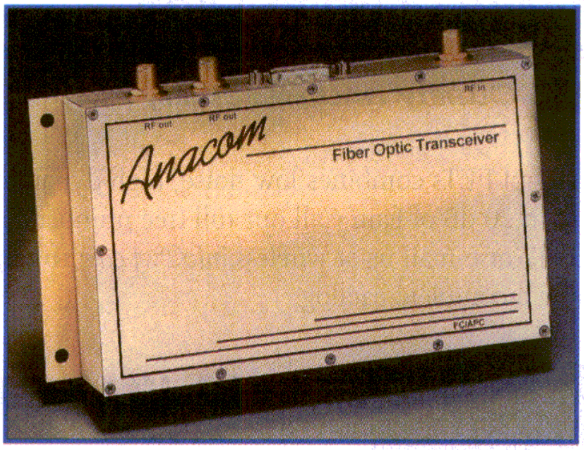
Fiber-optic links using WDM can be used in a wide range of wireless applications to minimize cost, signal loss, and RFI, as well as to maximize coverage and capacity.

Coverage, capacity, and cost are the "three Cs" of wireless systems. All service providers want the greatest possible coverage and capacity for the lowest cost, although these requirements are in direct conflict. Fortunately, fiber-optic transport systems, notably based on wavelength-division multiplexing (WDM), can help ease the pain of wireless system buildouts and make the dream of broadband services a reality.

In the early stages of a wireless system buildout, the goal is to provide full coverage at a reasonable cost until revenues start to flow. A wireless system buildout involves a creative mix of technologies and hardware approaches to achieve complete but cost-effective coverage. Fiber-optic WDM systems offer a practical solution in the buildout of practically any form of wireless system, including cellular, personal communications services (PCS), local multichannel-distribution systems (LMDS), multichannel, multipoint distribution systems (MMDS), and wireless local loops (WLLs).

Fiber-optic transport systems are based on broadband RF-to-optical converters (transmitters) and optical-to-RF converters (receivers), or combinations of the two in fiber-optic transceivers. The input to a fiber-optic transmitter is a 50-Ω RF connector and the output is a fiber-optic connector (Fig. 1). Inside the transmitter is a semiconductor laser diode that emits optical energy at a wavelength of 1300 nm and at an optical power level of 2 mW. The transmitter controls the bias to the laser diode ensuring that it is operating in its linear region. The transmitter circuit monitors the optical output of the laser and adjusts the bias current to ensure optimal linear operation over temperature and time.

The fiber-optic receiver accepts the optical signal and reconverts it to an RF signal. The receiver contains a high-speed, linear photodetector that is also matched to 50 Ω. The RF input and output circuitry matches the impedance of the laser and detector to 50 Ω, providing a conventional RF interface. A fiber-optic transmission link can be characterized as a 50-Ω system with gain, third-order intercept point (IP3), and input noise. Once these parameters for the RF/fiber-optic link are known, conventional RF system design techniques can be used. The table shows key performance parameters for an RF/fiber-optic link.



1. The input to a fiber-optic transmitter is a 50-Ω RF connector and the output is a fiber-optic connector.

Figure 2 shows two examples of system configurations for a fiber-optic-based RF transmission and distribution system. A fiber-optic link supports remote placement of an RF head from the base station or modulation equipment. The remote unit contains a power amplifier (PA), duplexer, and low-noise amplifier (LNA) in addition to the fiber-optic transceiver.

The original application for use of RF/fiber-optic systems was to reduce RF coaxial cable losses from the equipment hub to an antenna or to reduce the weight as well as the wind load on an antenna tower. Modern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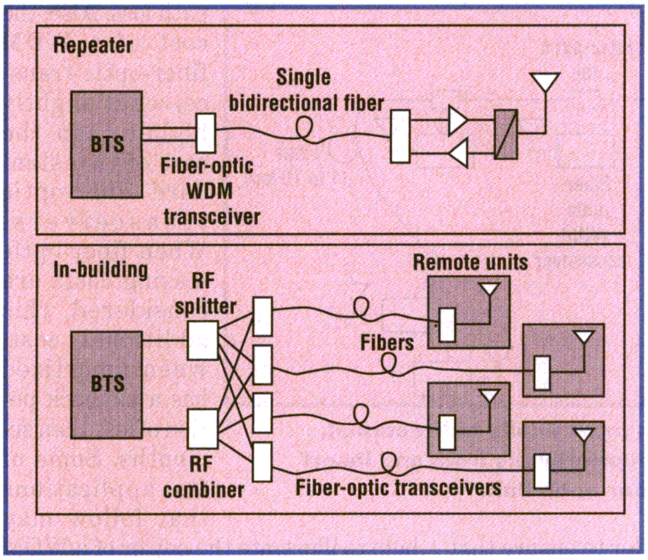


2. These are only two examples of system configurations for a fiber-optic-based RF transmission and distribution system.

systems use fiber-optic transmissions for advanced system configurations.

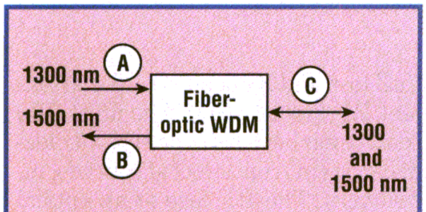
In conventional RF/fiber-optic distribution systems, one fiber is used for the uplink and a second fiber for the downlink. A key advantage in using fiber-optic technology, however, is the ability to easily multiplex multiple optical signals onto a single fiber-optic cable. This reduces the leasing cost of the fiber cable, reduces the required quantity of dark fibers (a fiber-optic cable that is installed in the field but not currently being used), as well as guaranteeing uplink and downlink gain balance since the two communications paths exhibit identical loss.

Optical multiplexing systems are analogous to electrical multiplexing systems. In time-division-multiplexing (TDM) systems, two or more signals are intermixed in the time domain. Portions of individual signals occupy alternating time slots. In frequency-division-multiplexing (FDM) systems, multiple signals are aligned in the frequency domain. WDM is most similar to FDM. Instead of RF separation between independent channels, separation is achieved through optical wavelength (essentially color).

Wavelength Windows

In a simple WDM RF/fiber-optic system, the uplink operates at a wavelength window centered at 1300 nm while the downlink operates within a wavelength window centered at 1500 nm. An optical filter or wavelength-division multiplexer is used to combine and separate the optical signals. The wavelength-division multiplexer is similar to an RF duplexer. The wavelength-division multiplexer has three ports—a common port and two input/output (I/O) ports (Fig. 3). The pathway from one of the I/O ports to the common port allows 1300-nm light to pass with very low loss. From the second I/O port through to the common port, 1500-nm light passes with very low loss. Of course, the 1500-nm pathway exhibits low loss for optical signals in the 1500-nm window while attenuating light at 1300 nm. (For more on optical signal loss, refer to the sidebar.)

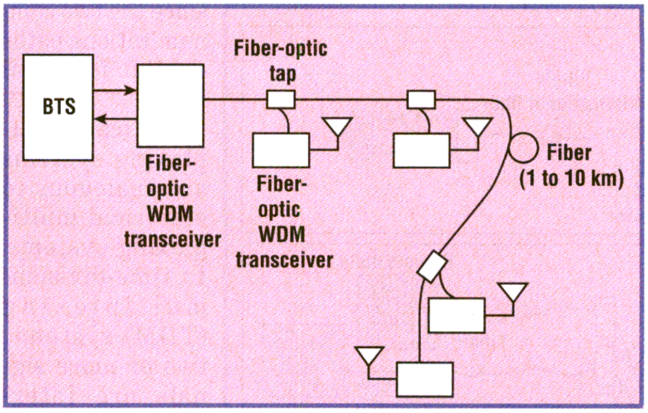
The optical passband of a simple bidirectional WDM filter is quite wide. This is important because the wavelength of a laser transmitter will vary with temperature. At room temperature, the wavelength must be situated in the middle of the fil-



Equivalent RF loss

Port	1300 nm	1500 nm
A to C	1 dB	40 dB
B to C	40 dB	1 dB
A to B	100 dB	100 dB
C to A	1 dB	40 dB
C to B	40 dB	1 dB

3. A wavelength division multiplexer has three ports—a common port and two I/O ports.



4. An optical tap is intrinsically bidirectional, allowing it to couple signals from and insert signals into a fiber-optic link.

ter's passband in order to ensure that the wavelength does not drift outside the WDM's cutoff wavelength with temperature. In two-path fiber-optic systems, this is quite readily achievable.

Fiber-Optic Benefits

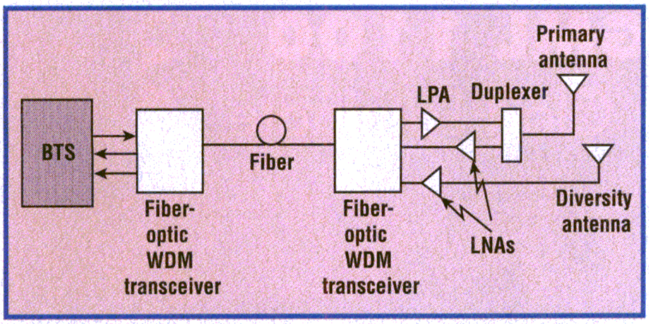
Once an RF/fiber-optic system is properly designed, it provides many benefits with minimal trade-offs in performance. The benefits include the reduction of fiber-optic cable usage and leasing costs, which in certain states or countries can be quite high. The trade-offs are relatively insignificant, including a slight amount of additional optical loss, which amounts to approximately 1 dB additional RF path loss. Also, the cost of a WDM fiber-optic transceiver is slightly higher than the cost of two standard fiber-optic transceivers. When fiber-optic leasing costs are considered, this additional cost, when amortized has a payback period of less than six months. Some of the applications that follow may help to illustrate the power of a WDM link when applied to different wireless systems.

Modern repeaters, for example, use fiber-optic signal transport to a great extent. Using repeaters during a wireless system buildout period can greatly improve the cash flow of an operator while ensuring full RF coverage. WDM transceivers when used within a fiber-optic repeater can further increase the cost savings of the repeater installation. A properly designed fiber-optic repeater can provide the same coverage footprint as a base-transceiver station (BTS), thereby enabling the reduction in number of costly base stations and their required T1 line backhauls.

Gauge RF attenuation versus fiber-optic loss

A 2:1 relationship exists between optical loss and RF loss. An optical loss of 1 dBo corresponds to an equivalent RF loss of 2 dBe. The units dBo and dBe have been chosen to eliminate confusion between optical and electrical decibels. Loss in an optical system can stem from several sources, including optical fiber, connectors, and splitters. The RF loss of an optical fiber is less than 1 dBe/km. Connectors typically exhibit less than 1-dBe loss. The loss of an optical splitter depends on the component's configuration. A 1×2 optical splitter has an optical loss of 3.5 dBo or an equivalent RF loss of 7 dBe.

For example, an RF/fiber-optic link was tested and characterized with a 1-m fiber-optic cable (with essentially no loss). The RF gain through the link and across the optical fiber is 0 dBe. If the link in the actual installation is expected to operate with an 8-km fiber cable with one 50:50 optical splitter, how much RF gain can be expected? The solution lies in understanding that the 8-km fiber-optic cable exhibits approximately 3.2 dBo of optical loss and the splitter exhibits approximately 3.7 dBo of optical loss, for a total optical loss of 6.9 dBo. This corresponds to an end-to-end equivalent RF loss across the fiber-optic link of 2.0×6.9 dBo or 13.8 dBe.



5. A three-path WDM fiber-optic link can be used for communication systems using diversity antennas.

As capacity increases, the repeaters can be used in new buildout areas. A WDM link operates effectively regardless of the modulation format, including time-division multiple access (TDMA), code-division multiple access (CDMA), or quadrature amplitude modulation (QAM).

Increasing Coverage

A classic problem in wireless system design is providing adequate coverage along a highway. A highway is a long, narrow route with a relatively high density of users. Fiber-optic technology offers a unique solution for this problem. With the appropriate WDM fiber-optic transceivers and optical building blocks, a linear bus system can be designed that operates over a single fiber. At certain points where a cell site is required, an optical tap can be used to couple a portion of the optical signal. Since the optical tap is intrinsically bidirectional, it can be used to tap the fiber-optic forward-path signal and insert the return-path signal. At a subsequent cell site, a tap can be used to couple that site's signal to and from the fiber-optic bus. This can be repeated for up to five or more cell sites (Fig. 4). Proper optical design is required to ensure balance across the optical system. This requires an analysis of the number of cell sites to be serviced on the bus and the fiber distance between cell sites.

A modem can be used with a broadband fiber-optic link for monitoring and control. Typically an RF modem that uses some type of digital keying of a subcarrier is employed. The subcarrier must be selected so that its harmonics or its intermodulation (IM) with the RF signal does not create in-band spurious products. Fortunately, with 2000 MHz of bandwidth available, the issue of finding the proper modem carrier is simplified.

Advanced WDM Systems

While WDM has been presented in dual-wavelength systems, WDM systems are not limited to two wavelengths. In a two-path system, the two major optical windows are at 1300 and 1500 nm. The WDM transceivers to separate these two wavelength windows are readily available. Laser transmitters with wavelengths tuned to the center of these major windows are also readily available. To add a third channel or more, one or both of these main wavelength windows must be split to create narrower passband channels. The filters required to do this become more complex and the laser transmitters must be designed to operate in these narrow optical windows. More important, the laser transmitters must ensure that the output wavelength

RF/fiber-optic link parameters at a glance

Parameter	Specification
Bandwidth	100 to 2000 MHz
Flatness across full band	62 dB
RF gain over 3000-ft. fiber	0 dB
Input/output VSWR	1.8:1
Third-order intercept point	+25 dBm
Equivalent input noise	2130 dBm/Hz
Operating temperature range	230 to +75°C
Power supply	+12 VDC at 250 mA

remains within the cutoff points of the optical filters. This usually requires thermoelectric coolers to maintain a laser's temperature at +25°C regardless of the ambient temperature. These coolers can draw up to 1 A current and may be a reliability concern. An improved technique developed by Anacom Systems Corp. (New Brunswick, NJ) eliminates the need for narrowband filters and power-hungry thermoelectric coolers. It offers three- or four-path multiplexing using a single optical fiber.

In addition to their low loss and high reliability, optical transmissions are inherently immune to radio-frequency interference (RFI).

An example of a WDM system with more than two paths is an application using diversity antennas. In this case, a three-path WDM fiber-optic system can be applied. This requires one downlink path, but with two optical uplink paths on the same fiber (Fig. 5). Three individual fiber-optic transmitters and receivers are still required, integrated into a single compact module. The wavelengths of the three transmitters and the optical sensitivities of the three receivers are set in order to allow three optical signals to pass along the single fiber cable but not to interfere with each other or to create crosstalk.

RF/fiber-optic links provide many benefits in wireless systems. In addition to their low loss and high reliability, optical transmissions are inherently immune to RF interference (RFI)—an important consideration with the increasing use of RF in wireless applications. Also, RF/fiber-optic links provide high performance that is independent of modulation format. The fiber-optic modules are compact and provide conventional RF interfaces for ease of integration into wireless systems. HSD

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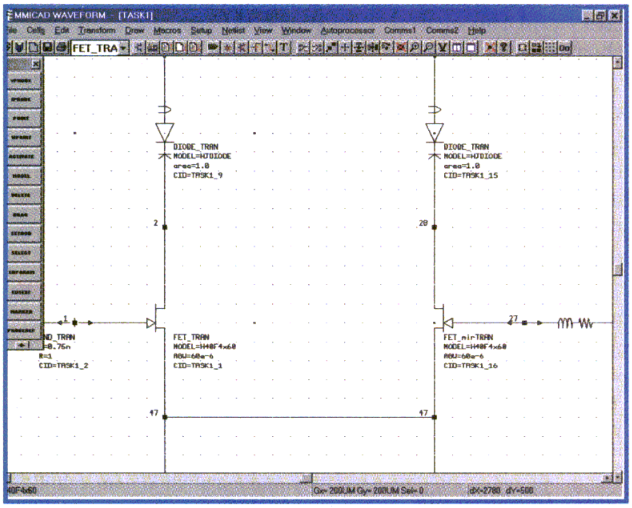
Software Models 10-Gb/s Differential Amplifier

A powerful new time-domain simulation tool makes it possible to predict the performance of high-speed digital and fiber-optic circuits and devices.

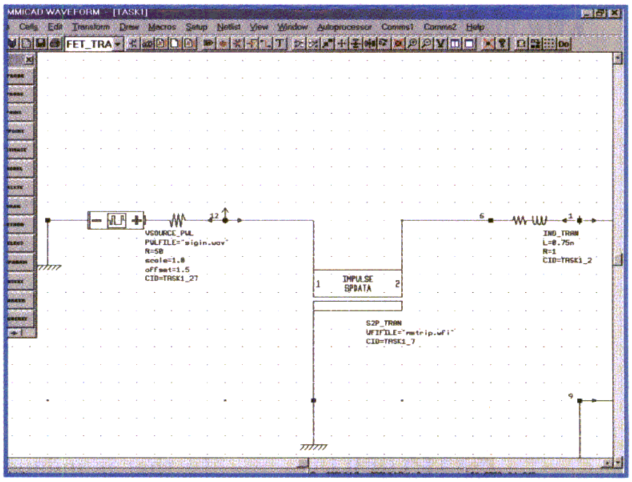
High-speed digital and optical circuits represent a modeling challenge for any simulation software. Fortunately, a new time-domain simulator from Optotek (Kanata, Ontario, Canada), MMICAD WAVEFORM™, represents a major advance in the accurate prediction of the nonlinear response of high-frequency and high-speed circuits. It can be used advantageously in the design of GaAs integrated circuits (ICs) for use in high-speed optical communication modules, improved microwave circuit packages, and nonlinear transmission lines.

The new MMICAD WAVEFORM software addresses transient analysis in strongly nonlinear circuits and combines the accuracy of frequency-domain simulation of passive circuit elements with time-domain simulation of nonlinear components using advanced models. By solving the response of fast microwave and optoelectronic circuits in the time domain, MMICAD WAVEFORM complements the capabilities of harmonic balance simulators conventionally used to predict the steady-state response of RF and microwave circuits. The strengths of time-domain analysis include the prediction of voltage waveforms at every node in a nonlinear circuit, the ability to examine pulsed RF network responses, the examination of transients and start-up times in oscillators, analysis of filter step-functions, visualization of switching waveforms in fast digital circuits, and the prediction of unintentional oscillations.

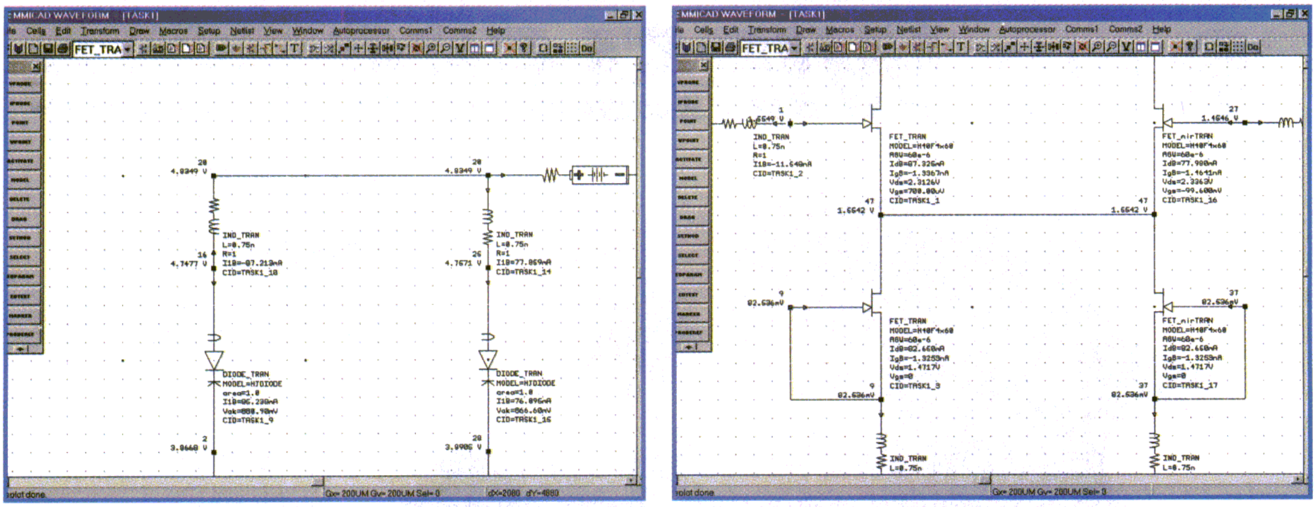
The unique capabilities of the software were demonstrated in application to the analysis of a laser-driver differential amplifier output stage operating at 10 Gb/s. The feasibility of operating at higher bit rates can also be explored using MMICAD WAVEFORM.



1. This differential amplifier schematic diagram was developed with the MMICAD WAVEFORM program.



2. This input signal was used in the simulation. A +1.5-VDC offset was used for each of the voltage source elements in order to achieve a 0-V gate-source voltage for each PHEMT driver.



3. These DC bias configurations are for the diode section (a) and the PHEMT section (b) of the differential amplifier.

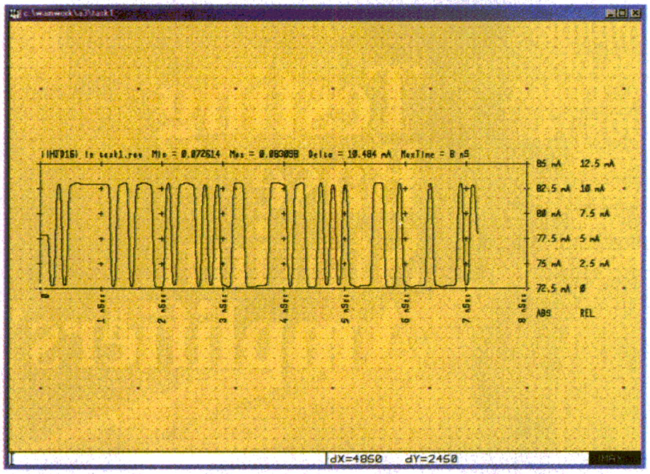
In the circuit design that was investigated, the signals to the differential amplifier arrive on a microstrip line, traveling through bond wires to reach the amplifier. In modeling this high-speed amplifier, the first task is to define the S-parameters for the microstrip line using a linear circuit simulator. The differential amplifier is intended to operate at 10 Gb/s. Therefore, the microstrip lines are characterized to 100 GHz. The parameters used for the microstrip line were that of R04350 material from Rogers Corp. (Chandler, AZ). S-parameter data were generated through the use of the MMICAD linear circuit simulator.

The MMICAD WAVEFORM software was then used to generate the equivalent impulse response of the frequency-domain S-parameter file. The resulting MMICAD WAVEFORM impulse file was used for the subsequent time-domain analysis.

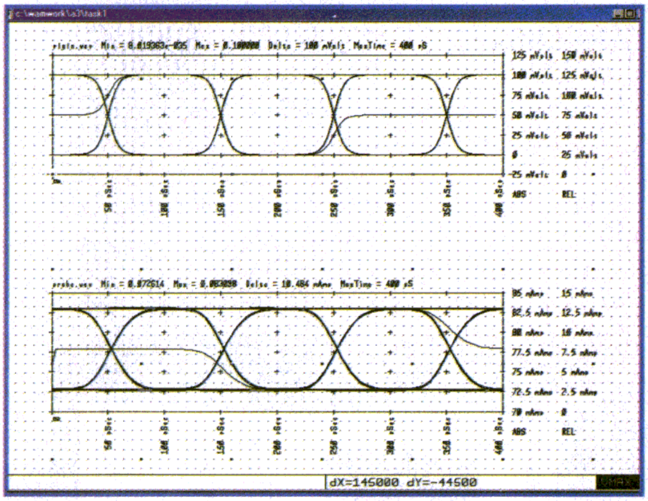
Circuit Schematic

MMICAD WAVEFORM's schematic-capture program was used to define the schematic diagram for the differential amplifier circuit, which has two laser diodes in the drains of the driver FETs (Fig. 1). This circuit uses the 0.25-mm MMT H40 pseudomorphic-high-electron-mobility-transistor (PHEMT) process from GEC Plessey (Northants, Caswell, England). The PHEMTs were the GEC MMT H40F4x60 devices, modeled using EEHEMT parameters. A standard heterojunction model was used for the diode. Inspection of the circuit shows that a +1.5-VDC offset is required for each of the VSOURCE PWL elements, corresponding approximately to a 0-V Vgs situation for each PHEMT driver (Fig. 2).

Next, a DC bias check was performed. The bias information generated by MMICAD WAVEFORM is shown in Figs. 3a and b. For the driver PHEMTs, Vds = +2.3 VDC, and for the constant-current PHEMTs in the source circuitry of the driver



4. This is the current waveform that was used to drive the differential amplifier's right-side laser diode, as viewed by MMICAD WAVEFORM's voltage probe.



5. These eye diagrams were generated for the differential amplifier simulated at 10 Gb/s.

PHEMTs, Vds = +1.47 VDC. The slight asymmetry is due to the bias supplied by the input-signal waveform (sigin.wav), and the complementary input from the inverted input-signal waveforms. For the purpose of the differential amplifier simulation, the bias condition appeared satisfactory.

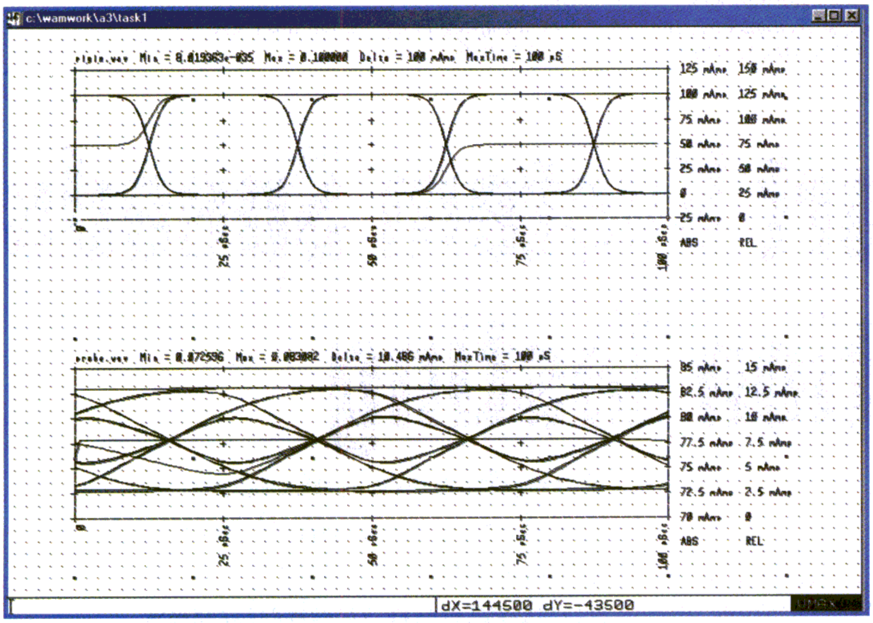
Waveform Analysis

Next, the program is instructed to perform a simulation of the circuit waveforms. The differential amplifier was fed with a 10-Gb/s pseudo-random-bit-sequence (PRBS) signal with 20-ms rise and fall times. The amplifier was simulated for a period of 7.2 ns.

The software's voltage-probe output was used to display the current waveform into the right-side laser diode (Fig. 4). The resulting eye diagrams are shown in Fig. 5. The upper trace shows the controlling voltage while the lower trace shows the predicted current through the laser diode. Note that the peak amplitude is approximately 10 mA for a driving signal level for the voltage source of 100 mV.

The feasibility of operating at a higher bit rate of 40 Gb/s was also investigated. The amplifier was simulated for 1.8 ns with 5-ps rise and fall times. The resulting eye diagram is presented in Fig. 6, showing that this particular design is not suitable for operation at 40 Gb/s.

The MMICAD WAVEFORM software supports the use of RLC lumped passive components, independent and controlled voltage as well as current sources, nonlinear SPICE-equivalent diode models, and advanced GaAs metal-semiconductor-field-effect-transistor (MESFET) and HEMT models, including the EEHEMT and version 3 of the Triquint-Only-Model (TOM3). The software can also use S-parameter data derived from linear and nonlinear circuit simulators, from electromagnetic (EM) simulators, or from vector-network-analyzer (VNA)



6. These eye diagrams were generated for the differential amplifier simulated at 40 Gb/s.

measurements. The software supports digital bit-stream definitions, with the capability to control a current or voltage source with an arbitrary waveform generator file. Users can verify the DC bias condition of a circuit by displaying the voltages at each node and the currents into each element in a circuit. In addition, the voltages at all nodes and the currents into each circuit element can be saved in a SPICE-compatible raw data file for each time step for additional analysis of bias-plane trajectories, circuit-transfer characteristics, as well as current-voltage (I-V) characteristics.

The MMICAD WAVEFORM time-domain simulator has been developed for use in the prediction of waveforms in fast microwave circuits where accurate S-parameter data can be imported and used in a simulation. The program allows high-frequency designers to include complex frequency-dependent effects in passive circuits. Since MMICAD WAVEFORM can import S- and Y-parameter data for passive networks with as many as 19 ports, designers can determine the transfer response for the passive circuitry that is external to a monolithic microwave IC (MMIC), such as the interactions between a MMIC and its package.

The use of the time domain has many advantages for high-frequency analysis. It can be applied for the prediction of voltage waveforms at every node in a nonlinear circuit. It can also be used for analyzing filter step functions and for examining the pulsed responses of a high-frequency or high-speed network. The software is suitable for visualizing switching waveforms in high-speed digital circuits and for evaluating transients and start-up times in microwave oscillators.

MMICAD WAVEFORM runs on an IBM personal computer (PC) or compatible machine with Windows 95, 98, or NT operating systems. The recommended computer configuration includes a Pentium-grade microprocessor running at 350 MHz or faster and a minimum of 64 Mb of random-access memory (RAM).

MMICAD WAVEFORM operates as a standalone software package. It can also be incorporated into the firm's MMICAD suite of software tools for seamless data transfer. **Opotek Ltd., 62 Steacie Dr., Kanata, Ontario K2K 2A9, Canada; (613) 591-0336, FAX: (613) 591-0584, e-mail: sales@opotek.com, Internet: http://www.opotek.com.** HSD

David J. Ballo, Product Manager
Agilent Technologies, Inc., 1400 Fountaingrove Pkwy., Santa Rosa, CA 95403; (707) 577-1400, e-mail: david_ballo@hp.com.

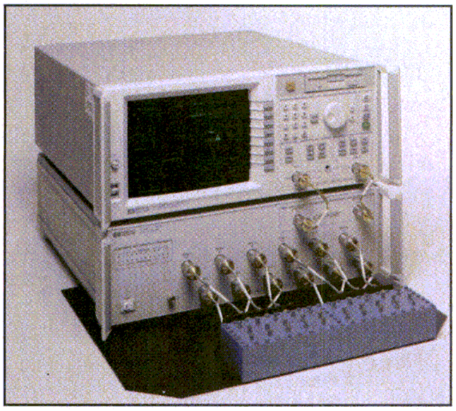
Multiport System Speeds Production Testing

A multiport network analyzer coupled with some innovative calibration techniques can increase production-testing throughput.

Not all high-frequency components are created with two ports--many have three or more. Testing these components with a conventional two-port vector network analyzer can be tedious and time consuming due to the number of connections. For example, an eight-port device may require as many as 56 connections to test all possible signal paths. Fortunately, there is a better way, using a specially designed multiport network analyzer and multiport test set. The new 87050E multiport test sets from Agilent Technologies (Santa Rosa, CA) are designed to work with the company's 8712ET/ES (1.3-GHz) and 8714ET/ES (3-GHz) RF VNAs to provide complete measurement systems for 50-Ω multiport devices.

Featuring solid-state switching with specified performance to 2.2 GHz, the test sets come with 4, 8, or 12 test ports. These multiport test systems eliminate time-consuming reconnections to the device under test (DUT) and compared to most other multiport test systems, dramatically reducing the time required for calibration. Side benefits include lowered risk of misconnections, reduced operator fatigue and repetitive-motion injuries, and minimal wear on cables, connectors, calibration standards, and the DUT. These attributes help increase production throughput while reducing manufacturing costs.

Calibrating a multiport test system without software or instrument firmware that is optimized for multiport test applications can be a time-consuming and tedious task. Agilent 87050E-based test systems feature internal calibration standards and advanced calibration techniques that eliminate redundant connections of reflection standards, reduce the number of through standards needed to calibrate all possible transmission paths, and minimize the effect of test-system drift (Fig. 1). Full two-port vector-error correction is supported with specified performance at the calibration plane, whether in a fixture or at the ends of test cables, providing excellent measurement accuracy.



1. An Agilent 8712E series VNA and Agilent 87050E multiport test set form a complete 50-Ω multiport test system.

Calibrating a multiport test system using two-port error correction and a traditional network analyzer (one without firmware designed to handle multiport calibration) requires a unique instrument state for each measurement path, with each measurement path consisting of a pair of test ports. This model of the test system forces many redundant connections of reflection-calibration standards. For example, there are six unique measurement paths on a four-port device (between ports 1 and 2, 1 and 3, 1 and 4, 2 and 3, 2 and 4, and 3 and 4). For each path, an open-, short-, and load-calibration standard is connected to each test port, for a total of six connections of reflection standards per path. Since there are six unique measurement paths, a total of 36 connections is made. Intuitively, each reflection standard should only have to be connected once to each test port, resulting in only 12 connections. As the number of ports increases, the number of connections required to calibrate all possible measurement paths grows exponentially (Fig. 2). For a 12-port test system, there are 66 possible measurement paths, requiring 396 connections of open-, short-, and load-reflection standards to calibrate all these paths, instead of the minimum possible value of 3 312 or 36.

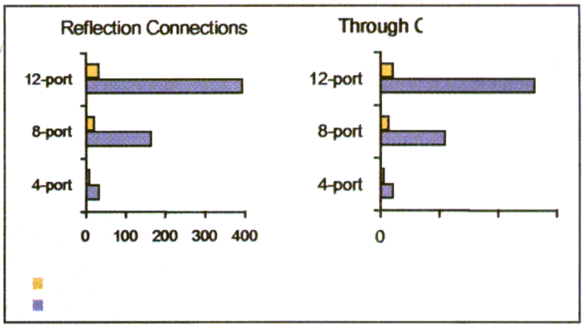
The 87050E-based multiport test systems feature a novel calibration procedure called Test Set Cal, which eliminates all redundant connections of reflection standards. An open-, short-, and load-calibration standard is connected and measured only once for each test port. In this way, no redundant data are collected. The raw measurement data of each calibration standard is saved in an internal data array, along with measured data of the through standards. When a user defines a measurement path, the analyzer selects the data corresponding to the two test ports, which comprise that particular measurement path. This data are then used to calculate the correction coefficients needed to perform vector-error correction.

Another unique aspect of Test Set Cal is that it greatly reduces the number of through connections needed to test all possible transmission paths. A traditional approach to calibrating a multiport test system would be to perform a through measurement for each measurement path (note: for simplification, this paper will treat the through calibration as one connection and one measurement). Continuing with the four-port example above (with six unique measurement paths), a traditional calibration would require six through measurements. Test Set Cal requires through connections only between adjacent port pairs. Adjacent port pairs are defined as port n and port n + 1, where n = 1, 3, 5, 7, 9 or 11. For the four-port example, only two through connections are required to characterize all six paths. During calibration, a through standard is connected between port 1 and port 2, and between port 3 and port 4. Note that for measurements on a three-port device, it is still necessary to calibrate four test ports using the minimum-through algorithm. However, a four-port Test Set Cal requires only 14 connections of calibration standards, whereas calibrating all possible paths of a three-port device using a traditional VNA requires 21 connections of calibration standards. Using Test Set Cal with a 12-port test system, only six through connections are needed to characterize all 66 possible transmission paths. The through standards can have zero or non-zero electrical length. Non-zero-length throughs must be characterized for electrical delay and loss, and this information must be entered into the network analyzer as part of the calibration-kit-definition file.

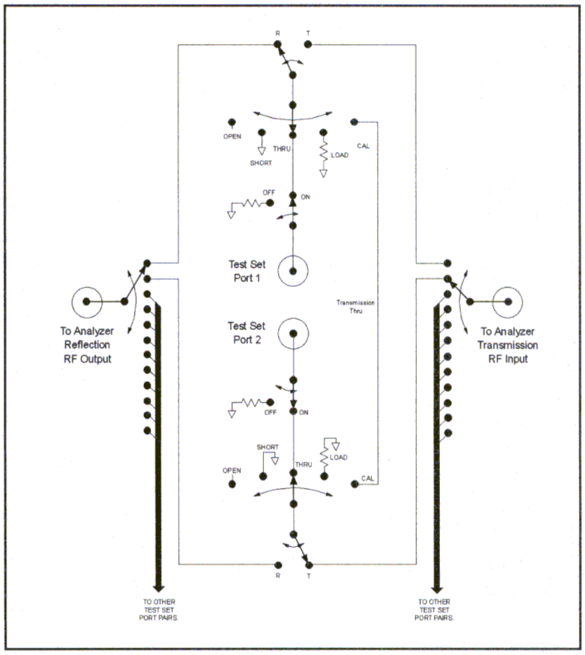
To achieve a minimum-through calibration, Test Set Cal uses internal calibration standards built into the test set (Fig. 3). These internal standards are also used during an automatic procedure where the test system recalibrates itself through a process known as SelfCal. The minimum-through portion of a Test Set Cal combines the measurement of an external through standard with reflection measurements of the internal calibration standards to separate each transmission path into parts--the network-analyzer response, the response of the test set's source port, and the response of the test set's load port. These individual responses can then be used to determine the transmission coefficients of any possible path. Since the individual parts are common to many transmission paths, the number of through measurements needed during calibration is greatly reduced. This technique can be used with calibrations associated with transmission/reflection network analyzers, and with full two-port calibration associated with S-parameter network analyzers.

The 87050E-based multiport tests systems feature a unique self-calibration feature called SelfCal. SelfCal is an internally automated calibration procedure that uses solid-state switches to measure calibration standards located inside the test set. SelfCal executes automatically in only a few seconds (at an interval defined by the user), so the impact to the test process is minimal. After a SelfCal executes, the multiport test system is restored to the same measurement accuracy that is achieved immediately after performing a Test Set Cal. SelfCal reduces the effects of test-system drift, which improves overall measurement accuracy between Test Set Cals.

With SelfCal, the interval between external-standards-based Test Set Cal can be much longer than the calibration interval required by a traditional test system. Test Set Cal intervals are typically between once-a-week and once-a-month, depending on environmental variations and the quality of the system components between the test set and the DUT. **Agilent Technologies, Inc., 1400 Fountaingrove Pkwy., Santa Rosa, CA 95403; (707) 577-1400, Internet: http:// www.agilent.com.** HSD



2. Test Set Cal reduces the number of connections required to calibrate all possible measurement paths for multiport testing.



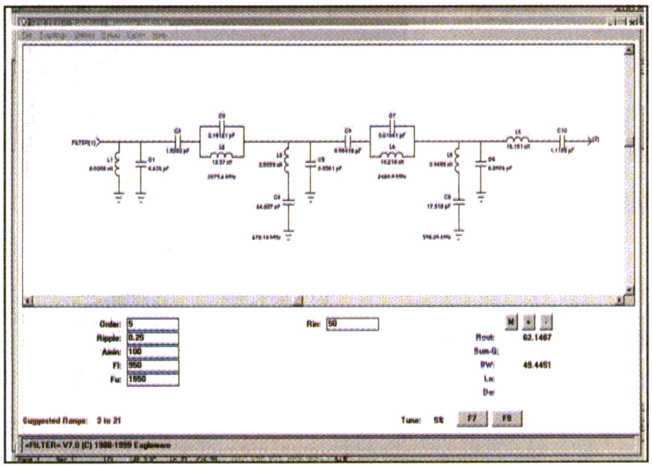
3. This simple block diagram shows one pair of internal calibration standards within the Agilent 87050E multiport test set.

Software Simplifies Linear Circuit Analysis

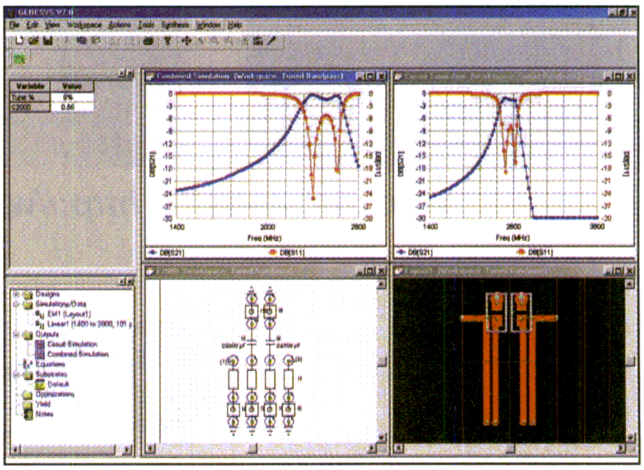
This flexible suite of CAE design tools combines linear circuit synthesis, simulation, and layout functions in a user-friendly Windows environment.

RF DESIGNERS OVER THE YEARS HAVE COME TO know the power of linear circuit design software from Eagleware, Inc., (Tucker, GA). The company's latest release, GENESYS 7, adds simulation and synthesis power, but also becomes easier to use than earlier versions. While previous versions loosely coupled multiple synthesis and simulation engines, the GENESYS 7 architecture was rebuilt from the bottom to support multiple simulation engines while also making full use of the 32-b Windows 95/97/NT operating system. The software suite employs object-oriented techniques to allow function modules and design elements to operate independently, yet to communicate with each other seamlessly and effortlessly.

Introduced this past August (see *Microwaves & RF*, August 1999, p. 141), GENESYS 7's use of object-oriented techniques improves simulation and optimization speeds by a factor of 10 or more compared to earlier versions of the software. By using diakoptic methods, results can be efficiently stored and reused in a tree structure of cached memory without the need for constant recalculations. Efficient memory use is achieved by eliminating unnecessary nodes during the initial parsing of a circuit schematic diagram. For example, simulations performed on a nine-pole elliptic filter are completed approximately 12 times faster in GENESYS



1. GENESYS 7's lumped-element design screen was used to develop this multistage filter.



2. The software's multifunction capabilities support a single screen with schematic diagram (lower left), layout (lower right), and simulated performance (upper plots).

Software Simplifies Linear Circuit Analysis

7 than the same simulation performed in earlier versions of the software suite. Solutions are arrived at quickly, with dramatic convergence for even large circuits.

GENESYS 7 features a new onscreen environment developed in the spirit of the latest Microsoft Windows standards. Operators can now organize schematic diagrams, circuit layouts, simulated performance graphs, and analyses within a single file. Also, multiple files can be opened simultaneously to compare and contrast results. Movable toolbars manage screen space. For rapid local changes, a click on the right-hand mouse button provides instant access to pop-up command menus. By using the undo and redo (virtual) buttons, a designer can experiment with different circuit topologies and formats.

A powerful new post-processing engine in GENESYS 7 increases the speed of importing and combining data. Data collected from several sources, such as electromagnetic (EM) simulators, circuit simulators, and actual test results, can be compared and processed or new parameters can be calculated from a single source of data. Once equations have been entered into GENESYS 7, results can be displayed in tables or graphs, allowing changes in parameters to be made through tuning keys. Tuning changes are shown by real-time changes to the graphical results. For example, Leeson's equation can be used to display oscillator phase noise. Similarly, relative gain, the difference between the maximum gain and the gain at any frequency, can be calculated and displayed. Conditional statements, such as IF-THEN and GOTO enable the development of processing flow-control systems.

GENESYS 7 comes with a complete range of lumped and distributed component models. It also includes microstrip, stripline, slabline, coaxial, and waveguide models and components. The software includes an extensive S-parameter library containing more than 30,000 device files from 14 vendors. The simulation program has been totally redesigned to accommodate circuits of any size, with no limits on the total number of subcircuits, ports, or simulation frequencies. An "intelligent" simulation feature saves processing time by only resimulating circuits or parts of circuits that have been changed or tuned from a previous simulation.

A typical design process begins with the user selecting of one of the seven synthesis programs. These include matching network synthesis, oscillator synthesis, inductor-capacitor (LC) filter synthesis, distributed filter synthesis, active filter synthesis, delay equalization, and transmission-line synthesis. A filter design was chosen for this review.

The opening page of the lumped-element filter-design program enables an operator to specify filter type, topology, number of sections, and frequency parameters (Fig. 1). Once filter parameters are specified, the program captures the design as a schematic diagram or net list for simulation and/or layout. Simulation outputs can include S, Y, H, and Z parameters plus noise and stability factors. Once simulated performance is plotted, an operator can assign variable and execute tuning on a design, and perform Monte Carlo and statistical analysis.

GENESYS 7's schematic-entry work area allows circuit diagrams, layouts, and predicted performance to be shown on the same screen (Fig. 2). In the case of this example filter, the swept response is plotted in two different scales to aid in analysis. In the schematic diagram, each component has a corresponding footprint, which is placed in the layout window and connected by "rubber-band" lines. With manual layouts, a design is created using lines, arcs, polygons, and other geometric forms. Predefined layout footprints can also be inserted along with free-form text.

The software can support up to 128 layers, including dielectric layers, metallization, silk screening, solder masks, and solder paste. Using GENESYS 7's integrated layout module, users can automatically create a layout from the circuit schematic built earlier, or manually create a layout through interactive design. Tuning and optimization can be performed through the schematic-entry or net-list formats.

Once a design is complete, a user can perform multilevel EM simulation using the =EMPOWER= ML tool. Typical multilevel designs include air bridges and cross-coupled structures. A new co-simulation (using circuit and EM simulators) feature enables an operator to quickly verify the accuracy of multilayer circuits with embedded lumped components without cumbersome data transfer. The co-simulation feature can analyze signals traveling on an unlimited number of layers with an arbitrary set of dielectric layers, and is suitable for analyzing microwave circuits containing transistors, lumped capacitors, and distributed components, such as Lange couplers and spiral inductors.

During a co-simulation, GENESYS automatically recognizes the lumped components, removes them, adds internal ports, and runs the EM simulation. Then, the multiport data are transparently included in a circuit simulation. Once the initial design is complete, the lumped components can be interactively tuned or automatically optimized at high speed. Upon completion of a design, the software can generate files for manufacturing using built-in Gerber and DXF writers.

The GENESYS 7 software runs on any IBM personal computer (PC) or compatible machine with Windows 95 or higher operating system, at least 32 Mb of random-access memory (RAM), and at least 30 Mb of available hard-disk memory. P&A: $1997 and up (depending on options); stock. **Eagleware Corp., 4772 Stone Dr., Tucker, GA 30084; (770) 939-0156, FAX: (770) 939-0157, Internet: http://www.eagleware.com.**

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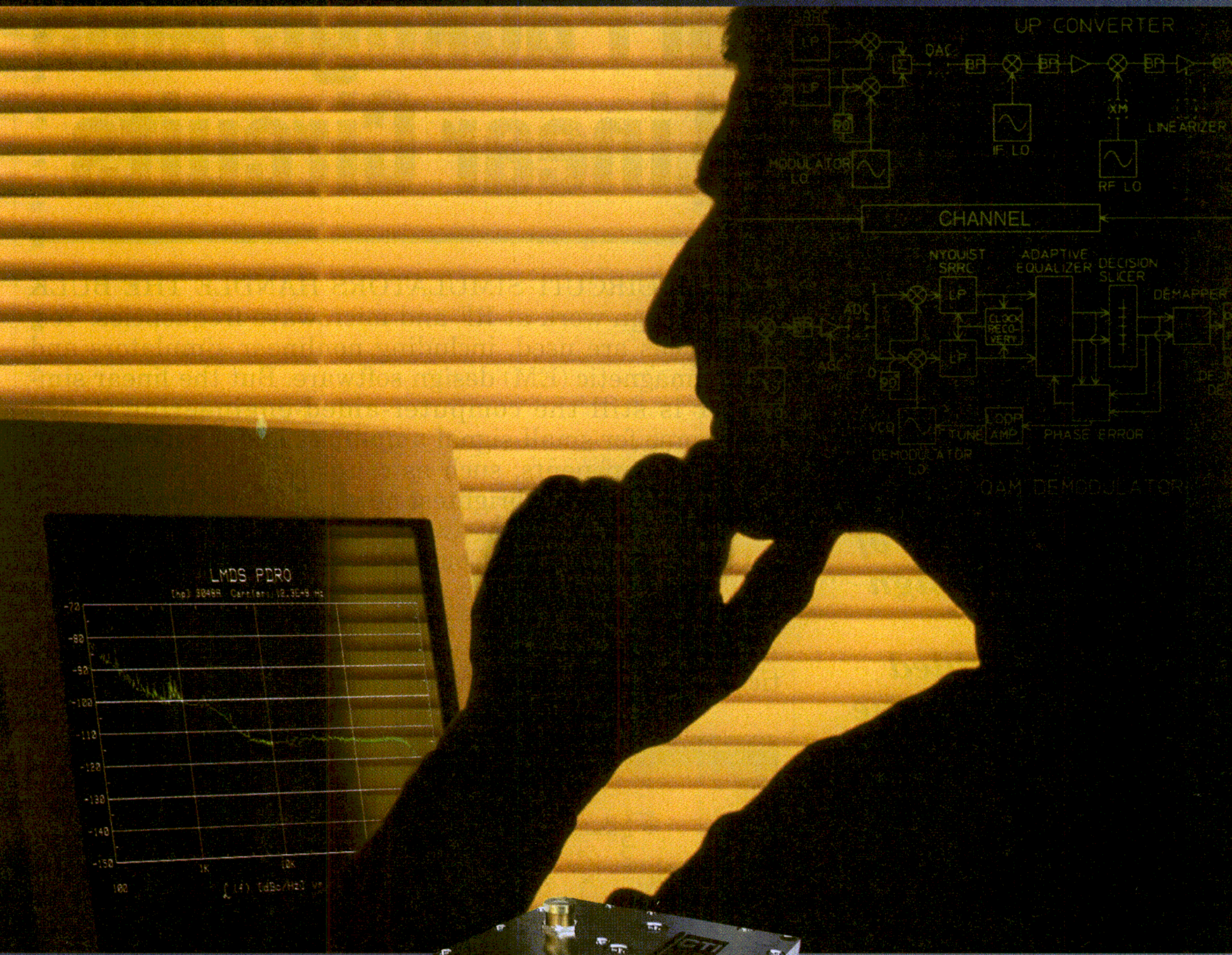

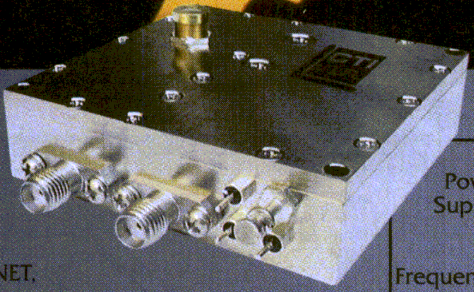

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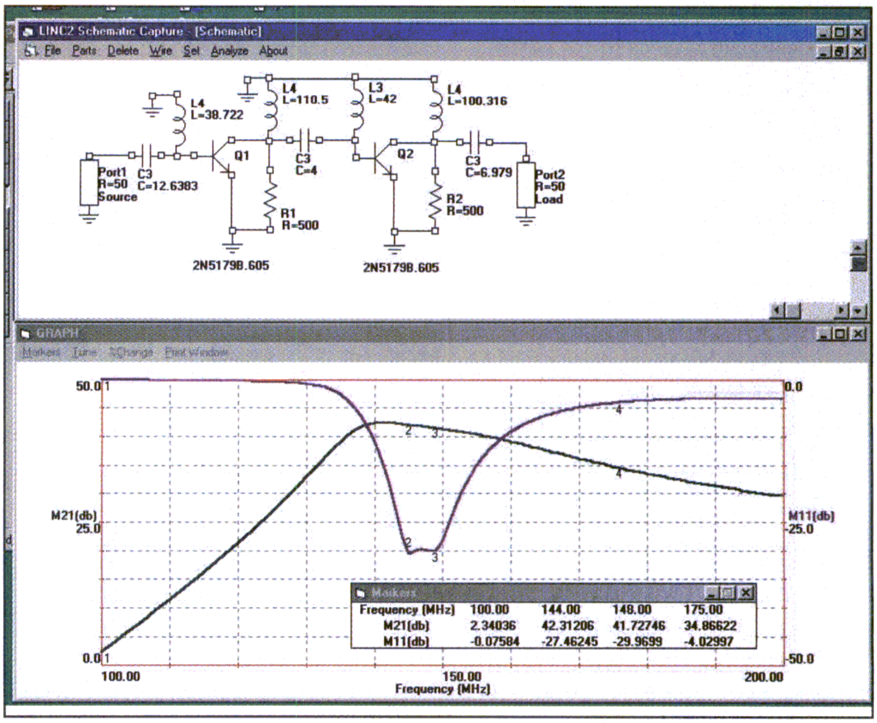
CIRCLE NO. 253

Economical Package Aids Design Of Linear Circuits

This cost-effective program offers all of the features of high-end design tools, with the added benefit of unique amplifier noise and gain trade-off tracking capabilities.

LINEAR-CIRCUIT SIMULATORS HANDLE THE BULK of the design work at RF and microwave frequencies. Yes, other tools are used, including nonlinear simulators and electromagnetic (EM) design software. But the linear simulator is still the computer-aided-engineering (CAE) workhorse for small-signal amplifiers and a wide range of passive components, such as couplers, filters, and power dividers. One of the brightest new and affordable additions to the current lineup of available linear-circuit simulators is LINC2 from Applied Computational Sciences (Escondido, CA). The LINC2 package combines a suite of RF analysis tools with a powerful RF and microstrip-circuit simulator. And the $495 price makes the software attractive for practicing engineers as well as engineering students.



This split-screen view shows LINC2's schematic capture and simulated performance-display capabilities.

Package Aids Design Of Circuits

LINC2 (see figure) is a personal-computer (PC)-based program that uses a nodal circuit-description format similar to those used in the Series IV suite of programs from Agilent Technologies (former HP/EEsof, Santa Rosa, CA) and the =SuperStar= suite of software tools from Eagleware (Tucker, GA). LINC2 incorporates matching network synthesis, microstrip and stripline transmission-line synthesis, pi- and t-pad design, and a circles utility for designing input (I)- and output (O)-matching networks around a two-port or transistor circuit. The software includes a generous collection of lumped-element component models.

The program is divided into two functional sections—swept-frequency analysis for broadband problems and single-frequency analysis. The swept-frequency analysis mode is used for active and passive circuit simulation. The single-frequency analysis with its circles utility is automatically invoked when an external S-parameter file is loaded from the main menu. This feature is primarily intended for the analysis of active device data such as a bipolar transistor or field-effect transistor (FET) at a specific frequency.

The circles utility is intended for automated amplifier design based on Smith Chart displays of operating power-gain circles, available power-gain circles, noise circles, and gain and noise circles, with adjustments made according to design trade-offs. Other displays include x-y plots, stability circles, to indicate the best choices for source and load terminations, and simultaneous (bilateral) conjugate matching at both ports when stability permits.

The circles utility automatically synthesizes input and output networks to provide good impedance matches for a user's choice of circuit topologies, including L, pi, t, and various transmission-line and stub forms. The networks generated by the circles utility are based on interactive displays of gain, noise figure, and stability circles overlaid on a Smith Chart.

LINC2's output data covers all four S-parameters, including magnitude (in linear or logarithmic formats) and phase of forward transmission (S_{21}), reverse transmission (S_{12}), input-reflection coefficient (S_{11}), and output-reflection coefficient (S_{22}). Other outputs include voltage standing-wave ratio (VSWR), group delay, maximum stable gain (MSG), K and delta stability indicators, and real and complex input and output impedances. Users can drag and drop frequency markers within a graphics window to provide details about a particular point. Any graphical output can be viewed and printed as a table.

LINC2 can import S-parameter data from test equipment or stored files for direct analysis or export S-parameter data generated as the results of an analysis session. In addition, S-parameter data can be imported according to the requirements of a circuit file to represent part of that file as a two-port circuit element, such as a transistor or passive circuit element.

The LINC2 program can tune any circuit component while displaying the effects of those changes on the computer screen for any circuit response or performance parameter. The tuned response is shown as a dashed line while the initial response remains on the screen as a solid curve or line. This capability enables instant visual comparison between initial and tuned responses. This type of instant tuning simulation provides invaluable insights into techniques for optimizing a design.

The sensitivity of a circuit to component tolerances can be quickly evaluated by tuning a part's value and noting the degree of movement in the response. Tuning is not limited to adjustment of component values. Parameters such as quality factor (Q), transformer turns ratio, transmission-line length, and characteristic impedance can also be tuned.

LINC2's statistical analysis section provides Monte Carlo yield analysis for uniform distributions of random variations in selected circuit parameter values. Monte Carlo analysis affords a means to study the performance deviations produced when the parameter values of one or more components are varied about a nominal value, such as a comparison in overall performance when using 5-percent resistors versus 10-percent resistors.

LINC2 is supplied with effective hard-copy documentation. The documentation includes models and examples of active and passive circuits, such as amplifiers, filters, and coupled transmission lines. Tutorials include stabilizing a potentially unstable transistor amplifier, amplifier design and simulation using bilateral conjugate matching techniques, and low-noise-amplifier (LNA) design. Included on the compact-disc-read-only-memory (CD-ROM) program disk are approximately 2000 S-Parameter files representing semiconductor devices from Agilent Technologies (formerly Hewlett-Packard Co.) and California Eastern Laboratories/NEC (Santa Clara, CA) for use in circuit designs. A synthesis and simulation design feature using the LINC2 program can also be found in an earlier issue of this magazine (see *Microwaves & RF*, August 1999, p. 123).

The LINC2 software runs on any IBM PC or compatible machine with an 80486 or newer microprocessor/math-coprocessor and the Windows 3.1 or later operating system. The computer should have at least 2 MB of random-access memory (RAM) along with 2 Mb of available hard-disk memory. A Windows-compatible graphics printer is required in order to produce hard-copy documentation.P&A: $495; stock. **Applied Computational Sciences, 1061 Dragt Pl., Escondido, CA 92029; (760) 612-6988, e-mail: comps ci@funtv.com, Internet: http://users.funtv.com/~compsci.**

CIRCLE NO. 523 or visit www.mwrf.com

ALAN "PETE" CONRAD
Special Projects Editor

Software Upholds New Design Standards

This new suite of software tools is specifically designed to meet emerging standards for unified mixed-signal simulation techniques.

INCREASING DEMAND FOR ELECTRONIC SYSTEMS, in automotive, avionics, communications, medical, and other applications, is outpacing the electronic industry's ability to cost-effectively design such systems. As a result, software developers are being driven to create a highly unified mixed-signal simulation language that can flow models from different functional tools, such as analog-design tools and SPICE simulators. One of the first fruits of this push toward integration is the ADVance platform from Mentor Graphics (Wilsonville, OR). The platform integrates digital, analog, and mixed-signal hardware-description-language (HDL) code with SPICE in a single simulation environment. The integrated software suite complies with the new standards set by the Institute of Electrical and Electronic Engineers (IEEE) for visual HDL (VHDL) and analog-mixed-signal (AMS) use.

The VHDL-AMS code can directly represent complex models by combining differential equations, algebraic constraints, and logical controls. The VHDL-AMS code can also be used to describe nonelectrical elements, such as device or component packaging or automobile braking systems.

The ADVance platform offers one possible solution to this need to more quickly design complex circuitry. The platform can directly represent a complex analog and mixed-signal model by combining differential equations, algebraic constraints, and logical controls. This architecture enables synergistic coexistence of digital- and analog-design methodologies based on industry standards. Conventional macromodeling may be used alone or in combination with direct modeling. Descriptions in VHDL-AMS that combine analog and event-driven elements are many times more efficient than SPICE-style macromodels. The new ADVance software suite comes with new levels of simulation for system-on-chip (SOC) designers while fully supporting the IEEE VHDL-AMS standard.

The CommLIB module within the ADVance platform contains 238 communications-related functions, from simple digital blocks and math functions to complex telecommunications functions. Each model can be programmed through input parameter definitions. The module's library of function blocks is extensive, and includes pre-emphasis and de-emphasis functions, modulators, demodulators, and companders. **Mentor Graphics Corp., 8005 SW Boeckman Rd., Wilsonville, OR 97070; (800) 547-3000, (503) 685-7000, Internet: http://www.mentor.com.**

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ALAN "PETE" CONRAD
Special Projects Editor

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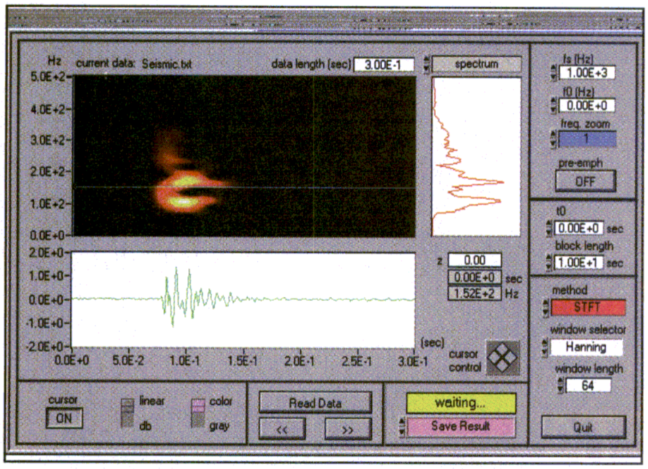
CIRCLE NO. 227

Toolset Sorts Through Signal Content

This easy-to-use collection of signal-processing routines simplifies the task of performing advanced analysis on complex waveforms.

SIGNAL PROCESSING IS MUCH SIMPLER WITH THE right tools or, to be precise, the right toolset. In this case, the toolset is virtual, contained within a package of programs from National Instruments Corp. (Austin, TX). The software toolset includes components for digital filter design, third-octave analysis, joint time-frequency analysis (JTFA), wavelet and filter-bank design, and spectral analysis. It also contains the Virtual Bench-Dynamic Signal Analysis (DSA) tool for dynamic signal acquisition, display, and analysis. All of the programs are accessed through a straightforward graphical user interface (GUI).

The toolset's digital filter-design component is a general-purpose design tool for signal-conditioning, control-systems, and digital-signal-processing (DSP) applications. Users can quickly and easily design digital filters for signal-conditioning and control-systems applications without being an expert in DSP technology. Users can interactively design filters such as lowpass, highpass, and bandstop filters, as well as digital band-pass finite impulse-response (FIR) and infinite-impulse-response (IIR) filters without programming experience. In addition, the digital-filter design application includes the ability to create arbitrary response filters by modifying the magnitude response plot.



The JTFA software was used to analyze this seismic waveform for its power spectrum (right-hand plot) and its time response (lower plot).

Unlike conventional signal-analysis technologies, the JTFA software examines signals in the time and frequency domains simultaneously. The JTFA software can be applied in almost all applications where Fast Fourier transforms (FFTs) are normally used, such as radar-image processing, vibration analysis, and dynamic signal analysis. In the analysis of a seismic waveform, for example, the simultaneous use of the time and frequency domains provides information about the power spectrum and time response of the waveform (see figure).

The wavelet and filter-bank design program is a unique tool for signal classification. By interactively selecting a wavelet prototype (equiripple or maxflat) and different FIR filter combinations, an operator can easily find the best wavelet or filter bank for an application. P&A: stock; $995.00. **National Instruments Corp., 6504 Bridge Point Pkwy., Austin, TX 78730-5039; (512) 794-0100, Internet: http://www.natinst.com.**

CIRCLE NO. 525 or visit www.mwrf.com

ALAN "PETE" CONRAD
Special Projects Editor

Tool Tackles Digital Filter Design

Even first-time users will be quickly designing advanced digital filters and generating C code without long hours spent on tutorial lessons or programming instructions.

DIGITAL FILTER TYPES SUCH AS FINITE-IMPULSE-response (FIR) and infinite-impulse-response (IIR) filters are widely used in cellular telephones and base stations as well as in other wireless communications system. For those responsible for designing and working with digital filters, the QEDesign 2000 program from Momentum Data Systems (Fountain Valley, CA) could prove to be an invaluable addition to a desktop or laptop computer. The easy-to-use software provides a menu-driven toolset for the design and implementation of FIR and IIR digital filters.

The QEDesign 2000 program includes extensive error-checking, extensive on-line help features, efficient 64-b floating-point calculations, and 128-b floating-point calculation for critical problems. Coefficient quantization is variable with scaling from 8 to 32 b. For FIR filters, the number of taps are determined by using the window calculation defined by a user's inputs. The coefficients for the taps are determined by using Fourier series design techniques for computing the impulse response and the window coefficients.

The QEDesign 2000 program supports the most useful methods of designing FIR filters, including window design and Parks-McClellan design approaches. Since all frequency functions are periodic on the unit circle of the Z-domain, the magnitude and phase of these FIR filters are periodic functions in the frequency domain. This allows the functions to be represented as Fourier series with Fourier coefficients representing the FIR filter coefficients.

The QEDesign 2000 program can design IIR filters by creating them first in the analog domain (S-plane) and mapping them to the digital domain (Z-plane), or by designing them directly in the Z-plane. The QEDesign 2000 package supports five types of analog-filter prototypes and three methods of transforming an S-plane design to the digital domain. QEDesign 2000 also provides an allpass filter with arbitrary group-delay capability, which is designed directly in the Z-plane.

QEDesign 2000 offers the unique capability to graphically design filters by adding or deleting poles and/or zeros as well as by moving existing poles and/or zeros. This capability is sometimes useful when creating filters that cannot be specified in a conventional manner. Changes in filter responses are simultaneously displayed as poles and zeros are moved or deleted. Rectangular or polar coordinate systems can be used together with zoom capabilities for precise placement of poles and zeros. **Momentum Data Systems, Inc., 17330 Brookhurst St., Suite 140, Fountain Valley, CA 92708; (714) 378-5805, FAX: (714) 378-5985, Internet: http:// www.mcs.com.**

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CIRCLE NO. 388

Free Software Determines Telecom System Features

This powerful suite of analysis and planning tools can transform a personal computer into a complete design center for passive RF communications systems.

COMMUNICATIONS SYSTEMS DESIGNERS NOW have a design tool that will not cost them an arm and a leg. In fact, it will not cost them anything. The Andrew Microwave System Planner (AMSP) software is offered free of charge from Andrew Corp. (Orland Park, IL). AMSP is a practical suite of software tools that helps electrical engineers configure the passive portion of a complete RF and microwave communications system at frequencies from 3 to 20 GHz. The software and its seven functional routines include all of the features necessary to design a communication site.

AMSP users can create and save communications-system designs for as many as five operating bands by selecting from a library of passive transmission-line components, such as coaxial cable assemblies. The software automatically checks transmission-line components for frequency compatibility and provides performance parameters, such as insertion loss and VSWR, for each transmission-line component, including coaxial cables and connectors. The program also calculates system insertion loss and VSWR for selected cables. A selection program for base-station antennas offers radiation-pattern envelopes (RPEs) for a wide range of antennas, and shows complete specifications for easy viewing, printing, and exporting into other software programs.

Using listings from a family of HELIAX® cable assemblies, designers can specify the exact length of cable run needed for a particular system design.

Engineers can create templates for future designs, simplify the design of multiple sites, obtain an instant visual display of a system's electrical characteristics, and examine changes in performance based on changes in components. Upon completion of a design, the AMSP software provides a user with a customized bill of materials for all of the Andrew parts necessary for the system. The software also enables the system designer to add items to the bill of materials and provides outputs in formats exportable to many other common applications. Users can access any section of the design cycle for review.

The software suite also includes the Andrew Broadcast System Planner (ABSP). This is a design tool for configuring digital- and analog-television broadcast systems. It supports analysis of antennas with various polarizations, and provides output-data-covering antenna patterns, tables of information, and power-analysis data. The ABSP program can generate electronic files of antenna patterns for propagation studies. It is equipped with more than 35 popular broadcast-transmission lines.

In addition, the free software suite also contains the Andrew Terrestrial Microwave Antenna Selection (ANTDES) and AntWind software programs. The ANTDES tool contains information on all the microwave

Software Determines Telecom System Features

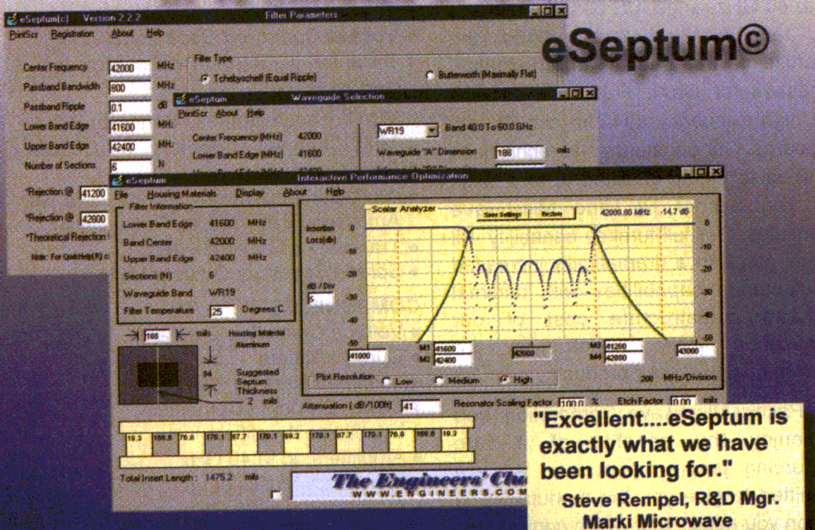
antennas listed in the latest Andrew catalog (No. 37). The program displays and prints radiation-pattern envelopes of all the antennas listed in that catalog. AntWind is a software tool that calculates wind forces transmitted to towers by the mounted antennas. Also, eZGuide is a small program that simplifies the process of ordering microwave-transmission lines. The exact component type, waveguide size, flange type, component dimensions, operating frequency, and finish can be specified. Each product is pictured on screen and diagrammed for easy reference.

Finally, the AMSP suite of tools contains the PSI Select Pressurization Planner, which offers complete information on pressurization products and accessories. The program performs system calculations and dehydrator selection either for a new site or for modifying an existing site. PSI Select Pressurization Planner also provides catalog information and several tutorial pressurization presentations in files compatible with Microsoft PowerPoint.

The AMSP software, which has a built in disabling function for a limited shelf life (but which also ensures that obsolete equipment is not listed in the software), is supplied on a compact-disc-read-only memory (CD-ROM) free of charge. The program runs on any IBM personal computer (PC) or compatible machine with an 80486 or higher microprocessor; a minimum of 6 MB of random-access memory (RAM); Windows 95, 98, or NT operating system; 4 MB of available hard-disk memory; a mouse or other point device; and video-graphics-array (VGA) capability. The software is also available to educational institutions involved in the teaching of RF design and theory. P&A: free; stock. **Andrew Corp., 10500 W. 153rd St., Orland Park, IL 60462; (800) 255-1479, FAX: (800) 249-5444, Internet: http://www.andrew.com.**

CIRCLE NO. 527

ALAN "PETE" CONRAD
Special Projects Editor



Increase test throughput with fast switches

Automatic-test-equipment (ATE) systems rely on fast switching networks to route signals to and from test gear and a device under test (DUT). An article in the November 1999 issue of *Test & Measurement News* from Agilent Technologies (Englewood, CO) details the HP 3499A and HP 3499B switches for ATE applications.

The HP 3499A is a five-slot, full-rack-width switching mainframe unit while the HP 3499B is a two-slot, half-width unit. The switch units operate from DC to 26 GHz. The former can route 200 channels while the later can switch as many as 80 channels.

The newsletter also provides information on new electromagnetic-interference (EMI) measurement software, millimeter-wave production test systems, multiport RF device testing, vector-signal-analyzer (VSA) measurements for digital radio designers, and a precision impedance analyzer. Copies of the November 1999 issue (Issue 59) of *Test & Measurement News* are free on request from: **Agilent Technologies, Test & Measurement News, P.O. Box 3828, Englewood, CO 80111-9998; (800) 452-4844, Internet: http://www.agilent.com/find/tmn59.**

CIRCLE NO. 194 or visit www.mwrf.com

Applying amplifiers to high-speed designs

Amplifier users and designers will find short but interesting product summaries in the October 1999 issue of *Amplifiers, The Analog Devices Solutions Bulletin.* In addition to announcing the availability of a free book for those who visit their website, the bulletin also summarizes a line of amplifier products and applications ranging from cable modems to wireless handsets.

For example, an application paragraph is devoted to the AD8313 RF detector integrated circuit (IC). Designed for RF detection to 2.5 GHz, the IC converts an RF signal to a decibel-scaled value. The IC provides a limiter output for accurate phase detection in phase-shift-keying (PSK) and frequency-shift-keying (FSK) applications.

Another application paragraph covers the AD8321, a single-ended cable-television (CATV) line-driver amplifier with low distortion. The literature explains how this digitally controlled, low-cost amplifier can eliminate the need for a differential-to-single-ended transformer in high-performance CATV systems, while achieving at better than 53-dB spurious-free dynamic range at 42 MHz when driving +11-dBm power into a 75-Ω load. Copies of the October 1999 issue of *Amplifiers, The Analog Devices Solutions Bulletin* are available on request (while supplies last) from: **Analog Devices, One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106; (781) 329-4700, (800) 262-5643, FAX: (781) 326-8703, Internet: http://www.analog.com.**

CIRCLE NO. 195 or visit www.mwrf.com

Exploring the basics of ATM networks

Data transmission occurs over networks tailored for speed. One such network, the asynchronous-transfer-mode (ATM) system, has become a global standard for high-speed telecommunications and data communications. For those interested in learning more about ATM, a handy little book called the *ATM Pocket Guide* is available from Wavetek Wandel Goltermann (Eningen, Germany).

The 64-page pocket guide offers an introduction to ATM, along with a review of the current markets for ATM services and equipment and projections for markets in the year 2000. Solid growth is expected throughout next year, especially in the wide-area-network (WAN) markets. The pocket guide explains this optimism due to the acceptance of ATM by British Telecom and the Germany Deutsche Telekom.

The well-written pocket guide offers a technical description of ATM as well as a simple analogy that helps explain the standard without technical terms. The text describes various ATM interfaces, differences in cell codes, how connections are made, an ATM reference model, network-management techniques, errors and alarms that can occur in ATM systems, as well as error-detection and correction methods.

This is a quite thorough and useful handbook on ATM. It even includes sections on signaling, measurement techniques, and a list of abbreviations. Copies are free from: **Wandel & Goltermann GmbH & Co., Marketing International, Postfach 1262, D-72795 Eningen, Germany; (49) 7121-86-1616, FAX: (49) 7121-86-1333, e-mail: info@wago.de, Internet: http://www.wg.com.**

CIRCLE NO. 196 or visit www.mwrf.com

System Automates Power-Amp Testing

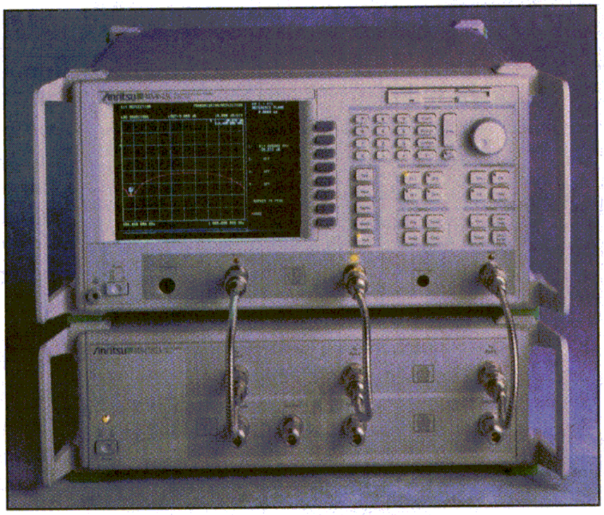
By leveraging the power and speed of a series of vector network analyzers, this measurement system can speed the design and production testing of power amplifiers.

JACK BROWNE
Publisher/Editor

POWER-AMPLIFIER (PA) testing can be one of the more time-consuming series of tasks in wireless system design. But the introduction of an automated Power Amplifier Test System (PATS) from Anritsu (Morgan Hill, CA) may change not only the nature of power-amplifier testing, but of wireless system design itself. The system, which automates and accelerates such complex amplifier tests as harmonic distortion and intermodulation distortion (IMD), is built around the company's series MS4600 "Scorpion®" vector network measurement systems. Versions of the analyzers, and PATS, are available for 10 MHz to 3 GHz and 10 MHz to 6 GHz.

The Scorpion systems revolutionized vector network analysis (see "Vector Analyzers Measure Noise Figure," *Microwaves & RF*, September 1998, p. 103). In addition to traditional S-parameter measurements, Scorpion systems added the capabilities to perform noise-figure measurements, IMD measurements, gain-compression and phase-distortion measurements, as well as harmonic-distortion measurements. The model ME7840A PATS (Fig. 1) builds upon the Scorpion foundation by adding increased power-handling capability through a new test set with all of the necessary precision components, and straightforward application software that allows even first-time users to automate complex PA measurements.

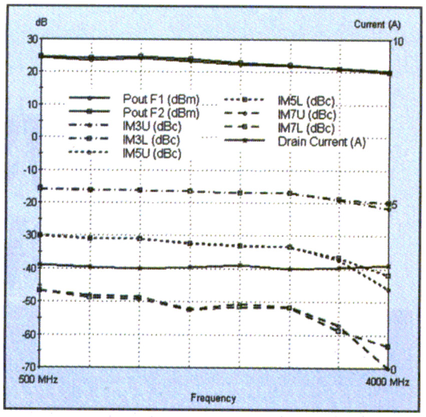
The system offers a wide range of automated measurements, including all four S-parameters (including "hot" S_{22} measurements), gain compression, phase distortion, IMD, as well as power-added efficiency (PAE) at different drain currents. The system can accommodate amplifiers under test (AUTs) at power levels to 100 W. PATS can provide a variety of output displays, including S-parameters as a function of frequency (data that are ideal for use in circuit simulators), compressed output power as a function of frequency, gain, and phase as a function of power, compression and IMD as a function of power, and the gain at compression or saturation. The system can even simultaneously show swept power for four different frequencies.



1. PATS combines a dedicated test set with a powerful vector network analyzer (VNA) and measurement software to automate once-difficult nonlinear amplifier measurements.

PATS includes either a model MS4622C Scorpion vector network measurement system (usable from 10 MHz to 3 GHz) or a model MS4623C system (10 MHz to 6 GHz, shown in Fig. 1), each with direct receiver access (DRA) option, a series MS4782A test set for high-power measurements, and series 2300-353 measurement automation and display software running on a personal computer (PC) [which can be supplied by Anritsu or the customer] equipped with a GPIB card. A block-diagram view of the PA measurement system can be seen in Fig. 2. A quick glance will reveal the internal dual-source architecture of the Scorpion vector network measurement system that makes possible the complex higher-order IMD and other amplifier measurements. Several options are also shown in the block diagram, including a spectrum analyzer, current probe, modulation synthesizer, and preamplifiers to boost the measurement dynamic range.

Each Scorpion vector-network-analyzer (VNA) system packs a great deal of test capability due to a flexible architecture. Each system features two independent, internal RF sources, each with a power range of −15 to +10 dBm. Individual step attenuators with 0-to-70-dB attenuation range (in 10-dB steps) are provided for the sources, resulting in an output-power range of −85 to +10 dBm for each source. A power combiner in each Scorpion system's test set makes IMD testing possible by combining signals from the two internal sources at different power levels and frequency offsets. The DRA option provides access to all four receiver channels for maximum flexibility in measuring forward and reverse S-parameters over a wide range of AUT output powers. Separation of incident and reflected signals for each Scorpion system occurs in the test set.

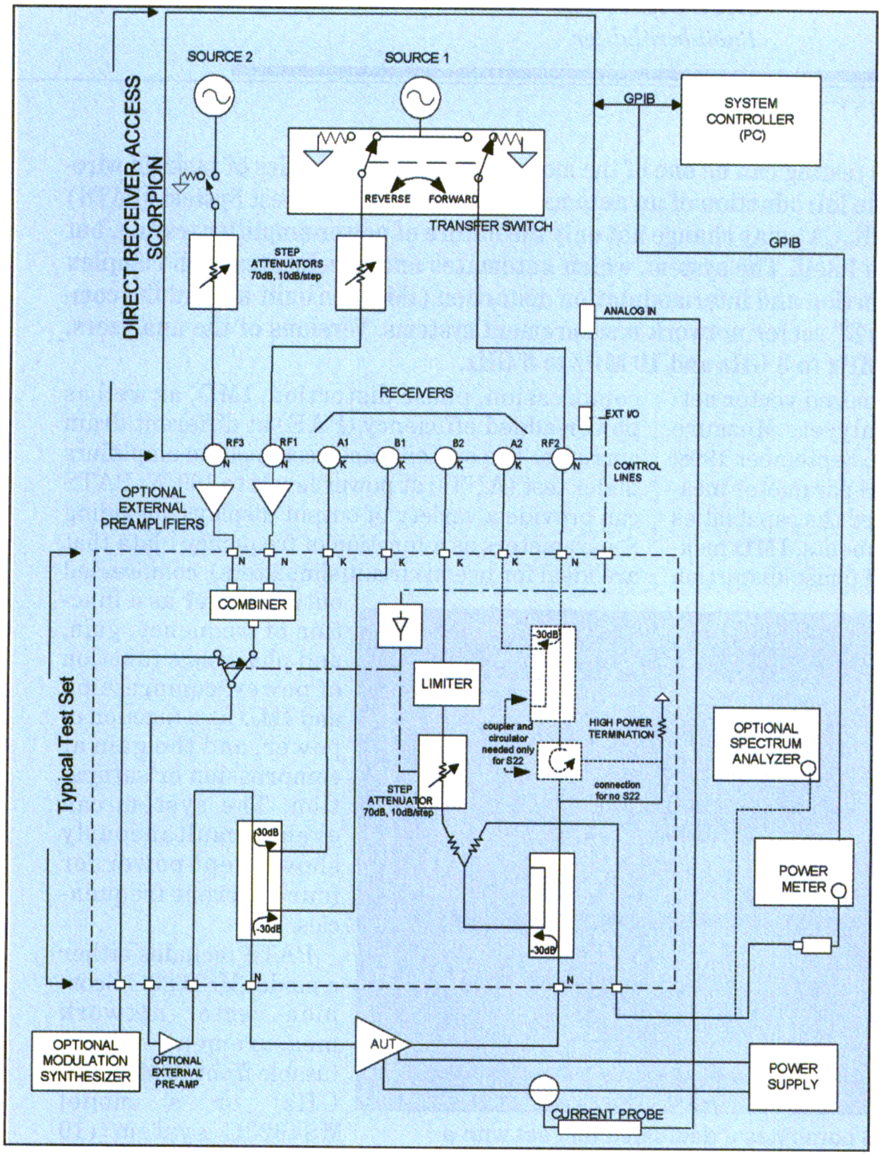


3. An example of the many measurements available with PATS are these output-power and IMD measurements made as a function of frequency. Similarly, gain, harmonic distortion, and PAE can be measured for a particular saturation or compression point.

The PATS system benefits from the measurement power of the Scorpion measurement systems. These analyzers achieve better than 100-dB dynamic range and extremely fast measurement speed—200-μs/point-sweep speed and 1-ms/point power-sweep speed over a 25-dB power-sweep range. This type of measurement speed supports real-time tuning with the Scorpion standalone systems and with PATS.

PATS itself covers a frequency range defined by its test set, typically 0.8 to 2.4 GHz (see table). PATS achieves an overall dynamic range of 80 dB with an IMD measurement dynamic range of 70 dB with two −20-dBm tones spaced 300-kHz apart and measured with a 10-Hz intermediate-frequency (IF) bandwidth. The IMD measurement accuracy is ±1 dB.

A Scorpion system with DRA operates within PATS under control of the software residing in a PC. The software supports tuning and align-



2. The basic architecture of PATS consists of a Scorpion VNA with direct-receiver-access (DRA) capability, a dedicated test set, and measurement software on a PC connected through GPIB.

ment operations by generating real-time graphic displays of the measured data on the PC screen. A user can select overlay plots with single-, double-, or four-channel simultaneous displays of different measurements. For two- and four-channel displays, each measurement occupies one half and one quadrant of the display screen, respectively. The software also supports limit checking and pass/fail testing. Under software control, third-, fifth- seventh-, and ninth-order IMD products can be measured and displayed. Also, the upper- and lower-sideband (USB and LSB) components of the IMD products are measured and can be displayed separately.

Optionally, an external modulation synthesizer and spectrum analyzer can be added to perform adjacent-channel-power-ratio (ACPR) or spectral-regrowth measurements.

The PATS system at a glance

Characteristic	Value	Notes
AUT power output	100 W maximum	Without S22 provision
	50 W maximum	With S22 provision. (Contact Anritsu for custom designs for higher power.)
Bandwidth through test set	0.8 to 2.4 GHz	Without S22 provision
	0.8 to 1.0 GHz or 1.5 to 2.4 GHz	With S22 provision. (Contact Anritsu for custom designs for greater bandwidth.)
AUT input-power range available from PATS	-85 to +10 dBm	This value is for each tone, at combiner input. Provision for preamplifiers provided greater levels.
Sweep rate and data displays	With 10-point power sweep in combination with 10-point frequency sweep selected, the following measurement results over the entire power and frequency ranges are updated on the PC screen within 0.5 s: output power, gain, third-, fifth-, and seventh-order IMD products (LSB and USB), drain current, and PAE. Data are displayed graphically by a combination of overlay and multichannel displays.	
IMD (third-order) dynamic range	70 dB minimum	With 10-Hz IF bandwidth at 300-kHz tone separation and −20-dBm tone levels
IMD accuracy	± 1 dB maximum	At >−60-dBc levels
Port power accuracy	± 0.1 dB maximum	With flat power calibration
	± 1 dB maximum	Without flat power calibration
Automatic calibration (AutoCal)	Provided as an option	
Drift over 60 h	0.15 dB max peak-to-peak	
Dynamic range	80 dB minimum	Overall system including test set
Port match (test ports 1 and 2)	40 dB minimum	Corrected value
Port match (test ports 1 and 2)	16 dB minimum	Incorrected value
Directivity	40 dB	0.8 to 2.4 GHz

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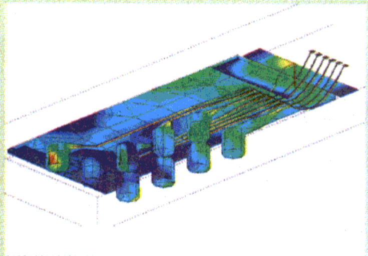
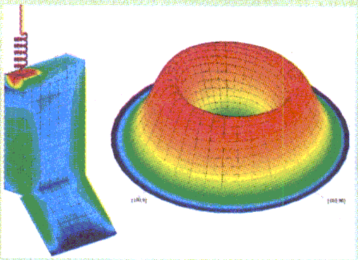
IE3D Simulation Examples and Display

The current distribution on an AMKOR SuperBGA model at 1GHz created by the IE3D simulator

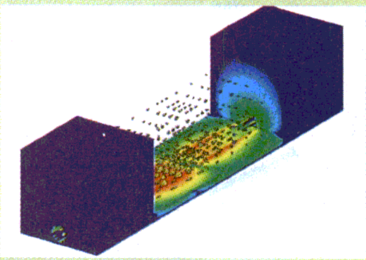


The current distribution and radiation pattern of a handset antenna modeled on IE3D

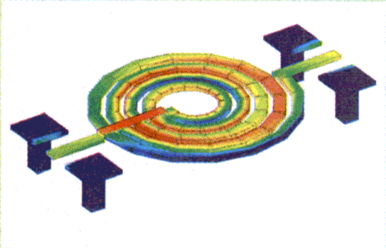


FIDELITY Examples

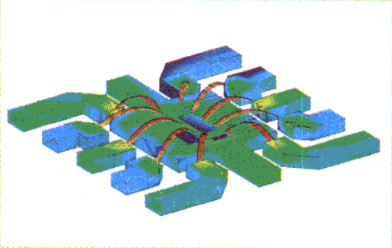
The near field and Poynting vector display on a packaged PCB structure with vias and connectors



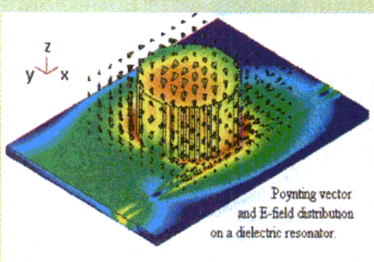
IE3D modeling of a circular spiral inductor with thick traces and vias



IE3D modeling of an IC Packaging with Leads and Wire Bonds



FIDELITY modeling of a cylindrical dielectric resonator and the Poynting vector display



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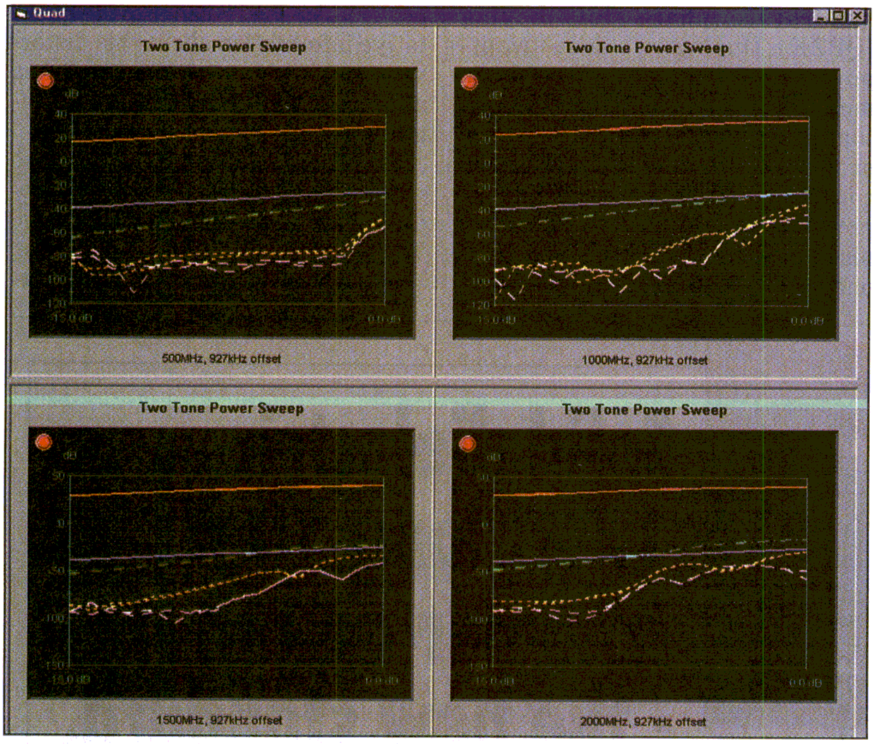
The test set is another important part of PATS. It incorporates a precision step attenuator, Wilkinson-type power combiner, limiter, and 100-W, 30-dB couplers for interconnection to the Scorpion's four test ports (two reference and two test channels). The PATS calibration is performed with the test set in place, at the connectors where AUT will be connected directly. Therefore, the test-set components and cables are included in the calibration loop and their effects are calibrated out, resulting in correct and accurate measurements of the AUT.

PATS offers a great deal of measurement power and flexibility, accommodating amplifiers at power levels to 100 W continuous wave (CW). For example, the system can evaluate output power as well as various orders of IMD as functions of swept frequency, while also displaying the DC current that is drawn by the AUT for the frequency range (Fig. 3). PATS actually has two measurement modes—S-parameter mode and power-measurement mode. The S-parameter mode is similar to the functionality offered by the standard Scorpion analyzers, with measurement results that are displayed on the PC screen. The power-measurement mode offers a variety of swept and multi-tone measurements. This includes two-tone power sweeps, where the input power of two tones is swept and measurements can be made of output power and compression (for each tone), IMD for the USB and LSB, PAE, and drain current.

In addition, measurements can be made of output power and IMD as a function of frequency for a particular two-tone 1-dB compression point (or any compression point from 0.5 to 3.0 dB), amplitude-modulation-to-phase-modulation (AM-to-PM) conversion, gain as a function of frequency for a particular compression point or saturation level, and (with an external current probe) measurement of the instantaneous power-supply current PAE.

The AM-to-PM-conversion test, for example, is a useful measure of the type of distortion that can degrade signals with PM, such as quadrature phase-shift keying (QPSK). During two-tone swept-power measurements, PATS can measure the gain and phase of each tone as a function of input power in order to determine the AM-to-PM conversion for each tone. When the power is swept, an AUT's output phase may change as a function of the output power (and, thus, the input power). The PATS can provide qualitative information about this distortion, and it gives engineers an idea about the expected effects of degradation on signals with PM.

PATS is a powerful tool for those who are involved in design and production of wireless and other PAs. The software provides an intuitive, Windows-based graphical user inter-



4. PATS can also be used to view four different measurements simultaneously, using its multiple-screen display capability.

face (GUI) that is easy to learn, while the hardware provides the measurement capability to thoroughly exercise the nonlinear characteristics of a medium-to-high-power amplifier. Tests performed in the power-measurement mode are updated as fast as 0.5 s (two updates per second), allowing four separate displays to be shown on the PC screen simultaneously (Fig. 4). Operators can select all four screens for one type of test, or use the screens for different tests to compare different performance parameters under a particular set of conditions. When two- or four-channel displays are selected, each display occupies one half or one quadrant of the PC screen, respectively. **Anritsu Co., 685 Jarvis Dr., Morgan Hill, CA 95037; (800) 230-2972, (408) 776-8300, FAX: (408) 776-1744, e-mail: kchurch @awc.anritsu.com, Internet: http:// www.anritsuwiltron. com.**

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Top Products of 1999

Innovations could be found in all areas during 1999, as important new products emerged in hardware, software, and test equipment.

JACK BROWNE
Publisher/Editor

FINISHING the decade with a flourish, the high-frequency industry reveals numerous product innovations in 1999 in all areas—hardware, software, and test equipment. It was a year with many peaks and valleys, with continued growth in commercial wireless markets and a predictable flatness to military markets. Many of the new products introduced in 1999 reflect optimism for an increase in wireless activity. What follows is a list of some of the year's outstanding product developments.

The Top Products roster is based not only on technological innovation, but also on practical merit to the high-frequency design community (i.e., how much benefit is offered to how many engineers). As expected, several integrated circuits (ICs) can be found on the list. As building-block components for larger systems, ICs often pave the way for future developments in systems and test equipment. For example, the AD8361 IC from Analog Devices (Wilmington, MA) is a true root-mean-square (RMS) power detector that will have a drastic impact on how engineers measure power levels in communications systems. Capable of evaluating continuous-wave (CW) and complex modulated signals, the silicon AD8361 supports measurements through 2.5 GHz using a patented technique. It performs an

Top Products of 1999 (in alphabetical order)

Agilent Technologies' ADS Version 1.3 software suite (November cover, p. 165)

Agilent Technologies' 8960 series 10 model E5515A wireless communications test set (March, p. 135)

ANADIGICS' microwave DC-to-DC converters (June cover, p. 125)

Analog Devices' AD8361 true RMS power detection IC (September cover, p. 140)

Anaren Microwave's Xinger line of passive components (May, p. 218)

Anritsu Corp.'s ME7840A Power Amplifier Test System (PATS) (December cover, p. 213)

Anritsu Corp.'s MS2711 handheld spectrum analyzer (May cover, p. 201)

Cree Research's CRF-20010 10-W SiC MESFET (October, p. 138)

Eagleware Corp.'s GENESYS Version 7 software suite (August cover, p. 141)

Giga-tronics' 8650A universal power meter (January, p. 132)

Maxim Integrated Products' MAX2600 line of SiGe ICs (February, p. 140)

Maxim Integrated Products' MAX104 2.2-GHz ADC (March cover, p. 128)

National Semiconductor's LMX3162 Bluetooth radio transceiver IC (April, p. 138)

Sonnet Software's free Sonnet Lite EM simulation software (August, p. 152)

STMicroelectronics' SD2923 300-W MOSET device (December, p. 228) implicit RMS computation, with the filtered output of a squaring circuit being applied to a square-rooting circuit with a conversion gain of 7.4 V/V RMS.

One of the first ICs to support Bluetooth and HomeRF applications (see special Bluetooth supplement starting on p. 145), the LMX3162 from National Semiconductor (Santa Clara, CA) is a bipolar-complementary-metal-oxide-semiconductor (BiCMOS) 2.4-GHz transceiver on a chip. It contains a 1.3-GHz phase-locked loop (PLL), a 2.5-GHz low-noise mixer, intermediate-frequency (IF) amplifier, frequency discriminator, received-signal-strength-indicator (RSSI) circuit, frequency doubler, and buffer amplifier. Building upon the company's strong foundation in Digital European Cordless Telecommunications (DECT) IC solutions, the LMX3162 has already been implemented in several European Bluetooth/HomeRF products.

Silicon (Si) processing also led to the year's most impressive analog-to-digital converter (ADC), the MAX104 from Maxim Integrated Products (Sunnyvale, CA). Using an Si-bipolar process capable of transistors with 27-GHz cutoff frequencies, the MAX104 offers sampling speed of 1 Gsamples/s with 8-b resolution, at conversion signal bandwidths exceeding 2.2 GHz. The MAX104 integrates a fast track-and-hold (T/H) amplifier and a high-speed quantizer for digitizing signals from DC to 2.2 GHz. With an analog input frequency of 125 MHz, the device achieves a spurious-free dynamic range (SFDR) of 68 dB.

The company also garnered a Top Product award for being among the first commercial suppliers of silicon-germanium (SiGe) ICs. The MAX2680, MAX2681, and MAX2682 downconverter mixers and the MAX2640 and MAX2641 low-noise amplifiers (LNAs) are fabricated not at IBM's well-known SiGe foundry (Hopewell Junction, NY) but in Maxim's own SiGe foundry (one of the few companies with such capabilities). The mixers are designed for applications from 400 to 2500 MHz, with varying levels of noise and dynamic range. The MAX2680, for example, has a noise figure of 6.3 dB at 900 MHz and 8.3 dB at 1950 MHz. It offers 11.6-dB small-signal gain at 900 MHz and 7.6-dB small-signal gain at 1950 MHz.

Perhaps the ultimate capabilities of the SiGe process may be more apparent in the LNAs, with performance rivaling that of GaAs LNAs. The MAX2640 LNA, for example, exhibits a noise figure of 0.9 dB at 900 MHz, with small-signal gain of 15.1 dB at that frequency. The higher-frequency model MAX2641 achieves a noise figure of 1.3 dB at 1900 MHz, with small-signal gain of 14.4 dB at that frequency.

Two other ICs of distinction aided engineers in digital and optical areas by making efficient use of a new DC-to-DC-converter technology. The two integrated GaAs photodetector/transimpedance amplifiers (TIAs) from ANADIGICS, Inc. (Warren, NJ), models AMT128502T46F/L (850-nm) and AMT121302T46F/L (1300 nm), incorporate the company's patented on-chip negative-voltage-generator circuitry to bias each circuit's photodetector. In contrast to conventional switched-mode DC-to-DC converters operating at switching frequencies to 250 kHz, these on-chip converters work at rates past 10 GHz. With such high switching frequencies, the DC-to-DC converters can be housed in conventional optical surface-mount packages. The optical ICs, which achieve minimum bandwidths of 1.5 GHz, are targeted at Gigabit Ethernet systems operating at 1.25 Gb/s and Fibre Channel applications at 1.064 Gb/s.

Not to be outdone by the ICs, two discrete devices made the Top Products list for 1999, the SD2923 N-channel metal-oxide semiconductor field-effect transistor (MOSFET) from STMicroelectronics (Montgomeryville, PA) and the CRF-20010 MESFET from Cree Research (Durham, CA)—the first commercial power transistor based on silicon carbide (SiC). The former is a single-ended, gold (Au)-metallized vertical MOSFET designed to generate as much as 300-W CW power through 150 MHz. It yields typical gain of 22 dB and efficiency of 55 percent at 30 MHz, with a low junction-to-case thermal resistance of 0.27°C/W for maximum power dissipation of approximately 650 W.

The latter transistor leverages Cree's experience with SiC to achieve 10-W output power from 400 to 2500 MHz, with 12-dB gain at 2 GHz.

Of course, not all components on the Top Products list were ICs or active devices. The Xinger line from Anaren Microwave (East Syracuse, NY) represents a dramatic advance in passive-component technology. Supporting the trend for shrinking size in printed-circuit boards (PCBs), these surface-mount components occupy little more space than a standard resistor. The Xinger line includes baluns, hybrid couplers, directional couplers, and power dividers for medium- and high-power applications through 4 GHz. For example, the tiny model 3W525 balun is ideal for personal-communications-services (PCS) and next-generation wireless systems. It operates from 1.8 to 2.5 GHz with maximum insertion loss of 0.3 dB. The peak-to-peak amplitude balance is ±0.4 dB while the unbalanced port return loss is 15 dB. The output ports are offset by a 180-deg. phase difference, accurate within 5 deg. In spite of the small size of only 0.65 × 0.48 × 0.075 in. (1.65 × 1.22 × 0.19 cm), the balun can handle CW power levels to 150 W.

Test equipment loomed large on the Top Products list for 1999, with several companies offering new twists to old ideas. The MS2711 from

Anritsu Co. (Morgan Hill, CA), represents a major redesign of a traditional test instrument—the spectrum analyzer—into a compact package that weighs only 4 lbs. (1.8 kg). In spite of measuring only 6.75 × 10.5 × 2.25 in. (17.145 × 26.67 × 5.715 cm), the MS2711 is a full-featured, frequency-synthesized spectrum analyzer capable of scanning 100 kHz to 3 GHz. With a displayed dynamic range of 65 dB, the handheld analyzer yields amplitude resolution of 0.1 dB with amplitude accuracy of ±1/5 dB.

The 8650A universal power meter from Giga-tronics, Inc. (San Ramon, CA) is an instrument with an eye to next-generation wireless-communications testing. With a video bandwidth in excess of 10 MHz, the 8650 can automatically measure the peak and average power levels of complex modulated signals, including the emerging standards for WCDMA and time-division-multiple-access (TDMA) signals. The meter, which operates from 10 MHz to 40 GHz with a power-measurement range of –70 to +47 dBm (depending upon choice of power sensor).

On a larger scale, the 8960 series 10 model E5515A wireless-communications test set speeds the manufacturing test of wireless communications handsets on the order of millions of pieces. Introduced in March as a Hewlett-Packard Co. (Spokane, WA) product, the test set is now an Agilent Technologies' product (with the measurement part of the company changing names in November). The first version of the 8960 series 10 model E5515A test set is aimed at GSM handset testing, although the system's modular design and flexible architecture will enable full support of virtually all wireless-communications standards, including TDMA and CDMA systems.

The mobile tester performs all the measurements needed for final GSM handset qualification, including call processing, transmitter testing, receiver testing, and audio testing. The test system represents the first use of the company's proprietary Reduced Instruction Parallel Processing (RIPP) architecture which simplifies remote programming of complex and parallel measurements while making it possible to run concurrent measurements (such as transmitter and receiver testing). In the test system, three microprocessors are run in parallel, with two independent receiver channels allowing call-processing measurements to be completely uncoupled from radio testing. Compared to earlier GSM test systems requiring 90 s for radio measurements on a handset, the new system requires only 9 s.

Another major test system, which is previewed in this issue (see p. 213), brings simplicity to complex amplifier measurements. The model ME7840A Power Amplifier Test System (PATS) from Anritsu Corp., the company's second product on the

Top Products list, performs once-difficult measurements, such as intermodulation distortion (IMD) and PAE, under computer control. Based on the firm's MS4600 Scorpion line of vector network measurement systems, the PATS provides typical frequency coverage of 0.8 to 2.4 GHz and can test amplifiers with output power levels up to 100 W.

Software was well-represented on the Top Products list, with three new products. Two of these were multifunction software suites, the GENESYS Version 7 from Eagleware Corp. (Tucker, GA) and Version 1.3 of the Advanced Design System (ADS) from Agilent Technologies. The third was an electromagnetic (EM) simulator, Sonnet Lite, amazingly offered free of charge by Sonnet Software (Liverpool, NY). GENESYS Version 7 brings new speed and power to low-cost simulations performed on a personal computer (PC). The software not only includes filter-, oscillator-, and amplifier-design modules, but introduces a fast EM simulator, =EMPOWER=, for multilayer circuit simulations.

Version 1.3 of the ADS software suite was the first new product announced by the newly formed Agilent Technologies. The new version offers for the first time Design Guides, which are dedicated modules focusing on particular application/design areas, such as PLLs. Authored by industry experts, DesignGuides allow designers to save time in the development of products within a specific technology area. The new version of ADS also introduces noise analysis at multiple frequencies, real-time tuning, SPICE import capability, and yield-sensitive histogram capability.

The last software tool, Sonnet Lite, may have created the most noise upon its introduction, with more than 3000 copies given away at the recent Microwave Theory & Techniques Symposium (MTT-S). The software can perform EM analysis of planar structures, compute S-, Y-, and Z-parameters as well as SPICE equivalent circuits, and plot responses on a wide range of formats, including Smith charts and Cartesian graphs. For those seeking an introduction to EM simulation and analysis, this compact-disc read-only memory (CD-ROM) is a "must have."

Many fine products introduced in 1999 did not make the Top Products list. Honorable mentions certainly belong to Mini-Circuits (Brooklyn, NY) for their development of an RF choke capable of operating to 8 GHz (see October cover, p. 131), to REMEC Magnum (San Jose, CA) for their innovative SectorShape hub-mounted local-multipoint-distribution-system (LMDS) antennas (see November, p. 177), and to RDL, Inc. (Conshohocken, PA). for their CTS-1000 cable-television (CATV) distortion measurement system (see September, p. 117).

High-Power MOSFET Targets VHF Applications

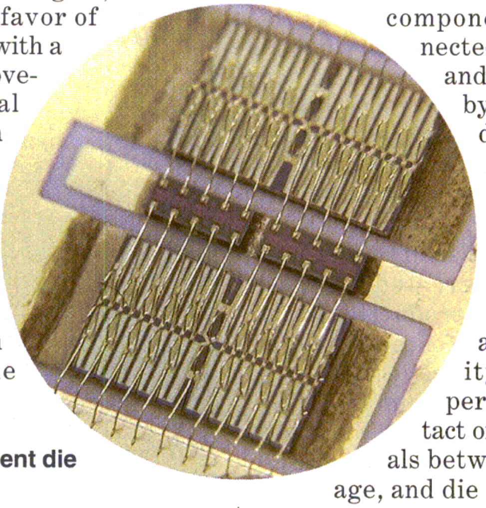
A single-ended silicon MOSFET offers 300-W output power and enhanced thermal packaging for a variety of applications.

Jim Davies
Design Engineer
Dr. Brett Hanson
Staff Engineer
STMicroelectronics, 141 Commerce Dr., Montgomeryville, PA 18936; (215) 361-6400, FAX: (215) 362-1293, Internet: http://www.st.com.

HIGH-OPERATING junction temperatures can consume the best high-power RF transistor. If consideration is not taken to remove the heat generated by the junction, degradation in device performance and reduction in its operating lifetime will be the consequences. The SD2923 300-W metal-oxide semiconductor field-effect transistor (MOSFET) from STMicroelectronics, Inc. (Montgomeryville, PA) overcomes these classic device limitations through a thermally enhanced package that has lower thermal resistance than widely used pedestal packages. The silicon (Si) MOSFET is suitable for use to 150 MHz with high gain which makes it ideal for various applications including plasma generation, excitation, and frequency-modulation (FM) broadcast amplifiers.

The thermally enhanced package has lower thermal resistance than the widely used pedestal (P) packages. A finite-element analysis was performed on a similar non-pedestal (NP) package and the results showed a 10°C lower peak temperature than the P package under the same thermal conditions. The SD2921-10 and a similar ST device were then chosen to further demonstrate the enhanced thermal properties of the NP package over the P package under normal operating conditions. These devices use the same transistor die and share the same mechanical dimensioning. The main difference between the devices is that the SD2921-10 is a NP package and the other was a P package. Both devices were operated under RF conditions and their corresponding die-junction temperatures were measured using an infrared (IR) imaging unit. Again, the results were in favor of the NP package with a 25-percent improvement in thermal resistance which corresponds to an operating life improvement of approximately 400 percent.

It should be noted that in comparison, the SD2923 is a larger device than the SD2921-10, but the overall structure of the SD2923 package and the SD2921-10 package are the same and both devices use the same transistor die.



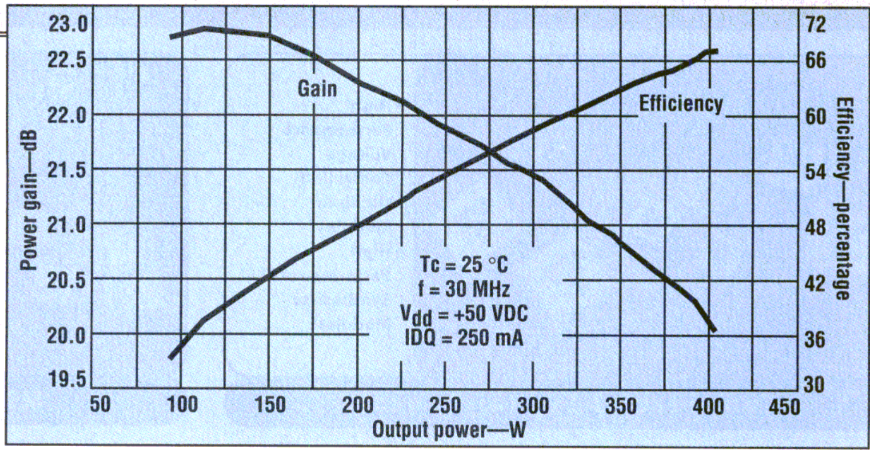
1. The SD2923 discrete component die consists of two enhancement-mode DMOS transistor die that are eutectically mounted in a parallel configuration.

The SD2923 discrete component design consists of two 40-cell, N-channel, enhancement-mode double-diffused-metal-oxide-semiconductor (DMOS) transistor die that are eutectically mounted in a parallel configuration (Fig. 1). Each cell consists of 60, 127-μm gate fingers, yielding a source periphery of 1220 mm, supporting a maximum drain current of 40 A. The transistor dice are separated by a metallized gate rail where two, thin-film, gold (Au)-metallized resistors are eutectically mounted.

For improved current capability and lower inductance, the components are connected to each other, and to the package by Au wire with a diameter of 2 mils (50 μm). Since the dice and package use Au metallization and the bond wires are also Au, reliability issues that pertain to the contact of dissimilar metals between wire, package, and die are eliminated. The package is sealed with a ceramic lid, ensuring the complete integrity of the wires and Si die while prevent-

ing foreign objects from entering the package which could cause device reliability problems.

The SD2923 has a very high transconductance (gfs) which denotes the DC gain of a MOSFET. It is defined as the ratio of the infinitesimal change in drain current corresponding to the infinitesimal change in gate voltage at a specified current



2. The SD2923 was characterized in a common-source mode at 30 MHz with a circuit optimized for best return loss and maximum power delivered to the load with a typical gain and efficiency of 22 dB and 55 percent, respectively.

level and drain bias. It is important to measure the gfs in the device's region of operation where the gfs is independent of the drain bias (V_{DS}). The gfs of the SD2923 measured at a drain-source voltage of +10 VDC and a corresponding drain current of 10 A is typically 13 S.

Impedance data across a range of frequencies may be the most important information that an amplifier designer needs. Without it, the RF performance may not come close to the values found in the data sheet. With properly measured data and sound impedance-matching techniques, many hours of circuit-design iterations can be saved. For this reason, impedances were measured to help design amplifiers in high-frequency, FM broadcast, and plasma-generation markets (see table).

An important item to note is the small change in input impedance from 30 to 150 MHz. This can be attributed to the gate resistors which presents a real impedance at the input across the full band of frequencies. Matching is accomplished by using transmission-line transformers and lumped elements that are commonly found in many amplifiers.

The SD2923 was characterized in a common-source mode at 30 MHz with a circuit optimized for best return loss and maximum power delivered to the load with a typical gain and efficiency of 22 dB and 55 percent, respectively (Fig. 2). The junction-to-case thermal resistance ($R_{TH\text{-}JC}$) was measured under RF oper-

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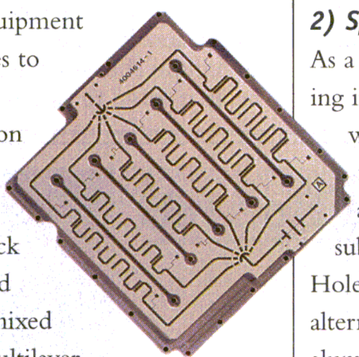

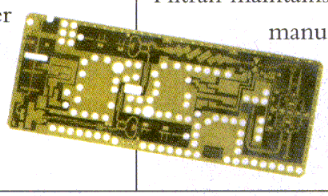

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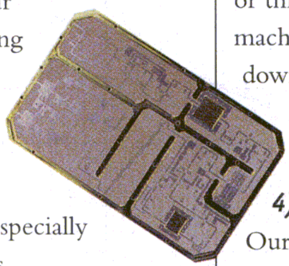

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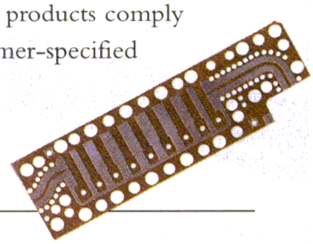

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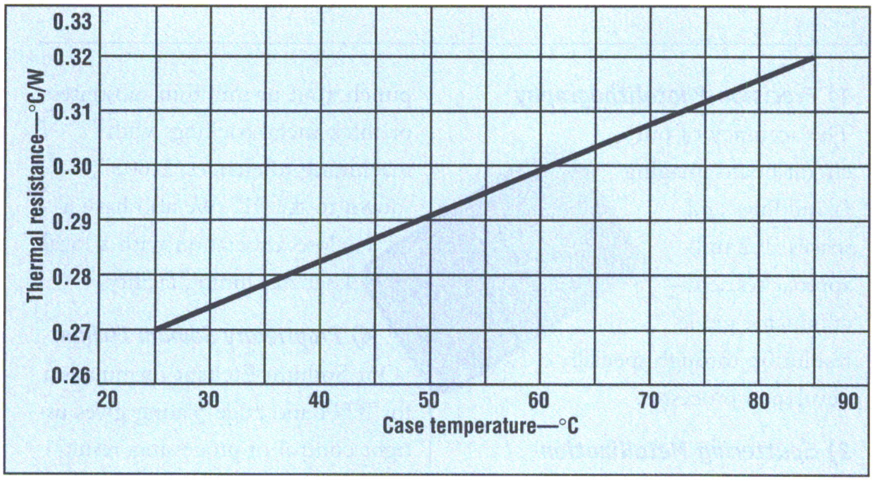
ating conditions using IR techniques to 0.27°C/W, supporting a maximum power dissipation of approximately 650 W (Fig. 3).

The SD2923 is rugged. Most DMOS failures that occur during operating conditions are due to the inability to support the effective drain voltage across the body-drain PN junction during an overvoltage condition when, for example, a mismatched load causes a large voltage-standing wave on the drain terminal. If the device is subjected to an excessive drain-to-source voltage, the electric field across this junction will reach a critical value where the avalanche current will be generated. Under these conditions, current flows from the source to the body, effectively biasing the internal parasitic bipolar transistor to an "on" state, creating a catastrophic failure rather quickly. The voltage that is required to turn on the parasitic transistor has a negative temperature coefficient. Therefore, this particular phenomena is more likely to occur at higher operating temperatures.

It can be noted that some manufacturers of high-power RF devices do not specify a load mismatch, but the SD2923 is guaranteed to sustain a 5:1 load mismatch across all phase angles without degradation in output power when it is returned to 50 Ω. The load mismatch is comparable to devices with similar output-power levels using a push-pull package configuration. The ability of the SD2923 to handle this severe mismatch can be attributed to two design improve-



3. This graph shows the maximum thermal resistance versus case temperature for the SD2923.

Impedance data for the design of amplifiers

Frequency (MHz)	Z_{IN} (Ω)	Z_{DL} (Ω)
30	1.8 – j0.2	2.8 + j2.3
108	1.9 + j0.2	1.6 + j1.4
150	1.9 + j0.3	1.5 + j1.6

ments over similar devices. The first attribute is a proprietary doping scheme of the transistor die during the fabrication process, supporting high current and voltage swings without inducing turn-on of the internal parasitic bipolar transistor. The second attribute is the lower thermal resistance of the packaging, supporting increased power dissipation of the device. These considerations result in a high breakdown voltage minimum rating of +125 VDC, with a typical value of +145 VDC.

Designing the SD2923 offered two challenges beyond the semiconductor device design. One was due to the high gain of the SD2923 in the high-frequency band and the other was due to the high-power dissipation of the single-ended device. The gfs of the device was very high. As a result, stabilizing the transistor was extremely critical. Without the use of any stabilization technique, the device would oscillate and destroy itself under bias conditions before the RF input was applied. To overcome potential instabilities, gate resistors were employed. These resistors, as previously mentioned, are eutectically mounted inside the package along with transistor die and are wired in series with each gate pad. The layout presents a series resistance to each gate site and, thus, any difference between the site-to-site impedances is small relative to the total. **STMicroelectronics, 141 Commerce Dr., Montgomeryville, PA 18936; (215) 361-6400, FAX: (215) 362-1293.**

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Spectrum Analyzers Facilitate High-Volume Production Testing

Two new spectrum analyzers can help telecom manufacturers develop and test second- and third-generation wireless systems.

DON KELLER
Senior Editor

SPECTRUM analyzers are indispensable instruments for testing and troubleshooting wireless devices and systems. With the inexorable consumer demand for increased versatility and functionality, telecommunications manufacturers must respond by developing and testing second- (2G) and third-generation (3G) equipment. To aid in this generation-transition process, Tektronix, Inc. (Beaverton, OR), in partnership with Rohde & Schwarz GmbH & Co. (Munich, Germany), has introduced two new mid-level spectrum analyzers—models FSP-3 and FSP-7 (see figure).

The FSP-3 and FSP-7 are swept spectrum analyzers (as opposed to real-time spectrum analyzers) and are designed for high-volume production testing of 2G and 3G wireless handsets and base stations. The analyzers support time-division-multiple-access (TDMA), code-division-multiple-access (CDMA), and wideband CDMA (WCDMA) standards. The main difference between the two analyzers is frequency range. The FSP-3 measures signals from 9 kHz to 3 GHz, while the FSP-7 measures signals from 9 kHz to 7 GHz. Frequency resolution—the ability to analyze two adjacent signals on the screen—is 0.01 Hz for both units.

This photo shows the model FSP-3 spectrum analyzer. The two models differ mainly in upper frequency limit.

In the frequency-domain mode, a swept spectrum analyzer repeatedly sweeps through an operator-selected span of frequencies, measuring the root-mean-square (RMS) amplitude value of the signals it encounters. The speed at which the FSP-3 and FSP-7 sweep through a selected frequency span is adjustable from 2.5 ms to 16000 s in 10-percent increments. A slow sweep time reveals more-detailed information, while a fast sweep time reveals fast-changing events. In addition to selecting the span and sweep rate, the operator must select the "chunk" of frequencies over which each amplitude measurement is taken. The width of this chunk is called the resolution bandwidth, and for these models it can be adjusted from 10 Hz to 10 MHz (–3 dB) in steps of 10 Hz, 30 Hz, 100 Hz, 300 Hz, etc.

In the time-domain mode, a swept spectrum analyzer repeatedly sweeps through a frequency span of 0 Hz at an operator-selected center frequency to detect transients—changes in the amplitude of a signal at a particular frequency. The speed at which the FSP-3 and FSP-7 sweep through the 0-Hz span is adjustable from 1 μs to 16000 s in five-percent increments. The maximum resolution is 125 ns. The resolution bandwidth has the same adjustment range in the time-domain mode as in the frequency-domain mode. In the time-domain mode, it should be set as wide as possible to include all the components of the signal.

Other RF characteristics of the analyzers include a total measurement error of 0.5 dB, which supports higher tolerances for the device under test and can increase production yield. A linearity error of 0.2 dB enables precise measurements of such parameters as gain control and adjacent-channel power ratio (ACPR). The RMS detector, used for measuring digitally modulated signals, boasts a dynamic range of 100 dB. The typical displayed average noise level is –155 dBm/Hz. Typical phase noise is –94 dBc/Hz at a carrier offset of 100 Hz, –113 dBc/Hz at 10 kHz, and –145 dBc/Hz at 10 MHz.

In support of their role as automated test instruments, these spectrum analyzers offer features such as computerized test interfaces and automatic test routines. Both models have general-purpose-interface-bus (GPIB), Centronics, and RS-232 interfaces. On the GPIB bus, the analyzers are capable of performing up to 30 measurements per second in the frequency-domain mode and 70 measurements in the time-domain mode, including trace transfer of 501 binary data. The analyzers contain automatic test routines for measuring third-order intercept (TOI), occupied bandwidth (OBW), and phase noise. Other features include a quasi-peak detector, statistical-measurement functions for determining crest factor and complementary cumulative distribution function (CCDF), split screen with separate settings and up to three traces per screen, and editable limit lines including pass/fail indication.

THE MAIN DIFFERENCE BETWEEN THE TWO ANALYZERS IS FREQUENCY RANGE. THE FSP-3 MEASURES SIGNALS FROM 9 kHz TO 3 GHz, WHILE THE FSP-7 MEASURES SIGNALS FROM 9 kHz TO 7 GHz.

The analyzers display their measurements on a thin-film transistor (TFT), 501 × 400-pixel color screen that measures 8.4 in. (21 cm) diagonally. Front-panel controls include dedicated hard keys and unit keys for parameters such as frequency and amplitude, while vertical and horizontal softkey bars support the convenient handling of complex measurement tasks. **Tektronix Measurement Group, P.O. Box 3960, Portland, OR 97208-3960; (800) 426-2200 request code 1176, FAX: (503) 222-1542, Internet: http://www.tektronix.com/measurement. Rohde & Schwarz GmbH & Co. KG, Muhldorfstrabe 15, D-81671, Munich, Germany; (49) 180-5124242, FAX: (49) 89-41293777, Internet: http://www. rsd.de.**

CIRCLE NO. 53 or visit www.mwrf.com

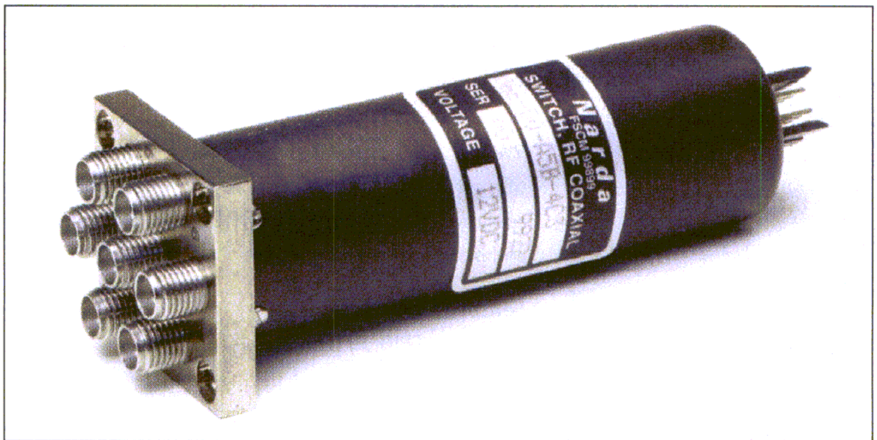
Compact Coaxial Switch Fits Single-Slot VXI Card

A proven coaxial switch design was made more compact by carefully reconsidering its mechanical and electrical configurations.

JACK BROWNE
Publisher/Editor

ELECTROMECHANICAL switch design requires a precise balance between mechanical and electrical requirements. In order to redesign a reliable single-pole, six-throw (SP6T) coaxial switch into a smaller enclosure, the engineers at Narda Microwave-East (Hauppauge, NY) had to consider not only the package, but associated electronic components, such as the solenoids. The end result, however, is a more compact DC-to-26.5-GHz SP6T switch that can readily fit the tight space requirements of a single-slot C-size VXI card.

Even though this new compact switch employs closely spaced ports (see figure), it achieves isolation of at least 65 dB across its full DC-to-18-GHz frequency range (45-dB isolation to 26.5 GHz). The cylindrical switch housing measures only 2.99 in. (7.5946 cm) long with a diameter of 0.993 in. (2.522 cm). According to the company's chief engineer for switch products, Vinnie Leikus, the new design sacrifices nothing in terms of reliability when compared to the firm's larger, older designs. "Because the connectors are closer together in the new switch, careful design techniques were required to maintain the high port-to-port isolation," offers Leikus. "In the process, we found that we needed a new cavity design as well," he adds. Electromagnetic (EM) simulation software proved to be invaluable in the redesign of the switch cavity, saving numerous prototyping steps.



This SP6T coaxial switch provides low loss and high isolation through 18 GHz and is designed to fit in a single-slot C-size VXI card format.

DESIGN PROJECT

Development of a more compact electromechnical switch was not a trivial task, notes Leikus, "We had to redesign not only the switch cavity, but the solenoids and the switch driver, using surface-mount technology to shrink the size of the circuit board." The redesigned switch cavity supports operation through 26.5 GHz, depending on the choice of coaxial connector.

The new switch design employs a self-wiping contact action for reliable electrical contacts. Since the switches are used in nonhermetic environments, organic films can accumulate over time on the switch contacts. By using switch con-

The compact switch at a glance

Frequency range	DC to 3 GHz	3 to 8 GHz	8 to 12 GHz	12.4 to 18.0 GHz	18 to 26.5 GHz
Maximum VSWR	1.25:1	1.30:1	1.40:1	1.50:1	1.9:1
Maximum insertion loss	0.2 dB	0.3 dB	0.4 dB	0.5 dB	0.9 dB
Minimum isolation	70 dB	60 dB	60 dB	60 dB	45 dB

tacts with a wiping action, contact can be made by cutting through this organic film, which can be as thick as 40 Angstroms. The self-wiping action cleans the contact every time the switch contact closes.

IMPROVED PERFORMANCE

The smaller size of the new switch design actually resulted in some improvements in insertion loss and VSWR compared to existing designs (see table). The maximum VSWR through 3 GHz is only 1.15:1, with performance of 1.25:1 to 8 GHz, 1.35:1 through 12 GHz, and reaching a maximum of only 1.45:1 at frequencies through 18 GHz. The switch also enjoys low insertion loss, with maximum loss of 0.15 dB through 3 GHz, and maximum insertion loss of 0.25 dB through 8 GHz, reaching a maximum of only 0.45 dB through 18 GHz. The isolation performance is also consistently good, with minimum isolation of 85 dB from DC to 3 GHz, dropping to a minimum of 65 dB through 18 GHz.

SP6T SWITCH

Development of the SP6T switch was part of Narda's joint Performance Partners program with Racal Instruments (Irvine, CA). In fact, the development of the compact SP6T coaxial switch has made possible the design of Racal's model 1260-67 VXI switch module (see Racal Instruments' website at http://www.racalinst.com for more information). The module, which can pack as many as six of the Narda SP6T switches into a single C-size VXI card slot, operates to 18 GHz or 26.5 GHz and supports complex signal-routing operations in high-throughput, automatic-test-equipment (ATE) systems.

The new switch is designed to channel signals across modern communications systems and is ideal for ATE applications. The switch connections self-terminate to 50 Ω when not selected. **Narda Microwave-East, 435 Moreland Rd., Hauppauge, NY 11788; (516) 231-1700, FAX: (516) 231-1480, Internet: http://www.nardamicrowave.com.**

CIRCLE NO. 54 or visit www.mwrf.com

Front-End RF IC Reaches 6 GHz

This monolithic transmit/receive front end serves spread-spectrum applications in the 5.1-to-5.8-GHz ISM band.

DON KELLER

Senior Editor

SPREAD-SPECTRUM devices for wireless local-area networks (WLANs), hyper LANs, portable data terminals, and remote-monitoring and unlicensed wireless devices in the industrial-scientific-medical (ISM) band are proliferating, and the demand for such devices is on the rise. To meet this demand, Araftek, Inc. (Freemont, CA) has developed a gallium-arsenide (GaAs) integrated-circuit (IC) transmit (Tx)/receive (Rx) RF front end that operates from 5.1 to 5.8 GHz.

The model AR7501 IC contains a low-noise amplifier (LNA), a power amplifier (PA), and an RF switch (see figure). The chip is designed to operate in a half-duplex transceiver. When the transceiver is in the Rx mode, the chip's PA is deactivated, the LNA is activated, and the RF switch feeds the received signal from an external antenna to the LNA input. The LNA output is then sent on to the other stages of the receiver. In the Tx mode, the LNA is deactivated, the PA is activated, the PA amplifies the transmission signal, and the RF switch feeds the amplified signal from the PA output to the external antenna. The chip's LNA and PA can operate individually, but not simultaneously.

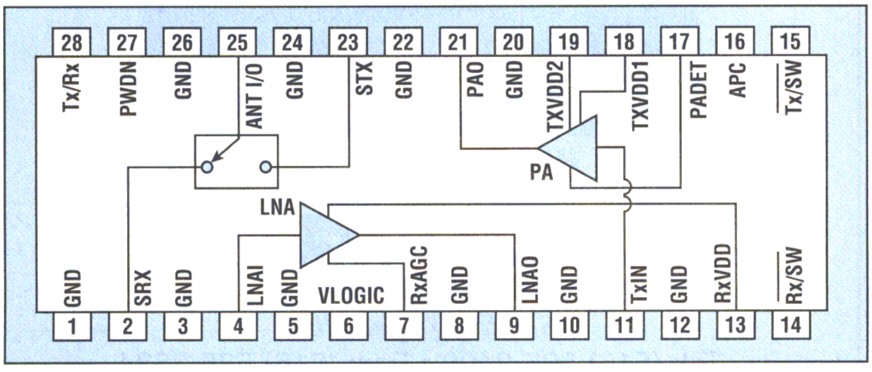
The LNA provides a typical gain of 21 dB that is flat to within ±1 dB from 5 to 6 GHz. Its typical power output at the 1-dB compression point is +3.5 dBm, and its typical noise figure is 3.5 dB. With partial external impedance matching, its typical input return loss is 8 dB and its typical output return loss is 12 dB. The LNA typically draws 36 mA from a +5-VDC power supply.

The PA provides a typical gain of 18 dB that is flat to within ±1 dB from 5.15 to 5.85 GHz. The chip's automatic-power-control (APC) pin gives designers access to an output-power control circuit that allows the PA output to be adjusted from +11 to +18 dBm. The PA's typical power output at the 1-dB compression point is +23.5 dBm at 5.15 GHz and +21.5 dBm at 5.85 GHz. With partial external impedance matching, its typical input return loss is 13 dB and its typical output return loss is 6 dB. The PA typically draws 308 mA from a +5-VDC power supply.

At 5.15 GHz, the RF switch presents a typical insertion loss of 2.3 dB in the Rx mode, and 2.2 dB in the Tx mode. With partial external impedance matching, the switch typically provides 13 dB of isolation and an input/output (I/O) return loss of 10 dB from 5 to 6 GHz. With a 10-pF load on the control line, the switching speed is less than 5 μs.

The AR7501 includes power-down logic circuitry that can be activated through the use of an external positive-metal-oxide-semiconductor (PMOS) transistor switch. The chip is housed in a 28-pin quarter-sized outline package (QSOP) with an exposed heat slug, making it compatible with Portable Computer Memory Card International Association (PCMCIA) card formats. **Araftek, Inc., 48531 Warm Springs Blvd., Suite 416, Freemont, CA 94539; (510) 580-2501, FAX: (510) 580-2508, Internet: http://www.araftek.com.**

CIRCLE NO. 56 or visit www.mwrf.com



This block diagram shows the three major functional components of the AR7501 front-end IC.

Power Module Line Expands To Suit DCS and PCS

A company expands its line of amplifier building blocks to accommodate DCS, PCS, and IMT-2000 (third-generation) base-station equipment.

PETER STAVENICK
Managing Editor

LINEAR-POWER-AMPLIFIER (LPA) manufacturing is often expensive and unpredictable in terms of time-to-market pressures. Yield-compromising hand-assembly steps are often the norm in LPA manufacturing. Yet, there is a way for an LPA to be automatically mounted, attached, and tested using conventional surface-mount-technology (SMT) components, reflow soldering, and automatic test equipment (ATE). The QPP-301 from XEMOD (Sunnyvale, CA) is an IMT-2000 third-generation (3G) 100-W QuikPAC™ module that spans the 2110-to-2170-MHz band. It is package and pin compatible with the cellular and digital-communications-services (DCS)/personal-communications-services (PCS) parts. The end result of modularization is a design cycle that is reduced by half with simplified board layouts and interchangeability in dual-band designs.

QuikPAC is a building-block system for the design and production of LPAs. The modules can be used as individual RF gain and power stages, or combined to provide very-high power-output sections. They can also be used in sets to create multistage amplifiers and to implement intermodulation-distortion (IMD) correction systems. All RF connections to QuikPAC modules are 50 Ω. This simplifies the matching of modules to other active or passive elements, while simplifying testing at the module or subassembly level. It eliminates the need to design complex matching structures for the low impedance that is common to RF power transistors.

Modules in the QuikPAC system include low-power gain stages with high intercept points to provide distortion-free gain in the input sections of medium to power high-linearity amplifiers for use in the error path of a feedforward design. These modules, which are multistage corrected amplifiers, can also be used as stand-alone units. Providing gain and high power for driver and output sections, power levels to 200-W peak envelope power (PEP) support the most advanced designs. Phase- and amplitude-modulation modules can adjust the phase and gain of signals in the error path in order to fine tune IMD suppression. When used with the phase/amplitude controller (PAC), this adjustment is continuous and automatic. The PAC circuit senses the amplitude and/or phase of the carrier at several points in the system and uses this information to fine tune the IMD cancellation.

The company's recent line of PCS products includes the QPP-201 with 25-W power stages (PEP) and the QPP-205 which offers 120-W power stages (PEP). DCS products, which span 1805 to 1880 MHz, include the QPP-207 with 25-W power stages and the QPP-211 with 120-W power stages (see table).

The standard version of the QPP-301 supports 100-W power, 9.5-dB typical gain, ±0.2-dB gain variation, and –26-dBc IMD. Drain efficiency for two-tone operation at rated PEP is 25 percent with less than 1.7:1 VSWR. In addition to 50-Ω RF connections, other features include top-side grounds, bias leads that are separate from RF, and single-polarity biasing. The compact device geometry leads to simpler and more consistent matching and higher specific output powers.

Comparing the RF power modules

Standard version	Frequency range (MHz)	Power (W)	Typical gain (dB)	Drain efficiency at two-tone operation	Typical input VSWR
QPP-207	1805 to 1880	25	10.5	30 percent	<1.7:1
QPP-211	1805 to 1880	120	10.5	30 percent	<1.7:1
QPP-201	1930 to 1990	25	10.5	30 percent	<1.7:1
QPP-205	1930 to 1990	120	10.5	30 percent	<1.7:1
QPP-301	2110 to 2170	100	9.5	25 percent	<1.7:1

XEMOD, Inc., 333 Soquel Way, Sunnyvale, CA 94086; (408) 733-7229, FAX: (408) 733-7327, e-mail: info@xemod.com, Internet: http://www.xemod.com.

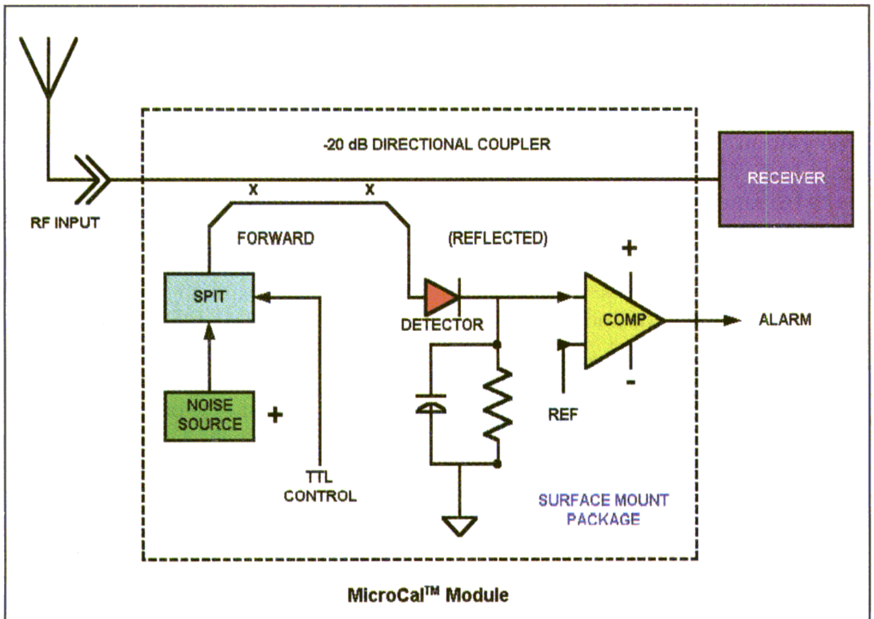
CIRCLE NO. 57 or visit www.mwrf.com

Noise Modules Track Receiver Fidelity

These custom noise modules can monitor antenna matching and receiver integrity over the full wireless and PCS bands.

W. Robert Nichols II
Design Engineer
Norm Mendoza
Applications Engineer
Micronetics Wireless, 26 Hampshire Dr., Hudson, NH 03051; (603) 883-2900, FAX: (603) 882-8987, Internet: http://www.micronetics.com.

BROADBAND noise is an ideal signal source for assessing the performance of virtually any electronic device or system that involves detection or processing of a signal. These include platforms such as wireless and land mobile communications systems, cellular-phone networks, satellite receivers for cable television (CATV), and even home-entertainment systems. Sources designed specifically to generate precise excess noise ratios (ENRs), such as the MicroCal™ line of noise sources from Micronetics Wireless (Hudson, NH), are ideal tools for characterizing and validating system performance.



1. This block diagram shows an example of a MicroCal noise module integrated with a SPST switch and dual directional coupler.

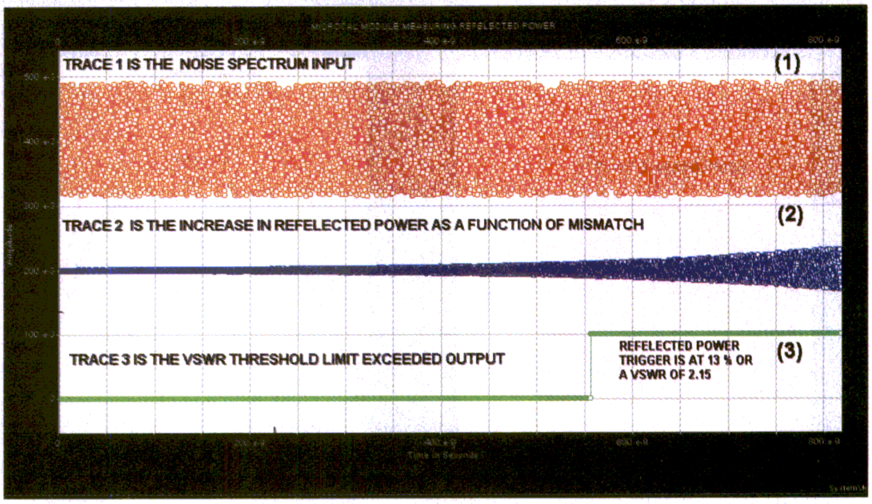
For example, MicroCal noise sources with integral VSWR monitors can be used to provide remote readings of a cellular or personal-communications-services (PCS) site antenna's performance levels. Inserted between the site's receiving antenna and its interconnecting cables, a MicroCal noise generator is ideal for remote monitoring of the antenna match to the receiver. Beyond the antenna, the MicroCal noise generators can be used as built-in-test (BIT) sources for tracking the performance profile of the active and passive components in a receiver channel.

The MicroCal generators represent the cumulative experience of a company involved in pioneering noise technology more than 25 years ago. The technology has evolved to its current generation of miniature surface-mount-technology (SMT) noise modules that are ideal for integration into active and passive components and subsystems. The compact size of the MicroCal modules makes them suitable for integration into a wide range of components, including amplifiers, antennas, cable connectors, and filters—especially in components where the physical location can make access impractical or impossible, such as mounted near antennas on communications towers. The MicroCal modules are well-suited for end-to-end system tracking of cellular and PCS base-station performance.

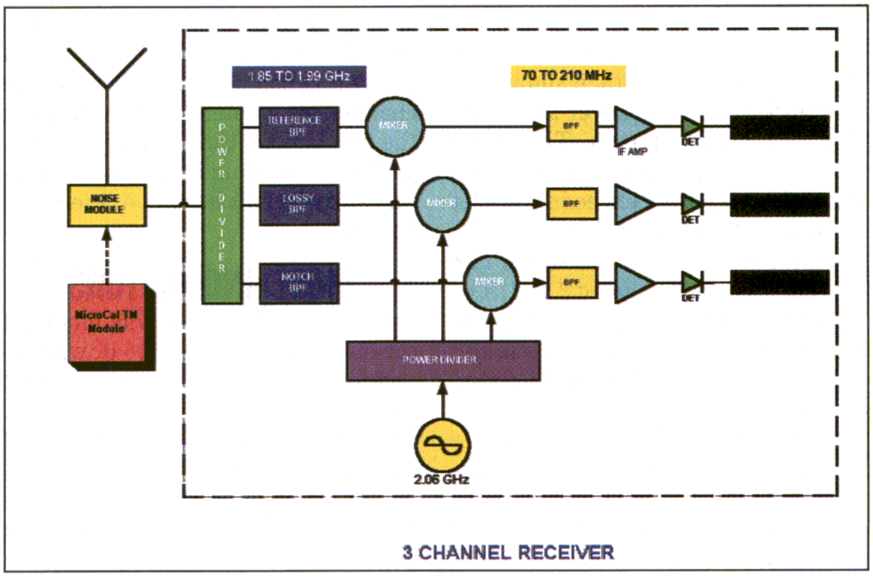
The MicroCal noise modules provide the predictable and repeatable performance needed for gauging component and system performance levels. For example, the noise sources have a flat power-density output versus frequency and only exhibit a small change in reflection coefficient (>0.01) when switching from the off to on states.

One way where a MicroCal noise source can be used for cellular or PCS base-station monitoring is when it is integrated with a dual directional coupler (Fig. 1). The design actually consists of an SMT noise source coupled to a single-pole, single-throw (SPST) nonreflective switch driving the forward path of the dual directional coupler. When inserted between a base-station antenna and the receiver input cable, this noise source can be used to actively monitor the antenna-to-receiver impedance match and to track any change in component characteristics through the receiver chain. The coupler is designed to mechanically match the antenna to the receiver-cable interface. The SPST switch can be controlled through transistor-transistor-logic (TTL) signals to form a continuous-wave (CW) or modulated noise source. The SystemView system-level simulation software from Elanix, Inc. (Westlake Village, CA) was used to model and predict the degradation of the antenna-to-receive input-port impedance matching, and simulate an alarm threshold function for monitoring purposes (Fig. 2).

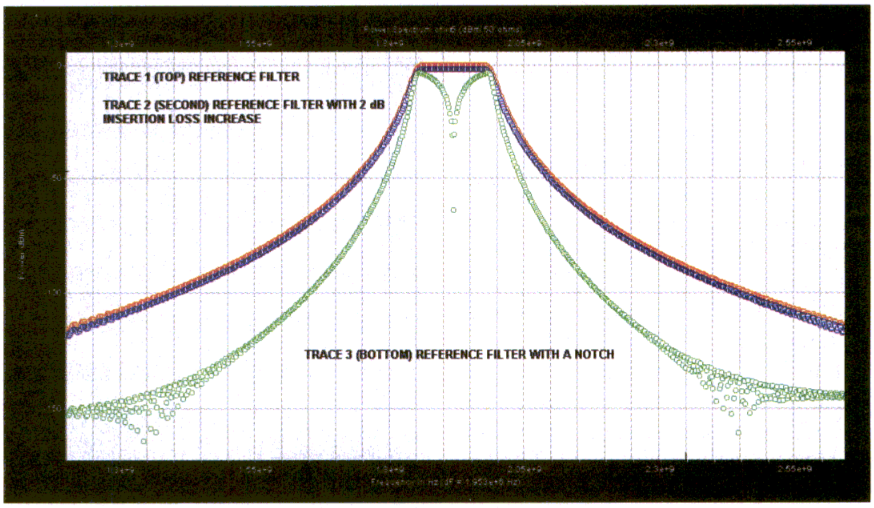
In this simulation, a diode detector senses the reflection of noise energy in the return path of the coupler. A terminating resistor provides a matched load for the detector. A capacitor integrates and stores the detected noise as a DC voltage. A comparator is used to compare the reflected DC level to a user-specified reference. An alarm is provided when the reference level is exceeded by the reflected noise.



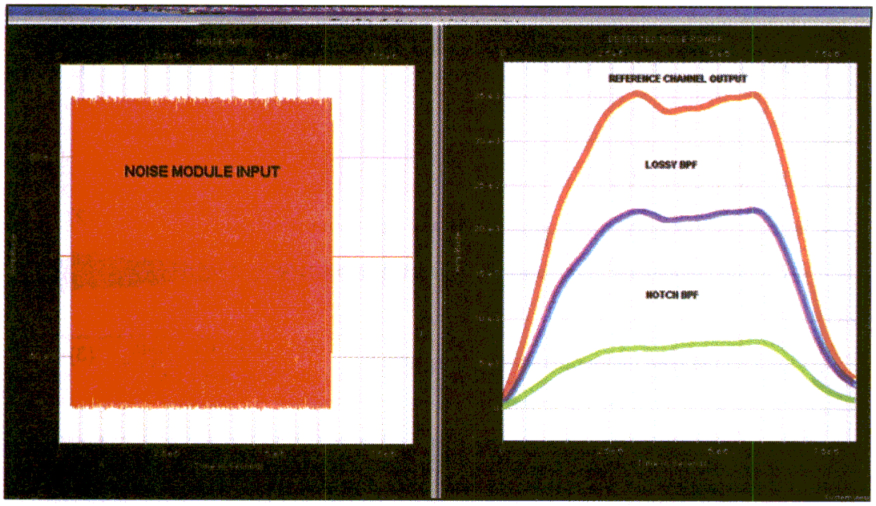
2. These three traces show the noise input spectrum (top), the increase in reflected noise power from a power impedance match (middle), and the VSWR threshold trigger (bottom).



3. This three-channel receiver was simulated with SystemView software to demonstrate the effectiveness of the MicroCal noise modules.



4. These three simulated filter responses are for the reference channel (top trace), the channel with 2-dB higher insertion loss than the reference (middle trace), and the channel with a passband notch (bottom trace).



5. This modulated noise signal (left) was used to generate the simulated responses shown at the right for the three receiver channels.

The first trace in the plot represents the through-path noise level at the output of the MicroCal noise source. The second trace shows the change in reflected power as a function of load mismatch. The third trace shows the alarm trigger when the reflected power exceeds a preset reference level. For this example, the alarm is activated when the VSWR exceeds a value of 2.15:1. The time base has been intentionally set for a short duration for this simulation. In a real-world application, the duration could be set for weeks, months, or years, depending on the monitoring and calibration requirements. Once a receiver has been characterized with the help of the noise source, future measurements can be compared with the original baseline value. Any change in the receiver chain will be revealed when new measurements are compared with the reference values.

Figure 3 is the block diagram of a three-channel receiver modeled with the aid of the SystemView. All channels operate over the frequency band of 1.85 to 1.99 GHz. The local-oscillator (LO) frequency for each channel is 2.060 GHz. Each channel has an intermediate-frequency (IF) bandwidth of 140 MHz, spanning a total IF bandwidth of 70 to 210 MHz.

The IF amplifier gains, detector parameters, and resistor-capacitor (RC) filter networks are identical for all three receiver channels. The top channel is considered the reference channel. The center-channel RF filter has been modeled with insertion loss that is 2 dB higher than that of the reference channel. The bottom channel has a notch filter centered in the passband of the RF filter. A compact noise module is used as the signal source to characterize each channel.

MODELING FACTORS

The filter response was modeled for each channel prior to downconversion to IF. The top trace of Fig. 4 shows the response of a good filter. The second trace is the response of the same type of filter with a 2 dB higher insertion loss. The third trace is the same filter with a notch at the center frequency. Although the amplitudes of each case are similar, detected excess noise from the three filters will clearly show the ability of the noise module's BIT function to identify each of the three conditions.

BY DISTRIBUTING THE MICROCAL NOISE MODULES WITHIN ALL OF A SYSTEM'S CRITICAL COMPONENTS, THE FAULT OR SOURCE OF A SYSTEM'S PERFORMANCE DEGRADATION CAN BE TRACED.

The left-hand side of Fig. 5 shows the modulated noise signal used to evaluate the three bandpass filters while the right-hand side shows the response of the three receiver channels. The plot on the left-hand side of Fig. 5 is the modulated noise input. The right graph shows the reference channel response to the modulated noise input at a level of 40 mV. The middle trace is the channel with an increase of 2 dB in insertion loss (compared to the reference channel) at a level of 25 mV. The bottom trace is the output of the channel with the notch in the passband at a level of 8 mV.

Since noise sources have a uniform distribution of random power, all of the filters appear to have the same response shape, however, they differ in detected amplitude due to the difference in detected noise power. This example shows the simplicity of using precision noise sources as a tool for tracking a receiver's performance characteristic. By distributing the MicroCal noise modules within all of a system's critical components, the fault or source of the system's performance degradation can be traced to the offending component or components with minimal effort and time.

Additional information on the topic of noise is available on the Micronetics Wireless website. In particular, there is an application note entitled "Understanding noise" (which can be accessed at the company's site at www.micronetics.com/products/understa.htm). The note defines the five parameters commonly used to specify noise—output level, output characteristics, noise characteristics, input power, and accuracy/stability. For example, noise characteristics such as peak factor (crest factor) and symmetry are defined, along with accuracy factors such as temperature coefficient and long-term drift. The application note also covers common noise-source conversions, such as effective noise ratio (ENR) to noise figure. **Micronetics Wireless, 26 Hampshire Dr., Hudson, NH 03051; (603) 883-2900, FAX: (603) 882-8987, Internet: http://www.micronetics.com.**

CIRCLE NO. 58 or visit www.mwrf.com

Digital Frequency Synthesis Demystified

Bar-Giora Goldberg

Bar-Giora Goldberg should need no introduction to readers of this magazine. A frequency contributor to the "Design Features," Goldberg was one of the founding members of Sciteq (San Diego, CA) where he developed and refined many direct-digital-synthesizer (DDS) products. His latest book, *Digital Frequency Synthesis Demystified*, provides a comprehensive view of both DDS architectures and fractional-N frequency synthesizers.

These sources must maintain good stability at narrow channel spacing, yet be priced according to cost-competitive markets such as cellular telephone, personal communications services (PCS), and wireless local loops (WLLs). *Digital Frequency Synthesis Demystified* focuses on the "digitalization" of signal generation.

The book's 10 chapters include an opening-chapter basic introduction to frequency synthesis. Chapter 2 covers synthesizer system analysis, while Chapter 3 details measurement techniques for analyzing the key parameters, including spurious noise and switching speed. Chapter 4 highlights the general architecture of a DDS while Chapter 5 offers insights on phase-locked-loop (PLL) frequency synthesizers. Chapter 6 provides extensive detail on a key DDS component, the accumulator, while Chapter 7 covers the read-only-memory (ROM) lookup table, and Chapter 8 describes the requirements for digital-to-analog converters (DACs). The final two chapters review products incorporating these various synthesis techniques.

The book is accompanied by a compact-disc read-only memory (CD-ROM), with software that will help readers analyze and manipulate the design methods described in the book. (1999, 350 pp., paperback, ISBN: 1-878707-47-7, $49.95.) **LLH Technology Publishing, 3578 Old Rail Rd., Eagle Rock, VA 24085; (800) 247-6553, (540) 567-2000, FAX: (540) 567-2539, e-mail: carol@LLH-Publishing.com, Internet: http://www.LLH-Publishing.com.**

PRODUCT TECHNOLOGY

GSM Radio Chip Set

GSM Radio Chip Set Works With Direct Conversion

A new radio architecture converts incoming RF signals directly to baseband to simplify the design of wireless phones.

GENE HEFTMAN
Senior Editor

BATTLING for dominance in cellular/digital wireless phone technology, competitors strive to make handsets smaller and cheaper, to consume less power, and operate over longer distances. One way to achieve these goals is through a (so-called) direct-conversion or zero-intermediate-frequency (IF) radio architecture where a single stage converts an RF signal directly to baseband. The difficult task of bringing this architecture to reality has been reached with the introduction of the GSM direct conversion radio chip set by Analog Devices (Norwood, MA). It is called the first Global System for Mobile Communications (GSM) direct-conversion solution available to the open market. Previously, GSM direct-conversion technology was proprietary and not available to GSM phone manufacturers.

Known by the company name, Othello™, the chip set consists of two integrated circuits (ICs)—the AD6523 transceiver and the AD6524 synthesizer (see figure). Together, the chips implement a Superhomodyne™, or direct-conversion architecture which is a radical departure from the traditional superheterodyne system used in receivers. The advantages of the new architecture suit the key objectives of phone manufacturers—fewer components, a smaller handset, lower power consumption, longer talk time, and multiband operation. Also, the Othello circuitry can handle the coming high-speed data-communications capabilities that will be part of GSM—enhanced data GSM environment (EDGE) and general-packet radio service (GPRS).

Direct conversion eliminates the need for IF devices which are often the most expensive in the radio portion of the phone. The IF surface-acoustic-wave (SAW) filters, for example, are very costly and consume a large amount of board space. In all, Othello can reduce the component count of a GSM radio from more than 150 devices to less than 90, with a corresponding reduction in materials cost.

Direct conversion is a much simpler architecture than traditional superhetrodyne. The AD6523, for example, is a single-chip RF IC that integrates full receive (Rx) and transmit (Tx) paths. The low-noise amplifier (LNA) is fully integrated along with support circuits such as a low-dropout regulator (LDO). The AD6524 is a complete fractional-N synthesizer (including the crystal oscillator). This architecture is used to attain fast lock times that conserve power and provide support for GSM data services such as GPRS.

Both devices are housed in low pin-count packages—the AD6523 is in a 28-pin thin-shrink small-outline package (TSSOP) and the AD6524 is in a 20-pin TSSOP. A 0.6-μm bipolar-complementary-metal-oxide-semiconductor (BiCMOS) process is used to fabricate both devices. The chip set is sampling now, and general availability and pricing will be forthcoming in the first quarter of next year. **Analog Devices, Inc., Ray Stata Technology Center, Wilmington, MA 01887; (781) 937-1428, FAX: (781) 937-1021, Internet: http://www.analog.com.**

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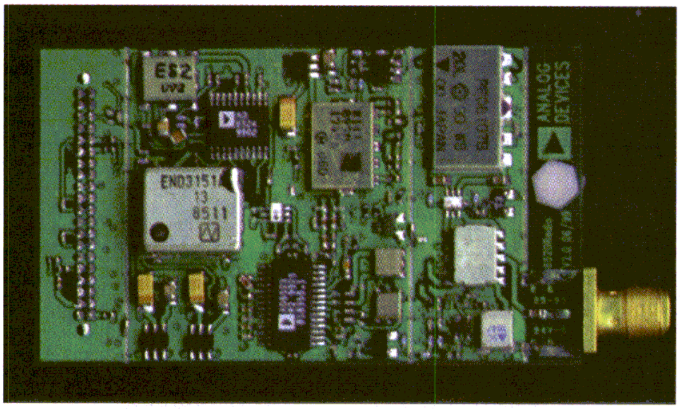


The AD6523 and AD6524 ICs from Analog Devices show how a direct-conversion architecture occupies a small amount of circuit-board area.

Dual-Band RF Synthesizer Enables Fast Datacom

A highly integrated synthesizer IC is designed for GPRS wireless data communications.

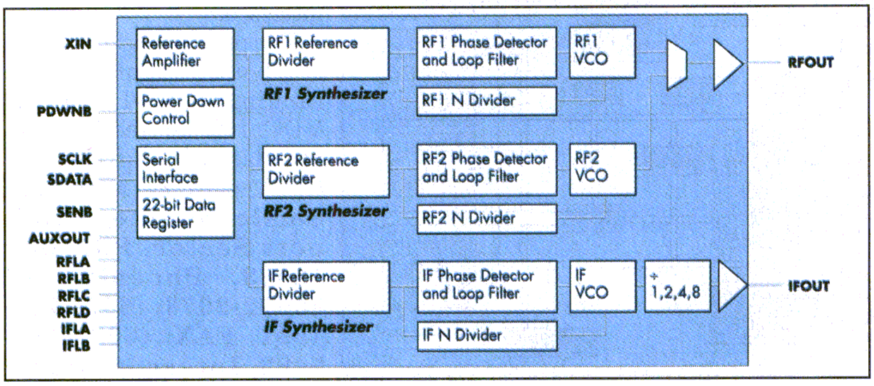
GENE HEFTMAN

Senior Editor

GENERAL Packet Radio Service (GPRS) data capability being planned for Global System for Mobile Communications (GSM) phones opens a new chapter for subscribers interested in obtaining wireless data at much higher speeds than currently possible (up to 100 kb/s versus 14.4 kb/s). To support such data communications, Silicon Laboratories (Austin, TX) has designed the Si4133G Dual-Band RF Synthesizer, a monolithic integrated circuit (IC) that performs RF and intermediate-frequency (IF) synthesis for GSM and GPRS wireless personal communications. The device is fabricated in 0.35-μm complementary-metal-oxide-semiconductor (CMOS) technology to make it easily producible and low in cost for manufacturers in the price-sensitive wireless phone market.

Built into the Si4133G are three voltage-controlled oscillators (VCOs), loop filters, reference and VCO dividers, as well as phase detectors (see figure). According to the company, this makes it the most highly integrated RF synthesizer available, allowing the synthesizer function to be implemented with only four discrete components. Conventional synthesizer functions require up to 41 components, so the IC can reduce the board space used by the synthesizer by up to 84 percent, along with a considerable reduction in power consumption.

The Si4133G uses an integer-N architecture rather than a fractional-N to eliminate the problem of fractional spurs that occur with the latter. This phase-locked-loop (PLL) architecture enables lock times below 150 μs, which meet GPRS class 12 requirements for high-speed data communications. This fast settling time can reduce the power consumption in a handset, a critical issue in talk and standby times. Fast settling time allows a system to wait for a longer time before turning on its power amplifier (PA), leading to power savings and extended battery life. Fast settling is achieved through a proprietary self-tuning algorithm and the unique PLL architecture. The architecture also supports the integration of VCO modules, which might otherwise be housed in metal-shielded packages, to be integrated on chip. A total of 35 discrete components and the resonator elements are integrated on the chip.



All the functions necessary to perform dual-band synthesis for high-speed wireless data are contained on a single 0.35-μm CMOS chip, the Si4133G from Silicon Laboratories.

The Si4133G performs RF synthesis in two bands, 900 MHz to 1.8 GHz and 750 MHz to 1.5 GHz. It operates from a +3-VDC supply voltage and typically draws 18-mA current when operational and 1-μA current when in standby mode. The IC is supplied in a low-profile, 24-pin thin-shrink small-outline package (TSSOP) rated for operating temperatures from –40 to +85°C. P&A: $6.50 (10,000 qty); evaluation board (Si4133-EVB), $150. **Silicon Laboratories, Inc., 4635 Boston Lane, Austin, TX 78735; (512) 416-8500, FAX: (512) 416-9669, Internet: http://www .sila bs.com.**

CIRCLE NO. 61 or visit www.mwrf.com

Baseband Processor Supports Many Wireless Standards

This processor combines a digital signal processor and a microcontroller to achieve high-data throughput.

DON KELLER
Senior Editor

BASEBAND processors perform the vital function of encoding and decoding baseband information in digital radios. With the proliferation of encode/decode formats for digital radio, the more formats that a processor can handle, the better. To this end, Motorola, Inc. (Phoenix, AZ) has released a baseband processor, the model DSP56690, which supports numerous mobile wireless and satellite standards.

The DSP56690 processor can execute most of the major existing wireless-subscriber standards, including Global System for Mobile Communications (GSM), integrated digital enhanced network (iDEN), and time-division multiple access (TDMA). The company intends to release future versions of the processor that also support code-division-multiple-access (CDMA) standards.

The processor is designed to support the mid-to-high-tier wireless applications, specifically those that take advantage of high data-throughput standards such as general-packet radio service (GPRS) and wireless-access-protocol (WAP)-enabled microbrowsers. The processor's architecture is also scalable to low-tier applications, and can take advantage of applications built around new software standards such as Java.

To achieve the high data throughput necessary to encode and decode the digital standards, the processor integrates two existing functional units—a digital signal processor (DSP) and a microcontroller unit (MCU)—onto one chip (see figure). The DSP is the company's DSP56600 core running at more than 100 MHz. The MCU is the company's MCORE M210, a 32-b device operating at more than 50 MHz. Both functional units have their own dedicated memory, and they communicate between a shared block of memory.

The DSP's memory includes 85.5 kb of 24-b programmable read-only memory (PROM), 3.5 kb of 24-b random-access memory (RAM), 4.4 kb of 16-b data ROM, and 18 kb of 16-b data ROM. The MCU's memory includes 16 kb of 32-b ROM and 6.5 kb of 32-b RAM. The processor also contains a universal-serial-bus (USB) module with a dedicated digital phase-locked loop (DPLL), an Advanced Mobile Phone Service (AMPS) accelerator module (AAM), two single-inline-memory (SIM) card interfaces, two universal asynchronous receiver/transmitters (UARTs) with serial-infrared (SIR) support, a GPRS encryption module (GEM), in addition to a one-wire (OWIRE) interface.

The processor can operate at a power-supply voltage ranging from +1.8 to +2.2 VDC. It is housed in a 256-pin plastic ball-grid-array (BGA) package. **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.**

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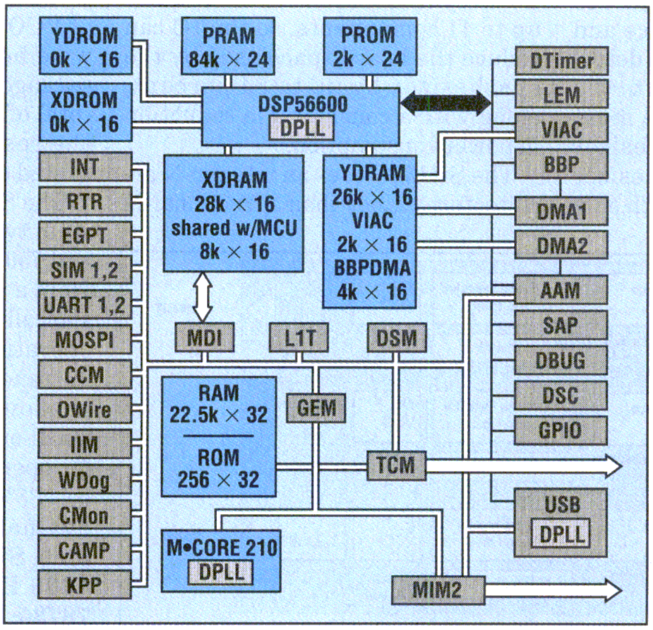

This block diagram shows the functional components of the DSP56690 baseband-processor integrated circuit (IC).

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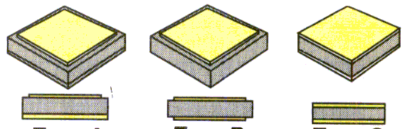

Type A *Type B* *Type C*

Type	Metallization	Attributes
A	Top: TiW / Au Bottom: TiW / Pt / Au	Safety Margin around Top Electrodes
B	Top: TiW / Au Bottom: TiW / Au	Safety Margin around Both Electrodes
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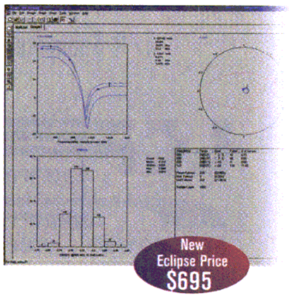

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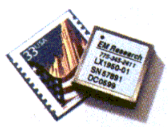

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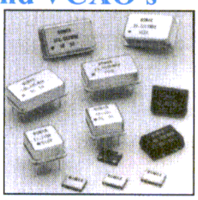

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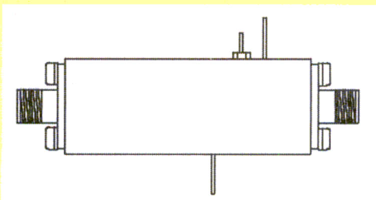

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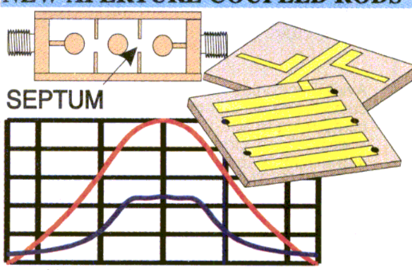

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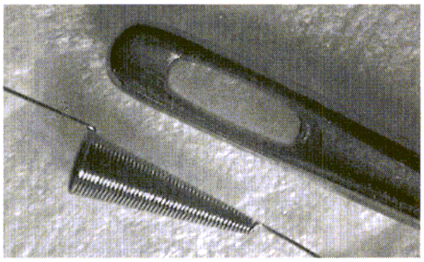
Chip capacitors aimed at hybrids

Two different types of tantalum (Ta) chip capacitors can handle a variety of applications. The TCM Series of Molded Chip Tantalum capacitors are the standard version designed for thick-film hybrid cir-



cuits. They are available in case sizes R (0805) through E and have a range of 0.1 through 330 µF. The TCR series are ultra-low equivalent series resistance (ESR) and high-ripple current types, with high resistance to inrush currents. They are available in case sizes A through V and have a capacitance range of 0.68 through 470 µF. **Venkel Corp., 4807 Spicewood Springs Rd., Austin, TX 78759; (512) 794-0081, FAX: (512) 794-0087, e-mail: sales@venkel.com, Internet: http://www.venkel.com.**

CIRCLE NO. 70 or visit www.mwrf.com

SPDT switch boasts high isolation

The model RSW-2-25P single-pole, double-throw (SPDT) switch operates from DC to 2.5 GHz and boasts a typical midband isolation of 50 dB. The switch can work with a positive switching voltage, simplifying control-signal generation. Across the band, its typical 1-dB compression is 26 dB or more and insertion loss ranges from 0.5 dB near DC to 1.2 dB at 2.5 GHz. Above 500 MHz, the switch can handle an absolute maximum RF power input of 1 W. **Mini Circuits Corp., P.O. Box 350166, Brooklyn, NY 11234-0003; (718) 934-4500, FAX: (718) 332-4661, Internet: http://www.minicircuits. com.**

CIRCLE NO. 71 or visit www.mwrf.com

Power FET amplifies DC to 18 GHz

The model EPA060-70 heterojunction power field-effect transistor (FET) amplifies signals from DC to 18 GHz. Its typical gain at 1-dB compression is 19 dB at 2 GHz and 9 dB at 12 GHz. Typical noise figure at 2 GHz is 0.4 when the amp is drawing 50 mA of drain current, and 0.6 when it is drawing 90 mA. The device is designed to operate at a maximum continuous drain-to-source voltage of 6 VDC and a maximum continuous drain current of 110 mA. It is housed in a non-hermetic, low-cost ceramic 70-mil package and can dissipate a maximum continuous power of 650 mW. **Excelics Semiconductor, Inc., 2908 Scott Blvd., Santa Clara, CA 95054; (408) 970-8664, FAX: (408) 970-8998, Internet: http://www.excelics.com.**

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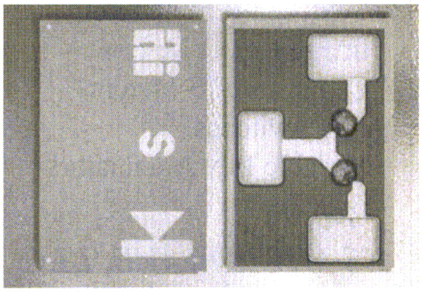
Stackable organizer stores small parts

A portable kitting system can securely store a wide range of small parts and protect sensitive components from damage from electrostatic discharge (ESD) at all stages of the production cycle. The Portfolio™ kitting system is a systematic approach to segregating and organizing components using a kit to facilitate product assembly. The advantages of the kitting system over traditional binning systems include improved quality control, increased productivity, along with decreased costs. In order to prevent ESD, the Portfolio's side panels and its trays are made of lightweight Kydex conductive plastic. The 50 "no-spill, no migration" bins can be arranged in numerous configurations. **Global Kiting Systems, P.O. Box 1757, Roseburg, OR 97470; (541) 672-5332, FAX: (541) 672-8737, e-mail: info@globalkitting.com, Internet: http://www.globalkitting. com.**

CIRCLE NO. 73 or visit www.mwrf.com

Flip-chip mixer diode designed as series pair

The DMK8001 is a gallium-arsenide (GaAs) flip-chip mixer diode designed in a series-pair configuration for use in balanced and double-balanced mixers. It is a single chip with a fully matched series pair suitable for either flip-chip mounting or wire bonding. The DMK8001 is aimed at millimeter-wave operating frequencies, either broadband or narrowband, in applications such as local multipoint distribution systems (LMDS), point-to-point, very small aperture terminal (VSAT), and



others. The device features low capacitance, low resistance, and low mixer-conversion loss. P&A: $1.92 (10,000 qty.). **Alpha Industries, 20 Sylvan Rd., Woburn, MA 01801; (800) 290-7200 ext. 306, FAX: (617) 824-4579, e-mail: sales@alphaind. com.**

CIRCLE NO. 74 or visit www.mwrf.com

MMIC PA spans 37 to 40 GHz

The model SGPA-07006-CC is a two-stage, monolithic-microwave-integrated-circuit (MMIC) power amplifier (PA) that spans the 37-to-40-GHz frequency range. The chip is designed on the company's 0.15-µm gallium-arsenide (GaAs), pseudomorphic-high-electron-mobility-transistor (PHEMT) process. **Sanders Co., 65 Spit Brook Rd., Nashua, NH 03061; (603) 885-2817, FAX: (603) 885-2813, Internet: http://www.sanders.com.**

CIRCLE NO. 75 or visit www.mwrf.com

Frequency upconverter has four modules

An upconverter assembly consists of four modules, which including two phase-locked loops (PLLs), an upconverter as well as a downconverter. The fixed-frequency synthesizer [local oscillator (LO) number 1] portion offers a tuning range of 1480 to 1560 MHz with a 1-MHz step size. The frequency-agile synthesizer (local oscillator number 2) has a tuning range of 400 to 700 MHZ in addition to a step size of 25 kHz. An evaluation board is available for the tasks involved in putting the modules through their paces. **Vari-L, Inc., 4895 Peoria St., Denver, CO 80239; (303) 371-1560, FAX: (303) 371-0845.**

CIRCLE NO. 76 or visit www.mwrf.com

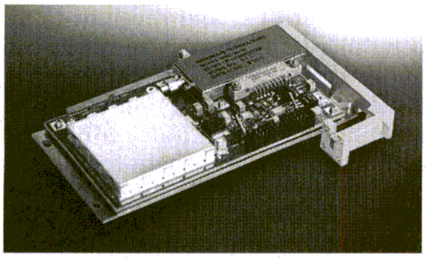
Lightning protector fends 20-kA strikes

The PTCOAMOAF lightning protector operates from DC to 3 GHz and offers bi-directional protection against multiple lightning strikes with peak pulse currents of 20 kA. It is specifically designed to protect local-multipoint-distribution-service (LMDS) networks against lightning strikes. From DC to 1.5 GHz, insertion loss is typically 0.1 dB and VSWR is 1.5:1. From 1.5 to 3 GHz, insertion loss is typically 0.2 dB and VSWR is 2.0:1. Mounting and grounding is through metal-to-metal contact on bulkhead or through optional bracket. The protector is resistant to moisture, vibration, and temperature shock and operates at temperatures from −40 to +90°C. **NexTek, Inc., 439 Littleton Rd., Westford, MA 01886; (978) 486-0582, FAX: (978) 486-0583, Internet: http://www.ultranet.com/~nextek.**

CIRCLE NO. 77 or visit www.mwrf.com.

Upconverter/amp serves LMDS

The model NW2728-31 upconverter/power amplifier (PA) is specifically designed for local-multichannel-distribution-system (LMDS)/ local-multipoint-communication-system (LMCS) applications. The unit operates at



intermediate frequencies (IFs) from 0.9 to 1.4 GHz and output frequencies from 27.0 to 31.5 GHz. The IF input-power level is −20 ±5 dBm, and output power at the 1-dB compression point is +31 dBm. Output-power flatness is ±1 dB over 300 MHz and ±2 dB over the entire bandwidth. The output power is adjustable from the 1-dB compression point −15 dB to the 1-dB compression point −1 dB. An automatic gain control (AGC) maintains the output-power set point to within ±1 dB of the required level. In-band spurious response is −60 dBc and out-of-band spurious response is −30 dBc. The local oscillator (LO) operates at 13.5 GHz at a power level of +10 to +15 dBm. Maximum IF and LO voltage standing-wave ratio (VSWR) is 2.5:1 and maximum output VSWR is 2.0:1. The upconverter/amplifier draws 2 A from a +12-VDC power source and operates at temperatures from −40 to +65°C. **Remec Nanowave Corp., 425 Horner Ave., Unit #1, Etobicoke, Ontario M8W 4W3, Canada; (416) 252-5602, FAX: (416) 252-7077, Internet: http://www.remec.com.**

CIRCLE NO. 78 or visit www.mwrf.com.

MMIC amplifier operates down to +3 VDC

The model SGA-3486 silicon-germanium (SiGe), heterojunction-bipolar-transistor (HBT), monolithic-microwave-integrated-circuit (MMIC) cascadable amplifier can operate at power-supply voltages as low as +3 VDC. The device amplifies frequencies from DC to 2000 MHz and has a typical gain of 19 dB at frequencies from 1000 to 2000 MHz. At 850 MHz, its typical output power at the 1-dB compression point is +25 dBm. Input and output VSWR is 1.3:1 and reverse isolation is typically 23.1 dB from 1000 to 2000 MHz. The output third-order intercept point (IP3) is typically +25 dBm from DC to 2400 MHz, and noise figure is typically 3 dB from 1000 to 2400 MHz. The amplifier draws 35 mA from a +3-VDC power supply and can operate at temperatures from −40 to +85°C. **Stanford Microdevices, Inc., 522 Alanor Ave., Sunnyvale, CA 94086; (800) 746-6642, FAX: (408) 739-0970, Internet: http://www.stanfordmicro.com.**

CIRCLE NO. 79 or visit www.mwrf.com.

Coaxial switch serves Ku-band

The 421 series of latching switches can route Ku-band signals from three inputs to two selected outputs, or from two inputs to two of three possible outputs. The switches use make-before-break contacts and are ideally suited for low-power redundancy switching. At 13.7 GHz, maximum VSWR is 1.2:1, maximum insertion loss is 0.4 dB, and minimum isolation is 70 dB. The switches operate at +28 VDC and include SMA-type female connectors. **Dow-Key Microwave Corp., 1667 Walter St., Ventura, CA 93003-5641; (805) 650-0260, FAX: (805) 650-1734, Internet: http://www.dowkey.com.**

CIRCLE NO. 80 or visit www.mwrf.com.

ADC targets low-frequency measurement

The model AD7707 16-b sigma-delta analog-to-digital converter (ADC) is designed for low-power, low-voltage, and low-frequency measurement applications including process control, battery monitors, current analyzers, as well as smart-temperature and pressure transmitters. The three-channel ADC offers two low-level, pseudo-differential analog input channels that accept ±100-mV full-scale input signals without DC-to-DC converters, charge pumps, or split supplies, and a high-level input channel for ranges to ±10 VDC. With a differential ±2.5-VDC input signal, the ADC exhibits a typical noise characteristic of 3.8-μV root mean square (RMS) at a 50-Hz output rate. The ADC includes an amplifier whose gain is programmable from 1 to 128. **Analog Devices, Inc., 804 Woburn St., Wilmington, MA 01887; (800) 262-5643, FAX: (781) 937-1021, Internet: http://www. analog.com.**

CIRCLE NO. 81 or visit www.mwrf.com.

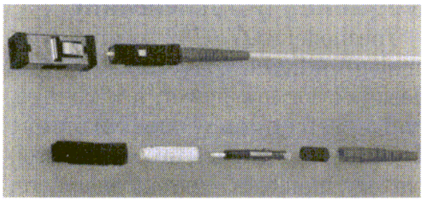
Compiler suite enhances MATLAB

The C/C++ compiler suite is a group of software tools that allows scientists and engineers to develop stand-alone C and C++ programming language applications based on the industry-standard MATLAB math and graphics program. The MATLAB C/C++ math library makes MATLAB's math functions accessible as a reliable, cross-platform foundation for stand-alone applications. The new MATLAB C/C++ graphics library makes MATLAB's graphics and graphical-user-interface (GUI) functions accessible from stand-alone C and C++ applications. **The MathWorks, Inc., 3 Apple Hill Dr., Natick, MA 01760-2098; (508) 647-7000, FAX: (508) 647-7001, Internet: http://www.mathworks.com.**

CIRCLE NO. 82 or visit www.mwrf.com.

Optical connectors save space and time

The SMU series single-mode optical connectors feature a new subassembly design that reduces the required number of component pieces from seven to five. The reduced part count saves space and assembly time for large installations and system



upgrades. The new connectors' small size is especially useful in backplane-connector applications, where space constraints are substantial. The series is composed of single-mode fiber, zirconia ceramic ferrule material that accommodates three fiber cordage diameters—2, 1.1, and 0.9 mm. The fiber cord is retained via a heat-sinking tube fixed to the kevlar, enabling easy assembly and mass production. The connector assemblies offer core-eccentricity adjustment in four positions and comply with flammability test standard UL94 V-0. They can be used in a variety of fiber-optic applications, including high-speed data communications, voice networks, telecommunications, and dense wavelength-division multiplexing (DWDM). The connectors have an insertion loss as low as 0.25 dB. Typical return loss ranges from 50 to 55 dB, depending on the polishing method. Designed with a familiar phone-jack style housing, the connectors snap easily into place and are compatible with JIS, CECC, IEEE, and IEC. **Seiko Instruments USA, Inc., Electronic Components Div., 2990 West Lomita Blvd., Torrance, CA 90505; (310) 517-7771, FAX: (310) 517-7792, Internet: http://www. seikofiber.com.**

CIRCLE NO. 83 or visit www.mwrf.com.

Analyzer evaluates base stations

The BaseStAR (base-station analysis receiver) interference analyzer identifies sources of RF interference (RFI) affecting cellular base stations. It allows service providers to determine if channels are being blocked inadvertently by unauthorized emissions and to identify the offending RFI source(s). In a typical test scenario, a base-station field technician deploys BaseStAR near the cell site being evaluated, attaches the antenna that is provided, and initiates the search. BaseStAR uses the Global Positioning System (GPS) to identify its own location and that of transmitters in the surrounding area. Using knowledge of the provider's licensed spectrum and the location of surrounding transmitters, the instrument evaluates potential RFI sources to determine which ones are creating interference. Multiple receivers in the unit work together to capture and evaluate emissions at frequencies to 2 GHz. It evaluates interference such as harmonics generated by high-power transmitters and intermodulation (IM) products created by co-located transmitters. The analyzer also has a logging feature to capture transitory interference during unattended, long-term monitoring. It allows site operators and managers to demonstrate the quality of their sites to prospective customers, and can serve as an ongoing maintenance tool for the benefit of their tenants. **Summitek Instruments, Inc., P.O. Box 64, Parker, CO 80134; (303) 768-8080, FAX: (303) 768-8181, Internet: http:// www.summitekinstruments. com.**

CIRCLE NO. 84 or visit www.mwrf.com.

MMIC power amp spans 29 to 33 GHz

The model SGPA-07016-CC is a two-stage, monolithic-microwave-integrated-circuit (MMIC) power amplifier (PA) that spans 29 to 33 GHz. The chip is designed on the company's 0.15-μm, gallium-arsenide (GaAs), pseudomorphic-high-electron-mobility-transistor (PHEMT) process. Its typical power output at the 1-dB compression point is 1.8 W and its typical linear gain is 10 dB. The amplifier is targeted at linear very-small-aperture-terminal (VSAT) and local-multichannel-distribution-system (LMDS) base-station applications. **Sanders Co., 65 Spit Brook Rd., Nashua, NH 03061; (603) 885-2817, FAX: (603) 885-2813, Internet: http://www. sanders.com.**

CIRCLE NO. 85 or visit www.mwrf.com.

Wireless transceiver serves MMDS

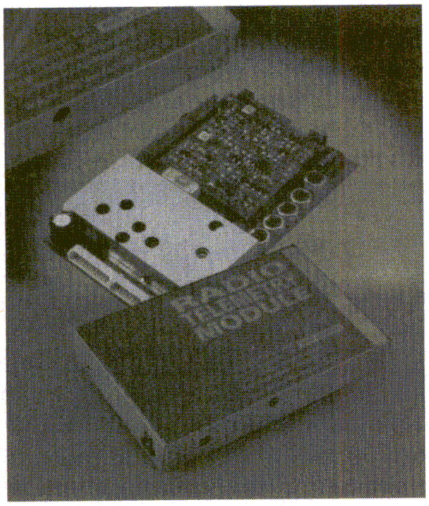
A new wireless transceiver has been designed specifically to serve high-speed multichannel, multipoint distribution systems (MMDS) such as Internet data, voice, video, interactive television, and telephone communica-

tions. It accommodates data-over-cable-service interface specification (DOCSIS) or other customer-specified channel plans through simple component replacement. This modular approach provides the flexibility to support other air interfaces such as multipoint distribution system (MDS), wireless communication service (WCS), wireless local loop (WLL), and local-multichannel-distribution-system (LMDS) frequencies. The transmitter and receiver sections of the transceiver use separate local oscillators (LOs) that are phase locked to a highly stable crystal reference. The transmitter (Tx) and receiver (Rx) ports maintain constant power levels to overcome changing environmental conditions. The Tx section operates over an RF range of 2550 to 2610 MHz and over an intermediate-frequency (IF) range of 145 to 205 MHz. Its linear gain is +60 ±2 dB and can be adjusted from 0 to −20 dB. Its output third-order intercept point (IP3) is greater than +43 dBm. Harmonic distortion and out-of-band spurious emission are −55 dBc. The transmitter uses a 50-Ω, N-type connector and draws 400-mA current from a +12-VDC power supply. The receiver portion operates over an RF range of 2640 to 2700 MHz and over an intermediate-frequency (IF) range of 640 to 750 MHz. **Renaissance Electronics Corp., 1300 Mass Ave., Boxborough, MA 01719; (978) 263-4994, FAX: (978) 263-4944, Internet: http://www. rec-usa.com.**

CIRCLE NO. 86 or visit www.mwrf.com.

Telemetry transceiver circumvents interference

The model SX850 is a credit-card-sized telemetry transceiver that uses the pan-European, license-exempt 868-to-870-MHz band to circumvent the United Kingdom's crowded, interference-prone, license-exempt bands at 418, 433, and 458 MHz. These bands have been especially



prone to disruptive interference since the recent introduction of the TETRA trunked-radio allocation surrounding 420 MHz. The transceiver is type-approved to the European EN 220 (telemetry) and ETS 300 086 (mobile-radio) specifications and is aimed primarily at manufacturers of professional, short-range telemetry and data-exchange systems for on-site monitoring, control, and security. The SX850 uses a frequency source referenced to a temperature-controlled crystal oscillator (TCXO), providing frequency stability to within ±2.5 PPM over an operating temperature range of −25 to +55°C. Its channels are programmable through a serial interface and can be selected through a serial or parallel port. It offers a 5-mW output-power mode for short-range applications and a 500-mW mode for longer-range telemetry systems. Operating from a +7.2-VDC power supply, the transceiver consumes less than 75 mA in the receive mode and typically less than 450 mA in the low-power and high-power transmission modes. It supports both analog and digital modulation. An optional Gaussian-minimum-shift-keying (GMSK) modem is available to provide data rates to 4800 or 9600 baud. Other features include a received signal-strength indicator (RSSI) and squelch (no-signal, audio-mute) outputs. The transceiver module measures 85.5 × 52.5 × 12.75 mm and weighs 60 g. **Wood & Douglas, Ltd., Lattice House, Baughurst Rd., Baughurst, Tadley, Hampshire RG26 5LP, England; (44) 0118 981 1444, FAX: (44) 0118 981 1567, Internet: http://www.woodanddouglas.co.uk.**

CIRCLE NO. 87 or visit www.mwrf.com.

Digital PLO serves IOP

A low-cost, phase-locked, dielectric resonator oscillator is ideal for Internet-on-pole (IOP) applications. The drop-in module uses a temperature-compensated internal reference crystal oscillator with a stability of 1 PPM at operating temperatures from −20 to +70°C. The oscillator uses an external reference whose frequency is anywhere from 10 to 20 MHz. It provides an output power of 15 dBm. At an operating frequency of 5.775 GHz, it provides a phase noise of −101 dBc/Hz at 10 kHz offset. The PLO requires a +5-VDC power supply and is housed in a 2 × 2-in. (5.1 × 5.1-mm) package. **PmT, Inc., 3 Nami Lane, Unit C-10, Mercerville, NJ 08619; (609) 586-8140, FAX: (609) 586-1231.**

CIRCLE NO. 88 or visit www.mwrf.com.

Waveguide switches reach 40 GHz

A line of electromechanical switches provides high isolation and low insertion loss over waveguide bands from 2.6 to 40 GHz. Typical units include switches with WR284 waveguide for frequencies from 2.6 to 3.95 GHz, units with WR62 waveguide for frequencies from 12.4 to 18 GHz, and WR28 waveguide for frequencies from 26.5 to 40 GHz. The minimum isolation for these switches is 70 dB and the maximum insertion loss is 0.1 dB. The maximum VSWR is 1.10:1 for switches operating below 18 GHz and 1.15:1 for switches operating beyond 18 GHz. The switches require a +28 -VDC standard solenoid voltage, feature a maximum switching speed of 125 ms. **ARRA, Inc., 15 Harold Court, Bay Shore, NY 11706-2296; (631) 231-8400, FAX: (631) 434-1116, Internet: http://www.arra.com.**

CIRCLE NO. 89 or visit www.mwrf.com

Double-balanced mixers boast wide bandwidths

Models MC41, MC45, and MC48 double-balanced mixers operate with wide RF and local-oscillator (LO) frequency bands. The MC41 operates with RF and LO frequencies from 2 to 10 GHz. The MC45 operates with RF and LO frequencies from 4 to 22 GHz. And the MC48 operates with RF and LO frequencies from 10 to 26.5 GHz. All three models operate with intermediate frequencies (IFs) to 6 GHz. LO power levels are available from +7 to +20 dBm. Typical performance includes a conversion loss of 6 dB, an L-R isolation of 35 dB and an L-I isolation of 33 dB. The mixers are open substrates on carriers for drop-in microstrip installation, but they are also available with SMA connectors. **Stellex Microwave Systems, Inc., Stanford Research Park, 3333 Hillview Ave., Palo Alto, CA 94303-1223; (800) 321-8075, Internet: http://www.stellexms.com.**

CIRCLE NO. 90 or visit www.mwrf.com.

Drop-in isolators boast high isolation

Models 2E2N and 2E4N are dual-junction drop-in isolators that boast higher isolation and lower loss than conventional single-junction isolators connected in series, and conserve space in circuit design. The isolators are ideal for wireless base-station applications. Model 2E2N is available for any 35-MHz band between 0.8 to 0.96 GHz, while model 2E4N is available for any 80-MHz band between 1.8 to 2.7 GHz. The isolators afford a minimum isolation of 45 dB and a minimum insertion loss of 0.6 dB. Maximum VSWR is 1.2:1. They have a power-handling capacity of 60 W in both the forward and reverse directions. **Renaissance Electronics Corp., 1300 Massachusetts Ave., Boxborough, MA 01719; (978) 263-4994, FAX: (978) 263-4944, Internet: http://www.rec-usa.com.**

Ultra-wideband amps cover K/Ka-bands

The QGU series of ultra-wide-band, pseudomorphic-high-electron-mobility-transistor (PHEMT) amplifiers cover the entire K- and /or Ka-frequency bands. They are ideally suited for very-wide-band power amplification. The amplifiers are offered with nominal gains of 20 dB and 40 dB, and nominal output power of 17 dBm. Each amplifier has internal bias circuitry that generates gate-control voltages, provides proper voltage sequencing, and reverse/over-voltage protection from a single external bias that can range from +8 to +12 VDC. The amplifiers are provided with K-female-connector input and output ports. Other ports, including standard rectangular waveguide and double-ridge waveguide (for 18 to 40 GHz) are also available. **QuinStar Technology, Inc., 24085 Garnier St., Torrance, CA 90505; (310) 320-1111, FAX: (310) 320-9968, Internet: http://www. quinstar. com.**

CIRCLE NO. 92 or visit www.mwrf.com.

Downconverter improves test instrument

A new downconverter for the NTS-1000B Phase Noise Analyzer test instrument lowers significantly the instrument's noise floor. Phase noise-floor specifications at 10 GHz for the downconverter are −124 dBc at 1-kHz offset, −131 dBc at 10-kHz offset, and −142 dBc at 100-kHz offset. With the downconverter installed in the NTS-1000B, the instrument's noise-floor specifications become −55 dBc at 10-Hz offset, −85 dBc at 100 Hz, −110 dBc at 1 kHz, and −130 dBc at 10 kHz. Another addition to the instrument is a special function that removes the amplitude-modulation (AM) portion of the signal under test to eliminate AM phase-noise contribution. **RDL Inc., 7th Ave. and Freedley St., Conshocken, PA 19428; (610) 825-3750, FAX: (610) 825-3530, Internet: http://www.rdl-instru mentation.com.**

CIRCLE NO. 93 or visit www.mwrf.com

Flexible coax cable fits tight spaces

The minibend® flexible coaxial cable assemblies replace small, custom, semi-rigid cable assemblies, eliminating the need for predefined custom lengths and bend configurations. They are designed for use as low-profile, internal point-to-point interconnections between RF modules within communications systems. Four different versions are available—a 24-GHz SMA-plug cable assembly, a 40-GHz assembly with 2.92-mm plug connectors (type K), a 26.5-GHz SMA assembly that exhibits lower loss than 0.086 semi-rigid cable (type L), in addion to an all-weather version with environmentally-sealed SMA plug connectors (type W). **Astrolab, Inc., 4 Powder Horn Dr., Warren, NJ 07059; (732) 560-3800, FAX: (732) 560-9570.**

CIRCLE NO. 94 or visit www.mwrf.com

Polyester laminates Handle high frequencies

A family of polyester copper (Cu)-clad laminates for high-frequency applications now has laminates with thicknesses of 0.0035 and 0.093 in. for both high-speed and high-frequency applications. These materials can replace polytetrafluoroethylene (PTFE) at lower cost and easier processing. The product line includes the GML 1100/1000 low-loss material for antennas and RF/microwave circuits, MC5 intermediate-loss, MC3D for controlled impedance circuits, and MC3 single-sided laminate for frequency sensitive or high-voltage circuits. **GIL Technologies, Inc., 175 Commerce Rd., Collierville, TN 38017; (901) 853-5070, FAX: (901) 853-3864, e-mail: gilam@ gilam.com.**

CIRCLE NO. 95 or visit www.mwrf.com

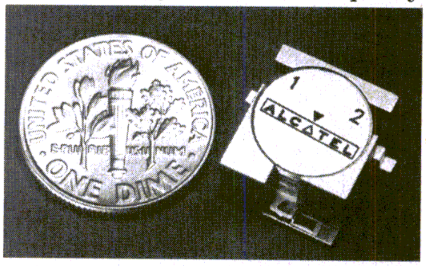
Notch filter/amplifier aids GPS receivers

For Global Positioning System (GPS) receivers operating near interfering S-band transmitters, the Model L5014 low-noise GPS notch filter/ amplifier improves system performance by combining filtering and amplification to mitigate interfering signals. A filter/amplifier assembly eliminates extra costs and difficulties encountered when using individual filters and amplifiers. The L5014 has a 1200-to-1600-MHz passband, a noise figure of 1.1 dB maximum, VSWR of 2.0:1 and rejection of 40 dBc from 2200 to 2400 MHz. The unit comes in 0.5 × 1.0 × 2.0-in. (1.27 × 2.54 × 5.08-cm) package with SMAF connectors. **Delta Microwave, Inc., 1301 Vanguard Dr., Oxnard, CA 93033; (805) 240-1044, FAX: (805) 240-9544, Internet: http://www. deltamicrowave.com.**

CIRCLE NO. 96 or visit www.mwrf.com

Surface-mount isolator Covers PCS frequencies

A miniaturized surface-mount isolator is designed for the personal-communications-systems (PCS) frequency



band of 1930 to 1990 MHz. Isolation is specified at 20 dB minimum, insertion loss is 0.4 dB maximum, VSWR is 1.25:1, and phase flatness is 0.3 dB, peak-to-peak. The isolator comes in a package measuring 0.44 × 0.50 × 0.25 in. (1.12 × 1.27 × 0.64 cm). The operating temperature range is 0 to 85°C. **Alcatel Ferrocom Ferrite Products, 6385 San Ignacio Ave., San Jose, CA 95119; (408) 229-8171, FAX: (408) 229-8506, e-mail: sales_ferrocom@aud. alcatel.com.**

CIRCLE NO. 97 or visit www.mwrf.com

Encapsulant protects PC board components

Chip-on-board component can be protected or encapsulated with the combination of AMICOM 50500-1 epoxy-based fill encapsulant and AMICOM 50300 HT damming material. Both ensure easy flow or to create glob outlines. The encapsulant as well as damming material can be used to protect multiple chips, or encapsulate components such as ball-grid arrays in applications that require a well-defined blob height. **Emerson & Cuming, One Matrix Dr., Monroe Township, NJ 08831; (800) 832-4929, FAX: (609) 409-5699, e-mail: emerinquiry@salessupp ort. com**

CIRCLE NO. 98 or visit www.mwrf.com

C-band VCO ICs are hermetically sealed

A family of C-band voltage-controlled oscillators (VCOs) is available in hermetically sealed TO-8 packages. The integrated circuits cover the frequency of 4.0 to 7.2 GHz with bandwidths of 400- to 800-MHz. Control voltage range is either 0- to 5-V, or 0- to 20-V. They draw 35 mA maximum from a +5- or +8-VDC power supply. They produce +2 to +8 dBm of RF power with ±1.5 dBm power flatness over the frequency band. Custom designs and specifications are available. **Emhiser Micro-Tech, P. O. Box 708, Verdi, NV 89439; (775) 345-0461, FAX: (775) 345-1152, e-mail: vco@emhiser.com, Internet: www.emhiser.com/vco.**

CIRCLE NO. 99 or visit www.mwrf.com

Synthesizer has small footprint

The PSS-75-1703 synthesizer for wireless applications operates over a frequency range of 1700 to 1900 MHz and is supplied in a miniature 0.75 × 0.75-in. (1.91 × 1.91-cm.) package. Phase noise is rated −102 dBc/Hz at 10 kHz offset from center frequency and −122 dBc/Hz at 100 kHz offset. The output power is 5 dBm when connected to a 5-V power supply. The operating temperature range is −20 to 70°C. **Princeton Electronic Systems, Inc. P. O. Box 8627, Princeton, NJ 08543; (609) 275-6500, FAX: (609) 799-7743, e-mail: pes@pesinc.com, Internet: http://www. pesinc.com.**

CIRCLE NO. 100 or visit www.mwrf.com

GaAs MMIC switches suited for handsets

A line of single-pole double-throw (SPDT) reflective switches is intended for high-power as well as low-power handset design applications. The gallium arsenide (GaAs) MMICs run from +3- to +5-VDC supply voltages and are housed in SOT-6, SOIC-8, or MSOP-8 plastic packages. High-power versions (AWS5501S13/03S15/04S13) can handle up to 38-dBm input power at the 1-dB compression point, and have a third-order intercept point (IP3) of 55 dBm at 1.9 GHz. P&A: $0.58 to $1.00 (100,000 qty). **ANADIGICS, 35 Technology Dr., Warren, NJ 07059; (908) 668-5000, Internet: www.anadigics.com.**

CIRCLE NO. 101 or visit www.mwrf.com

Harmonic tuner provides high mismatches

A precision, automated harmonic tuner, model MT999, can present a very high mismatch over the frequency range of 0.8 to 7.5 GHz. It is designed for harmonic load-pull or tuning measurements when a very high mismatch is required. The tuner is designed to work with the MT980 series automated tuner system (ATS). **Maury Microwave, 2900 Inland Empire Blvd., Ontario, CA 91764; (909) 987-4715, FAX: (909) 987-1112, Internet: http://www. mau rymw.com.**

CIRCLE NO. 102 or visit www.mwrf.com

Integrated components

Positive-intrinsic-negative (PIN)-diode absorptive attenuators, PIN-diode 360-deg. phase shifters, PIN diode in-phase and quadrature (I/Q) vector modulators, PIN-diode reflective and absorptive switches, PIN-diode modulators, and PIN-diode phase-invariant attenuators are featured in a 22-page catalog. Ordering information is included. Electrical specifications, environmental ratings, and outline drawings are provided. **G.T. Microwave, Inc.;** *(973) 361-5700, FAX: (973) 361-5722, e-mail: gtmicrowav@aol.com, Internet: http://www.GTmicrowave.com.*

CIRCLE NO. 111 or visit www.mwrf.com

Power dividers

A 152-page catalog covers power dividers, directional couplers, high-power dual directional couplers, diode detectors, directional detectors, waveguide couplers, as well as 90- and 180-deg. hybrids. Waveguide adapters, coaxial terminations, continuously variable attenuators, interdigital and bandpass filters, connectorized isolators and circulators, drop-in isolators and circulators, as well as voltage- and digitally controlled positive-intrinsic-negative (PIN) diode attenuators are featured. Product specifications and mechanical outlines are included. **Microwave Communications Laboratories, Inc.;** *(727) 344-6254.*

CIRCLE NO. 112 or visit www.mwrf.com

Delay lines

Fixed and variable high-speed delay lines are covered in an 18-page catalog. Descriptions, features, specifications, and outline drawings are included. A standard part-number list is provided. **Toko America, Inc.;** *(847) 297-0070, FAX: (847) 699-7864, e-mail: info@tokoam.com, Internet: http://www.tokoam.com.*

CIRCLE NO. 113 or visit www.mwrf.com

Ceramic resonators

A line of crystals, oscillators, filters, and resonators is featured in a 52-page catalog. Technical information is included. **Interquip USA;** *(760) 591-0879, FAX: (760) 591-3527, e-mail: iqlusa@interquip.com.*

CIRCLE NO. 114 or visit www.mwrf.com

Mixer products

A technical note describes special mixer products manufactured for the radar marketplace. The limitations in dynamic range of Schottky and metal-semiconductor-field-effect-transistor (MESFET) mixers are explained and front-end specifications using each mixer are outlined. In addition, several analog and digital radar phase-lock subsystems are described. Features, electrical specifications, and outline drawings are included. **MITEQ, Inc.;** *(516) 436-7400, FAX: (516) 436-7431, Internet: http://www.miteq.com.*

CIRCLE NO. 115 or visit www.mwrf.com

Interconnection products

A six-page brochure covers interconnection products and engineering as well as design services that are developed to meet high-power requirements. The brochure sections overview a variety of relevant connector types and cable assemblies. Engineering and design services discussed include signal-integrity modeling, touch screens, as well as customized backplanes, and cable assemblies. **AMP, Inc.;** *(800) 524-6579 ext. 2245, Internet: http://www.amp.com.*

CIRCLE NO. 116 or visit www.mwrf.com

Ceramic components

A brochure highlights design capabilities and current component technology for ceramic bandpass filters and diplexers, coaxial resonators, and patch antennas for RF/microwave wireless communications markets. Specifications for typical products are listed. **Trans-Tech;** *(301) 695-9400, FAX: (301) 695-7065, e-mail: transtech@alphaind.com, Internet: http://www.trans-techinc.com.*

CIRCLE NO. 117 or visit www.mwrf.com

Antenna design

Antennas, feeds, components, and subsystems are described in a 134-page catalog. Full specifications and application notes are included. An index is provided. **Seavey Engineering Associates, Inc.;** *(781) 829-4740, FAX: (781) 829-4590, e-mail: info@seaveyantenna.com, Internet: http://www.seaveyantenna.com.*

CIRCLE NO. 118 or visit www.mwrf.com

Network test

A 12-page application note looks at network test solutions. Testing of Synchronous Optical Network (SONET), synchronous-digital-hierarchy (SDH), piesiochronous-digital hierarchy (PDH), and dense-wavelength-division-multiplexer (DWDM) networks are examined. The application note compares manual and automatic measurements in terms of cost-effectiveness and reproductibility. **Wandel & Goltermann GmbH & Co.;** *+49 7121 86-1616, FAX: +49 7121 86-1333, e-mail: info@wwgsolutions.com, Internet: http://www.wwgsolutions.com.*

CIRCLE NO. 119 or visit www.mwrf.com

Communications test

A company specializing in communications test solutions is described in a 20-page brochure. The brochure includes an overview and history of the company. **Wavetek Wandel Goltermann, Inc.;** *(919) 941-5730, FAX: (919) 941-9361, Internet: http://www.wwgsolutions.com.*

CIRCLE NO. 120 or visit www.mwrf.com

Trimmer capacitors

A company's non-magnetic trimmer capacitors are highlighted in a 10-page brochure. Specifications and options are included. DC working voltage and DC withstanding voltage are listed for each individual capacitor. Outline drawings are provided. **Voltronics Corp.;** *(973) 586-8585, FAX: (973) 586-3404, e-mail: info@voltronicscorp.com, Internet: http://www.voltronicscorp.com.*

CIRCLE NO. 121 or visit www.mwrf.com

Test sets

A company's lines of test sets and handheld meters are covered in a catalog. The catalog also features wire and cable, computer and local-area-network (LAN) products, and communications products. **Jensen Tools, Inc.;** *(800) 426-1194, (602) 453-3169, FAX: (800) 366-9662, (602) 438-1690, e-mail: jensen@stanleyworks.com, Internet: http://www.jensentools.com.*

CIRCLE NO. 122 or visit www.mwrf.com

Wire connectors

A brochure features a line of twist-on wire connectors. Dry and damp, waterproof, and underground connectors are listed. Features, benefits, applications, as well as measurements are provided for each connector. **King Safety Products;** *(800) 633-0232, (314) 519-5400, FAX: (314) 519-5410, e-mail: kingsafety@stl-net.com, Internet: http://www.kingsafety.com.*

CIRCLE NO. 123 or visit www.mwrf.com

Power dividers

A 148-page catalog highlights power dividers/combiners, couplers, hybrids, isolators/circulators, terminations, and oscillators. Attenuators, power amplifiers (PAs), and switches are also presented. Features, electrical specifications, and outline drawings are included. **Microwave Communications Laboratories, Inc.;** *(800) 333-6254, (727) 344-6254, FAX: (727) 381-6116, e-mail: sales@mcli.com, Internet: http://www.mcli.com.*

CIRCLE NO. 124 or visit www.mwrf.com

Coaxial cable assemblies

Phase-stable coaxial cable assemblies are highlighted in a brochure. Information on cable specifications, cable-assembly specifications, attenuation curves, and power curves is provided. **Insulated Wire, Inc.;** *(203) 791-1999, FAX: (203) 748-5217, e-mail: iwconn@insulatedwire.com, Internet: http://www.insulatedwire.com.*

CIRCLE NO. 125 or visit www.mwrf.com

Measurement instruments

A 24-page short-form catalog covers test and measurement instruments. Clamp-on ground resistance testers, fall-of-potential ground testers, AC-to-DC current-measurement probes, digital/analog megohmmeters, hand-crank megohmmeters, micro-ohmmeters, power meters are featured. Professional multimeters, clamp-on multimeters, harmonic power meters, data loggers, lightmeters, transformer ratiometers, and flexible current probes are also discussed. **AEMC Instruments;** *(800) 343-1391, (617) 451-0227, FAX: (617) 423-2952, e-mail: sales@aemc.com, Internet: http://www.aemc.com.*

CIRCLE NO. 126 or visit www.mwrf.com

Frequency-control components

Frequency-control components are offered in a product selection guide. Surface-mount-technology (SMT) inductors and transformers, tuning varactors, and a range of air, ceramic, glass, mica, plastic, quartz, and sapphire dielectric trimmer capacitors are described. Surface-mount inductors, metallized inductors as well as inductive-capacitive (LC) tuners, microwave tuners, and tuning tools are also covered. Products that are suitable for surface-mount, lead-through-hole, panel-mount, and hybrid applications are offered. **Sprague-Goodman Electronics, Inc.;** *(516) 334-8700, FAX: (516) 334-8771, e-mail: info@spraguegoodman.com.*

CIRCLE NO. 127 or visit www.mwrf.com

Logic analyzers

Oscilloscopes, logic scopes, logic analyzers, spectrum analyzers, network analyzers, power meters, and signal generators are offered in a 672-page catalog. Electromagnetic-interference (EMI)/RF-interference (RFI) solutions, wireless communication test sets, optical network products, broadband transmission test products, access networks products, protocol analyzers, and arbitrary generators are also offered. Features, benefits, applications, characteristics, and ordering information are provided. **Tektronix, Inc.;** *(800) 426-2200, (503) 682-3411, Internet: http://www.tektronix.com/Measurement.*

CIRCLE NO. 128 or visit www.mwrf.com

HFC cable

A brochure contains solutions for hybrid-fiber-coaxial (HFC) cable modulator/demodulator applications. Solutions are offered for subscriber cable modems, evaluation boards, hybrid fiber/coax, upstream modulators, digital modulators, and demodulator application-specific integrated circuits (ASICs). The features of each item are included. Specifications are also provided. **Stanford Telecom;** *(408) 745-2660, FAX: (408) 541-9030, e-mail: tpg.marketing@stelhq.com, Internet: http://www.stelhq.com.*

CIRCLE NO. 129 or visit www.mwrf.com

SPST switches

A short-form brochure focuses on RF products for Global System for Mobile Communications (GSM) products. Integrated circuits (ICs) include attenuators; single-pole, single throw (SPST) switches; single-pole, double-throw (SPDT) switches; diversity switches; single-pole, four throw (SP4T) switches; power amplifiers (PAs); directional couplers; as well as power dividers. Discrete semiconductors include varactor diodes, positive-intrinsic-negative (PIN) diodes, as well as Schottky mixer and detector diodes. Solutions for GSM handsets include switching, routing, a power detector, a PA, a fast voltage-controlled oscillator (VCO), mixers, as well as intermediate-frequency (IF) and demodulator VCOs. **Alpha Industries, Inc.;** *(781) 935-5150, FAX: (617) 824-4579, e-mail: sales@alphaind.com, Internet: http://www.alphaind.com.*

CIRCLE NO. 130 or visit www.mwrf.com

Low-noise amplifiers

A brochure covers 12-way power dividers and low-noise amplifiers (LNAs). Features and descriptions are provided for each item. Options are also included. **CAP Wireless, Inc.;** *(805) 499-1818, FAX: (805) 499-6649, e-mail: sales@capwireless.com, Internet: http://www.capwireless.com.*

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Capacitors/filters

A 16-page catalog highlights ceramic capacitors, electromagnetic-interference (EMI)/RF-interference (RFI) suppression filters, military filters, passband filters, along with subminiature connectors. Outline drawings are provided, along with a section of application notes. **Metuchen Capacitors, Inc.;** *(800) 899-6969, (732) 679-3366, FAX: (732) 679-3222, e-mail: sales@metcaps.com, Internet: http://www.metcaps.com.*

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RF Process Engineer
Lead the development of new or modified manufacturing processes using your extensive knowledge of semiconductor assembly. Responsible for production support including the qualifications of new materials and piece parts. 5–10 years experience. BSEE preferred.

RF Product Engineer
Responsible for product transfer from design to high volume production, specifically transistor failure analysis, die evaluation, manufacturing product support, product yields and RF/DC fixture troubleshooting. Minimum 5 years experience. BSEE preferred.

For complete information about our employment opportunities in Morgan Hill, California, please visit our web site at **www.ericsson.com/rfpower** or call us at 408-776-0600.

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These positions offer the stimulation of working on advancing the boundaries of MMW wireless technology while applying principles of design for manufacturability. Candidates must have 3 to 5 years of "hands-on" experience in the design and implementation of RF/microwave circuits from 100 MHz to 10GHz, using filters, oscillators, amplifiers, and other RF components for commercial wireless communications equipment. Higher frequency experience and familiarity with Bellcore, UL, CSA, CE, and/or ETS requirements would be an added advantage. MSEE preferred; BSEE required.

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• Waveguide Filter Design Engineer •
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Systems and Components, RF, PCS, Microwave, Antenna, Network, Software, Sales, Dig, & Analog. Mixed Signals, many more. Resume to: Peter Ansara, c/o ABF, P.O. Box 6037, 50 Resnik Road, Suite 104, Plymouth, MA 02360. Tel:(508)830-0079, Fax: (508) 830-1424 or email pa@ansara.com.
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Space Engineering

The Johns Hopkins University Applied Physics Laboratory (APL), located midway between Baltimore, MD and Washington, DC, is a national leader in scientific research and development. Presently, we are seeking experienced engineers to join our Space Department.

RF Oscillator Design Engineer

You will lead the development of new technology in the areas of precision signal sources with an emphasis on high stability, low noise and crystal oscillators. You will also identify and develop new time and frequency concepts, applications and technologies; present these new applications to the technical community; analytically and experimentally evaluate concept feasibilities; take the lead in identifying new sponsors; and write new proposals. Candidates must possess an MS or PhD in the electrical engineering field, or equivalent, with 5 or more years' experience designing frequency and timing systems. You must also have expertise with RF microwave and experience with standard RF test and measurement equipment. **(Dept. 0801441299)**

Microwave/Optical R&D Engineer

You will develop new technology in the areas of RF microwave and optical systems; assist in the development of new space program initiatives; and pursue new funding sources in space-related technology fields. These activities will involve research and development of sensor systems, advanced ultra-stable oscillator development for space applications, optical communications and precision electromagnetic measurements. Candidates must possess a PhD in an engineering field, or equivalent, with a strong emphasis on experimental and analytical skills. Demonstrated capability to be technically innovative and to lead an R&D team, and willingness to author test plans, test reports and publications, are also required. **(Dept. 0010041299)**

RF Communications Engineer

In this position, you will design, develop, test and flight qualify microwave radio communications systems and microwave hardware components (e.g., transmitters, receivers, antennas) using state-of-the-art technologies. A demonstrated ability to provide leadership and innovation in the development of new communications system concepts and hardware is highly desirable. You must possess a BS degree in electrical engineering, or equivalent, and 5-10 years' recent direct experience in the design of RF communications circuits and systems. You must also possess the ability to lead supporting engineers and technicians, knowledge of current/emerging technologies and experience with computer-aided design (CAD). **(Dept. 0800131299)**

Antenna System Design Engineer

Candidates must have a broad range of leadership experience in the antenna design field, as well as possess the capability of creating new, innovative concepts in antenna systems and design. You must also have a demonstrated ability to interact with, and present new design concepts to, potential sponsors. A background that includes a combination of hands-on and analytical design experience is highly desirable, as is an MS or PhD degree in electrical engineering, or equivalent, with 5 or more years of relevant experience. **(Dept. 0800921299)**

Communications Systems Engineer

You will perform conceptual design of advanced communications, navigation and radar systems; perform analytical evaluation of new communications, navigation and radar system concepts; and document work through internal and external publications and presentations. This position requires an MS or PhD in electrical engineering or related field, or equivalent, with 7-10 years of relevant experience. Strong analytical capability in solving complex problems relating to radio communications, radio navigation and/or radar; experience with modeling and simulation of signals and systems; and the desire to implement conceptual designs with other engineers on current/future spacecraft is also required. **(Dept. 0800941299)**

Receiver/Transmitter Design Engineer

You will implement advanced signal processing hardware and techniques for RF communications and radar system designs; incorporate analog and digital signal processing techniques into the design of receivers, transmitters, demodulators, modulators, bit synchronizers, phaselock loops, AGC loops, filters, phase detectors, etc.; and design novel packaging techniques for state-of-the-art receiver and transmitter designs. You must possess a BS or MS degree in electrical engineering or closely related field, with 3-10 years of relevant work experience. You must also have recent direct experience in analog and digital circuit design and experience using CAD tools. A candidate capable of generating new ideas and providing leadership and a background in DSP analysis and design are highly desirable. A background in phaselock loop techniques is preferred. **(Dept. 0801151299)**

All positions require highly motivated individuals with strong interpersonal, oral and written communications skills and the ability to work independently or in a team environment. Applicants must also have US citizenship and meet security clearance requirements.

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PRINCIPAL RF ENGINEERS

Individuals will be expected to act as leaders and/or major technical contributors to a cross functional development team, with hands on responsibility for the design of RF systems, circuitry, and hardware. Individuals will lead from definition of requirements through the integration and testing of the completed product, manufacturing and fielding of equipment. Successful candidates will have a BS in Electrical Engineering, (MS in Electrical Engineering is highly desired); 10+ years of experience with the development of RF circuitry; experience as a key technical contributor and/or project leader on an RF design project; system level experience and knowledge of radio systems; and experience developing innovative design solutions to radio products.

LEAD RF ENGINEERS

Individuals will be members of a cross functional development team with hands on responsibility for the design and support of RF hardware from the definition of requirements through the integration and testing of the completed product. Successful candidates will have a BS in Electrical Engineering or equivalent; 5+ years of experience with the development of RF circuitry. Individuals should be self-directed, and focused on meeting customer requirements and on the production of a high quality, profitable product.

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We are currently seeking qualified candidates for these positions who will be responsible for the development of RF hardware in support of advanced VHF/UHF two way radio products.

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In addition to advancement opportunities throughout our organization, we offer excellent salaries and benefits. For immediate consideration, please send your resume to: ***Harris Corporation, RF Communications Division, 1680 University Avenue, Rochester, NY 14610; FAX: (716) 242-4711; or E-mail: LmcCandl@harris.com*** *EOE*

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Support specification, design and simulation of complex digital cellular and cordless communication systems; perform trade-off studies to provide specification subsystems. Requires MSEE or equivalent; 5 years hands-on experience in systems design, including receivers, transmitters, and synthesizers; ability to apply system work toward implementation of RF ASIC devices.

RF IC DESIGN ENGINEERS

Design, circuit analysis, simulation & verification of RF ICs for wireless applications such as cellular & cordless communications. Requires MSEE or equivalent; directly related experience in RF IC design using state-of-the-art analog and mixed-signal simulation tools (HSPICE, HP ADS, Cadence SpectreRF); experience in CMOS, Bipolar, or BiCMOS process technologies. Positions also available in our new Boston Design Center.

CUSTOMER DESIGN CENTER ENGINEERS

Will be liaison between customers & design team to accelerate customer design-in of wireless cordless & cellular communications products; create & present seminars; write application notes, articles & other technical marketing documents. Positions in technical areas of RF circuits for GSM handsets; real-time embedded software in C for GSM handsets & GPS products; real-time embedded software in Assembly for DSS products. Requires BSEE or equivalent; experience in product applications or field applications engineering; strong background in RF circuit or MMI software design. Domestic and international travel required.

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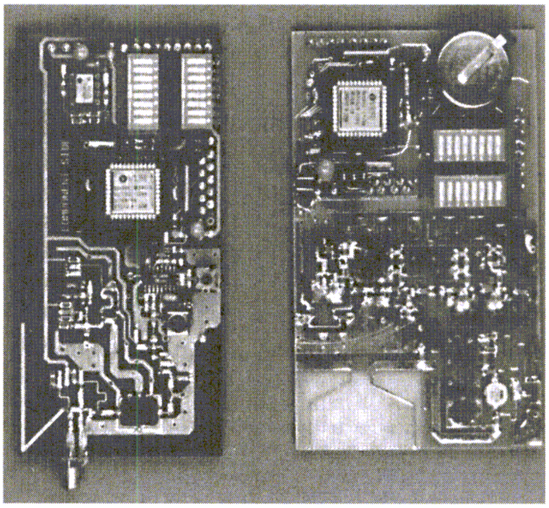

Ten years ago, a special report on emerging commercial applications spotlighted Hillier Technologies (Princeton, NJ) and their Hi-TEK spread-spectrum evaluation kit. The kit included receivers, transmitters, and a sample address programming card and was said to be able to support some applications for as little as $10.

Microwaves & RF January Editorial Preview

Issue Theme: Test & Measurement

News

The first issue of 2000 is dedicated to that all important segment of high-frequency electronics—test and measurement. Do not miss this exclusive News Story on the state of high-frequency measurement markets and technologies.

Design Features

Measurement technology is the basis for most advances in electronics, since test capability provides data about the performance of a new component or system. January's Design Features highlight this important part of the high-frequency industry with several articles, including a comparison of available calibration techniques for on-wafer measurements through 110 GHz, the use of confidence-interval analysis in wireless measurements, and the application of a high-speed logarithmic amplifier to capture wide-dynamic-range pulsed signals.

Product Technology

January's Product Technology section spotlights new instrumentation for a new market—a test set designed for cable-modem measurements. Additional Product Features in January will cover a high-power amplifier for wireless base stations, and a handheld test set for evaluating the wireless spectrum through 2 GHz.