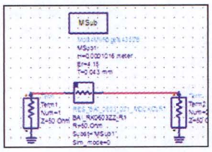
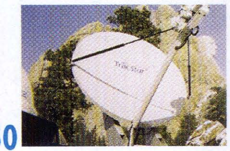
INSIDE TRACK with **JIM DOYLE,** ECM DISTRIBUTORS p32

MODELING CIRCUIT SUBSTRATES p68



SERVING SATCOM SYSTEMS p50



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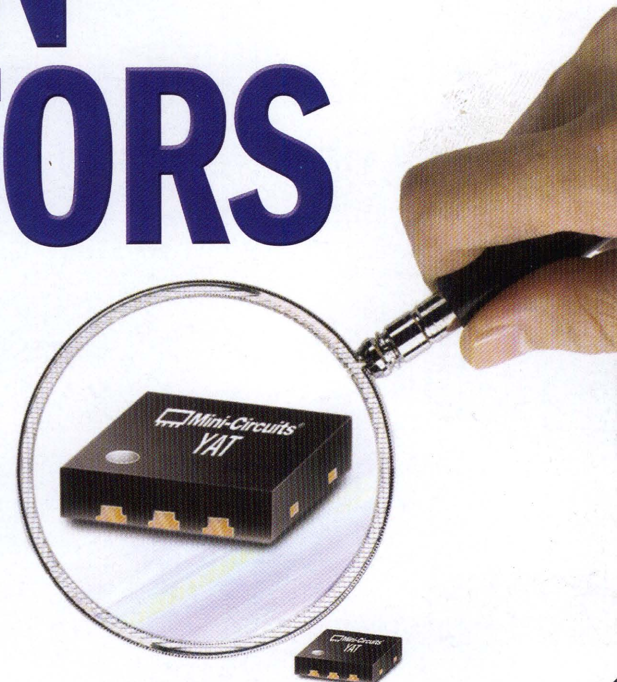

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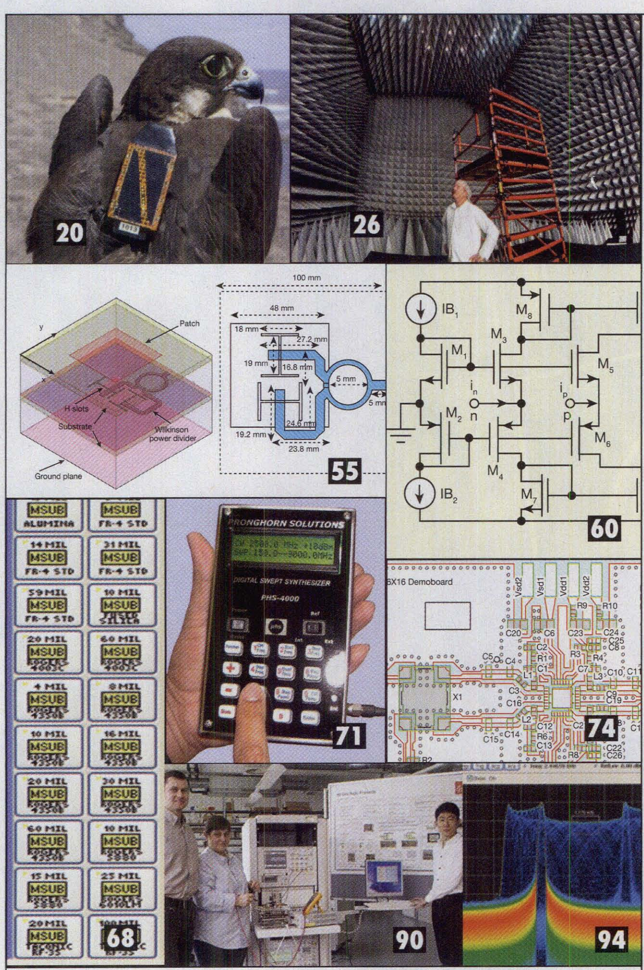
CONTENTS

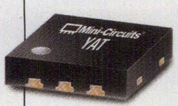


INDUSTRY TRENDS AND ANALYSIS

DESIGN FEATURES

PRODUCT TECHNOLOGY

COVER STORY



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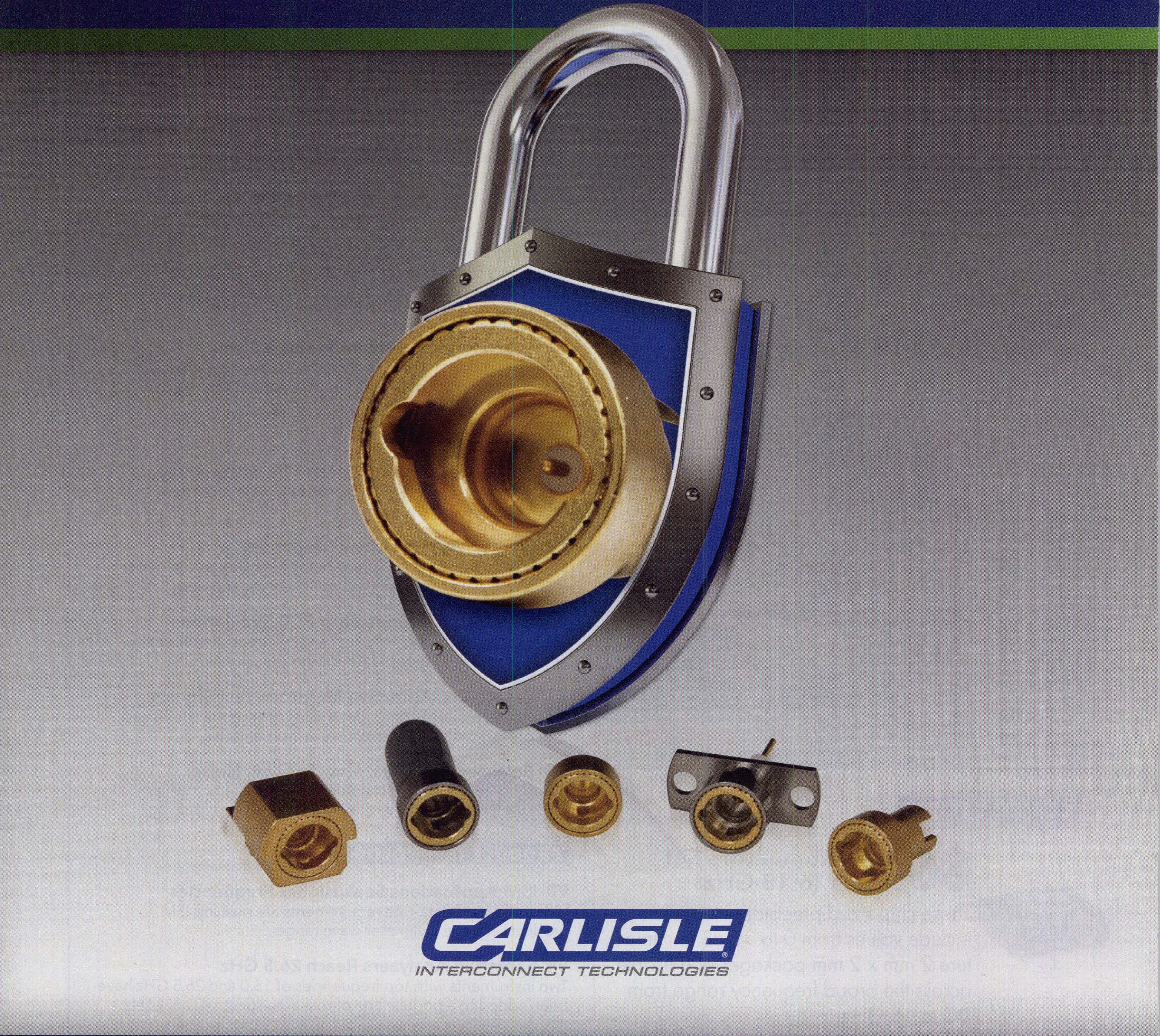

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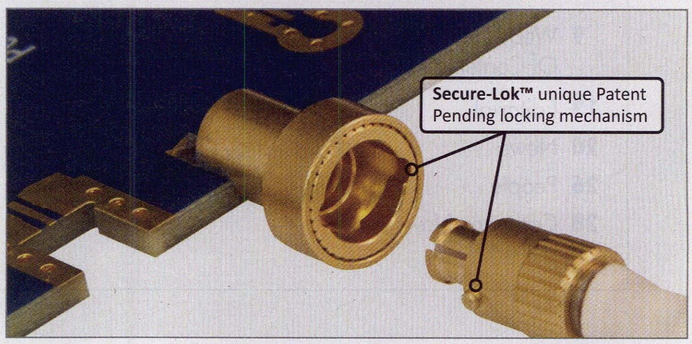

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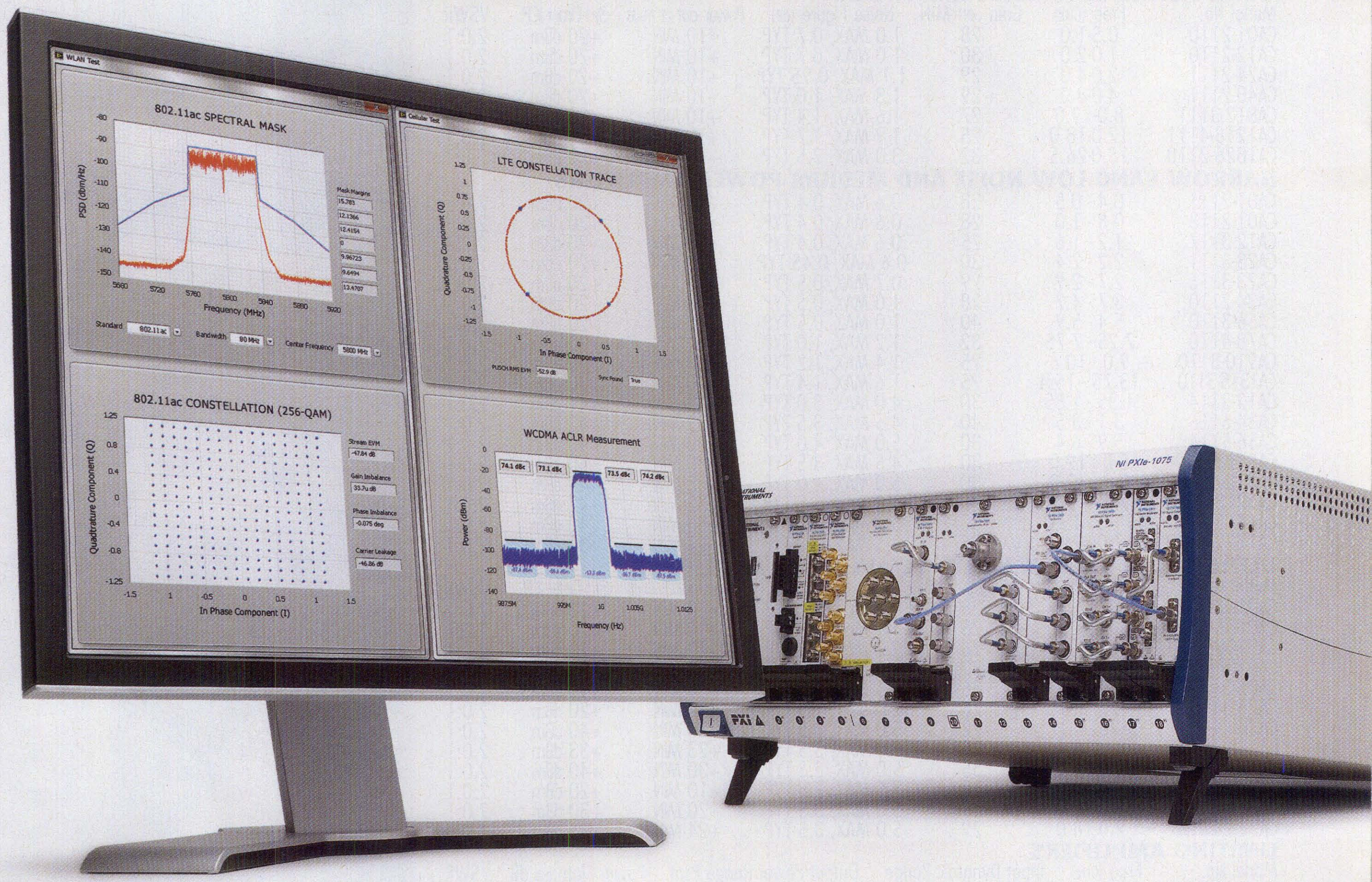

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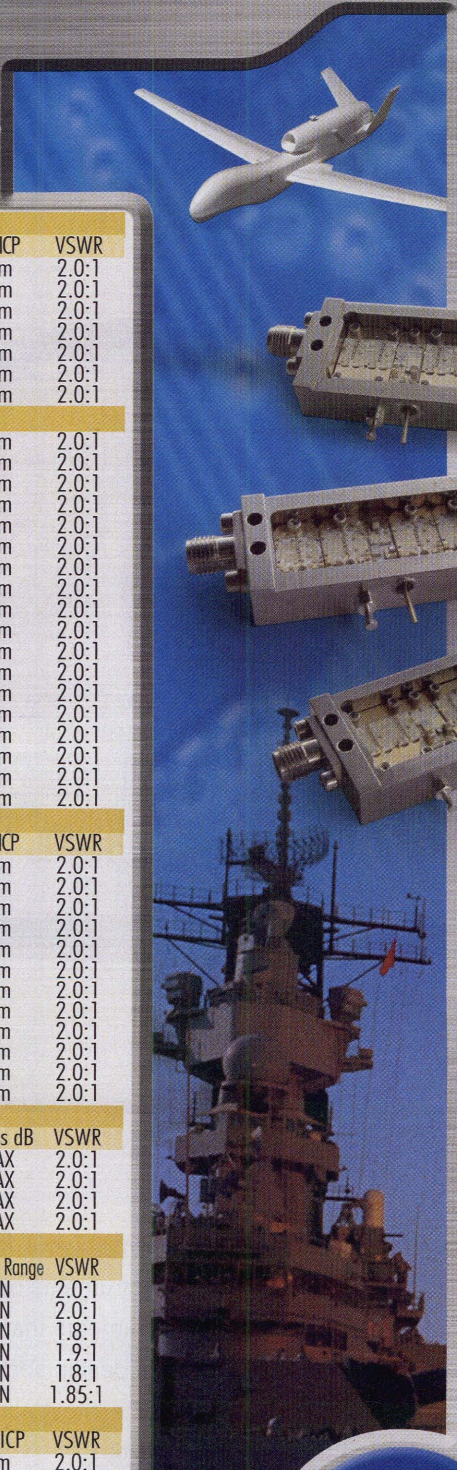

OCTAVE BAND LOW NOISE AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA01-2110	0.5-1.0	28	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA12-2110	1.0-2.0	30	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA24-2111	2.0-4.0	29	1.1 MAX, 0.95 TYP	+10 MIN	+20 dBm	2.0:1
CA48-2111	4.0-8.0	29	1.3 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA812-3111	8.0-12.0	27	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA1218-4111	12.0-18.0	25	1.9 MAX, 1.7 TYP	+10 MIN	+20 dBm	2.0:1
CA1826-2110	18.0-26.5	32	3.0 MAX, 2.5 TYP	+10 MIN	+20 dBm	2.0:1

NARROW BAND LOW NOISE AND MEDIUM POWER AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA01-2111	0.4 - 0.5	28	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA01-2113	0.8 - 1.0	28	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA12-3117	1.2 - 1.6	25	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA23-3111	2.2 - 2.4	30	0.6 MAX, 0.45 TYP	+10 MIN	+20 dBm	2.0:1
CA23-3116	2.7 - 2.9	29	0.7 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA34-2110	3.7 - 4.2	28	1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA56-3110	5.4 - 5.9	40	1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA78-4110	7.25 - 7.75	32	1.2 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA910-3110	9.0 - 10.6	25	1.4 MAX, 1.2 TYP	+10 MIN	+20 dBm	2.0:1
CA1315-3110	13.75 - 15.4	25	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA12-3114	1.35 - 1.85	30	4.0 MAX, 3.0 TYP	+33 MIN	+41 dBm	2.0:1
CA34-6116	3.1 - 3.5	40	4.5 MAX, 3.5 TYP	+35 MIN	+43 dBm	2.0:1
CA56-5114	5.9 - 6.4	30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6115	8.0 - 12.0	30	4.5 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6116	8.0 - 12.0	30	5.0 MAX, 4.0 TYP	+33 MIN	+41 dBm	2.0:1
CA1213-7110	12.2 - 13.25	28	6.0 MAX, 5.5 TYP	+33 MIN	+42 dBm	2.0:1
CA1415-7110	14.0 - 15.0	30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm	2.0:1
CA1722-4110	17.0 - 22.0	25	3.5 MAX, 2.8 TYP	+21 MIN	+31 dBm	2.0:1

ULTRA-BROADBAND & MULTI-OCTAVE BAND AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA0102-3111	0.1-2.0	28	1.6 Max, 1.2 TYP	+10 MIN	+20 dBm	2.0:1
CA0106-3111	0.1-6.0	28	1.9 Max, 1.5 TYP	+10 MIN	+20 dBm	2.0:1
CA0108-3110	0.1-8.0	26	2.2 Max, 1.8 TYP	+10 MIN	+20 dBm	2.0:1
CA0108-4112	0.1-8.0	32	3.0 MAX, 1.8 TYP	+22 MIN	+32 dBm	2.0:1
CA02-3112	0.5-2.0	36	4.5 MAX, 2.5 TYP	+30 MIN	+40 dBm	2.0:1
CA26-3110	2.0-6.0	26	2.0 MAX, 1.5 TYP	+10 MIN	+20 dBm	2.0:1
CA26-4114	2.0-6.0	22	5.0 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA618-4112	6.0-18.0	25	5.0 MAX, 3.5 TYP	+23 MIN	+33 dBm	2.0:1
CA618-6114	6.0-18.0	35	5.0 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA218-4116	2.0-18.0	30	3.5 MAX, 2.8 TYP	+10 MIN	+20 dBm	2.0:1
CA218-4110	2.0-18.0	30	5.0 MAX, 3.5 TYP	+20 MIN	+30 dBm	2.0:1
CA218-4112	2.0-18.0	29	5.0 MAX, 3.5 TYP	+24 MIN	+34 dBm	2.0:1

LIMITING AMPLIFIERS

Model No.	Freq (GHz)	Input Dynamic Range	Output Power Range Psat	Power Flatness dB	VSWR
CLA24-4001	2.0 - 4.0	-28 to +10 dBm	+7 to +11 dBm	+/- 1.5 MAX	2.0:1
CLA26-8001	2.0 - 6.0	-50 to +20 dBm	+14 to +18 dBm	+/- 1.5 MAX	2.0:1
CLA712-5001	7.0 - 12.4	-21 to +10 dBm	+14 to +19 dBm	+/- 1.5 MAX	2.0:1
CLA618-1201	6.0 - 18.0	-50 to +20 dBm	+14 to +19 dBm	+/- 1.5 MAX	2.0:1

AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	Gain Attenuation Range	VSWR
CA001-2511A	0.025-0.150	21	5.0 MAX, 3.5 TYP	+12 MIN	30 dB MIN	2.0:1
CA05-3110A	0.5-5.5	23	2.5 MAX, 1.5 TYP	+18 MIN	20 dB MIN	2.0:1
CA56-3110A	5.85-6.425	28	2.5 MAX, 1.5 TYP	+16 MIN	22 dB MIN	1.8:1
CA612-4110A	6.0-12.0	24	2.5 MAX, 1.5 TYP	+12 MIN	15 dB MIN	1.9:1
CA1315-4110A	13.75-15.4	25	2.2 MAX, 1.6 TYP	+16 MIN	20 dB MIN	1.8:1
CA1518-4110A	15.0-18.0	30	3.0 MAX, 2.0 TYP	+18 MIN	20 dB MIN	1.85:1

LOW FREQUENCY AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure dB	Power-out @ P1-dB	3rd Order ICP	VSWR
CA001-2110	0.01-0.10	18	4.0 MAX, 2.2 TYP	+10 MIN	+20 dBm	2.0:1
CA001-2211	0.04-0.15	24	3.5 MAX, 2.2 TYP	+13 MIN	+23 dBm	2.0:1
CA001-2215	0.04-0.15	23	4.0 MAX, 2.2 TYP	+23 MIN	+33 dBm	2.0:1
CA001-3113	0.01-1.0	28	4.0 MAX, 2.8 TYP	+17 MIN	+27 dBm	2.0:1
CA002-3114	0.01-2.0	27	4.0 MAX, 2.8 TYP	+20 MIN	+30 dBm	2.0:1
CA003-3116	0.01-3.0	18	4.0 MAX, 2.8 TYP	+25 MIN	+35 dBm	2.0:1
CA004-3112	0.01-4.0	32	4.0 MAX, 2.8 TYP	+15 MIN	+25 dBm	2.0:1

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THE EFFECT OF MOORE'S LAW on RF Instruments

DAVID A. HALL

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To read the article in its entirety, go to http://mwrf.com/test-amp-measurement/effect-moore-s-law-rf-instruments.

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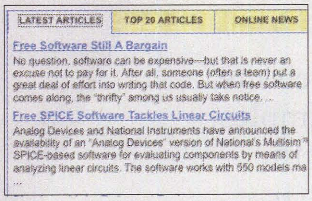
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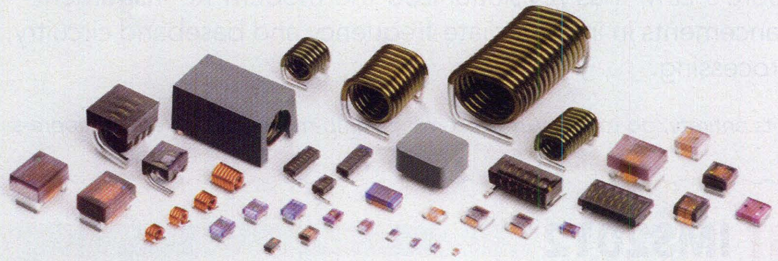

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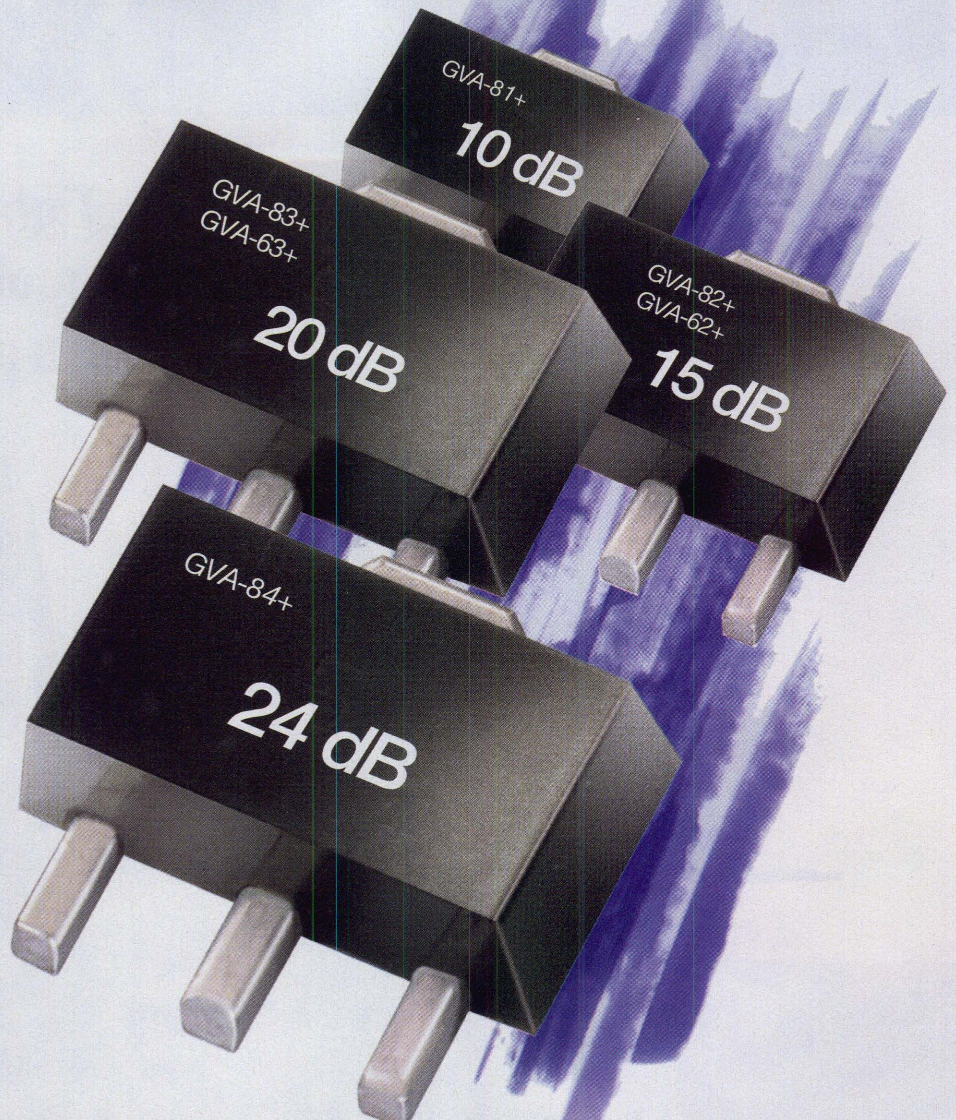
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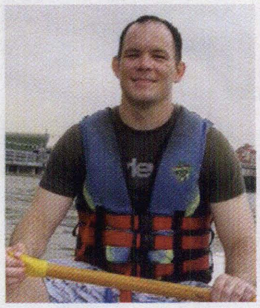
From the Editor

GaN, Death, And Distrust

IN THE MICROWAVE INDUSTRY, we pride ourselves on the innovative spirit, genius, and dedicated work ethic of so many engineers. Upon reading the story of a recently deceased, young engineer under mysterious circumstances, however, I wonder if we are overlooking the dangers of the international market—in addition to "turning a blind eye" to the applications for some of our technology. In an article from *The Financial Times* (www.ft.com) titled "Death in Singapore," Raymond Bonner and Christine Spolar tell the story of Shane Todd's death. The 31-year-old Todd—with a doctorate from the University of California, Santa Barbara, for work on transmission lines—had toiled for 18 months at Singapore's Institute of Microelectronics (IME; www.ime.a-star.edu.sg). Amidst preparations to return to the US, he allegedly committed suicide by hanging.

Todd's family had been worried about him because he repeatedly told them that he was concerned about the work he was doing at IME in gallium-nitride (GaN) research, thinking that it could jeopardize US national security. Upon arriving at his apartment in Singapore, his parents immediately noticed that the scene did not match what they had been told in terms of how their son had arranged his death. And the apartment seemed frozen in time, as Todd had clearly been in the middle of doing laundry and packing.



The Singapore police had confiscated his laptops and mobile phone. Upon leaving, however, Todd's mother noticed what looked like a speaker and took it. When they got home, they discovered it was actually an external hard drive that contained copies of their son's computer files. The files included Todd's work at IME and a timetable and plan for a project between IME and Huawei Technologies to "co-develop" a GaN amplifier by the end of 2014.

Although it is possible that Todd did indeed commit suicide, some aspects of this story point to foul play. For instance, Todd—who communicated with his family via Skype weekly—told them to call the American Embassy if they didn't hear from him in a week. In addition, Todd's knuckles were bruised and he had a bump on his head. Judging by pictures, a pathologist in the US said that the bruising around his neck also was inconsistent with hanging by suicide and instead pointed to a rapid death. The computer analyst also found something worrisome: Three days after Todd's death, someone looked at several of Todd's IME folders. One of the files was a PowerPoint presentation of the "Layer structure and summary of Veeco grown HEMT wafer."

The Todds continue to do what they can to push this story forward, hoping to raise awareness of possible dangers in today's international business market—particularly in engineering, where most of the game-changing R&D is now done offshore. A petition directing the Department of Justice to investigate Shane Todd's death is being circulated at http://petitions.whitehouse.gov. MWRF

Nancy K. Friedrich

Editor-In-Chief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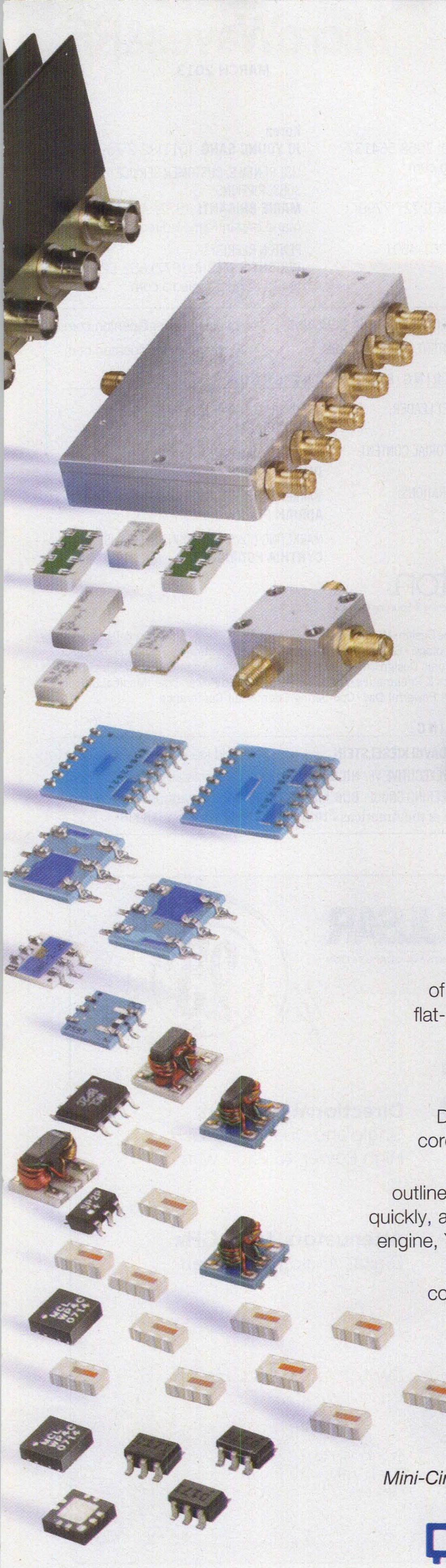

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IS GaN FOR REAL?

Having read your magazine for many years, it is customary to see stories that highlight "the next great thing" that is going to save our industry. And when reading the February issue of *Defense Electronics* that was tucked inside of your regular February issue of *Microwaves & RF*, I couldn't help but notice that the latest "savior technology" appears to be gallium nitride (GaN). In an article written by your Technical Contributor about CTT (www.cttinc.com) and their latest line of high-power solid-state amplifiers (see p. S32), the author alludes to these broadband amplifiers as possible replacements for traveling-wave-tube amplifiers (TWTAs). From what I could see from the performance data listed in the article, these GaN amplifiers have a long way to go before they give even low-power TWTAs a run for their money, or any kind of consideration for replacement in military electronic systems.

Admittedly, the GaN amplifiers are capable of some extremely broadband coverage, with models shown for frequency ranges that included 2 to 6 GHz, and even 2 to 18 GHz. But the very broadband amplifiers were showing maximum output powers of only about 8 W at 18 GHz, which is no serious threat to the high power levels possible with traveling-wave tubes (TWTs). While it may be true that GaN offers great promise for high-power amplification in future commercial and military systems, it may be a bit premature to hold out these particular amplifiers as "TWTA replacements."

MAX CANTRELL
DELAWARE, NY

EDITOR'S NOTE

It is true that newer technologies can sometimes be presented as solutions for virtually everything that ails the RF/microwave industry. And, as with gallium arsenide (GaAs) before it, the US Defense Advanced Research Projects Agency (DARPA) has invested considerable resources in GaN as a possible high-power technology replacement for aging vacuum tubes in RF/microwave electronic-warfare (EW), radar, satellite-communications (satcom), and surveillance systems.

The CTT amplifiers you referenced are very high-gain, broadband models, but not the highest-power GaN amplifiers available today. They were meant to show some of the high-power capabilities of GaN devices over such broad bandwidths, such as the 2-to-18-GHz range that you mention. Future amplifier designs can benefit from combining active devices and amplifier stages to achieve higher power levels as needed, gaining the high reliability that comes with solid-state designs.


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News

Human Body SERVES AS Secure Communications Channel

TECHNOLOGY DREAMERS envision a future in which individuals do not use access points, but instead function as their own communications hubs. Among the companies moving the world closer to that reality is Microchip Technology, Inc. (www.microchip.com), which just unveiled its BodyCom technology. This technology gives designers a framework to use the human body as a secure communication channel. Compared to existing wireless methods, it promises to provide lower energy consumption while increasing security via bidirectional authentication. Because no RF antennas are required, BodyCom technology also allows for simple circuit-level designs and a low bill of materials (BOM).

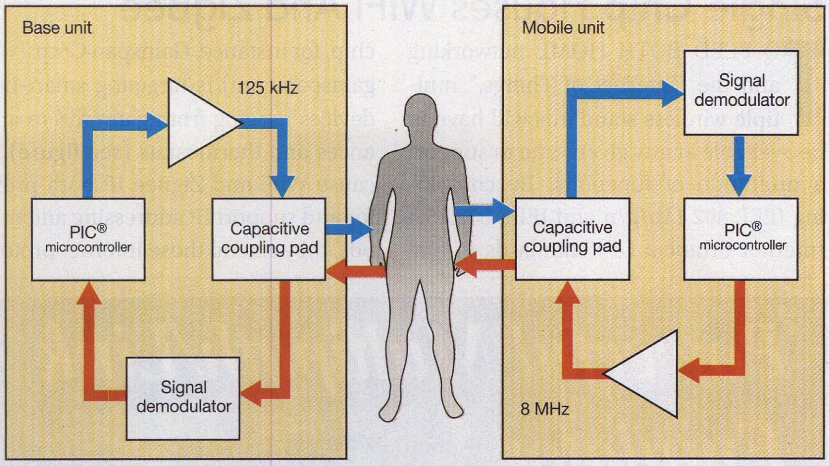
At its heart, BodyCom technology is activated by capacitively coupling to the human body (**see figure**). The system then begins communicating bidirectionally between a centralized controller and one or more wireless units. By eliminating the need for a wireless transceiver or high-power inductive fields, BodyCom technology lengthens battery life.

In addition to eliminating the need for antennas, BodyCom simplifies development by using a low-frequency framework with a common microcontroller and standard active-front-end (AFE) frequencies (125 kHz and 8 MHz). Thus, no external reference crystals are needed. Because it complies with Federal Communications Commission (FCC) Part 15-B for radiated emissions, the technology also eliminates the cost and complexity of certification.

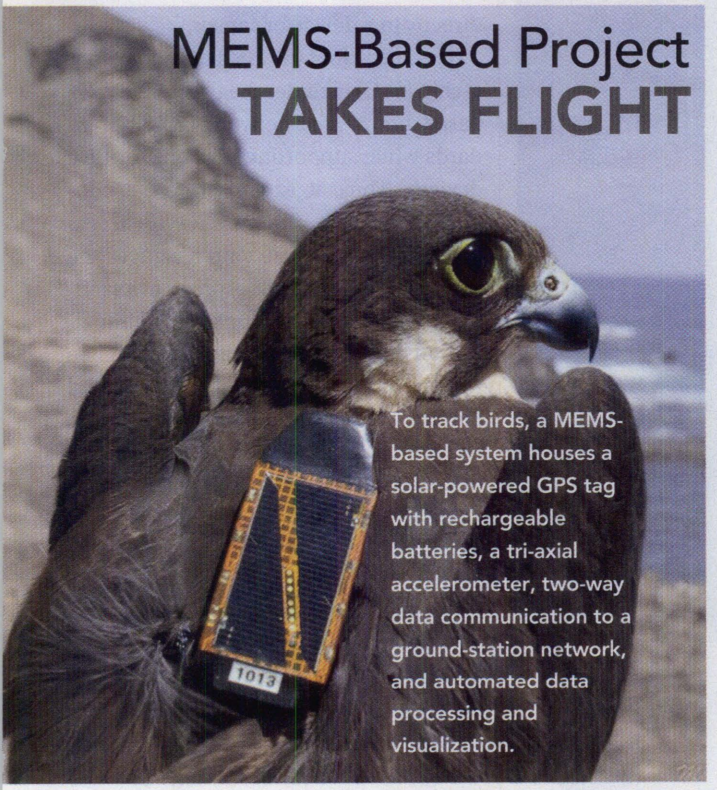
To keep this human-body-network secure, bidirectional authentication can be added. It supports advanced encryption,

Driving the evolution of the body-area network (BAN), this technology promises to provide a secure, low-cost method for implementing short-range, low-data-rate wireless communication with low power consumption.

such as KeeLoq technology and Advanced Encryption Standards (AES). For example, Body-Com technology promises to help prevent the "Relay Attack" problem that is typical in automotive passive remote-keyless-entry (RKE) security systems. Example applications for this technology include access control (security systems, home/industrial door locks, pet doors); personal safety and security (equipment access/disable, power tools, firearms, computer systems); medical (patient monitoring, hospital-room access, equipment tracking); and consumer (profile management for gaming consoles and exercise equipment).



MEMS-Based Project TAKES FLIGHT



To track birds, a MEMS-based system houses a solar-powered GPS tag with rechargeable batteries, a tri-axial accelerometer, two-way data communication to a ground-station network, and automated data processing and visualization.

Technologies like Global Positioning System (GPS) and RF-identification (RFID) have greatly enhanced researchers' abilities to study animals. At the University of Amsterdam (UvA; www.UvA.nl) Faculty of Science, for example, a sophisticated bird-tracking system was recently developed using microelectromechanical-systems (MEMS) technology from STMicroelectronics (www.st.com). These tracking systems are essentially data loggers, which can be attached to the backs of birds **(see photo)**.

To ensure that they will not impede the birds' flight, the systems weigh as little as a 20-euro-cent coin. In terms of size, they are smaller than a car key. The trackers measure the birds' GPS position every 3 s.

The tracker also collects acceleration and direction data from STMicroelectronics' LSM303DLM digital compass. This compass integrates low-power, high-performance motion and magnetic sensing. The MEMS chip monitors the direction and vertical/horizontal orientation of the animal. It can therefore determine the body angle of birds flying in a crosswind.

The sensors in the tracker measure air temperature and the device's internal temperature. A ZigBee transceiver manages wireless data communication to and from the device. Power is provided by a lithium battery, which is charged by a triple-junction solar cell. Data from the trackers is being used to verify computer models that predict bird behavior and migration patterns.

MARKETWATCH

OEM spending on semiconductors for wireless applications is set to rise by 13.5% this year to reach a value of **$69.6 BILLION—** up from $62.3 billion in 2012, according to the IHS iSuppli Semiconductor Design & Spend Analysis Service (www.ihs.com).

In wireless infrastructure, the top OEMs for this year will again be Ericsson, Huawei, Alcatel-Lucent, and Nokia Siemens Networks. Ericsson and Huawei are battling for the market-leadership position.

IN NOVEMBER OF LAST YEAR, e2v (www.e2v.com) image sensors on board the Japanese Aerospace Exploration Agency's (JAXA) Hinode satellite captured an image of the moon traveling across the front of the sun. Launched in 2006, Hinode's mission is to explore the magnetic fields of the sun. Scientists hope to shed new light on explosive solar activity that can interfere with satellite communications and electric power-transmission grids on Earth. (Courtesy of SAO, NASA, JAXA, and NAOJ)

Single Chip Houses WiFi And ZigBee

TO FEED BOTH HOME networking and the "Internet of Things," multiple wireless standards will have to be available at any given time to support a multitude of functions. By combining IEEE 802.11b/g/n and IEEE 802.15.4 Internet Protocol (IP) standards in one chip, for instance, Gainspan Corp. (www.gainspan.com) is targeting smart-home devices ranging from gateways to appliances and thermostats (**see figure**). Because WiFi and ZigBee IP both provide for and support IP addressing and methods, they extend those Internet protocols

This SoC, which integrates a multi-mode baseband and RF on a single die, features a flexible dual-core architecture based on the ARM Cortex-M3 processor. It targets low-power and line-powered applications supporting the "Internet of Things," such as smart energy.

directly to a device or sensor.

The key is that the GS2000 system-on-a-chip (SoC) includes the two wireless IP-based home-area-network (HAN) standards while supporting IPv4 and/or IPv6 devices. Thus, it extends Internet connectivity wherever there is a WiFi access point or hotspot. The chip leverages the high data rates and widespread availability of WiFi along with the small channelization and meshing capability of ZigBee wireless communications. In residential applications, for example, the solution will bridge the gap between smart meters using ZigBee and connected white appliances integrating WiFi.

The GS2000 system-on-a-chip (SoC) device features a dual-mode IPv4/IPv6 TCP/UDP networking stack along with additional networking services. Thus, it enables a complete networking solution for embedded microcontroller (MCU)-based applications. The SoC supports wireless-local-area-networking (WLAN) software and networking features, ZigBee IP (which is based upon 6LoWPAN), and IP-based addressing and methods over the IEEE 802.11x and 802.15.4 standards.

The chip also provides support for station/client mode, limited access point for easy provisioning or connecting to smartphones, and Wi-Fi Direct. In addition, Wi-Fi Direct with concurrent mode allows a device to act simultaneously as an access-point station and an access point for other devices. The GS2000 SoC and associated modules will be sampling this month with full production slated for later this year.

KUDOS

TEKTRONIX COMPONENT SOLUTIONS—The company's Beaverton, OR manufacturing facility and headquarters has received AS9100 Rev C certification for the commercial aerospace, defense, and space industries. The company's component test laboratory in Orlando, FL achieved the same certification last year.

RAYTHEON BBN TECHNOLOGIES—Has been awarded the National Medal of Technology and Innovation for its work in acoustics, signal processing, and information technology. National Medals are the highest honor presented by the US government to scientists, engineers, and inventors. Raytheon BBN Technologies received the award from President Barack Obama in a recent White House ceremony.

DIELECTRIC LABORATORIES—Has received a 2012 Performance Excellence Award from Boeing. In receiving this annual supplier distinction, Dielectric Laboratories maintained a Silver composite performance rating for 12 consecutive months.

MURATA—The company's MAGICSTRAP RFID tag—integrated with Cogiscan's TTC Middleware offering—has won the 2013 New Product Introduction (NPI) Award from Circuits Assembly. Murata was honored in the Labeling Equipment category.

AT4WIRELESS—Has been selected by Telefonica as its Global Mobile Testing Laboratory. With this designation, AT4wireless will test any mobile device selected by Telefonica in Latin America and Europe.

LOCKHEED MARTIN—Angela Heise, the company's Vice President of Enterprise IT Solutions for IS&GS-Defense, has won a 2013 Federal 100 (FED 100) Award. Fed 100, sponsored by Federal Computer Week, recognizes distinguished leaders in the government information technology community.

TESEQ—The firm's Edison, NJ calibration laboratory has renewed its ISO/IEC 170 accreditation. This renewal follows an assessment by the American Association for Laboratory Accreditation (A2LA).

ANRITSU CORP.—The company has exceeded 10,000 validated Long Term Evolution (LTE) protocol-conformance test cases. This milestone was achieved at a recent meeting of the Global Certification Forum (GCF) in Farnborough, UK. It was accomplished via Anritsu's ME7834 mobile-device test platform.

NANO MATERIALS INTERNATIONAL CORP. (NMIC)—The firm has shipped its 10,000th aluminum-diamond, metal-matrix-composite (MMC) heat spreader. This offering is used in gallium-nitride (GaN) RF power transistors and monolithic microwave integrated circuits (MMICs).

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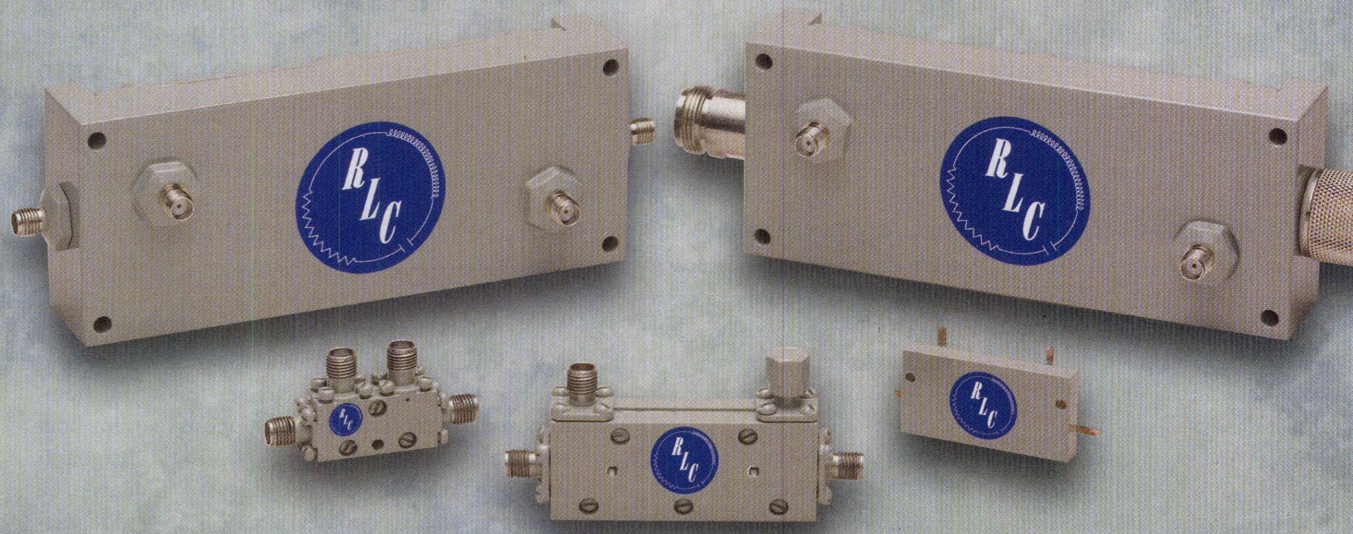

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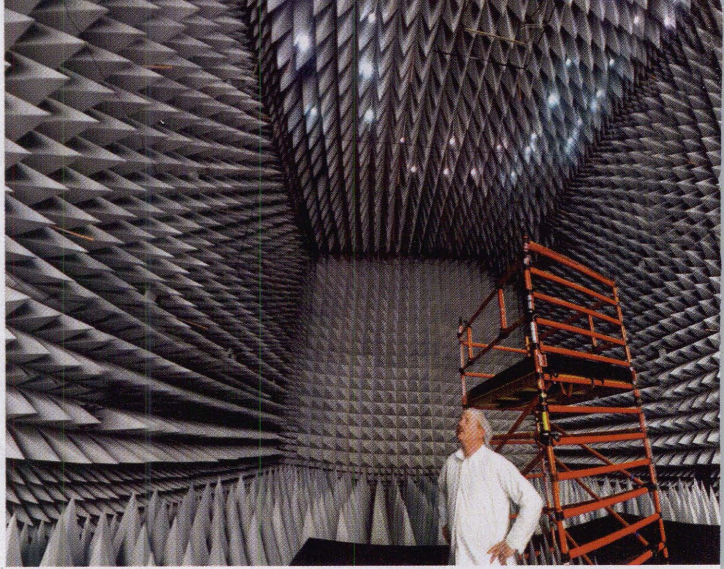
News

GPS III Program Achieves Power Milestone

ASIDE FROM REPLACING AGING GLOBAL POSITIONING SYSTEM (GPS) SATELLITES, the US Air Force's GPS III program promises to make GPS more nimble—improving its ability to meet the evolving needs of military, commercial, and civilian users. In addition to higher accuracy, for example, GPS III satellites will deliver enhanced anti-jamming power. They also will add a new civil signal, which is designed to be interoperable with international global navigation satellite systems. Such capabilities look to be on track for launch availability next year. The Lockheed Martin (www.lockheed-martin.com) team developing the GPS III satellites recently turned on power to the system module of the program's first spacecraft, designated GPS III Space Vehicle One (SV-1).

Successfully powering on GPS III SV-1 demonstrates mechanical integration while validating the satellite's interfaces **(see photo)**. It also paves the way for electrical and integrated hardware-software testing. Assembly, Integration, and Test (AI&T) on the satellite will be completed in Lockheed Martin's new GPS Processing Facility (GPF), which has been designed for efficient and affordable satellite production. Each GPS III satellite will move through sequential workstations for various AI&T operations, culminating with shipment to the launch site.

Lockheed Martin is currently under contract for production of the first four GPS III satellites. The firm also has received advanced procurement funding of long-lead components for the fifth, sixth, seventh, and eighth satellites through two fixed-price contracts totaling $120 million. The Air Force plans to purchase as many as 32 GPS III satellites.



Pictured is Jim Keyser, Manager of Lockheed Martin's GPS Processing Facility. He stands in the anechoic test chamber, where the company will perform tests on the GPS III spacecraft to ensure that all of its signals and interfaces work properly.

For GPS III, the Air Force initiated a "back-to-basics" acquisition approach. That strategy emphasizes early investments in rigorous systems engineering, industry-leading parts standards, and the development of a full-size GPS III satellite prototype. The GPS III team is led by the Global Positioning Systems Directorate at the US Air Force Space and Missile Systems Center. Lockheed Martin is the GPS III prime contractor with teammates ITT Exelis, General Dynamics, Infinity Systems Engineering, Honeywell, ATK, and other subcontractors.

PEOPLE

RUCKUS WIRELESS—David Stephenson has joined the company as Senior Principal Engineer within the System Architecture Group. Stephenson is the current Chair of the Wi-Fi Alliance Hotspot 2.0 Technical Task Group. Most recently, he worked at Cisco Systems within its Wireless Networking Business Unit.

STEPHENSON

AR—Joseph DiBiase has joined the company as an Application Engineer. DiBiase was most recently Senior Manager of Compliance Engineering at Motorola Mobility, where he led product regulatory-qualification efforts.

DiBIASE

EUTELSAT COMMUNICATIONS—Ross McInnes has joined the company's board of directors. He also has assumed Chairmanship of the board's Audit Committee. McInnes currently serves as Deputy Chief Executive Officer of Safran.

WUHAN XINXIN SEMICONDUCTOR MANUFACTURING (WXIC)—Has appointed two new members to its executive team. Dr. Walter F. Lange has been named Senior Vice President of Marketing and Sales. Previously, he served as Vice President of Marketing for Chartered Semiconductor (now part of Global Foundries). In addition, Dr. Shaoning Mei has joined WXIC as Chief Technology Officer. Most recently, Mei held the role of CTO at Huanghong NEC Electronics Co. Ltd.

NASA Seeks STEM Education Partners

NASA IS LOOKING FOR POTENTIAL PARTNERS to help it achieve some ambitious goals for education. Based on the agency's unique missions, discoveries, and assets, NASA supports learning both inside and outside the formal classroom. Its goal is to inspire and motivate educators and students of all ages in science, technology, engineering, and mathematics (STEM). The agency is seeking unfunded partnerships with organizations to engage new or broader audiences across a national scale.

Potential partnership activities are varied. NASA is receptive to a wide range of possibilities. All categories of domestic groups—including US federal government agencies—are eligible to respond. In particular, NASA seeks responses from creative organizations with wide-ranging areas of expertise. NASA will accept responses through December 31, 2014 with the review process beginning April 1, 2013. To find out more, go to http://go.nasa.gov/VgRZYt.

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CONTRACTS

Newtec—Has signed a Basic Ordering Agreement (BOA) with the NATO Communications and Information Agency (NCIA). This procedure is intended to provide a streamlined acquisition method for COTS hardware, software, and services. Newtec's satellite-communications equipment currently has a large installed base within government and defense operations.

Mercury Systems—Has been awarded a three-year indefinite-quantity/indefinite-delivery (IDIQ) contract by the US Naval Research Laboratory (NRL) Tactical Electronic Warfare Division (TEWD). Worth up to $16.7 million, the contract calls for Mercury to supply mixed-signal digital receivers for prototype electronic-warfare (EW) applications.

MERCURY SYSTEMS Wins $16.7-million Navy IDIQ deal

ANITE Re-ups with Deutsche Telekom

Anite—Has signed a further three-year agreement with Deutsche Telekom to provide interoperability test solutions. Deutsche Telekom, owner of the T-Mobile brand, is a long-term user of Anite's SAS test offering.

Aptilo Networks—Has won a third WiFi offload contract in Taiwan—awarded by an undisclosed mobile operator—for its Aptilo SIM Authentication Server offering.

FRESH STARTS

Richardson RFPD—Has launched a new micro-website, the Avionics & Radar Tech Hub, which can be accessed via its www.richardsonrfpd.com website. This micro-website features news and new-product announcements related to avionics and radar applications. In addition, the company has made a gallium-nitride (GaN) informational resource available on its website. Widening its distribution network, Richardson RFPD also has reached an agreement with Lime Microsystems to distribute field-programmable RF transceivers (FPRFs).

BLiNQ Networks—Has joined the Cambridge Wireless industry forum. The UK-based organization comprises more than 300 companies with expertise in wireless technology.

Raytheon UK—Has opened a SiC manufacturing facility in Glenrothes, Scotland.

Würth Elektronik—Has joined the Alliance for Wireless Power (A4WP), a consortium of wireless companies focused on the creation of a new wireless-power-transfer technology.

Peregrine Semiconductor—Is collaborating with Intel on the latest generation of its DuNE tuning solution, which will be utilized in Intel's LTE-platform reference design.

AtlanTecRF—The firm's Components Catalog is now accessible through its website at www.atlantecrf.com. Encompassing more than 600 product lines, this online version features search and zooming functionality.

Cornell Dubilier (CDE)—Has launched its redesigned website at www.cde.com. The revamped site now features a Technical Center, which includes application notes, SPICE models, and life and temperature calculators for various CDE products.

(l-r) Pictured are Didier Thibaud, President of Mercury Systems' Commercial Electronics business unit; Terrence Curtin, President of TE Connectivity's Industrial Solutions business; Kevin Rock, President, Aerospace, Defense and Marine, TE Connectivity; and Mark Aslett, President and Chief Executive Officer of Mercury Systems.

Mercury Systems—At a recent executive meeting, the firm formalized its working relationship with TE Connectivity. The two companies have collaborated on the development of high-speed connectors for rugged environments.

ETL Systems—The UK-based firm has opened a North American regional headquarters located in Washington, DC.

RFEL—Has launched a new website at www.rfel.com.

Computer Simulation Technology (CST)—Has signed a distribution agreement with Delcross Technologies. CST is now the authorized reseller of Delcross' EMIT and Savant software offerings.

Master Electronics—Has been awarded the Panasonic Industrial Devices franchise for distribution. This product line includes capacitors, resistors, RF modules, inductors, electromechanical switches, thermal and circuit protection offerings, and discrete components.

GreenPeak Technologies—Has established a new European office in Paris, France. Based out of Utrecht, the Netherlands, this is the firm's second base of operations on the continent.

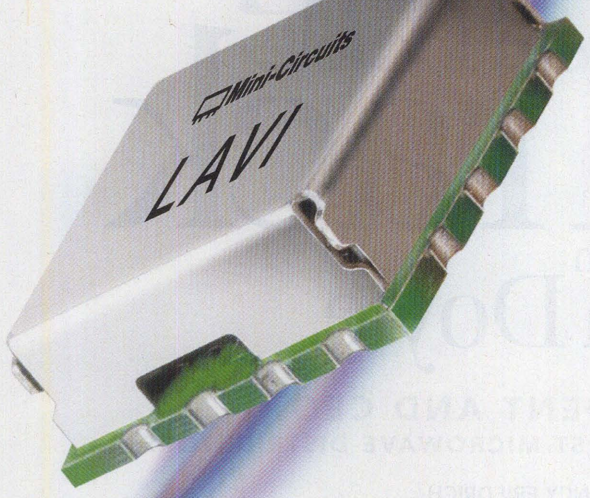
PPG Industries—The company's Industrial Coatings business has created a dedicated Electronic Materials group. This entity will integrate products and technologies acquired last year from Spraylat Corp.

Skyworks Solutions—Has secured a reference design with Texas Instruments for smart-energy, industrial, and networking applications. These will include electric, gas, and water meters; street lighting; and telematic and tracking systems.

AR Europe—Has signed an exclusive distribution agreement with Eastern Optx for the European market (with the present exception of Germany). New Jersey-based Eastern Optyx manufactures fiber-optic delay systems.

AT4wireless—Has signed a partnership with Toyo Corp. to offer joint Long Term Evolution (LTE) testing services in Japan. Tokyo-based Toyo Corp. currently acts as AT4wireless's agency office for the Japanese market.

RFMW—Is offering design and sales support for Sangshin Elecom's ceramic monoblock filters. These filters target automatic-dependent surveillance-broadcast (ADS-B), universal-access-transceiver (UAT), and traffic-collision-avoidance-system (TCAS) avionics applications.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Inside Track with Jim Doyle,

PRESIDENT AND CEO, EAST COAST MICROWAVE DISTRIBUTORS

Interview by NANCY FRIEDRICH

NF: You are taking the reins from Bruce Cooper, who has been President and CEO of East Coast Microwave Distributors, Inc. (ECM) for 24 years. Has he given you any advice?

JD: Bruce has been a great inspiration to me. I think more than giving me a few words of advice, he has shown me that when you instill positive values, teamwork, strong ethics, and leadership—coupled with passion and empathy—you can create long-term success, no matter what industry or field you choose. Over the last two-and-a-half decades, Bruce has grown East Coast Microwave into one of the most successful suppliers of microwave, RF-component, and interconnect solutions.

NF: Coming from XMA Corp., you are certainly no stranger to the microwave and RF industry. Have you spent a lot of time in this industry over your career?

JD: I've been very fortunate to work in and around leading-edge technology most of my career. Over the last 20 years, I've worked for Fortune 100 companies in embedded computing, as well as smaller firms focused on electronic packaging and unique interconnect solutions serving the telecommunication, medical, and military markets. In addition, I've had the opportunity to work in Washington, DC with many technology innovators. That experience greatly strengthened my personal understanding of the needs of the men and women who utilize these technologies to communicate—and even defend our nation, when called upon. It's been a great journey so far, and there is no question that I still have a lot more to learn.

NF: What are your goals for ECM?

JD: We understand that there are changes occurring in the marketplace—not just in technology for higher frequency ranges or increased power levels. Today, the way in which we provide products requires us to evolve, learn, and improve the way we define "value" as an organization. I believe our long-term goals are aligned with these challenges. As we continue to build and grow the organization, we will add human talent and core technologies that create solutions for our customers. Moreover, our goals will include investments that improve our customers' experience, making it easier for them to find solutions and create more efficient ways for them to do business with us.

With that said, I think the most challenging aspect of these goals for any CEO is understanding how to accomplish them over the course of not just a few months or quarters, but to sustain the momentum of change in today's business environment. My personal goal at ECM is to see that we, "the team," continue to focus daily on what is truly important to our customers.

NF: ECM currently stocks product for more than 20 manufacturers of RF coaxial connectors, cables, cable assemblies, and microwave components. Do you plan to add manufacturers and/or product lines going forward?

JD: We have incredibly strong long-term relationships with our manufacturing partners. We have grown our businesses together. Without them, we would not have had the industry recognition we have enjoyed over the last 24 years. I certainly see us strengthening these core ties in the future. We also will evaluate potential manufacturing partners that could enhance and support our core business.

NF: How much pressure is ECM getting from the bigger distributors in terms of service, price, availability, etc? I've noticed many of them trying to raise their profiles in the RF and microwave market.

JD: I am a strong supporter of competition. I believe it encourages innovation, makes people earn their customers, and drives improvements in customer service. There are several larger distributors that are trying to do more within the microwave and RF space. They have tremendous size and scale. But what they lack may be something less tangible than resources.

To use a sports or golf analogy, we believe our only competitor is ourselves. Instead of focusing on the other golfers around us, if we focus on "our" game, play the course, and practice and work hard to improve, so shall our game. Our goals each time we service a customer—regardless of how big or small they are—are to always beat our own last performance.

NF: What strengths does ECM offer compared to those larger and broader distributors?

JD: The greatest strength of ECM is the people and team we have in place and the way they interact and support our customers. Every business metric and process we analyze for improvement is driven with the customer in mind, from on-time delivery and what we carry in inventory to our customer satisfaction measurements. These continuous improvement methods—coupled with our technical knowledge, extensive on-site inventory, and value-added services for cable and cable-assembly solutions—give us a competitive advantage over other distributors. In addition, we have instilled trust among our customers. They know that ECM is willing to go the extra step to support their needs.

"I believe competition encourages innovation, makes people earn their customers, and drives improvements in customer service."

NF: I imagine there is a lot of pressure to raise ECM's profile on the Internet, so that engineers find you amongst the different sources. A lot of smaller microwave and RF firms are still struggling to produce effective websites. Do you have any advice?

JD: Most design engineers—if not all—utilize the Internet as their initial search method. Having a presence on the web is important. But it can also be dangerous if not approached carefully. Tremendous amounts of money and resources can be allocated through the use of paid keyword searches and analytics.

In my opinion, the trouble with focusing on this as a singular strategy for small business is what happens after you're found—not to mention the overall expense. Anyone can throw money at a website. But not everyone can supply "authorized-franchised" name-brand products that are guaranteed to not be counterfeit directly from the factory. My advice is to work with your manufacturing partners, understand the products you're supplying and your niche, and plan how to best communicate to the customers you're trying to reach.

NF: Has ECM had to deal with any counterfeiting issues? What steps do you have in place so that counterfeit components do not enter your supply chain?

JD: We are very fortunate at ECM that we are an authorized-franchised distributor for every one of our manufacturing partners. We will not carry or distribute a product that does not come directly from the OEM manufacturer, thereby alleviating concerns over the origin of our products. In addition, ECM has strong internal controls with documented ISO procedures for handling and containing products within our inventory.

NF: ECM is a woman-owned firm, which makes it unique in the microwave industry. Yet Bruce Cooper is credited as Founding Director. Can you tell us a little bit of how the firm evolved?

JD: The company was founded based on Bruce's extensive knowledge and experience in the microwave and RF industry. Bruce started out as a design engineer and ultimately became an entrepreneur and leader of electronic distribution businesses. We also are very fortunate to have Sheri Cooper, Director of Operations and Majority Shareholder, as an integral part of the day-to-day operations of the business. Her main focus at this time is to help improve our IT infrastructure and strengthen internal processes. Both of these individuals have a passion for the industry, and have fostered an organization that is based on shared business ethics and a commitment to superior customer service.

NF: What type of atmosphere do you plan to foster?

JD: Being a new CEO in an organization is always challenging. There are established cultures, procedures, and strategies that have built the company into what it is today. I believe we can harness the positives from the past and incorporate new visions for the future.

I hope to foster greater empowerment of our employees through values and passion, reaching every customer as an individual, and engaging with them—to better understand their specific needs, to bring back lessons learned, and to improve the velocity of our innovation. In simple terms, I hope to foster an environment of respect, professionalism, and altruism to help not only our customers, but the community around us. MWRF

Precisely Model UWB Antenna Pulses

BECAUSE ULTRAWIDEBAND (UWB) pulse and antenna lengths are comparable, the antenna will radiate distorted versions of its input pulse in different directions. To design UWB radio devices, it is therefore critical to effectively model pulse distortions. At the University of Alberta in Canada, a method of modeling pulse distortions has been developed by Adrian Eng-Choon Tan, Michael Yan-Wah Chia, Kevin Khee-Meng Chan, and Karumudi Rambabu. Their approach models the antenna's radiated and received transient fields at various angles. Using this model, designers of UWB radios can gain prior knowledge of pulse distortion.

The researchers modeled and compared received pulses from three different antennas—a ridged horn, dielectric load horn, and Vivaldi—with the measured received pulses. A comparison of pulse shape, amplitude, and energy showed good agreement. To evaluate the proposed method, different input pulses were examined.

To estimate the angle-dependent impulse responses, time-domain measurements were conducted in an anechoic chamber. In each measurement, identical antennas were used as transmitting and receiving antennas. The received pulses were recorded with a sampling oscilloscope.

The least-squares approach was used to perform deconvolution of the measured pulses. As a result, certain conditions had to be met. Both the boresight and off-boresight measured pulses were recorded at the same sampling rate. Their discrete time data also was finite in length. In addition, the pulse data for off-boresight measurements was longer than for that of the boresight pulse measurements. Finally, the impulse response was assumed to be zero outside of its deconvolution data range.

The least-squares approach for deconvolution expresses the convolution process in matrix form. By premultiplying both sides with the transpose of the convolution matrix, the engineers were able to express the impulse response in the form of an inverse Toeplitz matrix. That matrix could then be solved with the conjugate gradient method. See "Modeling the Transient Radiated and Received Pulses of Ultra-Wideband Antennas," *IEEE Transactions On Antennas And Propagation,* Jan. 2013, p. 338.

4-x-LO-Based VCO Shrinks Bluetooth Transceiver

DUE TO Bluetooth's prevalence in cellular-phone platforms, there has been pressure to achieve smaller die size and reduce external printed-circuit-board (PCB) components. Following this trend, a 4 x local-oscillator (LO) -based VCO has been proposed by a team at MediaTek, Inc: Sam Chun-Geik Tan; Fei Song; Renliang Zheng; Jiqing Cui; Guoqin Yao; Litian Tang; Yuejin Yang; Dandan Guo; Alexander Tanzil; Junmin Cao; Ming Kong; KianTiong Wong; Soong Lin Chew; Chee-Lee Heng; Osama Shana'a; and Guang-Kaai Dehng.

Their design strives to reduce the LO pulling effect and achieve superior receive (Rx) out-of-band blocking performance without requiring an external RF bandpass filter. As chip area is reduced, the traditional 2 x LO-based voltage-controlled oscillator (VCO) becomes more susceptible to interference from the power-amplifier (PA) second-harmonic products. Strong PA-to-VCO coupling can induce a frequency-pulling effect, which in turn degrades the transmitter modulation accuracy.

Here, the 4-x-LO-based VCO is implemented to reduce LO pulling. It also minimizes transmit out-of-band spurious emissions. The transmitter provides +10 and +7 dBm output power in basic-data-rate (BDR) and enhanced-data-rate (EDR3) modes, respectively. It provides 1.5-kHz frequency stability and less than 6% root-mean-square (RMS) differential error vector magnitude (DEVM). Receiver sensitivity is –95.5, –96.5, and –89.0 dBm, respectively, for BDR, EDR2, and EDR3 modes. See "An Ultra-Low-Cost High-Performance Bluetooth SoC in 0.11-µm CMOS," *IEEE Journal Of Solid-State Circuits,* Nov. 2012, p. 2665.

UHF/UWB Antenna Supports Indoor Tracking

FOR APPLICATIONS RANGING from public-safety to targeted mobile advertising, the need for indoor real-time location systems is quickly rising. Although solutions are available commercially, they are costly and not completely reliable. A design that combines the potential of high-resolution ultrawideband (UWB) impulse radio with the typical range of ultra-high-frequency (UHF) RF-identification (RFID) systems has been proposed by Catarina C. Cruz, Jorge R. Costa, and Carlos A. Fernandes from Portugal's Technical University of Lisbon.

The team developed a planar antenna for hybrid passive tag systems. It operates in both the UHF-RFID and Federal Communications Commission (FCC) UWB bands. In a system, the reader may activate the tag's chip through a narrowband UHF signal. The tag could then answer with short UWB pulses, determining position with centimeter-class resolution.

The co-designed UHF and UWB antenna elements are printed back to back on each side of a common substrate, which paves the way for integration onto a single UHF-UWB RFID chip. In experimental results, the hybrid antenna performed comparably to available solutions working on just a single band. See "Hybrid UHF/UWB Antenna for Passive Indoor Identification and Localization Systems," *IEEE Transactions On Antennas And Propagation,* Jan. 2013, p. 354.

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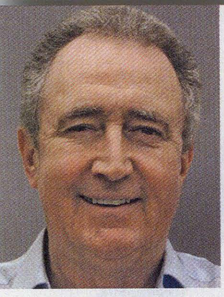
IF/RF MICROWAVE COMPONENTS

482 Rev. E



PAUL WHYTOCK, *European Editor*

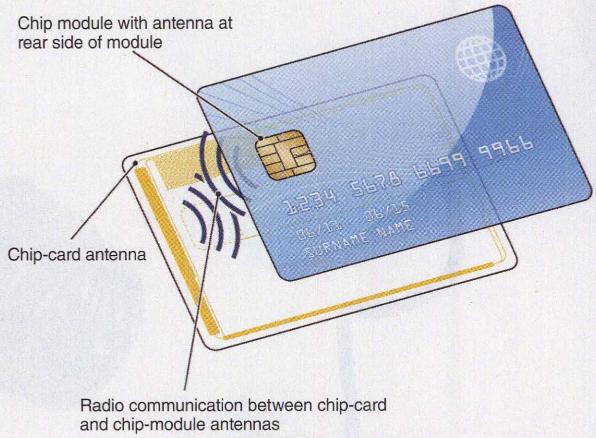
Card Payments Get **Faster** And **Safer**

IN 2012, the number of dual-interface cards used in the worldwide payment-chip-card market was 672 million. According to IMS Research (www.imsresearch.com), that number will grow to 6.1 billion by 2017. This potential for growth is providing incentive for a number of companies to develop products for contact and contactless card applications. Infineon Technologies, for example, recently announced its Coil-on-Module chip package designed for use in dual-interface bank and credit cards.

This package combines a security chip and an antenna for an RF connection to the antenna embedded on the plastic payment card. According to engineers at Infineon, employing an RF link rather than a more traditional mechanical-electrical connection between the card antenna and the module results in a number of advantages, such as a 5X increase in speed. Among the other benefits are stronger construction of the payment card, simplified design, and less expensive manufacturing.

The card owner's personal data is stored on the security chip of the dual-interface card. During a payment transaction, that data is transmitted via the card antenna to the card readers. In conventional card manufacturing processes, the chip module is connected to the card antenna via mechanical-electrical procedures, such as soldered connections or conductive paste. The Coil-on-Module technology uses the antenna integrated on the back of the chip module to transmit data to the card antenna. This process relies on inductive coupling. Using contactless data transfer rather than the traditional, stressful mechanical connections, the new dual-interface card is more robust than older payment cards. With this design, it is much easier and quicker for card manufacturers to embed the Coil-on-Module in the card.

Card makers also have the advantage of being able to use all Infineon chip/module combinations with a universal card antenna. (That antenna's design parameters were developed by Infineon.) In addition, existing production plants for contact-based chip cards can be used for dual-interface cards with no further plant investments. Each Infineon Coil-on-Module now uses the same type of card antenna, reducing the card manufacturer's design and testing expenses while simplifying stock management.



The Coil-on-Module package combines a security chip and antenna, which enables an RF connection to the antenna embedded on the plastic payment card. By using an RF link rather than a mechanical-electrical connection, this solution provides as much as a 5X increase in speed compared to conventional solutions.

In addition to its card developments, Infineon Technologies has been targeting the payment industry's security gaps. According to the company, its communication interface for near-field communications (NFC) applications, dubbed the Digital Contactless Bridge (DCLB) interface, provides a secure connection between an embedded Secure Element and an NFC modem. Because a DCLB interface is free, it has been widely implemented by manufacturers of NFC modems and Secure Elements for handsets.

The DCLB interface is suitable for NFC applications requiring fast response times, such as mobile payment, access control, or ticketing in public transport. It promises to improve performance of the connection between an NFC modem device and the secure element, where the transaction is partially executed by supporting peak data rates of 848 kb/s. In addition, Infineon's security controller is the first embedded secure element awarded with the security certificate, the Common Criteria EAL 6 *(see sidebar)*.

AN OVERVIEW OF EALs

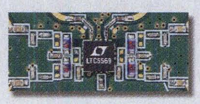
THE EVALUATION ASSURANCE Level (EAL) of a product is a numerical grade, ranging from EAL1 to EAL7, which is assigned following the completion of a Common Criteria security evaluation—an international standard in effect since 1999. The increasing assurance levels reflect added requirements that must be met to achieve Common Criteria certification. The intent of the higher levels is to provide higher confidence that the system's principal security features are reliably implemented. The EAL does not measure the system's security. Rather, it states at what level the system was tested.

To achieve a particular EAL, the computer system must meet specific assurance requirements. Most of these requirements involve design documentation, design analysis, functional testing, or penetration testing. The higher EALs involve more detailed documentation, analysis, and testing than the lower ones.

4G 4 U

Dual RF Mixer Needs Only 600mW

Actual Size



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The LTC®5569 is the lowest power dual mixer with the highest performance and widest bandwidth. Its small form factor is optimized so you can pack more diversity or MIMO receiver channels in compact Remote Radio Heads. The mixer's wide frequency range allows you to build a wide range of multiband radios cost effectively. With integrated RF and LO balun transformers, the LTC5569 saves cost and precious board space. Each channel can be independently shut down, providing maximum flexibility to efficiently manage energy use.

Dual Mixer Family

Part Number	Frequency Range	IIP3 (dBm)	Conv. Gain (dB)	NF/5dBm Blocking (dB)	Power (mW)	Package
LTC5569	0.3GHz to 4GHz	26.8	2	11.7/17.0	600	4mm x 4mm QFN
LTC5590	0.9GHz to 1.7GHz	26.0	8.7	9.7/15.5	1250	5mm x 5mm QFN
LTC5591	1.3GHz to 2.3GHz	26.2	8.5	9.9/15.5	1260	5mm x 5mm QFN
LTC5592	1.7GHz to 2.7GHz	26.3	8.3	9.8/16.4	1340	5mm x 5mm QFN
LTC5593	2.3GHz to 4.5GHz	26.0	8.5	9.5/15.9	1310	5mm x 5mm QFN

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PASSIVE COMPONENTS PACK MORE POWER

System architects would like to shrink as many RF/microwave passive-component functions as possible, integrating them with active functions when it makes sense.

Passive RF/microwave components rarely grab headlines like their active counterparts. But without the functions provided by components like attenuators, couplers, dividers, filters, and terminations, there would be no military radar systems or modern commercial wireless systems. And while system-level designers often take the performance of passive components for granted, suppliers of these components continue to improve their products by trimming size, weight, and even insertion loss with frequency. A number of factors contribute to those improvements, including the availability of evolving computer-aided-engineering (CAE) simulation software and higher-quality printed-circuit-board (PCB) materials that make possible better performance levels from proven stripline and microstrip passive circuits.

High-power passive components with minimal loss are still built around waveguide housings, while extremely broadband passive components typically reside in coaxial housings, with SMA, 3.5-mm, or some other form of high-frequency connectors. But in recent years, the number of passive components in smaller packages, such as drop-in or surface-mount-technology (SMT) housings, has grown. Circuit designers can use modern CAE programs to analyze the effects of different transmission-line structures without building them, and they have access to improved, low-loss circuit materials that contribute to higher performance at high frequencies.

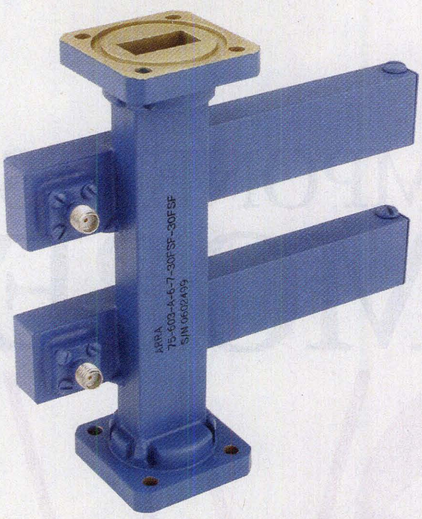
Many high-frequency component suppliers, such as ARRA (www.arra.com) and Microwave Communications Laboratories, Inc. (MCLI; www.mcli.com), offer products in both coaxial and waveguide housings. Waveguide passive components can handle extremely high power levels but operate within the limited frequency range of the waveguide transmission lines and flanges. Passive components with coaxial connectors can also achieve broad bandwidths. As an example, 90-deg. hybrid model HB-57 from MCLI operates from 1.2 to 12.0 GHz with SMA female connectors. It measures just 3.150 × 1.000 × 0.504 in. but can handle 50 W average power and 2 kW peak power.

A passive component that combines coaxial and waveguide connections, model 75-603-A-6-7-30FSF from ARRA, is a cross-guide directional coupler available with both coaxial and waveguide coupled ports (**Fig. 1**). This particular model, designed with WR75 rigid waveguide (10 to 15 GHz), is available with coupling values from 20 to 60 dB and at least 15-dB directivity.

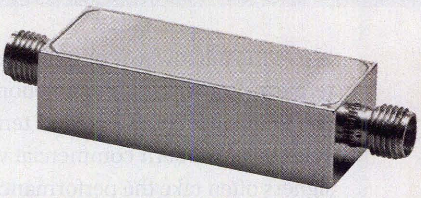
Most system-level specifiers want components that are smaller and can handle higher power levels, whether for portable commercial electronics or military backpack radios. In passive-component structures based on transmission-line technologies such as stripline, microstrip, and coplanar-waveguide (CPW) approaches, the improved thermal characteristics of circuit-board materials enables higher power levels from smaller circuits. Most leading PCB material suppliers now offer thermally enhanced circuit materials.

At least one of these firms, Rogers Corp. (www.rogerscorp.com) offers guidance on selecting materials for fabricating passive components with increased power density, in the form of a presentation ("Using High Frequency PCB Laminates For Improving Thermal Management Issues"). Available as a free download (https://www.printedcircuituniversity.com/content/articles/Using%20High%20Frequency%20Laminates%20for%20Improving%20Thermal%20Management%20Issues.pdf), this presentation reviews laminate properties critical to handling high power levels and how to achieve proper thermal management in high-frequency passive components. A number of PCB material properties are necessary for handling high power levels, including high thermal conductivity, high glass transition temperature (T_g), low dissipation factor, and even a smooth copper surface profile for the conductive layers. As passive components become smaller and are used for higher power levels, these thermally enhanced PCB materials become even more essential for properly dissipating heat from smaller components.

In addition, many passive-component designers have experienced the benefits of low-temperature-cofired-ceramic (LTCC) circuit materials, especially for components where high-power-handling capabilities must be combined with small size. One company that has pushed LTCC across a total range of DC to 44 GHz is Anaren (www.anaren.com), including in its miniature Xinger® surface-mount passive components. As an example of high power in a small package size, model 1G1304-30 is a 30-dB directional coupler with frequency range from 800 to 1000 MHz for cellular communications. With 0.25-dB maximum insertion loss and 15-dB minimum directivity, it is only 0.56 x 0.35 in. but achieves impressive 150-W CW power-handling capability. (For more on directional couplers, see p. 46.)



1. This cross-guide coupler employs WR75 waveguide for operation from 10 to 15 GHz, with low insertion loss and high directivity. [Photo courtesy of ARRA (www.arra.com).]



2. There is still much need for traditional LC filters such as this coaxial component, when low passband loss and high out-of-band rejection are needed. It measures just 2.0 x 0.5 x 0.5 in. and is suitable for airborne applications. [Photo courtesy of Trilithic (www.trilithic.com).]

To create smaller passive components, some firms have taken advantage of traditionally active-component technologies. For example, the miniature attenuators from Mini-Circuits (www.minicircuits.com) featured in this issue's Cover Story (see p. 86) provide precision fixed attenuation values and power-handling capabilities of several watts in transistor-sized packages. They are fabricated with a gallium arsenide (GaAs) monolithic-microwave-integrated-circuit (MMIC) semiconductor process. Yet, they represent but one passive component product line among the many now being offered by companies generally regarded as semiconductor suppliers, such as M/A-COM Technology Solutions (www.macomtech.com), SkyWorks Solutions (www.skyworksinc.com) and TriQuint Semiconductor (www.triquint.com).

For example, model MAFL-010256-CB0AD0 is a 75-Ω bandpass filter from M/A-COM Technology solutions developed for Multimedia over Coax Alliance (MoCA™) applications from 1125 to 1550 MHz. This lead-free, RoHS-compliant component achieves 1.7 dB typical passband insertion loss with 53-dB stopband rejection from 5 to 300 MHz, 44 dB from 300 to 800 MHz, 40 dB from 800 to 1002 MHz, and 35 dB from 2250 to 3000 MHz. Because it is intended for cost-competitive cable-television (CATV) applications, the low-cost filter is supplied in a miniature housing of only 15 × 15 × 4 mm that can easily be integrated into other set-top equipment enclosures.

SkyWorks Solutions is another company associated with semiconductor-based products, and another firm with an extensive line of miniature surface-mount passive components, including fixed RF/microwave attenuators, 90-deg. hybrid couplers, and directional couplers in SOT-6 housings. For many of these passive components, the company applies semiconductor technologies to fabricate miniature circuits with excellent electrical characteristics. As an example, its model DC25-73LF is a monolithic directional coupler with typical insertion loss of only 0.2 dB from 2.30 to 2.60 GHz. It delivers 33-dB typical port-to-port isolation and handles as much as 4 W continuous-wave (CW) input power in an SOT-6 housing measuring just 2.8 × 2.9 × 1.19 mm.

TriQuint Semiconductor is yet another "semiconductor" company with an extensive line of compact passive components, including Lange couplers and Bessel filters. Model TGB4001 is a Lange coupler with only 0.25 dB insertion loss from 18 to 32 GHz; a number of other versions are available for use from 12 to 21 GHz and 27 to 45 GHz. Designed to handle power levels to 1 W, it measures 1.0 × 3.0 × 0.1 mm. Even smaller, model TGB-2010-10 is a Bessel filter that is 0.49 × 0.49 × 0.10 mm and provides a ±0.5-GHz passband from DC to 10 GHz.

Another semiconductor-driven company, Analog Devices (www.analog.com), made news a few years ago by introducing a pair of wideband passive frequency mixers—models ADL5811 and ADL5812—for communications applications from 700 to 2800 MHz. Although lacking the bandwidth of active mixers, these passive mixers deliver low-noise performance and excellent linearity over their operating range, with a single-sideband (SSB) noise figure of 11 dB and input third-order-intercept point of +24 dBm. The passive mixers are well suited for software-defined radios (SDRs), cellular picocells, and wireless infrastructure equipment.

An advantage of realizing passive components by means of monolithic fabrication processes is the option to integrate functions when necessary. In addition, semiconductor processes also offer active devices, making it possible to combine amplifiers with any needed passive components. Of course, this has been done for years with larger components, in the form of microwave integrated circuits (MICs), and many of the companies working with LTCC substrates have realized the benefits of that material's excellent thermal characteristics for mixed active and passive component assemblies. And numerous long-term suppliers of MIC components also can combine multiple functions into a single assembly. Narda Microwave (www.nardamicrowave.com), for example, has continued to enhance its integrated microwave assembly (IMA) technology over the years to combine active and passive components into ever-smaller modules.

Suppliers of more traditional distributed-element-type passive components are also finding ways to reduce the size of their products, using housings often just large enough for mounting coaxial connectors. For instance, Trilithic (www.trilithic.com) recently introduced a series of inductive-capacitive (LC) bandpass filters for Iridium applications **(Fig. 2)**.

These filters measure just 2.0 × 0.5 × 0.5 in. even with connectors making them ideal for airborne applications. They pass signals from 1616.0 to 1626.5 MHz with 2.6-dB insertion loss or less and achieve

at least 15-dB isolation of Global-Positioning-System (GPS) L1 signals and at least 70-dB isolation of GPS L2 signals. They also provide 45-dB isolation of signals from 1710 to 1850 MHz, and more than 55 dB isolation of signals through 10 GHz. The company also offers PCB-mount versions without the connectors.

Similarly, Planar Monolithics Industries (www.pmi-rf.com), which designs and manufactures lumped-element filters across a total frequency range of 1 to 6000 MHz, has developed a GPS bandpass filter with 1575.42 MHz center frequency and 140-MHz bandwidth measuring a mere 0.75 × 0.50 × 0.50 in. with female SMA connectors. Passband insertion loss is 1.80 dB or less while suppression of unwanted signals is 32 dB at 1065 MHz and 60 dB or more at 2500 MHz.

For many years, filters at RF and lower microwave frequencies have achieved miniaturization through the use of surface-acoustic-wave (SAW) technology, and a good number of firms still offer filters based on that technology in compact housings, including Amplitronix (www.amplitronix.com), EPCOS/TDK (www.epcos.com), Murata (www.murata.com), RF Monolithics (www.rfm.com), Sawtron (www.sawtron.com), TriQuint Semiconductor, and Vectron International (www.vectron.com).

SAW filters rely on the motion of mechanical waves along the surface of a piezoelectric substrate. They are formed with a pair of interdigital transducers at the input and output to convert an applied voltage to mechanical waves at the input and then back to a voltage at the output. They can achieve reduced size and weight across their frequency range compared to other filter technologies and are very reliable. As an example, Vectron's model TFS 403 SAW bandpass filter has a tight 1.5-MHz passband around a 403.5-MHz center frequency. The passband insertion loss is nominally 4.6 dB, while the rejection of unwanted signals is 32 dB just 9 MHz outside of the passband.

Finally, one circuit approach seeing increased use in higher-frequency passive components is microelectromechanical-systems (MEMS) technology; this is essentially the use of micromachined three-dimensional (3D) mechanical structures in electronic circuits. Radant MEMS (www.radantmems.com) and RFMD (www.rfmd.com) are just two of the companies currently offering small RF/microwave switches and other passive components based on MEMS technology, with tremendous promise for this technology based on the interest and investments from such organizations as the US Defense Advanced Research Projects Agency (DARPA) and Raytheon (www.raytheon.com). MWRF

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Keeping Power Levels In Check

Directional couplers and power dividers/combiners are essential components for RF/microwave applications in which signals must be combined or divided.

POWER LEVELS OFTEN must be maintained and monitored in RF/microwave systems, and those tasks can depend on simple-but-important passive components: directional couplers and power dividers/combiners. They are available in a variety of package styles—including compact surface-mount housings, coaxial packages, and even waveguide housings—with many different frequency ranges, from high-frequency (HF) bands through millimeter-wave frequencies. Suppliers for these components number many; a fundamental knowledge of essential mechanical and electrical characteristics for each component type can help simplify the specification process.

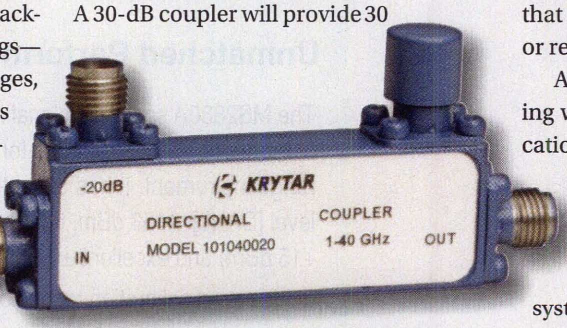
Directional couplers are often used to measure power levels or to monitor signals by tapping off or sampling a small amount of the main signal. It is known as a "directional" coupler since this component can separate and sample signal components based on the direction of signal flow. By placing signal transmission paths close enough in a directional coupler's circuitry, part of the signal from the main-line transmission path can be transferred to a coupled path and made available at a coupled output port. The coupling ratio is the difference between the power level of the main-line signal at its output port and the power level of the coupled signal, or:

Coupling ratio = $10\log(P_{out})$ of the coupled path/P_{in})

where:

P_{out} = the output signal power and
P_{in} = the input signal power.

Directional couplers are available commercially with different coupling factors or ratios, such as 10, 20, and 30 dB. A 30-dB coupler will provide 30 dB of the input power at its coupled port, or about a factor of 0.001 of the input power at the coupled port. For high-power levels, this is a convenient means of providing a lower-level signal for analysis with a sensitive power meter. Very high-power measurements may even call for a directional coupler with coupling factor as high as 40 dB.



This is one of the industry's more broadband directional couplers, with 20-dB coupling from 1 to 40 GHz by means of stripline circuitry and SMA coaxial input and output connectors. [Photo courtesy of Krytar (www.krytar.com).]

Along with its frequency range and coupling factor, RF/microwave directional couplers can be differentiated by a number of performance parameters, including directivity, loss, VSWR, and maximum input power rating. Directivity, which is a measure (in dB) of how well the component isolates forward and reverse (or reflected) signals, is critical when a directional coupler will be used to measure return-loss levels. Directional couplers with high directivity enable high measurement accuracy when using that coupler in a test system for forward or reflected power measurements.

A directional coupler's voltage standing wave ratio (VSWR) provides an indication of how closely the component is matched to its designed characteristic impedance; this is typically 50 Ω but can be 75 Ω in video and cable-television (CATV) transmission systems. Low VSWR is to be preferred, and using a directional coupler with low VSWR is a way to minimize impedance mismatch errors and to improve power measurement accuracy.

Loss through a coupler represents the amount of signal power that is attenuated due to power dissipated through coaxial connectors, printed-circuit boards (PCBs), and resistive circuit elements. Depending upon the manufacturer, a directional coupler's loss may be defined as insertion loss, which is separate from coupling losses, or as transmission loss, which combines insertion and coupling losses. As with VSWR, lower values are to be preferred, since they mean that more of the input power to a directional coupler will be preserved at its output ports.

The maximum input power rating of a directional coupler is often dependent on the coupler's package style, with

small surface-mount housings offering the lowest input power ratings because of the small size. Couplers with coaxial connectors are limited in power-handling capabilities to some degree by the connectors, with SMA connectors typically handling about 50 W CW power.

As an example of how the key performance parameters appear for a commercial directional coupler, model 101040020 from Krytar (www.krytar.com) is a recently introduced coaxial directional coupler with extremely broadband frequency coverage from 1 to 40 GHz using stripline circuitry and SMA coaxial connectors **(Fig. 1)**. It has a nominal coupling value of 20 dB across that frequency range and serves a variety of commercial and military applications, including signal monitoring and measurement, antenna beam forming, and electromagnetic-compatibility (EMC) testing. The 20-dB coupling is flat within a ±1-dB window, while the insertion loss (not including coupling loss) is less than 0.85 dB from 1 to 20 GHz and less than 1.5 dB from 20 to 40 GHz. The directivity is higher than 14 dB from 1 to 20 GHz and higher than 10 dB from 20 to 40 GHz. The maximum VSWR at any port is 1.50:1 to 20 GHz and 1.70:1 to 40 GHz. The directional coupler is rated for maximum average input power of 20 W, but as much as 3 kW peak input power (short pulses).

Power dividers/combiners are often used to create multiple versions of a signal for a system or to combine multiple inputs into one signal for a system. Power dividers are usually designed so that an equal amount of the input power is distributed to the output ports. In a two-way power divider, one-half of the input power is available at each output port; in a four-way power divider, 25% of the input power is available at each output port; and so on.

An ideal two-way power divider would provide two output signals at precisely one-half the power level as the input signal. In the real world, however, a power divider suffers some amount of insertion loss, along with other forms of loss (such as return loss from reflections, and

Along with frequency range and coupling factor, directional couplers can be set apart by a number of performance parameters.

impedance mismatches at connections to and from the power divider). And real power dividers/combiners are sometimes designed with as many as 64 output ports.

The performance of these components is described by similar parameters as for directional couplers, such as insertion loss and VSWR. In addition, ports are characterized by the amount of isolation between them, the amplitude balance (or imbalance) between ports, and the phase balance (or imbalance) between ports. Power dividers/combiners come in many forms, including as quadrature (90-deg.) and 180-deg. hybrid couplers. A quadrature hybrid splits an input signal into two output signals, each at one-half or 3 dB the power level and offset 90 deg. in phase. A 180-deg. hybrid splits an input signal into two equal-amplitude output signals that are offset 180 deg. in phase.

Although many of the basic design concepts behind directional couplers and power dividers/combiners have changed little in several decades, increased attention is being paid to newer parameters—such as passive intermodulation (PIM)—which can impact how these components perform in modern communications systems. Systems using digital modulation formats, for example, require couplers and power dividers/combiners with minimal levels of PIM.

Designers of these components are also exploring the value of different building-block materials, such as low-temperature-cofired-ceramic (LTCC) circuit substrate materials. These materials feature excellent thermal conductivity characteristics for handling high power levels and high operating temperatures compared to conventional PCB materials.

Suppliers of directional couplers, hybrids, and power dividers/combiners offer products in many different package styles, including miniature drop-in and surface-mount housings, coaxial packages, and high-power waveguide enclosures. Suppliers include ARRA (www.arra.com), Bird Technologies (www.bird-electronic.com), Connecticut Microwave (www.connecticutmicrowave.com), Fairview Microwave (www.fairviewmicrowave.com), Innovative Power Products (www.innovativepp.com), JFW Industries (www.jfwindustries.com), Krytar (www.krytar.com), M/A-COM (www.macomtech.com), MCLI (www.mcli.com), Meca (www.e-meca.com), Marki Microwave (www.markimicrowave.com), Mini-Circuits (www.minicircuits.com), MITEQ (www.miteq.com), Narda East (www.nardamicrowave.com), Pasternack (www.pasternack.com), PMI (www.pmi-rf.com), Pulsar Microwave (www.pulsarmicrowave.com), Skyworks Solutions (www.skyworksinc.com), Synergy Microwave Corp. (www.synergymwave.com), TRM Microwave (www.trmmnicrowave.com), and Werlatone (www.werlatone.com). The most complete listings for these products can be found online at the *Microwaves & RF* Product Data Directory (http://mwrf.com/product-data-directory).

For those seeking fundamental background information on directional couplers and power dividers, an excellent eight-page white paper, "Microwave Power Dividers and Couplers Tutorial," is available free of charge from Marki Microwave (http://www.markimicrowave.com/menus/appnotes/microwave_power_dividers_and_couplers_primer.pdf). In addition, Mini-Circuits offers a free application note, "Directional Couplers," which explains the use of these passive components for test and systems applications (http://www.minicircuits.com/app/COUP7-2.pdf). MWRF

JACK BROWNE | Technical Contributor

Components Help Satcom Systems Fly

A large number of high-frequency component suppliers are sensitive to the physical and electrical needs of satellite-communications systems, both in space and on the ground.

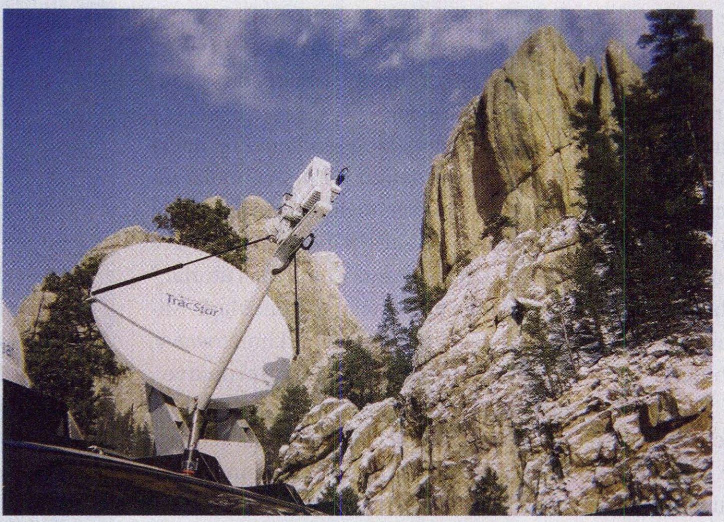
SATELLITE-COMMUNICATIONS (SATCOM) SYSTEMS are not the most cost-effective means of connecting two points. They have limited bandwidth and capacity, to say nothing of the effort required to get a satellite into orbit. However, compared to terrestrial metal wire, optical fiber, and even wireless communications systems, satcom links do offer some advantages.

Satcom systems can connect with difficult-to-reach areas, operate with variable information rates, and be adapted to the needs of many different customers. Some customers—in particular, those needing communications links to new areas at short notice, such as in broadcast and satellite-news-gathering (SNG) applications—have found satcom services to be as invaluable as they are reliable. And military customers [e.g., those using satellites for surveillance functions or for remote control of unmanned aerial vehicles (UAVs) in hostile locations] are finding satellites difficult to replace.

As a business, demand for satcom services is strong and growing. Because satellites can support reliable voice and video communications and high-speed data communications almost anywhere on the planet (including on ships and planes), they have become the preferred means of communication for commercial and military customers alike. In fact, with many US military customers become more cost-conscious, satcom service providers are exploring novel possibilities—e.g., using one rocket to launch multiple satellites, or consolidating capabilities once handled by multiple satellites on board a single one.

Satcom systems consist of the space-based equipment [such as antennas, receivers, frequency converters, filters, low-noise amplifiers (LNAs), switches, transmitters, and high-power amplifiers (HPAs) for transmission on board a satellite], as well as the earth-based equipment based on the same lineup of components, stored in a fixed or movable earth terminal. Fixed-earth terminals **(Fig. 1)** can be integrated with earth-based communication infrastructure, including fiber-optic links and wireless networks. Mobile terminals **(Fig. 2)** offer the flexibility of portability and being able to make connection points where needed.

The components that support these satcom links operate at assigned frequencies, including C-, Ku-, and Ka-band frequency bands. These components must overcome path loss from the earth to the satellite (also known as the uplink) and from the satellite back to the earth (the downlink). Satcom systems employ higher frequencies for the uplink than for the downlink. In a C-band satcom system, for example, uplink frequencies extend from 5.925 to 6.425 GHz while downlink frequencies stretch from 3.70 to 4.20 GHz. In a Ku-band satcom system, the uplink frequencies span 14.0 to 14.5 GHz while the downlink frequencies are from 11.7 to 12.2 GHz. Satcom systems also work with S-band frequencies (from 2 to 4 GHz) and Ka-band frequencies (from 26.5 to 40.0 GHz).



1. Large, fixed satcom earth-station terminals such as this dish on Mount Rushmore provide reliable communications at high data rates. [Photo courtesy of Cobham plc (www.cobham.com).]

For example, one of the world's leading satcom service providers, Intelsat Global Services Corp. (www.intelsat.com), holds the rights to different sectors around the globe for satcom services at C-, Ku-, and Ka-band frequencies, with typically one frequency band per satellite. But the firm's new Intelsat Epic^{NG} series of satellites will feature an open architecture; they are

TINY

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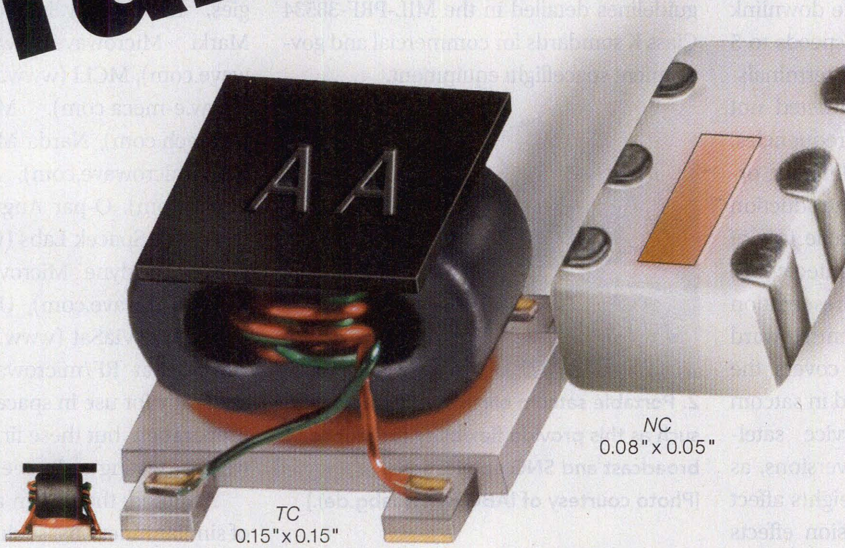

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intended to use wide beams and spot beams for high throughput data communications, in addition to operating with all three frequency bands per satellite. The Intelsat Epic satellites are being groomed for broadband connectivity across North America, including Internet access aboard commercial aircraft and ocean liners.

The first of the Epic satellites, to be built by Boeing (www.boeing.com), is scheduled for launch in 2015. Until then, Intelsat will be launching the first of its Boeing-built Ka-band Global Express (www.igx.com) satellites in 2013, with full global coverage achieved by 2014. The Global Xpress network is expected to provide downlink speed to 50 Mb/s and uplink speeds to 5 Mb/s, employing compact user terminals.

Satcom systems are constructed not only with many different frequencies, but with satellites at many different orbital heights. An excellent introduction to satcom technology is available free of charge from MITEQ (www.miteq.com), in the form of a PowerPoint presentation prepared by company President Howard Hausman. The presentation covers the different types of satellites used in satcom systems, including fixed-service satellites (FSS) and geostationary versions, as well as how satellite orbital heights affect coverage areas and transmission effects (such as transmission latencies and Doppler shifts that can impact the complexity of a satcom transceiver design). Geosynchronous satellites, for example, orbit 35,800 km (22,300 miles) above the Earth, at about 11,000 km/hour, to remain in the same location orbiting above the earth and providing radio coverage for about one-third of the planet.

Satellites that are not geostationary fly at greatly reduced distances above the earth. Low-earth-orbit satellites (LEOS) cruise about 100 to 300 miles above the earth, with reduced launch costs and much less path losses than geosynchronous satellites, but much less visibility of the earth. The IRIDIUM network is an example of a LEOS system. At somewhat higher distance from the earth, medium-earth-orbit satellites (MEOS) networks maintain their space vehicles about 6000 to 12,000 miles above the earth.

Orbital locations are regulated by the International Telecommunications Union (ITU; www.itu.int). Satellites transmit over a 17.3-deg. beamwidth to achieve that one-third coverage of the planet. They are spaced at least 1.5 to 2.0 deg. apart so that antennas on satcom earth terminals will not illuminate more than one satellite at a time. Components that comprise the payloads on board these satellites must be extremely reliable, and guidance for what defines a "space-qualified" component can be found in documentation prepared for the US Department of Defense (DoD), such as guidelines detailed in the MIL-PRF-38534 Class K standards for commercial and government spaceflight equipment.

2. Portable satcom earth-station terminals such as this provide flexibility for mobile broadcast and SNG applications. [Photo courtesy of IABG (www.iabg.de).]

Requirements for satcom components differ for ground-based and space-based applications. While components used on satellite must be as small and lightweight as possible, similar components used in the terrestrial portions of satcom systems are not driven by the same needs. In some cases, satcom component suppliers such as MITEQ may even incorporate different technologies for the space-based and ground-based satcom terminals, such as solid-state power amplifiers (SSPAs) for in space and traveling-wave-tube amplifiers (TWTAs) for ground terminals.

Suppliers of complete satcom systems include some very large companies, such as Boeing, Northrop Grumman (www.northropgrumman.com), and Lockheed Martin (www.lockheedmartin.com). Sources of RF/microwave components for those systems include MITEQ, its high-power-amplifier company MCL (www.mcl.com), and a large number of component and subsystem suppliers that design and produce hardware for both satellite payloads and earth-station terminals. These include Admiral Microwaves (www.admiral-microwaves.co.uk), Aeroflex Corp. (www.aeroflex.com), Cobham plc (www.cobham.com), Communications & Power Industries (www.cpii.com), EM Solutions (www.emsolutions.com), Epsilon Lambda Electronics Corp. (www.epsilon-lambda.com), ESA (www.esa.int), General Dynamics Satcom (www.gdsatcom.com), Krytar (www.krytar.com), Linx Technologies, Inc. (www.linxtechnologies.com), Marki Microwave (www.markimicrowave.com), MCLI (www.mcli.com), Meca (www.e-meca.com), Millitech (www.millitech.com), Narda Microwave (www.nardamicrowave.com), PMI RF (www.pmi-rf.com), Q-par Angus Ltd. (www.q-par.com), Spacek Labs (www.spaceklabs.com), Teledyne Microwave (www.teledynemicrowave.com), UKRF (www.ukrf.com), and ViaSat (www.viasat.com). Ensuring that RF/microwave components are ready for use in space requires proper preparation, but these firms are equipped with the testing and screening capabilities.

As noted, the design and construction of similar functions, such as antennas and amplifiers, can differ significantly whether that component is intended for earth or space use. Of course, in some cases, a single design may prove suitable for both applications, such as the model MT2100 TWTA from MCL that was engineered for airborne applications. The tube amplifier delivers as much as 125 W CW power from 6 to 18 GHz but weighs only 25 lbs. and can be adapted to military flight qualification requirements.

Finally, in addition to offering a variety of high-power TWTA-based amplifiers for indoor and outdoor satcom use, the CPI Satcom Division of Communications & Power Industries also designs solid-state PAs for satcom applications at C-, X-, Ku-, and Ka-band frequencies. These include output-power levels to 100 W at Ku-band frequencies and 200 W at C-band frequencies. MWRF

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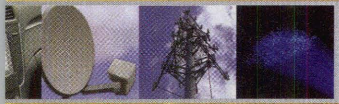

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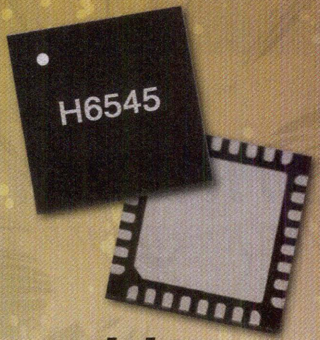

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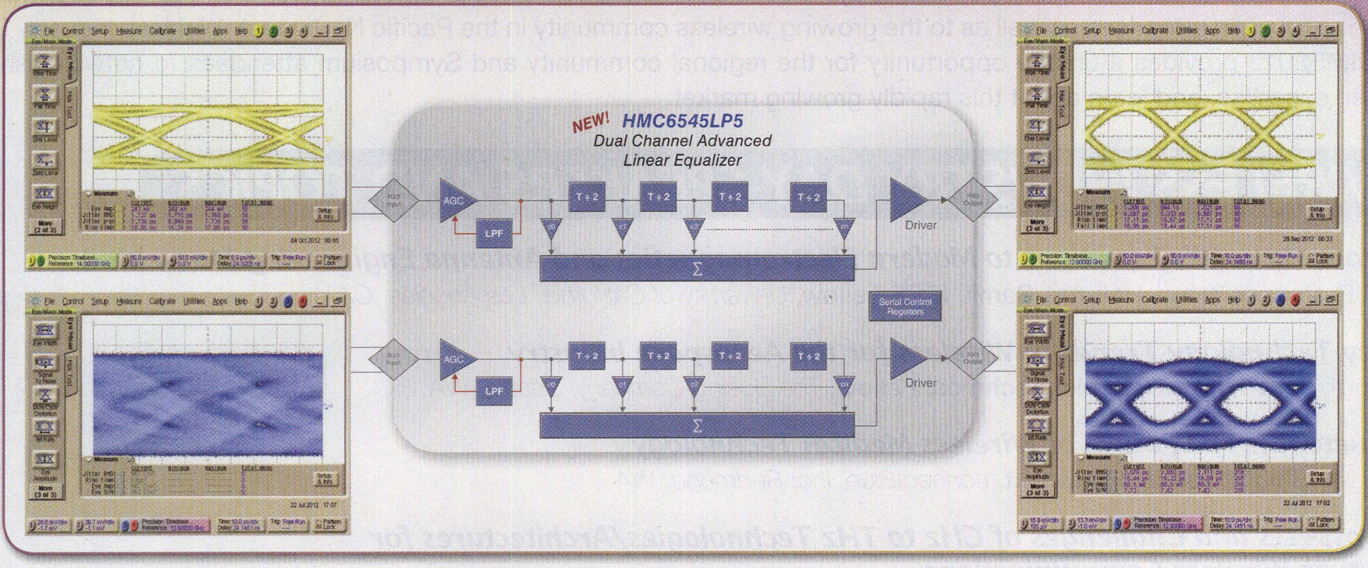

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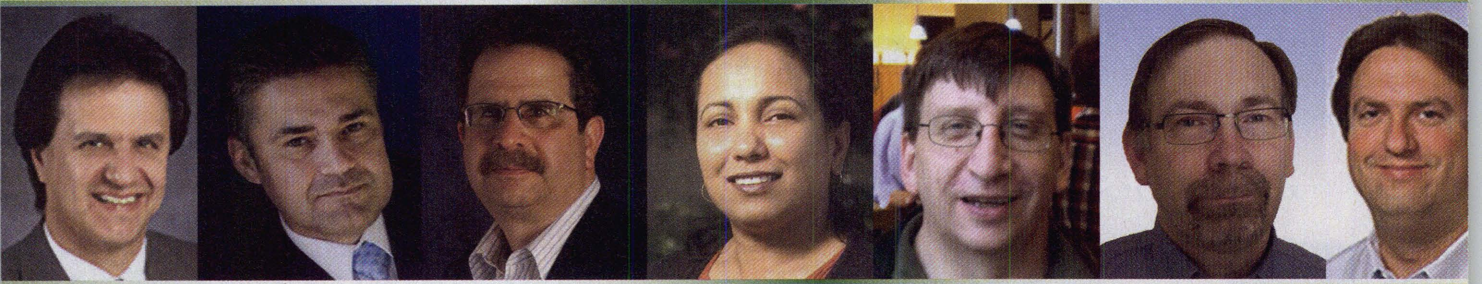

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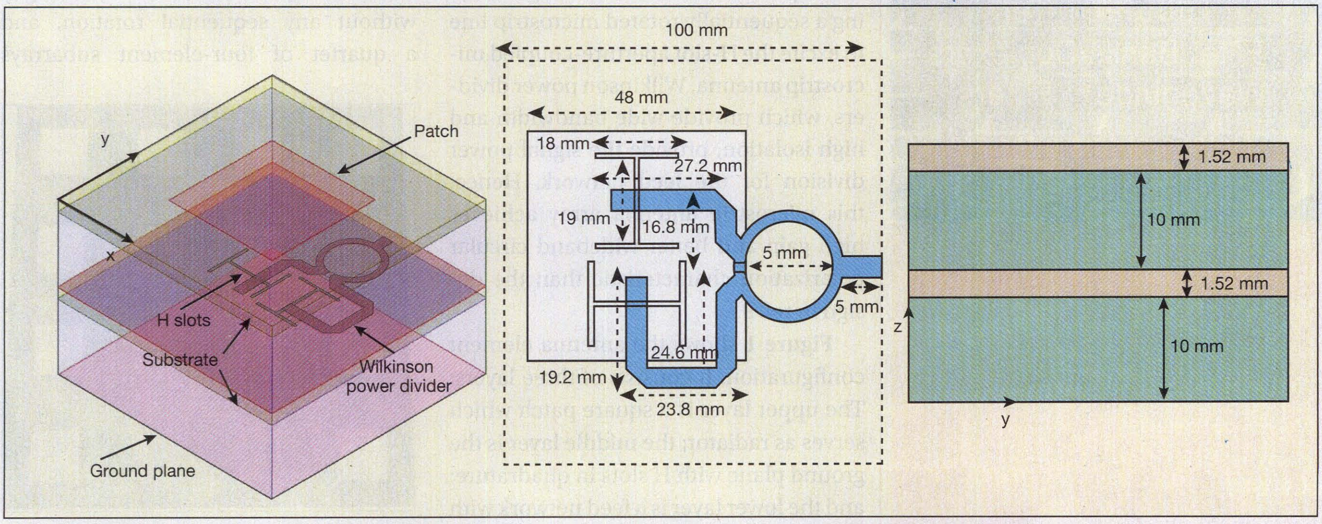
SEQUENTIAL ROTATION Feeds Microstrip Array

THIS ANTENNA DESIGN APPROACH BUILDS A SIMPLE ARRAY FROM MICROSTRIP ANTENNA ELEMENTS, FORMING A BROADBAND CIRCULARLY POLARIZED WAVE.

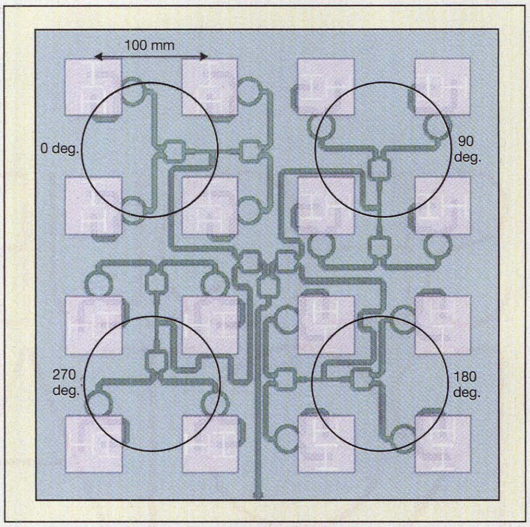
MICROSTRIP ANTENNAS offer many benefits, including low profile, light weight, and low cost; they are fairly simple to manufacture and easy to integrate with other planar circuits. Unfortunately, microwave antennas are notoriously narrowband in nature, limiting their use for many applications. A number of approaches have been applied to overcome the inherently narrow bandwidths of microstrip antennas—one dating as far back as 1985.[1] That technique was based on the use of an aperture-coupled feed structure.

Other attempts have involved different slot shapes in the ground plane of the microstrip antenna,[2] with the result being that the antenna's magnetic (H) slot has larger coupling. The current design incorporates H slots in quadrature, to obtain a wideband circular polarization wave. The H slots are fed by a Wilkinson power divider, using its 90-deg. phase-shifted outputs with the same amplitudes.



1. These different views show (l-r) the wideband microstrip antenna geometry, the top view of the antenna element, and the side view of the antenna element.

In recent years, various microstrip antenna arrays have been designed using a sequential rotation technique, with the aim of improving polarization purity, impedance matching, and pattern symmetry across wider bandwidths.[3-12] These designs include the use of linearly polarized elements,[3-5] circularly polarized microstrip elements,[6-10] and feed networks incorporating serial or parallel feeds.[11,12] Such approaches can improve the circularly polarized bandwidth, but tend not to impact the axial ratio bandwidth.



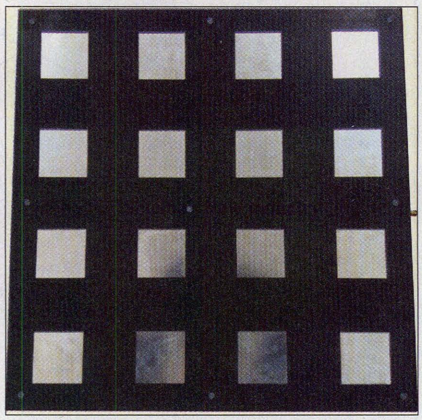
2. The microstrip array antenna, with each element offset by 90 deg., is depicted in this layout.

For example, the best results registered for axial ratio bandwidth by these researchers was 45%. In this case, a wideband aperture-coupled microstrip antenna was employed as the basic resonant element, although the element is also referred to as an aperture-coupled microstrip antenna in the literature.[9] It adopts a branch-line coupler to feed two orthogonally located feeds quadrature to each other. The coupler has a extra load port and a parasitic patch to improve the impedance bandwidth but with a penalty of increased height.

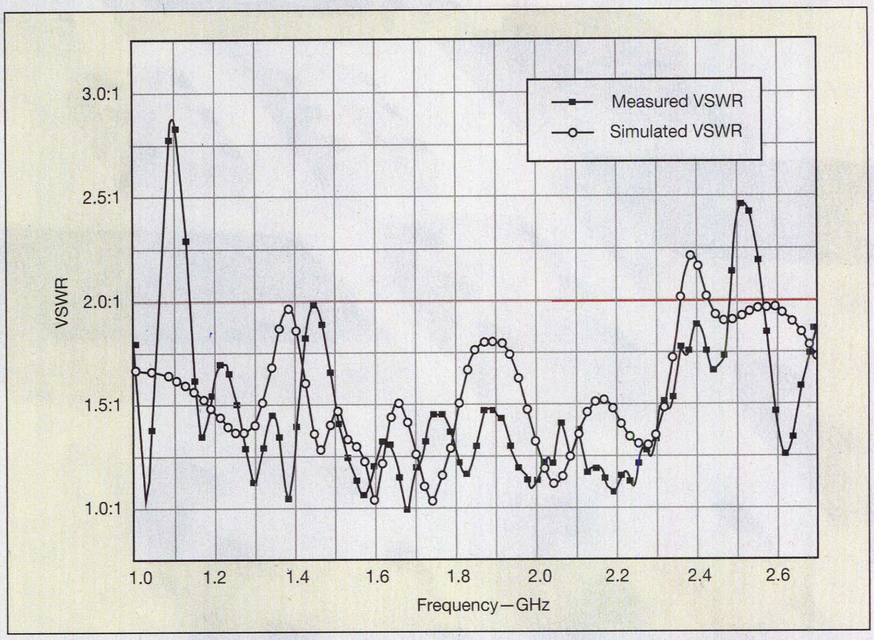
As an alternative antenna design approach, a 4 × 4 circularly polarized microstrip antenna array was designed using a sequentially rotated microstrip line to excite the H-slot aperture-coupled microstrip antenna. Wilkinson power dividers, which provide wide bandwidth and high isolation, provide the signal power division for the feed network. Hence, this microstrip antenna array achieves high gain and better wideband circular polarization characteristic than the design in ref. 9.

Figure 1 shows the antenna element configuration. It consists of three layers: The upper layer is a square patch which serves as radiator; the middle layer is the ground plane with H slots in quadrature; and the lower layer is a feed network with a Wilkinson power divider featuring two quadrature output arms, supplying a 90-deg. phase shift to obtain a circularly polarized wave. After mass simulation and optimization using version Ansoft HFSS10.0 of the High-Frequency Structure Simulator (HFSS) finite-element computer-aided-engineering (CAE) simulation software from Ansys (www.ansys.com), the ultimate parameters used for the microstrip antenna array design are indicated in **Fig. 1**.

To obtain high gain and good wideband circular polarization performance, the H-slot aperture-coupled microstrip antenna was used as the basic element in an array. A four-element microstrip antenna was created as a subarray without any sequential rotation, and a quartet of four-element subarrays



3. The fabricated broadband microstrip antenna is shown in this photograph.



4. These plots show simulated and measured VSWR versus frequency for the wideband microstrip antenna.

were then fed with a sequential rotation technique using a 90-deg phase shift between each other (as shown in **Fig. 2**). The distance between adjacent elements is 100 mm ($0.67\lambda_0$, where λ_0 is the free-space wavelength of the center frequency of interest).

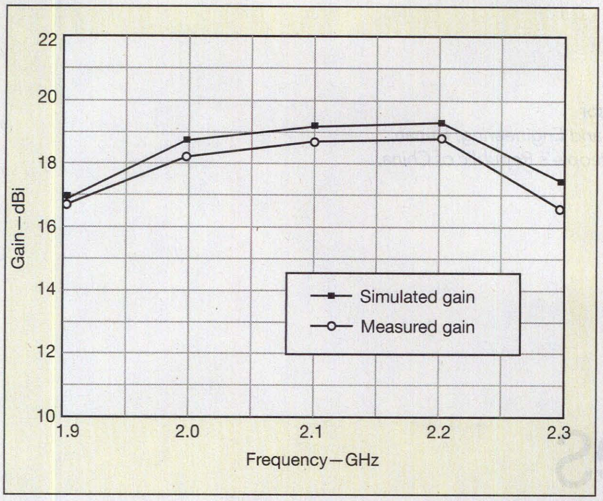
For the sequentially rotated feed network, the feeding point to the full array is at the edge of the substrate. This is because the distance between the reflection board and the feed layer is just 10 mm. This is not easy for an SMA connection with probe feeding, so this structure will exhibit a little higher conductor loss due to the added microstrip line.

The microstrip line feeds of the patch antenna array are arranged for a 90-deg. phase shift with respect to the neighbor with same width of 50 Ω in spite of the 100-Ω microstrip line used in the Wilkinson power divider. The feed network should be carefully designed to confirm that the phase shift sent to each element is at the specific, required values. For example, the corner number should be reduced and the distance between the feed lines should be more adequate for reduced coupling.

To validate the authors' design approach, a prototype of a 16-element aperture-coupled microstrip antenna was fabricated and tested **(Fig. 3)**. The VSWR was simulated with commercial CAE software, and measured with the assistance of a model E8363B vector network analyzer (VNA) from Agilent Technologies (www.agilent.com). The simulated and measured VSWR results are shown in **Fig. 4**.

The design shows an impressive bandwidth of 74% from 1.13 to 2.48 GHz with measured VSWR of less than 2.0:1 across the bandwidth. The measured bandwidth shows a slight shift towards higher frequencies than the simulated performance, likely due to measurement errors and fabrication inconsistencies. **Figure 5** shows simulated and measured gain versus frequency, with gain of more than 16.6 dBi over an 18.9% bandwidth from 1.92 to 2.32 GHz, and peak gain of 18.7 dBi at the center frequency. **Figure 6** shows the simulated and measured axial ratio, indicating a 3-dB bandwidth of 57% from 1.5 to 2.7 GHz.

In short, a wideband and high-gain, circularly polarized, aperture-coupled microstrip antenna array is presented



5. These plots show simulated and measured gain versus frequency for the wideband microstrip antenna.

here. A 16-element array was obtained by adopting a sequential rotation feeding technique to achieve a wider circular polarization bandwidth than normally possible, using the H-slot aperture-coupled microstrip antenna as an element in the array.

The impedance bandwidth (for a VSWR of less than 2.0:1) and 3-dB axial-ratio bandwidth register 74% and 57%, respectively. The microstrip array achieves 18.7-dBi gain at the center of the band and represents a viable candidate for a number of wideband communications applications. MWRF

ACKNOWLEDGMENT

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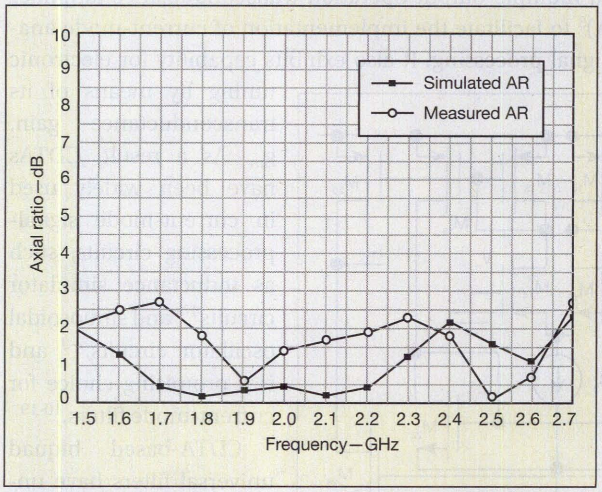

6. These plots show simulated and measured axial ratio (AR) as functions of frequency from 1.5 to 2.7 GHz for the wideband microstrip antenna.

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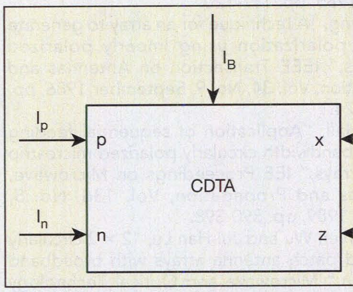
Single Filter Has Many Responses

This unique resistorless, current-mode filter design can realize a variety of filter responses, including lowpass, highpass, bandstop, and all-pass responses without changing topology.

FILTERS ARE crucial parts of RF/microwave systems—so much so that, often, many different types of filters and filter responses are needed within a single network. Fortunately, a new general synthesis method has been developed for designing resistorless nth-order current-mode universal filters capable of providing a number of different filter responses. These include lowpass, highpass, bandpass, bandstop, and all-pass responses, and do not necessitate changes to the basic filter topology.

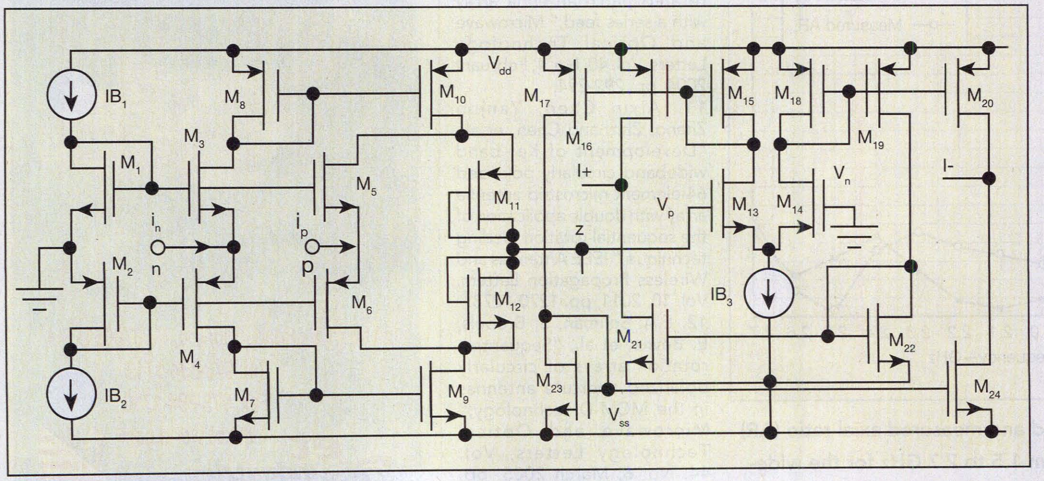


1. This simple diagram represents a basic symbol for a current differencing transconductance amplifier (CDTA).

Such a "universal" filter is based on a current differencing transconductance amplifier (CDTA) and features a current-mode, multiple-input, single-output structure. Different responses are achieved by changing how the external current signals are combined. Constructed without resistors, such a filter is assembled with n active components and n grounded capacitors, making it suitable for integrated-circuit (IC) fabrication processes. The values of the passive elements are found from the coefficients of the desired transfer function. As an example of how to realize such a filter, a simulation will be performed for a fourth-order Butterworth filter with the aid of the PSpice® simulation software from Cadence® (www.cadence.com).

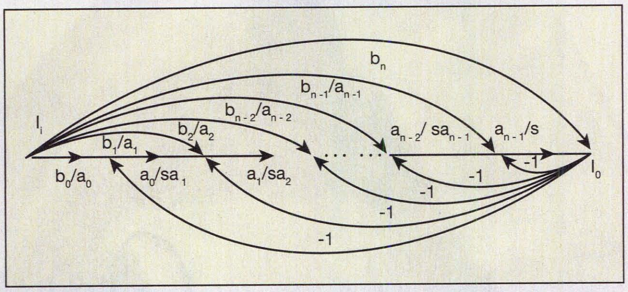
Filters are used for many purposes in communications systems, such as for image rejection at RF and microwave frequencies and for channel selection at intermediate frequencies (IFs). Filters fabricated on semiconductor chips mainly apply switched capacitors or a continuous-time structure, especially for continuous-time current-mode techniques. Recently, a new current-mode active element with two current inputs and two kinds of current output, called a current differencing transconductance amplifier (CDTA), was developed and shows good versatility.[1]

The CDTA represents a synthesis of the well-known advantages of a current-differencing buffered amplifier (CDBA)[2] and a multiple-output operation transconductance amplifier (OTA)[3] to facilitate the implementation of current-mode analog signal processing. It also exhibits capability for electronic tuning by means of its transconductance gain, g_m. As a result, CDTAs have been widely used in current-mode signal-processing circuits, such as inductance simulator circuits[4-6] and sinusoidal oscillator circuits,[7-9] and is a promising choice for current-mode filters.[10-19]



2. This circuit is a realization of a CMOS-based CDTA filter.

CDTA-based biquad universal filters have undergone considerable study. For example, refs. 20 and 21 detail work

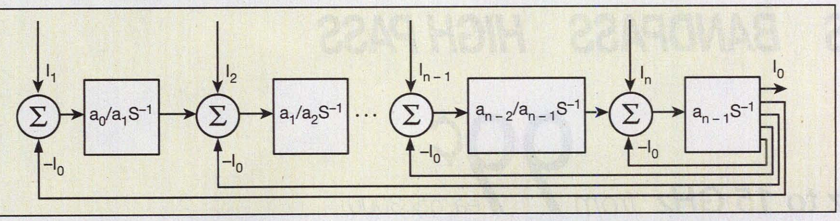


3. This is an nth-order equivalent signal flow graph for the universal filter.

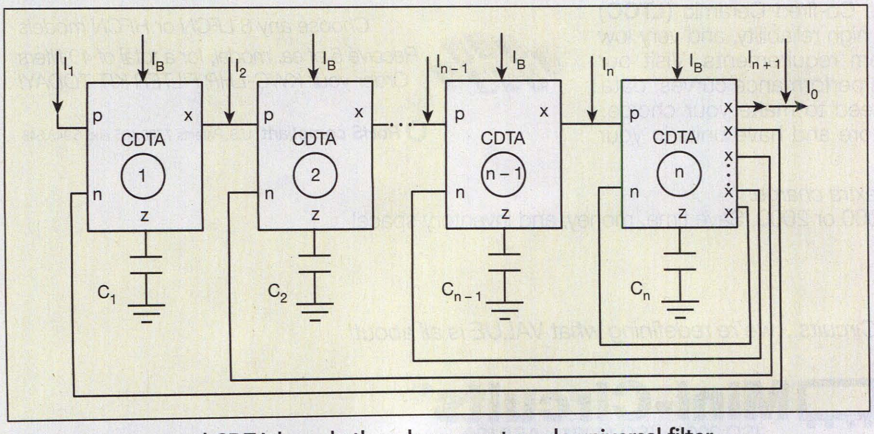
on a CDTA-based Kerwin-Huelsman-Newcomb (KHN) current-model filter and a multiple-input, single-output universal filter, respectively. Both filters incorporate two CDTAs, two grounded capacitors, and simple structures. Reference 22 also reports on a CDTA-based universal filter which can be cascaded while simultaneously providing all standard filter functions. However, in spite of these reported filter circuits, research on nth-order CDTA-based filters has been inadequate.[23-26]

References 23 and 24 proposed two kinds of nth-order current-mode filters using CDBAs. These filters are realized with the aid of a signal-flow graph and employ too many passive components. Reference 25 details a CDTA-based nth-order lowpass filter with a simple structure and n grounded capacitors. It is based on the analysis of a signal-flow diagram. Reference 26 proposes a method for creating an nth-order circuit, in which a fourth-order bandpass filter is designed.

These design approaches suffer drawbacks, however. They can only realize nth-order single filter functions, such as a lowpass filter,[25] and do not meet the requirements of a universal filter. These approaches employ circuit structures with single inputs to single outputs.[23-26] When needing to change the filter function, the circuit's topology must be changed simultaneously, not taking full advantage of the port characteristics and providing only limited filter flexibility. Another drawback is that these circuits are complicated and require many passive components; for example, the circuits in refs. 23 through 25 require external resistors and more CDTAs than the circuit of ref. 26.



4. This is an nth-order functional equivalent circuit block diagram for the universal filter.



5. This is a proposed CDTA-based nth-order current-mode universal filter.

Because of the shortcomings of these different universal filter design approaches, a new general synthesis method for CDTA-based resistorless nth-order current-mode universal filters was developed; it is based on mathematical analysis of transfer functions and signal-flow graphs. The circuit realization is obtained from a signal-flow graph, and the circuits developed from this approach feature a current-mode, multiple-input, single-output structure. By manipulating the amount and mode of joining the external current signals, a single circuit can provide lowpass, highpass, bandpass, bandstop, and all-pass filter functions without changing the topology.

The natural angular frequency of the filter, ω_0, can be adjusted properly by means of current I_B. The circuit configuration is simple: It contains n active components, n grounded capacitors, and no resistors, which is advantageous for IC fabrication. The required values of the passive elements can be found from the coefficients of the transfer function to be realized. Such a universal filter can be used in many applications, including in RF/microwave transmitters/receivers, in phase-locked-loop (PLL) frequency-modulation (FM) demodulators, in test instrumentation, and in wireless communications systems. It can also be used for an active filter in place of the surface-acoustic-wave (SAW) filters typically used in GSM systems.

The circuit symbol of the CDTA is shown in **Fig. 1**, where p and n are positive and negative current input terminals, z and x are current output terminals. Its current characteristics can be described by the matrix of Eq. 1:

$$\begin{bmatrix} V_p \\ V_n \\ I_z \\ I_x \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 1 & -1 & 0 & 0 \\ 0 & 0 & \pm g_m & 0 \end{bmatrix} \begin{bmatrix} I_p \\ I_n \\ V_z \\ V_x \end{bmatrix} \qquad (1)$$

where $V_z = I_z * Z_z$; g_m = the transconductance gain; and Z_z = an external impedance connected at terminal z.

According to Eq. 1, the currents through terminal z follow the difference of the currents through terminals p and n ($I_p - I_n$), and flows from terminal z into an impedance Z_z. The voltage drop at terminal z is transferred to a current at terminal x (I_x by means of transconductance g_m, which is electronically controllable by an external bias current, I_B.

Such a universal filter can be constructed using a number of techniques: a possible CMOS-based CDTA circuit suitable for IC fabrication is shown in **Fig. 2.**[20] The transconductance stage can be copied in a circuit, so the number of x ports for the CDTA can be chosen as needed.

For the design of an nth-order universal filter, the transfer function can be written as Eq. 2:

$$I_o = \frac{b_n s^n + b_{n-1}s^{n-1} + \cdots + b_1 s + b_0}{s^n + a_{n-1}s^{n-1} + \cdots + a_1 s + a_0} I_i \quad (2)$$

where:

$$\begin{aligned} I_o = {} & I_i\left(b_n + b_{n-1}s^{-1} + \cdots + b_1 s^{-n+1} + b_0 s^{-n}\right) \\ & -\left(I_o a_{n-1}s^{-1} + \cdots + I_o a_1 s^{-n+1} + I_o a_0 s^{-n}\right) \end{aligned} \quad (3)$$

To present the feedback coefficient with units of gain and to simplify the design of the circuit, Eq. 3 can be modified, using the equivalent signal-flow graph shown in **Fig. 3.** According to the signal-flow graph, and using the Mason formula leading with the input variable, the output signal can be described by Eq. 4:

See Eq. 4 in box on p. 64.

where $I_1, I_2 \ldots I_{n+1}$ is the input variable with relationship to input signal I_i described by Eq. 5:

$$I_{j+1} = \frac{b_j}{a_j} I_i \quad (j = 0, 1, 2 \cdots n) \quad (5)$$

The system block diagram for Eq. 4 is shown in **Fig. 4.** Using **Fig. 4**, the proposed CDTA-based nth-order current-mode universal filter can be obtained as shown in **Fig. 5.** By routine analysis, the single-output-current function realized by this circuit configuration is:

See Eq. 6 in box on p. 64.

where:

$\tau_0 = g_{mn}/C_n$,

$\tau_1 = g_{mn}g_{m(n-1)}/C_n C_{n-1}, \ldots$

$$\tau_{n-2} = \frac{\prod_{i=0}^{n-2} g_{m(n-i)}}{\prod_{i=0}^{n-2} C_{n-i}} \qquad \tau_{n-1} = \frac{\prod_{i=0}^{n-1} g_{m(n-i)}}{\prod_{i=0}^{n-1} C_{n-i}} \quad (7)$$

That is:

$$\tau_k = \frac{\prod_{i=0}^{k} g_{m(n-i)}}{\prod_{i=0}^{k} C_{n-i}} \quad \left(0 \le k \le n-1\right) \quad (8)$$

and g_{mi} is the transconductance gain parameter of the ith CDTA.

From Eq. 6, through a rational chang-

$$I_o = \frac{a_0 I_1 s^{-n} + a_1 I_2 s^{-n+1} + \cdots + a_{n-2} I_{n-1} s^{-2} + a_{n-1} I_n s^{-1} + a_n I_{n+1}}{1 + a_{n-1} s^{-1} + \cdots + a_1 s^{-n+1} + a_0 s^{-n}} \quad (4)$$

$$I_o = \frac{I_1 \tau_{n-1} + s I_2 \tau_{n-2} + \cdots + s^{n-2} I_{n-1} \tau_1 + s^{n-1} I_n \tau_0}{s^n + s^{n-1} \tau_0 + s^{n-2} \tau_1 + \cdots + s \tau_{n-2} + \tau_{n-1}} + I_{n+1} \quad (6)$$

ing of the amount and mode of joining the external current signals, it is possible to derive the filter function in the following five ways:

1) If $I_1 = I_{in}$ and $I_2 = \ldots I_n = I_{n+1} = 0$, the lowpass filter response can be realized.

2) When n is an even number, if:
$I_{n/2} = I_{in}$, and the other input currents are zero, or when n is an odd number, if $I_{(n-1)/2} = I_{in}$ or: $I_{(n+1)/2} = I_{in}$ and the other input currents are zero, a bandpass filter response can be realized.

3) If $I_{(n+1)} = I_{in}$ and $I_1 = \ldots = I_n = -I_{in}$, a highpass filter response can be realized.

4) If $I_{(n-1)/2} = I_{in}$ and $I_2 = \ldots = I_n = -I_{in}$, and $I_1 = 0$, a bandstop filter response can be realized.

5) When n is an even number, if $I_{n+1} = I_{in}$,
$I_n = -2I_{in}$,
$I_{n-1} = 0$,
$I_{n-2} = -2I_{in}$,
$I_{n-3} = 0, \ldots, I_2 = -2I_{in}$,
$I_{n-1} = 0$, or when n is an odd number, if:
$I_{n+1} = I_{in}$,
$I_n = -2I_{in}$,
$I_{n-1} = 0$,
$I_{n-2} = -2I_{in}$,
$I_{n-3} = 0, \ldots, I_2 = 0$, and
$I_1 = -2I_{in}$,
an all-pass filter response can be realized.

The CDTA represents a synthesis of the well-known advantages of a CDBA and an OTA to facilitate the implementation of current-mode analog signal processing.

From Eqs. 6, 7, and 8, when calculating the required component parameters, if all g_{mi} values are known (according to the filter transfer function), the value of capacitance C_n can be found from τ_0 and then the value of C_{n-1} can be found from τ_0, τ_1. The other values can then be confirmed, and so forth, since it is fairly straightforward to find the required values of passive elements from the coefficients of the transfer function to be realized. It is also apparent that the angular frequency of the filter, ω_0, can be adjusted properly by adjusting current I_B.

To verify this theoretical analysis, a simulation was performed in PSpice, for a current-mode fourth-order Butterworth filter using the CMOS-based CDTA circuit of **Fig. 2**. The filter was modeled in PSPICE with 0.5-µm CMOS parameters, available upon request from the authors. The cutoff frequency of the fourth-order Butterworth filter is 13 MHz,[27]

The filter has a transfer function denominator polynomial of $D(s) = s^4 + 2.14 \times 10^7 + 2.292 \times 10^{12} s^2 + 1.437 \times 10^{17} s + 4.506 \times 10^{21}$. The CDTA element in this case has a bandwidth of approximately 420 MHz, and the circuit is supplied with symmetrical voltages of ±2.5 VDC. The external bias currents are $I_{B1} = I_{B2} = 85\ \mu A$, $I_{B3} = 200\ \mu A$, and the transconductance gain, g_{mi}, is 457.83 µS. One of these CDTAs is modified from the circuit in **Fig. 2** and is chosen with five x ports. It is easy to obtain the value C_i from the above parameters: $C_1 = 15$ pF, $C_2 = 7.3$ pF, $C_3 = 4.27$ pF, and $C_4 = 2.14$ pF. **Figure 6** shows the simulation results, with theoretical test and computer simulation results in good agreement. MWRF

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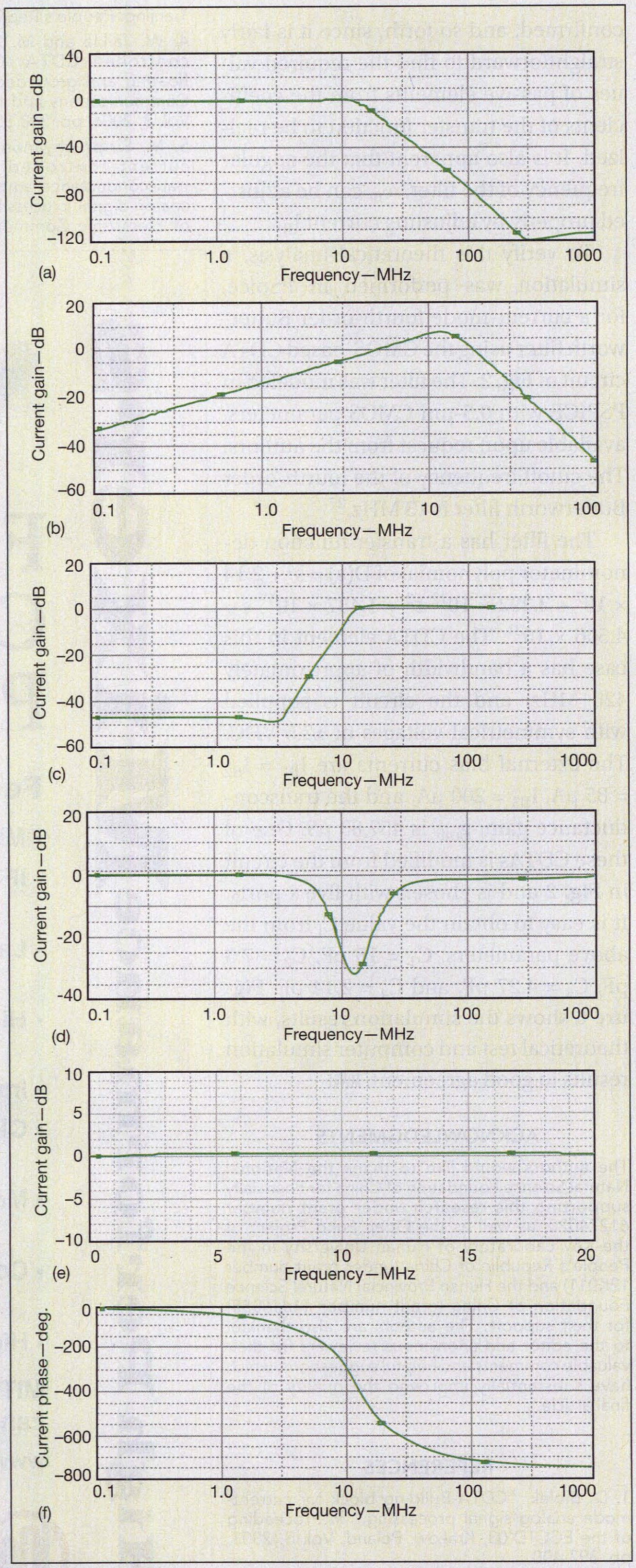

6. These frequency responses show the different proposed filter functions: (a) lowpass, (b) bandpass, (c) highpass, (d) bandstop, (e) all-pass frequency response, and (f) all-pass phase response.

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Substrate Libraries Ease PCB Simulations

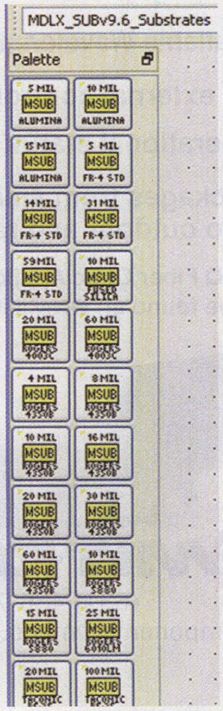
These measurement-based substrate model libraries can significantly improve the accuracy and efficiency of RF/microwave printed-circuit-board design simulations by including key circuit-material characteristics.

HIGH-FREQUENCY CIRCUIT models require a great deal of knowledge about the passive resistive-inductive-capacitive (RLC) components used in those circuits, as well as the circuit-board materials, thicknesses, and operating conditions—including temperatures. To aid RF/microwave circuit designers, Modelithics (www.modelithics.com) has developed Global Models™. These are software simulation models of different RLC component families that make possible rapid RF and microwave circuit design and manufacturing success by means of scalability of multiple parameters within the passive component models. Scalable input parameters include part value and specific substrate characteristics, such as circuit board thickness (H) and dielectric constant (ε_r) along with a number of other parameters.[1] This modeling process finds success by being able to quickly evaluate a model's performance as it is mounted on different substrate materials, and being able to perform statistical analyses using tolerances of part values for components as well as for substrate parameters.[2] This approach helps to ensure a higher probability of manufacturing success based on the software models.

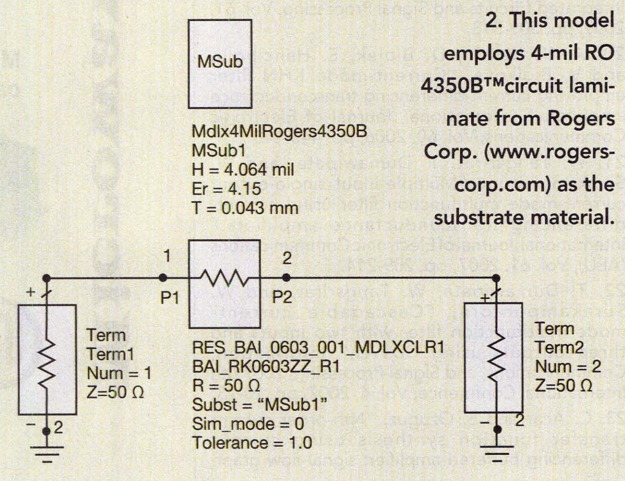
The dielectric materials used for printed-circuit boards (PCBs) at RF and microwave frequencies are too often taken for granted as part of computer-aided-engineering (CAE) models, even though these materials consist of a blend of multiple dielectric and metal materials. Developing models for any circuit parameters—including PCB materials—requires accurate measurements to better understand how a component or material behaves under typical application circuit (e.g., microstrip) operating conditions.

As a byproduct of the characterization/testing performed to develop the Global Model library, a number of properties were also obtained for some of the more popular substrate materials used at RF and microwave frequencies, from leading materials suppliers. In fact, new measurement-based substrate libraries are included beginning with Version 9.0 of the Modelithics COMPLETE Library for the Advanced Design System (ADS) software suite from Agilent Technologies (www.agilent.com) and Version 8.3 of the Modelithics COMPLETE Library for the Agilent Genesys software suite. The substrate library provides for improved accuracy and convenience in simulating PCB-based designs. Some examples will be presented here for using the substrate library to generate scattering (S) parameter plots for passive models in the ADS and Genesys software tools, working with different thicknesses of some leading commercial PCB materials.

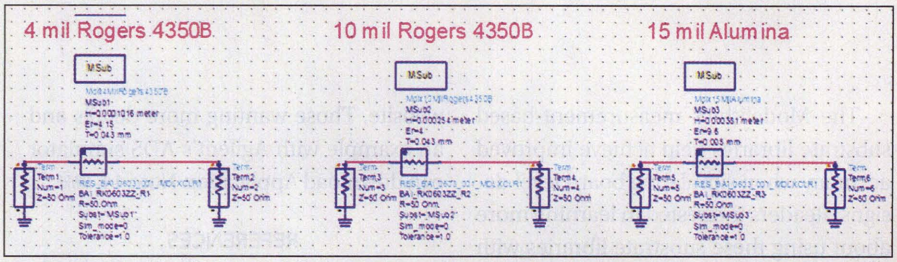
When using the ADS simulator, substrate information can be found by scrolling to the MDLX_SUBv(*.*)_Substrates choice in the pull-down menu located above the Palette tab. An available substrate is selected from this palette and placed in the schematic window. A selected PCB substrate material is assigned to a specific model by entering the substrate's instance name into the model's "Subst" parameter. **Figures 1 and 2** provide examples



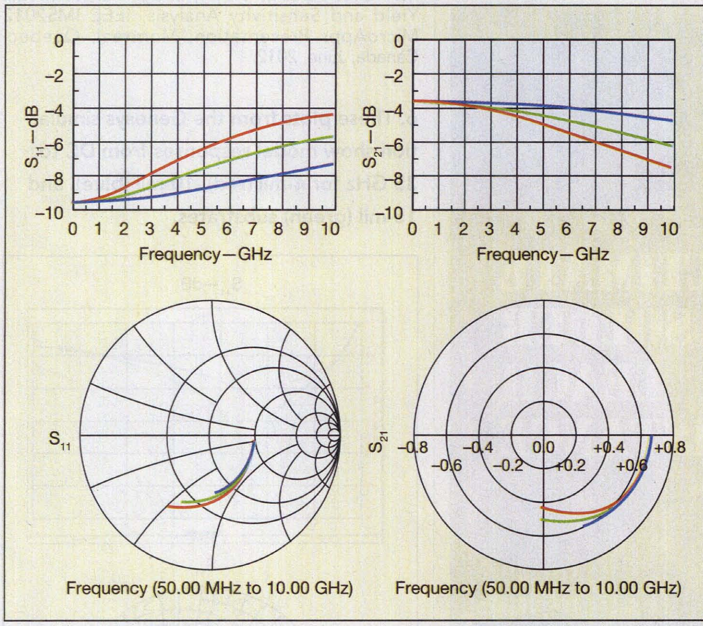
1. This substrate library is located in the palette's tab of an ADS schematic.



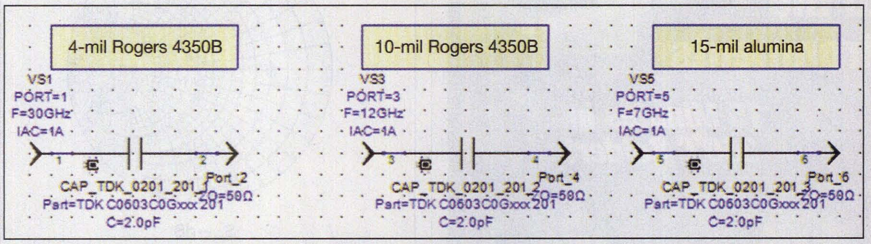
2. This model employs 4-mil RO 4350B™circuit laminate from Rogers Corp. (www.rogerscorp.com) as the substrate material.



3. This S-parameter schematic in ADS shows simulations for models for several popular substrate materials at three different thicknesses.



4. This ADS display shows the results of simulating the schematics in Fig. 3 from DC to 10 GHz for 4-mil (red), 10-mil (blue), and 15-mil (green) circuit substrates.



5. This S-parameter schematic in Genesys shows simulations for models based on some commonly used substrate materials with three different thicknesses.

of the substrate library location and substrate assignment.

Figure 3 offers an example of Modelithics resistor model RES-BAI-0603-001. In **Fig. 3**, it is shown simulated with three different substrates: 4- and 10-mil Rogers 4350B™ laminates and 15-mil alumina material. **Figure 4** shows the S_{11} and S_{21} responses of the simulation. In this example, the red trace is 4-mil Rogers 4350B laminate, the blue trace is 10-mil Rogers 4350B laminate, and the green trace is alumina.

When using the Agilent Genesys software, the substrate to be considered as part of a circuit must be added to the Workspace from the Modelithics substrate library. For this article, three different cases were evaluated: the aforementioned 4-mil-thick Rogers 4350B laminate, 10-mil-thick Rogers 4350B laminate, and 15-mil alumina.

In the "Model Properties" window of the Modelithics Global Model, there is a pull-down tab that shows what substrate information is linked to this Workspace. Once the model properties window is open, the substrate information can be changed by selecting a new substrate from the "SUBST" tab in the program.

Figure 5 offers an example of Modelithics capacitor model CAP-TDK-0201-201 and how is it is simulated with the three different s ubstrate materials previously mentioned. **Figure 6** provides S_{11} and S_{21} responses at frequencies through 35 GHz, allowing the three substrate materials to be compared.

The Modelithics measurement-based substrate libraries help achieve improved accuracy when simulating board level designs. Readers interested in learning more about using these substrate libraries with the Genesys simulator can download Application Note 43 from the Modelithics website. Those wanting more details and an example with Agilent's ADS simulator can download Application Note 44. MWRF

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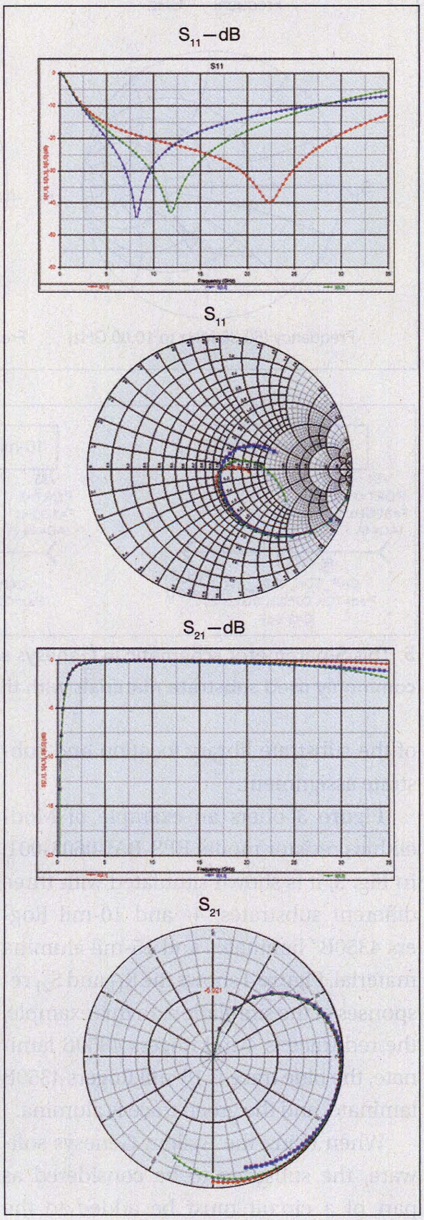
1. "Comprehensive Models for RLC Components to Accelerate PCB Designs," Microwave Journal, May, 2004.
2. Larry Dunleavy and L. van der Klooster, "Improved MW Circuit Design Flow Through Passive Modal Yield and Sensitivity Analysis, IEEE IMS2012 MicroApps Presentation, Montreal, Quebec, Canada, June, 2012.

6. These plots from the Genesys simulation show model responses from DC to 35 GHz for 4-mil (red), 10-mil (blue), and 15-mil (green) substrates.



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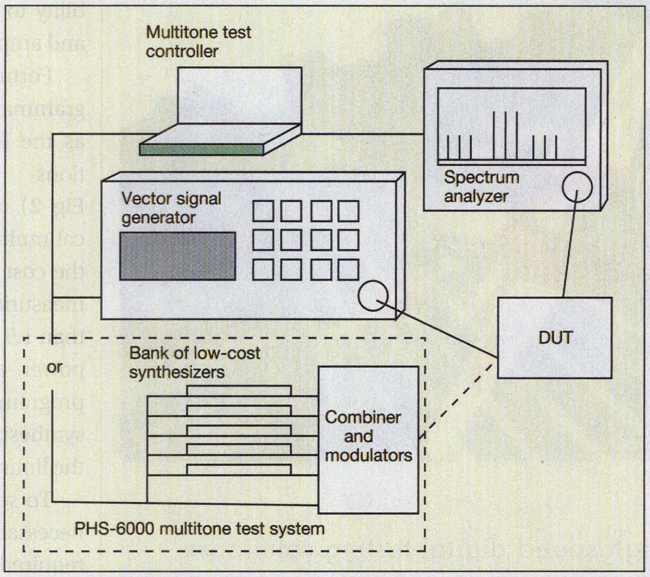
Create Cost-Effective Multitone Test Signals

Generating the multiple-tone signals needed for system and component linearity testing does not require a full-sized rack of high-priced RF/microwave instrumentation.

MODERN APPETITES for increased information from wireless devices has driven the complexity of communications modulation formats, as well as the complexity of the signal sources needed to test those communications systems. Advanced modulation formats often cannot tolerate linearity shortcomings of components in those systems, often visible as unwanted intermodulation distortion (IMD). Testing active and some passive components for susceptibility to IMD usually requires multitone test signals, which can be expensive. Fortunately, a host of new, compact, signal generators have made it easier to create the signals needed for multitone RF/microwave testing.



1. Two possible approaches for producing multitone test signals are the vector signal generator and multiple modular frequency synthesizers.

Multitone testing (**Fig. 1**) is usually required in every terrestrial and satellite-communications (satcom) application. Multitone test signals are created by combining two or more single-frequency signals according to a frequency plan. For broadband component testing, multitone signals may cover an octave or more and may be performed with fixed test tones or on a swept-frequency basis. When considering different options for generating multitone test signals, it can be helpful to understand how they can differ and how to compare different multitone signal sources. First and foremost, multitone test signals must be high quality, with well-behaved spectral characteristics in terms of harmonics, spurious, and phase noise. For example, the relative phase between different tones can influence the IMD produced by a device under test (DUT). When a DUT, such as a high-gain amplifier, is known to have this sensitivity to test-signal phase, the resulting IMD may need to be measured not only as a function of frequency spacing between the tones but also by the phase differences between tones. Amplitude differences between the tones can also affect measured IMD results, so that signal sources for multitone testing should be stable in terms of frequency, phase, and amplitude.

The two traditional methods for generating multitone signals are vector signal generators (VSGs) and multiple combined signal generators. These are shown in **Fig. 1**, where either acts as the input to the DUT and the output is monitored on a spectrum analyzer. Multitone test signals are traditionally produced by combining the outputs of separate test sources; depending upon the cost of each source, however, this can be an expensive solution. Multitone test signals can be represented as time functions of multiple sinusoidal signals. In the case of n sinusoidal signals with associated voltages of V_1, V_2, V_3 to V_4, the total voltage waveform, $V_i(t)$ as a periodic function of time can be written as:

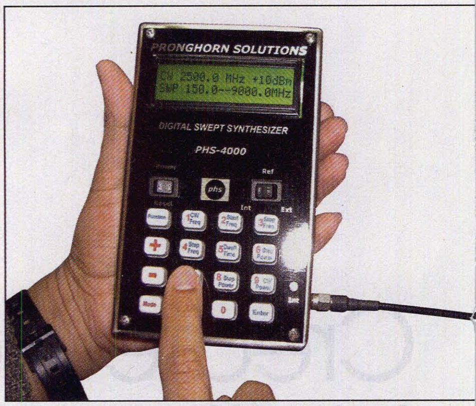
$$V_i(t) = V_1 \sin(\omega_i t) + \varphi_i + V_2 \sin(\omega_2 t) + \varphi_2 + V_3 \sin(\omega_3 t) + \varphi_3 + V_n \sin(\omega_n t) + \varphi_n$$

2. By adding modular synthesized sources, multitone test signals of any required complexity can be created by adding more sources.

where:

ω_1, ω_2, ω_3, and ω_n are the frequencies ($2\pi f$) and φ_1, φ_2, φ_3, and φ_n, are the phases of the n signals. The combined multitone signal is fed to the input of the DUT, with its outputs monitored on a spectrum analyzer as shown in **Fig. 1**, and the results are fed back to the controller for analysis.

VSGs produce multitone signals by modulating a single synthesized carrier frequency with a complex waveform to create the desired multitone output. But the approach has its limitations: a VSG that can create two tones as much as 80 MHz apart can only create as many as 16 tones that are each 5 MHz apart. And if the VSG provides +10-dBm output power, the most power per tone for an eight-tone test signal will be less than +2 dBm. The capability to control individual signal phases and amplitudes with a VSG is also limited.



3. Battery-powered multitone signal sources can simplify on-site testing.

Fortunately, with cost-effective programmable broadband synthesizers such as the PHS-5000 from Pronghorn Solutions (www.pronghorn-solutions.com; **Fig. 2**), it is now possible to create practical multitone test signals. At a fraction of the cost of a VSG—with each synthesizer measuring only 6 x 3 x 0.5 in., weighing less than 1.5 lbs, and consuming less than 5 W power, and with IVI and other standard programmability functions—the multiple synthesizer multitone method overcomes the limitations of the VSG approach.

To select a multitone test source, it is necessary to specify the number of tones required, the frequency range of each tone, the power range and level accuracy of each tone, the frequency accuracy and spectral purity, any phase adjustment requirements, and any modulation requirements. Small size, light weight, and low power consumption are often important, especially for on-site applications where battery operation is often desirable.

This "new generation" of low-cost signal generators can be combined for multitone testing, and including compact, battery-powered units such as the PHS-4000 signal generator. This handheld signal source **(Fig. 3)** offers a fundamental frequency range of 150 MHz to 9 GHz that can be extended to 50 MHz to 18 GHz. Multiple PHS-4000 generators can be combined for multitone testing, and each unit runs about four hours on a rechargeable battery for on-site testing. MWRF

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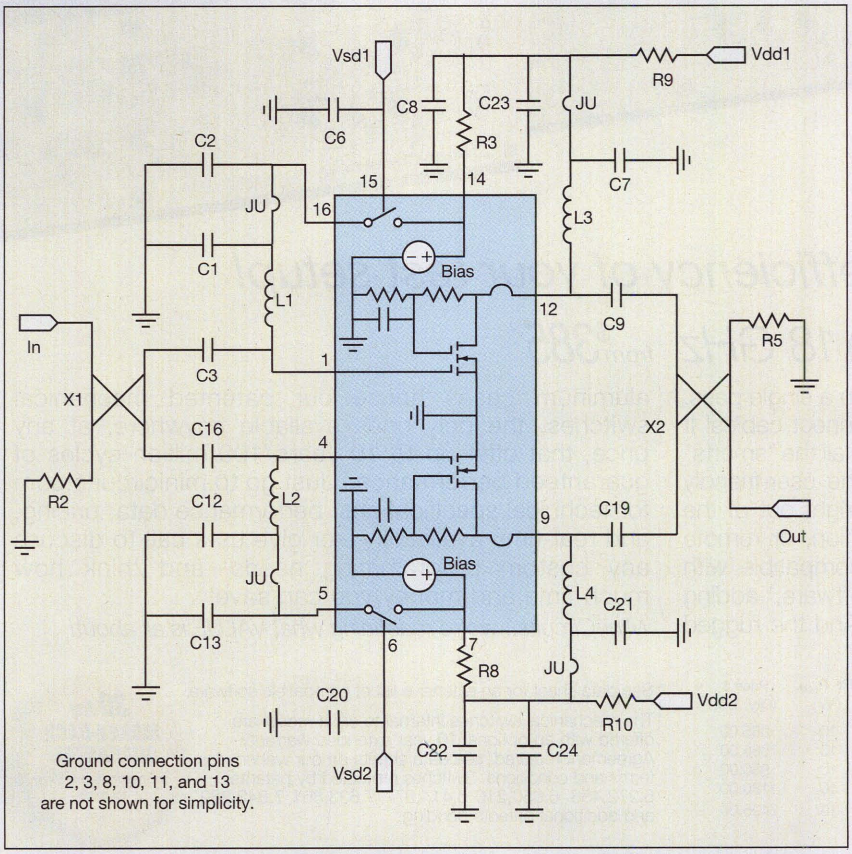
Balanced Amplifier Aims For Low Noise

Based on GaAs HEMT technology, this balanced amplifier presents low noise figure with good impedance matching while also achieving unconditional stability at 1.9 GHz.

MINIMIZING NOISE has been an ongoing challenge for architects of communications systems, especially for designers of low-noise amplifiers (LNAs). A balanced LNA configuration can provide many advantages compared to single-ended amplifiers in terms of very low mismatch and stability, albeit with slightly higher current requirements. For high performance at 1.9 GHz, a balanced LNA was developed based on a new dual-amplifier GaAs high-electronic-mobility-transistor (HEMT) monolithic microwave integrated circuit (MMIC). It features low noise figure and high gain, and is based on readily available commercial circuit components and printed-circuit-board (PCB) materials.

A key to achieving low noise figure in a balanced amplifier is the choice of quadrature 3-dB couplers (also known as 90-deg. or hybrid couplers) used to join the constituent amplifiers.[1,2] A balanced amplifier configuration can also provide improved reliability, linearity, and bandwidth compared to a single-ended amplifier,[3] albeit while requiring twice the current and circuit components of the single-ended amplifier.



1. This block diagram shows the on- and off-chip components for the balanced LNA, where the components labelled JU are 0-Ω chip resistors that bridge breaks in the copper traces (but not essential to the design).

Of course, in a balanced amplifier, the quadrature couplers represent additional cost, occupy substantial PCB space, and exhibit insertion losses that degrade amplifier noise figure, gain, and output power. For applications like tower-mounted amplifiers (TMAs), LNAs should ideally be as small and light in weight as possible. Shrinking the couplers can be critical to reducing the balanced LNA size.[4-9] Integrating multiple functions at the module[11,12] or chip[13-15] levels can also minimize the size of an LNA for use as a TMA. But efforts at LNA miniaturization are usually limited by the levels of performance expected from the amplifier, since a small size usually means limited performance.

A high-performance 1.9-GHz balanced LNA was achieved by integrating dual amplifiers and other key functions on a new MMIC chip and using that as the basis for the LNA **(Table 1)**. To minimize component count, dual amplifiers, electrostatic discharge (ESD) protection, active bias, and shutdown functions were integrated on MMIC (the yellow area in **Fig. 1**). Combining

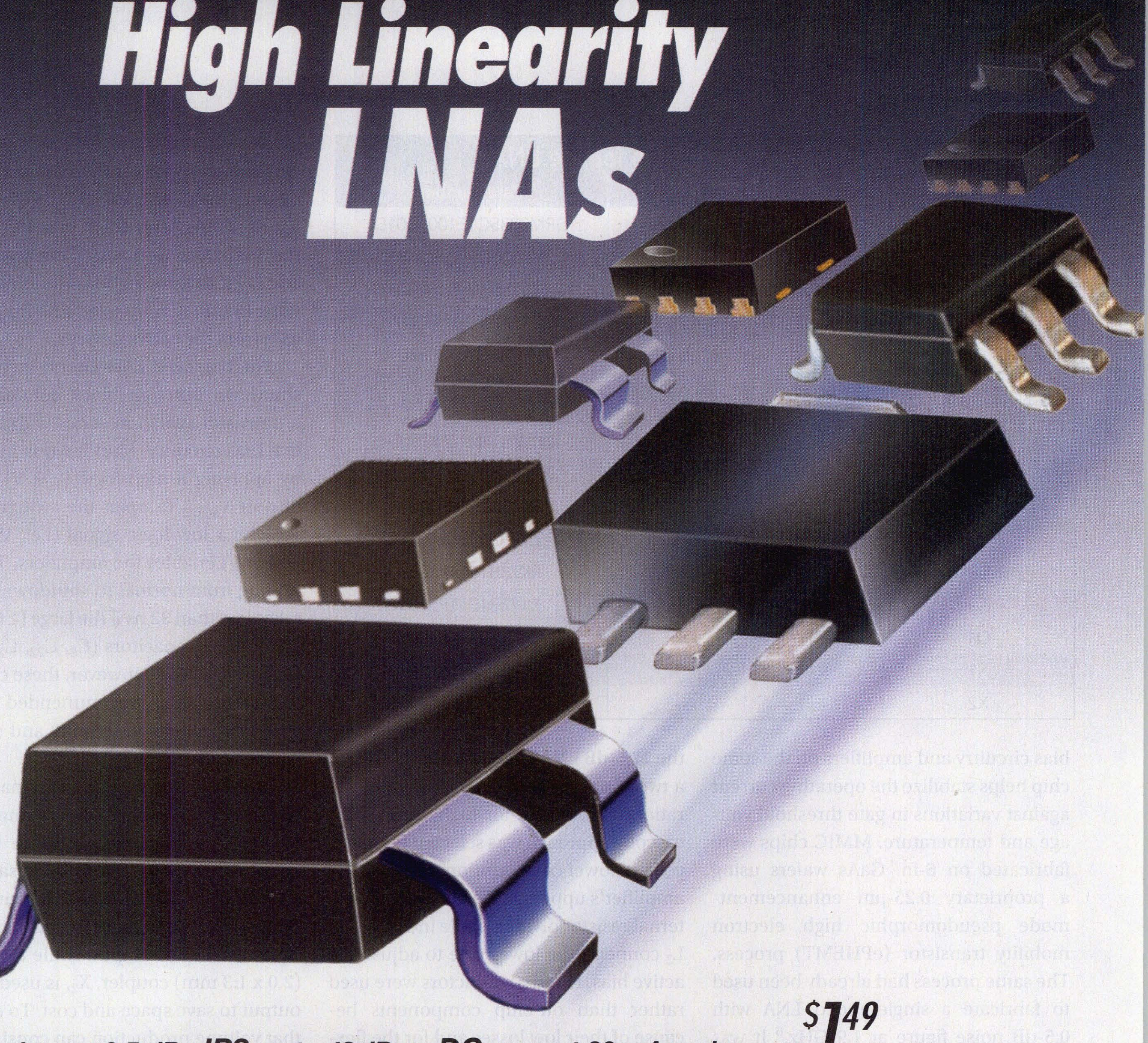


Table 1: Bill of materials for the LNA.

Component	Size	Value	Part number
C1, C12	0201	10 pF	GRM0335C1E100JD01D
C3, C9, C16, C19	0402	18 pF	GJM1555C1H180JB01D
C2, C8, C13, C22	0402	0.1 µF	GJM1555C1HR10BB01D
C6, C20, C23, C24	0805	4.7 µF	GRM21BR60J475KA11L
C7, C21	0201	15 pF	GJM0336C1E150JB01D
C4, C5, C10, C11, C14, C15, C17, C18	0402	Not used	
L1, L2	0603	10 nH	LQW18AN10NG00D
L3, L4	0603	4.7 nH	LQW18AN4N7D00D
R1, R4, R6, R7	0402	0 Ω	RK73B1ETTP0R0J
R3, R8	0402	1 kΩ	RK73B1ELTP102J
R9, R10	0402	10 Ω	RK73B1ETTP100J
R2, R5	0402	51 Ω	RK73B1ETTP510J
Q1	QFN4x4		Avago MGA-16216
X1	-	-	Anaren X3C19P1-03S
X2	-	-	Anaren C1720J5003AHF

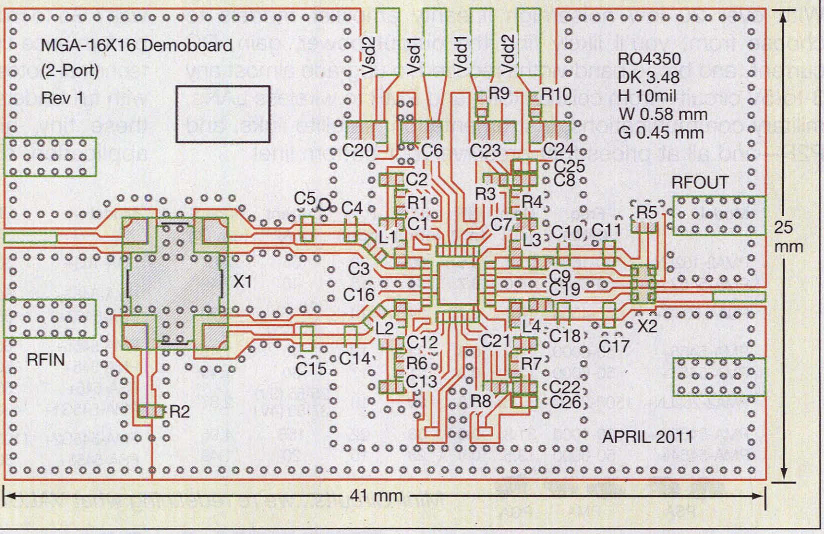
bias circuitry and amplifiers on the same chip helps stabilize the operating current against variations in gate threshold voltage and temperature. MMIC chips were fabricated on 6-in. GaAs wafers using a proprietary 0.25-µm enhancement-mode pseudomorphic high electron mobility transistor (ePHEMT) process. The same process had already been used to fabricate a single-ended LNA with 0.5-dB noise figure at 1.9 GHz.[6] It was thus thought to be possible to provide a balanced amplifier with 0.7-dB noise figure and target gain of better than 17.6 dB at 1.9 GHz, after considering the coupler's loss.

The ePHEMT process features a relatively high transition frequency (f_T) of better than 30 GHz and peak transconductance of about 615 mS/mm, with stable linearity down to +2 VDC.[7] This is essential for a cascade amplifier arrangement where each transistor only receives one-half of the power supply. The MMIC chips were placed on a copper leadframe, connected to the amplifier leads with bond wires, and then epoxy molded to form a 16-pin, 4 × 4 × 0.85 mm quad flat no-lead (QFN) package.

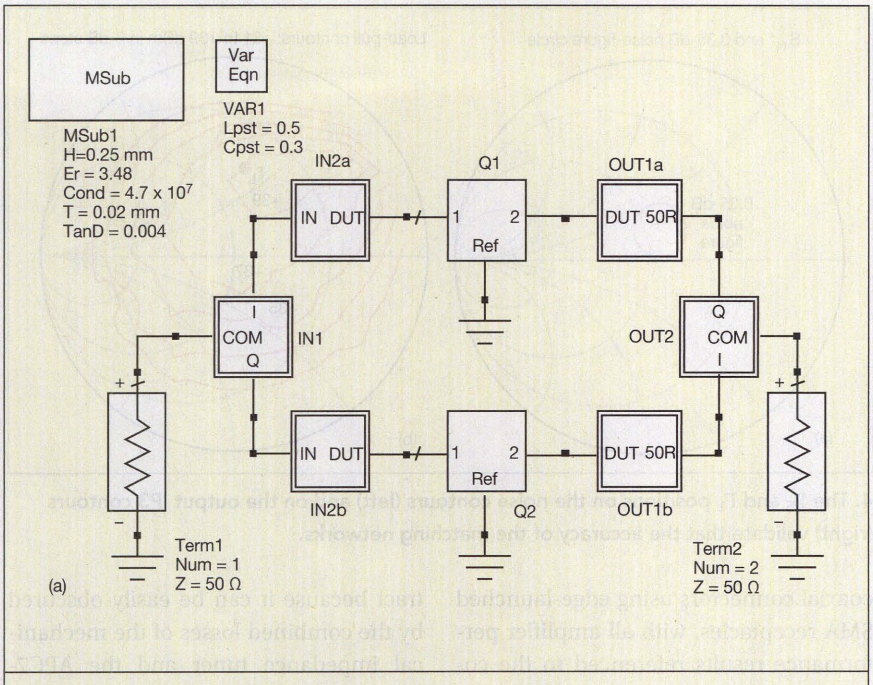
Because a single common-source ePHEMT stage falls about 1.6 dB short of the 17.6-dB LNA gain target at 1.9 GHz,[11] a two-stage cascade or cascode configuration was needed for higher gain. The cascode approach was selected for its excellent power consumption. The cascode amplifier's upper gate is biased by an internal resistor divider, while inductor L_1/L_2 connects the lower gate to adjustable active bias. External inductors were used rather than on-chip components because of their low losses and for the flexibility of tuning if necessary. Wire-wound chip inductors rather than multilayer inductors were used to achieve low noise figure. Along with their bias functions, the inductors and series capacitors C_3 and C_{16} also form highpass filtering functions to roll off unneeded low-frequency gain from the active devices.

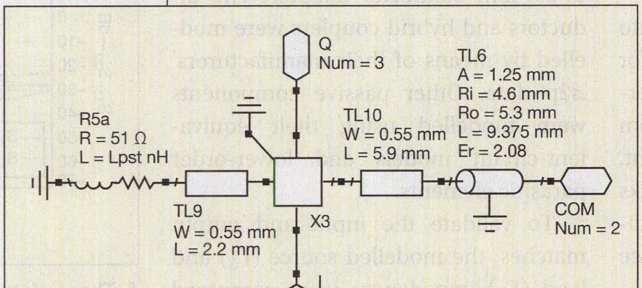
The balanced LNA circuit includes a shutdown function block consisting of a transistor switch in series with the active bias circuitry. Shutdown is initiated by applying a high-logic (≥ 2 V) signal at port $V_{sd1/2}$ to open the switch. Conversely, a low-logic signal (i.e., $V_{sd1/2} \leq$ 500 mV) enables the amplifiers. Transitioning from normal to shutdown mode takes less than 32 ns if the large (≥ 0.1 µF) decoupling capacitors (C_8, C_{22}, C_{23}, and C_{24}) are omitted. However, these capacitors are generally recommended to ensure low-frequency stability and supply transient dampening.

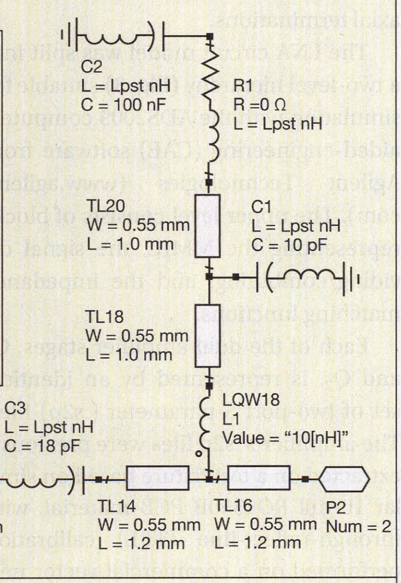
The balanced amplifier's signal splitting and combining utilize commercially available multilayer quadrature hybrid couplers, denoted X_1 and X_2, to save design effort and PCB space. To minimize input loss, a larger (6.4 x 5.1 mm) coupler, X_1, is used at the input, while a smaller (2.0 x 1.3 mm) coupler, X_2, is used at the output to save space and cost. To ensure that volume production can consistently

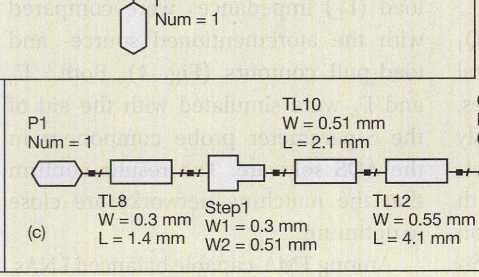
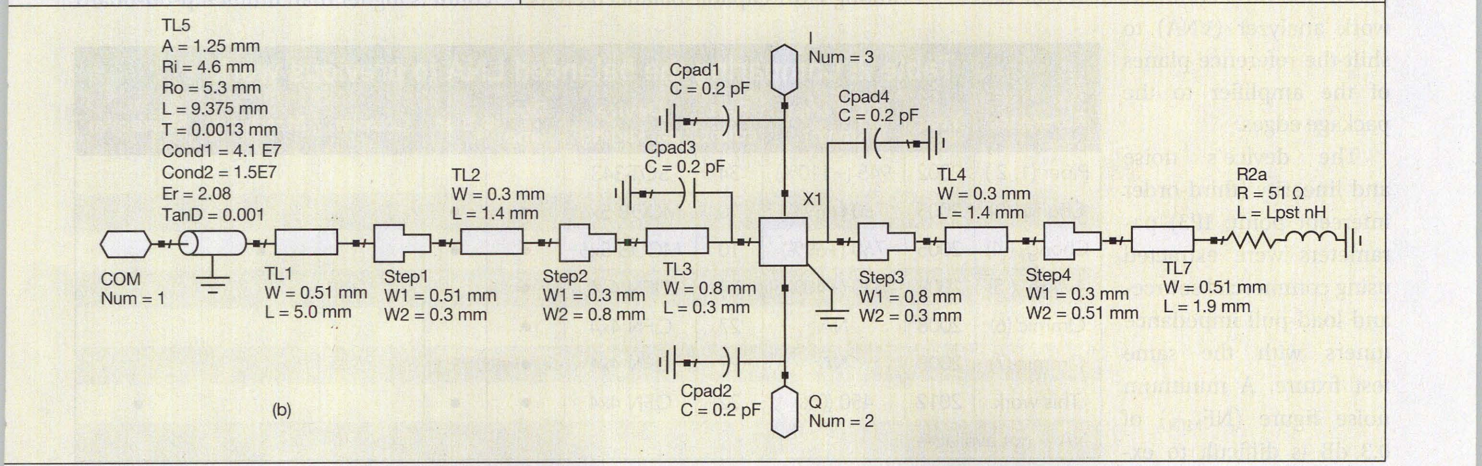


2. This PCB layout shows the placement of components in the balanced LNA, all within a 30 x 15 mm area.





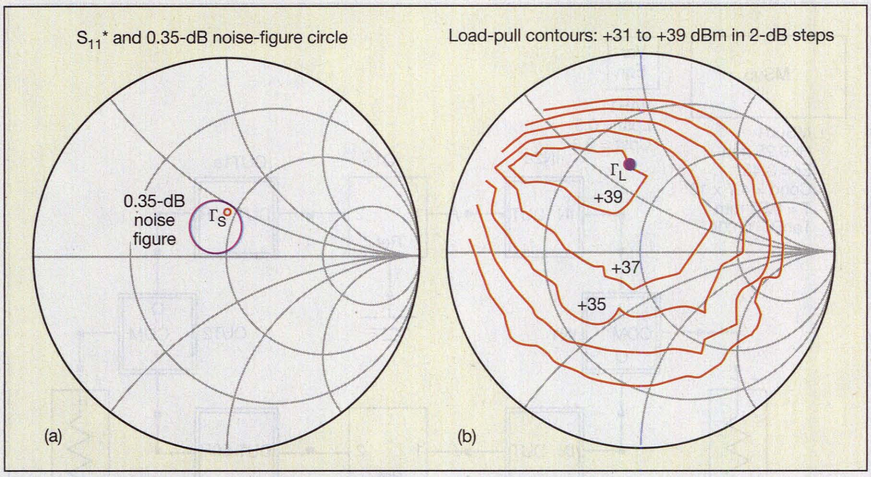


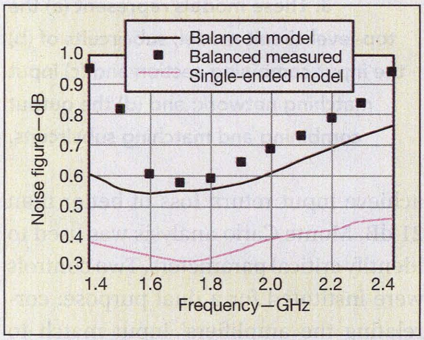
3. These models represent (a) the top-level circuit model; subcircuits of (b) the input combining section and (c) input matching network; and (d) the output combining and matching subcircuits.

achieve input return loss of better than 21 dB, Monte Carlo analysis was used to identify critical parameters. Two controls were instituted for a dual purpose: correlating the amplifiers' input match to $|S_{11a} - S_{11b}| < 0.025$, and ensuring that the input coupler delivers more than 26-dB isolation. The first control is satisfied by assembling with adjacent chip while the second control requires tightening the coupler isolation above the guaranteed 23 dB.[8] The output coupler is not critical in achieving these goals.

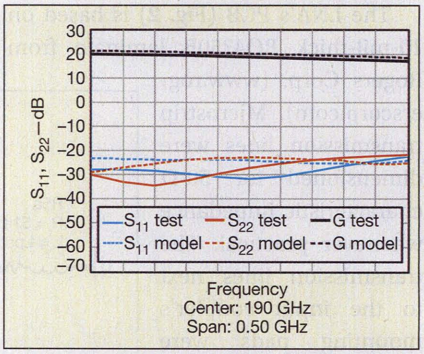
The LNA's PCB **(Fig. 2)** is based on 10-mil-thick RO4350B laminate from Rogers Corp. (www.rogerscorp.com). Microstrip transmission lines were dimensioned for 50-Ω characteristic impedance whenever practical. The transmission lines next to the input coupler's mounting pads were scaled down following the coupler manufacturer's recommendations to compensate for the parasitic capacitances of the coupler pads. An FR-4 layer was added to the RO4350B to increase the stack height to 1.6 mm. Input and output microstrip lines were transitioned to



4. The Γ_S and Γ_L positions on the noise contours (left) and on the output IP3 contours (right) validate that the accuracy of the matching networks.



5. The modelled and measured noise figures for the balanced LNA agree closely. The single-ended amplifier noise figure is also shown as a reference since its difference from the noise figure of the balanced amplifier allows the input coupler's loss to be estimated.



6. These plots show the modelled and measured gain and return loss for a center frequency of 1.9 GHz.

coaxial connectors using edge-launched SMA receptacles, with all amplifier performance results referenced to the coaxial terminations.

The LNA circuit model was split into a two-level hierarchy **(Fig. 3)** suitable for simulation with the ADS2009 computer-aided-engineering (CAE) software from Agilent Technologies (www.agilent.com). The upper level consists of blocks representing the MMIC, the signal dividing/combining, and the impedance matching functions.

Each of the dual amplifier stages, Q_1 and Q_2, is represented by an identical set of two-port S-parameter (.s2p) files. The amplifier's .s2p files were previously extracted on a test fixture based on similar 10-mil RO4350B PCB material, with through-reflect-line (TRL) calibration performed on a commercial vector network analyzer (VNA) to shift the reference planes of the amplifier to the package edges.

The device's noise and linearity (third-order intercept point; IP3) parameters were extracted using commercial source- and load-pull impedance tuners with the same test fixture. A minimum noise figure (NF_{MIN}) of 0.3 dB is difficult to extract because it can be easily obscured by the combined losses of the mechanical impedance tuner and the APC7-to-3.5-mm connector adapter. The inductors and hybrid couplers were modelled by means of their manufacturers' .s2p data. Other passive components were modelled using their equivalent-circuit models and lower-order parasitic elements.

To validate the input and output matches, the modelled source (Γ_S) and load (Γ_L) impedances were compared with the aforementioned source- and load-pull contours **(Fig. 4)**. Both Γ_S and Γ_L were simulated with the aid of the S-parameter probe component in the ADS software. The results confirm that the matching networks are close to optimum.

Among TMA-capable balanced LNAs, this new LNA design sets new milestones in size reduction and function integration **(Table 2)**. It is 40 to 110% smaller than those earlier designs. The parts count is higher than multichip-on-board

Table 2: Comparing the balanced LNA to previous work.

Reference	Year	PCB area (mm^2)	Part count	Device packaging	Dual amp	Bias	Coupler	Matching	Shutdown
Piper (1, 2)	2002	945 (+110%)	34	SOT-343					
Chong (3)	2005	760 (+69%)	10	MCOB 5x6	•	•		•	
Chong (4)	2005	760 (+69%)	10	MCOB 5x6	•	•		•	
Avago (5)	2009	630 (+40%)	34	QFN 4x4	•				
Ommic (6)	2008	NA	27	QFN 4x4	•				
Ommic (7)	2008	NA	27	QFN 4x4	•				
This work	2012	450 (0%)	32	QFN 4x4	•	•			•

NA = not available.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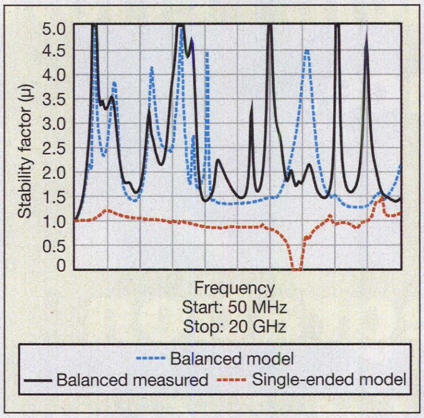
(MCOB) designs with integrated impedance matching,[11,12] but the new LNA's external matching enables lower noise figure; its monolithic fabrication is also lower in cost than those other designs. The dual-amplifier MMIC also integrates as many functions as the best of the prior arts, and appears to be the first dual-amplifier MMIC that integrates the shutdown function.

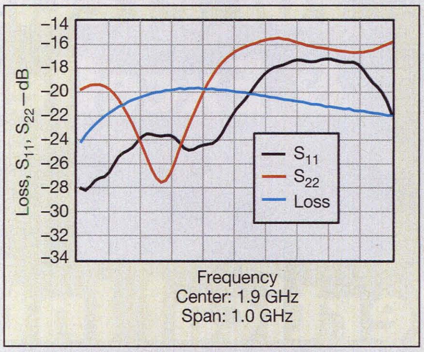
Miniaturization need not detract from noise performance; in fact, the new design's noise figure is second only to a competing design using a shorter-gate-length device[14] as noted in **Table 3**. The LNA's experimental noise figure is 0.65 dB at 1.9 GHz, or within 0.1 dB of the prediction **(Fig. 5)**. The simulation model's errors increase towards the band edges. Both predicted and experimental (measured) noise figure minima are offset to 1.7 GHz, but retuning is not necessary since the potential improvement will only be about 0.05 dB.

Since the device-level noise figure of a single-ended amplifier is about 0.3 dB, a noise figure of 0.3 dB is inferred for the combined loss of the coaxial connector, coupler, and input impedance matching network. The noise figure is only marginally worse (about 0.01 dB) than a previous design that used a 55% larger coupler,[13] even though the two couplers' maximum loss specification differs by 0.1 dB (0.22 dB vs. 0.12 dB).



7. The excellent return loss (better than 16 dB) during the balanced LNA's shutdown mode may eliminate the need for bypassing the amplifier.

In spite of the efforts to achieve a miniature design, the LNA achieves best-in-class return-loss and gain performance levels. The gain is 19 dB at 1.9 GHz, with 32-dB input return loss and 27-dB output return loss **(Fig. 6)**, and good agreement between simulated and measured results. The best input return loss is at 1.9 GHz because it coincides with the center frequency of the input coupler. Similarly, the best output return loss is at 1.75 GHz, and this is also a property of the coupler. Although the circuit model is less accurate for return loss than for gain, the mismatch is minimal—at less than 22 dB across a 500-MHz span. The LNA's bandwidth exceeds 500 MHz at the 20-dB return-loss points. The best achievable return loss is limited by the couplers' finite isolation and by the microstrip discontinuities.



8. The balanced LNA features simulated and measured stability factor, μ, of better than unity across a wide frequency range.

When the MMIC's shutdown function is activated, the amplifier is transformed into a nonreflective attenuator, which can be used to prevent overloading. In this state, it provides 20-dB attenuation at 1.9 GHz, with input and output return losses of 22.0 and 16.5 dB, respectively **(Fig. 7)**. It achieves good match during shutdown mode since reflected energies are cancelled in the couplers. In contrast, an unpowered single-ended amplifier will be highly reflective, requiring that it

Table 3: Comparing balanced LNAs.

Reference	Year	Process, gate length	Frequency (GHz)	Noise figure (dB)	Gain (dB)	Input return loss (dB)	Output IP3 (dBm)	Power supply (W)	OIP3/ PDC
Piper (1, 10)	2002	GaAs HEMT, 0.5 μm	1.9	0.75	16	19	+39.0	0.6	13.2
Jensen (8)	2002	GaAs HEMT, 0.5 μm	1.9	0.8	18.5	20	+32.0	0.4	4.0
Chong (12)	2005	GaAs HEMT, 0.5 μm	1.9	0.75	30.1[b]	22	+43.5	2.85	7.9
Chong (13)	2005	GaAs HEMT, 0.5 μm	1.9	0.7	30.0[b]	22	+42.1	0.93	17.4
Gao (9)	2007	GaAs HEMT, 0.15 μm	1.9	0.9[a]	12.0[a]	NA	NA	NA	NA
Ommic (15)	2008	GaAs HEMT, 0.13 μm	1.9	0.42	19.0	23	+35.0	0.5	6.3
Avago (14)	2009	GaAs HEMT, 0.25 μm	1.9	0.64	16.5	19	+35.5	0.5	7.1
Mandeep (4)	2010	GaAs HEMT, 0.5 μm	2.3	0.92	13.2	16	+37.0	0.39	12.9
This work	2012	GaAs HEMT, 0.25 μm	1.9	0.65	19.0	32	+38.9	0.51	15.6

[a]Simulated.
[b]Cascade of two amplifiers. NA = not available.

HIGH RESOLUTION

i2S® INTELLIGENT INTERACTIVE SYNTHESIZERS

MTS2500-110250-10

Output Frequency		1100 - 2500 MHz
Bandwidth		1400 MHz
External Reference		10 MHz
Step Size		Programmable to 1 Hz
Bias Voltage		+5 / +3.3 V
Output Power		+9 dBm (Min.)
Spurious Suppression		60 dB (Typ.)
Harmonic Suppression		15 dB (Typ.)
Typical Phase Noise	Offset	dBc/Hz.
	1 kHz	-93
	10 kHz	-95
	100 kHz	-110
Settling Time	Within 1 kHz	<22 mSec
	Within 10 Hz	<36 mSec
Operating Temperature Range		-20 to +70 ºC

MTS2500-200400-10

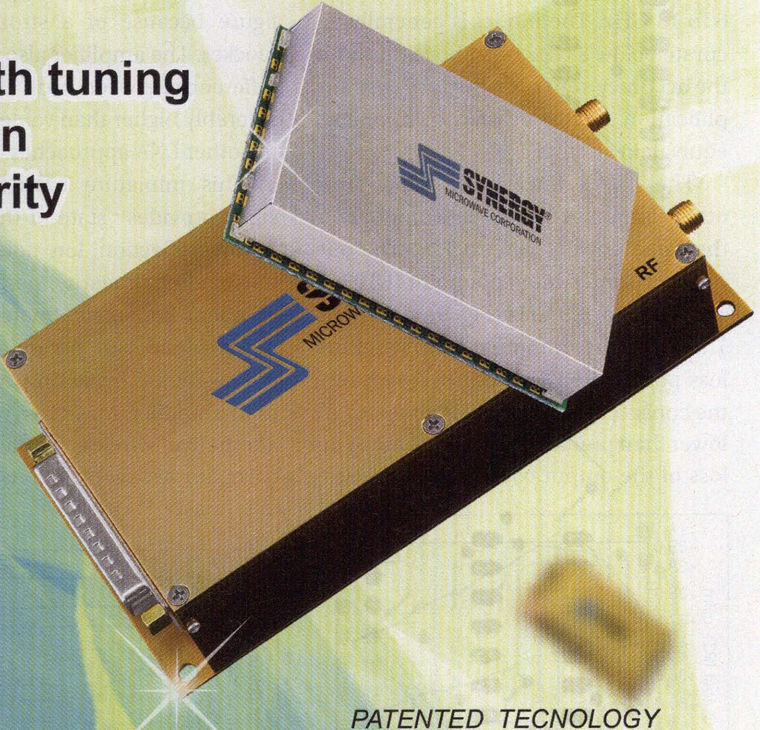
Output Frequency		2000 - 4000 MHz
Bandwidth		2000 MHz
External Reference		10 MHz
Step Size		Programmable to 1 Hz
Bias Voltage		+5 / +3.3 V
Output Power		+5.5 dBm (Min.)
Spurious Suppression		60 dB (Typ.)
Harmonic Suppression		10 dB (Typ.)
Typical Phase Noise	Offset	dBc/Hz.
	1 kHz	-88
	10 kHz	-87
	100 kHz	-100
Settling Time	Within 1 kHz	<10 mSec
	Within 10 Hz	<20 mSec
Operating Temperature Range		-20 to +70 ºC

MTS2500-300600-10

Output Frequency		3000 - 6000 MHz
Bandwidth		3000 MHz
External Reference		10 MHz
Step Size		Programmable to 1 Hz
Bias Voltage		+5 / +3.3 V
Output Power		+2 dBm (Min.)
Spurious Suppression		60 dB (Typ.)
Harmonic Suppression		20 dB (Typ.)
Typical Phase Noise	Offset	dBc/Hz.
	1 kHz	-87
	10 kHz	-83
	100 kHz	-108
Settling Time	Within 1 kHz	<6 mSec
	Within 10 Hz	<12 mSec
Operating Temperature Range		-20 to +70 ºC

Features

> Over an octave bandwidth tuning
> Small step size resolution
> Outstanding spectral purity
> High spurious rejection
> Fast lock settling time



Programming Interface:
-- 3.3V SPI (Standard)
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Also available in connectorized package with the following options.
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A balanced amplifier configuration **can also provide improved reliability, linearity, and bandwidth** compared to a single-ended amplifier, albeit while requiring twice the current and circuit components.

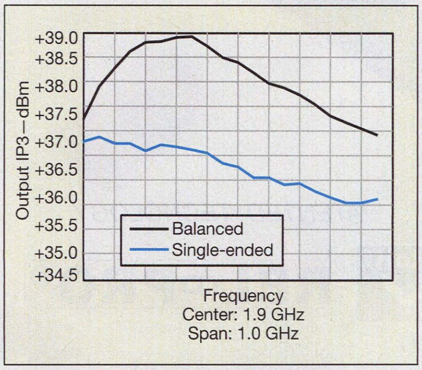
be bypassed to prevent detuning of any connected antenna and filter.

The balanced LNA is unconditionally stable even when its constituent amplifiers are not. The stability factor, μ, exceeds unity from 50 MHz to 20 GHz **(Fig. 8)** when modelled or measured. The balanced topology proves to be self-stabilizing even when modeled with unstable (μ < 1) individual amplifiers from 6 to 18 GHz. The model is generally accurate below 8 GHz but, above this limit, the accuracy suffers from gross oversimplification of the passive components' equivalent circuits.

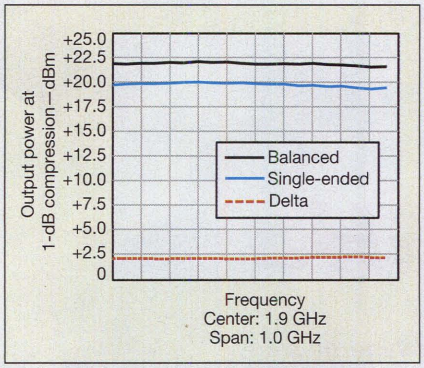
The LNA's linearity is superior to other amplifiers that consume about the same power, about 0.5 W. The output third-order-intercept point (OIP3) is +38.9 dBm at 1.9 GHz **(Fig. 9)**, peaking at 1.75 GHz, the minimum output-return-loss point. The OIP3 improvement over the constituent amplifiers is about 0.7 dB lower than predicted by theory due to the loss of the output coupler. The linearity figure of merit calculated from the ratio of the OIP3 to the DC power is 7.943/0.51 or approximately 15.6.

The balanced amplifier provides +22.4-dBm output power at 1-dB compression (P1dB) at 1.9 GHz. This is about 0.6 dB lower than a single-stage design theoretically due to the output coupler's loss **(Fig. 10)**. High P1dB provides better immunity to changes in gain and noise figure because of a strong interferer/blocker. The amplifier also has a 16.9-dB difference between P1dB and OIP3, considerably higher than values achieved by the other LNA approaches.

This miniature balanced LNA design provides state-of-the-art results for low reflection, low noise-figure, and outstanding linearity performance. Its excellent impedance matching in shutdown mode can potentially eliminate the need for bypassing the LNA. The dual-amplifier MMIC is well suited to alternative wireless applications, such as balun-less connections to balanced antennas.[18,19] MWRF



9. The output third-order-intercept performance for the balanced amplifier is considerably higher than for a single-stage amplifier across the same frequency range.



10. Output power at 1-dB compression remains flat across a 1-GHz bandwidth centered at 1.9 GHz.

ACKNOWLEDGMENTS

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ENSURE SUCCESS In SAW-Filter Choices

IN TODAY'S CROWDED RF spectrum, system designers must satisfy strict regulatory requirements without sacrificing performance. For filters, this translates into the need for high selectivity, low insertion loss, flat passbands, and uniform group delay. Filters also must be highly repeatable, small in size, and low in cost—all while potentially operating in adverse environmental conditions. Answering these needs are surface-acoustic-wave (SAW) filters, which can simplify RF designs as long as they are correctly specified. An overview of that specification process is provided in a white paper from Spectrum Microwave titled, "Specifying the Proper SAW Filter."

That four-page document begins by explaining that SAW filters depend on the mechanical properties of piezoelectric crystals. Through transducers that are deposited on the crystal, SAW devices convert an RF signal into a mechanical displacement. In doing so, they create a surface wave across the device. They then convert it back into an RF signal.

The filtering characteristics of SAW devices depend on the properties of the selected crystalline material, the length of total displacement, and the transducer's design, placement, and thickness. Thus, designers must consider a number of factors beyond center frequency and filter bandwidth. System operation will be affected by insertion loss, signal group delay, out-of-band rejection, and thermal stability. In addition, the allowable ripple must be specified for amplitude, phase, and group-delay responses.

The paper provides an example of a typical filter and discusses the issues that it may invite. For instance, the stop-band level is limited by the device's ability to dampen undesired vibrations. If a design requires greater rejection than what one filter provides, two or more SAW filters will have to be run in cascade.

Another key filter parameter is insertion loss, as these devices are passive. Thus, no internal amplification will compensate for the energy lost in piezoelectric coupling, which converts the signal between electrical and mechanical forms of energy. The magnitude of the insertion loss is mostly a function of filter bandwidth together with the crystalline bandwidth used. Yet material affects more than insertion loss. The note explores its effect on group delay, for example. It closes with a discussion of computer simulation and its benefits.

Spectrum Microwave, 324 Clark St., Worcester, MA 01606; (508) 852-5400, www.spectrummicrowave.com.

3D BEAMFORMING Bolsters Small Cells

SMALL WIRELESS-NETWORK CELLS are being deployed in growing numbers. For the most part, they are being used to provide capacity improvements in hot spots, where high subscriber densities overwhelm the macro cell. Compared to a macro cell, they provide lower output power in a lighter-weight, smaller form factor. In a recent study, NEC and Ubidyne partnered to investigate the benefits of three-dimensional (3D) -beamforming small cells with the use of active antenna technology. Titled "Enhanced Network Capacity and Coverage with 3D Beamforming Small Cells," the resulting 15-page white paper benchmarks passive small cells with active-beamforming small cells.

Active-beamforming small cells are expected to be an integral part of future Long Term Evolution (LTE)/fourth-generation (4G) heterogeneous networks (HetNets). Yet small cells still face major obstacles. Backhauling, for example, is becoming more challenging for operators in terms of transport network complexity, the variety of backhauling options, and their ability to find the optimal solution. In dense urban areas, however, the biggest problem faced by operators is probably site acquisition and maintenance.

Ubidyne GmbH, Magirusstr. 43, 89077 Ulm, Germany; +49 731 880071-0, www.ubidyne.com.

NEC Corp., 7-1, Shiba 5-chome, Minato-ku, Tokyo 108-8001, Japan, www.nec.com.

Some of these challenges may be addressed with the array or 3D beamforming small cell. According to the firms' study, 3D beamforming can lead to an average macro-cell load reduction (offloading) of 40%. An active 3D beamforming small cell comprises several antenna elements and transceivers, which are arranged in a matrix. Each antenna element has its own transceiver underneath it. A central controller and a baseband unit are located below the 4 × 4 transceiver matrix.

The antenna elements are spaced a fixed distance apart, relative to the wavelength of the transmitted and received signals. On the transmit side, signals from all transceiver elements superimpose to form a larger beam. That beam's shape can be changed simply by varying the phase and amplitude transmitted by each transceiver. Receive beamforming is done in similar fashion. Thus, the matrix enables flexible vertical and horizontal beamforming—including independent beam shaping in the downlink (DL) and uplink (UL). Multiple simultaneous beams per cell with individual tilt optimization per beam also can be applied, as can multiple beams for multi-sector operation.

According to the firms' investigations, 3D beamforming and individual tilt optimization for multi-beam, active small-cell antenna arrays outperform existing passive small-cell solutions. In addition to providing about 4X higher offloading, beamforming can help to improve coverage, reduce the number of small cells and backhauling requirements, and reduce inter-cell interference. These advantages lower the cost of site acquisition and network-wide power consumption while improving network optimization.

JACK BROWNE | Technical Contributor

Tiny Attenuators Set Levels

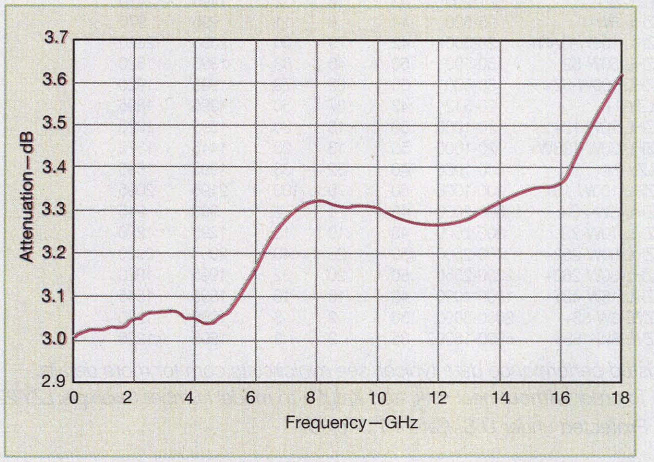
1. YAT-Series fixed attenuators are supplied in a tiny surface-mountable package measuring just 2 mm x 2 mm.

ATTENUATION HAS saved many systems and circuit designs, especially when it can be added in precise, consistent amounts. Attenuation comes in many forms and sizes, but perhaps few packages that are smaller than the new 2 × 2 mm chip-sized YAT-Series fixed attenuators from Mini-Circuits (www.minicircuits.com). Available in 1-dB increments from 0 through 10 dB, and with as much as 30-dB attenuation packed into that tiny housing, these attenuators are actually fabricated with an advanced semiconductor process for consistency.

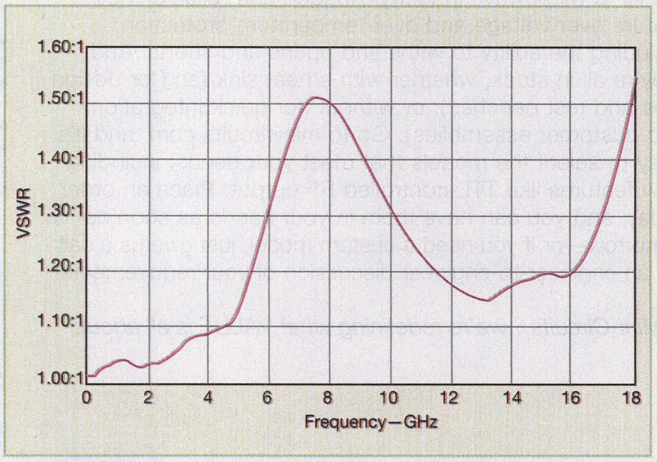
With a frequency range of DC to 18 GHz, the YAT-Series fixed attenuators can serve a wide range of commercial, industrial, and military applications, including cellular and wireless communications systems and in radar and electronic-warfare (EW) equipment. In spite of the size, the fixed attenuators can handle as much as 2 W (+33 dBm) power while still effectively dissipating any heat generated.

The YAT-Series attenuators **(Fig. 1)** are miniature 50-Ω passive components that can be added to a design to reduce signal levels, increase isolation between different sections, or improve impedance-match and return-loss performance. They are available in attenuation values through 30 dB, with minimal attenuation above and beyond their rated attenuation values.

The fixed attenuators are fabricated with a gallium-arsenide (GaAs) monolithic-microwave-integrated-circuit (MMIC) semiconductor process using thin-film resistors that exhibit consistent character-



2. As characterized in a CPW fixture, the attenuation for the YAT-3+ 3-dB fixed attenuator was measured from DC to 18 GHz.



3. The VSWR of the YAT-3+ fixed attenuator was measured from DC to 18 GHz.

These chip-sized precision attenuators include values from 0 to 30 dB in miniature 2 mm x 2 mm packages and usable across the broad frequency range from DC to 18 GHz.

To 18 GHz

istics over a wide temperature range. The YAT-Series fixed attenuators are designed to handle operating temperatures from –40 to +85°C with minimal variations in rated attenuation values over temperature and over frequency. In terms of attenuation as a function of temperature, attenuators of all types will exhibit increasing loss with frequency resulting in some increase above nominal rated attenuation value as frequency increases. The YAT-Series attenuators are no different **(see table)**, with slight increases above the nominal rated attenuation value for each model across the highest portion of the frequency range (15 to 18 GHz).

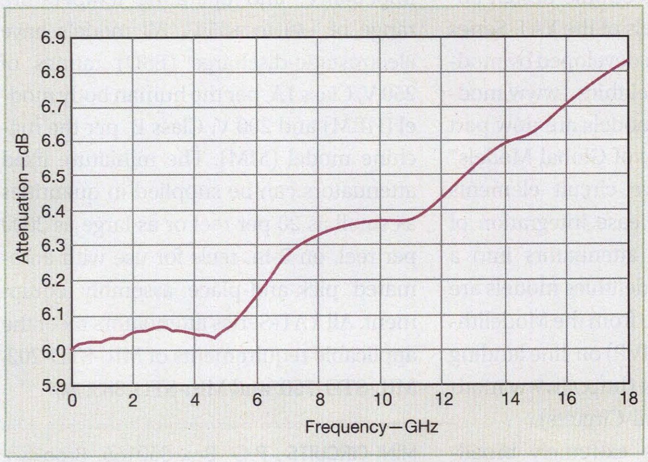
To achieve a maximum power rating of 2 W from DC to 18 GHz for such small passive devices, the YAT-Series attenuators were designed using sound thermal-management practices. To augment the dissipation of power though the silicon substrate material, the thin-film resistors used in the YAT-Series attenuators employ copper-metallized viaholes to create a reliable thermal path from the resistors to the MMIC ground plane and package base. Not only does the proper thermal management ensure good long-term reliability, but it also contributes to the consistent attenuation with temperature, frequency, and input power for the YAT-Series fixed attenuators.

In communications, radar, EW, and other broadband, high-frequency systems, it is often necessary to drop the power level at the input of an amplifier or decrease the output level of an oscillator, and one of the easiest level adjustments is simply to drop the signal levels at a critical point in a system or circuit by one-half the power. As a result, 3-dB attenuators are among the more popular attenuation values in high-frequency circuits and systems—including in test equipment—because of the simplicity of reducing the power level by one-half the known level.

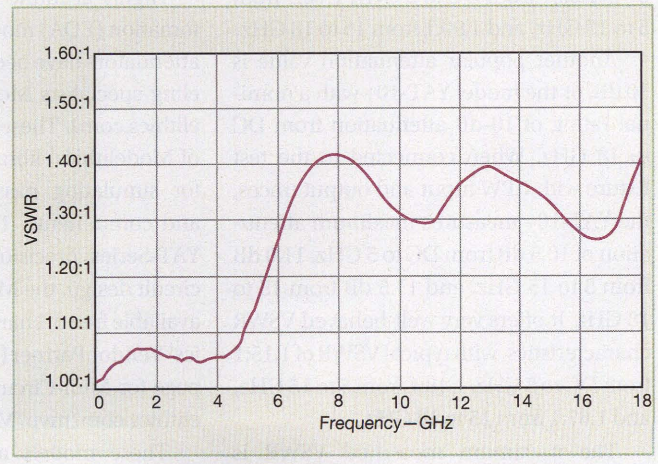
The YAT-3+ is a 3-dB attenuator that provides consistent attenuation across its wide DC-to-18-GHz frequency range at a cost ($2.99 each USD in quantity of 20) that will fit most budgets. When characterized at room temperature (+25°C) through swept-frequency measurements in a coplanar-waveguide (CPW) test fixture, it exhibits the expected trend of rising attenuation with frequency **(Fig. 2)**. The measured minimum attenuation for the model YAT-3+ fixed attenuator is 2.80 dB from DC to 5 GHz, 2.90 dB from 5 to 15 GHz, and 3.00 dB from 15 to 18 GHz.

The measured maximum attenuation for the YAT-3+ is 3.3 dB from DC to 5 GHz, 3.8 dB from 5 to 15 GHz, and 4.0 dB from 15 to 18 GHz. The YAT-3+ also maintains low VSWR across its operating frequency range **(Fig. 3)**, with typical VSWR of 1.15:1 from DC to 5 GHz, 1.48:1 from 5 to 15 GHz, and 1.54:1 from 15 to 18 GHz. It maintains maximum VSWR of 1.25:1 from DC to 5 GHz, 1.70:1 from 5 to 15 GHz, and 1.90:1 from 15 to 18 GHz.

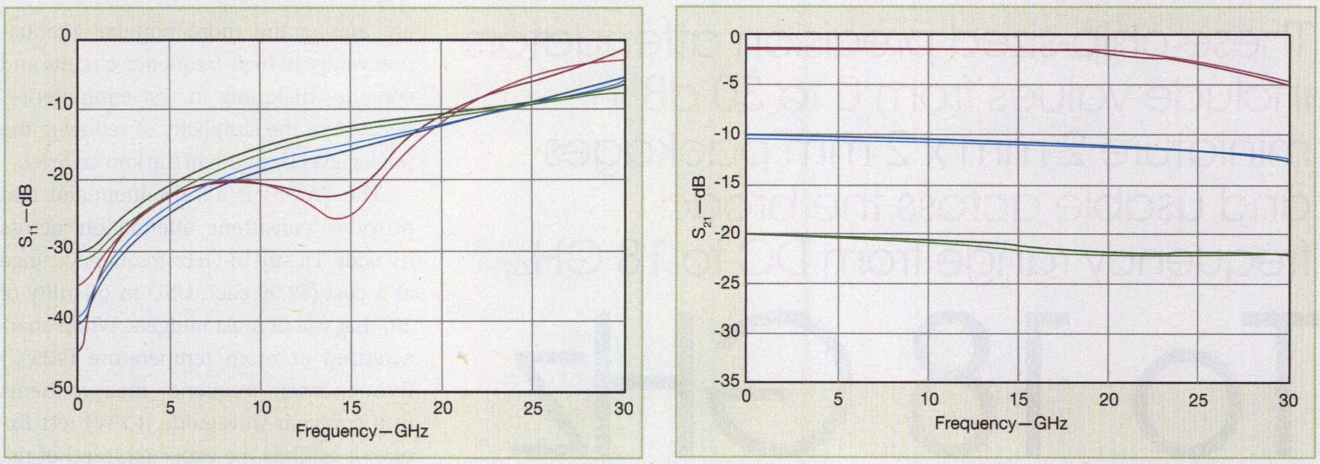
When more than a 3-dB drop in power is necessary, a 6-dB model such as the YAT-6+ can be very useful, allowing for a doubling in attenuation without occupying any more space in the design than the 3-dB attenuator. The YAT-6+ is rated for



4. Also characterized in the CPW fixture, the attenuation for the YAT-6+ 6-dB fixed attenuator was measured from DC to 18 GHz.



5. The VSWR of the YAT-6+ fixed attenuator was measured from DC to 18 GHz.



6. Free-of-charge simulation models available from Modelithics for the YAT-Series attenuators provide simulated S_{11} (left) and S_{21} (right) magnitude responses almost identical to measured performance through and above the specified upper-frequency range, as shown here for 1-, 10-, and 20-dB attenuators measured and modeled from DC to 30 GHz.

6-dB attenuation from DC to 18 GHz, with attenuation that remains extremely flat at the lower frequencies. It only exhibits the expected increase in attenuation with frequency above about 6 GHz (**Fig. 4**).

When characterized at room temperature with the CPW test fixture, the YAT-6+ demonstrated measured minimum attenuation of 5.6 dB from DC to 5 GHz, 5.8 dB from 5 to 15 GHz, and 6.0 dB from 15 to 18 GHz. The measured maximum attenuation for the YAT-6+ is 6.4 dB from DC to 5 GHz, 6.9 dB from 5 to 15 GHz, and 7.3 dB from 15 to 18 GHz. The typical VSWR for the YAT-6+ fixed attenuator (**Fig. 5**) is 1.15:1 from DC to 5 GHz, 1.42:1 from 5 to 15 GHz, and 1.50:1 from 15 to 18 GHz. The YAT-3+, the maximum VSWR for the YAT-6+ is 1.25:1 from DC to 5 GHz, 1.70:1 from 5 to 15 GHz, and 1.90:1 from 15 to 18 GHz.

Another popular attenuation value is 10 dB, or the model YAT-10+ with a nominal rating of 10-dB attenuation from DC to 18 GHz. When connected to the test fixture with CPW input and output traces, the YAT-10+ measures maximum attenuation of 10.5 dB from DC to 5 GHz, 11.0 dB from 5 to 15 GHz, and 11.5 dB from 15 to 18 GHz. It offers very well-behaved VSWR characteristics, with typical VSWR of 1.15:1 from DC to 5 GHz, 1.48:1 from 5 to 15 GHz, and 1.67:1 from 15 to 18 GHz.

The maximum measured VSWR is 1.25:1 from DC to 5 GHz, 1.70:1 from 5 to 15 GHz, and 1.90:1 from 15 to 18 GHz. This makes the YAT-10+, as with all of the YAT-Series fixed attenuators, an excellent choice for broadband impedance-matching applications.

One of the more intriguing models is the 0-dB YAT-0+ fixed attenuator. In theory, boasting a 0-dB attenuator helps improve isolation and impedance match in a circuit or system without significant penalty in signal loss. For broadband applications, it is vital that such an attenuator maintains consistent electrical characteristics across frequency and temperature. The YAT-0+ attenuators exhibit some increase in insertion loss with frequency, with maximum attenuation of 0.2 dB from DC to 5 GHz, 0.4 dB from 5 to 15 GHz, and 0.5 dB from 15 to 18 GHz..

Highly accurate electronic-design-automation (EDA) models of the YAT-Series attenuators have been developed by modeling specialists Modelithics (www.modelithics.com). These models are now part of Modelithics' library of Global Models™ for simulating passive circuit elements and components. To ease integration of YAT-Series precision attenuators into a circuit design, the Modelithics models are available free of charge from the Modelithics' Vendor Partner (MVP) on-line landing page for Mini-Circuits (http://www.modelithics.com/mvp/Mini-Circuits).

These models are extremely broadband, covering DC to 30 GHz, with modeled S_{11} and S_{21} characteristics almost identical to measured responses for all attenuation values (**Fig. 6**). These YAT-Series attenuator models include dielectric and ground effects for popular circuit materials—such as RO4350B™ laminates from Rogers Corp. (www.rogerscorp.com)—and are designed to simulate the behavior of the attenuators in microstrip and grounded coplanar-waveguide (CPW) applications. The attenuator models are currently available for the Advanced Design System (ADS) software from Agilent Technologies (www.agilent.com) and Microwave Office from AWR Corp. (www.awrcorp.com).

The YAT-Series fixed attenuators all feature a maximum power rating of 2 W, a small size of 2 × 2 mm, 50-Ω characteristic impedance, and operating temperature range of –40 to +85°C. All models have electrostatic-discharge (ESD) ratings of 250 V, Class 1A, per the human body model (HBM) and 200 V, Class B, per the machine model (MM). The miniature fixed attenuators can be supplied in quantities as small as 20 per reel or as large as 2000 per reel, on 7-in. reels for use with automated pick-and-place assembly equipment. All YAT-Series attenuators meet the applicable requirements of MIL-STD-202, MIL-STD-750, and MIL-STD-883. MWRF

MINI-CIRCUITS., P.O. Box 350166, Brooklyn, NY 11235-0003; (718) 934-4500, FAX: (71) 332-4661, www.minicircuits.com.

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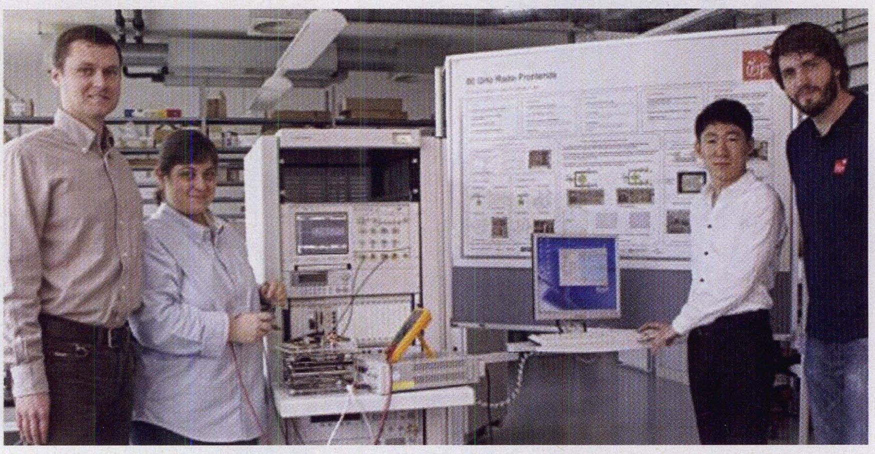
ISM Applications Seek Higher Frequencies

Low-cost wireless applications have flourished in ISM bands below 6 GHz, but video and high-data-rate communications requirements are pushing ISM products into the millimeter-wave range.

UNLICENSED WIRELESS communications and uses for RF/microwave signals that do not require licensing have long appealed to developers of cost-sensitive applications. Around the world, government organizations set aside bands of frequencies for "free," unlicensed use, with some rules to help minimize interference between different applications in the same frequency range. These open frequencies are known as the industrial-scientific-medical (ISM) bands, since they were initially set aside for such applications as microwave heating and medical diathermy.

Any products that are developed and added to the ISM bands must be tolerant of the emissions from legacy applications. For RF/microwave hardware suppliers, the ISM bands around the world provide excellent opportunities for all of the components needed to assembly communications systems.

Various organizations around the world help regulate the use of frequencies in the various ISM bands. In the United States, the Federal Communications Commission (FCC; www.fcc.gov) is the regulating agency, with Part 18 of the FCC rules governing the uses of designated ISM bands in the US and Part 15 impacting unlicensed communications devices in those ISM bands. In other parts of the world, the International Telecommunication Union (ITU; www.itu.int) sets guidelines for designated ISM bands according to ITU Radio Regulations 5.138, 5.150, and 5.280 and any appropriate national regulations in the affected area. The ITU's ISM bands reach well into the millimeter-wave frequency range, with ITU ISM bands that include 902 to 928 MHz, 2.4 to 2.5 GHz, 5.725 to 5.875 GHz, 24.00 to 24.25 GHz, 61.0 to 61.5 GHz, 122 to 123 GHz, and 244 to 246 GHz.



Standing in front of a large poster of 60-GHz radio fundamentals, this design team is creating ISM applications for high-speed data and video streaming at millimeter-wave frequencies. [Photo courtesy of IHF Microelectronics (www.ihf-microelectronics.com).]

In the US, three of the more popular ISM bands governed by the FCC Part 15 rules are 902 to 928 MHz, 2.400 to 2.4835 GHz, and 5.725 to 5.875 GHz. The Part 15 rules establish such operating parameters as maximum transmit power. The maximum transmit power that can be fed to the antenna within these frequency bands is +3 dBm (1 W). The maximum effective isotropic radiated power (EIRP) is +36 dBm (4 W). The EIRP value can be determined by adding the transmit output power (in dBm) to the antenna gain (in dBi). Any loss from the cable feeding the antenna must be subtracted.

ISM bands are often associated with lower-frequency applications, such as 900-MHz cordless telephones, near-field communications (NFC) devices, or 2.4-GHz Bluetooth devices. The aforementioned microwave oven, for example, coexists with numerous communications devices at or near that frequency band, including wireless local area networks (WLANs), wireless sensor networks, and cordless telephones. The number of manufacturers supporting these applications with a variety of components, including antennas, amplifiers, and radio-frequency integrated circuits (RFICs), is already quite large, making the market for lower-frequency ISM-and components extremely competitive.

By way of example: Several years ago, RF Micro Devices (www.rfmd.com) introduced its model RF3858 front-end module for ISM applications in the 900-MHz band. Priced at less than $2.50 USD in 10,000 piece quantities, the RF3858 contains a power amplifier, transmit/receive transfer switch, low-noise amplifier (LNA), and matching components. Designed to reduce the number of parts in an ISM product, the module includes a power amplifier that can deliver +31.5-dBm output power at 915 MHz, while the low-noise amplifier provides 27-dB gain with 1.3-dB noise figure. Not long ago, either of these amplifiers would be difficult to find for that price as a separate component.

OPPORTUNITY KNOCKS

Adoption of higher-frequency ISM bands may open some opportunities for companies with millimeter-wave engineering capabilities. The ITU's designation of several millimeter-wave frequency bands for ISM use, for example, presents an opportunity for development of short-range communications links and high-speed data links for computer networks by taking advantage of the wide available bandwidths at those millimeter-wave ISM frequencies.

One company, Hittite Microwave Corp. (www.hittite.com), has already seized the opportunity for a millimeter-wave ISM-band transceiver solution with their HMC6000LP711E transmitter and HMC6001LP711E receiver silicon-germanium (SiGe) chipset for 60-GHz short-range ISM applications. These antenna-in-package (AiP) ICs combine SiGe chips built around frequency synthesizers with 60-GHz antennas in 7 × 11 mm QFN plastic packages for low-cost, surface-mount printed-circuit-board (PCB) assembly. The devices require no special PCB fabrication measures and knowledge of handling millimeter-wave components. Hittite also offers a complete AiP transceiver evaluation kit, model EKIT01-HMC6450, with both ICs, configuration software, and everything needed to build a bidirectional millimeter-wave link at 60 GHz with a range of 4 m. A universal analog in-phase (I) and quadrature (Q) interface translates baseband analog I and Q signals with single-sideband (SSB) bandwidth to 880 MHz to and from the 60-GHz ISM band.

For international equipment suppliers considering higher-frequency ISM applications, Frankfurt, Germany-based IHP-Microelectronics (www.ihp-microelectronics.com) offers circuit-prototyping services for communications and other applications at 60 GHz and other ISM millimeter-wave frequencies. The firm has already fabricated and successfully tested radio transmitter and receiver front ends for ISM applications at frequencies as high as 245 GHz, as well as a complete radio front-end device capable of data rates to 4 Gb/s at 60 GHz. The 60-GHz demonstration circuit **(see figure)** was developed nominally for video streaming applications.

The firm is also developing a silicon-based system-on-chip (SoC) radio device for use in the 122-to-123-GHz ISM band. The SoC employs a direct-down-conversion transceiver architecture and is suitable for short-range distance and speed sensing.

As ISM applications extend from lower frequencies through millimeter-wave bands, demand grows for some of the pieces needed to build these final ISM products [including printed-circuit-board (PCB) materials and antennas]. At higher frequencies, circuit materials should provide good dielectric stability with temperature, and typically require a different physical makeup. For applications extending to 60 GHz and beyond, PCB materials should be thinner than at lower frequencies, with a typical rule of thumb calling for dielectric PCB materials that are about one-eighth the measure of the wavelength of the frequency of interest. Similarly, the copper conductor on these PCB materials should be thinner at these higher frequencies, with minimal copper roughness to trim circuit losses at millimeter-wave frequencies.

As examples, Taconic Advanced Dielectric Division (ADD; www.taconic-add.com) has developed its TacLamPLUS PCB material for millimeter-wave applications. The non-reinforced substrate material is a cost-effective building material for higher-frequency ISM-band circuits, with typical thickness of 100 μm. It features a dielectric constant of 2.10 in the z-direction at 50 GHz and dissipation factor of 0.0008 at 50 GHz.

Similarly, the RT/duroid® 5870 and 5880 PCB materials from Rogers Corp. (www.rogerscorp.com) offer the mechanical and electrical characteristics that suit ISM applications at higher millimeter-wave frequencies. These polytetrafluoroethylene (PTFE) composites are reinforced with glass microfibers to provide good dielectric stability, and the materials exhibit low values of dielectric constant: 2.33 for RT/duroid 5870 in the z-direction (thickness) at 10 GHz and 2.20 for RT/duroid 5880 in the z-direction at 10 GHz. The materials have dissipation factors of 0.0012 or less at 10 GHz.

Millimeter-wave signals tend to provide shorter-distance communications links than their lower-frequency counterparts, due to atmospheric losses, but they also offer wide available bandwidths for high-speed data and video services. Certainly, as the demand for these higher-frequency ISM bands grow, the supply of components and such needed building blocks as PCB boards will grow—and their prices will drop accordingly. MWRF

Spectrum Analyzers Reach 26.5 GHz

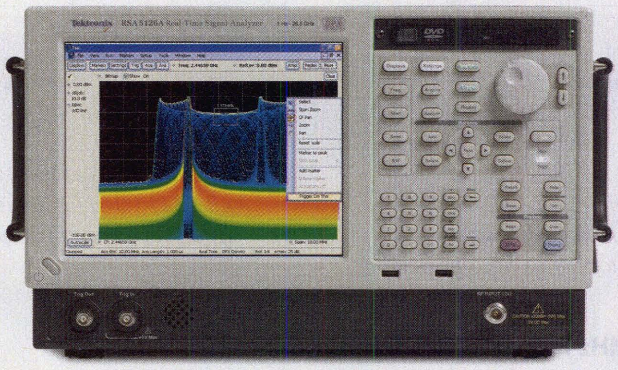
Two instruments with top frequencies of 15.0 and 26.5 GHz have been added to a popular line of real-time spectrum analyzers, targeting the capture and analysis of complex RF/microwave signals.

REAL-TIME SPECTRUM analyzers (RSAs) are designed to let no signal pass—they provide the measurement capabilities to capture the most dynamic signals. And for those with test needs through 26.5 GHz, one of the best known lines of RSAs—the RSA5000 Series from Tektronix (www.tek.com)—has recently been expanded with analyzers for use from 1 Hz to 15.0 GHz and 1 Hz to 26.5 GHz. Known respectively as models RSA5115A and RSA5126A, these analyzers can be specified with acquisition bandwidths as wide as 110 MHz to capture the most complex modulated signals.

Both new models **(see figure)** feature a computer-like control panel and full-color display screen. They are available with a wide range of options and capabilities, including acquisition bandwidths of 25, 40, 85, and 110 MHz; versatile triggering functions; and preamplifiers. Both new analyzers can trigger on power, runt signals, signal density, frequency, and—as an option—specific frequency masks.

The instruments show results on the firm's DPX® spectrum display with live color view of signals changing over time in the frequency domain. The DPX display can also be used as part of a DPX Density™ trigger, which works on the measured frequency of occurrence of an event or the density of the DPX display. A Trigger On This™ function allows an operator to point an on-screen cursor at a signal of interest on the DPX display and automatically set a trigger level to capture signals below the measured density level.

Both analyzers can capture very low-level signals in the presence of much higher-level signals. Minimum event capture durations are 30.7 μs for a 25-MHz acquisition bandwidth, 11.4 μs for a 40-MHz acquisition bandwidth, and 3.7 μs for an 85- or 110-MHz acquisition bandwidth. Trigger position timing uncertainties are minimal for the Frequency Mask Trigger: only ±20 ns for a 25-MHz acquisition bandwidth, ±15 ns for a 40-MHz acquisition bandwidth, and ±12 ns for an 85- or 110-MHz acquisition bandwidth.



Model RSA5126A, with a measurement range of 1 Hz to 26.5 GHz, is a new addition to the RSA5000 Series of real-time spectrum analyzers (RSAs) from Tektronix (www.tek.com).

Both RSAs feature wide amplitude measurement ranges. They exhibit a displayed average noise level (DANL) of –155 dBm/Hz at 2 GHz and –142 dBm/Hz at 26.5 GHz, coupled with a high third-order-intercept (TOI) point of +17 dBm at 2 GHz for both analyzers. The instruments include options for an internal preamplifier capable of providing a DANL of –167 dBm/Hz at 1 GHz and –156 dBm/Hz at 26.5 GHz. They offer excellent amplitude characteristics, with frequency responses of ±1.0 dB from 1 Hz to 15 GHz and ±1.2 dB from 1 Hz to 26.5 GHz, when measured with 10-dB attenuation and no preamplifier. The absolute amplitude accuracy at a measurement center frequency, with 95% confidence, is ±1.5 dB from 1 Hz to 15 GHz and ±1.8 dB from 1 Hz to 26.5 GHz.

Both RSAs operate from an internal 10-MHz frequency reference oscillator and can also work with an external 10-MHz reference source. Both instruments can perform high-speed sweeps, such as across 1 GHz, with a 10-kHz resolution bandwidth filter in less than 1 s. They offer resolution-bandwidth (RBW) filters from 0.1 Hz to 5 MHz, with an option for 10 MHz, and video-bandwidth filters from 1 Hz to 5 MHz.

The RSAs, which are ideal for communications, radar, and even electronic-warfare (EW) signal analysis, can acquire more than 7 s signal time with a 110-MHz acquisition bandwidth. The instruments are available with a wide range of options and can perform any number of programmable measurements. P&A: $47,900 and up (USD, 26.5-GHz model).—*JB*

TEKTRONIX, INC., 14150 SW Karl Braun Dr., P.O. Box 500, Beaverton, OR 97077; *www.tek.com.*

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POWER DIVIDERS RoHS

Model #	Frequency (MHz)	Insertion Loss (dB) [Typ./Max.] ◊	Amplitude Unbalance (dB) [Typ./Max.]	Phase Unbalance (Deg.) [Typ./Max.]	Isolation (dB) [Typ./Min.]	VSWR (Typ)	Input Power (Watts) [Max.] ▫	Package
2-WAY								
CSBK260S	20 - 600	0.28 / 0.4	0.05 / 0.4	0.8 / 3	25 / 20	1.15:1	50	377
DSK-729S	800 - 2200	0.5 / 0.8	0.05 / 0.4	1 / 2	25 / 20	1.3:1	10	215
DSK-H3N	800 - 2400	0.5 / 0.8	0.25 / 0.5	1 / 4	23 / 18	1.5:1	30	220
P2D100800	1000 - 8000	0.6 / 1.1	0.05 / 0.2	1 / 2	28 / 22	1.2:1	5	329
DSK100800	1000 - 8000	0.6 / 1.1	0.05 / 0.2	1 / 2	28 / 22	1.2:1	20	330
DHK-H1N	1700 - 2200	0.3 / 0.4	0.1 / 0.3	1 / 3	20 / 18	1.3:1	100	220
P2D180900L	1800 - 9000	0.4 / 0.8	0.05 / 0.2	1 / 2	27 / 23	1.2:1	5	331
DSK180900	1800 - 9000	0.4 / 0.8	0.05 / 0.2	1 / 2	27 / 23	1.2:1	20	330
3-WAY								
S3D1723	1700 - 2300	0.2 / 0.35	0.3 / 0.6	2 / 3	22 / 16	1.3:1	5	316

◊ In excess of theoretical split loss of 3.0 dB
▫ With matched operating conditions

HYBRIDS RoHS

Model #	Frequency (MHz)	Insertion Loss (dB) [Typ./Max.] ◊	Amplitude Unbalance (dB) [Typ./Max.]	Phase Unbalance (Deg.) [Typ./Max.]	Isolation (dB) [Typ./Min.]	VSWR (Typ)	Input Power (Watts) [Max.]	Package
90°								
DQS-30-90	30 - 90	0.3 / 0.6	0.8 / 1.2	1 / 3	23 / 18	1.35:1	25	102SLF
DQS-3-11-10	30 - 110	0.5 / 0.8	0.6 / 0.9	1 / 3	30 / 20	1.30:1	10	102SLF
DQS-30-450	30 - 450	1.2 / 1.7	1 / 1.5	4 / 6	23 / 18	1.40:1	5	102SLF
CSDK3100S	30 - 1000	0.8 / 1.2	0.05 / 0.2	0.2 / 3	25 / 18	1.15:1	50	378
DQS-118-174	118 - 174	0.3 / 0.6	0.4 / 1	1 / 3	23 / 18	1.35:1	25	102SLF
DQK80300	800 - 3000	0.2 / 0.4	0.5 / 0.8	2 / 5	20 / 18	1.30:1	40	113LF
MSQ80300	800 - 3000	0.2 / 0.4	0.5 / 0.8	2 / 5	20 / 18	1.30:1	40	325
DQK100800	1000 - 8000	0.8 / 1.6	1 / 1.6	1 / 4	22 / 20	1.20:1	40	326
MSQ100800	1000 - 8000	0.8 / 1.6	1 / 1.6	1 / 4	22 / 20	1.20:1	40	346
MSQ-8012	800 - 1200	0.2 / 0.3	0.2 / 0.4	2 / 3	22 / 18	1.20:1	50	226
180° (4-PORTS)								
DJS-345	30 - 450	0.75 / 1.2	0.3 / 0.8	2.5 / 4	23 / 18	1.25:1	5	301LF-1

◊ In excess of theoretical coupling loss of 3.0 dB

COUPLERS RoHS

Model #	Frequency (MHz)	Coupling (dB) [Nom]	Coupling Flatness (dB)	Mainline Loss (dB) [Typ./Max.]	Directivity (dB) [Typ./Min.]	Input Power (Watts) [Max.] ▫	Package
KDS-30-30	30 - 512	27.5 ±0.8	±0.75	0.2 / 0.28	23 / 15	50	255 *
KFK-10-1200	10 - 1200	40 ±0.75	±1.0	0.4 / 0.5	22 / 15	150	376
KBS-10-225	225 - 400	10.5 ±1.0	±0.5	0.6 / 0.7	25 / 18	50	255 *
KDS-20-225	225 - 400	20 ±1.0	±0.5	0.2 / 0.4	25 / 18	50	255 *
KBK-10-225N	225 - 400	10.5 ±1.0	±0.5	0.6 / 0.7	25 / 18	50	110N *
KDK-20-225N	225 - 400	20 ±1.0	±0.5	0.2 / 0.4	25 / 18	50	110N *
KEK-704H	850 - 960	30 ±0.75	±0.25	0.08 / 0.2	38 / 30	500	207
SCS100800-10	1000 - 8000	10.5 ±1.5	±2.0	1.2 / 1.8	8 / 5	25	361
KBK100800-10	1000 - 8000	10.5 ±1.5	±2.0	1.2 / 1.8	8 / 5	25	322
SCS100800-16	1000 - 7800	16.8 ±1.5	±2.8	0.7 / 1	14 / 5	25	321
KDK100800-16	1000 - 7800	16.8 ±1.5	±2.8	0.7 / 1	14 / 5	25	322
SCS100800-20	1000 - 7800	20.5 ±2.0	±2.0	0.45 / 0.75	12 / 5	25	321
KDK100800-20	1000 - 7800	20.5 ±2.0	±2.0	0.45 / 0.75	14 / 5	25	322

* Add suffix - LF to the part number for RoHS compliant version.
▫ With matched operating conditions

Unless noted, products are RoHS compliant.

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YIG Oscillators Fit Surface-Mount Packs

Based on permanent-magnetic YIG resonators, these low-noise oscillators provide broadband frequency tuning from 2 to 13 GHz in compact housings.

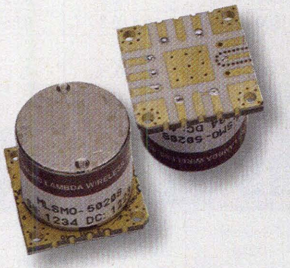
YTTRIUM-IRON-GARNET (YIG) oscillators are renowned in the RF/microwave frequency industry for their linear tuning and superb spectral purity over wide frequency ranges. But the tradeoff for this performance has traditionally been housing size, with YIG oscillators requiring large, round packages to hold their magnetic components. That has changed dramatically, however, with a new line of surface-mount models from Micro Lambda Wireless (www.microlambdawireless.com).

The firm's new MLSMO-Series permanent-magnet YIG-tuned oscillators are supplied in tiny TO-8 surface-mount packages only 0.50 in. high. The oscillators feature silicon-germanium (SiGe) active devices to achieve low-noise output levels. They are available in portions of the frequency range from 2 to 13 GHz with at least +8 dBm output power across their tuning ranges, and with outstanding spectral purity.

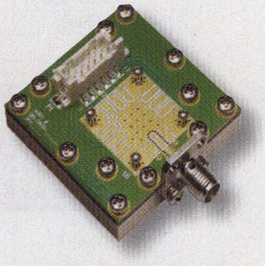
The MLSMO-Series TO-8 YIG oscillators **(Fig. 1)** are available in octave and multi-octave frequency tuning ranges, such as the 3-to-6-GHz model MLSMO-50306 and the 3-to-8-GHz model MLSMO-50308. Both provide minimum output power of +8 dBm across their tuning ranges, with minimum harmonics of –15 dBc and spurious content of –70 dBc. The worst-case phase noise for either oscillator is –103 dBc/Hz offset 10 kHz from the carrier and –128 dBc/Hz offset 100 kHz from the carrier. Both YIG oscillators are rated for worst-case frequency drift of ±10 MHz for a standard operating-temperature range of 0 to +65°C. Extended-temperature models for use from –40 to +85°C are also available.

At higher frequencies **(see table)**, model MLSMO-50409 tunes from 4.0 to 9.0 GHz while model MLSMO-50613 covers a full octave from 6.5 to 13.0 GHz, both with +8-dBm minimum output power across their tuning ranges. Both exhibit –12 dBc minimum harmonic levels and –70 dBc minimum spurious levels. The lower-frequency model has worst-case phase noise of –103 dBc/Hz offset 10 kHz from the carrier and –128 dBc/Hz offset 100 kHz from the carrier, while the higher-frequency source has minimum phase noise of –124 dBc/Hz offset 10 kHz from the carrier and -98 dBc/Hz offset 100 kHz from the carrier.

All MLSMO-Series TO-8 YIG oscillator models measure 0.7 x 0.7 x 0.562 in. A coaxial test fixture is available with SMA connector to simplify testing these sources **(Fig. 2)**. All surface-mount YIG oscillators have main coil tuning sensitivity of 9.7 MHz/mA and frequency-modulation (FM) coil sensitivity of 300 kHz/mA to control a typical 3-dB FM bandwidth of 1 MHz with ±50-MHz FM deviation. They have typical power requirements of 60 mA at +8 VDC and 15 mA at –5 VDC.



1. The MLSMO-Series permanent-magnet YIG oscillators are supplied in miniature TO-8 housings measuring just 0.7 x 0.7 x 0.562 in.



2. A coaxial test fixture is available to simplify setup and tuning of the MLSMO-Series surface-mount YIG oscillators.

The compact YIG oscillators suffer worst-case output-power variations of 4 dB across their frequency tuning ranges, with typical pulling of 2 MHz into a 12-dB return-loss load and typical pushing of 2 MHz/V for a +8 VDC supply. The MLSMO-Series oscillators are available in RoHS-compliant versions.—*JB*

The MLSMO-Series Surface-Mount YIG Oscillators At A Glance.

Model	Frequency range	Output power	Phase noise offset 100 kHz
MLSMO-50204	2 to 4 GHz	+8 dBm	-128 dBc/Hz
MLSMO-50306	3 to 6 GHz	+8 dBm	-128 dBc/Hz
MLSMO-50308	3 to 8 GHz	+8 dBm	-128 dBc/Hz
MLSMO-50409	4 to 9 GHz	+8 dBm	-128 dBc/Hz
MLSMO-50613	6.5 to 13.0 GHz	+8 dBm	-124 dBc/Hz

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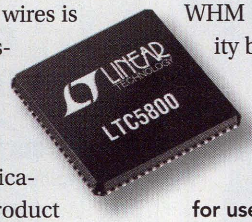
SoCs Power Wireless Sensor Networks

These highly integrated SoCs and controller modules provide the intelligence and smart power management for reliable data communications in wireless sensor networks.

ELECTRONIC SENSORS are everywhere, monitoring and controlling temperature, power, fluid levels, and other variables. Integrated-circuit (IC) sensors continue to be made smaller and less expensive, but the cost of installing such sensors with wires is still high. For that reason, using sensors as part of a wireless sensor network (WSN) makes a great deal of sense.

In support of WSN applications, the Dust Networks® product group of Linear Technology Corp. (www.linear.com) has announced its SmartMesh® WirelessHART™ LTC5800-WHM WSN system-on-chip (SoC) wireless sensor device and its LPT5903-WHR network manager, all based on the IEEE 802.15.4 wireless standard. In spite of the extremely low current consumption for each SoC, these devices and modules combine for highly reliable wireless data exchanges for monitoring and control. They use direct-sequence-spread-spectrum (DSSS) and channel-hopping communications techniques from 2.4000 to 2.4835 GHz.

The SoCs and modules employ the SmartMesh™ wireless sensor technology developed by Dust Networks (www.linear.com/products/wireless_sensor_networks), a company acquired by Linear Technology in December 2011. A SmartMesh WSN is formed of nodes, or "motes," which gather and relay data, and a network manager. The latter monitors and manages the data from the motes and sends it to a host application, such as a vehicular controller in an automobile. A SmartMesh network makes use of time, frequency, and spatial diversity techniques to achieve ease of use with the lowest power consumption possible.



The LTC5800-WHM SoC is designed for use in low-power wireless sensor networks at 2.4 GHz.

An LTC5800-WHM is actually a WSN mote within an SoC. Each LTC5800-WHM incorporates WSN capability based on Dust Networks' Eterna™ IEEE 802.15.4e-compliant SoC technology in a compact 72-pin 10 x 10 mm QFN package (**see figure**). The IEEE 802.15.4 standard defines a physical layer (PHY) and medium access control (MAC) layer for short-range, low-power operation at low data rates (to 250 kb/s) and small packets (less than 128 bytes). Each SoC contains full wireless radio components, requiring only a decoupling capacitor and connection to an antenna to become part of a WSN. The LTC5800-WHM features single-ended transmit and receive paths, which allows direct connection to a single-ended 50-Ω antenna. The SoC is powered by a single pin connection and has two on-chip DC/DC converters to generate on-chip supplies and conserve energy use. It can be used within line-powered, battery-powered, or energy-harvested applications.

To conserve power while ensuring reliable network communications, these devices incorporate the aforementioned SmartMesh technology. Within a WSN, every mote works like a router, and can run for as long as 10 years on a battery supply or draw power by means of harvesting. The WSN formed with these devices is a self-forming, self-healing mesh that uses path diversity and per transmission channel hopping for high reliability. These SmartMesh motes are controlled and coordinated for efficient channel hopping, using multiple transmissions to optimize available bandwidth. The devices operate by means of a time-synchronized mesh protocol (TSMP) compatible with the IEEE 802.15.4 standard. It works by dividing time into slots and providing a mechanism to map timeslots to channels with a pre-assigned hopping sequence.

The LTC5800-WHM SoC has a recommended supply range of +2.1 to +3.76 VDC. It operates across a frequency range of 2.4000 to 2.4835 GHz using 15 channels and 5-MHz channel separation. The SoC provides a raw data rate of 250 kb/s. It can handle RF input levels as high as +10 dBm and operates with antennas representing a mismatch of a VSWR as high as 3.0:1.

The SoC has an operating temperature range of –40 to +85°C. The LTC5800-WHM can be integrated directly onto a customer's printed-circuit board (PCB), and is also available in two FCC-certified modules: the LTP5901-WHM PCBA module (which measures 42 x 24 mm), and LTP5902-WHM PCBA module (which is 37.5 x 24 mm).*—JB*

LINEAR TECHNOLOGY CORP., 1530 McCarthy Blvd., Milpitas, CA 95035-7417; (800) 4-LINEAR, (408) 432-1900, *www.linear.com.*

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Teledyne's A3CP6025 Broadband Amplifier
0.01 to 6.0 GHz. Gain is 24 dB typical, output power is +25 dBm, 3rd order intercept +34 dBm. Reverse isolation -50dB. Operates on 15 VDC, 300 mA.
Broadband Amplifiers
Teledyne's ACP20015 Ultra-Broadband Amplifier
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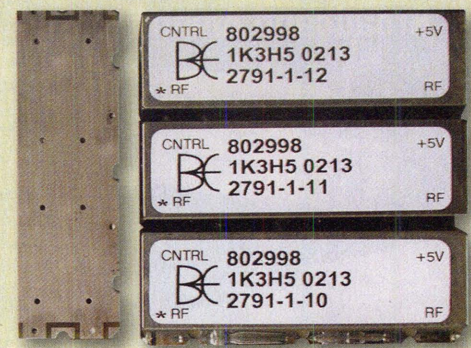
Compact Switched Filters Hit 8 GHz

A line of switched filter banks from Bree Engineering serves applications through 8 GHz. Measuring just 1.5 × 0.5 × 0.4 in. in surface-mount packages, these low-loss, multiple-channel switched filters feature TTL control and operate on +5-VDC bias with 0/+5-VDC control voltage. As an example, model P/N 802998 is a switched filter bank for Global Positioning System (GPS) applications. Designed for GPS bands L1 and L2, it minimizes passband insertion loss to 1 dB for GPS L1 passband from 1562 to 1585 MHz and to only 1 dB for GPS L2 passband from 1214 to 1237 MHz, with better than 14-dB return loss for both filter passbands.



The switched filter provides at least 30-dB rejection of signals outside the GPS L1 passband, at 1425 MHz and below and 1800 MHz and above. It also delivers high rejection of unwanted signals outside GPS band L2, with better than 30-dB rejection at 1170 MHz and below and better than 30-dB rejection at 1370 MHz and above. In addition to this GPS switch filter, Bree Engineering can design and deliver filters and switch filter assemblies according to a customer's specific requirements.

BREE ENGINEERING CORP., 1275 Stone Dr., San Marcos, CA 92078; (760) 510-4650, FAX: (760) 510-4959, e-mail: sales@breeeng.com, ***www.breeeng.com.***

Tube Amplifier Powers Ku-Band Systems

Suited for satellite communications (satcom) and satellite-news-gathering (SNG) applications, model MT2400 is a traveling-wave-tube (TWT) amplifier from MITEQ/MCL designed for outdoor installations. Supplied in a compact, light-weight, weather-resistant package, the TWT amplifier is available for Ku-band use from 13.75 to 14.50 GHz. It provides 240 W continuous-wave (CW) output power and 400 W peak output power. The amplifier weighs approximately 32 lbs. (14.5 kg) and is designed to meet MIL-188-164A requirements. It can be customized to include a number of different options, including an input L-band frequency upconverter, solid-state input preamplifier, and an internal linearizer.

MITEQ, INC., 100 Davids Dr., Hauppauge, NY 11788-2043; (631) 439-9108, FAX: (631) 436-7431, e-mail: satcomsales@miteq.com, ***www.miteq.com.***

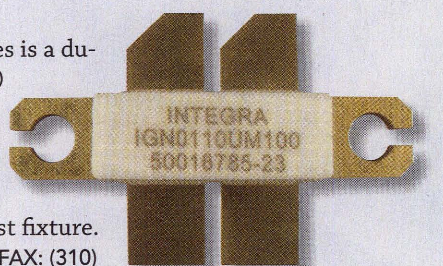
Surface-Mount Baluns Extend To 6 GHz

A pair of broadband surface-mount balanced/unbalanced (balun) transformers from Marki Microwave provides frequency coverages to 3 and 6 GHz, respective. Model BAL-0003SM operates from 500 kHz to 3 GHz with 6-dB typical insertion loss and 180-deg. nominal phase shift. It features matched 50-Ω input and output ports with amplitude balance of typically ±0.3 dB and phase balance of typically ±3 deg. The balun has 35-dB common-mode rejection, with 9-dB typical isolation and 17-ps typical rise/fall time. Higher-frequency model BAL-0006SM exhibits 6-dB typical insertion loss from 500 kHz to 6 GHz with amplitude balance of typically ±0.4 dB and phase balance of typically ±3 deg. It achieves 35-dB common-mode rejection with 9-dB typical isolation and 17-ps typical rise/fall time.

MARKI MICROWAVE, 215 Vineyard Ct., Morgan Hill, CA 95037; (408) 778-4200, FAX: (408) 778-4300, e-mail: info@markimicrowave.com, ***www.markimicrowave.com.***

GaN Device Drives 100 W At 1 GHz

Specified for Class AB operation, model IGN0110UM100 from Integra Technologies is a dual-lead packaged gallium-nitride (GaN) high-electron-mobility-transistor (HEMT) device capable of at least 100 W continuous-wave (CW) output power from 100 MHz to 1 GHz. It provides 12-dB gain over that range and under those conditions, and can also drive high output-power levels with pulsed signals. It maintains excellent spectral purity into all phases at load mismatches as severe as a 3.0:1 VSWR. All devices are 100% screened using large-signal parameters in a broadband precision test fixture.



INTEGRA TECHNOLOGIES, INC., 321 Coral Circle, El Segundo, CA 90245; (310) 606-0855, FAX: (310) 606-0865, e-mail: sales@integratech.com, ***www.integratech.com.***

Fractional-N PLL Tunes 33 To 4100 MHz

Model HMC835LP6GE from Hittite is a wideband fractional-N phase-lock-loop (PLL) source with integrated voltage-controlled oscillator (VCO) that provides continuous frequencies from 33 to 4100 MHz. It features PLL figure of merit for phase noise of –230 dBc/Hz in integer mode, –227 dBc/Hz in fractional mode, and typical VCO phase noise of –134 dBc/Hz offset 1 MHz from a 4-GHz carrier. Two separate charge-pump outputs allow seamless switching between integrated or external VCOs during operation. Suitable for scalable multiple-input, multiple-output (MIMO) and beamforming applications, the PLL provides two differential output ports and delivers +7 dBm typical output power. It runs on +3.3- and +5.0-VDC supplies.

HITTITE MICROWAVE CORP., 2 Elizabeth Dr., Chelmsford, MA 01824; (978) 250-3343, FAX: (978) 250-3373, e-mail: sales@hittite.com, ***www.hittite.com.***