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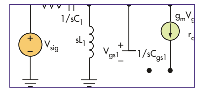

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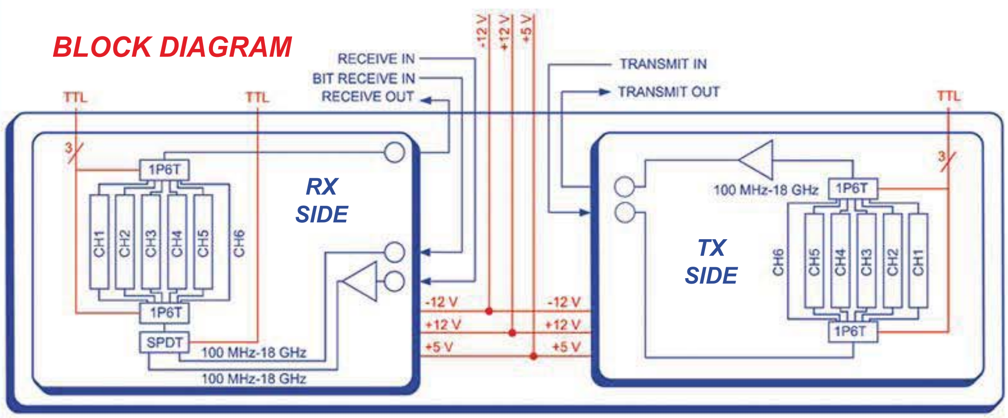

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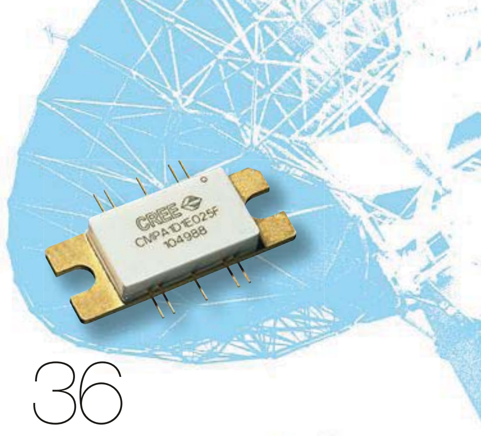

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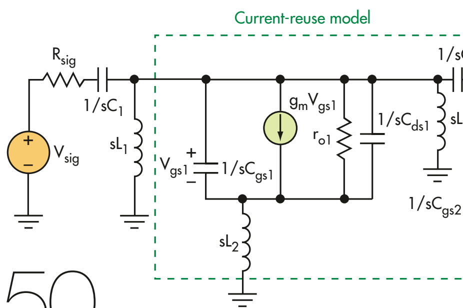

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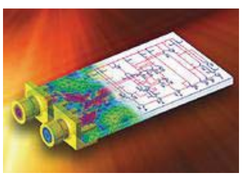

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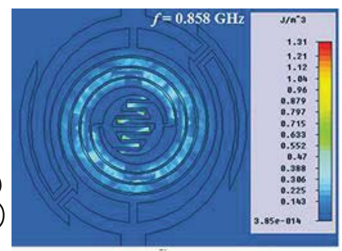

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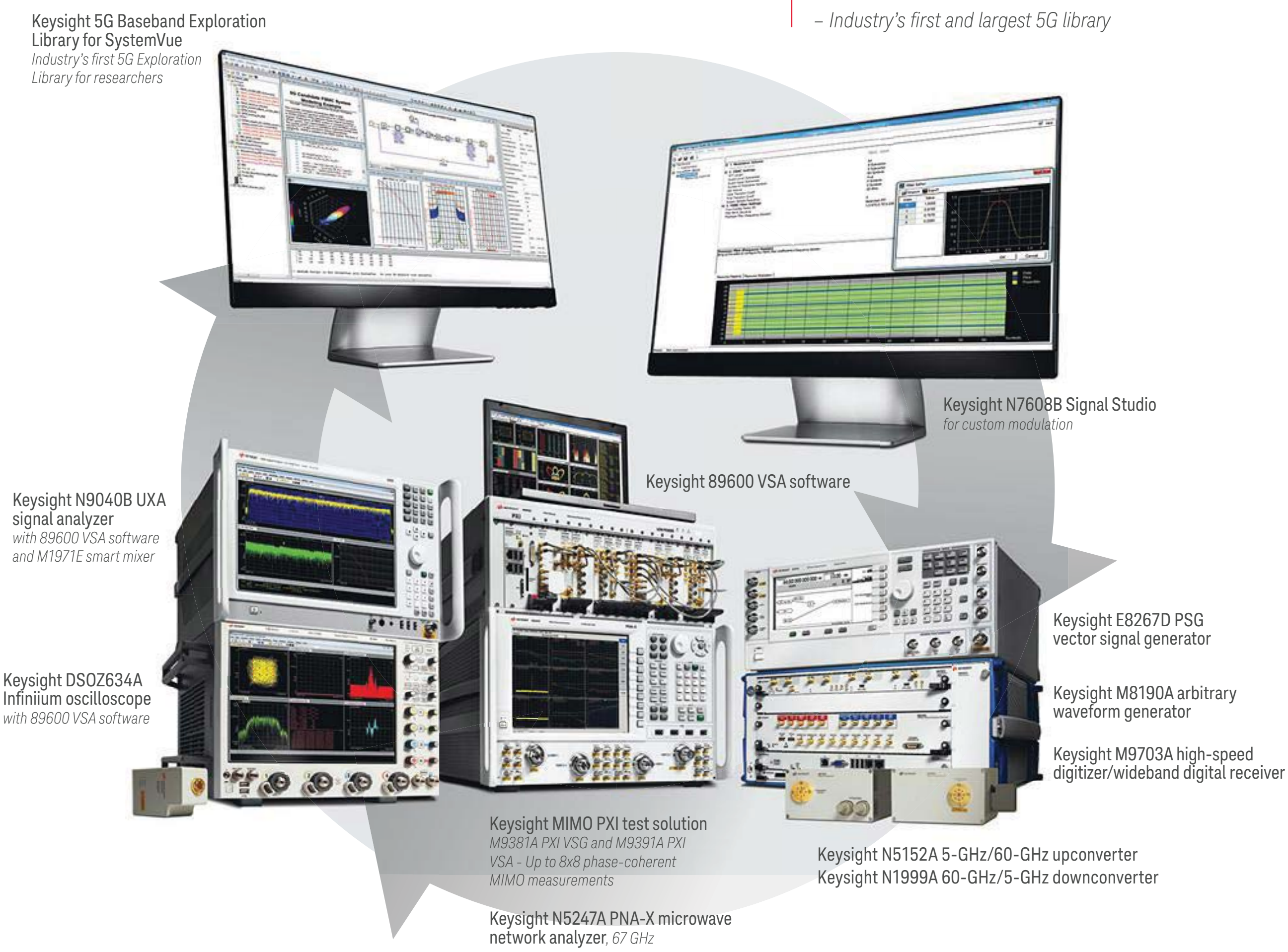

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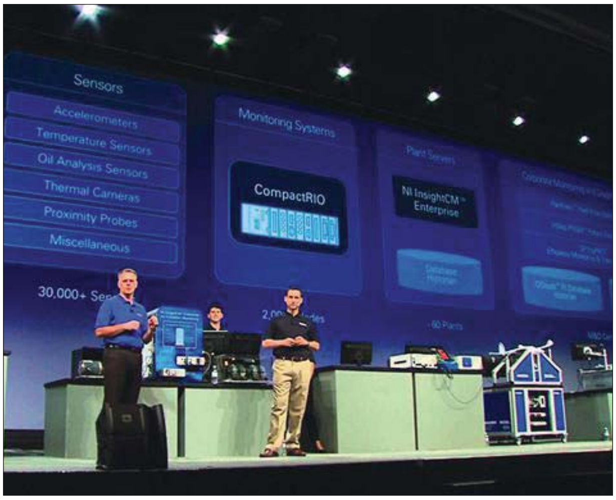

NI WEEK HIGHLIGHTS IOT, WIRELESS

http://mwrf.com/blog/iot-and-5g-highlighted-niweek-2015

Held the first week of August in Austin, Tex., NIWeek drew more than 3,000 engineers and other technical professionals—as well as several dozen partner exhibitors—to showcase new products and applications. This year's event featured a number of sessions on wireless and the Internet of Things, as well as many new products of interest.

PORTABLE BY DESIGN

http://mwrf.com/blog/making-measurements-portable-design

In his latest blog, Technical Contributor Jack Browne makes the case that modern portable RF/microwave test instruments can perform quite well in a laboratory as well as making on-site measurements in the field. In fact, companies on tight budgets can fill many measurement needs with a single portable instrument, such as a spectrum analyzer or a vector network analyzer (VNA).

(Image courtesy of Anritsu)

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UPDATE: THE LATEST GPS III DEVELOPMENTS

http://mwrf.com/systems/update-gps-iii-control-system-boosts-navigational-accuracy

In the latest news on the GPS III satellites, Raytheon announced that it has finished installing the first operational hardware for the GPS OCX control system. The Launch and Checkout System (LCS) hardware was installed at the Shriever Air Force Base in Colorado, the eventual home of the GPS OCX Master Control Station.

(Image courtesy of Thinkstock)

GALLERY:

MULTI-FUNCTION MICROWAVE/RF INSTRUMENTS

http://mwrf.com/test-measurement-analyzers/gallery-multi-function-microwaverf-instruments

As RF/microwave testing becomes more complex and devices with radios continue to proliferate, demands will intensify for test instruments that can handle a wide range of applications. Click through the gallery to see some of the latest solutions.

(Image courtesy of Keysight)

NANCY K. FRIEDRICH
Content Director
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This Is Your Brain on IoT

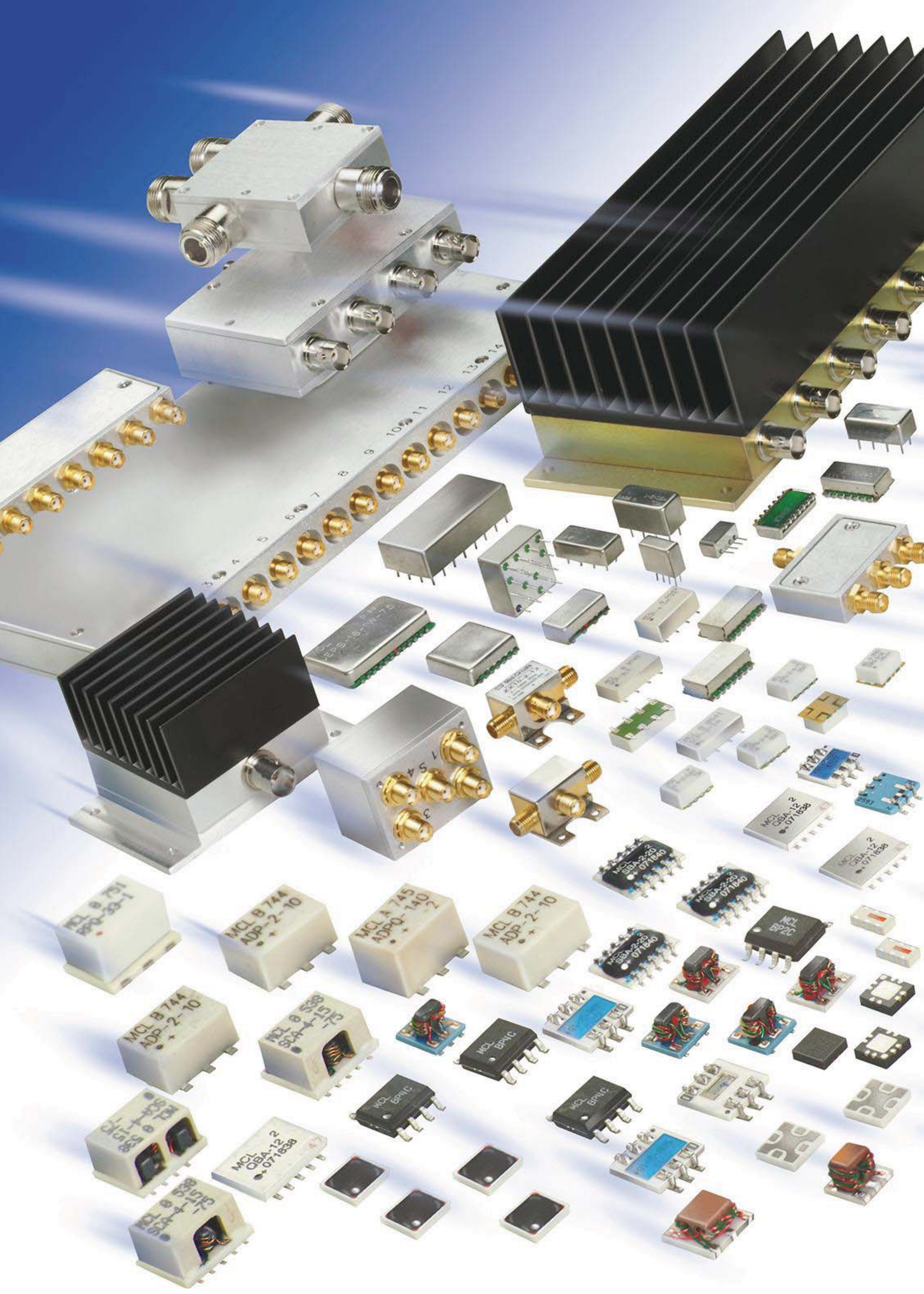
The Internet of Things (IoT) will reach and connect all aspects of life, ranging from home management to parking apps in smart cities. In the healthcare sector, pushing data into the cloud has already resulted in the growing adoption of telemedicine. From managing patients remotely to using handheld devices to input patient details and manage care, telemedicine brings flexibility to the extremely hectic healthcare environment. As more of our infrastructure becomes connected and interactive, however, the U.S. and many other countries are expected to graduate from in-depth patient tracking and monitoring to diagnosis and health maintenance. A key focus for such applications and capabilities is maintaining brain health.

In a report titled "The Digital Brain Health Market 2012–2020," SharpBrains tracked developments at more than 50 companies that offer automated applications targeting brain functioning. Specifically, the companies offered Web-, mobile-, and biometrics-based solutions to assess, monitor, and improve cognition and brain functioning. Based on its findings, SharpBrains is assuming that more than 1 million adults (taking into account only North America) will undergo a yearly brain-health check-up via their tablets by 2020. Similarly, iPad-based cognitive screenings will inform more diagnoses of Alzheimer's disease and MCI than neuroimaging. In at least 10 countries, SharpBrains expects patients with multiple sclerosis to begin addressing their condition with a mix of online cognitive training and drug-based therapy.

Cognitive tests taken on mobile devices also will help athletes better diagnose and manage possible concussions. Other brain apps are targeting the treatment of insomnia and depression with cognitive treatment. For example, the report notes that the first brain-based bio-market will be cleared by the FDA within the next five years, enabling responses to depression treatment to be predicted on an individual basis.

Such medical advances can only be quickly achieved if the vast networks and related technologies are in place to allow this "big data" to be sent, received, stored, and secured. The microwaves and RF industry is thus at the center of this trend. For an industry that has been largely vested in the communications and defense industries, enabling the IoT is the goal on the horizon.

The IoT takes us beyond just commercial or defense applications to a universal approach, where everything is connected. Yet success for the IoT still will rely on the microwave market resolving technical challenges, overcoming interference, pushing new standards forward, performing thorough testing, etc.—in other words, doing what this industry has always done best. It's an exciting time to be an individual in such a rapidly connecting world, but it's even better to play such a prominent role in the IoT as part of the microwave industry. mw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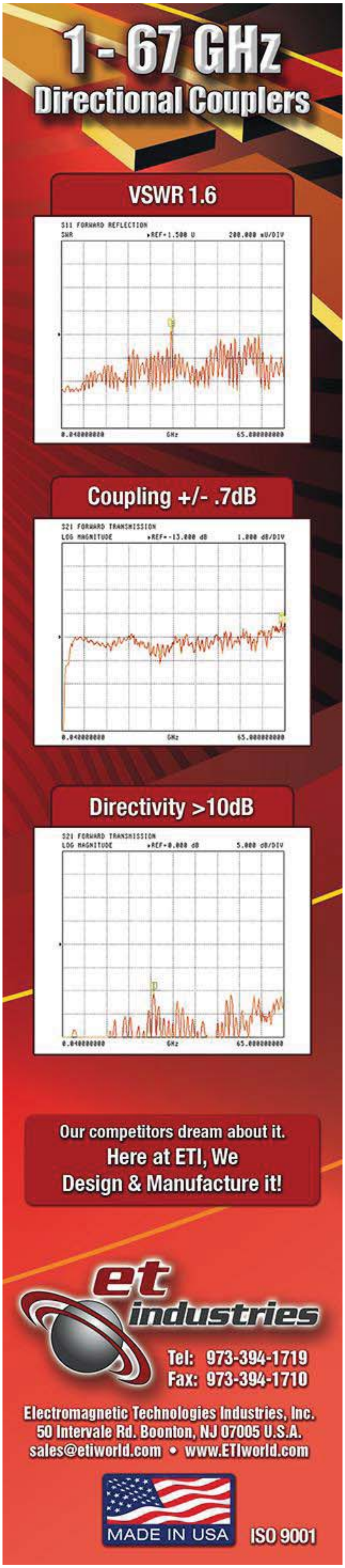

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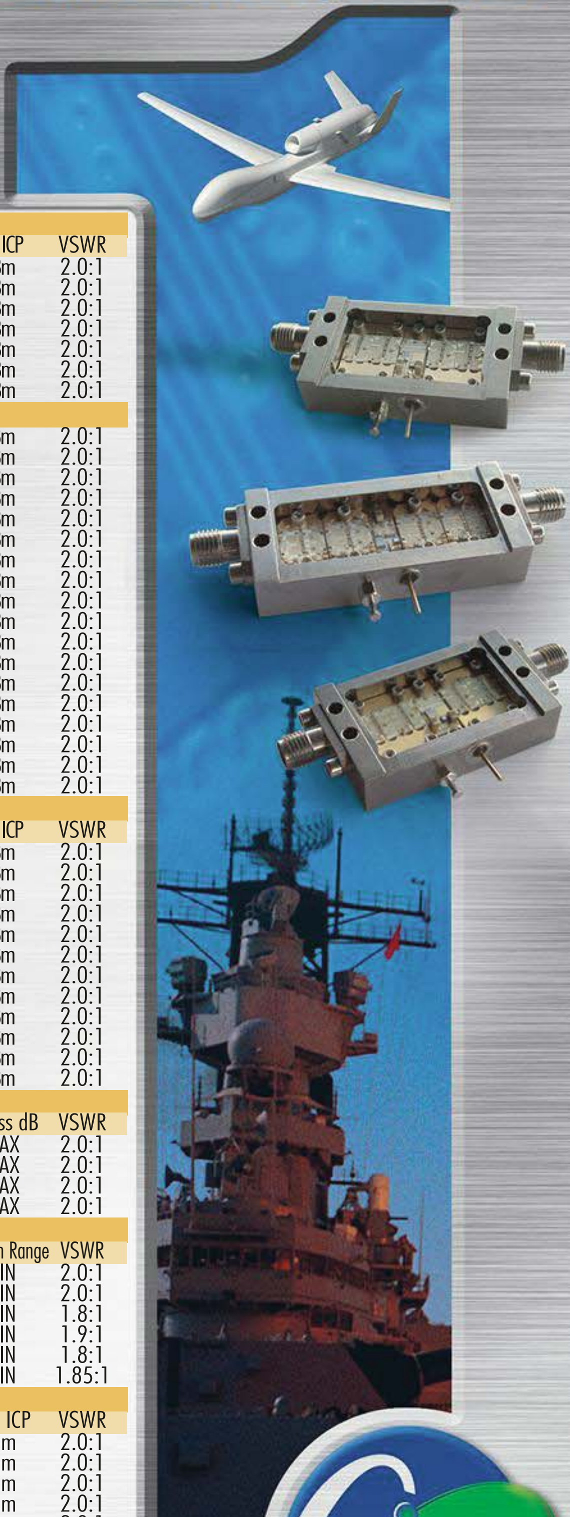

OCTAVE BAND LOW NOISE AMPLIFIERS

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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SHOWING UP ON THE SCREEN

Kudos to your August issue's tutorial story on radar technology and how it is moving into so many different markets. As the story pointed out, radar is no longer just a "military technology," but is now as likely to appear within the electronic circuitry of a modern commercial or consumer transportation product as on board a seaborne military vessel.

Give credit to the automakers for applying radar technology to modern commercial communications. Notably, work on commercial vehicular radar systems began in the early days of what is now known as wireless technology, when automakers were exploring different ways to cost-effectively generate the millimeter-wave signals that could be used in automotive radar systems. The early days of your own publication's Wireless Symposium & Exhibition were never without presentations on vehicular radar systems at millimeter-wave frequencies, and how this technology would soon be a widespread means of improving road safety.

Granted, the impact of wireless radio technology has been great as part of modern wireless communications. But pulsed wireless signals in modern commercial radar systems are quickly showing users another important application for those high-frequency signals, and why military users have been so dependent upon these signals for so long.

RICHARD FARLEIGH

EDITOR'S NOTE

Radar has long been a technology that is synonymous with battleships because of the size of the radar system's large antennas, power tubes, and other (once) necessary space-occupying components. But, as with most of high-frequency technology, radar has advanced a great deal in the last several decades. With the advances in solid-state transmitters at higher frequencies, and improved sensitivity of radar receivers, it is now possible to incorporate radar systems where they simply wouldn't have fit in the past. With a market as powerful as the worldwide automotive market behind it, vehicular radar systems are sure to continue improving and shrinking, with a growing number of drivers learning to depend on the technology.

JACK BROWNE
TECHNICAL CONTRIBUTOR

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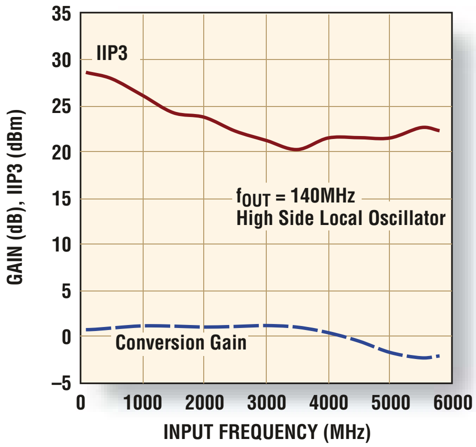

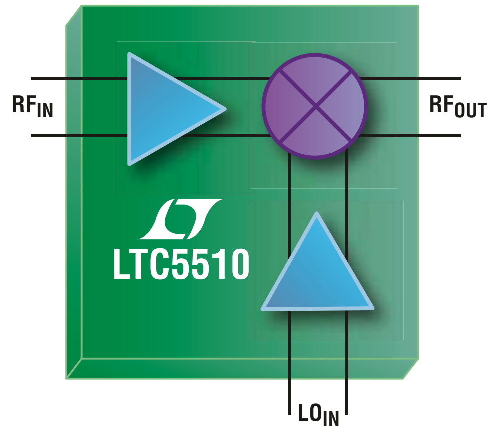

Excellent Dynamic Range, High Port-to-Port Isolation

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Signal Chain Components

	LTC5567	+26.9dBm IIP3, 1.9dB Gain Mixer	Detector	LTC5582	10GHz, 57dB Dynamic Range RMS Detector
	LTC5569	Dual +26.8dBm IIP3, Low Power Mixer		LTC5587	6GHz 40dB Dynamic Range RMS Detector + ADC
	LTC6430-15	+50dBm OIP3 @240MHz, 15dB Gain Differential Amplifier		LTC6412	31dB Gain Control, Analog VGA with +35dBm OIP3
	LTC6431-15	+47dBm OIP3 @240MHz, 15dB Gain Single-Ended Amplifier		LT®5554	16dB Gain Control, 0.125dB/Step Digital VGA
ADC	LTC2158-14	Dual 14-Bit, 310Msps ADC		LTC6946	Low Phase Noise Integer-N PLL + VCO
	LTC2209	16-Bit, 160Msps ADC		LTC6945	Low Phase Noise Integer-N PLL

Info & Free Samples

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LINEAR TECHNOLOGY

News

COMMUNICATIONS-BASED TRAIN SIGNALING

Integrates 4G LTE Network

The first successful pilot test of a communications-based-train-control (CBTC) signaling system with 4G LTE capabilities has been completed on metro lines in France. Using ground-to-train wireless communications, the system not only controls trains automatically but also provides metro operators with closed-circuit television (CCTV) and real-time passenger information. The tests were conducted by Huawei Technologies on the Urbalis Fluence CBTC system developed by Alstom, one of the largest train manufacturers in the world.

CBTC systems are typically deployed in high-capacity metro lines to ensure that the infrastructure remains safe and efficient. *(Image courtesy of ThinkStock)*

CBTC systems are typically deployed in high-capacity metro lines to ensure that the infrastructure remains safe and efficient. In these systems, trains are constantly communicating their exact position and speed via radio signals to the wayside equipment set out along the track. The trains receive information about the position of other trains on the line and adjust their speed to remain a safe distance from them. Ideally, operators will be able to safely reduce the time interval between the trains, increasing the overall capacity of the metro line.

The Urbalis Fluence CBTC system is based on an enterprise LTE (eLTE) network developed by Huawei for public-safety and mission-critical applications. With the addition of 4G LTE, this system has the potential to not only improve CBTC reliability but also to provide metro operators with passenger information and voice trunking services. eLTE can support downlink data rates to 100 Mb/s with uplink data rates reaching 50 Mb/s, according to Huawei.

The eLTE solution serves as a trunked communications system, allowing operators to share one group of radio channels for sending voice, video, and broadband data. In this way, metro operators can more effectively manage infrastructure traffic and reduce operational costs. This is increasingly important as population growth leads to higher-capacity mass-transit networks.

The eLTE system from Huawei has been integrated into several railways around the world, although Alstom has been the first to upgrade its signaling system with 4G LTE capabilities. For instance, an eLTE network has been deployed in the Zhengzhou Metro Line 1, providing bidirectional wireless transmission channels for its ground-to train voice and data services. eLTE is also being implemented in heavy-haul railways, such as the Shuo Huang Railway (SHR). It is using the technology for multi-locomotive synchronous control and train-to-ground wireless communications.

The LTE pilot test was agreed upon in April 2014, when Huawei and Alstom signed a memorandum of understanding. For the pilot test, Huawei provided the eLTE network and Alstom supplied the train and LTE-compliant onboard equipment. Huawei has signed 111 eLTE network contracts and established 53 eLTE commercial networks, according to a recent press release from the company. ■

VORACIOUS WI-FI CONSUMPTION Drives WLAN Market Growth

THE INTERNET OF Things (IoT) is being introduced into a rapidly growing ecosystem of radio access points that connect to wireless local-area networks (WLANs). These short-range networks are expected to be the primary means for IoT technologies to connect to wireless networks, according to a report from the Dell'Oro Group. The installed base of WLAN access points is expected to reach almost one billion in the next five years. As the IoT ecosystem continues to expand, the market for WLAN equipment will experience a wave of revenue growth through 2020, according to the report.

The report notes that the WLAN market is expected to earn revenues of almost $1.3 billion in 2019, representing a 30% revenue increase from 2015. This growth will be supported by the widespread installation of IEEE 802.11ac Wave 2 access points and the continued usage of cloud-managed WLAN services. The rise of IEEE 802.11ac Wave 2 technologies can be largely attributed to the sudden increase in wireless traffic introduced by IEEE 802.11ac Wave 1 access points, the report noted.

"Enterprises have experienced significant and immediate wireless traffic increases immediately after 802.11ac Wave 1 installations are complete," explained Chris Depuy, vice president at Dell'Oro. "Users are consuming whatever Wi-Fi bandwidth is made available to them in high-usage settings like universities and K-12 schools." The IEEE 802.11ac Wave 2 wireless specification has the potential to increase maximum wireless speeds to 6.93 Gbits/s – a significant increase from 3.47 Gbits/s with Wave 1 technologies.

In addition to private enterprises, the report notes that the WLAN equipment market will benefit from manufacturers of Wi-Fi access points. The introduction of the 2.5/5G Ethernet interface, a standard being developed by the IEEE 802.3 organization, will enable manufacturers to improve WLAN speeds without a wiring upgrade. The higher data rates of the IEEE 802.11ac Wave 2 standard cannot be handled by installed access points that depend on 1G Ethernet for connection to the WLAN. The report concluded that these flexible Ethernet switch ports will give manufacturers a cost incentive to expand the installed base of WLAN access points. ■

As the IoT ecosystem continues to expand, the market for WLAN equipment will experience a wave of revenue growth through 2020. *(Image courtesy of ThinkStock)*

RECTENNA SERVES 2.45-GHz Wireless Power Transmission

DEVELOPED BY THE Alliance for Wireless Power (A4WP), the Rezence standard transmits up to 50 W of energy to compatible devices. This specification delivers wireless power to multiple devices without the need for precise alignment or direct physical contact, although the device cannot be further than 5 cm from the charging pad. The specification is able to charge cell phones, smartphones, tablets, notebooks, laptops, and desktop-PC peripherals.

Wireless charging through metal backs has been one of the main obstacles to widespread use of the technology, according to Steve Pazol, general manager of wireless charging at Qualcomm. "Building a wireless charging solution into devices with metal exteriors is a significant step forward for moving the entire industry," Pazol noted. "Today, more device manufacturers are choosing to utilize metal alloys in their product designs to provide greater structural support and, of course, aesthetics." The reference designs for the new technology are available only to WiPower licensees.

Qualcomm was one of the founding members of the A4WP organization, which earlier this year finalized a merger agreement with Power Matters Alliance (PMA), another standards group in the wireless charging industry. The organization is competing against the Qi standard being developed by the Wireless Power Consortium (WPC), which was recently upgraded to support fast charging for mobile phones. ■

WIRELESS-CHARGING TECHNOLOGY WORKS With Metal Cases

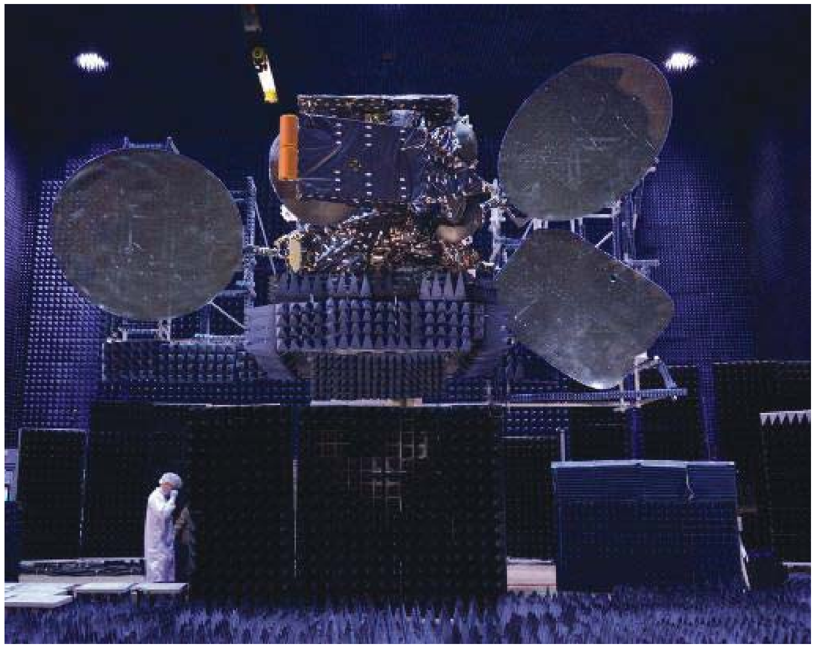
AS THE WIRELESS-CHARGING race heats up, the Rezence standard has been upgraded to charge devices with metal exteriors. Qualcomm Technologies Inc., a wholly-owned subsidiary of Qualcomm Inc., has introduced this capability into its WiPower wireless-charging technology. This was achieved without sacrificing the power output of WiPower charging pads, which send up to 22 W of energy to devices compatible with the Rezence standard.

The Rezence technical specification uses magnetic resonance between inductive couplers to support wireless charging over short distances. This specification operates with a transmission frequency of 6.78 MHz, a frequency that is more tolerant of metal objects that come within the charging field. Previously, this aspect had allowed metal objects, such as keys and coins, to remain near the charging pad without causing interference. The new version of the WiPower solution, however, extends this capability to devices with metal backs. ■

Qualcomm has upgraded its WiPower charging pads, allowing them to charge devices with metal backs. *(Image courtesy of the Alliance For Wireless Power)*

DUAL C- AND KU-BAND PAYLOAD

Replaces Outdated Broadcast Satellites



The Intelsat-34 satellite will provide increased capacity for Latin American content distribution and broadband services in the North Atlantic region. ***(Image courtesy of SSL)***

WITH THE RAPID EVOLUTION and progression of satellite technology, it is only natural that new approaches and advanced payloads are often replacing existing satellites. The Intelsat-34, for example, is set to replace the outdated Intelsat-805 and Galaxy-11 satellites located at 304.5 degrees E. The satellite, designed and built by Space Systems/Loral (SSL), was recently launched from the European Spaceport in Kourou, French Guiana, aboard an Ariane 5 launch vehicle.

Equipped with dual C-band and Ku-band payloads, Intelsat-34 will provide increased capacity for Latin America content distribution and broadband services in the North Atlantic region. The satellite will have an area of coverage similar to that covered by both the Intelsat-805 and Galaxy-11 satellites. The 24 Ku-band, 36-MHz transponders provide direct-to-home (DTH) television and digital signals to Mexico, Central America, Brazil, Europe, parts of the United States, and the northern part of the Atlantic Ocean. In addition, a specialized Ku-band payload will support broadband networking to mobile maritime and aeronautical companies serving in the North Atlantic Ocean.

The downlink frequency of the Ku-band transponders is 11.45 to 12.20 GHz, while the uplink frequency ranges from 14.00 to 14.50 GHz. The Ku-band beams will be projected into Brazil and North America as the primary regions. The typical edge-of-coverage effective isotropic radiated power (EIRP) is expected to be greater than 44.7 dBW in Brazil and 43.4 dBW in North America, according to pre-launch statistics from Intelsat. The beam peak in Brazil could reach up to 53.6 dBW with antenna gain-to-noise-temperature (G/T) ranges up to 8.2 dB/K. In North America, the beam peak could reach up to 47.3 dBW with G/T ranges around 0.9 dB/K.

The satellite is also designed with 24 C-band, 36-MHz transponders to provide communications services in North and South America and Europe. The downlink frequency of these transponders spans 3700 to 4200 MHz, while the uplink frequency ranges from 5925 to 6425 MHz.

The C-band beam peak is expected to reach up to 41.2 dBW with antenna G/T ranges to 0.6 dB/K. The edge-of-coverage (EIRP), on the other hand, will typically be greater than 34.8 dBW.

The Intelsat-34 satellite will serve the role originally intended for the Intelsat-27 satellite, which was destroyed in the Pacific Ocean after a launch failure in 2013. The Intelsat-27 satellite also carried an ultra-high frequency (UHF) payload for mobile military communications, but the same payload was not equipped on Intelsat-34 after the Department of Defense withdrew from the project. Intelsat-34 was built around the SSL 1300 satellite bus platform with two deployable solar arrays and a Hall effect thruster for electrical propulsion. ■

AEHF SATELLITE TERMINAL Completes Security Design Review

A RESEARCH TEAM supported by Lockheed Martin, Northrop Grumman, and TeleCommunications Systems (TCS) has completed a review of security elements for an Advanced Extremely High Frequency (AEHF) satellite terminal. The review has validated the critical design features of the low-cost terminal (LCT), which is being designed to provide secure communications to highly mobile military forces. With the review complete, researchers can start building hardware and software for the information assurance terminal or end cryptographic unit (ECU).

AEHF-system satellites are capable of providing jam-resistant communications to tactical military forces. But existing extremely high-frequency (EHF) terminals are not widely available due to size and cost. The LCT program is focused on developing a more secure and affordable alternative to currently fielded terminals. Without more affordable terminals, military forces will continue to rely primarily on vulnerable Wideband Global System satellites for command and control operations.

The ECU will be added to a Protected Communications On-The-Move (P-COTM) terminal. Customized with EHF power amplifiers based on the application, the terminal is being configured with the XDR waveform to support mobile ground, maritime, and airborne communications. The ECU will be integrated with the existing antenna and RF systems of the P-COTM prototype to create a full-scale terminal.

Also being upgraded with the ECU is a protected Secure Internet Protocol Router Network/Non-secure Internet Protocol Router (SIPR/NIPR) access-point (P-SNAP) terminal. This transportable ground terminal is designed with P-COTM components to provide satellite communications to soldiers in remote areas beyond the line-of-sight. Supporting modular quick-change feeds, the P-SNAP terminal is backward compatible with SNAP operations in the Ku-band and military Ka-band.

A technician inspects part of an AEHF satellite before it enters active service in support of U.S. military forces. ***(Image courtesy of Lockheed Martin)***

Three AEHF satellites are currently in an operational orbit, providing almost ten times the capacity of the legacy Milstar satellites. The satellites are connected by a series of crosslinks, allowing them to relay signals directly instead of using ground stations. The uplinks and crosslinks between the satellites operate at 44 GHz in the EHF range, while downlinks operate at 20 GHz in the super-high-frequency (SHF) range. In terms of security, the phased-array antennas can change their radiation patterns to guard against potential signal jamming. The AEHF system, which is being developed by Lockheed Martin and Northrop Grumman, will eventually field six satellites.

An early prototype of the LCT terminal has been fully integrated and tested with an AEHF payload engineering model. The research team, which splits the development costs involved with the project, is planning to test the terminal with an AEHF satellite by the end of 2015. It expects full certification in 2016. ■

Company News

CONTRACTS

API Technologies Corp.— Extended its manufacturing partnership with Blighter Surveillance Systems with the announcement that it is to partner on the production of Blighter's latest radar, the Blighter A400 Series. The Blighter A400 Series radars are modular non-rotating, electronic-scanning systems using power efficient PESA (passive electronically scanned array) and FMCW (frequency modulated continuous wave) technologies to provide industry leading levels of reliability and requiring zero maintenance.

COM DEV International Ltd.— Received an order to supply equipment for two commercial communications satellites. The initial Authorization to Proceed (ATP) is valued at approximately $8.25 million, and is expected to lead to a full contract in excess of $33.7 million. The expected contract represents COM DEV's largest-ever commercial order with this long-standing customer, a major satellite prime contractor that cannot be identified for contractual reasons.

TASC Navigates GPS Deal

TCS Extends U.S. Marine Contract

TASC— Has been awarded a $67 million contract to provide systems engineering and integration (SE&I) for the U.S. Air Force Global Positioning Systems (GPS) Directorate, the agency responsible for ensuring the space-based satellite navigation system is operational. The contract, known as the GPS SE&I, has a two-year base with options to extend TASC's support to 6.5 years with a value of more than $200 million. The award represents new work and was made by the USAF Space and Missile Systems Center.

Magal Security Systems Ltd.— Received an order to secure 200-plus km of buried pipeline with its fiber optic sensor system. The system is based on Magal's COTDR long-range fiber solution, which uses standard single-mode communication fiber to detect any unlawful attempt to dig close to the pipeline—be it for terror or criminal tapping.

PCTEST Engineering Laboratory Inc.— Has upgraded its Rohde & Schwarz TS8980FTA-2, CMW-PQA, and CMW500 systems to accommodate the new eMBMS test plans for 3GPP conformance and carrier acceptance testing.

Rohde & Schwarz— Was selected by the British company BAE Systems for the Royal Navy's Type 26 Global Combat Ship. In June 2015, the two companies concluded a contract to equip three Type 26 Global Combat Ships each with a communications system. The ships will be deployed by the Royal Navy, and follow-up orders are in the pipeline.

Mercury Systems Inc.— Received a $4.4 million follow-on order from an international customer for digital-signal processing subsystems for a naval radar application.

TeleCommunication Systems Inc.— Announced that the Defense Information Systems Agency (DISA) has exercised its second-year task-order option for TCS to continue to provide Ku satellite bandwidth, terrestrial support, and 24-hour support services for the U.S. Marine Corps' Tactical Satellite Communications Network. The additional $14.2 million funding covers the period from Aug. 1, 2015, through July 31, 2016.

FRESH STARTS

Qualcomm Inc.— Announced that its indirect, wholly-owned subsidiary, Qualcomm Global Trading Pte. Ltd., completed its acquisition of CSR plc, a fabless provider of end-to-end semiconductor and software solutions for the Internet of Everything (IoE) and automotive segments. The acquisition, which was completed at an enterprise value of approximately $2.2 billion ($2.4 billion equity value), complements Qualcomm Technologies' current offerings by adding a portfolio of new products, sales channels, and a large number of customers in the areas of IoE and automotive—both key growth priorities for Qualcomm Technologies.

In other Qualcomm news, the company's subsidiary, Qualcomm Atheros, entered into a definitive merger agreement to acquire Ikanos Communications, a broadband networking semiconductor and software provider enabling both central-office and home-gateway solutions.

Anite— Joined the 5G Innovation Centre at the University of Surrey, the largest UK academic research center dedicated to the development of the next generation of mobile and wireless communications.

Peregrine Semiconductor Corp.— Was awarded qualified manufacturers list (QML) certification, class Q (military) and V (space). After a thorough evaluation, Peregrine demonstrated to the Defense Logistics Agency (DLA) Land and Maritime that it fully complies with MIL-PRF-38535, the performance specification used by the U.S. Department of Defense for monolithic integrated circuits that operate in severe environments.

Qorvo— Completed its $200 million share repurchase program authorized by its Board of Directors in February 2015. Under the February 2015 share repurchase program, Qorvo repurchased approximately 3.1 million shares of common stock at an average price of $63.80 per share. The company also announced that its board of directors has authorized a new share-repurchase program to repurchase up to $400 million of its common stock.

Subcarrier Communications— Announced its $2.1 million purchase of Houston-based AC Site Management effective June 1, 2015. With the Houston office serving as its Southwest territory base, Subcarrier aims to deepen its presence throughout the Southwest U.S. region.

Inside TRACK with Chris Ziomek,

Vice President and General Manager, LitePoint Design Test Solutions

Interview by CHRIS DeMARTINO

CD: What are some of the challenges created by needing to support all of the latest wireless standards?

CZ: Wireless standards continue to evolve at a very rapid pace. The latest gadgets and apps constantly push for more bandwidth, which is constrained by available wireless spectrum. Consequently, system architects and engineers find clever ways to apply digital communication theory and techniques to deliver higher data rates.

This creates challenges for wireless-device designers and the test-equipment designers who serve them. Our focus is directed at helping our customers tame complex technology and get products to market quickly. We work closely with the newest chipsets, stay abreast of the latest technology, and focus on shortening the time-to-test for our customers.

CD: What are the latest requirements for power amplifier (PA) testing?

CZ: RF front ends are becoming much more complex. A front end for a world phone must support many more bands, modes, and antennas than it did just a few years ago. Also, multi-mode multi-band (MMMB) power amplifiers are being developed to shrink and reduce the cost of mobile-device designs. With the additional bands, modes, and antennas, the number of RF power amplifiers in a mobile device has grown quickly. At the same time, test coverage demands have become more challenging with testing requirements for carrier aggregation, MIMO, envelope-tracking, and digital pre-distortion (DPD).

For example, the latest IEEE 802.11ac Wave 2 chipsets add MU-MIMO, VHT-160, and possibly 1024-QAM. Also, Wave 2 chipsets may be the first WLAN chipsets to employ DPD to achieve desired EVM performance. A PA targeted for use with these Wave 2 chipsets must be characterized for the wider 160-MHz bandwidth, possibly with 80+80 MHz channels. We now see IEEE 802.11ac PAs for Tier1 mobile devices commonly being tested for use with DPD.

CD: What new testing requirements do you anticipate seeing in the near future?

CZ: The IEEE 802.11ac Wave 2 is the current push in WLAN, as described previously. For LTE, two-carrier aggregation for downlink is now common and three-carrier aggregation downlink has started rolling out. This increase in channel bandwidth pushes the performance requirements for front-end components, such as PAs. Another new initiative in LTE is the proposed use of LTE in the unlicensed 5-GHz band. LTE-Unlicensed will drive new requirements for cellular test equipment, which has traditionally been focused on the licensed cellular bands (<4 GHz).

CD: How difficult is it to maintain support of the diverse and numerous wireless chipsets being designed into products today and in the near future?

CZ: This is, of course, a big challenge. LitePoint has a dedicated team of engineers working with wireless chipset companies to assist them with the test and development of its latest generation of products. This win-win relationship gives the chipset designers access to test technology early. It also provides them with a partner to test their devices within a reference design.

CD: What software improvements are being implemented to advance automated wireless testing?

CZ: For our design verification testing (DVT) customers, it is all about time-to-test and time-to-verify a new design. To support them, we have integrated many standard test operations, sequences, and measurements into our software tools. Essentially, we are focusing on ease-of-use to enable our customers to start DVT testing immediately.

For production-test customers, we focus on providing optimized solutions to test multiple DUTs at the same time. If certain features within the test equipment architecture are harnessed to provide faster test times, factory floors will be more efficient. The cost of test also will be lowered.

Related to this, one of the challenges of multi-DUT test is that the number of RF connection points between the tester and the DUT is increasing—particularly in cellular devices. Each connection point is a potential failure mechanism in the factory. To address this challenge, we have introduced a suite of software tools to monitor the quality of the connection between the tester and DUT. These "Factory Efficiency" features detect changes in the RF path, which lead to failures. They also detect when the DUT has been properly placed in the test fixture, minimizing yield fallout due to poor connection. Such tools increase test station uptime while speeding the process of debugging a bad fixture when maintenance is required.

CD: What type of impact will the emergence of the Internet of Things (IoT) have on automated test requirements?

CZ: In the mobile-device market, there is a handful of chipsets manufacturers that supplies the wireless core of the vast majority of mobile devices. This is less so with IoT, where there are many more chipsets. Here, wireless connectivity appears in potentially millions of different products from different manufacturers ranging from home automation to wearables to automotive, etc. Often, the companies developing IoT products have little RF or wireless expertise.

One key differentiator for manufacturers of IoT devices is time to market. Because of the wide variety of products and chipsets, IoT device makers typically rely on good reference designs from the chipset companies. There are not enough RF engineers to re-engineer each product and test solution. We are providing reference test platforms for those reference designs and looking at smarter ways to address the specific needs of IoT products, as these products—particularly for the consumer market—are very cost-sensitive. The nature of the economics for high-mix, lower per-stock-keeping unit (SKU) volume of IoT devices compared to smartphones and tablets is driving new test methodologies.

"One of the main challenges with 5G today is how broad the definition has become."

CD: What efforts are being made to prepare for 5G?

CZ: One of the main challenges with 5G today is how broad the definition has become. Unlike the previous transitions from 2G to 3G to 4G, 5G is not so much a "new wireless technology" as it is a new data-access technology. Technologies are being proposed as part of 5G that typically are not found in mobile devices, such as millimeter-wave radio frequencies. But these technologies have already been used with deployments in wireless backhaul and some early wireless video applications.

The main challenge of 5G will be the interoperability of existing technologies. With a common "always-on" connection to a traditional cellular network (such as LTE), devices in a "5G network" will need to be smarter to seek out the best option for data access. This could be through the existing cellular network, a nearby Wi-Fi hotspot, a commercial/enterprise "small cell" (femtocell), the proposed unlicensed-band, or an entirely new mobile device technology (such as millimeter-wave). Test solutions for each of these technologies have individually been in production many years. For instance, the launch of another millimeter-wave technology, IEEE 802.11ad, is scheduled for next year.

The challenge with 5G is really in testing the interoperability and seamless handover of these systems in the dense environment of a smartphone. This must be done without causing inter-system noise, effectively inducing de-sensitization of the devices and in turn reducing performance. The focus for 5G test challenges will be "user experience" testing.

Meanwhile, 4G still has significant lifespan and new technology deployments planned, such as more carrier aggregation (both inter-band and intra-band), heteronet topologies, etc. LTE penetration is high in the US, but is currently experiencing rapid growth in areas like China and India. We believe that there is still a significant need for test equipment and new test technology required for 4G—at least for the next few years. mw

TERAHERTZ IMAGING HELPS ANALYZE BREAST TUMOR TISSUE

BREAST CANCER is a major medical concern among aging and even younger women. Smaller breast tumors can be medically removed, but they must first be identified and properly analyzed for removal, and pulsed terahertz (THz) imaging technology may be able to help. Researchers from the University of Arkansas (Fayetteville, Ark.) and Northwest Arkansas Pathology Associates, P.A. (Fayetteville, Ark.) used a commercial TPS Spectra 3000 THz imaging spectrometer from TeraView (www.teraview.com) to produce THz imaging pulses. The system uses a spectral range from 100 GHz to 4 THz with a reflection imaging module (RIM) to perform two-dimensional analysis of breast tissue samples. The module incorporates microminiature motors to enable changes in area of study as small as 50 μm when raster scanning a sample.

The researchers initially scanned tissue samples with 10 μm thickness using step sizes of 200 and 400 μm, and then shifting to a smaller raster scan step size of 50 μm to focus on tissue areas of interest. The goal of the THz imaging is to differentiate regions of the breast tissue, in order to identify carcinoma tissue from healthy tissue. The time-domain THz images help to distinguish the different regions in cancerous and non-cancerous breast tissue even for tissue samples that were extremely thin or dehydrated. This use of THz imaging technology indicates the potential usefulness of this high-frequency pulsed signal technology for identifying cancerous tissues from healthy tissues for many different parts of the body, but should provide more immediate benefits for women with concerns about breast cancer.

See "Terahertz Imaging of Excised Breast Tumor Tissue on Paraffin Sections," *IEEE Transactions on Antennas and Propagation*, May 2015, p. 2088.

GENERATING FREQUENCY-TUNABLE CONTINUOUS-WAVE THz SIGNALS

TERAHERTZ SIGNALS are being explored for a wide range of applications, including high-resolution imaging, medical science, short-range wireless communications, and homeland security systems. Of course, generating practical THz energy at such high frequencies, typically from 100 GHz to 30 THz, can be challenging. Fortunately, researchers from a number of different facilities in Canada, performing work sponsored by the Natural Science and Engineering Research Council of Canada, have developed an all-fiber approach to THz signal generation using a periodically poled optical fiber. In this approach, a continuous-wave (CW) THz signal is generated at the fiber by beating two optical wavelengths from two laser sources with the wavelength spaced in proportion to the desired frequency of the THz wave.

Terahertz signals have been generated through the use of nonlinear crystal devices, such as those based on gallium arsenide (GaAs) or gallium phosphide (GaP) substrate materials, although such approaches tend to be expensive.

As a lower-cost solution, a periodically poled optical fiber was used to generate a tunable terahertz wave by beating two wavelengths with a wavelength spacing corresponding to a THz wave at the periodically poled fiber.

The periodically poled fiber is made by a length of twin-hole optical fiber with its fiber core between the two holes. After the twin-hole fiber is drawn, two silver electrodes are inserted into the two holes. The twin-hole fiber is then thermally poled at a high temperature (about +260°C) with a voltage of +3.3 VDC applied to the two silver electrodes to instigate second-order nonlinearities into the nonhomogeneous glass of the fiber.

An ultraviolet laser source is then used to periodically erase the thermal poling induced second-order nonlinearity to achieve quasi-phase matching (QPM) to enhance the energy conversion efficiency of the THz source. In this way, a THz CW signal can be produced using a periodically poled optical fiber based on an optical difference-frequency-generation (DFG) approach.

To evaluate this THz signal generation approach, an experiment was conducted in which CW signals at 3.8 THz were produced using incident light waves of 1530.0 and 1560.1 nm. Using a THz detector, signal power of about 0.5 μW was measured and a conversion efficiency of about 2.9×10^{-5} was also measured.

Although the experimenters admitted that the theoretical signal power levels and conversion efficiency were somewhat higher than the values obtained in the experiment, improved performance could be achieved if the emitted terahertz wave is completely collected and a longer periodically poled fiber is used.

The frequency of the generated wave was tunable from 2.2 to 3.8 THz, corresponding to a wavelength in free space from 136.36 to 78.95 μm, in support of a variety of different THz applications. While still an experiment, this use of a periodically poled fiber to generate THz signals shows great promise for future THz applications.

See "Frequency Tunable Continuous THz Wave Generation in a Periodically Poled Fiber," *IEEE Transactions on Terahertz Science and Technology*, May 2015, p. 470.

USB & ETHERNET

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USB Control Switch Matrices

Model	# Switches (SPDT)	IL (dB)	VSWR (:1)	Isolation (dB)	RF P_{MAX} (W)	Price $ (Qty. 1-9)
NEW USB-1SP4T-A18	1 (SP4T)	0.25	1.2	85	2	795.00
USB-1SPDT-A18	1	0.25	1.2	85	10	385.00
USB-2SPDT-A18	2	0.25	1.2	85	10	685.00
USB-3SPDT-A18	3	0.25	1.2	85	10	980.00
USB-4SPDT-A18	4	0.25	1.2	85	10	1180.00
USB-8SPDT-A18	8	0.25	1.2	85	10	2495.00

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RC-1SP4T-A18	1 (SP4T)	0.25	1.2	85	2	895.00
RC-2SP4T-A18	2 (SP4T)	0.25	1.2	85	2	2195.00
RC-1SPDT-A18	1	0.25	1.2	85	10	485.00
RC-2SPDT-A18	2	0.25	1.2	85	10	785.00
RC-3SPDT-A18	3	0.25	1.2	85	10	1080.00
RC-4SPDT-A18	4	0.25	1.2	85	10	1280.00
RC-8SPDT-A18	8	0.25	1.2	85	10	2595.00

*The mechanical switches within each model are offered with an optional 10 year extended warranty. Agreement required. See data sheets on our website for terms and conditions. Switches protected by US patents 5,272,458; 6,650,210; 6,414,577; 7,633,361; 7,843,289; and additional patents pending.

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Special Report

CHRIS DeMARTINO | Technology Editor

5 Areas Impacting the FUTURE OF SATCOM

Today's satcom market can be analyzed by examining five focal points: Ka-band products, GaN devices, solid-state power amplifiers (SSPAs), traveling-wave-tube amplifiers (TWTAs), and passive components.

1. This MMIC amplifier provides 40 W saturated output power from 13.75 to 14.50 GHz. *(Courtesy of Cree)*

The latest RF/microwave technology is enhancing performance for the satellite-communications (satcom) industry with a wide range of products. Among the products leading this charge are high-power gallium-nitride (GaN) devices, which are empowering the next generation of solid-state power amplifiers (SSPAs). Because GaN technology can achieve performance levels beyond previous-generation technology, SSPA manufacturers can develop their products with better performance in smaller sizes. While GaN technology has certainly received a significant amount of attention, traveling-wave-tube (TWT) technology remains a vital aspect of the satcom industry. Ka-band is another major focus, as the usage of this frequency band has significantly increased in recent years. Many Ka-band products are on the market today, as manufacturers seek to support this frequency band. In addition, manufacturers of passive components are supporting the satcom industry with a wide range of products intended for satcom applications. By taking a closer look at these five areas, it is possible to track the near-term evolution of satcom and discover how RF/microwave technology is enabling the satcom industry.

KA-BAND COMMUNICATIONS

Ka-band is the most recently utilized frequency band to be authorized for commercial satcom. In comparison to other satcom bands, such as Ku-band, Ka-band uses bandwidth more efficiently and is less congested. Thus, Ka-band has become a popular choice for satellite operators in recent years. Although there are some differences worldwide in regards to its exact frequency range, Ka-band is generally considered to span 17.3 to 31.0 GHz. A vast array of RF/microwave products intended for Ka-band satcom applications is available today.

Typical block upconverters (BUCs) used in satellite uplink transmissions convert a band of signals from the L-band frequency range to a higher frequency band, such as C-, Ku-, and Ka-band. The block downconverters (BDCs) that are typically used in satellite downlink transmissions perform the reverse function. They convert a band of signals from a frequency range, such as C-, Ku-, and Ka-band, down to the lower L-band frequency range.

With Ka-band communications becoming more prevalent, high-performance Ka-band BUCs and BDCs are needed to support these requirements. Among companies offering Ka-band BUCs and BDCs are L3 Narda-MITEQ, GeoSync Microwave, Cross Technologies, Jersey Microwave, and WORK Microwave, to name a few. Some suppliers offer the option to purchase these BUCs/BDCs as either an outdoor unit intended for antenna-mounting or as an indoor unit intended for rack-mounting.

HIGH-POWER GaN DEVICES

Today, high-power GaN devices are being used to create the next-generation of GaN-based SSPAs. Prior to the advent of GaN technology, high-power gallium-arsenide (GaAs) devices were widely used to design SSPAs. Thanks to GaN technology's continuous improvements, SSPA manufacturers are now building SSPAs with GaN devices. GaN technology offers a number of performance benefits in comparison to the older GaAs technology. A GaN device can deliver significantly more power density than a GaAs device. Thus, GaN-based SSPAs can be designed by power-combining fewer devices, resulting in greater efficiency. This also enables GaN-based SSPAs to be built in smaller package sizes than GaAs-based SSPAs. New high-power GaN devices have recently been released, providing additional high-power solutions to the satcom market.

These SSPAs will soon be available for both Ku- and Ka-band, providing output power levels to 100 W and 50 W, respectively. *(Courtesy of Mission Microwave Technologies)*

With its portfolio of high-power GaN devices, Cree is one company enabling GaN technology to be utilized in satcom applications. The company recently added to its product line with the release of a new high-power monolithic microwave integrated circuit (MMIC) (*Fig. 1*). This GaN MMIC is a two-stage high-power amplifier (HPA) intended for Ku-band applications. It is available in a 10-lead, 25-×-9.9-mm, metal/ceramic flanged package (model CMPA1D1E025F) or as bare die (model CMPA1D1E030D).

"Cree's Ku-band GaN MMIC HPA was specifically designed in response to customer requests for higher-power and higher-efficiency Ku-band amplifier solutions," said Tom Dekker, director of sales and marketing, Cree RF. "By delivering higher power, gain, and efficiency at an affordable price point, this amplifier will set the new standard for Ku-band performance."

Dekker added, "Covering the 13.50-to-14.75-GHz commercial satcom band, the 30-W gallium-nitride-on-silicon-carbide (GaN-on-SiC) MMIC, two-stage high-power amplifier (HPA) enables the satcom industry to achieve higher-power and more efficient Ku-band solutions than the incumbent traveling-wave-tube (TWT) or GaAs solutions used currently. Applications include unmanned intelligence, surveillance, and reconnaissance (ISR), satcom-on-the-move (SOTM) ground vehicles, manned and unmanned aircraft, and maritime vessels."

High-power GaN devices from Cree are also available for other satcom bands. An example is model CGHV96050F1, which is intended for X-band applications. Ka-band products are also currently being developed.

In addition, Qorvo recently released GaN power amplifiers (PAs) intended for commercial very-small-aperture-terminal (VSAT) and military satcom applications. Those PAs include the TGA2239-CP, TGA2595-CP, and TGA2594-HM. The TGA2239-CP is intended for Ku-band applications, while the TGA2595-CP and TGA2594-HM both target Ka-band applications. The TGA2239-CP provides 35 W output power from 13.4 to 15.5 GHz. The TGA-2595-CP is an 8-W PA covering 27.5 to 31.0 GHz, while the TGA2594-HM provides +36.5 dBm of output power from 27 to 31 GHz. These PAs add to the company's existing portfolio of high-power GaN products.

For its part, Toshiba has a line of high-power GaN devices that are suitable for C-, X-, and Ku-band applications. A new Ka-band, high-power GaN MMIC is also scheduled to be released by the end of this year. This MMIC, the TGM2931-15, will provide 15 W output power from 29 to 31 GHz. The company also recently began production of the TGI5867-130LH, which is a C-band, 130-W GaN device.

SOLID-STATE POWER AMPLIFIERS

With high-power GaN devices available on the market, SSPA manufacturers can design their products using the latest GaN technology. Advantech Wireless, for example, has an extensive product line of GaN-based SSPAs. The company offers GaN-based products for C-, X-, DBS-, and Ku-band. As part of the company's SapphireBlu series, C- and X-band SSPAs with output power levels as high as 6.6 kW are available as well as Ku-band SSPAs with output power levels as high as 3 kW.

One newcomer to the scene is Mission Microwave Technologies. Founded in 2014, the company offers SSPAs with integrated BUCs in a cylindrical package (*Fig. 2*). The company utilizes advanced GaN transistors, power-combining technology, and novel full-system designs to create compact SSPAs.

"The amplifiers in the new Javelin and Stinger product lines deliver more than 100 W and 55 W at Ku-band, respectively," said Francis Auricchio, Mission Microwave Technologies' president and CEO. "Unmatched prime power efficiencies of over 20% are achieved in lightweight, compact form factors that include upconverters, linearization, and integrated power supplies. Both the Stinger and the Javelin amplifiers include a standard user-friendly Bluetooth mobile app remote for monitor-and-control, which makes it simple for users to adjust power levels on the fly without a physical connection to the amplifier. Ruggedized for harsh outdoor environments, our Ku-band amplifiers are available now, with 50-W and 25-W Ka-band amplifiers following right behind."

Explaining the innovative packaging of these SSPAs, Auricchio noted, "Our unique packaging was developed as we worked to realize the absolute minimum in amplifier size, weight, and volume, which is difficult to achieve by more traditional methods without sacrificing performance and reliability. Typical rectangular-shaped units tend to have heatsinking across the amplifier that is either uniform and underutilized or inefficient and unbalanced. Our cylindrical package optimizes the heatsinking to where it is needed most and provides airflow over the complete amplifier body. These aspects together maintain thermal performance—even in a small form factor. Satcom customers continue to request smaller and lighter units, especially for mobile and man portable applications. By optimizing the form factor of our products, we have been able to deliver this without sacrificing performance."

GaN-based SSPAs are also offered by Teledyne Paradise Datacom. Outdoor SSPAs are available for S-, C-, X-, and Ku-band with a wide range of output power levels. The company provides various packaging options for these SSPAs.

The Outdoor PowerMAX, Teledyne Paradise Datacom's new high-power SSPA system, was recently unveiled. Its system architecture is a multi-module amplifier system, which allows PowerMAX systems to be configured with a large variety of output power levels. It also is a scalable amplifier system, as an Outdoor PowerMAX system may be initially configured with four modules and later upgraded to eight modules in the field. The C- and X-band versions of the Outdoor PowerMAX system can generate an output power level as high as 10 kW, while the Ku-band version provides as much as 5.7 kW output power.

3. Ku-, DBS-, and Ka-band TWTAs are now boasting output power levels as high as 1250 W. *(Courtesy of Tango Wave)*

TRAVELING-WAVE-TUBE AMPLIFIERS

With the excitement created by GaN technology, it may seem like traveling-wave-tube amplifiers (TWTAs) have been abandoned. However, TWTAs are still being used today. In fact, the technology has advanced in recent years. TWTA manufacturers continue to release new products, demonstrating that this technology is alive and well.

Yet the debate between SSPAs and TWTAs continues. Manufacturers of SSPAs like to point out the advantages that SSPAs have over TWTAs. The introduction of GaN technology has added fuel to the fire, as GaN-based SSPAs can provide performance improvements over previous-generation GaAs-based SSPAs. While SSPAs do have their benefits, TWTAs can still provide advantages over SSPAs in some applications. Thus, deciding on a preferred amplifier technology is dependent on the specific application.

One company providing TWTAs to the satcom market is Tango Wave. The company offers TWTAs for DBS-, Ku-, and Ka-band with output power levels as high as 1250 W (*Fig. 3*). Those products are designed for direct-to-home (DTH), global up-linking, satellite news gathering (DSNG/SNG), broadcasting, voice/data, mobile up-linking, and maritime applications.

Comtech Xicom Technology recently introduced the Ku- and DBS-band SuperPower Series TWTAs, available in both frequency bands as either outdoor antenna-mount units or as indoor rack-mount units. The XTD-2000KHE model is a Ku-band TWTA that provides 750 W of linear output power while drawing less than 3200 W of prime power. The XTD-1500DBSHE model is a DBS-band TWTA that provides 560 W of linear power while drawing only 2500 W of prime power.

The SuperLinear TWTA product line from Communications & Power Industries ranges in efficiency from 13% for lower-power models to over 22% for 2500-W amplifiers. LifeExtender is its new, patented technology, designed to increase a TWT's lifespan by preserving the active coating on the cathode surface. A TWT reaches the end of its life when its cathode barium reserve is exhausted. The rate of barium evaporation is determined by the cathode temperature, which is in turn determined by the cathode heater voltage setting. With LifeExtender, the cathode heater voltage is adjusted over time to minimize the rate of barium depletion, thereby maximizing the life of the cathode. As a result, a TWT's lifespan can increase by 30% to 50%.

PASSIVE COMPONENTS

Passive components are an integral part of any satcom system. These components include filters, couplers, isolators, and more. Many manufacturers offer a wide range of passive components for satcom applications.

For example, Advanced Technical Materials (ATM) offers an entire product line of components for Ka-band applications. These components cover the uplink frequency range of 27.5 to 31.0 GHz and the downlink frequency range of 18.3 to 20.2 GHz. The company offers both coaxial and waveguide models. The product line includes power dividers, attenuators, phase shifters, couplers, and more.

Another example of a company providing passive components to the satcom market is ETG Canada. The company's SSPA original equipment manufacturer (OEM) product line is intended to allow SSPA OEMs to purchase waveguide components from the same vendor. This product line includes adapters, circulators/isolators, terminations, and couplers.

To summarize, a significant amount of activity is occurring in the RF/microwave industry in support of satcom applications. GaN technology is receiving a significant amount of attention, as it is enabling the next-generation of SSPAs. New high-power GaN devices will continue to be released in the near future. TWT technology also continues to be an important contributor to the satcom industry. And as Ka-band satellites continue to be implemented, suppliers are providing components to support this frequency band. mw

Cree, Inc. Celebrates 15 Years of GaN MMIC Technology

In August 2000, Cree, Inc. announced the successful fabrication of a GaN monolithic microwave integrated circuit (MMIC), an amplifier which—in its first iteration—provided 20 watts pulsed RF output power at 9 GHz. The paper announcing the achievement was presented at the Biennial IEEE Cornell University Conference on Advanced Concepts in High Performance Devices [1], stating, "The latest developments have allowed us to demonstrate the first operational MMIC amplifier in the GaN-on-SiC HEMT platform." Figure 1 shows the basic structure of the process used for the first device, while Figure 2 is a die photo of the completed MMIC amplifier.

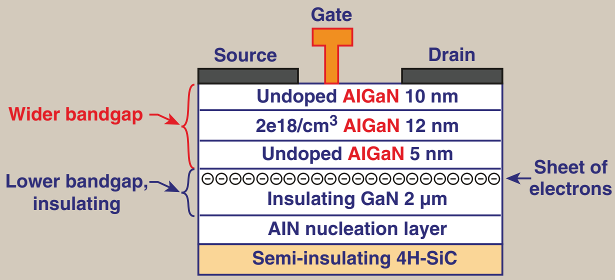

Figure 1. GaN/AlGaN HEMT epilayer structure on a semi-insulating silicon carbide substrate.

This initial demonstration of GaN MMIC technology showed that it was not only a viable alternative to GaAs devices, but was greatly superior in power density, not just to support higher power output, but also allowing smaller die size for equal power. By comparison, wide band gap GaN-on-SiC technology can produce five times the power as GaAs on the same size die; or the same power on a die one-quarter the area.

Further developments launched in this first wave of GaN technology included the first substrate vias, which eliminated the need for coplanar waveguide structures and other complex ground-independent layouts. 100 µm gold-plated vias through the thinned SiC and GaN layers provide ground connections with minimal resistance. Another development was the high voltage (>150 volts) MIM capacitors required for the higher power level and the device's operating voltage of +50 VDS.

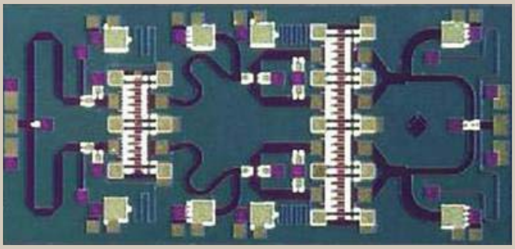

Figure 2. The operational two-stage MMIC amplifier, with a 3 mm input stage driving a 6 mm output stage, using on-chip matching and biasing.

History of Cree's GaN MMIC Development

Following the 2000 announcement of the first practical MMIC, Cree continued to refine the fabrication process and develop additional devices at various operating frequencies and power levels. Among the company's efforts was extensive research that has created accurate, scalable models for GaN HEMT power devices, giving designers of both discrete circuits and MMICs the necessary tools for product development. Volume production of MMICs began in 2008 with the CMPA0060002 (Figure 3) and CMPA2560025F parts designed into counter-IED jammers.

Also in 2008, Cree announced the first commercially available GaN RF MMIC products. Broadband power amplifier MMICs, the CMPA0060002 and CMPA2560025 (Figure 4), were the first "catalog" MMICs released in packaged and die formats. The CMPA0060002 is a wideband 5-watt distributed amplifier operating from DC to 6 GHz, while the CMPA2560025 is a higher-power, 25-watt reactively matched amplifier. At the same time Cree also announced the expansion of its standard full-wafer (SFW) MMIC Foundry service to include shared multi-project (SMP) "pizza mask" foundry runs on a quarterly basis.

The January 2010 release of a new GaN HEMT MMIC power amplifier, the CMPA0060025F, gave military and ISM product designers a device that provides 25 watts output power over an instantaneous bandwidth of 20 MHz to 6 GHz. Taking advantage of its high power density, the CMPA0060025F is packaged within a 0.25 square inch footprint, the smallest available device for this power and bandwidth at the time.

Satcom applications were addressed in 2011 with the CMPA5585025F MMIC, a 50 ohm, 25 watt peak power two-stage GaN HEMT HPA in a multi-pin ceramic/metal package measur-

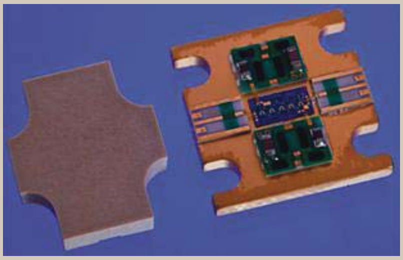

Figure 3. The CMPA0060002F was the first GaN MMIC in volume production, becoming available in 2008.

ing 1” x 0.38”. It provides 15 watts of linear power with 20 dB power gain over an instantaneous bandwidth of 5.8 GHz to 8.4 GHz. This is the first GaN MMIC to be demonstrated for satellite communication applications, providing outstanding linear efficiency and power gain. In addition, this device operates at 28 volts vs. 12 volts for GaAs MESFETs, drawing less current and reducing power distribution losses. These advantages have a large impact on thermal management and enable reductions in both size and weight.

Also in 2011, the CMPA2735075 was released, the first GaN MMIC to achieve >60% PAE for S-Band RADAR applications (RF pulse width of 300 μs and a 20% duty cycle). This device is a two-stage GaN HEMT high power MMIC amplifier providing a saturated RF output power of 75 watts over 2.7 to 3.5 GHz with a power gain of 20 dB in a small package footprint (0.5” x 0.5”).

Cree MMICs have included low noise amplifiers (LNAs) since 2010. The CMLA2540001D was the first commercial low noise GaN HEMT MMIC, featuring 1.7 dB Noise Figure in the 2.5 to 4 GHz band. The device had a small-signal gain of 28 dB and input/output return losses of greater than 10 dB. Input/output third order intercept points were 12 dBm and 38 dBm, respectively.

As of April 2011, the company had shipped commercial GaN-on-SiC RF power transistor and MMIC products with more than 10,000,000 watts of combined RF output power. The milestone demonstrated the consistency, reliability and proven performance of Cree’s GaN HEMT and GaN MMIC technology. The 10 million watt figure included only commercial RF products and excluded an additional 1.5 million watts shipped for GaN MMIC foundry services.

Cree attained this milestone while maintaining a remarkable failure-in-time rate (FIT rate) of less than 10-per-billion device hours, which is up to 80% lower than the typical FIT rates for other RF power transistor technologies. With support from DARPA and Title III, this reliable process earned the U.S. Department of Defense (DoD) manufacturing readiness level eight (MRL 8) designation. Awarded for its production of GaN monolithic microwave integrated circuits (MMICs), this designation verifies Cree’s ability to provide assured, affordable and commercially viable production capabilities and capacities for items essential to national defense. The designation was granted upon Cree’s successful completion of the DoD’s Defense Production Act (DPA) Title III Gallium Nitride on Silicon Carbide Production Capacity Program.

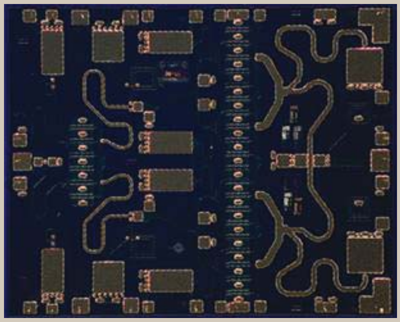

Figure 4. The first commercial MMICs from Cree were the CMPA0060005 and CMPA2560025 (shown here).

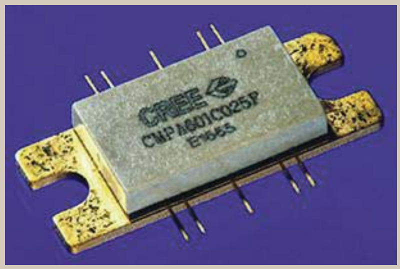

Figure 5. Wide bandwidth is the primary feature of the CMPA601C025F, which covers 6-12 GHz with 25 watts output power.

Recent MMIC Advancements

Cree recently introduced the CMPA601C025F, a broadband 6-12 GHz, 25W MMIC PA. This wide bandwidth device is an excellent choice for the design of EW systems, instrumentation, and broadband communication systems in this frequency range. This GaN HEMT MMIC is housed in a thermally enhanced, 10-lead ceramic package (Figure 5).

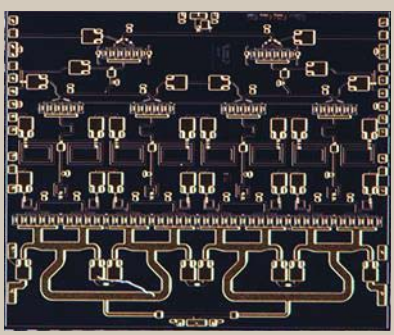

Figure 6. Cree’s newest development is a high power Ku-Band MMIC providing 30 watts in the 13.5-14.75 GHz commercial satellite band.

Among the most recent advances is the highest power Ku-Band MMIC known to be available on the market, the CMPA1D1E025F. Covering the 13.5-14.75 GHz commercial satcom band, the new 30W GaN MMIC two-stage high power amplifier (HPA) will allow the satcom industry to achieve higher power, more efficient Ku-Band solutions than the incumbent TWT or GaAs solutions utilized today. The device is offered in 10-lead, metal/ceramic flanged package or as a bare die (CMPA1D1E030D, shown in Figure 6). The 50 ohm device operates at 40V VDD and delivers performance of 20 dB linear gain, 42 dBm average output power and drain efficiency of 20% while maintaining linearity providing -33 dBc adjacent channel power with the satcom OQPSK signal.

Summary

2015 marks the 15th anniversary of the first GaN MMIC devices, developed by Cree, Inc. for applications in military countermeasures, radar, satcom, instrumentation from S-Band through Ku-Band. From the first announcement of a 9 GHz power amplifier, to the current array of MMIC products, Cree has continued to advance the state-of-the-art in GaN device design, fabrication and packaging. These advances have been made in cooperation with military and commercial customers that will benefit from the high performance, smaller size and higher efficiency achieved with GaN technology. ■

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1. S. T. Sheppard, W. L. Pribble, D. T. Emerson, Z. Ring, R. P. Smith, S. T. Allen, J. W. Milligan and J. W. Palmour, “*Technology Development for GaN/AlGaN HEMT Hybrid and MMIC Amplifiers on Semi-insulating SiC Substrates.*” 2000 IEEE/Cornell Conference, Ithaca, NY.
2. Complete product data for the devices noted above, as well as other Cree MMICs, is available at: *www.cree.com/rf*

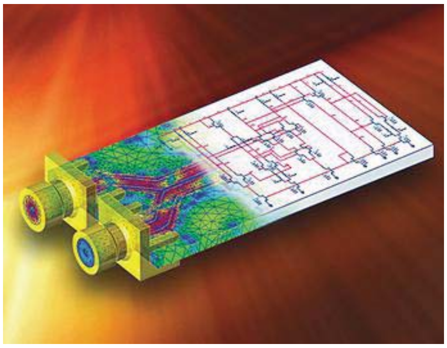
CREE

JACK BROWNE | Technical Contributor

Solidify Design Efforts Using EM Simulators

Once considered software curiosities, EM simulators are now essential tools for many high-frequency circuit and system designers wanting to predict EM field patterns.

AT ONE TIME, RF engineers were resigned to fabricating several iterations or "takes" of a circuit design before fixing all the flaws and achieving expected performance levels. With modern electromagnetic (EM) simulation software, however, designers can predict the performance of their circuits down to the impedances and connections between circuit elements on a printed-circuit board (PCB), so that the design can be fabricated successfully the first time.



1. A full 3D EM simulator such as EMPro is capable of modeling the fields around a 3D structure such as a connector and its interface to a PCB to help optimize impedance matching. *(Image courtesy of Keysight Technologies)*

EM simulators have advanced from mere curiosities to dependable design tools. With their capabilities to characterize the EM fields in and around circuit components and PCBs, and to design circuits using qualified models of circuit components and PCB materials, these software tools are now design necessities for many RF/microwave engineers. They are helping to eliminate or at least minimize all those extra prototyping steps once associated with fine-tuning a high-frequency circuit design, by allowing designers to perform fine-tuning of a circuit on a PC loaded with a choice of EM simulation software. Many excellent commercial EM software tools are currently available, as software modules within multiple-function computer-aided-engineering (CAE) software suites and as stand-alone EM simulators. The choice depends on the demands of each application.

EM simulation software is based on three different technology approaches, all relying on the solution of Maxwell's equations for a particular EM structure: the finite-element method (FEM), the method of moments (MoM), and the finite-difference-time-domain (FDTD) method. All three approaches are effective for a wide range of EM circuit and system simulation challenges but, as with any other high-frequency CAE software tool, an EM simulator is only as good as the models it uses.

MODELING METHODS

These three EW simulation numerical modeling methods (there are more) apply different techniques to arrive at the same solution. The FDTD method operates in the time domain while the FEM and MoM approaches work in the frequency domain. This means that the FDTD method represents a structure to be analyzed by means of a number of equations for the EM field patterns around and through the structure, and solves for these equations in discrete steps in time. The FEM approach solves for differential equations representing the characteristics of the EM fields around a component and its interconnecting circuitry, dividing the structure of a component to be analyzed into finite elements. Linear equations solve for the scalar or vector electrical potential differences between elements, with large components resulting in larger volumes to be modeled and larger numbers of equations to be solved.

For EM simulators based on the FDTD numerical modeling approach, Maxwell's equations are solved directly in the time domain, which allows relatively fast solution of larger electrical problems, such as antennas. This EM analysis approach has also shown to be effective for solving broadband as well as ultrawideband (UWB) circuit designs in a single run, rather than having to execute multiple iterations of an analysis to achieve a final result. An FDTD simulator can provide a great deal of deal in a single modeling pass, including EM near-field and far-field results in the same simulation run.

A great deal of research has been performed to compare the different numerical modeling methods for EM simulation and analysis, without any clear superiority evident for any one method. In all cases, the requirements of a particular application will help decide which of the numerical methods is a better fit for that application. Some researchers have concluded that both the FEM and FDTD methods provide a great deal for small electrical problems while EM simulators based on MoM techniques will require less computer processing power and time to solve for electrically large EM analysis problems, such as antennas. Others have found that FDTD-based EM simulators can also do quite well when modeling electrically large designs, depending upon the application and the circuit materials, so there is no clear choice for an EM simulator based on these numerical solution approaches.

CHOICE OF TOOLS

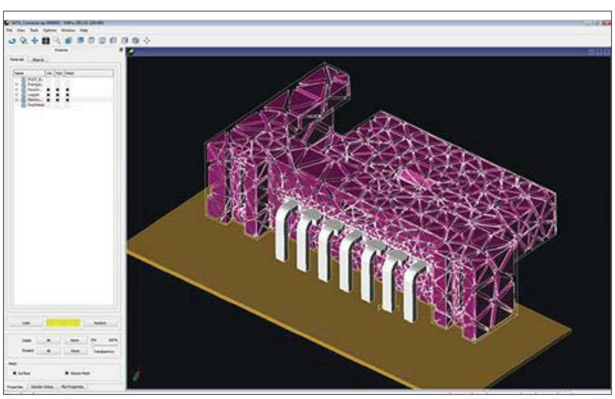
As noted, EM simulators can be found as integrated modules within suites of software simulators or as dedicated software programs that allow a user to focus just on performing an EM simulation. An example of the former case is the popular Advanced Design System (ADS) software suite from Keysight Technologies (www.keysight.com), which contains the firm's EMPro full three-dimensional (3D) EM simulation software and Momentum 3D planar EM simulation software programs. The full 3D EM simulation software provides the means for analyzing the EM fields around all the dimensions of an electrical structure, such as a connector (*Figs. 1 and 2*) while a 3D planar EM simulator is an effective tool for studying the EM field responses along the surface of a circuit or through a microstrip or stripline transmission line. In addition to these EM simulators, the ADS software suite boasts a host of circuit and system simulation software tools, circuit and system optimization tools, an electro-thermal simulator to analyze thermal effects in designs, access to extensive libraries of models, and connectivity to the company's extensive lines of test equipment.

This capability to work with different test equipment, such as microwave vector network analyzers (VNAs), makes it possible to capture component S-parameters for building new EM models when needed. ADS also works with the firm's EMPro software, a separate, dedicated 3D EM modeling and simulation tool. Tight compatibility between ADS and EMPro allows objects and models modeled and analyzed in EMPro to be saved in ADS libraries for use by other software programs. In addition, EMPro contains some practical functions for circuit designers, such as the capability to draw structures and create arbitrary 3D shapes and structures for EM analysis. The program offers the unique capability to shift from its normal FEM technology basis to the use of FDTD technology when modeling and analyzing electrically large structures, such as antennas.

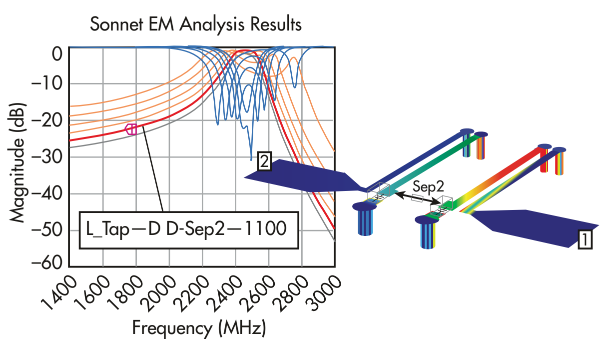
Similarly, the NI AWR Design Environment from National Instruments (www.ni.com), with its Microwave Office suite of software design tools, combines a large number of modeling and simulation software program modules within a single PC package. The software suite, developed by Applied Wave Research (AWR) which was acquired by National Instruments, includes circuit schematic and layout design, linear and nonlinear circuit simulation, and EM simulation.

The EM simulators, the AXIEM and Analyst software programs, combine for many noteworthy features, including a function known as Automatic Circuit Extraction (ACE) which reduces the time to model circuits transferred from layout programs by automatically identifying transmission lines and interconnections and assigning best-case models for a simulation. The NI AWR Design Environment software collection also includes the Visual System Simulator software for system simulation and Analog Office for analog circuit design. As with the Keysight Technologies software simulation suite, this software suite is compatible with the company's many lines of test instruments to aid in modeling and analysis.

A firm long associated with EM simulation solutions as well as with Maxwell and his equations, Sonnet Software



2. The use of full 3D EM simulation, such as this connector example from EMPro, can predict the EM field patterns to be expected from a complex electronic structure. *(Image courtesy of Keysight Technologies)*

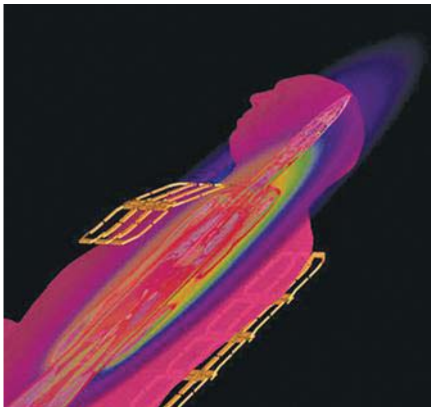


3. Planar 3D EM simulation software can model the EM field effects of transmission lines and interconnections at high frequencies, to help determine wideband performance. *(Image courtesy of Sonnet Software)* (www.sonnetsoftware.com), offers EM simulation software rather than on integrated collections of different software programs. The firm's Sonnet Suites provide 3D EM planar analysis of different electronic structures, including PCBs and their interconnections, allowing users to work with files from popular circuit layout programs for modeling purposes as well as to create circuit and component models with internal layout tools. The Sonnet Suites can model and analyze single- and multiple-layer PCBs on different circuit-board materials as well as the viaholes that interconnect the circuit layers (*Fig. 3*).

The Sonnet Suites feature tight compatibility with other companies' software tools, including the ADS tools from Keysight Technologies and the AWR Microwave Office suite of simulators from National Instruments (www.ni.com). In addition to the Sonnet Suites, the company offers Blink, an EM simulator tailored for the design of passive circuit elements on integrated circuits (ICs), and SonnetLite, a free, scaled-down version of the Sonnet Suites EM simulator software.

Another firm long associated with EM simulation, ANSYS (www.ansys.com), also offers a software tool dedicated to EM simulation, in the form of its High Frequency Structure Simulator (HFSS) software. This full-wave 3D EM analysis tool is well known for its capabilities in modeling the lowest-frequency circuits, such as power supplies, through the highest-frequency designs, at millimeter-wave frequencies. The EM simulator can actually combine multiple numerical modeling methods (FEM and MoM) to achieve the most accurate solutions of EM field equations in the shortest computational time possible. A user can select a numerical solution approach for a given design and the software program will automatically generate a mesh for solving the design's EM field equations. The EM simulation software even incorporates a linear circuit simulator to aid with designing and modifying matching networks when optimizing the performance of a design. The EM simulator is fully compatible with commercial electronic design automation (EDA) software programs such as tools from Cadence Design Systems (www.cadence.com) for the design of analog and digital ICs.

Remcom (www.remcom.com) also offers a software tool dedicated to EM simulator, now available in Release 7.5: the XFdtd EM simulation software. Based on FDTD numerical analysis, the latest release of this EM simulator features a new circuit element optimizer module (for such circuit elements as resistors, capacitors, and inductors) to speed the matching of antennas for portable communications devices, including such effects as whether an antenna is being held in a user's hand or the effects of being near a user's hand. This represents a complex modeling challenge, given the dielectric variations represented by a human hand (*Fig. 4*), but modeling information that can impact the performance of active electronics as well as a portable communication device's antenna. This simulator has been used for a wide range of commercial, industrial, and military simulation tasks, from optimizing the impedance matching of wireless antennas to the modeling of ground-penetrating-radar (GPR) systems.



4. Some EM simulators may rely on multiple numerical solvers or combinations of solvers to achieve the most effective simulation results. *(Image courtesy of Remcom)*

Integrated Engineering Software (www.integratedsoft.com) has developed a number of different simulation engines, including for EM and magnetic-field simulation and analysis. Some of their software tools operate with three or more numerical solvers, including their own boundary element method (BEM) which is effective in modeling the EM fields in the space around a component or transmission line. By combining different solvers, such as BEM, FEM, and FDTD, within the same EM simulator, hybrid solution approaches can be employed which combine the capabilities of the different field solvers.

For any RF/microwave engineer interested in learning more about the rewards of using an EM simulator as part of the high-frequency design process, an excellent starting place is the Sonnet Software website and SonnetLite, a free EM simulation software program. Although this is a feature-limited version of the firm's powerful Sonnet Suites 3D planar EM simulation tools, it is quite capable of performing analysis on a wide variety of RF/microwave circuits. The firm also provides a 150-page "Getting Started" guide to the Sonnet Suites for free download. It is a useful educational tool on EM simulation in general and in learning how to use the Sonnet software, including SonnetLite, in particular.

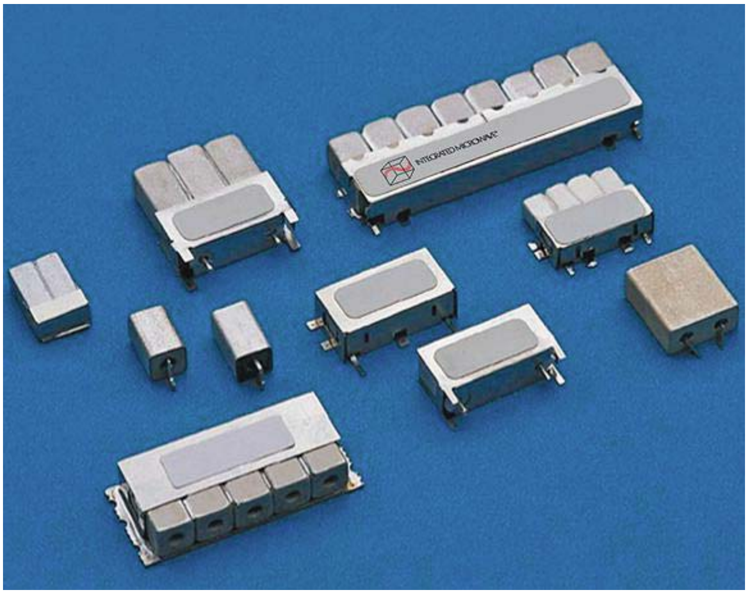
In addition to this and other free EM simulation software tools, many EM simulator suppliers provide demonstration version of their software. These are either programs limited in function, or software that provides full analysis and simulation functionality but is usable only for a short time. For example, Keysight Technologies is currently offering free trials of its various software programs, including the ADS software suite with its EM simulators and the system-level simulator SystemVue. Also, ANSYS offers complimentary copies of its ANSYS Student software for educational purposes. In all cases, EM simulation software is a useful tool for RF/microwave circuit and system design, and is steadily becoming a larger part of many high-frequency engineers' design routines. mw

CHRIS DeMARTINO | Technology Editor

6 Types of Resonators Used Across the RF/Microwave Universe

By examining different resonators, it is possible to determine how they can be implemented in component designs.

RESONATORS ARE KEY to the performance of a range of RF/microwave components, such as oscillators and filters. The types of available resonators include coaxial, dielectric, crystal, ceramic, surface acoustic wave (SAW), and yttrium iron garnet (YIG). Given this variety, it is essential for designers to understand the characteristics of the various resonators.



1. These ceramic resonators can be used in applications spanning 200 MHz to 10 GHz. *(Courtesy of Integrated Microwave Corp.)*

COAXIAL RESONATORS

Coaxial resonators are commonly used to design components like voltage-controlled oscillators (VCOs), coaxial-resonator oscillators (CROs), and filters. This form of resonator is essentially a ceramic coaxial line. Often, coaxial resonators are implemented in oscillators as high-quality-factor (high-Q) inductors, thereby creating a resonant circuit when paired with a capacitor or varactor diode. A coaxial resonator has an outer conductor with an approximately square-shaped cross-section and a cylindrical center conductor.

Coaxial resonators have two different forms: a quarter-wavelength ($\lambda/4$) resonator with one end shorted and the opposite end open; and a half-wavelength ($\lambda/2$) resonator with both ends open.

Because a coaxial resonator's material has a high dielectric constant (ε_r) value, components designed with them can be reduced in size. Typical ε_r values range from 10 to 100.

Ceramic coaxial resonators are offered by companies like Integrated Microwave Corp. (*Fig. 1*). These resonators are intended for a range of applications, including oscillators, bandpass/bandstop filters, and electromagnetic-interference (EMI) filtering. They can be used to satisfy frequency requirements ranging from 200 MHz to 10 GHz. Customers can select from nine different sizes, which range from 2 to 18 mm. In addition, IMC offers the resonators in five different materials.

For its part, Trans-Tech offers a line of coaxial resonators that are intended to serve as ceramic coaxial line elements. They are available in seven sizes and four ε_r values. The company offers these resonators for applications that span from ultra-high frequency (UHF) to 6 GHz.

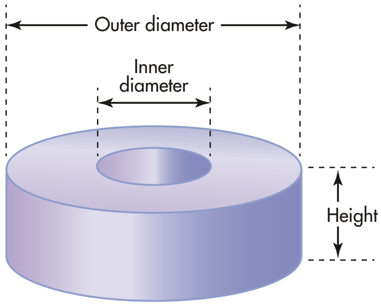
Ceramic coaxial resonators are also offered by Tusonix. The company offers these products in four sizes and four ε_r values. They cover 800 MHz to 5.9 GHz. Their intended applications include oscillators, filters, and duplexers.

Meanwhile, Temex Ceramics offers a product line of coaxial resonators intended for telecommunications, military and space, industrial, and wireless applications. The resonators are offered for applications from 300 MHz to 6 GHz. In addition, selections can be made from different sizes along with several ε_r values.

> Electromagnetic fields are largely confined within a dielectric resonator, allowing radiation losses to be extremely small.

DIELECTRIC RESONATORS

A dielectric resonator can be used to replace resonant cavities in components, such as filters and oscillators. It is typically a disc-shaped material with a high ε_r value. This high ε_r value provides a significant advantage, enabling the size of a circuit designed with a dielectric resonator to be significantly smaller than when an air-filled cavity resonator is employed. Electromagnetic fields are largely confined within a dielectric resonator, allowing radiation losses to be extremely small and a high quality-factor (Q) to be achieved (*Fig. 2*).



2. This illustration represents a typical disc-shaped dielectric resonator.

Although a dielectric resonator will resonate in several modes, the $TE_{01\delta}$ (transverse-electric) mode is most commonly used in many applications. When operating in this mode, a dielectric resonator may be magnetically coupled to a circuit by several different methods. One method is to couple the resonator to a microstrip line. This approach can be used to create components like dielectric-resonator oscillators (DROs).

One company offering dielectric resonators is MCV Microwave. These components are typically used in oscillators, satellite-based communication equipment, microwave filters, and combiners. They can be selected for applications spanning 260 MHz to 26 GHz.

In addition to their line of coaxial resonators, Temex Ceramics offers a selection of dielectric resonators. They are intended to be used for applications like telecommunication infrastructures, alarms/detection, military and space, and automotive. The resonators cover 800 MHz to 50 GHz. They are available in six different materials.

Dielectric resonators are also offered by Trans-Tech for both commercial and military applications. Among their applications are cellular base station filters and combiners, direct broadcast satellite (DBS) receivers, and motion detectors. They are intended for applications ranging from below 850 MHz to above 32 GHz.

CRYSTAL RESONATORS

Quartz crystals can be used as high-quality electromechanical resonators. Their piezoelectric properties allow them to be used as frequency-control elements in crystal oscillators. Quartz crystals offer high Q and superior frequency stability. In fact, their high Q is the main reason why crystal oscillators are often employed instead of LC oscillators.

Piezoelectric materials have the capability to convert mechanical energy into electrical energy and vice versa. When a mechanical stress is applied, an electric charge is generated. This electric charge is proportional to the applied mechanical stress. The same material becomes strained when an electric field is applied.

In a quartz crystal resonator, a thin slice of quartz is placed between two electrodes. This quartz slice is obtained by cutting the original material at specific angles in regard to the various axes, which determines the resonator's physical and electrical parameters. Thus, a quartz crystal can be classified by the manner it was cut from the original material. Resonators can be generated from a variety of cuts, such as the widely used AT- and SC-cuts.

According to IQD Frequency Products, when the frequency of an applied voltage approaches one of the mechanical resonance frequencies of the quartz slice, the amplitude of the vibrations becomes very large. The accompanying displacement current also increases, which decreases the magnitude of the device's effective impedance. Thanks to the impedance's rapid change as the frequency varies near resonance, quartz crystal resonators can be used as frequency-control elements in crystal oscillators.

Near a resonant frequency, a quartz crystal can be represented by an equivalent electrical circuit (*Fig. 3*). C_0 represents the shunt capacitance of the electrodes in parallel with the holder capacitance. L_1 is the electrical equivalent of the critical mass, while C_1 represents the crystal stiffness or elasticity. R_1 represents heat loss due to mechanical friction.

As an example, IQD Frequency Products offers a range of quartz crystals spanning 10 kHz to 250 MHz with frequency stability as low as ±5 ppm. High-specification AT-cut quartz crystals are also offered, providing a fundamental mode frequency from 10 to 42 MHz. In addition, the company offers crystals for automotive applications.

Crystek also offers a range of quartz crystals in various packaging options from 1.8432 to 150 MHz. Among the additional suppliers of crystal resonators are Vectron, Murata, Oscilent, and Abracon, to name a few. Murata, for example, claims that its crystals can be used for communication satellites, mobile communication devices, automotive electronics, TVs, personal computing, and home information appliances.

CERAMIC RESONATORS

Ceramic resonators are a viable alternative to quartz crystals. Although they are less accurate than quartz crystals, ceramic resonators do offer other benefits. For instance, they can be manufactured in smaller packages and at lower costs. In addition, they provide a lower start-up time than quartz crystals.

Ceramic resonators utilize the mechanical resonance of piezoelectric ceramics, such as lead zirconium titanate (PZT). Two metal electrodes are evenly placed on both the top and bottom of the ceramic substrate. When a voltage is applied, the substrate vibrates between the electrodes. The resonant frequency is determined by the substrate's thickness. A ceramic resonator's equivalent electric circuit is identical to a quartz crystal. Because its operation is similar to a crystal, it can be used in the same oscillator configurations.

For example, Murata offers the CERALOCK Series ceramic resonators. These products are intended for a range of applications including automotive electronics, communications, personal computing, and medical/healthcare equipment. Other suppliers of ceramic resonators include Oscilent and Abracon.

SAW RESONATORS

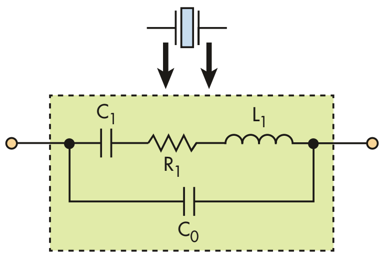
A surface acoustic wave (SAW) that is propagating at the surface of a piezoelectric crystal can be used to carry information. A basic SAW resonator consists of an interdigital transducer and two grating reflectors, which are fabricated on a piezoelectric material by a photolithographic process. The reflectors form a resonant cavity, which the transducer couples to the external circuit. Like crystal resonators, SAW resonators can be used to build oscillators—often in higher-frequency applications. They can also be used to build bandpass filters, such as those offered by Qorvo, Phonon, and Vectron, to name a few. The crystal resonator's equivalent LC circuit takes the same form. Automotive remote-keyless-entry (RKE) devices, security systems, and garage door openers are some examples of consumer products that commonly use SAW resonators.

As an example, ECS Inc. International offers a variety of SAW resonators. They are available in both surface-mount and through-hole packages. The

company offers these SAW resonators for wireless security and remote control applications.

A portfolio of SAW resonators from Murata spans 300 MHz to 1 GHz while achieving center frequency tolerances as low as ±50 kHz. The resonators are available in a variety of packages.

In addition, Abracon offers a line of SAW resonators covering 117.2 to 916.5 MHz. These products are intended for applications like wireless remote controllers and mobile communications. They are available in both surface-mount and through-hole packages. Lastly, a range of SAW resonators covering 100 MHz to 1.1 GHz is offered by Golledge Electronics. The products are available in a variety of packages. In addition, custom specifications are available.



3. This electrical circuit represents a quartz crystal's electrical equivalent near a resonant frequency.

YIG RESONATORS

Yttrium iron garnet (YIG) resonators can be used to design oscillators and filters. A YIG is a crystal that has a very high Q, enabling oscillators to be designed with very low phase noise. Multi-octave bandwidths are another benefit than can be achieved by using YIG resonators.

YIGs are most often used in a sphere configuration. However, other shapes have also been used over the years. A YIG will resonate at microwave frequencies when it is immersed in a direct-current (DC) magnetic field. This resonance is directly proportional to the strength of the applied magnetic field, which is generated using an electromagnet, a permanent magnet, or a combination of both.

A number of YIG-based products are offered by Micro Lambda Wireless. That company's YIG-tuned oscillators cover 500 MHz to 44 GHz with output power levels that range from 0 to +23 dBm. The company also offers a line of YIG-tuned filters that span 500 MHz to 50 GHz.

In summary, a wide range of resonators is available from a plethora of suppliers. With many potential applications, it is important to have an understanding of the different varieties and how they can be implemented in a design. Each type of resonator is well suited for different applications, which prompts the need to understand the performance characteristics offered by each resonator type. mw

Design Feature

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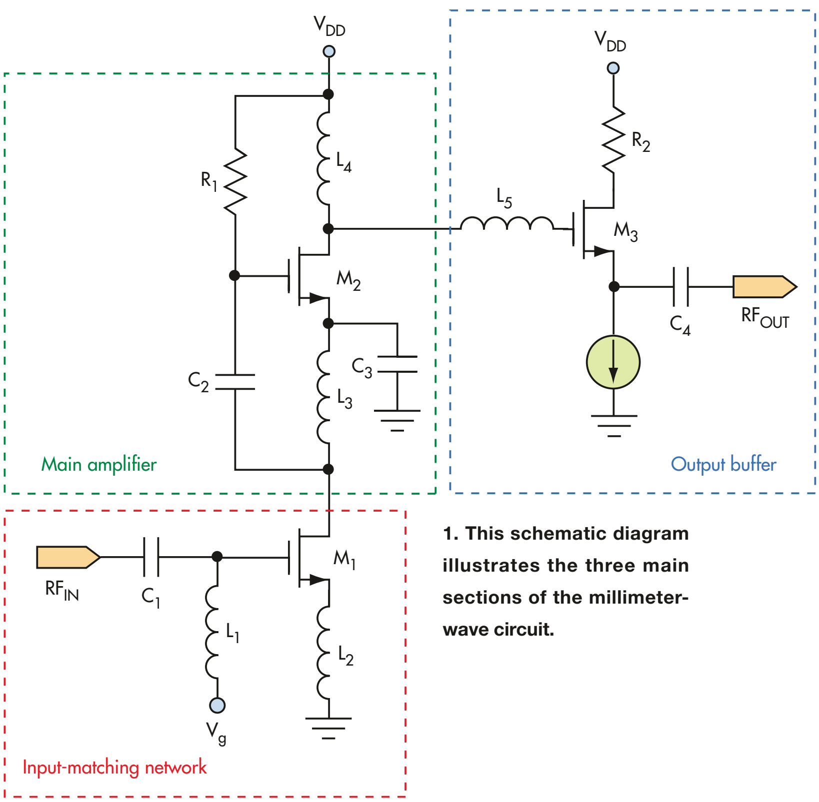
60- to 80- Boosts E-Band Radios

Based on GFET device technology, this broadband amplifier provides a powerful combination of high gain and low noise figure at millimeter-wave frequencies.



1. This schematic diagram illustrates the three main sections of the millimeter-wave circuit.

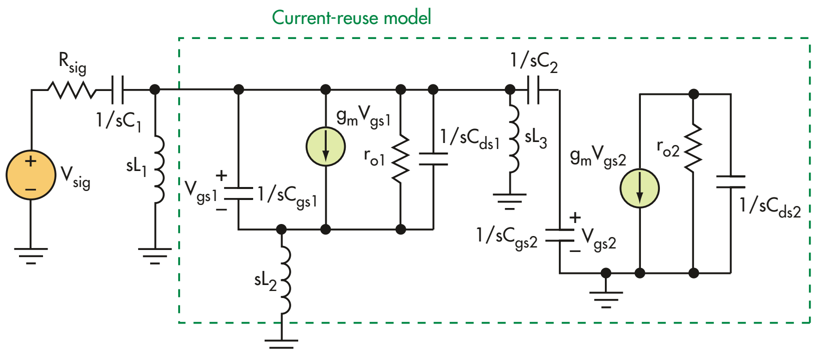
As wireless communications continuously push toward higher frequencies, bandwidth for radio waves that support high data rates has become available at millimeter-wave frequencies (above 30 GHz). Components are needed in support of communications systems at those frequencies, with one key component being the low-noise amplifier (LNA).

Among other functions, LNAs are vital for achieving high sensitivity and extended radio range in millimeter-wave receivers. With an eye to extending communications to frequencies at 60 to 80 GHz, an LNA based on graphene field-effect-transistor (GFET) active devices was designed and constructed for E-band radios. But, rather than use a traditional cascaded circuit stage, the amplifier employs current-reuse techniques, with a stagger tuning approach used to achieve wideband gain. Essentially, the LNA's first stage

GHz LNA

reduces power dissipation through current reuse, while the second stage provides high gain via precision tuning for excellent output impedance matching.

In terms of active devices, FETs have seen wide use in high-frequency applications thanks to their quick responses to variations in gate voltage.[1] This can be achieved by using a small gate length and high mobility of charge carriers.[2] However, due to short-channel effects, FETs can suffer from drain-current saturation and drain-induced barrier lowering, as well as threshold-voltage rolloff issues.[3,4] The impact of these effects on amplifier performance can be minimized by using an FET with a very small gate-controlled area.[5]



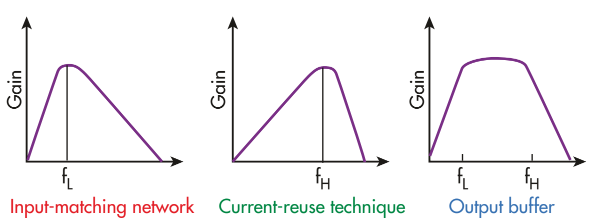
2. Shown is an equivalent-circuit small-signal model of the LNA (without the buffer).

A MOVE TO GRAPHENE

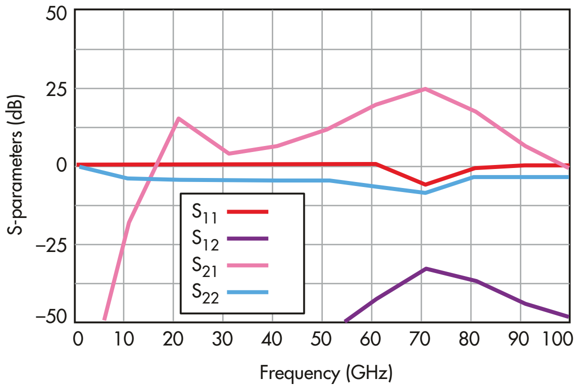
Numerous semiconductor materials other than silicon have been utilized to implement millimeter-wave LNAs with high performance levels. These materials include graphene and compounds formed of Group III-V elements on the chemical periodic table of elements. Since graphene substrate material is composed of only a one-atom-thick, single layer of carbon atoms, it significantly reduces the channel area controlled by the transistor gate.

High-electron-mobility-transistor (HEMT) active devices based on Group III-V semiconductor materials have a channel thickness of 10 to 13 nm, which is greater than that of graphene-based FETs. Some silicon-on-insulator (SOI) FETs reported in the technical literature feature channel thickness of 2 nm, but they suffer low carrier mobility because of poor interfaces.[6] These FETs are also characterized by variations in channel thickness, which result in fluctuations in device threshold voltage. This same problem occurs in HEMTs based on Group III-V materials if the channel thickness is reduced to 2 nm.[7]

To address these issues, research is being carried out on GFET-based devices for high-speed, high-frequency RF/microwave applications. Such research includes the design and development of a GFET-based LNA for milli-



3. A stagger tuning technique helps to achieve the impedance matching needed for high wideband gain at millimeter-wave frequencies.



4. The LNA's measured S-parameters are: $S_{11} < -9$ dB; S_{21} (peak) = 25 dB; $S_{12} < -35$ dB; and $S_{22} < -10$ dB.

meter-wave applications. In this LNA, a current-reuse stage is used for low power dissipation and to achieve high gain over a wide frequency range. It also includes a highpass inductive-capacitive (LC) filter to attain good input impedance matching. To improve noise performance, the amplifier incorporates an output buffer comprised of a source follower structure with no feedback.

MILLIMETER-WAVE LNA SETUP

Figure 1 shows a schematic diagram of the millimeter-wave low-noise amplifier. In the first stage, transistors M_1 and M_2 are mounted in a common-source configuration. An equal amount of bias current is shared between the two transistors to realize higher gain than an LNA in a conventional cascaded configuration. The source follower placed in the output stage acts as a buffer to achieve extended bandwidth by using the series LC resonance with the gate capacitance of transistor M_3, C_{gs3}.

The design of the millimeter-wave LNA can be detailed according to its three main sections: the input matching circuit, the main amplifier circuit, and the output buffer circuit.

While the LNA's first stage is implemented with the function of reducing overall amplifier power consumption, the second stage's design aims for good output impedance matching and achieving optimum amplifier gain across the frequency range of interest. The source of transistor M_1 is connected via an inductor to stabilize the bias current. Coupling this source-degenerated inductor with the integral highpass filter (HPF) of the LNA produces input matching.

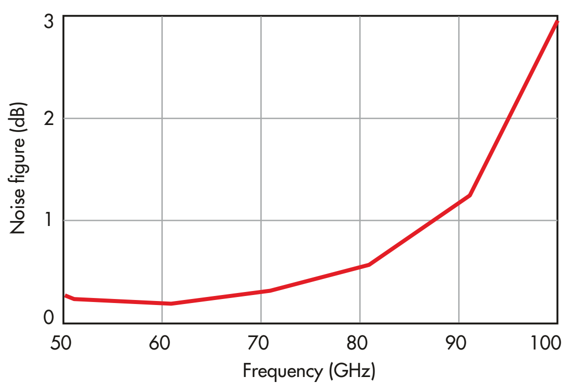
Since added resistance at this stage would increase noise figure for the overall circuit, the input impedance-matching network does not contain any resistors. As such, the source-degenerated inductor, L_2, is used for input impedance-matching purposes. Using a T-equivalent model and the parasitic capacitance of the transistor eliminates the imaginary part for the impedance. Furthermore, the real part of the impedance is responsible for the 50-Ω impedance matching.

Figure 2 presents a simplified, low-frequency, small-signal, equivalent-circuit model of the impedance-matching network. The small-signal equivalent input impedance from transistor M_1 to transistor M_2 is calculated by calculating the following relationship for that impedance, which is designated as Z_{M12}:

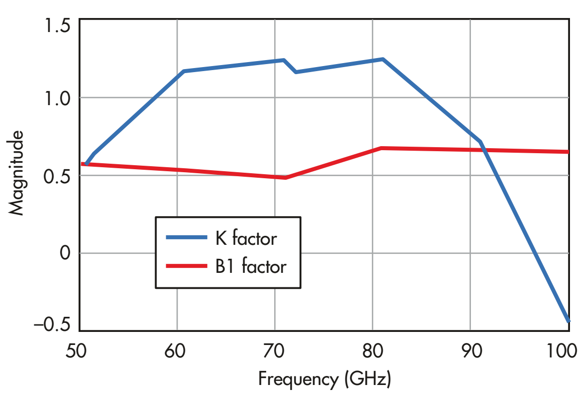
$$Z_{M12} = (r_{o1}||1/sC_{ds1}) + [(1/sC_{gs2} + 1/sC_2)||sL_3] \quad (1)$$

where the gate-to-source capacitance of transistor M_2 is denoted by C_{gs2}. Inductor L_3 and capacitor C_2 are used for interstage impedance matching. Moreover, the output channel resistance of transistor M_1 is r_{o1} and C_{ds1} is the capacitance between the source and drain of transistor M_1. According to the resistance reflection rule, the input impedance Z_{input} can be written as:

$$Z_{input} = 1/sC_1 + (sL_1||(1/sC_{gs1} + [sL_2||Z_{M12}/(1 + g_{M1}r_{o1})]) \quad (2)$$



5. The LNA maintains noise figure of less than 0.6 dB across its operating bandwidth.



6. The LNA's K and B1 factors indicate excellent stability for the millimeter-wave circuit.

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For lower power consumption, the LNA design employs a current-reuse configuration. The LNA makes use of two-stage cascade architecture for high gain and wide bandwidth. The first and second stages are designed to resonate at the lower and higher frequency bands of interest, respectively *(Fig. 3)*.

Broadband operation is realized via a stagger tuning method, using the resonances of the two amplifier stages to achieve flat frequency response.[8] The LNA's first-stage lower resonant frequency, f_{Low}, can be expressed as:

$$f_{Low} = (1/2\pi)(1/L_3C_2)^{0.5} \quad (3)$$

The higher resonant frequency for the LNA's second stage can be derived from Eq. 4:

$$f_{High} = (1/2\pi)(1/L_4C_4)^{0.5} \quad (4)$$

"The GFET-based LNA shows significantly improved noise-figure performance compared to reported CMOS/HEMT technologies and may help boost the development of radio receivers operating in the 60- to 80-GHz frequency range."

In this LNA design, the f_{Low} and f_{High} frequencies were chosen as 60 and 80 GHz, respectively.

The transfer of signal energy from the amplifier's input to output ports for high gain is accomplished with the output buffer. This portion of the amplifier includes the output impedance-matching circuitry. Transistor M_4 serves as the source follower. The low-frequency equivalent output impedance can be approximated by using the relationship of Eq. 5:

$$R_{out} = (1/g_{M3})(||r_{o3}||r_{o4}) \quad (5)$$

In general, if an LNA's Rollett's stability factor (or K factor) is greater than unity, the amplifier will be unconditionally stable over the full operating frequency range. Another parameter often used to evaluate the stability of an

Top 10 Tips for GaN Success

High-performance gallium nitride on silicon carbide (GaN on SiC) semiconductor technology is making inroads in infrastructure, aerospace, defense, and commercial products. Qorvo™ — a pioneer of GaN for high-power RF devices, power amplifiers, transistors, oscillators, switches, and more — strives to deliver high-performance, reliable devices to solve the RF challenges for the world's leading companies. What are the hallmarks of a quality GaN supplier? Read on to learn what to look for.

1 PROVEN DESIGN TOOLS

Nonlinear models, electromagnetic finite element modeling, and stability and loop stability analyses aid in designing best-in-class power and efficiency in high-power MMICs. Qorvo's robust design methodology leads to more first-pass successes and reliable designs.

2 ROBUST POPULATION TESTING

Industry standards allow testing of small samples of GaN products. Although this is usually adequate, Qorvo has fully characterized product failure modes by testing large populations at temperatures of interest over extended times.

3 HIGH MEDIAN TIME TO FAILURE (MTTF)

MTTF estimates a device's lifetime. Suppliers should measure device reliability at a minimum of three temperatures because higher temperatures lead to shorter device life. All Qorvo GaN products have an MTTF at 200°C extrapolated to over 10^7 hours.

4 NO PRECONDITIONING

Some suppliers add time and cost by requiring a preconditioning or burn-in step before delivery. Qorvo's GaN solutions have maturity in performance, reliability and manufacturing yield data that enables products to ship without preconditioning, confident in delivering high-quality performance every time.

5 JUNCTION TEMPERATURE CHARACTERIZATION

Low-resolution techniques like infrared microscopy underestimate product life expectancies and peak junction temperatures. Qorvo's thermal models and finite element analyses are verified with micro-Raman measurement, permitting more accurate temperature and device-life prediction.

6 ACCURATE FAILURE CRITERIA

One common parametric failure criteria is a current drop of 20% of I_{max}. Qorvo sets its I_{max} parametric failure at a 10% drop, ensuring less than 1dB of power degradation over the life of the part.

7 LOW FALLOUT RATES

Reliability is also measured by rates of catastrophic failure or fallout. Less than 0.002% of Qorvo's GaN devices fallout per 1 million hours at 200°C. Also check the expected operating life, T1, T5, and T10, at which 1%, 5%, and 10% of devices, respectively, will have failed based on a large population of devices.

8 PROVEN FIELD PERFORMANCE

Do your GaN supplier's products have a demonstrated track record of reliability in the field? Qorvo's fielded GaN power amplifiers have accumulated more than 65,800,000 device-hours with a field failure rate of less than 0.013% failures per million device-hours.

9 HIGH TOLERANCE FOR ENVIRONMENTAL STRESS

Check for devices that stand up to the highly accelerated stress test. (HAST), which measures device performance after 96 hours at 105°C, 85% relative humidity, and atmospheric pressure up to 4 atm. THB compliance is also a critical measurement.

10 MANUFACTURING READINESS LEVEL

MRL is the Department of Defense's measurement of a supplier's ability to transition a product successfully from the factory to the field with operational maturity, technology development; and quality and manufacturing management. Qorvo was the first GaN supplier to achieve MRL 9.

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LNA is the B1 factor. If the B1 factor has a positive value, the LNA is said to be stable.

PERFORMANCE RESULTS

The millimeter-wave LNA circuit implements a GFET with channel length of 100 nm. The LNA's power consumption was 12 mW with a +3-V dc supply voltage. The amplifier provides peak gain, S_{21}, of 25 dB at 70 GHz. Across the full frequency range, peak gain measures 25 dB and average gain is 18 dB *(Fig. 4)*.

In addition, noise figure is less than 0.6 dB for the full operating frequency range of 60 to 80 GHz, which is a significant achievement at this E-band spectrum *(Fig. 5)*. The amplifier achieves S_{11} of less than –9 dB, S_{22} of better than –10 dB, and S_{12} of better than –35 dB. Also, K and B1 factor test results reveal high stability *(Fig. 6)*. The *table* offers a comparison of the millimeter-wave LNA's performance parameters with a sampling of available state-of-the-art LNAs at these frequencies.

In short, this graphene-based LNA is a strong candidate for E-band wireless receivers and transceivers. The multistage design uses the same bias current for both common-gate and common-source stages, and features a cascode-based, current-reuse topology for low power consumption. Use of LC HPF circuitry accomplishes input matching and applying a stagger tuning technique achieves wideband gain. The GFET-based LNA shows significantly improved noise-figure performance compared to reported CMOS/HEMT LNA technologies *(see the table)* and may help to boost the development of radio receivers operating in the 60- to 80-GHz frequency range. mw

COMPARING MILLIMETER-WAVE LNAs

Research source	Ref. 11	Ref. 10	Ref. 9	This work
Technology	mHEMT	pHEMT	CMOS	GFET
Frequency (GHz)	60 – 90	50 – 65	57.9 – 80.4	60 - 80
DC power (mW)	45	15.2	10	12
Noise figure (dB)	2.0	1.0	4.8	0.6
S_{11} (dB)	≤9	≤7	≤10	≤9
S_{12} (dB)	≤30.2	≤50	≤40	≤35
S_{21} (dB)	27	23.5	11.2	25
S_{22} (dB)	≤25	≤10	≤10	≤10

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Compact Bandpass Filter Serves Dual-Band Needs

A novel circuit configuration yields a miniaturized bandpass filter with dual passbands that helps save space in GSM/DCS wireless-communications systems.

Bandpass filters help sort the many different frequency bands used in modern communications systems. With the growth of portable electronic communications devices, miniaturization of these filters takes on greater importance. On that front, designers leveraged an Archimedes spiral capacitor and ground-loaded elliptical ring stubs to develop a compact dual-band bandpass filter (BPF). The filter, with passbands of 0.77 to 1.07 GHz and 1.65 to 2.02 GHz, is well-suited for GSM/DCS wireless-communications systems.

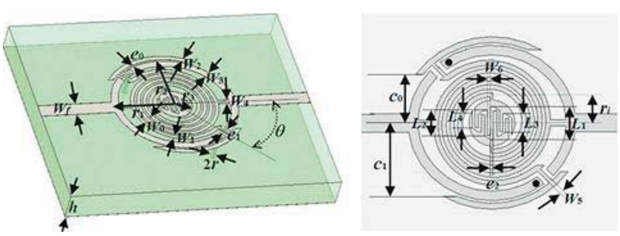
By using these novel circuit techniques, the filter can be made quite small on a printed-circuit board (PCB). The Archimedes spiral capacitor's spiral arms can be extended for connection to the outer portion of the ground-loaded stubs to achieve a second resonant mode for dual-band operation. The filter's size is determined by $0.051\lambda_g \times 0.052\lambda_g$, where λ_g is the guided wavelength of the center frequency of the lower-frequency band in the dual-band filter configuration.

When fabricated and characterized with the aid of commercial RF/microwave test equipment, the filter's two 3-dB passbands were found to be 0.77 to 1.07 GHz (the 32.6% passband at 0.920 GHz) and 1.65 to 2.02 GHz (the 20.2% passband at 1.835 GHz). As a result, the filter becomes a good component complement to GSM/DCS wireless-communications systems.

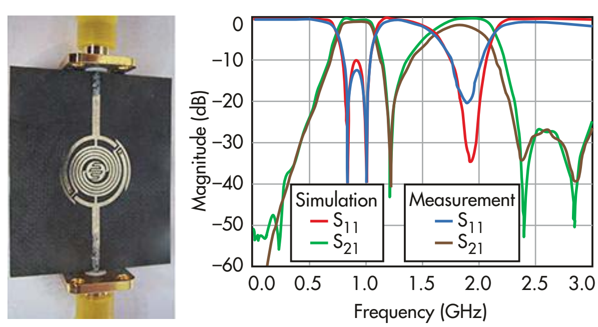
STAYING SEPARATE

Wireless-communications systems such as GSM/DCS-based networks rely on economical and highly integrated (preferably small) dual-band BPFs to maintain separation between occupied frequency bands.[1-5] For example, as ref. 1 details, half-wavelength stepped-impedance resonators were used for dual-band filter designs.

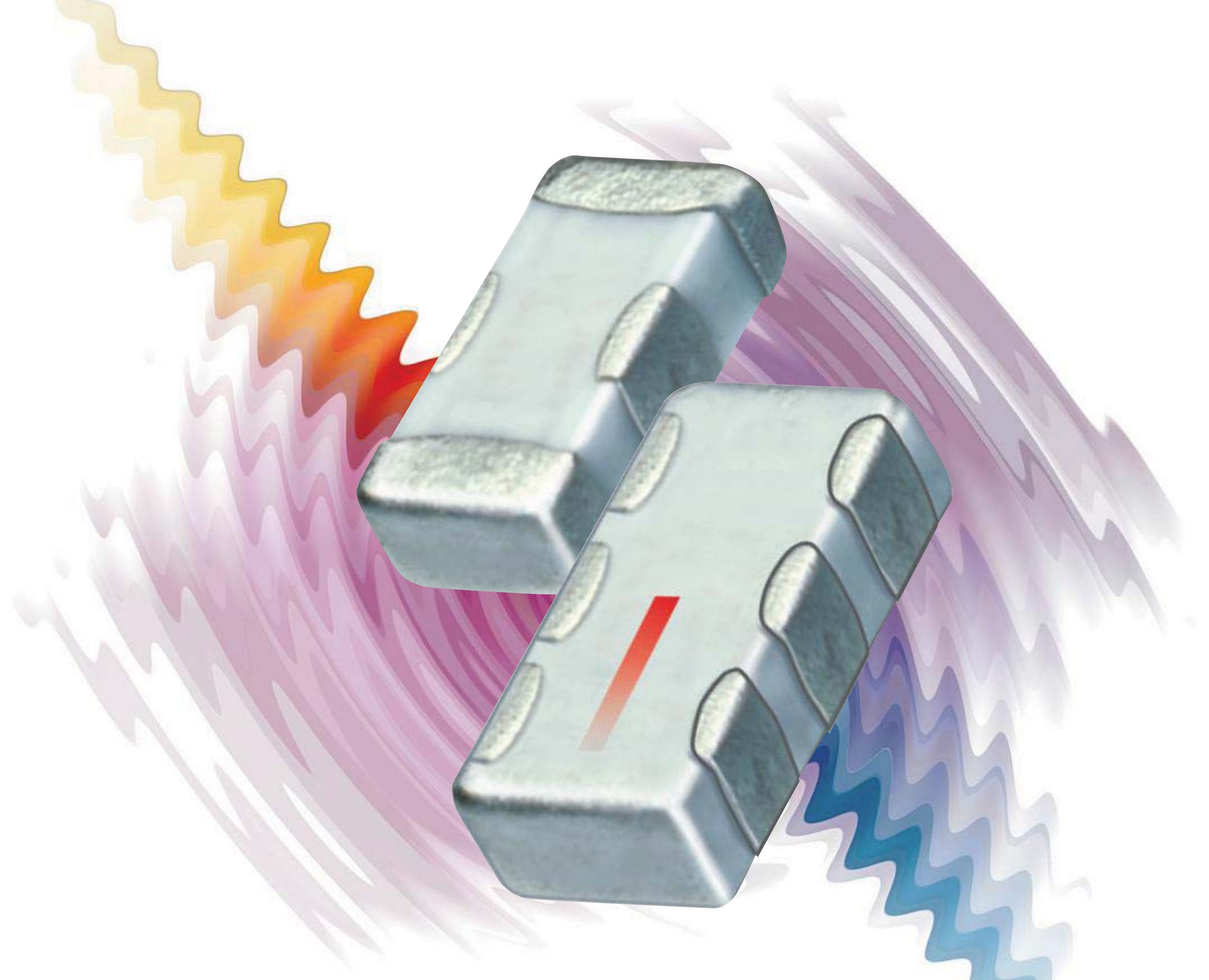
The design approaches in refs. 2 and 3 employed two different resonators to achieve the dual-mode resonances required for a dual-band filter. In ref. 4, multilayer structures and embedded resonators were used for a dual-band filter design.



1. The compact BPF is shown in a three-dimensional (3D) view (left) and in a view from the top (right).



2. The fabricated BPF (left) achieved a close match between computer-simulated performance and actual measured performance (right).



In ref. 5, series and shunt resonators were proposed as a practical solution to a dual-band filter.

While the performance levels of these various dual-band filter approaches were quite good, they all shared one mechanical trait—none of the design methods yielded compact circuitry. In terms of achieving filter miniaturization, a compact BPF based on an Archimedes spiral capacitor and short-loaded stubs was presented in ref. 6, but it is a single-band filter. As a solution for a compact dual-band filter, the latter design approach was adapted by extending the spiral arms of the Archimedes spiral capacitor for connection with the outer portions of the ground-loaded stubs to excite a second resonant mode. This made it possible to fabricate an extremely compact dual-band BPF.

Figure 1 shows the configuration of the compact dual-band filter, with a three-dimensional (3D) view *(left)* and a top view *(right)* of the filter. It was fabricated on 5580 PCB material from Rogers Corp. (www.rogerscorp.com). The substrate material has relative permittivity (ε_r) of 2.2 and height (h) of 0.508 mm.

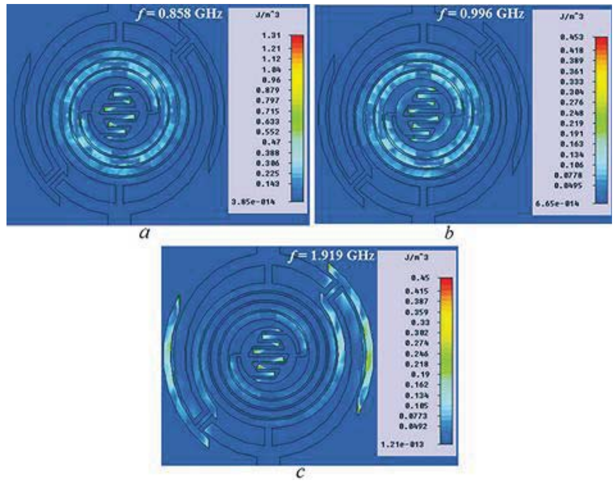
A two-turn Archimedes spiral capacitor in this circuit extends to the etched gap of an elliptical ring. Then, the two arms of the lengthened spiral are connected with the outer elliptical stubs. The elliptical ring connects with the ground plane by means of two viaholes with radius r. The parameters of the spiral capacitor *(Fig. 1)* include r_i = 2.1 mm, W_0 = 0.8 mm, W_1 = 0.5 mm; the gap of the spiral is determined as $(W_0 - W_1)/2$ = 0.15 mm.

Additional parameters for the spiral capacitor are W_f = 1.52 mm; W_2 = 0.5 mm; W_3 = 0.8 mm; W_4 = 0.5 mm; W_5 = 0.3 mm; W_6 = 0.3 mm; r_1 = 6.9 mm; r_2 = 6.4 mm; r_3 = 1.9 mm; e_0 = 0.2 mm; e_1 = 1 mm; e_2 = 0.2 mm; c_0 = 4 mm; c_1 = 6 mm; L_1 = 2.7 mm; L_2 = 2.1 mm; L_3 = 1.5 mm; L_4 = 0.8 mm; h = 0.508 mm; and $\theta = 45°$.

The novel filter was fabricated on low-loss commercial PCB circuit material as shown on the left in *Fig. 2*. Good agreement exists between the measured and simulated performance results of the bandpass filter *(Fig. 2, right)*. The measured and simulated results reveal the two passbands, with S_{21} forward-transmission responses in good agreement for passband 3-dB bandwidths.

The 3-dB bandwidths of the first passband are 0.75 to 1.08 GHz and 0.77 to 1.07 GHz. The 3-dB bandwidths of the second passband are 1.59 to 2.14 GHz and 1.65 to 2.02 GHz. The first passband has two simulated resonances, at 0.858 and 0.996 GHz, and the second passband has a simulated resonance at 1.919 GHz. Three measured transmission zeros occur at 1.22, 2.38, and 2.85 GHz, with respective attenuation levels of –40.99, –34.66, and –39.44 dB.

Electric energy densities at resonant frequencies of 0.858, 0.996, and 1.919 GHz are depicted for the bandpass filter in *Figs. 3a, b, and c*, respectively. Electric energy densities at 0.858 and 0.996 GHz are concentrated on the spiral and the center interdigital capacitor. Furthermore, the electrical energy density is exceptionally strong at the outer elliptical stubs at 1.919 GHz.



3. These plots show the measured electrical energy density of the BPF at 0.858 GHz (a), 0.996 GHz (b), and 1.919 GHz (c).

The filter provides relatively wide bandwidths of 32.6% and 20.2% in its two passbands in a relatively small circuit structure, compared to previous efforts to design and fabricate dual-band BPFs for similar commercial wireless-communications applications. Its small size is achieved through novel use of an Archimedes spiral capacitor, ground-loaded elliptical ring stubs, center-loaded interdigital capacitor, and outer elliptical stubs. Another key benefit is that the filter can be fabricated on low-cost, commercially available PCB material with excellent results.

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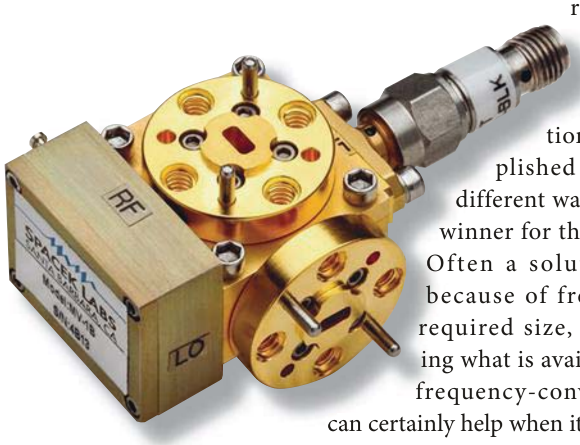
JACK BROWNE | Technical Contributor

Sort Through FREQUENCY-CONVERSION

Many methods are available for translating frequencies higher or lower in many forms, including monolithic and discrete components and integrated assemblies with additional functions.

Frequency conversion is part of a large number of RF/microwave systems, for many different applications. Signals are shifted higher or lower in frequency for different reasons, often to accommodate the signal-processing requirements of transmitters or receivers. Frequency translation can be accomplished in a number of different ways, with no clear winner for the best approach. Often a solution is chosen because of frequency range, required size, or cost. Knowing what is available in terms of frequency-conversion options can certainly help when it is time to decide which is the optimum frequency-translation technique for a particular application.



This mixer employs waveguide connectors for millimeter-wave frequency coverage and an SMA coaxial connector for an IF range of 10 MHz to 3 GHz. *(Photo courtesy of Spacek Labs)*

Frequency mixers are probably the most commonly used RF/microwave component for frequency conversion, whether as discrete components or as part of an integrated circuit (IC). Mixers are so named because they mix two input signals to produce an output signal. They rely on a nonlinear device, such as a Schottky diode or a GaAs field-effect transistor, to achieve the frequency translation. A mixer's three ports *(see figure)* are commonly referred to as the radio frequency (RF), local oscillator (LO), and intermediate-frequency (IF) ports. The LO port is always for an input signal, typically provided by a stable, low-noise signal source that is mixed with a signal at one of the other two ports. In a typical mixer configuration, the RF port handles a higher range of frequencies than the IF port, so that when the LO is mixed with a signal at the IF port, the two signals essentially add in frequency and a higher-frequency signal is produced at the RF port. The process is called "frequency upconversion." When the LO is mixed with signals at the RF port, the frequencies of the two signals subtract and a lower-frequency difference signal is produced at the IF port, in a process called frequency downconversion.

Both forms of frequency conversion are widely used in high-frequency communications systems, often to upconvert signals into a frequency band reserved for modulation and transmission, and then to downconvert them at a receiver for demodulation and signal processing to recover voice, video, or data carried by those signals. Mixers are available in several formats, including for single-sideband (SSB)

CHOICES

and double-sideband (DSB) frequency conversion. In a DSB mixer, two sidebands are produced from the combining of the two input signals and available at the mixer's output port. In an SSB mixer, one of the sidebands is filtered within the mixer, so that only one of the translated-frequency sidebands is available at the mixer's output port.

Mixers have been fabricated with single nonlinear devices, in circuits known as single-balanced mixers, as well as with multiple diodes and transistors, known as double-balanced or triple-balanced mixers. Mixer configurations have also been optimized for specific performance characteristics, such as image-reject mixers and in-phase/quadrature (I/Q) mixers for phase-modulated signals. Frequency mixers have long proven their reliability and consistency over a wide range of operating conditions, and are the most popular RF/microwave component solution for frequency conversion applications.

Frequency mixers have long been one of the most popular methods for performing frequency upconversion and/or frequency downconversion in high-frequency electronic systems.

Frequency mixers can be characterized by a number of performance parameters, including the frequency ranges of the three ports, the conversion loss of the frequency translation through the mixer, the isolation between ports, the component's 1-dB compression point or output power, the voltage standing wave ratio (VSWR) at the ports for impedance-matching purposes, the noise figure, and the intermodulation distortion (IMD). For those seeking an introduction to frequency-mixer performance parameters, Marki Microwave (www.markimicrowave.com) offers its "Mixer Basics Primer" for free download from its website. In addition, a recent article in *Microwaves & RF*; "Understanding Mixers and Their Parameters" (July 2015, http://mwrf.com/components/understanding-mixers-and-their-parameters) provides a full review of key mixer-performance parameters and different mixer types.

DIVIDING AND MULTIPLYING

Of course, a frequency mixer is only one of a number of different approaches to RF/microwave frequency conversion, with frequency dividers and frequency multipliers also commonly used for frequency downconversion and frequency upconversion, respectively. As their names suggest, frequency dividers and frequency multipliers provide division or multiplication of an input signal typically by means of a nonlinear active device, such as a diode or a transistor, and also by means of passive circuits, such as filters that are used to select specific harmonic or subharmonic frequencies as an output from a fundamental-frequency input signal.

Frequency dividers and multipliers typically operate at integer division and multiplication ratios, according to the harmonic relationships of a signal of interest. For example, frequency dividers are commonly available in divide-by-2, divide-by-4, and divide-by-8 formats to effectively perform downconversion on an input signal. Similarly, a frequency multiplier can be specified for multiplication at integer multiplication ratios, such as multiply-by-2, multiply-by-4, and multiply-by-8 formats. Frequency dividers are often realized as integrated-circuit (IC) prescalers. These ICs can be furnished in compact surface-mount-technology (SMT) packages, with high division ratios and additional circuit functions such as amplification and filtering to minimize the number of additional components needed for frequency downconversion.

In frequency downconversion applications where extreme frequency translation may be needed, such as in a receiver to shift input RF signals to a much lower intermediate-frequency (IF) range, or for frequency synthesis in a phase-locked loop (PLL)—where the phase of a higher-frequency source is being compared to a lower-frequency reference source to stabilize the higher-frequency source—prescalers with high division ratios are often used.

By combining a pair of frequency dividers in one component, it is possible to create a dual-modulus prescaler or prescaler with two selectable division ratios, such as divide-by-N and divide-by-N +1 division ratios where N is an integer. In fact, dual-modulus prescaler ICs are not uncommon, with division ratios of 32/33 and 64/65. The division ratio of such miniature frequency dividers, often supplied in SMT and multipin device packages, is typically selected by standard logic control, such as CMOS or transistor-transistor-logic (TTL) control signals.

INTEGRATING HIGHER

As with frequency dividers, frequency multipliers can be designed as active or passive circuits. Passive frequency multipliers, which are most often doublers, are available for some

> "One of the trade-offs in using these IC-based frequency-conversion devices is limited input-power range because of the small sizes of the devices."

extremely high-frequency applications, such as the model HMC1105 passive frequency multiplier fromAnalog Devices (www.analog.com). It operates with input signals from 20 to 40 GHz and produces output signals from 40 to 80 GHz. (The company, which also supplies prescalers at similarly high frequencies, added a large number of frequency multiplier products with its acquisition of IC developer Hittite Microwave Corp.) Active frequency multipliers typically include frequency conversion circuitry as well as additional supporting circuit functions. Miniature frequency upconverters from MACOM, for example, provide output signals to 40 GHz in surface-mount and QFN packages. Based on balanced, image-reject mixer technology, these packaged upconverters feature a single IC that incorporates the mixer, an LO buffer amplifier, an LO frequency doubler or variable attenuator, and an RF buffer amplifier.

FACING TRADE-OFFS

One of the trade-offs in using these IC-based frequency-conversion devices is limited input-power range because of the small sizes of the devices. Input power for frequency translation is usually limited to 1 W (+30 dBm) or less, which results in limited-power upconverted or downconverted output signals, especially in passive devices with conversion loss. For applications such as battery-powered radios and other portable communications devices, the low signal levels are usable for many systems. But in systems that rely on higher-level signals, such as EW and radar systems, frequency-conversion solutions capable of handling larger input-signal ranges are required. This type of frequency-translation solution is usually realized in the form of a subsystem module assembled with discrete components capable of operating at higher-signal power levels

Due to size and space constraints in modern electronic systems, frequency upconversion and downconversion functions are increasingly provided as part of integrated assemblies which may include a frequency mixer, LO and IF amplification, and even a PLL-stabilized LO source. Such integrated frequency-conversion assemblies are typically tailored to a specific application and set of environmental conditions to provide optimized performance.

For generating the high-frequency signals needed for satcom systems, for example, a number of manufacturers have developed frequency upconverters known as block upconverter (BUC) or block downconverter (BDC) assemblies. Although they are physically much larger than the IC-based prescalers and multipliers used in portable applications, these frequency-conversion assemblies can be equipped with many additional useful functions, including built-in test equipment (BITE) and integrated frequency-synthesized LO sources. A BUC or BDC typically includes all necessary components, including filters and amplifiers, for full frequency translation over a required frequency range without need of additional components.

As an example, a BUC/BDC assembly, developed by Mercury Systems (www.mrcy.com) for satcom applications at Ku-band and L-band frequencies. For satellite uplink applications, the assembly enables frequency upconversion from L-band to Ku-band frequencies. For satellite downlinks, the assembly can also perform frequency downconversion from Ku-band to L-band frequencies. The upconverter portion of the assembly includes input and output power level detection, multiple amplification stages, multiple filter stages, and programmable temperature compensation. The downconverer section features output power level detection, multiple amplification stages, multiple filter stages, and a high-performance oscillator. The assembly, which works with an external 10-MHz reference oscillator, includes PLL-stabilized synthesized LOs for up- and downconversion.

FILTER-BASED APPROACHES

In addition to these frequency conversion methods, different filter-based approaches and techniques with nonlinear amplifiers are sometimes employed to generate and isolate desired harmonic multiples of an input signal or to create short pulses as needed for radar systems. Step-recovery diodes, for example, are often used as the basis for harmonic comb or impulse generators, to create a pulse or a higher-frequency harmonically related output signal from a supplied input signal. A line of step-recovery-diode-based comb generators from Herotek (www.herotek.com) works with input signals from 10 MHz to 10 GHz (and power levels to 1 W), providing output signals to 26 GHz. These comb frequency multipliers can fit within hermetic drop-in houses for tight packaging requirements.

This is a sampling of the different frequency conversion techniques available to RF/microwave engineers, with clear differences in such attributes as frequency range, size, and power-handling capabilities. If any trend is apparent, it is the growing integration of functions found in smaller IC-based prescalers as well as in larger BUCs and BDCs. The increased integration ultimately translates into simpler design at the design level with reliable performance as a result of single-function components that have been well matched in impedance and performance levels. mw

JACK BROWNE | Technical Contributor

Making Links with CABLES AND

Interconnecting components come in many shapes and sizes, with performance a function of rigidity or flexibility, mechanical design, and construction materials.

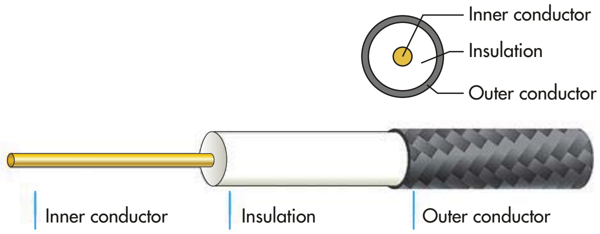
Cables and connectors are often overlooked in the course of designing a high-frequency system. Specifiers typically consider basic requirements—including frequency range, insertion loss, impedance, power-handling capability, and even length and diameter—but a number of other cable/connector characteristics can impact system performance. Not all cables, connectors, and cable assemblies are the same, and knowing the differences can help secure optimum interconnection components for a particular application.

Proper design practices will treat cables and connectors as any other component in a high-frequency system. Cables and connectors are specified by frequency range and numerous other performance parameters, like insertion loss, power-handling capability, and voltage standing wave ratio (VSWR). Many cables, connectors, and cable assemblies appear to be relatively simple mechanical structures.

Nevertheless, the various junctions between cables and connectors and within connectors represent opportunities for impedance mismatches and signal reflections, leading to performance degradation. Achieving high performance levels from any cable and connector requires sound mechanical design and reliable manufacturing processes capable of delivering repeatable, tight mechanical tolerances.

Cables and connectors for RF/microwave applications are designed for a characteristic impedance of 50 Ω, in contrast to the 75-Ω cables and connectors used for video and broadcast applications. The 50-Ω impedance represents a compromise between the characteristic impedance of a low-loss air-filled coaxial line at 77 Ω and maximum power transfer at 30 Ω.[1]

Cable types have expanded over the years from just rigid, semi-rigid, and flexible coaxial varieties. Present-day versions embody some characteristics of both flexible and semi-rigid cables. Formable cables, for instance, boast performance levels approaching those of semi-rigid cables in terms of attenuation and phase stability, yet can be formed into required shapes and forms without special tools.



1. Two-conductor RF/microwave cables consist of inner and outer conductors separated by some form of dielectric material.

In general, the price of flexibility in coaxial cables means some sacrifice in electrical performance, with rigid and semi-rigid cables typically providing the best amplitude and phase performance of the cable types. For example, flexible cables fabricated with braided outer shields have been known to suffer performance anomalies when cables are kinked or tightly bent, especially at higher frequencies.

Cables with solid outer shields tend to provide more consistent performance and better shielding for applications operating under conditions of electromagnetic interference (EMI). Cables with special materials have also been developed to provide phase and temperature stability for measurement applications, such as with a vector network analyzer (VNA).

Two-conductor RF/microwave cables consist of inner and outer conductors separated by some form of dielectric material *(Fig. 1)* and often surrounded by an outer jacket. The outer conductor is typically some form of braided metal shield. Since loss through the cable will come from a combination of conductor and dielectric losses, cable manufacturers usually select low-loss materials for the conductors.

Examples include silver-plated copper or stainless steel and temperature-stable low-loss dielectric materials, including

CONNECTORS

fluoropolymer (FEP), polyethylene (PE) foam, or polytetrafluoroethylene (PTFE) dielectric materials. Cables are commonly produced in three standard diameters for RF/microwave applications—0.047, 0.085, and 0.141-in. diameters—in the various cable types used with different coaxial connectors.

MAKING CONNECTIONS

Connectors have been developed for different frequency ranges, depending on connector dimensions, from relatively large Type-N connectors *(Fig. 2)* for use from dc through about 11 GHz to much smaller 2.92- and 3.5-mm connectors for applications through millimeter-wave frequencies. Because of their extensive uses in military and aerospace applications, coaxial connectors are governed by numerous mechanical and electrical standards, including general MIL-C-39012 requirements, MIL-STD-348 mating interface requirements, and MIL-STD-202 requirements for mechanical shock and vibration.

The upper frequency limit or moding frequency of a connector is a function of the connector dimensions and the dielectric constant of the loading material within the connector (separating inner and outer conductors). For this reason, precision connectors have been designed with air dielectric rather than dielectric loading material, since air exhibits a low dielectric constant of unity.

2. The Type-N connector, developed around the time of World War II, provides reliable performance from dc to 11 GHz. *(Photo courtesy of Amphenol RF, www. ampenolrf.com)*

Connector performance is highly dependent on controlling the impedance at each transition within a connector. Therefore, reflections can be minimized and optimum transfer of energy can occur through the connector.

Tight impedance control in the design and manufacturing of coaxial connectors will yield lower VSWR and tighter VSWR tolerances for a given connector type, regardless of frequency range. Some connector mating interfaces offer less impedance control than others, depending on such factors as the center conductor recessing and the dielectric loading.

Still, no matter how well designed, every connector is subject to mechanical variations from a manufacturing process. These tolerances are limited so that some loss will occur in the best designed and machined connectors, especially at higher frequencies. For those seeking more information on controlling connector losses, Micro-Coax (www.micro-coax.com) offers a useful three-page guide to specifying low-loss connectors,"Connector Selection for Low Signal Reflections and Loss," available for free download from the firm's website.

In efforts to provide greater flexibility in matching connectors to cables, some manufacturers have made modifications that allow for greater liberties when terminating different types of cables. As an example, Spectrum Elektrotechnik GmbH (www.spectrum-et.org) developed its SpectrumFlex flexible coaxial cables for use with a wide range of connectors. Rather than requiring termination with connectors specifically developed for flexible cable, these cables can be terminated with any semi-rigid cable connector.

The flexible cables are available in the three popular diameters (0.047, 0.085, and 0.141 in.) as possible replacements for semi-rigid cables. They are claimed to provide the performance of semi-rigid cables without the difficulty of machining those cables.

With slightly less flexibility, a line of hand-formable semi-rigid cables from Pasternack (www.pasternack.com) allows users to create their own shapes with the cables without sacrificing electrical performance. These hand-formable cables, which are designed to be electrically equivalent to semi-rigid cables, are available for termination with the standard connector types—among them Type-N, TNC, SMA, and MCX connectors.

The hand-formable semi-rigid cables employ a tinned copper-braid outer shield to achieve high RF shielding of better than 100 dB. The cables are constructed so that they can be formed more than once without causing damage to the outer conductor.

For some applications, such as test and measurement, more flexible cable solutions are required because of the number of flexures that take place during normal testing operations. For this reason, companies providing cables and cable assemblies aimed at test applications typically stress the durability of their connectors along with the electrical performance *(Fig. 3)*.

3. Flexible cable assemblies for test applications must endure many flexures with no degradation in performance. *(Photo courtesy of Microlab, www.microlab.fxr.com)*

As an example, the Hand Flex line of flexible test cables from Mini-Circuits (www.minicircuits.com) is available in different lengths and with different connectors for applications from dc to 40 GHz. The cables come in different sizes, such as cable diameters of 0.086 and 0.141 in. with bend radii of 6 or 8 mm, respectively. Notably, these cables are qualified to maintain performance even after more than 20,000 bend cycles, as might be incurred over time with repetitive testing on a production line.

Coaxial cable assemblies for measurement applications are often constructed of special selected materials and designed for durability because of the repeated operations in testing. For example, the Lab-Flex series of test cables from EMC Labs/Florida RF Labs (www.emc-rflabs.com) use solder sleeves for the connector-to-cable termination to ensure a reliable and repeatable connection between the cable outer conductor braid and the connector interface.

With the solder sleeve, the connector's inner and outer conductor braids are both soldering the full 360 deg. around the connector sleeve for a durable connection. The cable assemblies are available for measurement applications through 50 GHz.

For cable assemblies used in applications in which timing is critical, such as in avionics and navigation, a parameter known as the velocity of propagation (VOP) can be important. It is a measure of how signal propagation is slowed through a particular cable relative to the speed of light in free space (100% VOP). This parameter is largely caused by the dielectric material in a cable or connector, which will be higher than the unity dielectric constant of air.

When comparing cables and cable assemblies for timing applications, longer delays are associated with lower values of VOP. For example, a cable with 70% VOP will exhibit longer timing delays than a cable with 90% VOP.

Since communications-systems developers have more clearly identified the effects of passive intermodulation distortion (PIM) on communications systems performance, cable and connector suppliers are now offering product lines optimized for low PIM performance. PIM is the undesired generation of spurious signal products caused by the mixing of two or more frequencies in a passive component, such as a cable or connector.

The mixing occurs due to nonlinear electrical junctions or materials in the signal path of a cable or connector. It has posed interference problems for many wireless-communications systems, including in-building systems such as wireless local-area networks (WLANs). By means of connector design, careful materials selection, and extensive testing, the performance of these cables and connectors can be verified for low PIM levels to minimize the effects of intermodulation distortion on system performance.

As an example, the SRX line of low-PIM cable assemblies and coaxial adapters from San-tron (www.santron.com) has been designed to minimize the generation of PIM. Usable for both short and long cable runs, these cables, with typical PIM levels of better than −160 dBc at 7 GHz depending on the connector, also achieve low VSWR and insertion loss. They are available with a number of different connectors, including Type-N, TNC, and SMA connectors.

Some cable suppliers offer online tools to help guide specifiers in need of achieving certain performance levels for a cable assembly. W.L. Gore & Associates (www.gore.com), for example, earlier this year introduced a second online tool as a companion for its existing GORE Microwave/RF Assembly Builder. The addition of the GORE Microwave/RF Assembly Calculator makes it possible to predict insertion loss, VSWR, and various other performance parameters for the firm's different cable and connector combinations.

The software helps when a cable type has not been determined for an application, and performance values can be calculated for different types of cables with a given set of coaxial connectors. As many as three cables can be compared on a single screen. The calculator includes a page for performing common conversions, such as for distance, frequency, power, temperature, VSWR/return loss, and weight. Both cable selection tools are designed for use on personal computers (PCs).

Similarly, Pasternack provides free "cable builder" software on its website, which allows users to gauge the performance of cable assemblies using different cables and connectors (see *Microwaves & RF*, July 2015, p. 74). mw

REFERENCE

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USING SOFTWARE TO STREAMLINE ANTENNA DESIGN

ANTENNAS ARE A critical component in any wireless system. To design an antenna for wireless local-area-networks (WLANs), one of several techniques can be implemented. A printed-circuit-board (PCB) antenna is one type that can be used for these applications. In a six-page application note titled "Design and Simulation of a 2.4 GHz/5.6 GHz WLAN Antenna on PCB Technology," National Instruments provides a description of the design and simulation of PCB antennas for WLAN applications using the NI AWR Design Environment software. The application note describes a 2.45 GHz single-band antenna as well as a dual-band antenna intended for use at 2.45 and 5.6 GHz.

The application note begins by describing the planar inverted-F antenna (PIFA) shape, which is the basis for the design examples. The first example described is a single-band antenna intended for use at 2.45 GHz. The application note demonstrates the software's capability to fine-tune the antenna to achieve desirable results at the 2.45 GHz target frequency. The simulated results for the antenna's gain and directivity are presented.

The layout of the single-band antenna is then modified to create a dual-band antenna. A second radiator element is added, and approximate radiator lengths for 2.45 and 5.6 GHz are applied. The application note again demonstrates the tuning performed by the software to achieved the desired results at the target frequencies of 2.45 and 5.6 GHz. Simulation results of the dual-band antenna are presented.

The final step analyzed the antenna's sensitivity to PCB material tolerances. FR4, which is the PCB material used to design the antenna, has a dielectric constant ranging from 4.0 to 4.9. The original simulations were performed with the dielectric constant's value set to 4.47. To demonstrate the amount of resonance shifting as the dielectric constant changes, additional simulations were performed with the dielectric constant set to both 4.2 and 4.9. The results obtained from this final analysis can determine, depending on the actual requirements, if a PCB material with a smaller tolerance is necessary.

National Instruments Corp., 11500 N Mopac Expwy., Austin, TX 78759-3504; (877) 388-1952; www.ni.com

IMPEDANCE ANALYZERS PROVIDE ACCURATE CHARACTERIZATION

IMPEDANCE ANALYZERS CAN perform accurate measurements across a wide impedance range, enabling high-quality components to be accurately characterized. In an application note titled "Power of Impedance Analyzer," Keysight Technologies discusses why it can be essential to characterize components and materials beyond the characteristics specified in a manufacturer's datasheet. The application note then describes how impedance analyzers can be used to perform these measurements.

The characteristics of components and printed-circuit-boards (PCBs) can depend on their operating conditions. When a component is integrated in a circuit, the operating conditions of the circuit may not correspond with the test conditions of the component when specified by the manufacturer. Thus, while a component may meet the manufacturer's specifications, it may exhibit different characteristics upon actual integration. Therefore, manufacturers of electronic devices may find it necessary to evaluate the materials or components used in their products under actual operating conditions.

To achieve characterization, components or materials may need to be accurately measured across a wide impedance range. In addition, low-loss and high-stability measurements may also be required. The application note analyzes the capability of Keysight's E4990A and E4991B impedance analyzers to provide these measurements.

To demonstrate the E4990A's capability to accurately perform high-impedance measurements, a 10 pF capacitor is measured over the entire frequency range of the E4990A. Similarly, a 22 nH inductor is measured to demonstrate the E4990A's capability to accurately perform low-impedance measurements. Measurement results from both the E4990A and a network analyzer are presented. The company claims that the E4990A achieves greater measurement accuracy over a wide impedance range than the network analyzer.

The application note also demonstrates how impedance analyzers can be used to perform low-loss measurements. Low-loss measurements with the E4990A are performed by measuring a 10 pF capacitor's dissipation factor (DF). Similarly, the E4991B's low-loss measurement capability is demonstrated by measuring a 22 nH inductor's quality factor (Q). Lastly, the measurement stability of both impedance analyzers is demonstrated, as measurements are recorded over a time interval of 5 hours.

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JACK BROWNE | Contributing Editor

Amplifier Trims Noise from 0.5 to 8.0 GHz

This miniature monolithic surface-mount amplifier combines low noise figure and high gain across a broad bandwidth of 0.5 to 8.0 GHz.

1. Model PMA3-83LN+ is a compact packaged low-noise amplifier (LNA) with noise figure of 1.3 dB from 0.5 to 8.0 GHz.

AMPLIFIERS WITH LOW NOISE FIGURES are usually relatively narrow in bandwidth, achieving the excellent noise performance through precise impedance matching for a given frequency range. The model PMA3-83LN+ low-noise amplifier (LNA) from Mini-Circuits breaks with tradition by providing impressive noise-figure performance of 1.3 dB from 0.5 to 8 GHz.

Admittedly, while commercial amplifiers are available with sub-1-dB noise figures, they typically lack the bandwidth of the PMA3-83LN+. The wide bandwidth, in addition to the amplifier's generous small-signal gain and respectable output power at 1-dB compression, positions this amplifier as a strong candidate for broadband front-end receiver applications through 8 GHz, as well as a single solution for a wide range of more narrowband applications through that upper frequency limit.

The broad frequency range accompanied by such a low noise figure makes this amplifier an attractive fit for many applications. In addition to serving a host of different radio receivers throughout that frequency range, the LNA's low noise figure can help achieve improved performance in Global Positioning System (GPS) satellite receivers operating at 1.575 GHz, as well as in S- and C-band satellite-communications (satcom) radios.

For example, using just a portion of the LNA's total bandwidth, this amplifier can support a variety of octave-wide 2-to-4-GHz S-band applications. The amplifier can help miniaturize S-band radar receivers without sacrificing overall performance. It can be used in weather radar applications across that frequency range, as well as in maritime radio systems. The amplifier can also find use in the many satcom systems operating at S-band frequencies, including in mobile satellite services (MSS) systems.

In addition, S-band frequencies are increasingly used in medical applications, such as medical linear accelerators for radiation treatment. The amplifier can also be used for multiple-band applications, which might otherwise require multiple LNAs to achieve the required combination of gain and noise figure.

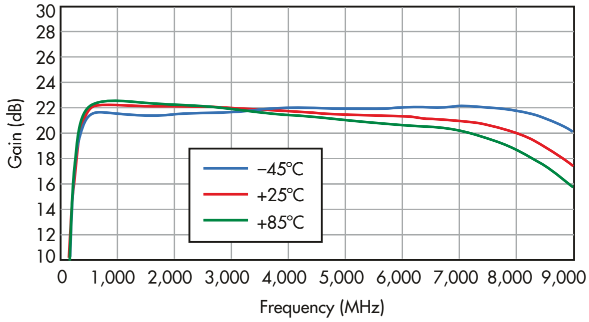
The model PMA3-83LN+ LNA *(Fig. 1)* is a monolithic-microwave-integrated-circuit (MMIC) amplifier based on a GaAs pseudomorphic high electron mobility transistor (pHEMT) semiconductor technology. It is housed in a low-profile 12-lead (MCLP) package (most of those 12 pins are not used or used to enhance ground connections) that is well matched to 50 Ω to maintain the low noise figure and flat gain across the frequency range.

The small size of this housing makes it convenient for installation on densely packed printed circuit boards (PCBs). With the package's paddle connected to ground, the amplifier achieves reliable electrical and thermal connections to a PCB. The package measures just 3.00 × 3.00 × 0.89 mm.

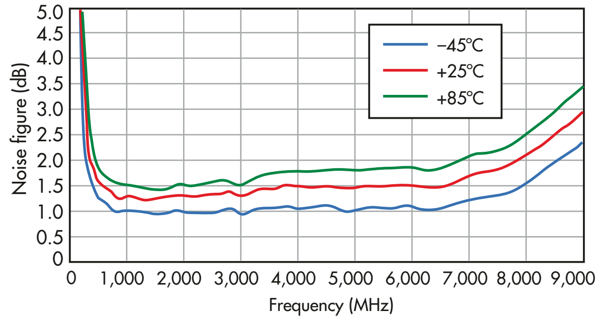
SMALL SIZE, BIG PERFORMANCE

As with most LNAs, the amplifier has been characterized for noise, gain, and other parameters at room temperature (+25°C), and it performs well under those environmentally controlled conditions. The LNA operates on a single +5 or +6 VDC supply, with little compromise in performance based on the choice of bias voltage. When tested with a bias voltage of +5 VDC, the noise figure is typically 1.5 dB at 0.5 GHz, rising to typically 2.06 dB at 8 GHz. The gain is typically 21 dB at 0.5 GHz under the same bias conditions, dropping to 19 dB at 8 GHz. At +5 VDC, the output power at 1-dB compression is typically +19.7 dBm at 0.5 GHz and +17.7 dBm at 8 GHz.

Even with the low operating voltage, the tiny amplifier is capable of quite respectable output power at 3-dB compression (IP3), of +37 dBm at 2 GHz and +29.3 dBm at the 8-GHz upper band edge. The tiny LNA also registers outstanding input and output return-loss performance; typical input return loss is 14 dB at 0.5 GHz, dropping to 8 dB at 8.0 GHz, and typical output return loss is 12.8 dB at 0.5 GHz, falling to 10.7 dB at 8.0 GHz, with all return loss values measured for a bias voltage of +5 VDC. At room temperature, the amplifier maintains flat gain of ±0.7 dB from 0.5 to 7.0 GHz and within ±1.1 dB across the full



2. Amplifier gain remains steady across a wide operating-temperature range compared to room-temperature performance at +25°C.



3. Noise figure is well controlled across the wide frequency range even when subjected to a wide range of operating temperatures.

bandwidth from 0.5 to 8.0 GHz.

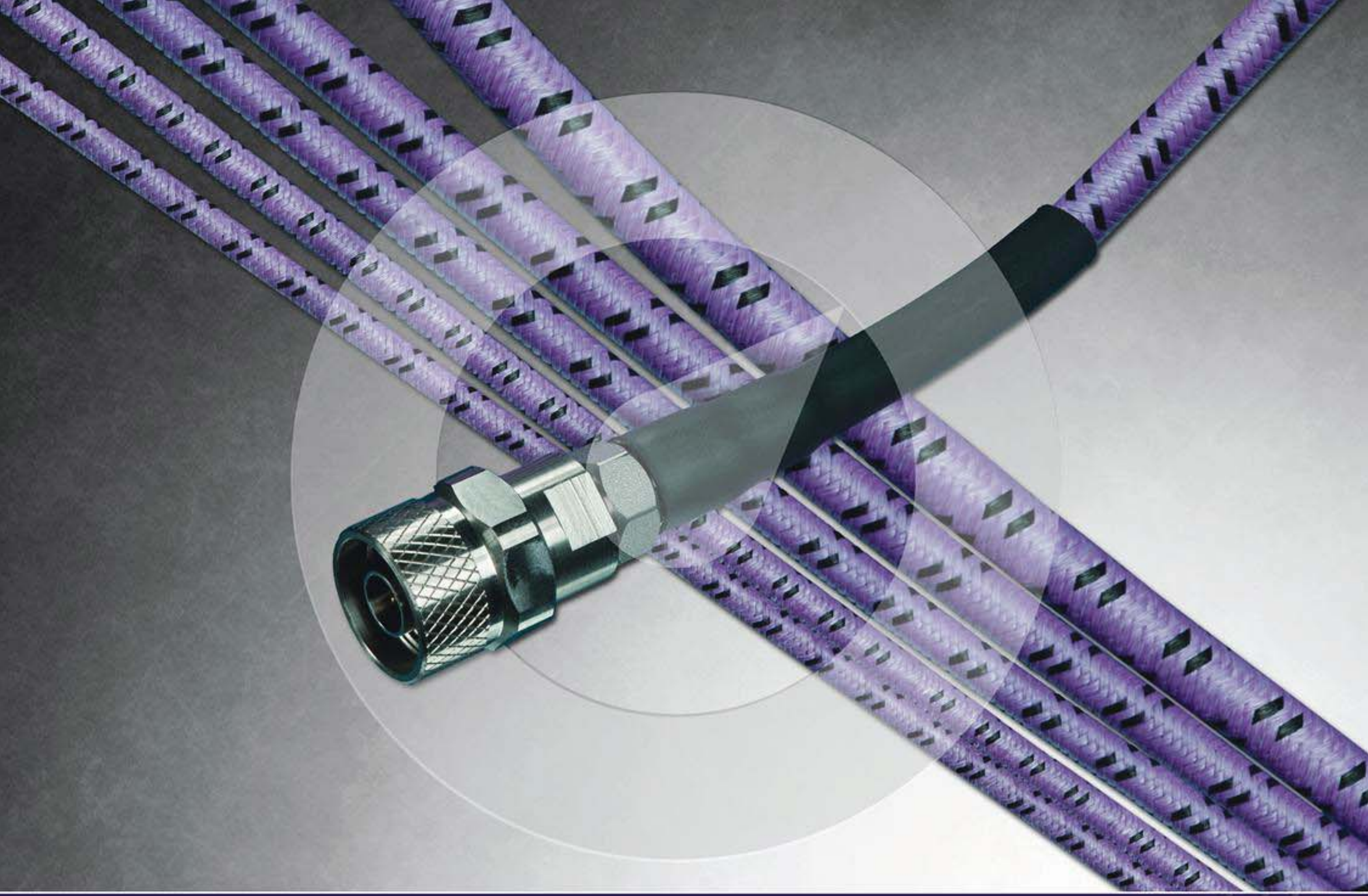
When the bias voltage is increased to +6 VDC, the noise figure remains consistent, with a slight increase in gain and an expected increase in output power at the higher voltage. For example, the model PMA3-83LN+ exhibits noise figure of typically 1.53 dB at 0.5 GHz and 2.06 dB at 8 GHz. At +6 VDC, the gain is typically 21.7 dB at 0.5 GHz and 19.8 dB at 8 GHz. When operating at the higher bias voltage, the output power at 1-dB compression is typically +22.2 dBm at 0.5 GHz and +18.6 dBm at 8 GHz. The IP3 performance is somewhat higher at the higher bias voltage, reaching +34.0 dBm at 0.5 GHz and +29.3 dBm at the LNA's upper band edge frequency of 8 GHz.

The model PMA3-83LN+ also performs admirably when subjected to changes in temperature. The amplifier is specified for a wide operating temperature range of –40 to +85°C, and it handles the changes in temperature with only slight variations in performance. When full-band gain was measured at room temperature and at the extremes of the temperature range, as expected, the gain remained high at –40°C throughout the amplifier's bandwidth. But at +85°C, the gain response, albeit somewhat lower than at room temperature, actually tracked the room-temperature gain response through 8 GHz *(Fig. 2)*.

Similarly, the amplifier's noise figure is very well controlled with temperature across the full frequency range *(Fig. 3)*. When tested with a bias voltage of +6 VDC, the LNA exhibited the expected drop in noise figure at the lowest operating temperature; however, only a slight increase in noise figure was noted at the highest operating temperature, closely tracking the noise-figure response with frequency at room temperature. Likewise, the output IP3 performance remains steady with temperature, especially above about 3 GHz.

The amplifier typically draws 85 mA current at +6 VDC and 63 mA at +5 VDC. It is qualified to electrostatic-discharge (ESD) rating per the human body model (HBM) of Class 1A (250 to <500 V) in accordance with the ANSI/ESD STM 5.1-2001 standard, as well as an ESD rating per the machine model (MM) Class M1 per the ANSI/ESD STM5.2-1999 standard. It also features a moisture sensitivity level (MSL) rating of MSL1 per the IPC/JEDEC J-STD-020D standard. An evaluation board (model TB-830+) is available for designers wishing the verify performance in their own laboratories. mw

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



JACK BROWNE | Contributing Editor

Taking the Measure of Microwave Power Meters

Power measurements are an important part of high-frequency design, and are now available using the measurement capabilities of a USB sensor and the control of a personal computer.

MICROWAVE POWER METERS are among a collection of instruments, such as oscilloscopes, spectrum analyzers, signal generators, and vector network analyzers (VNAs), that should be on every high-frequency designer's workbench. Over the last decade, the variety of available RF/microwave power meters has grown, to where these instruments are now available in many shapes and sizes, from rack-mount units to portable instruments and even meters that can be powered and controlled by a laptop computer using a USB connection. Along with the meters, the "other half" of the instrument, the power sensor, is also available in many varieties, providing engineers with a tremendous assortment of meters and sensors for almost any application. Understanding the different performance parameters for power meters and their sensors can help when comparing different available instruments.

RF/microwave power meters can be judged and compared by a number of key specifications that serve as a starting point when trying to find an instrument suited for a particular application. These parameters include frequency range, power measurement dynamic range and resolution, whether power measurements can be made on pulsed or continuous-wave (CW) signals, and whether a meter/sensor combination can measure peak envelope power (PEP).

A power meter's performance limits, such as frequency range and power measurement range, are basically those of its connected power sensor. Several different technologies are used in power sensors to measure power, including those based on diode detection and those measuring power as a function of thermal effects, like thermistor- and thermocouple-based power sensors. Each has different performance levels in terms of power measurement range and accuracy, but each is effective depending on the needs of an application.

For more details on the basics of making RF/microwave power measurements, including the differences between average power measurements and pulsed power measurements, Keysight Technologies offers an excellent, 80-page application note (64-1B), "Fundamentals of RF and Microwave Power Measurements," for free on its website (www.keysight.com). The application note includes information on the different power sensor technologies along with a brief explanation of power sensor calibration methods and the use of the microcalorimeter power-measurement reference standard established by the National Institute of Standards & Technology (NIST) at its facility in Boulder, Colo.

1. This traditional power meter and sensor combination provides power measurements from –39 to +20 dBm at frequencies from 100 kHz to 40 GHz. *(Image courtesy of Krytar Inc.)*

POWER IN SMALLER PACKAGES

Measuring power, which is essentially energy per unit time, has traditionally been performed by a combination of a power meter and a sensor, and the power meter has typically been among the most compact of instruments on an RF/microwave test bench. Perhaps the most evident trend in modern power meters has been the shift away from this two-part instrument combination toward smaller, more integrated power-measurement solutions, usually powered by means of a USB port and a PC.

As an example of the traditional power meter/sensor combination, the model 9000B power meter from Krytar (www.krytar.com) uses diode-based sensors to measure average CW power from −39 to +20 dBm over a frequency range of 100 kHz to 40 GHz (*Fig. 1*). This compact instrument is fully portable and can be used in the field as well as on a benchtop for swept measurements. It features NIST-traceable accuracy of ±0.05 dB when measuring 0 dBm (1 mW) at 50 MHz and room temperature (+25°C). Power measurement linearity is ±0.025 dB at room temperature. The compact power meter is 3.625 × 8.3125 × 11.50 in. and runs for more than 12 hours on rechargeable internal batteries.

2. These power sensors use USB connections to a PC with the proper software to make average and peak power measurements. *(Image courtesy of Keysight Technologies)*

Some applications, such as radar systems, may require power measurements on pulsed signals, and the model 4500B peak power analyzer from Boonton and the Wireless Telecom Group (www.boonton.com) has been well established as a reliable measurement tool for pulsed power measurements. With a frequency range of 1 MHz to 40 GHz and video bandwidth as wide as 65 MHz, the power meter/sensor measures power levels from −50 to +20 dBm for pulse widths as narrow as 6 ns and at rise times of 7 ns or less. Voltage from the meter's sensitive diode

The programmable meter can be set to trigger on a specific event or with a specific time delay when attempting to measure signals of interest. Voltage from its sensitive diode-based peak power sensors are processed by a 14-b analog-to-digital converter (ADC) to create digital measurement data that can be displayed on a color LCD screen or processed further for such functions as statistical analysis.

THE PC CONNECTION

This combination of power meter and sensor has long been the way to make power measurements at RF/microwave frequencies, but the increasing use of the

PC, measurement software, and the USB is leading to the development of power sensors that can connect directly to PCs via the USB, with the computational power once provided by the separate power meter now handled by the PC. For example, several series of diode- and thermocouple-based USB power sensors from Keysight Technologies provide full-sized power measurement capabilities with the simplicity of USB connections to a PC (*Fig. 2*). The U2040 X-Series of USB power sensors are geared for wide-dynamic-range measurements, with a power measurement range of –70 to +26 dBm for a frequency range of 10 MHz to 33 GHz (depending upon sensor). The U2020 X-Series USB sensors provide peak and average power measurements across a power measurement range of –35 to +20 dBm for a frequency range of 50 MHz to 40 GHz (depending upon sensor). The U8480 Series USB thermocouple power sensors measure to 67 GHz (depending upon sensor) with better than 0.8% linearity for a power measurement range of –35 to +20 dBm.

3. This line of power meters and monitors provides portability and the ruggedness needed for constant in-field use. *(Image courtesy of Narda Microwave-East)*

The PWR series of USB power sensors from Mini-Circuits (www.minicircuit.com) demonstrate just how small power measurement solutions have become at RF/microwave frequencies. The broadband model PWR-8GHS USB power sensor performs CW power measurements from –30 to +20 dBm at frequencies from 1 to 8000 MHz in a sensor package size of only 4.89 × 1.74 × 0.95 in. Designed for use with any PC with Windows or Linux operating system, the power sensors are supplied with measurement software. They feature automatic calibration and temperature compensation and achieve 30-ms measurement speed. The power sensors also include a Type-N-to-SMA coaxial adapter and a quick-locking USB cable for reliable connectivity.

As a form of bridge between the traditional power meter/sensor combination and these latest USB power sensors, Narda Microwave-East (www.nardamicrowave.com) offers its compact 8400 Series of portable power meters and monitors (*Fig. 3*) provide power measurement ranges as wide as 1 μW to 1 mW at frequencies from 10 MHz to 12.4 GHz (and usable to 26.5 GHz). These completely portable measuring tools include analog meters on some models and field-replacement detection elements for long-term use in the field. They are compact and built with the ruggedness needed to survive in-field use.

Of course, with the simplicity of one connection to a PC with the proper installed software, the ease of setting up power measurements with a USB power sensor/meter explains the rapidly growing popularity of this method of power measurement. A large number of companies currently offer USB power sensors/meters for CW and peak power measurement, including Anritsu Co. (www.anritsu.com), Bird Technologies (www.bird.rf.com), Coherent Inc. (www.coherent.com), Giga-tronics (www.gigatronics.com), Ladybug-Tech (www.ladybug-tech.com), Rohde & Schwarz (www.rohde-schwarz.com), Satori Technology (www.satori-technology.com), Telemakus (www.telemakus.com), and Tektronix (www.tek.com). mw

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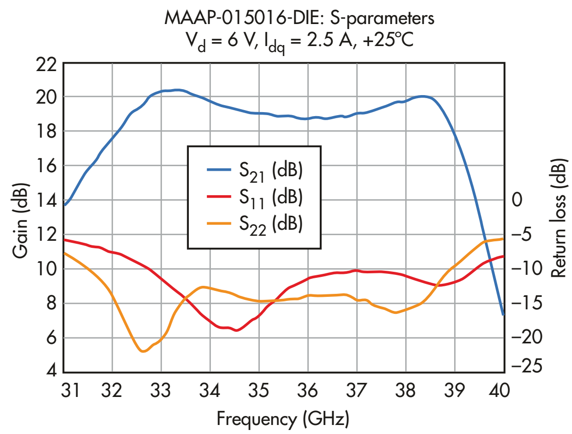
Design 4-W MMIC PAs for Ka-Band Applications

Practical use of load-pull tuners and EM simulation software helped design the impedance-matching circuitry for this robust MMIC power amplifier that works from 32 to 38 GHz.

KA-BAND ACTIVITY IS on the rise, for both military radar systems and commercial point-to-point communications systems, thus driving the need for compact, efficient power amplifiers (PAs) to boost signals within those systems at Ka-band frequencies (26.5 to 40.0 GHz).[1] Potential applications include television and broadband data services, commercial airborne communications, and military payloads.

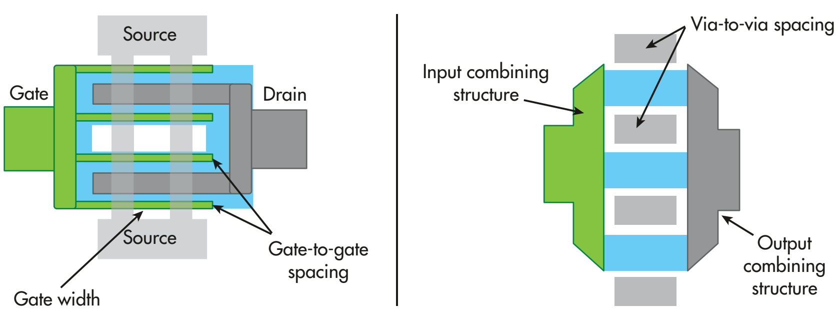
Several previously published reports have demonstrated power, bandwidth, and efficiency for PAs in this frequency range.[2,3] The current report details the design, simulation, and measured performance of a compact broadband 4-W PA monolithic microwave integrated circuit (MMIC) developed by MACOM (www.macom.com) for Ka-band operation from 32 to 38 GHz.

The 4-W MMIC PA, a four-stage Ka-band PA chip—model MAAP-015016-DIE—from MACOM, is fabricated on a 2-mil, 0.15-µm, gallium-arsenide (GaAs), pseudomorphic high-electron-mobility-transistor (pHEMT) process. The design process employed semiconductor-foundry device models that were verified through a combination of small- and large-signal measurement. This characterization included S-parameter and load-pull measurements taken over wide temperature ranges using load-pull impedance tuners from Maury Microwave Corp. (www.maurymw.com).



2. Optimum input and output impedances for the Ka-band PA were determined with the aid of measured and simulated load-pull data.

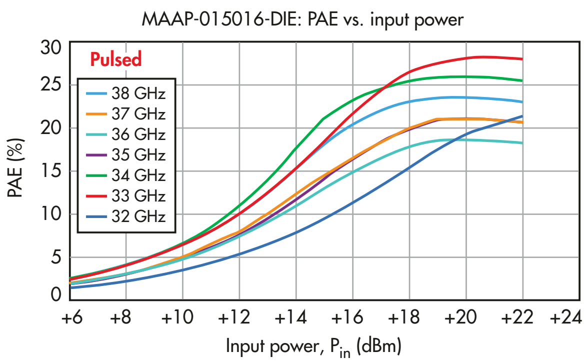
To optimize RF performance in a multiple-gate finger cell at Ka-band, both the gate width and the physical length of the connecting structures were considered. The ideal arrangement was determined through simulation, which defined the basic cell structure utilized throughout the design. *Figure 1* shows the GaAs cell layout, along with the layout of the multiple-cell combining structure. Measured and simulated load-pull data from NI AWR Design Environment simulation software was used to determine the optimum input and output impedances for the MMIC PA (*Fig. 2*).

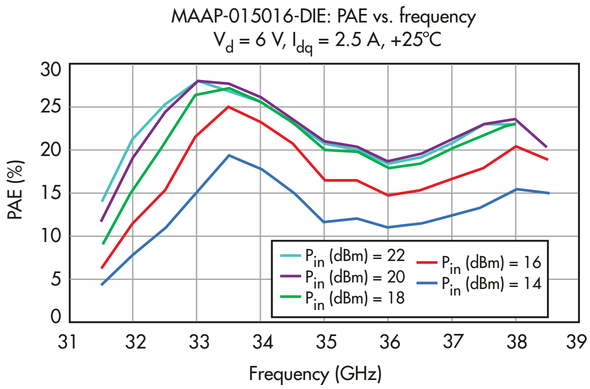


1. This layout shows the configuration of the Ka-band PA, including its multiple-cell combining structure.

THERMAL ANALYSIS

Another important factor in compact PA designs concerns thermal performance on a device cell level in terms of via arrangements and gate-to-gate spacing. For the Ka-band PA, optimal thermal performance was analyzed





3. As the pulsed data shows, the GaAs MMIC PA achieves PAE between 18% and 27% across the full frequency range.

using SYMMIC thermal simulation software from Capesym (www.capesym.com), a Software Alliance partner with National Instruments (formerly AWR Corp.; www.ni.com/awr). Thermal analysis was critical since the amplifier must meet performance levels under both continuous-wave (CW) and pulsed operating conditions.

COMPARISON OF Ka-BAND MMIC AMPLIFIERS

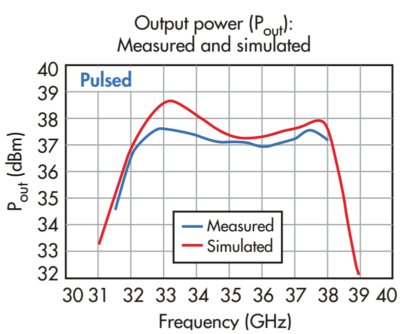
Parameter	Model TGA2575	Model MAAP-015016-DIE
Size	4.1 × 5.4 mm	3.09 × 5.67 mm
Area	22.14 mm^2	17.52 mm^2
Frequency range	32 to 38 GHz	32 to 38 GHz
Saturated output power	+35.5 dBm	+36.5 dBm
Gain	19 dB	19 dB
Input return loss	12 dB	10 dB
Output return loss	12 dB	13 dB
Drive current	3.0 A	3.8 A
PAE	22%	23%

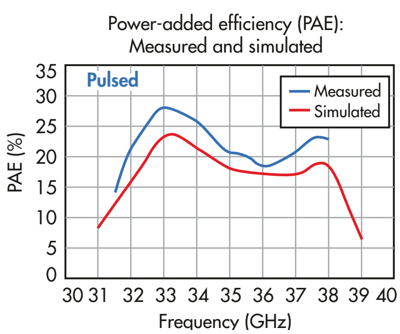
Note: Model TGA2575 is produced by and available from TriQuint Semiconductor (www.triquint.com).

Each device cell was stabilized individually using a parallel resistive-capacitive (RC) arrangement, and overall circuit stability was verified under typical drive conditions. Thermal imaging analysis of the die revealed a peak temperature rise of 60°C above the PA's base temperature, corresponding to a mean time to failure (MTTF) of 5×10^7 hours. Electrostatic-discharge (ESD) diodes were included on the PA die, with measured performance levels for charged device model (CDM) and human body model (HBM) ESD conditions graded as Class 1 and 1B, respectively.

The PA's design and measurement reference planes are to an external 50-Ω transmission line on an alumina substrate. Bondwire transitions were optimized by means of three-dimensional (3D) electromagnetic (EM) software simulation using the Analyst and AXIEM EM simulators within the NI AWR Design Environment software. For accuracy, an application circuit used to evaluate the Ka-band MMIC PA leverages a baseplate arrangement designed to match the GaAs die's coefficient of thermal expansion (CTE). Regarding measurements, the RF input/output pads are bonded to an external probe pattern, so that the test arrangement replicates the 3D EM simulation of the transition. External decoupling capacitors help improve the low-frequency stability of the MMIC PA.

Thanks to the decoupling capacitors, the MMIC PA can operate efficiently under both drain-pulsed and CW conditions. Under CW conditions, power dropped by only about 0.5 dB compared to pulsed conditions *(see table)*. Compared to a competitive device, the MAAP-015016-DIE MMIC PA provides similar performance but with greatly reduced real estate and improved output-power performance across the Ka-band frequency range.





4. Close correlation between measured and simulated output-power performance indicates the quality of the circuit design and the simulation software.

TEST RESULTS

The Ka-band amplifier's small-signal performance was measured for pulsed *(continued on p. 96)*

JACK BROWNE | Contributing Editor

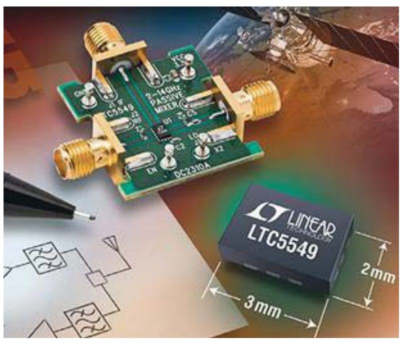
Double-Balanced Microwave Mixer Translates 2 to 14 GHz

This highly integrated mixer, which includes a balun transformer and LO buffer amplifier, simplifies the design of broadband transmitters/receivers through 14 GHz.

FREQUENCY CONVERSION IS an essential function within receivers and transmitters for untold high-frequency applications. Looking to bolster this capability, Linear Technology Corp. developed the LTC5549 microwave mixer, which provides RF/microwave designers with greater degrees of performance and flexibility.

Housed in a QFN package, this broadband mixer operates from 2 to 14 GHz and can perform both frequency upconversion and downconversion, to serve both transmitters and receivers, respectively. It's suits wireless base stations, satellite-communications (satcom) systems, radar, and test equipment.

The model LTC5559 *(see the figure)* maintains an RF range of 2 to 14 GHz, a local-oscillator (LO) frequency range of 1 to 12 GHz, and an intermediate-frequency (IF) range of 0.5 to 6.0 GHz. All three mixer ports are matched to 50-Ω impedance. The device maintains low conversion loss across its frequency range, with typically 7.8-dB conversion loss for an RF of 2 GHz and an LO of 3.89 GHz and 9.4-dB conversion loss for an RF of 9 GHz and an LO frequency of 7.11 GHz.



Packaged in a plastic QFN, this broadband mixer with integrated LO buffer amplifier features an RF range of 2 to 14 GHz, LO frequency range of 1 to 12 GHz, and an IF range of 0.5 to 6.0 GHz.

For temperature-sensitive applications, this is a mixer that can operate from –40 to +105°C with negligible 0.009 dB/°C variation in conversion loss as a function of temperature. The mixer boasts respectable single-sideband noise figure in the range of the conversion loss—typically 7.9 dB for an RF input of 2 GHz and an LO frequency of 3.89 GHz, and typically 10.2 dB for an RF input of 8.5 GHz and an LO frequency of 6.61 GHz.

EASES SYSTEM DESIGN

The LTC5549 integrates a number of components that simplify receiver and transmitter design. For instance, a local-oscillator (LO) buffer amplifier enables the mixer to operate with only 0-dBm LO drive level, eliminating the need for an additional LO drive amplifier. In addition, an on-chip switchable frequency doubler for the LO input allows the use of lower-frequency, lower-cost LO sources to drive the mixer. The LTC5549 also incorporates a wideband balun transformer that supports the mixer's wideband frequency range and enables single-ended operation.

Filtering requirements are minimized by the mixer's high port-to-port isolation, typically better than 45 dB from RF to LO ports across the full frequency range and better than 35 dB from the RF to IF ports from 2 to 14 GHz. Signal leakage between ports is low, typically better than –35 dBm from LO to RF ports from 1 to 5 GHz and better than –30 dBm from LO to IF ports from 1 to 5 GHz.

The multipurpose mixer provides outstanding linearity, with an input third-order-intercept (IIP3) point of +24.3 dBm at 9 GHz. The LTC5549 double-balanced mixer comes in a 12-lead, 3- × 2-mm plastic QFN package and is rated for case temperatures from –40 to +105°C. It features rugged electrostatic-discharge (ESD) protection with a 2-kV ESD human-body-model (HBM) rating on all pins.

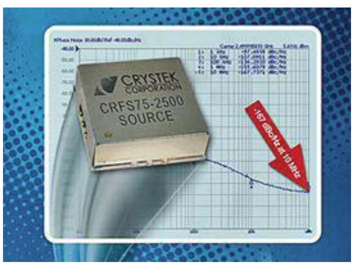
The LTC5549 is optimized for operation at +3.3 V dc and draws nominal 115-mA current. An enable/disable pin, which can be employed to turn the mixer on or off, changes states in less than 0.2 µs. When the mixer becomes deactivated, the "sleep mode" or standby current draw reaches a maximum of only 100 µA. P&A: $9.50 and up (quantities of 1000) from stock. mw

LINEAR TECHNOLOGY CORP., 1630 McCarthy Blvd., Milpitas, CA 95035-7417; (408) 432-1900, FAX: (408) 434-0507, *www.linear.com*

Phase-Locked Source Clocks at 2.5 GHz

STABLE SOURCES ARE vital for maintaining time and frequency in most networks and radios, and the model CRFS75-2500 phase-locked clock source from Crystek Microwave shows its stability at 2.5 GHz in terms of extremely low phase noise. The compact module measures just 0.75 × 0.75 in. in a surface-mount-technology (SMT) package but includes a phase-locked-loop (PLL) frequency source with internal reference. Leveraging proven surface-acoustic-wave (SAW) resonator technology, the low-noise source achieves phase noise of –105 dBc/Hz offset 10 kHz from the carrier, and –130 dBc/Hz offset 100 kHz from the carrier, with a noise floor of –167 dBc/Hz at 2.5 GHz. The root-mean-square (RMS) phase jitter is typically only 70 fs.

The compact source module produces fixed-frequency sine wave output signals at minimum output power of +5 dBm operating on a +5-VDC supply voltage, with typical current draw of 110 mA. Frequency stability is rated as ±25 ppm for an operating temperature range of –20 to +70°C. Second harmonics are typically –20 dBc.



Model CRFS75-2500 is an SMT-packaged, PLL clock source with low-noise, fixed-sine-wave output of 2.5 GHz.

The miniature phase-locked clock source is screened to the applicable requirements of MIL-STD-883 for mechanical shock and vibration, thermal shock, and moisture resistance for use in the most demanding applications. The rugged clock source is also built to the applicable requirements of MIL-STD-202 for solvent resistant and resistance to soldering heat for inclusion in a wide range of circuit and system manufacturing environments. Each oscillator is equipped with a suggested circuit layout and a recommended reflow-solder profile for attachment. It is usable in a wide range of applications, including in communications systems and test-and-measurement equipment.

CRYSTEK CORP., 12730 Commonwealth Dr., Fort Myers, FL 33913; (800) 237-3061, (239) 561-3311; *www.crystek.com*

Model 803358 is a coaxial highpass filter with total bandwidth of DC to 18 GHz. It is supplied with female SMA connectors.

Highpass Filter Passband Runs 2 to 18 GHz

FILTERING UNWANTED SIGNALS is an essential function of many electronic systems, including commercial and military platforms such as communications, electronic-warfare (EW), and radar systems. One of the choices for filter responses is the highpass filter, which suppresses signals lower in frequency and ideally passes signals higher in frequency unaffected. Model 803358 is the latest highpass filter from Bree Engineering Corp. with an impressive passband of 2 to 18 GHz. The filter is available from stock for immediate delivery.

The highpass filter achieves 40-dB minimum rejection of signals at frequencies below 1,650 MHz, with as much as 70-dB minimum rejection of unwanted signals from DC to1500 MHz. Within the nominal passband from 2 to 18 GHz, the insertion loss is less than 1.2 dB and typically less than 1.0 dB. The return loss is 14 dB or better and typically 17 dB over the passband from 2 to 18 GHz.

"Model 803358 is the latest high-pass filter from Bree Engineering Corp. with an impressive passband of 2 to 18 GHz. The rugged model measures 1.50 × 0.50 × 0.40 in."

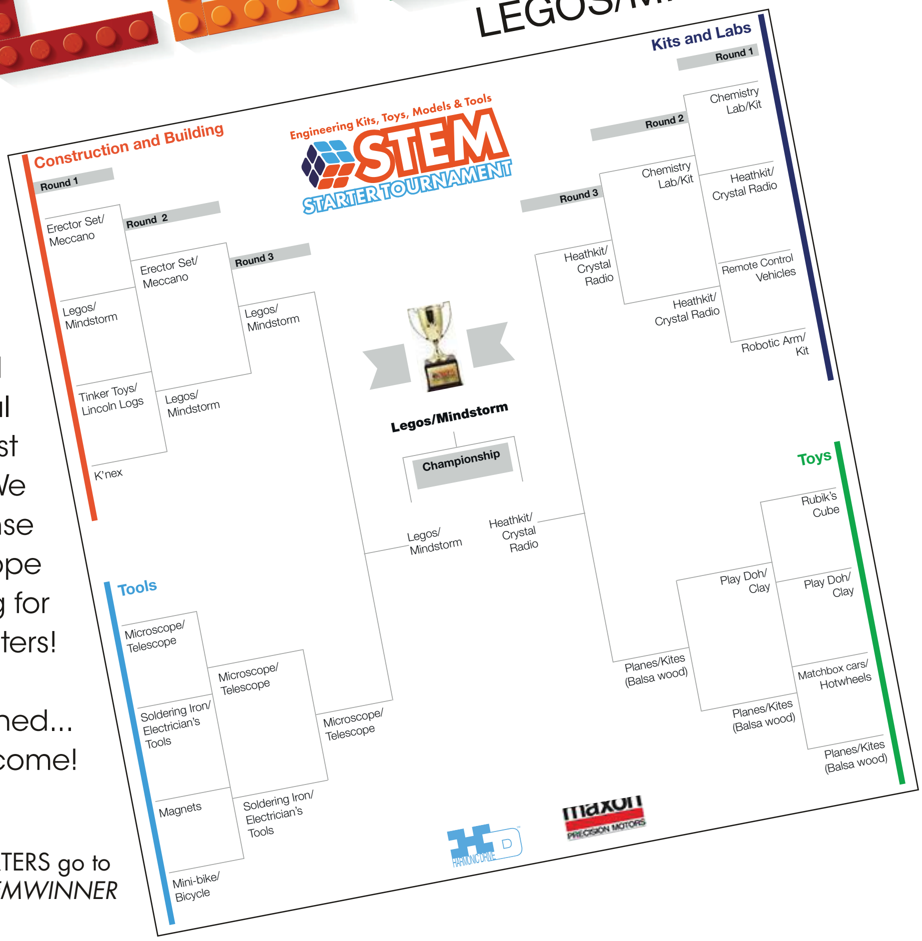
The rugged model 803358 highpass filter measures 1.50 × 0.50 × 0.40 in. and is supplied with female SMA coaxial connectors at input and output ports. Other package configurations are also available upon request. The firm offers a wide range of filter types and related products, including lowpass, highpass, bandpass, band-reject filters, multiplexers, switched filter banks, and bias tees for applications from 1 MHz through 20 GHz. All components are available in various package styles, including miniature surface-mount-technology (SMT) packages, with axial and radial pins, as well as coaxial connectors.

BREE ENGINEERING CORP., 1275 Stone Dr., San Marcos, CA 92078; (760) 510-4950; *www.breeeng.com*

And the WINNER is...

LEGOS

LEGOS/MINDSTORM



The tournament has come to an end and **Legos/Mindstorm** has claimed the title! Thanks to all of the participants who voted throughout the past several weeks of The World's Greatest STEM Starter Tournament. We had a tremendous response from the community and hope that all of you had fun voting for your favorite STEM Starters!

Stay tuned... more excitement to come!

For all the details on STEM STARTERS go to *http://electronicdesign.com/STEMWINNER*

InfoCenter

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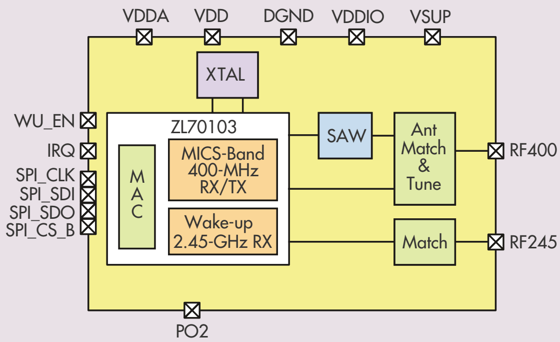
RF Module Cures Medical Design Woes



A MINIATURE wireless radio module has been developed specifically for implantable medical devices such as pacemakers, cardiac defibrillators, and neurostimulators. The model ZL70323 module measures just 5.5 × 4.5 × 1.5 mm and complements the firm's ZL70120 module at the other side of the communications link. The module employs a low-power transmitter and receiver operating in the Medical Implantable Communications Service (MICS) band at 402 to 405 MHz, along with a 24-MHz crystal reference oscillator and surface-acoustic-wave (SAW) filters. It includes a "wake-up" receiver at 2.45-GHz which can be used as needed. The module communicates health status data and, with its small size, can be implanted with only extremely small incisions required.

MICROSEMI CORP., One Enterprise, Aliso Viejo, CA 92656; (800) 713-4113, (949) 380-6100; e-mail: RFMWMOD@microsemi.com, *www.microsemi.com*

Amplifier Drives 20 to 500 MHz

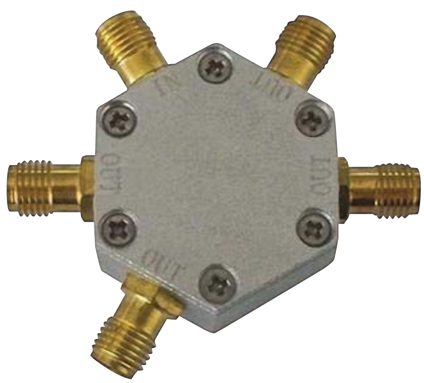
DESIGNED FOR high output-power levels in a compact housing, model RAMP-M-20-500M-40d-Sf-100W-L21 is a RoHS-compliant amplifier that generates 100 W output power from 20 to 500 MHz. It offers 40-dB minimum gain while working in Class-AB operation with a +50-VDC supply. The rugged amplifier module is supplied with SMA female connectors. It measures 8.0 × 4.0 × 1.5 in. and weighs 2 lb. It is available with an option heat sink

and fan for thermal management.

RADITEK INC., 1702L Meridian Ave., San Jose, CA 95125; (408) 266-7404; e-mail: sales@raditek.com, *www.raditek.com*

Four-Way Divider Runs DC to 6 GHz

MODEL WT-D0093-04 is a resistive, four-way power divider capable of flat amplitude response from DC to 6 GHz. The insertion loss is 12 dB or less with ±1.5 dB flatness across the frequency range. The VSWR is 1.30:1 or less from DC to 3 GHz and 1.50:1 or less from 3 to 6 GHz. The power

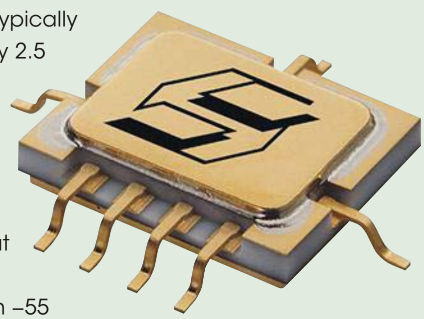


divider, which handles input power levels to 2 W across its frequency range, is supplied with female SMA connectors on all ports.

CHENGDU MICROWAVE COMMUNICATION TECHNOLOGY CO. LTD., 11F-1108, Building #1, No. 37, Jiancai Road, Chengdu 61005, China; +86-28-84300332; *www.cdweitong.com*

GaAs IC Switch Spans DC to 8 GHz

DESIGNED FOR applications from DC to 8 GHz, model ISO13286 is a single-pole, double-throw (SPDT) switch with high isolation and low loss. It offers 50-dB isolation at 4 GHz and 45-dB typical isolation at 8 GHz. The insertion loss is typically 0.8 dB through 4 GHz and typically 2.5 dB through 8 GHz. The absorptive GaAs pseudomorphic high-electron-mobility-transistor (pHEMT) integrated-circuit (IC) switch is supplied in a seven-pin hermetic package. The switch handles input power to +26 dBm as well as operating case temperatures from –55 to +125°C. The switch operates with control voltages from –7.5 to +1.0 VDC.



ISOLINK INC., 880 Yosemite Way, Milpitas, CA 95035; (408) 946-1968; e-mail: sales@isolink.com; *www.isolink.com*

Cable Assemblies Conquer 26.5 GHz

A CATALOG full of standard precision coaxial cable assemblies includes a wide range of assembly lengths and terminating connectors such as straight SMA male to straight SMA male, straight SMA male to right-angle male, SMA straight male to SMA female bulkhead, and right-angle SMA male to SMA female bulkhead. The cable assemblies are available in lengths from 6 in. to 120 in., all for applications from DC to 26.5 GHz. The cable assemblies feature velocity of propagation of 69.5% and cutoff frequency of 35 GHz, with greater than 90-dB RF shielding. The cable assemblies offer an operating temperature range of –50°C to +205°C; additional lengths are available.

BRACKE MANUFACTURING LLC, P. O. Box 12319, Newport Beach, CA 92658; (949) 756-1600; e-mail: sales@brackemfg.com, *www.brackemfg.com*

GaN Amplifier Powers 9 to 10 GHz

MODEL BME99109-40 is an X-band solid-state power amplifier suitable for use with pulsed and continuous-wave (CW) signals. With 40 W (+46 dBm) output power from 9 to 10 GHz, the compact amplifier delivers 46-dB nominal gain with a 30-dB dynamic range. Based on gallium-nitride (GaN) semiconductor technology, the amplifier is designed for input signal levels to +1 dBm. It exhibits second-harmonic levels of typically –60 dBc and third-harmonic levels of typically –80 dBc. The amplifier operates on +36 to +46 VDC with maximum power consumption of 225 W. It measures 4.00 × 4.00 × 3.33 in. and weighs 2.5 lb. with SMA female connectors and WG-90 bottom-mounted output port. The amplifier is constructed to meet MIL-STD-810F requirements and an operating temperature range of 0 to +55°C.

COMTECH PST, 105 Baylis Rd., Melville, NY 11747; (631) 777-8900; *www.comtechpst.com*

Variable Attenuators Reach 110 GHz

A LINE of continuously variable attenuators has been developed for millimeter-wave applications through 110 GHz. Available in ridged waveguide sizes from WR-10 through WR-22, the five models cover five frequency bands from 33 to 110 GHz (33 to 50, 40 to 60, 50 to 75, 60 to 90, and 75 to 110 GHz), all with attenuation that can be adjusted over a range from 0 to 30 dB. The attenuation level for each unit is adjusted using a micrometer, enabling repeatable and rapid re-setting to different attenuation levels. Attenuation remains flat with frequency and insertion loss ranges from a low of 0.5 dB at the lowest frequencies to 1.0 dB at the highest frequencies. The rugged variable attenuators are suited for a wide range of uses, including in medical, industrial, aerospace, and military applications.

PASTERNACK ENTERPRISES, 17802 Fitch, Irvine, CA 92614; 866-727-8376, e-mail: sales@pasternack.com, *www.pasternack.com*

Control Devices Reach 40 GHz

MODELS MPS4101-012S and MPS4102-013S are control devices that serve as excellent replacements for beam-lead PIN diodes in broadband microwave switches across the full frequency span of 50 MHz to 40 GHz. These single-chip, silicon-monolithic, series-shunt circuit elements exhibit less than 1.5 dB insertion loss and more than 25 dB isolation at 36 GHz. They offer fast switching time of 5 ns and can handle continuous-wave (CW) power at levels f 3 W or more. The monolithic control elements are RoHS compliant and are well suited for high-reliability applications.

MICROSEMI CORP., One Enterprise, Aliso Viejo, CA 92656; (800) 713-4113, (949) 380-6100, e-mail: RFMWMOD@microsemi.com, *www.microsemi.com*

VCXOs Cut Noise from 131 to 200 MHz

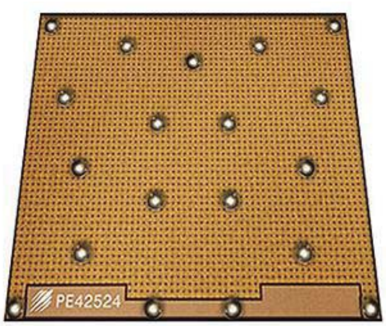
AVAILABLE FOR frequencies from 131 to 200 MHz, model CVHD-952 is a HCMOS low-phase-noise voltage-controlled crystal oscillator (VCXO) with low phase noise. Designed for voltage supplies of +3.30 VDC, the oscillator exhibits phase noise of –70 dBc/Hz offset 10 Hz from the carrier, –148 dBc/Hz offset 10 kHz from the carrier, and a noise floor of –150 dBc/

Hz. Typical jitter is 0.5 ps at all offset frequencies. Standard units have an operating temperature range of 0 to +70°C; as an option, sources can be supplied for an operating temperature range of –40°C to +85°C. The VCXO is supplied in a surface-mount-device (SMD) package measuring 9 × 14 mm.

CRYSTEK CORP., 12730 Commonwealth Dr., Fort Myers, FL 33913; (239) 561-3311, (800) 237-3061; *www.crystek.com*

SPDT Switch Controls 10 MHz to 40 GHz

FOR BROADBAND signal control, Richardson RFPD has announced full design support for the model PE42524 HaRP reflective single-pole, double-throw (SPDT) switch die from Peregrine Semiconductor. The UltraCMOS switch, which operates from 10 MHz to 40 GHz, achieves 47-dB isolation and only 2.2-dB insertion loss at 30 GHz. The active port return loss is 17 dB at that same frequency. Isolation remains 33 dB at 40 GHz while insertion loss climbs to only 5.5 dB at 40 GHz. The switch chip is well suited for



applications in broadband communications and in test equipment.

RICHARDSON RFPD, 1950 S. Batavia Ave., Ste. 100, Geneva, IL 60134; (630) 262-6800; *www.richardson rfpd.com*

Hybrid Links 500 to 1000 MHz

Designed for broadband use from 500 to 1000 MHz, model 2164-90 is a 90-deg. hybrid coupler with better than 25-dB isolation between ports across the full frequency range. It operates with maximum VSWR of 1.25:1 and suffers maximum insertion loss of 0.25

db while maintaining amplitude balance of ±0.5 dB across the 500-MHz bandwidth. The rugged hybrid coupler handles 100 W average power and 5 kW peak power across the full frequency range. It is supplied in an aluminum housing per MIL-C-39012 specifications with SMA female connectors.

ARRA INC., 15 Harold Court, BayShore, NY 11706-2296; (631) 231-8400; e-mail: sales@arra.com, *www.arra.com*

Low-Noise Amplifier Boosts 2 to 22 GHz

MODEL TGA2227-SM is a packaged, broadband, low-noise amplifier from Qorvo/TriQuint Semiconductor suitable for applications in commercial, industrial, and military systems from 2 to 22 GHz. It achieves typical noise figure of 2.7 dB with typical gain of 15.7 dB. The amplifier, which can run on drain voltages of +5 to +15 VDC, typically draws 125 mA at +8 VDC. It provides +22 dBm output power at 1-dB compression. The rugged amplifier can survive input levels as high as +40 dBm. It is based on gallium-nitride-on-silicon-carbide (GaN-in-SiC) semiconductor technology and is supplied in a 14-pin housing measuring just 4.0 × 4.0 × 1.7 mm.

QORVO, 2300 NE Brookwood Pkwy., Hillsboro, OR 97124; (877) 800-8584; *www.triquint.com, www.qorvo.com*

SDLVA Tracks 4 to 18 GHz

DESIGNED FOR broadband systems operating from 4 to 18 GHz, model SDLVA-418-65-16MV-12DBM is a successive-detection, log-video amplifier (SDLVA) with 65-dB dynamic range over that frequency span. It features a nominal log slope of 16.7 mV/dB with tangential signal sensitivity (TSS) of –64 dBm. The SDLVA handles +20 dBm maximum input levels with a –55 to +10 dBm video logging range and ±1.8 dB video logging linearity. It achieves video rise time of 10 ns and video fall time of 15 ns with 30-ns maximum recovery time and less than 2-ns delay time. It works with pulse widths as narrow as 25 ns and runs on 850 mA at +12 VDC and 250 mA at –12 VDC. The amplifier measures 4.24 × 0.994 × 0.38 in. with nickel-plated finish per MIL-C-26074 and maximum weight of 3 oz. It features an operating temperature range of 0 to +85°C.

PLANAR MONOLITHICS INDUSTRIES INC., 7311-F Grove Rd., Frederick, MD 21704; (301) 662-5019,6620-5019; e-mail: sales@pmi-rf.com, *www.pmi-rf.com*

Coupler Handles High Power to 6 GHz

MODEL 12A7NA-40S is a compact directional coupler with 40-dB nominal coupling from 5 to 6 GHz. It provides ±0.75 dB coupling variation across frequency and a VSWR of 1.25:1. The directional coupler achieves 25-dB directivity with low insertion loss of 0.25 dB. It handles 225 W average power and 1500 W peak power and is supplied in a compact housing measuring 1.90 × 0.89 × 0.50 in. with coaxial connectors.

RENAISSANCE ELECTRONICS & COMMUNICATIONS LLC, 12 Lancaster County Road, Harvard, MA 01451; (978) 772-7774; e-mail: sales@rec-usa.com, *www. rec-usa.com*

Power Dividers Extend to 6 GHz

A LINE of Wilkinson power dividers has been developed with Type-N coaxial connectors (model 80X-4-3.250WWP) for applications from 0.5 to 6.0 GHz. The power dividers are available in 2-, 4-, 8-, and 16-way configurations with power-handling capabilities to 30 W. Well suited for indoor and outdoor applications, these power dividers are IP67 rated and exhibit typical VSWR from 1.20:1 through 1.30:1. The minimum isolation between ports is 17 to 20 dB with amplitude and phase balance rivaling the performance of much more narrowband components.

MECA ELECTRONICS INC., 459 East Main St., Denville, NJ 07834; (866) 444-6322; e-mail: sales@e-meca.com, *www. e-MECA.com*

Highpass Filter Runs 2 to 18 GHz

MODEL WT-A0166-HS is a coaxial highpass filter with less than 1-dB insertion loss across a wide passband of 4 to 18 GHz. It exhibits less than 2.0:1 VSWR with more than 40-dB out-of-band rejection at 2.5 GHz. The filter, which is supplied with female SMA connectors, can handle power levels to 10 W. It can be finished in guide oxygen or black paint to endure the most challenging environments.

CHENGDU MICROWAVE COMMUNICATION TECHNOLOGY CO. LTD., (86) 28-84300332, ext. 808; e-mail: yanqiu@cdwweitong.com, *www.cdweitong.com*

MMIC Power Amplifier *(continued from p. 84)*

operating conditions (*Fig. 2*). The small-signal gain is about 19 dB, with input and output return losses of better than 10 and 13 dB, respectively, across the band of interest. While output power varies across the wide frequency range for various input-power levels, the amplifier can deliver about +37 dBm output power at 1-dB compression across a bandwidth of 33 to 38 GHz, with a rated output power of +36.5 dBm at 1-dB compression. Across the full 32-to-38-GHz band, the device also achieves the required +36-dBm output power at 1-dB compression.

Figure 3 shows the power-added-efficiency (PAE) performance for pulsed operation. As the data reveals, the amplifier achieves a PAE of between 18% and 27% across the full frequency band.

A comparison of measured results with simulated performance as predicted with NI AWR Design Environment software (*Fig. 4*) shows good correlation that validates the design process. As is typical, output power performance measured slightly lower than simulation, while measured PAE is slightly better than predicted by simulation. Despite the variation in magnitude of these parameters, the similar shape of the response curves indicates that the circuit was accurately characterized in simulation.

The MAAP-015016-DIE four-stage Ka-band PA provides 4-W output power with 19-dB typical gain from 32 to 38 GHz in a small-sized chip. It was designed for RF/microwave performance as well as for thermal longevity, with the aid of modern computer-aided-engineering (CAE) software simulation tools. Fabricated with a reliable 0.15-μm GaAs pHEMT semiconductor process, the PA is a strong candidate for both military and commercial applications at Ka-band frequencies, as more systems extend toward these higher frequencies. mw

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