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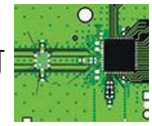

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2 Watts CW

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9.25 GHz (+/- 30

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25 Watts CW

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- Isolation: 25 dB typ., 20 dB min.
- Switching Speed: 100 ns max.
- VSWR: 2.0:1 typ.

4 Watts CW

500 MHz to 18.0GHz

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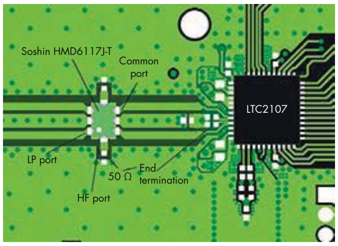

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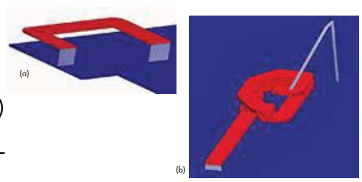

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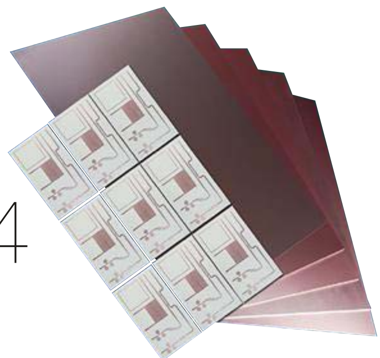
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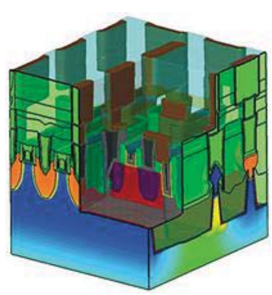
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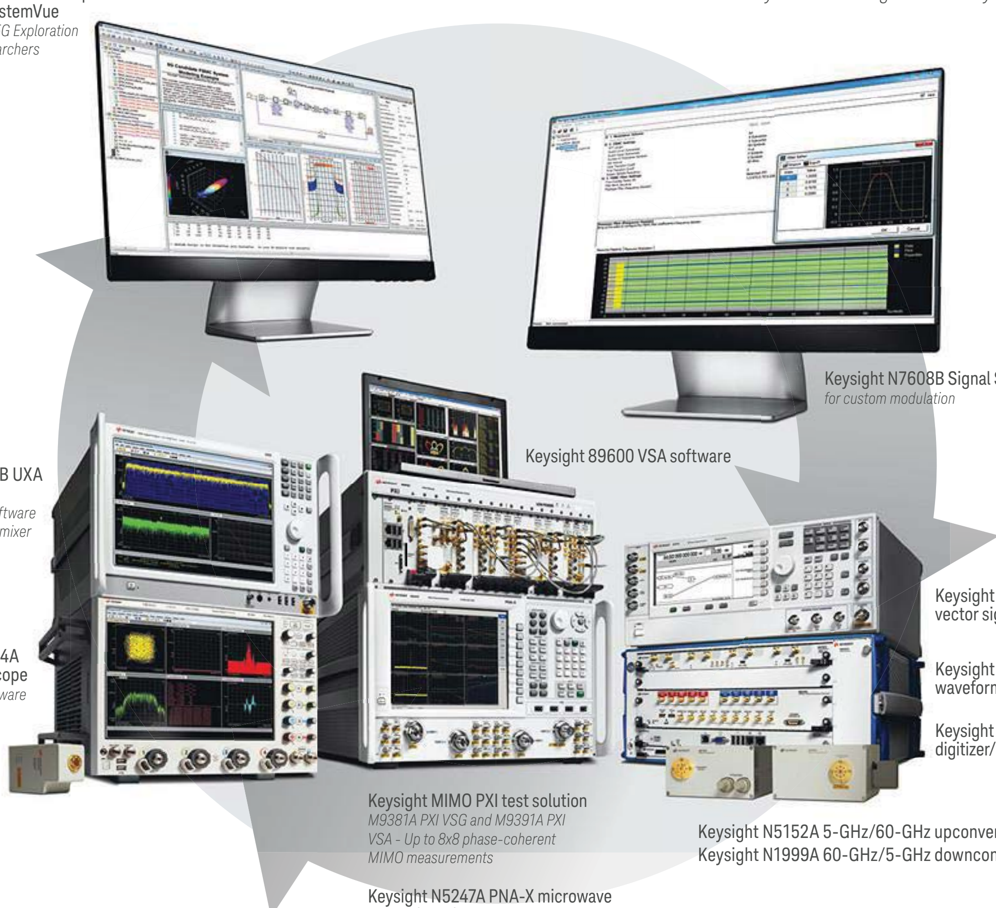

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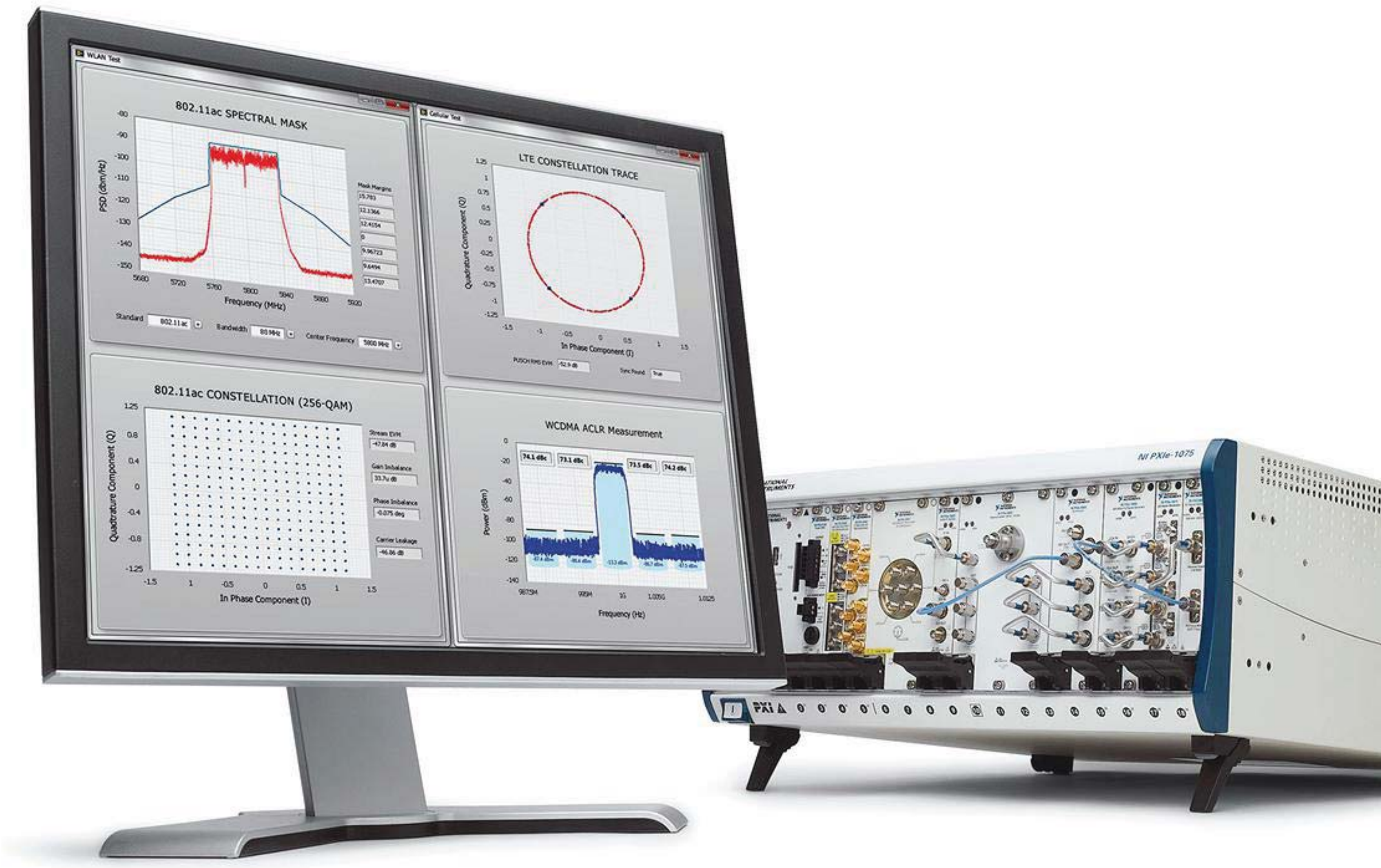

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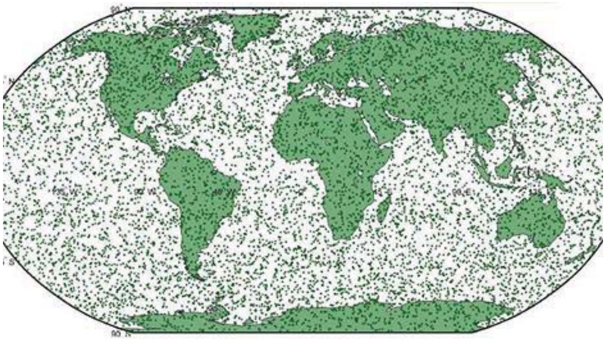

WEATHER SENSOR REACHES LOWEST ATMOSPHERE LAYERS

http://mwrf.com/systems/next-gen-weather-sensor-reaches-lowest-atmosphere-layers

The newly introduced PlanetiQ Pyxis weather instrument uses next-generation sensor technology to penetrate through clouds and storms, producing the highly calibrated data required to improve weather forecasting, climate monitoring, and space weather prediction.

EVALUATING EMC MEASUREMENT NEEDS

Image courtesy of: Google Play

http://mwrf.com/blog/evaluating-emc-measurement-needs

Having countless wireless devices in a crowded location requires that these electronic products meet strict requirements for levels of electromagnetic interference (EMI) and electromagnetic compatibility (EMC), lest the transmission from one device block the reception of another device nearby. For this reason, EMC testing of different wireless electronic products can be considered a truly underrated part of the electronic product manufacturing process.

5 THINGS YOU SHOULD KNOW ABOUT 5G CELLULAR

http://mwrf.com/blog/5-things-you-should-know-about-5g-cellular

While the forthcoming 5G cellular system is still in its R&D phase, with lots of options being considered, one fact is becoming quite clear: 5G will be a significant leap beyond 4G LTE. Read Lou Frenzel's latest blog for his five facts about 5G that you should know.

VIDEO: DIGITAL FRONT-END SoC FOR CELLULAR BASE STATION RADIOS

http://mwrf.com/freescale-s-airfast-digital-front-end-soc-cellular-base-station-radios

In this video, John Vaglica from Freescale Semiconductor introduces the industry's first fully software-programmable Digital Front End (DFE) System-on-Chip (SoC) for cellular base station radios, the AFD4400. This DFE SoC virtually eliminates hardware logic design, allowing integrators to concentrate instead on software development and product integration.

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Editorial

CHRIS DeMARTINO

Technical Editor

chris.demartino@penton.com

GaN Taking Control

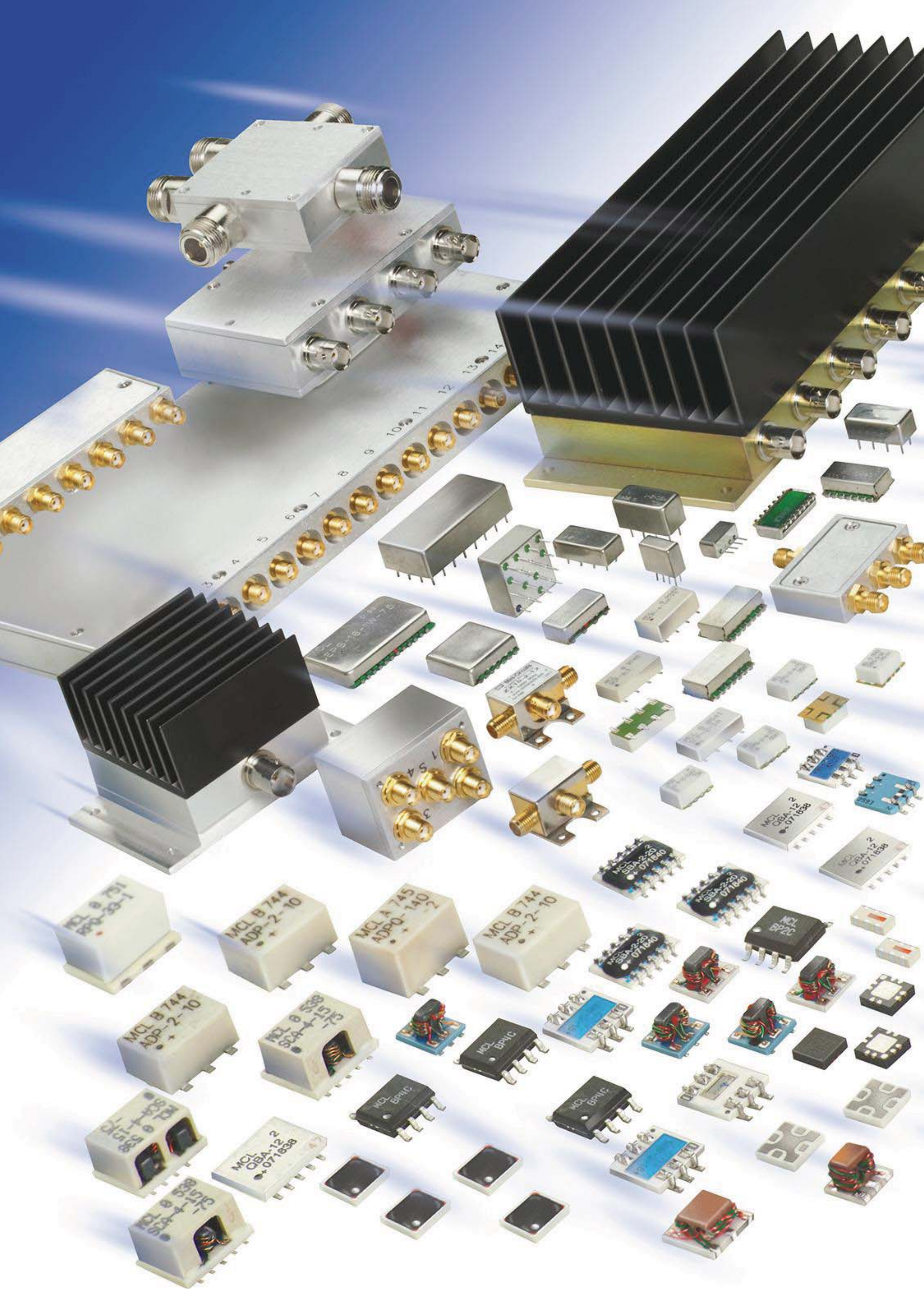
By now, most in the RF/microwave community are familiar with gallium-nitride (GaN) technology and the benefits it can offer. The utilization of GaN technology continues to increase, as many applications are taking advantage of its performance enhancements. In comparison with other device technologies such as gallium-arsenide (GaAs), GaN offers several improvements in performance. Because GaN outperforms other device technologies in several aspects, its use is becoming more widespread.

In the early days of GaN, it seemed like the technology would only be suitable for expensive military applications. However, as the technology has matured and manufacturing costs have decreased, GaN is now being employed in a wide range of applications. Some of these include wireless infrastructure, radar, and satellite communications (satcom). GaN devices are available in both packaged and die form.

Satcom is one arena where GaN technology is playing a prominent role. Manufacturers of solid-state power amplifiers (SSPAs) are now using high-power GaN devices to achieve high power levels at high frequencies. In the past, high-power GaAs devices were widely used to design these SSPAs. Today, however, many high-power GaN devices intended for these applications are available on the market. These devices provide the performance required by these SSPAs. Although many SSPAs still utilize GaAs devices, GaN is taking control of this segment.

Although power amplifiers are the predominant application for GaN technology today, other applications also can benefit from GaN. Low-noise amplifiers (LNAs) are one example. GaN LNAs are capable of handling very high input signal levels without incurring any damage. In many front-ends, a limiter is placed before the LNA. This limiter protects the LNA from high incident signal levels. Since GaN LNAs can already withstand high input signal levels, the limiter can be removed altogether, which improves the overall noise figure. New GaN LNAs have recently been released that provide this capability.

Several companies have released new GaN products in the last few months alone. Freescale Semiconductor recently released its first GaN power transistor for cellular base stations. Custom MMIC has expanded its portfolio with the release of a new GaN LNA. And Qorvo also recently released new GaN products for both satcom and radar applications. These are just a few examples of the recent activity that has occurred in the GaN marketplace. With performance requirements continuing to increase, we can expect to see more activity in the very near future. mw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SUBJECT TO FURTHER REVIEW

I just received the July 2015 edition of *Microwaves & RF* magazine, which I read to see if you completed your review of software companies at the IMS2015, per our earlier discussion ("IMS Omissions," July Feedback). Ansys HFSS was mentioned In in your article, but newFASANT in Booth No. 108, Aurora Software in Booth No. 1039, Altair Engineering in Booth No. 1729, and others were still not reviewed. Did I miss this information in the July issue, or was it deleted for some reason?

I am looking forward to your reply.

DR. SCOTT BEST
CHIEF TECHNOLOGY OFFICER
SIBERSCI, LLC

EDITOR'S NOTE

With our deadlines, it is often difficult to cover everyone all the time. Fortunately, we have a few more articles appearing in this issue on software (among them, "PXI Offers Complete Test Solutions" on p. 44, "Programming The Right Simulator for the Task" on p. 60, and "Simulators Predict System-Level Behavior" on p. 75), so we'd recommend you give those a read.

Keep in mind that no matter what size article we may devote to a specific topic or show roundup, it is more-or-less impossible to cover everyone. I read a great deal in markets ranging from commercial and consumer electronics and music equipment through vacuum physics manuals, and I can tell you that I have not seen a complete survey article yet in 40 years of doing so.

Microwaves & RF certainly appreciates the support of its advertisers. But we perhaps value the needs of our readers even more, and we try to serve our readers' needs on a daily basis with our website (www.mwrf.com) and on a monthly basis with our printed magazine. Product Features and reviews will provide details on specific products, but we do not attempt to steer our readers towards one product or another—we simply provide the educational background that they may need to help them in the product specifying process. In the case of software, there are many fine programs and suppliers of products for simulating everything from integrated circuits (ICs) to complete systems. We cannot hope to detail every applicable product and company in these reports, but we do try to provide our readers with enough "fuel" to ease their decision-making.

As always, thanks for your patience and understanding.

JACK BROWNE
TECHNICAL CONTRIBUTOR

FEEDBACK THANKS

I saw that you printed my feedback ("IMS Recognition," July Feedback). Thanks for including my input!

JONATHAN HARRIS
PRODUCT APPLICATIONS ENGINEER
ANALOG DEVICES

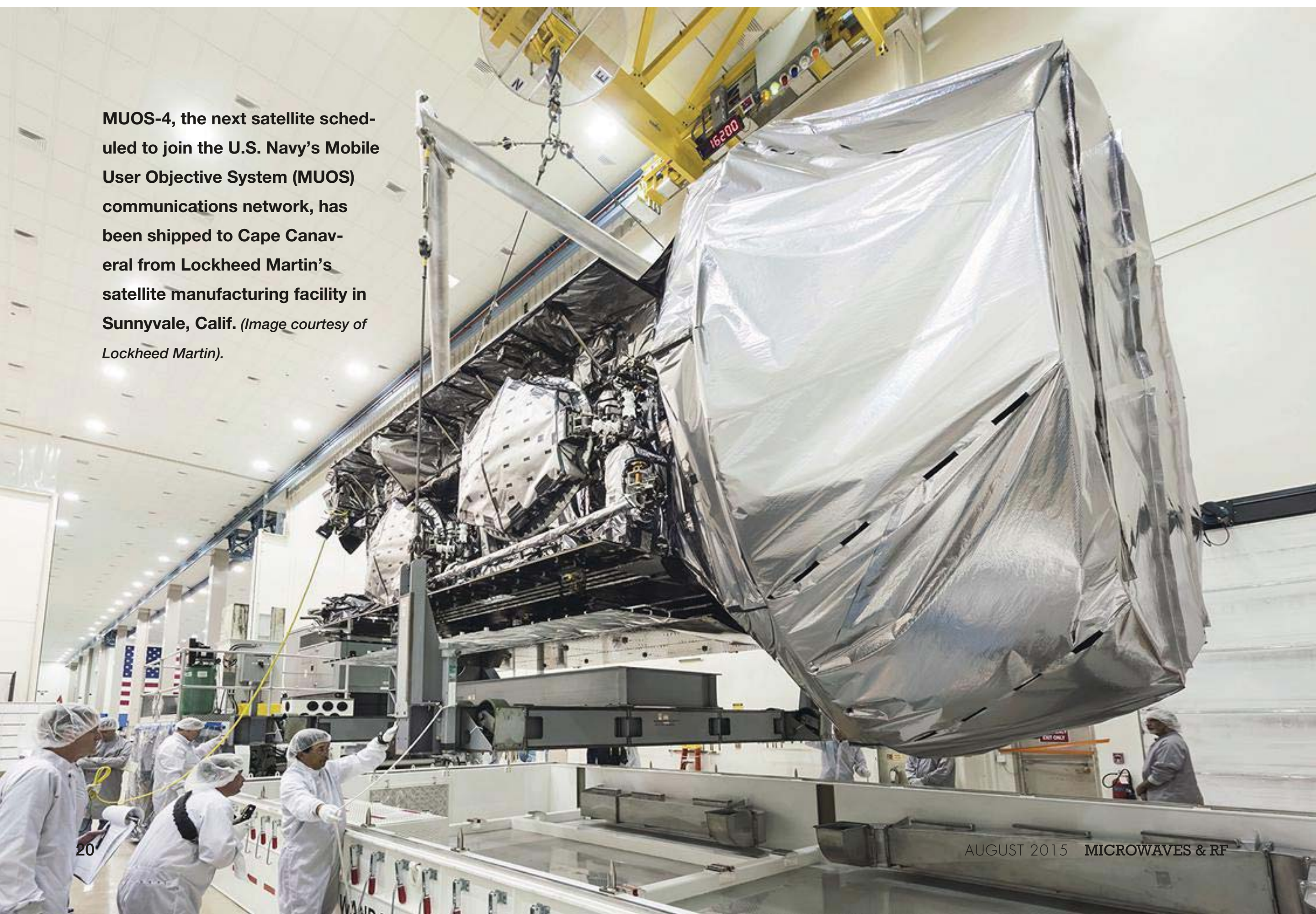
News

FINAL MUOS SATELLITE
Delivered for Pre-Launch Tests

The next generation of the U.S. Navy's highly mobile communications network is one step closer to being fully operational. The fourth and final satellite in the Mobile User Objective System (MUOS) has been delivered to Cape Canaveral Air Force Station where it will conduct a series of pre-launch tests. The satellite, MUOS-4, is scheduled to launch this month aboard a United Launch Alliance Atlas V rocket.

Designed and manufactured by Lockheed Martin, the MUOS-4 satellite is the final piece of an integrated network of orbiting satellites and relay ground stations. When it reaches an operational orbit, the satellite will extend the MUOS network to near global coverage, according to Iris Bombelyn, vice president of narrowband communications at Lockheed Martin. With access to MUOS terminals, military forces will be able to share information seamlessly while traveling beyond line-of-sight.

Mirroring the capabilities of a modern cellular network, the MUOS is designed to free mobile military forces from the yoke of conventional ultra-high frequency (UHF) communications. Bombelyn noted that previous systems, such as the legacy UFO network, only allowed soldiers to share information within the coverage area of the same satellite. The MUOS network does not have the same restraints, according



MUOS-4, the next satellite scheduled to join the U.S. Navy's Mobile User Objective System (MUOS) communications network, has been shipped to Cape Canaveral from Lockheed Martin's satellite manufacturing facility in Sunnyvale, Calif. *(Image courtesy of Lockheed Martin).*

to Bombelyn. Military forces will be able to share simultaneous voice, video, and mission data without having to consider where they are in relation to a satellite.

Assembled in Lockheed Martin's Sunnyvale, Calif., facility, the MUOS-4 satellite was shipped to Cape Canaveral from Moffett Federal Airfield in California. In preparation for the satellite's launch, Astrotech Space Operations, a subsidiary of Lockheed Martin, will complete processing on the MUOS-4 module.

The MUOS network is expected to be fully operational by the end of the year. After the MUOS-4 completes a series of in-orbit tests, it will be moved to an operational orbit for active service.

The other three MUOS satellites are currently in operation, and the four associated ground stations have been finished. More than 55,000 currently fielded radio terminals can be upgraded to be compatible with the MUOS network. In most cases, this could be done with a software update. ■

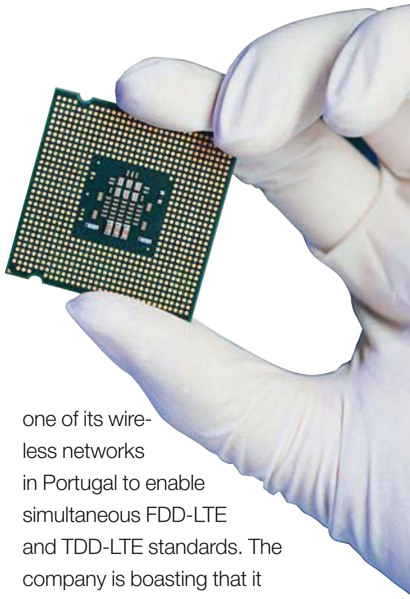
ROAD TO CARRIER Aggregation Paved with Chinese Chipsets

THE ADVANCED LONG Term Evolution (LTE-A) network is set to launch in China before the end of the year. During this period, domestic Chinese chipset and mobile brands that support carrier aggregation are predicted to burst into the global market. Competition within the Chinese market is pushing development of carrier aggregation, according to the latest report from the RF and Wireless Components division at Strategy Analytics. As other countries transition into a more heterogeneous network (HetNet) infrastructure, Chinese manufacturers are expected to take an early lead in the market.

The Strategy Analytics report, "China to Lead Global Carrier Aggregation in 2016," notes that demand for increased bandwidth and higher data rates is driving the growth of LTE-A in relation to carrier aggregation. Also referred to as channel aggregation, carrier aggregation increases data throughput by sharing the total aggregated bandwidth between wireless carriers. As opposed to 4G LTE standards, which only function on a maximum bandwidth of 20 MHz, the LTE-A standard will operate on a bandwidth between 40 and 100 MHz. To do this, it will aggregate up to three 20-MHz carriers simultaneously.

Under the 4G LTE standard, spectrum is highly fragmented and costly to operate. For that reason, wireless carriers have started looking at open-source infrastructure as an alternative. These heterogeneous alternatives include strategically deployed small cells, carrier Wi-Fi, and distributed antenna systems (DASs). As the number of these cells grow, it will become increasingly important for devices to smooth out the frequent handoffs between serving cells—and, by extension, carriers. LTE-A with carrier

As wireless carriers transition to a HetNet infrastructure, domestic Chinese chipset and mobile brands that support carrier aggregation are predicted to burst into the global market.



aggregation was designed to address these issues.

According to Guang Yang, a senior analyst with Strategy Analytics, China Mobile is at the vanguard of LTE-A technology in the domestic Chinese market. It holds large tracts of the B41 spectrum available for carrier aggregation. In recent trials of the LTE-A standard, China Mobile has achieved download speeds of more than 300 Mb/s on devices powered by Qualcomm's Snapdragon 810 processor. Other wireless vendors, such as China Telecom and China Unicom, are also using carrier aggregation to compete for a slice of the market. But due to the high cost of spectrum, these companies have developed LTE standards in frequency-division-duplexing (FDD) bands.

FDD standards are being implemented by other wireless carriers around the world. UK-based Vodaphone, for instance, recently upgraded one of its wireless networks in Portugal to enable simultaneous FDD-LTE and TDD-LTE standards. The company is boasting that it is the first mobile vendor to implement FDD-LTE/TDD-LTE carrier aggregation in a commercial market.

As more 4G LTE systems get upgrades, Chinese equipment vendors are expected to flourish. This growth will be supported by the wide availability of chip sets that support carrier aggregation. Qualcomm was the leading supplier in 2014. But this year, companies like Intel and Samsung have stepped into the arena. This diversity will allow Chinese OEMs to challenge current industry leaders at a wide variety of price points in both domestic and export markets. ■

MORE-REFINED 5G STANDARDS on Tap from 5G Lab Germany

AS CAPACITY DEMANDS begin to strain fourth-generation (4G) wireless networks, research is actively being carried out to define the capacity of next-generation systems. Bell Labs, the industrial research arm of Alcatel-Lucent, has become the latest big player to invest in the future of fifth-generation (5G) networks. The company has partnered with the 5G Lab Germany, a research group focused on using wireless mobile networks to support "tactile Internet" technology, such as automated driving and remote surgery.

Founded by the Technische Universität Dresden (DRE), the 5G Lab Germany is made up of around 20 professors from the university and more than 500 engineers from private companies. The organization is in the process of researching the entire value chain related to 5G networks, ranging from semiconductor chipsets to data transmission. As a new member of the research team, Bell Labs will initially focus its energy on developing a pair of standards for 5G communications.

The first is a method for coordinating multiple access technologies to boost the capacity of next-generation networks. This standard is meant to specifically exploit the shift to a Heterogeneous Network (HetNet) infrastructure. Populated by strategically deployed small cells, carrier Wi-Fi, and distributed antenna systems (DASs), the HetNet ecosystem is bursting with radio access points. The most important goal is to develop a low-complexity interface for this increasingly complex system of access technologies.

As a result, Bell Labs is looking for ways to simultaneously connect a single device to multiple radio nodes. Using these access points together not only increases the capacity of the network but, according to the research group, also makes it more reliable. For instance, if there is a problem with one network, the device can draw on other networks with a stronger signal. On top of that, Bell Labs also is involved with linking devices to a combination of 5G and 4G LTE links, further increasing network reliability. Aside from consumer applications, researchers will focus on how this design can support mission-critical applications, such as transportation and emergency responders.

The second standard being analyzed by the research group is an "air interface" proposal for 5G prototype networks. Of particular interest is the Universal Filtered-Orthogonal Frequency-Division Multiplexing (UF-OFDM) waveform, a Bell Labs system that is being considered for 5G standardization. Alcatel-Lucent developed the waveform as an

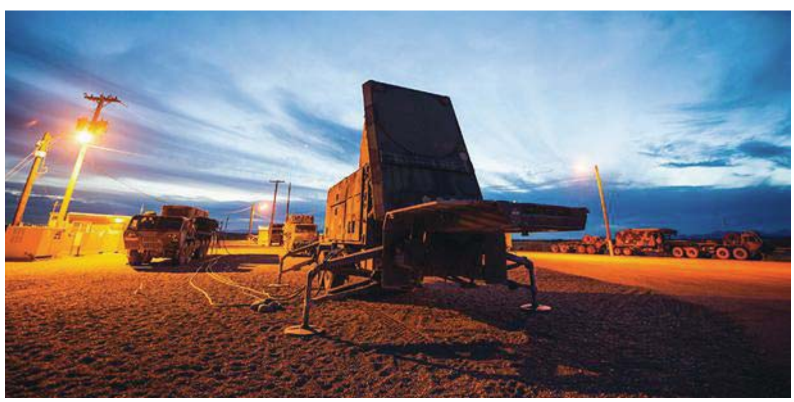
improvement of the OFDM, the digital modulation method used in 4G LTE networks. While the OFDM waveform is only optimized for smartphone data traffic, the UF-OFDM was designed to support a more diverse pool of traffic. This includes smartphones, machine-to-machine devices, and the tactile Internet technology being studied by the 5G Lab Germany. As the Internet of Things (IoT) continues expanding, networks will have to manage a large volume of sensor-based data that will come from the machine-to-machine devices of the future. Bell Labs holds that UF-OFDM will reduce the complexity of 5G networks and increase the number of devices they can support.

For Bell Labs, the research agreement with the 5G Lab Germany is the latest in a long line of collaborations. In the past, the company has signed agreements with NTT Docomo, KT Communications, and Freescale, among others. As for the 5G Lab Germany, along with Alcatel-Lucent, it has partnered with National Instruments, Vodafone, Nokia, Rohde & Schwarz, and Ericsson. ■

GaN-BASED AESA RADARS Near Full Production

GALLIUM-NITRIDE (GaN) TRANSISTORS have become a staple in military-grade radars, thanks to their ability to boost the amplification of microwave signals. GaN also carries a higher voltage than other semiconductor materials, such as silicon, allowing the system to operate on less power and produce less heat. Because of these properties, Raytheon is using GaN-based active electronically scanned arrays (AESAs) to refine the Patriot Air and Missile Defense System. With this latest upgrade, Raytheon is one step closer to replacing the single forward panel on existing Patriot systems with a series of AESA radar antennas. Full production is scheduled for early next year.

Measuring about 9 ft. wide and 13 ft. tall, the main AESA array is a replacement antenna that will bolt onto the front of the current Patriot radar module. Operating in a similar manner as the current forward panel, the antenna will be oriented toward a primary target. A series of rear panel antennas will be directed behind and to the sides of the vehicle, generating 360-deg. coverage. The system, equipped with the AESA technology, is capable of simultaneously detecting and tracking a number of airborne and ground targets from all sides. The higher resolution will allow the system to detect drones, advanced aircraft, and ballistic and cruise missiles from a greater distance.



With the addition of GaN-based active electronically scanned arrays (AESAs), the Patriot Missile Defense System will be capable of detecting and tracking airborne threats in a 360-deg. radius. *(Image courtesy of Raytheon)*

By using GaN semiconductors to increase the radar system's efficiency, Raytheon avoided having to build a new Patriot module with a larger generator. To reduce the cost of development, the radar arrays were designed to be compatible with back-end hardware and updated system software. Several months ago, Raytheon conducted a series of preliminary tests, integrating the new panel antennas with the Patriot system. The tests confirmed the increased capabilities of the final system.

To date, the main antenna's superstructure and power and cooling subsystem are complete. But additional upgrades must be made to improve operational availability. Before the system is ready for combat situations, for example, more work must be done to integrate the subsystems and populate the superstructure with GaN-based transmit-receive units (TRLRUs).

The GaN-based AESA radar system will be operated from an open-architecture common command and control (CC2) node. It will retain backwards compatibility with the current Patriot Engagement Control Station. The CC2 node will be fully compatible with NATO and the Integrated Air and Missile Defense Battle Command System (IBCS). ■

GPS III CONTROL System Boosts Navigational Accuracy

HAVING MAINTAINED the Global Positioning System (GPS) since it was invented in the 1970s, the Department of Defense is again looking to upgrade it both for military and civilian applications. Through a series of operational tests, for example, Raytheon is in the process of demonstrating the latest ground control system for the GPS satellite network. The Next Generation Operational Control System (GPS OCX) is set to increase the number of satellites supported by the current network. It also promises to improve the network's targeting and tracking capabilities.

The GPS OCX system shifts the main control features, which used to be carried out manually, to software. That software uses a version of the Kalman filter algorithm to provide accurate tracking information despite interference. Using that algorithm, the system is able to observe the signals uploaded to the GPS monitor stations and then measure overall system variance. As a result, the system can recursively update the location of vehicles and devices equipped with GPS receivers. Designed for the next generation of navigational satellites—the GPS III series—the software is designed to improve the precision of the GPS network in areas like urban canyons and mountainous terrain. It also will aid mission-critical applications like air traffic control and emergency response.

The Next Generation Operational Control System (GPS OCX) is set to increase the number of satellites supported by the current GPS network. It also promises to improve its targeting and tracking capabilities. (*Source: U.S. Department of Defense*)

Further improving the accuracy of the system is its compatibility with other navigational satellites in orbit. The GPS was the only one of its kind for several years and was developed with a closed architecture. As more and more satellite networks emerge for civilian applications, however, the GPS OCX system is using them to increase signal reliability. The control system is capable of assimilating both legacy signals from the current satellite network and new types of signals, including the jam-resistant military M-code and civil signals such as L1C, L2C, and L5. Working together in support of the system, these signals eliminate atmospheric distortions and provide signal redundancy to mitigate radio-frequency interference. According to Raytheon, the resulting measurements are almost ten times more precise than their predecessors.

The GPS OCX will be delivered in several phases or blocks. The Block 0 Launch and Checkout System (LCS)—a system developed by Raytheon to support and test the GPS III satellites in orbit—is currently being installed at Shriever Air Force Base. This version will introduce the full capabilities of the L2C navigation signal. GPS OCX Block 1, which will fully introduce the new control system, is scheduled to enter service in 2018. ■

FRESH STARTS

Synopsys Inc.—Acquired the Bluetooth Smart IP from Silicon Vision, expanding Synopsys' extensive portfolio of DesignWare IP for the Internet of Things (IoT), which includes security IP recently obtained through the acquisition of Elliptic Technologies, as well as logic libraries, memory compilers, nonvolatile memory, data converters, interface IP, power-efficient ARC processors, a sensor and control IP subsystem, and an embedded vision processor.

Lockheed-Martin—Updated its A2100 spacecraft, which will be used as the basis for the U.S. Air Force's newest infrared surveillance and missile warning satellites. The update improves system affordability and resiliency while also adding the flexibility to use future payloads. The fifth and sixth Space-Based Infrared System (SBIRS) Geosynchronous Earth Orbit (GEO) satellites will receive this advanced spacecraft technology at no additional cost to the existing fixed-price contract. The SBIRS program is responsible for America's early-missile-warning and infrared-surveillance missions.

Anritsu Company—Signed a formal agreement whereby Electro Rent is a preferred reseller for Anritsu test solutions throughout the U.S. and Canada. Under terms of the agreement, Anritsu benchtop and field instruments will be available through Electro Rent, which will provide customers with sales and service support through its four offices throughout North America. Electro Rent has three regional U.S. offices, in Norcross, Ga.; Pearland, Texas; and Van Nuys, Calif. The company's Canadian operations are based in Mississauga, Ontario.

Anite—Announced that its Propsim F32 Channel Emulator was selected by AT4 wireless for its first anechoic MIMO Over-the-Air (OTA) test laboratory in Spain. The laboratory has been set up to perform device testing compliant with CTIA certification requirements prior to market introduction. AT4 wireless selected Anite's Propsim F32 for its ability to support LTE and LTE-Advanced device testing of up to 32 channels in a single unit, thereby simplifying setup and reducing cost.

Cobham Wireless—Launched the TeraVM elastic test bed, a first-to-market NFV test solution, allowing network function vendors and service providers to share lab assets between facilities. This enables engineers to create virtual test pods to "stress test" network functions, reducing ownership costs by eliminating the need for multiple labs all using proprietary hardware.

DEKRA—Is taking over the testing company AT4 wireless in Malaga, Spain. A contract to this effect was signed on June 29, 2015. With this move, DEKRA is completing its range of testing services for wireless communication and electromagnetic compatibility (EMC). This is already DEKRA's third transaction this year in the field of product testing, strengthening its position as service provider to the consumer and automotive electronics industries. In January, DEKRA acquired the EMC service provider QuieTek in Taiwan and in May, the Joint Venture DEKRA iST, also based in Taiwan, was announced.

Electro Enterprises Inc.—Was named an authorized distributor of W.L. Gore Microwave/RF Assemblies, serving the military-aerospace market in North America. With Electro stocking common configurations of Gore assemblies, product can now be shipped same-day to customers in North America. Electro Enterprises, a women-owned small business, recently expanded its Oklahoma City, Okla., headquarters warehouse by 36,000 square feet.

Hirose Electric—Has developed a fiber optic cabling value-added reseller (VAR) program to complement its line of ruggedized connectors to deliver complete fiber optic solutions for a wide range of commercial, data com/networking, medical, military/aerospace, surveillance and telecommunication applications. Through partnerships with Timbercon and Atlantic Teleconnect Inc. (ATI), two suppliers of fiber optic cabling products and services, Hirose now offers custom and standard cable assemblies that utilize its selection of industry-standard and custom fiber optic connectors.

Raytheon Co.—Signed an agreement with Kongsberg to extend their partnership on the National Advanced Surface-to-Air Missile System (NASAMS) for another 10 years. The Raytheon-Kongsberg collaboration is focused on optimal system performance and capabilities from sensor to effector for NASAMS users around the world, including incorporation of the new AMRAAM-ER (extended range) missile.

The Wi-SUN Alliance—Announced a new adopter class of membership, created specifically to make it easier and more cost-effective for utilities and municipalities to deploy the Wi-SUN solution set to meet their growing SmartGrid and Smart City needs. With more than 80 member companies worldwide, the Wi-SUN Alliance is focused on accelerating the implementation of a smarter grid and smarter cities by enabling the global adoption of interoperable solutions based on the IEEE 802.15.4 and related open global standards.

CONTRACTS

MERCURY Stays On the Radar

DISA Extends TCS Agreement

Mercury Systems Inc.—Received a $4.4-million follow-up order from an international customer for high-performance digital signal processing subsystems for a naval radar application. The order was booked in the company's fiscal 2015 fourth quarter and is expected to be fulfilled over the next several quarters.

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.

Inside TRACK with Ryan Pratt,

FOUNDER AND CEO, GUERRILLA RF

Interview by CHRIS DeMARTINO

CD: What opportunities inspired you to create a MMIC startup at this time?

RP: I saw an industry preoccupied with the needs of smartphones. This is understandable due to the unprecedented size of the smartphone IC market. But there is also an enormous opportunity to innovate in the high-performance space aimed at the infrastructure markets. Knowing our industry as I do, I see a lot of stale MMIC products that are ripe for disruption.

Another big opportunity we see is how the smartphone explosion is challenging cellular infrastructure to keep up from a capacity point of view. This leads to new technologies like small cells, carrier-class Wi-Fi, and wireless backhaul experiencing explosive growth. We believe these technologies are not well served by the MMICs focused on traditional base stations or cellular handsets, due to their unique performance and form-factor needs.

Personally, the primary inspiration for me to create this startup was to be able to work on the products and technologies I wanted to without needing to uproot my family. When I left my last company, my choice seemed to be to either take a job working in a less interesting area of the industry or relocate. With a special-needs child and a lot of family and friends in this area, relocation was not on the table. That is when my father suggested creating a startup. With my wife's support, I did just that.

CD: What are some of the challenges of being a startup and competing with larger, more well-established companies?

RP: The biggest overall challenge of being a startup in the semiconductor industry right now is access to capital. In my experience, traditional venture capital is not a plausible path for chip companies except in very rare instances. We were extremely fortunate to gain the support of local angel investors in order to launch Guerrilla RF.

In terms of competing with larger well-established companies, we do not see this as a huge challenge. It goes to the roots of our name, Guerrilla RF. We see numerous underserved market segments that the larger companies are not interested in addressing. As with guerrilla warfare, we seek weak areas to attack. In our case, this means finding and developing products for these under-served niches. As indicated earlier, we feel some examples of these are small cells, carrier-class Wi-Fi, and wireless backhaul. We feel that our team of industry veterans and outstanding supply-chain partners enable us to compete with the bigger companies whenever necessary.

CD: Do you believe all of the consolidation that has occurred among companies in the semiconductor business is good or bad thing for the RF/microwave industry?

RP: I think the consolidation is generally a good thing. It has definitely been a great thing for us, as we see many opportunities emerging due to these consolidations. Instances where older products get obsoleted by competitors and really good people become available due to layoffs have benefited our company enormously.

I also think consolidation is a good thing for the industry, because many products were getting commoditized. There should now be enough profitability to pay for the R&D needed to sustain the amazing wireless network growth we have seen in the last several years.

Of course, the negative side is that jobs are being lost. Ultimately, it worries me greatly that we are losing some really talented people from the industry.

CD: You mentioned the loss of jobs. Since you also went through a career transition, what advice would you give RF/microwave engineers so that they can continue to thrive in this industry?

RP: The first thing I would advise is to take a good look at your financial situation to make sure you will be ready for your career transition. Layoffs are a reality in our industry and you need to be able to take the necessary time to find a new job you will like. In my experience, you need at least three months of savings if possible.

Next, I would recommend taking a deep breath and considering all of your options. I felt a panicky need to find a new job as quickly as possible right after I was let go. Some of the best advice I got was to take some time to be with my family and carefully consider what my next step was going to be. Rushing into a new position seemed like the right thing, but in retrospect I am really happy that I did not. To guide your thinking, keep in mind your career goals and figure out how your next position will get you closer to them.

"In terms of competing with larger, well-established companies, we do not see this as a huge challenge. It goes to the roots of our name, Guerrilla RF."

CD: That is great advice. I am sure our audience will appreciate it. Getting back to MMICs, what applications are creating the highest demand for them in today's market?

RP: There are a mind-boggling number of applications related to MMICs. Some of the hottest ones we see are drones/UAVs, Wi-Fi access points/home gateways, and wireless backhaul. Defense and instrumentation are also sizable application areas for MMICs.

CD: What specific requirements will drive the development of new MMICs?

RP: We believe lower noise figure and higher linearity/power are the key driving forces in new MMIC products. This is an area where products like our new Power-LNA family are garnering a lot of customer interest. When you can offer low noise and very good linearity simultaneously, some pretty cool levels of system performance become possible.

In the near future, we see the push to higher frequencies becoming much more important. Starting from 3.5 GHz up to the 5.0- to 6.0-GHz bands and even to K-band and above, we see ever-increasing demand for new products. This is being driven by the overcrowding seen in the lower-frequency bands, as well as the insatiable demand for greater wireless data bandwidth. Cellular carriers are looking for more spectrum, which leads to the need for high-performance MMICs at much higher frequencies.

CD: What role do you see gallium-nitride (GaN) technology playing in the overall realm of the MMIC marketplace in the future?

RP: As things move up in frequency on the infrastructure side, GaN will become absolutely essential. To put out any appreciable power above 2.5 GHz, I currently see no other technology choice. The big problems with GaN are its high cost and the difficulty of implementing it in a system, due to the negative gate-voltage requirements. As demand increases, I think these challenges will be overcome with some innovation to take GaN mainstream.

CD: How much impact do you think the emergence of the Internet of Things (IoT) will have on the demand for MMIC products?

RP: I think the IoT's emergence will have a large impact on MMIC products. I don't see the small end-node clients of the IoT using many MMICs. But the infrastructure connecting everything will use a lot of these components. When you have many devices trying to connect over a larger area, the infrastructure must have a higher level of performance to accommodate it all. To me, this means high-performance MMICs will be a must have.

GRAPHENE FETs EXTEND
BEYOND MILLIMETER WAVES

GRAPHENE POSSESSES INTERESTING optical, mechanical, and thermal properties for all sorts of applications, including flexible electronic circuits and electromagnetic-interference (EMI) shielding. It also holds great promise in the RF/microwave arena, with carrier mobility that's about 100 times greater than silicon and about 10 times the speed of indium-phosphide (InP) substrate materials.

To demonstrate some of the capabilities of this material, Jeong-Sun Moon and fellow researchers from HRL Laboratories LLC (www.hrl.com), Malibu, Calif., explored the fabrication and performance of different graphene field-effect transistors (GFETs). Starting with a gate length of 1 μm, the experimenters achieved dc amplifier gain of 100 for an input signal level of –12.3 dBm at 30 GHz. By cutting the gate length in half to 0.5 μm and using a source-to-drain spacing of 1 μm, the devices yielded responsivity of 33 V/W at frequencies as high as 110 GHz. The researchers estimated a 3-dB bandwidth of approximately 50 GHz for the smallest of these devices.

As linear detectors, the GFETs showed the ability for direct detection of RF power at 170 and 214 GHz when operating at zero bias, with drain-source and gate-source voltage of 0 V dc. When using nominal low bias voltage levels, and comparing the dynamic range of these GFET detectors to existing silicon-germanium (SiGe) detectors, the GFET detectors achieved RF power-detection dynamic range of better than 40 dB (from –50 to –9 dBm) at 30 GHz (with 0-V dc drain-to-source voltage and 0.5-V dc gate-to-source voltage). When compared with silicon CMOS detectors, the researchers made projections that these GFET detectors could deliver the 40-dB detection range at frequencies through 110 GHz.

Their work in graphene as a semiconductor material included fabrication of graphene heterostructure diodes and design of a 200-GHz graphene diode detector on a sapphire substrate. See "Graphene and Lateral Heterostructure for THz Imaging," *IEEE Transactions on Terahertz Science and Technology*, May 2015, p. 344.

MIMO ANTENNA INSENSITIVE
TO HUMAN-BODY EFFECTS

MOBILE-COMMUNICATIONS BANDS HAVE more users than ever across more frequency bands, calling for either more antennas per system or antenna designs that handle multiple frequency bands. Swedish and Danish experimenters pursued the latter, developing a multimode, multiple-input, multiple-output (MIMO) antenna system for mobile-terminal applications. It incorporates cellular and Wi-Fi antenna structures for wide frequency coverage.

With multimode excitation, the MIMO antenna can handle frequency bands of 830 to 900 MHz, 1.7 to 2.2 GHz, and 2.4 to 2.7 GHz. The Wi-Fi antenna operates at 2.4 to 2.5 GHz and 5.2 to 5.8 GHz. The system's metal ring design operates primarily in loop mode for effective voice and datacom performance.

Researchers explored the effects of a user's body on antenna performance through simulation and actual measurements. Effects in the cellular bands were found to be trivial. See "Body-Insensitive Multimode MIMO Terminal Antenna of Double-Ring Structure," *IEEE Transactions on Antennas and Propagation*, May 2015, p. 1925.

FOLDED-PATCH ANTENNA
TARGETS VEHICULAR GPS APPS

TO SATISFY GROWING demands for Global Positioning System (GPS) receivers, researchers from various Taiwanese institutions developed a miniature, low-cost, folded-patch GPS antenna for vehicular applications. It operates at the GPS center frequency of 1575 MHz with right-hand circular polarization (RHCP) in two orthogonal linear resonant modes.

RHCP enables a flexible orientation angle between the GPS receiver on the car and the satellite-based transmitter, reducing multipath reflections. The antenna was printed on two layers of FR-4 printed-circuit-board (PCB) material to lower cost. To obtain RHCP, the antenna is fabricated with four different lengths of meander strips connected to the four edges of a square circuit patch. The four meander lines are folded and the patch is excited by a single coaxial probe.

To better understand the antenna's behavior, it was designed with different ground planes to ensure effective operation when mounted on the metal roof of an automobile. The antenna was simulated via Ansoft's HFSS software (www.ansoft.com). A vector network analyzer from Agilent/Keysight Technologies (www.keysight.com) performed return-loss measurements.

Simulations indicated that locating the antenna on a vehicle roof only slightly affected performance, and does not impact the circular polarization performance. Measurements revealed impedance bandwidth of about 2.1% for 10-dB return loss, from 1560 to 1593 MHz. See "Miniature Folded Patch GPS Antenna for Vehicle Communication Devices," *IEEE Transactions on Antennas and Propagation*, May 2015, p. 1891.

CHRIS DeMARTINO | Technology Editor

Metamaterials

Provide Technology for the Future

Metamaterials offer potential for exciting new technologies, as well as for existing devices to be made smaller, faster, and more efficient.

Metamaterials have generated a significant amount of interest over the last 15 years. Due to their unique properties, they offer possibilities in technology that cannot be achieved by natural materials. The field of metamaterials has become a major research topic, as countless research publications have been written on the subject since the year 2000. Metamaterials encompass a variety of disciplines, such as physics, electrical engineering, material science, and optics.

The term "metamaterial" is actually derived from the Greek word "meta," which means "beyond." Metamaterials can be defined as artificially engineered materials with properties that are not seen in natural materials. These man-made materials consist of microstructures that are smaller than the wavelength of incident radiation. The metamaterial's electromagnetic properties are determined by these subwavelength microstructures, resulting in a material with unusual electromagnetic properties. These microstructures can also be known as "metamolecules" or "metaatoms." Metamaterials can be used to control and manipulate light, sound, and many other physical phenomena.

The electromagnetic properties of a material are defined by two material parameters: electric permittivity (ε) and magnetic permeability (μ). These describe a material's coupling to the respective electric and magnetic field components of an electromagnetic wave.

The index of refraction is a dimensionless number that explains how electromagnetic radiation propagates through a medium. The index of refraction (n) is mathematically defined as the speed of light in vacuum divided by the speed of light in the medium, as follows:

$$n = \frac{c}{v_p}$$

where

c = velocity of light in a vacuum

v_p = velocity of light in the medium

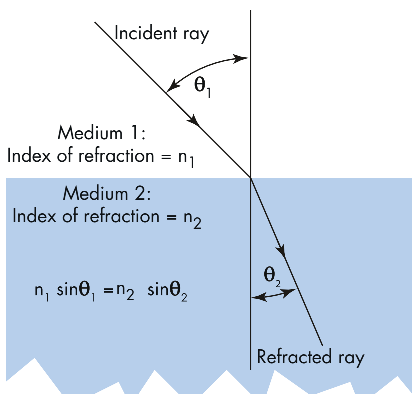
The index of refraction is related to the electric permittivity and magnetic permeability by the Maxwell relation, as follows:

$$n = \sqrt{\varepsilon \mu}$$

Refraction, simply put, is the bending of a wave as it passes across a boundary separating two media. The amount of bending is described by Snell's Law *(Fig. 1)*. Snell's Law is defined by the following equation:

$n_1 \sin\Theta_1 = n_2 \sin\Theta_2$

where



1. Snell's Law describes the relationship between angles of incidence and refraction as a wave passes through the boundary from one medium to another.

n1 = index of refraction of the incident medium
n2 = index of refraction of the refractive medium
Θ1 = angle of incidence
Θ2 = angle of refraction

Metamaterials can be classified by describing both their electric permittivity and magnetic permeability. They can be grouped into four combinations based on these two parameters:

$\varepsilon > 0, \mu > 0$
$\varepsilon > 0, \mu < 0$
$\varepsilon < 0, \mu > 0$
$\varepsilon < 0, \mu < 0$

Left-handed metamaterials exhibit both negative electric permittivity and magnetic permeability, which results in a negative index of refraction. A negative index of refraction offers great potential because this property is not found in any non-synthetic material. Because of their potential applications, left-handed metamaterials have attracted a great deal of attention from researchers. The term "left-handed" originated because the wave vector is antiparallel to the usual right-handed cross product of the electric and magnetic fields.

VICTOR VESELAGO'S CONCEPT

Russian physicist Victor Veselago first investigated left-handed metamaterials in the late 1960s. In 1968, Veselago published a paper that theoretically described the electromagnetic properties of a hypothetical material with simultaneously negative values for the electric permittivity and the magnetic permeability. Veselago concluded that a material such as this would have a negative index of refraction.

This conclusion carried enormous implications for almost all electromagnetic phenomena. A negative index of refraction would reverse the Snell effect at the interface between a left-handed material and a normal material.

MODERN BREAKTHROUGHS

Unfortunately for Veselago, left-handed materials were not known to exist at that time. Thus, his concept remained a mere curiosity for more than 30 years, until the first left-handed material was finally conceived and demonstrated experimentally. Sir John Pendry and David R. Smith are regarded as two of the pioneers of metamaterials. In 1999, Pendry and his colleagues proposed a variety of structures they predicted would form metamaterials. They demonstrated that a network of conductor split ring resonators (SRRs) could achieve negative magnetic permeability. This followed the discovery that a three-dimensional network of thin wires could achieve negative electric permittivity.

In 2000, David R. Smith and his colleagues demonstrated the first left-handed metamaterial at microwave frequencies. The following year, Smith and his colleagues continued with a second experiment that confirmed the reversal of Snell's Law, as previously discussed by Veselago. These experiments generated an enormous amount of interest in regards to metamaterials and the possibilities they could offer to extend the properties of conventional materials. Indeed, a tremendous expansion in the field of metamaterials has occurred since the time of these experiments.

MICROWAVE COMPONENTS BASED ON METAMATERIALS

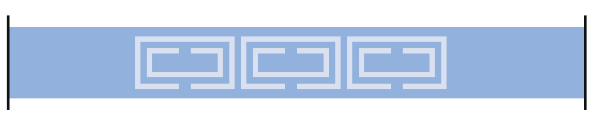
The design flexibility offered by metamaterials creates numerous technological possibilities. Metamaterials promise great advancements in the fields of electronics, optics, and more, prompting researchers to propose a wide range of metamaterial-based devices. In the case of RF/microwave components, metamaterial technology can provide significant benefits. Miniaturized, low-noise versions of existing components (such as waveguides, filters, and antennas) can be realized.

Microwave filters can significantly benefit from metamaterial technology, as it has been demonstrated that left-handed metamaterials based on planar transmission lines can be achieved. By using both split-ring resonators (SRRs) and complementary split-ring resonators (CSSRs), metamaterial filters can be built for use at microwave frequencies. These filters can be fabricated in significantly smaller sizes than conventional planar filters.

As demonstrated by Pendry, the SRR is one of the essential structures of metamaterials. The CSSR, which is a dual counterpart of the SRR, can be energized by an axial electric field rather than a magnetic field. A metamaterial-based bandstop filter can be built by etching an array of CSSRs onto a microstrip line *(Fig. 2)*. This filter can be built in a significantly smaller size than a conventional bandstop filter. A bandstop filter can also be built by etching CSRRs into the ground plane of a printed-circuit board (PCB). These are just two examples of metamaterial-based microwave filters.

Antennas can greatly benefit from metamaterial technology. Small size, low cost, broad bandwidth, and good efficiency are desirable characteristics of an integrated antenna. Because traditional methods of antenna optimization have not had a significant impact, metamaterials have been researched as a means to improve antenna performance.

A great deal of research has occurred to develop small antennas based on metamaterials. These metamaterial-based antennas have been proposed to provide antennas with size miniaturization while maintaining good radiation performance.



2. A bandstop filter can be designed using complementary split-ring resonators (CSSRs).

3. The mTenna suite of antennas provides technological innovations to satellite communications. *[Courtesy of Kymeta (www.kymetacorp.com).]*

They also can provide improvements in efficiency-bandwidth. SRRs and other planar structures have been applied in some antenna fabrications to enhance radiation performance and minimize size.

Other designs that have been proposed incorporate artificial magnetic materials with stacks of SRRs under patch antennas. However, achieving wide bandwidth still proves to be a challenge in metamaterial-based antennas. Many approaches have been proposed to increase bandwidth. Research is still ongoing in this area.

One company commercializing metamaterial-based antennas is Kymeta, launched in 2012. The company's mTenna suite of antennas for satellite communications is built on metamaterial technology *(Fig. 3)*. These extremely thin Ku- and Ka-band antennas use a holographic approach to electronically acquire, steer, and lock a beam to any satellite—without any moving parts.

The mTenna products incorporate tunable elements that are arranged in a precisely calculated pattern. RF energy is scattered when the elements are activated, holographically generating a beam. The direction of the beam is defined by the specific elements that are electronically activated, enabling a design that allows for both continual and instantaneous changes in direction. Earlier this year, Intellian, a provider of stabilized marine satellite antenna systems, announced plans for the next generation Ku-band maritime satellite terminals to integrate mTenna antennas. Kymeta also has plans to release development kits to industry leaders, terminal integrators, and manufacturers.

Another example of a company looking to bring metamaterial-based products to the market is Echodyne. Founded in 2014, the company's patented metamaterial electronically scanning array (MESA) provides advancements in radar technology. The MESA is thin, light, and relatively inexpensive. Discrete phase shifters embedded in the antenna are used to control the beam direction in traditional electronically scanned phased arrays.

MESA, in contrast, does not require phase shifters at the antenna elements. By eliminating phase shifters, the system's complexity dramatically reduces, primary sources of power loss are eliminated, and waste-heat dissipation is simplified. MESA supports all radar methodologies and spans the entire radar frequency spectrum from L- to W- band. The company believes MESA has the potential to be used in many applications, including unmanned-aerial-vehicle (UAV), surveillance, aeronautical, and more.

TERAHERTZ APPLICATIONS

The terahertz (THz) frequency range from 0.1 to 10 THz has been known as the "THz-gap" because technological progress at this frequency range has been slow. The lack of technology capable of producing adequate output power levels in this frequency band has been a major obstacle. As efforts have been made to fill this terahertz gap, metamaterials have attracted interest because of their potential use in terahertz applications. Although efforts are still in the early stages, researchers are working hard to make advancements in this area.

WIRELESS POWER TRANSFER

Wireless power transfer has been the focus of research efforts in recent years. Several commercial applications have been developed in the last decade, including wireless charging of mobile devices and wireless powering of radio-frequency-identification (RFID) tags. However, these applications are restricted by limitations on the distance, as well as the efficiency of current wireless power transfer technology. By using metamaterials, researchers at Duke University's Center for Metamaterials and Integrated Plasmonics (CMIP) have discovered a way to wirelessly transmit power over much greater distances.

A method of wirelessly transferring power from a source to a receiver is by means of electromagnetic near-fields. However, the distance between the source and the receiving item must be very small—usually no more than a few feet. Because they can manipulate and focus near-fields, much as a lens can focus or modify visible light, metamaterials have a potentially interesting role to play in wireless power transfer.

Researchers from Duke's CMIP have demonstrated that the distance between a source and a receiver can be increased with the insertion of a metamaterial near-field lens between them. This technology may lay the foundation for ubiquitous wireless power transferring in the future.

In summary, metamaterials have come a long way in the last 15 years. Researchers today have gained a better understanding of the technology. With companies moving towards production of metamaterial-based devices, metamaterials offer the possibility of being used in a wide range of applications.

Terahertz applications and wireless power transfer are two areas where metamaterials offer the potential to make a significant impact. Microwave components can also benefit greatly, with metamaterials providing improvements in size and efficiency. As efforts are underway to transition metamaterial-based products from the laboratory to the marketplace, we can expect to see more of this technology in the near future.

JACK BROWNE | Contributing Editor

Growing from Military Tool to Everyday Use

Radar technology has greatly evolved over more than seven decades of development, now serving many different commercial and military applications on the ground, in the air, and at sea.

1. The AN/SPY-6 air and missile defense radar (AMDR) system features S- and X-band radar systems. *[Photo courtesy of Raytheon Co. (www.raytheon.com).]*

RADAR HAS BEEN a significant RF/microwave technology since the days of World War II. During that time, radar (a shortening of "radio detection and ranging") proved an invaluable military tool for locating threats and targets and providing advanced warnings of an adversary's position and direction. The basic operation of a radar system involves transmitting a high-frequency signal (usually a pulsed signal) towards the location of an expected target and receiving signals reflected from said target. By performing signal processing on these radar returns, information can be extracted regarding the target, its position, and its speed.

Military uses were once the only applications for radar technology, but times have changed. Radar technology is now being used in many commercial, industrial, medical, weather, and especially automotive systems. These new and growing application areas are keeping radar designers—from integrated-circuit (IC) to system-level engineers—busy in search of high-performance, cost-effective solutions from RF through millimeter-wave frequencies.

Military systems still represent the most plentiful source of radar applications, with military radar systems found on land, at sea, and in the air (and in lesser numbers, in space-borne systems). Radar systems have been used in military applications for ground surveillance, missile control, fire control, air traffic control (ATC), moving target indication (MTI), weapons location, and vehicle search.

As land-based radar systems were being developed in support of American troops during World War II, the U.S. Naval Research Labs (NRL) developed radar systems for maritime applications, including onboard submarines. For such uses, a submarine would draw close to the water surface level, enabling a radar antenna to rise above the surface of the sea water to transmit signals in search of enemy aircraft.

Modern ground-based radar systems are transportable by personnel as well as by vehicles, with some systems—such as the AN/PPS-5A/B ground surveillance radar system—in service for a number of decades. Older military radar systems, whether of the ground-, maritime-, or avionic-based variety, are continuously

> **Military uses were once the only applications for radar technology, but times have changed. Radar technology is now being used in many commercial, industrial, medical, weather, and especially automotive systems.**

upgraded as newer technologies become available.

With the AN/PPS-5A/B system, for example, systems based on magnetron tube power sources and weighing 125 lb. have largely been replaced by systems using solid-state transmit amplifiers and weighing only 70 lb., with a slight tradeoff in transmit power. This is considered a man-portable radar system that has been packed in waterproof enclosures for dropping into locations with infantry via parachute.

The AN/PPS-5A/B is fairly representative of a ground-based surveillance radar, operating over a fairly narrow bandwidth in the frequency range from 8.8 to 9.0 GHz with a pulse repetition frequency (PRF) of 4 kpulses/s. The system transmits pulses with 1 kW peak power and achieves ranges of about 6 km for detecting personnel and 10 km for detecting vehicles. The system is built for U.S. military customers by a number of different suppliers, including Eaton Corp. (www.eaton.com), Telephonics Corp. (www.telephonics.com), and the Thales Group (www.thalesgroup.com)

UP IN THE AIR

In the air, Lockheed Martin has long been an innovative developer of reliable military radar systems for surveillance. The company's Tactical Reconnaissance and Counter-Concealment (TRACER) radar system provides effective long-term surveillance of suspect operations by means of synthetic-aperture-radar (SAR) technology. The basic principle of SAR is to use data from multiple radar returns to form the equivalent image that would be produced by a single large aperture antenna. The time delay information from returned radar signals also is converted to spatial dimensional information to produce additional details about a target.

TRACER is a dual-band (UHF and VHF) radar system capable of detecting targets through foiliage, rainfall, and even dust storms, providing real-time tactical ground imagery from the air. The use of the lower-frequency, longer-wavelength UHF and VHF signals compared to higher-frequency signals in many radar systems enables detection through dense foiliage.

The radar signals work with the company's foliage penetration (FOPEN) technology to detect vehicles, buildings, and large metallic objects. TRACER features a portable ground station that works with the airborne electronics to collect and process data and develop precise ground images. The TRACER system is designed for use at low through high altitudes, either from manned or unmanned aircraft.

Military radar systems also are increasingly integrated into other weapons systems for guidance. One of the long-time suppliers of defense-based radar systems, Raytheon Co. (www.raytheon.com), has developed its Small Diameter Bomb II (SDB II) system for the Air Force and Navy to improve missile efficiency under all weather conditions, even when visibility is limited. The firm is currently involved in integrating the radar system onto F-35 Joint Strike Fighter aircraft, F/A-18E/F Super Hornet, and F-15E Strike Eagle aircraft.

The SDB II missile seeker system actually combines several different technologies, with a millimeter-wave radar to detect and track targets through adverse weather, an infrared (IR) imaging system to provide enhanced target discrimination, and a semi-active laser system that allows the SDB II system to track an airborne or ground-based laser designator for identification by allied troops. The radar/IR/laser weapons |system can fly more than 45 miles to find a fixed or moving target, providing a great deal of flexibility to an airborne military team.

Raytheon's AN/SPY-6 system is a next-generation air and missile defense radar (AMDR) system that incorporates multiple-frequency radar subsystems at S- and X-band frequencies. To be installed on DDG 51 Navy guided-missile destroyers beginning in 2016 *(Fig. 1)*, the system packs receivers and transmitters together in a compact radar modular assemblies (RMAs) measuring just 2 × 2 × 2 ft. The RMAs are stacked together to form a complete system within the spacing requirements of each naval ship. The AN/SPY-6 AMDR is claimed to provide many times the range and sensitivity of existing naval shipboard radar systems, employing adaptive digital beamforming and advanced digital signal processing (DSP) to achieve the improvements in performance.

On the commercial side of marine radar, Raymarine (www.raymarine.com) is a major supplier of ship-board radar systems for a wide range of sea vessels for commercial and consumer applications such as boating and fishing. The company has grown steadily through the years, launching its popular Pathfinder radar system in 1997, and acquiring Raytheon's recreational marine division in 2001. The firm, which also supplies sonar systems and VHF radios, offers a variety of different radar radome and array antennas for different environments, applications, and radar transmit power levels (for increased range).

In contrast to traditional radar systems in which EM waves propagate through the air to strike a target, ground-penetrating-radar (GPR) systems propagate through different media (usually rock and soil) before striking a target of interest.

2. An increasing integration of radar and camera technologies into commercial vehicles is designed to provide safer driving environments. *[Photo courtesy of ZF TRW (www.safety.trw.com).]*

GPRs usually operate from about 300 to 3000 MHz, at relatively low transmit power levels. Different three-dimensional (3D) scattering patterns will be formed by different target shapes, such as dielectric spheres, in different soils.

The usual wave qualities must be studied in the radar returns—such as signal phase shifts, time delays, and signal attenuation—but the effects of the different propagation media must also be calculated. A forward-looking radar wave will exhibit different vector components when striking the ground, depending upon the composition of the ground (e.g., clay versus sandy soil).

GPRs were initially developed during the Vietnam War for the detection of enemy tunnels. Different types of GPR systems include time-domain-based impulse radar systems, which use short pulses and measure the propagation time to and from the target, and stepped-frequency or frequency-modulated-continuous-wave (FMCW) systems, where the magnitude and phase of each frequency signal is measured and analyzed.

Depending upon whether GPR systems are operating with transverse electromagnetic (TE) or transverse magnetic (TM) polarization, radar system performance can be improved by finding the optimum height for the radar antenna above the ground. For even the short distance that the EM waves propagate through the air, the difference in propagation characteristics between the air and the soil must be calculated, and the refraction point at which the radar waves enter the soil must be found.

For example, an innovator in GPR systems, BAE Systems (www.baesystems.com), used a stepped-frequency approach in their GPR systems for tactical ground-based military applications. With 20 transmit/receive antenna pairs in a forward-looking, vehicular-mounted system, the GPR operated from 0.5 to 2.0 GHz in 5-MHz steps and was effective in locating mines through a wide range of soil types. Penetrader Corp. (www.penetrader.com) also is a supplier of GPR systems.

DRIVING THE FUTURE

While radar technology has long been used for tracking and mapping weather patterns, and weather-based applications represent a strong market area for the technology, perhaps the most promising opportunities for radar technology lie in traffic and the consumer automobiles that make up that traffic. Many leading electronics and systems firms, such as Infineon (www.infineon.com) and ZF TRW (www.safety.trw.com), have developed millimeter-wave automotive collision-avoidance radar systems for operation at 77 GHz.

In addition, numerous semiconductor companies, including Freescale (www.freescale.com) and TriQuint Semiconductor (www.triquint.com), are developing radar ICs for the transmit and receive functions at millimeter-wave frequencies. TRW, in fact, now offers automotive radar systems in three different frequency bands—24, 77, and 79 GHz—with the recent introduction of its AC1000 automotive radar system for use at 79 GHz.

The firm's earliest automotive radar system model, the cost-effective model AC100, operates within the 24-GHz ISM band, across the 100-MHz bandwidth from 24.150 to 24.250 GHz. Using a planar patch antenna, it is capable of accurate readings at velocities as high as 250 km/hr. The company's long-range AC3 automotive radar system operates at 77 GHz and is already in the third generation of the product line. The most-recent system, the AC1000 automotive radar, operates at 79 GHz; it supports front-facing collision-warning, side- and rear-facing radar detection, and adaptive cruise control functions for a wide range of driving scenarios *(Fig. 2)*.

ZF TRW earlier this year launched a commercial vehicle system that fuses radar with camera technology. The system uses a common set of sensors to combine data from the radar system and multiple cameras for increased vehicular safety. According to Ken Kaiser, vice president of engineering for the ZF TRW Global Electronics Business, "Fusing the data from camera and radar every 30 to 40 milliseconds helps to confirm when a situation warrants action from on-board systems such as rapid braking via the electronic stability control system for Automatic Emergency Braking."

The trend of integrating radar technology with other electronic systems is quite strong for commercial automotive applications, as in military radar systems, and will continue as radar technology is applied to achieve complete 360-deg. safety around a commercial vehicle.

Radar technology comes in many forms and packages, and this article has only scratched the surface of the different types available, including in continuous-wave (CW) form in frequency-modulated CW (FMCW) radar systems. With the help of high-frequency IC manufacturers, radar technology is reaching well into the millimeter-wave frequency range at prices affordable and competitive for automobile manufacturers, who will be able to include radar-based safety features on commercial automobiles for customers in virtually every price range. mw

CHRIS DEMARTINO | Technology Editor

PXI Offers Complete Test Solutions

As the latest technology forces test requirements to increase, PXI-based test systems can provide complete test solutions to meet those advanced demands.

AS DEVICES BECOME more advanced, the amount of necessary testing increases. Rising costs are thus associated with validating these new products. PXI (an acronym for PCI eXtensions for Instrumentation) was created specifically to address the challenges in the automated test industry. In comparison with traditional box instruments, PXI-based test setups can be customized with the instrumentation modules needed to meet each new test requirement. They provide complex test setups while retaining flexibility.

Next-generation devices have prompted suppliers of PXI-based test products to provide complete test solutions to meet the complex testing requirements of these devices. By combining modular PXI-based hardware with measurement software, these test solutions provide comprehensive results with benefits in test time and cost.

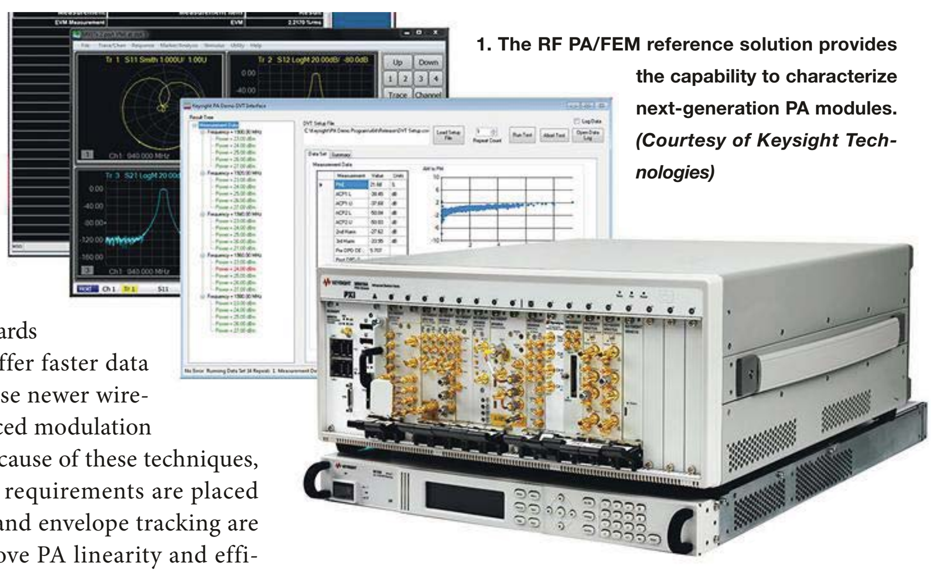
POWER-AMPLIFIER TEST SOLUTIONS

The LTE and IEEE 802.11ac wireless standards are being deployed across the globe. Although these new standards offer a number of benefits, they also create additional test challenges. In the case of the RF power amplifier (PA), engineers must take these standards into account to meet performance requirements. Because of these standards, PAs are becoming more complex, thus significantly increasing testing requirements.

The LTE and IEEE 802.11ac standards both use wider bandwidths and offer faster data speeds than earlier standards. These newer wireless standards must employ advanced modulation schemes and signal processing. Because of these techniques, stringent linearity and efficiency requirements are placed on the PA. Digital pre-distortion and envelope tracking are popular techniques used to improve PA linearity and efficiency, respectively. However, these technologies also require additional test capabilities.

Minimizing distortion is a key challenge when designing a PA. Digital pre-distortion is a signal-processing technique used to improve a PA's linearity, thereby reducing distortions. The PA's input signal is intentionally distorted to compensate for the distortion generated by the PA itself. This pre-distorted input signal produces an undistorted signal at the PA's output, thus improving the PA's linearity. Digital pre-distortion algorithms can be grouped into three broad categories: look-up table, memoryless polynomial, and polynomial with memory. Digital pre-distortion is used in many PA chipsets to improve linearity.

Envelope tracking is a popular technique used to improve a PA's efficiency. The envelope tracking technique dynamically adjusts the PA's dc supply voltage to track the instantaneous amplitude of the PA's input signal. Thus, higher voltages are delivered to the PA only when needed, improving battery consumption and heat dissipation. Envelope tracking is expected to become a standard feature in LTE phones. In the case of IEEE



1. The RF PA/FEM reference solution provides the capability to characterize next-generation PA modules. *(Courtesy of Keysight Technologies)*

802.11ac implementations, envelope tracking is also gaining interest.

With PAs becoming more complex, test setups must provide solutions to accommodate the increased testing requirements of these devices. Specifically, the increased amount of PAs implementing digital pre-distortion and envelope tracking forces test setups to have the capability to support these techniques. Suppliers of PXI-based test products are offering solutions to provide the testing required in support of these technologies. These test systems are intended to provide automated testing capabilities for high-volume production test environments. National Instruments (NI) is one company that offers PXI-based testing solutions to meet the needs of these PAs.

2.The zSeries PA/FEM test solution is optimized for PA/FEM testing. *(Courtesy of LitePoint)*

"NI's test system enables engineers to solve difficult PA test challenges like automating testing of digital pre-distortion and envelope tracking PAs," said David Hall, the company's principal product marketing manager. "Our test system provides solutions for digital pre-distortion and envelope tracking through a software experience that automates all of the necessary instruments. These instruments include NI's vector signal transceiver, arbitrary waveform generators for envelope tracking testing, power supplies, a digital I/O module, and a high-speed oscilloscope. In the case of engineers who want to automate envelope tracking/digital pre-distortion PA testing over multiple frequencies or power levels, the test system provides a series of open-source LabVIEW examples that can be easily modified."

The test system can be configured with National Instruments' standard PXI instrumentation. The NI PXIe-5646R vector signal transceiver combines a vector signal generator and a vector signal analyzer into one module. With a bandwidth of 200 MHz and a frequency range from 65 MHz to 6 GHz, the NI PXIe-5646R is well suited for PA testing. Additional products include the NI PXIe-5451 arbitrary waveform generator, the NI PXIe-4139 precision source measure unit, the NI PXIe-5162 10-bit digitizer, and the NI PXIe-6556 high-speed digital I/O module.

Further explaining the digital pre-distortion and envelope tracking capabilities offered by the test system, Hall noted: "In the case of digital pre-distortion testing, the system performs basic PA model extraction using the vector signal transceiver. By extracting a model of the PA, the system's software can implement a range of digital pre-distortion models, including a memoryless look-up table and multiple memory polynomial models. In the case of envelope tracking testing, the solution uses information regarding the instantaneous power of the waveform, as well as a look-up table, to provide a modulated power supply by means of an arbitrary waveform generator. One of the benefits of using PXI for envelope tracking testing is that all PXI modules can be tightly synchronized. In fact, tight synchronization between the arbitrary waveform generator and vector signal generator is an essential requirement for envelope tracking PA testing."

For its part, Keysight Technologies is addressing the challenges of testing next-generation RF power amplifiers/front-end modules (PAs/FEMs). Keysight's PXI-based PA/FEM reference solution is intended to be used both FOR the design validation and production testing of these next-generation devices (*Fig. 1*). The PA/FEM reference solution combines hardware and software to provide a complete architecture.

"Greater demands for longer battery life and improved data throughput for wireless devices are creating challenges," said Steve LaCourse, wireless solutions program manager at Keysight. "Designers and test engineers must find new approaches to address linearity, bandwidth, and power efficiency in wireless components. These designers and engineers are challenged to improve the efficiency of the RF PA, which is one of the largest power consumers in wireless devices."

LaCourse added: "As the RF PA now supports multiple modes, frequency ranges, and modulation formats, there is more to test—thousands of tests are not uncommon. Techniques like digital pre-distortion and envelope tracking are often employed to help linearize the PA and increase its power efficiency. But these techniques only add complexity and additional tests, which further slows the design and test process. Envelope tracking, digital pre-distortion, and other techniques are being offered as part of a reference solution for RF PA/FEM characterization and test. The reference solution combines both Keysight and non-Keysight hardware with software to provide optimized speed and performance. The new M9451A PXIe measurement accelerator, an FPGA processing card, was recently added to make envelope tracking and digital pre-distortion characterization even faster."

This PA/FEM reference solution enables full characterization of next-generation PA modules, providing the capability to perform a wide range of measurements. S-parameters, demodulation, power, adjacent-channel-power (ACP), and harmonic distortion can be measured with the PA/FEM reference solution.

The reference solution consists of several of Keysight's PXI test instruments. The configuration includes the M9381A vector signal generator, the M9391A or M9393A vector signal analyzer, M937XA vector network analyzers, the M9195A digital stimulus/response module, and the M9451A measurement accelerator. The SD AWG-H3353 arbitrary waveform generator from Signadyne also is included.

The latest releases are the M9451A measurement accelerator and the M9195A digital stimulus/response module. The M9451A measurement accelerator provides significant improvements in speed, as digital pre-distortion and envelope tracking measurements can be made in just tens of milliseconds. The M9195A digital stimulus/response module provides 16 bidirectional input/output channels with programmable logic levels.

The PA/FEM reference solution also incorporates the recently released M937XA Series of PXI vector network analyzers (VNAs). The M937XA is a full two-port VNA that fits into just one slot. This VNA is ideal for those who simply wish to make basic S-parameter measurements. Each module is a completely independent two-port network analyzer, and as many as 16 modules can be added to a chassis. This aspect enables multiport measurements as well as simultaneous measurements of different devices.

Software is a main component of the PA/FEM reference solution. The N7614B Signal Studio for Power Amplifier Test software supports digital pre-distortion, envelope tracking, and crest factor reduction technologies.

Another example of a PXI-based PA test solution is the zSeries PA/FEM from LitePoint (*Fig. 2*). Optimized for testing the PAs and FEMs used in mobile devices, the zSeries PA/FEM includes the necessary hardware and software required for the characterization and testing of the latest RF front-end components.

The zSeries PA/FEM test solution's hardware consists of a number of LitePoint's PXI test instruments. The hardware includes the following: the zSeries 18-slot chassis; z8651 vector signal analyzer; z8751 vector signal generator; z8801 local oscillator; z8811 front-end module; z471 source measure unit; z5211 arbitrary waveform generator; z4441 digitizer/oscilloscope; z488xx RF switches/multiplexers; and the z3975 embedded controller. The z8751 vector signal generator operates from 250 MHz to 6 GHz while providing modulation bandwidth to 500 MHz. The z8651 vector signal analyzer also operates to 6 GHz with 160 MHz of instantaneous bandwidth. The test solution's software includes a digital pre-distortion application for PA linearity characterization. The waveform creation and analysis application supports wireless standards like LTE-Advanced and IEEE 802.11ac.

3. The Semiconductor Test System (STS) is well suited for semiconductor production test environments. *(Courtesy of National Instruments)*

SEMICONDUCTOR TEST SYSTEM

The Semiconductor Test System (STS) from NI is a PXI-based alternative to traditional automatic-test-equipment (ATE) systems (*Fig. 3*). The STS combines PXI modular instrumentation with system-design software for production testing. The STS can be equipped with an RF subsystem, enabling the STS to provide fully integrated RF test capabilities.

With the RF subsystem, the STS can be used as a production test platform for RF integrated circuits (RFICs). The RF subsystem is built around NI's vector signal transceiver, which features FPGA-based real-time signal processing and control. The STS can provide S-parameter measurements for as many as 48 ports by means of an integrated port module. The TestStand software is designed to help users quickly develop and deploy test programs. Users can develop test sequences that integrate code modules written in multiple programming languages.

PXI-based test systems are being implemented to provide complete test solutions in response to increased requirements. A range of trends are increasing the cost and complexity associated with testing the latest devices. In the case of RF PAs, as support begins for multiple modes, frequency ranges, and modulation formats, the amount of necessary testing during the design validation phase also increases. The latest PXI-based test solutions aim to provide the capability required to test and characterize next-generation devices, while providing time and cost benefits. mw

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DIFFERENTIAL DIPLEXER Drives Sampling ADCs

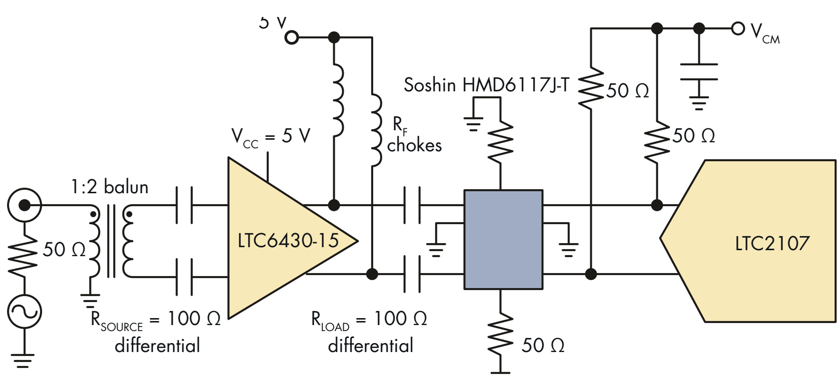
The combination of a differential diplexer and a differential amplifier/ADC driver can help improve the performance of direct-sampling ADCs.

Direct-sampling pipeline analog-to-digital converters (ADCs) produce a large collection of mixing products, much like passive RF/microwave mixers. In high-speed ADCs, these mixing products are sum-and-difference image signal components that extend to microwave frequencies. They are the result of transient signal events—glitches that result from the abrupt connection of sample capacitors when the ADC resumes tracking.

In addition, disturbances conducted into the input network immediately prior to sampling must not be returned during the sampling process. The higher the sampling speed and the greater the resolving power of these ADCs, the more apparent the effects of poor control over these commutation products become—henceforth referred to as "these products." By paying attention to signal-integrity concerns for these high-speed ADCs, however, it's possible to limit the damage from these unwanted mixing products.

Simple sum-and-difference products would fold back onto the frequencies at which they appear with the baseband frequency range, and with the exception of some gain error, would disappear. However, unavoidable nonlinear products accompany these simple mixing products and, unless dissipated or absorbed, will result in distortion. A time element is involved, so distance and settling behavior have roles to play in minimizing such distortion.

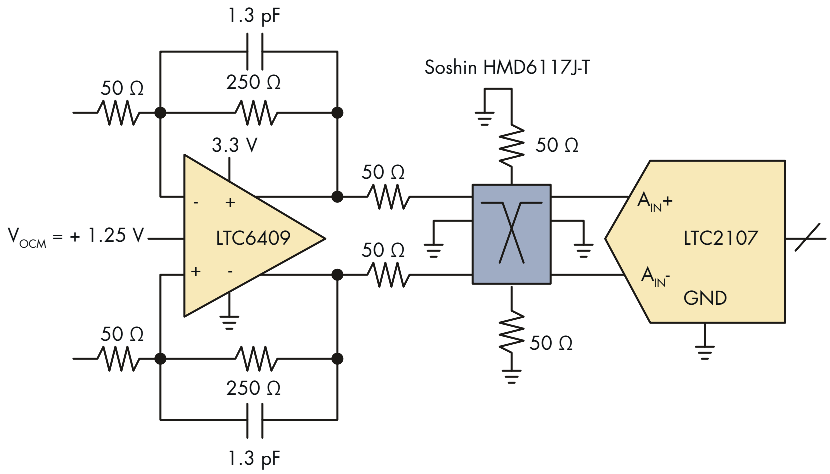
RF/microwave engineers faced with the task of controlling similar mixing products in a passive mixer will recognize the need for an absorptive network on both the RF and intermediate-frequency (IF) paths, if not on the local-oscillator (LO) path. Engineers may not immediately recognize that they're dealing with these same issues in an ADC. Once aware of this similarity, an experienced RF engineer is better prepared to deal with the issues. But, the degree of absorption can still be a surprise. The notion of settling behavior is often understood by analog and signal-integrity (SI) engineers.



1. This inexpensive double-terminated driver suits applications from 20 to 400 MHz.

However, it may not be common knowledge that a network exhibiting complete absorption over the broad range of frequencies doesn't necessarily mean it will exhibit good settling characteristics.

Take, for example, the 210-Msample/s, 16-b LTC2107 ADC from Linear Technology Corp. (www. linear.com), which has a 80-dB signal-to-noise ratio (SNR). For optimum performance, the VSWR of the analog input path must be very good out through microwave frequencies—the frequency range where these mixing products eventually roll off significantly. This point often goes unrecognized as being a noteworthy concern extending past 5 GHz in modern high-speed ADCs. These mixing products, which are images of the input signal mirrored around every harmonic of the clock source, don't even start to roll off until beyond 2 GHz. The high SNR of the LTC2107 ADC is a double-edged sword in that the larger sample capacitors employed in this digitizer increase the power in these mixing products, and unfortunately, enhance the capability to resolve the effects of reflections returned from impedance discontinuities.



2. This source-terminated, dc-coupled driver can be used to 100 MHz.

Absorptive filters have proven to produce good results with these ADCs, but their layout complexity and cost can be daunting. The component count of an absorptive bandpass filter is at least two to three times that of a reflective bandpass of the same order. Even greater complexity may result from measures needed to control the effects of self-resonant frequency (SRF) in final inductors.

Lower-frequency applications can be addressed by using a high-speed feedback amplifier, such as the LTC6409 differential amplifier/ADC driver from Linear Technology Corp. Its source port is terminated, with its low output impedance padded to produce correct source termination, but followed with a lumped-element differential diplexer for performing the task of mixing-signal absorption at higher frequencies. As such, this functions as an absorptive source for the high-speed analog-to-digital converter. Simple series source termination fails to produce good return loss (in terms of S_{22} performance) above a certain frequency as amplifier output impedance rises upward.

At microwave (GHz) frequencies, it can be challenging to achieve adequate return loss for fully absorptive inductive-capacitive (LC) filters, such as bandpass filters (BPFs) or lowpass filters (LPFs), due to limitations imposed by the SRFs of inductors, inductance of capacitors, effects of short transmission-line segments between elements, and the more obvious parasitic pad capacitance under the elements. To address these issues, Soshin Electric Japan (www.soshin-ele.com) developed a low-temperature-cofired-ceramic (LTCC) differential diplexer (model HMD6117J-T) for Linear Technology that presents a simple, compact way of answering the shortcomings of various input networks.

The LTC6430 high-linearity, differential RF/IF amplifier/ADC driver is a wideband differential gain block, matched to 50 Ω (100 Ω in differential hookups). However, above about 500 MHz, its return loss is inadequate for the needs of the LTC2107 ADC. At 1 GHz, the output return loss is about 10 dB, whereas the ADC requires better than 20-dB return loss to achieve its full spurious-free dynamic range (SFDR). A 10-dB return loss at 1 GHz and above can produce more than a 20-dB compromise in SFDR.

Soshin's HMD6117J-T differential diplexer handles the mixing products for frequencies above 400 to 500 MHz, and presents an absorptive character extending to 3 GHz and beyond to the ADC. In the process, it diverts the higher-frequency mixing products into a pair of termination resistors placed on the high-band ports. In doing so, it also reduces the high-frequency disturbances and mixing products seen by the amplifier. Used in conjunction with the LTC6430 differential gain-block amplifier/ADC driver *(Fig. 1)*, the combination produces a compact inexpensive driver solution, suitable for frequencies extending from about 20 to 400 MHz. Anti-aliasing should be performed prior to the amplifier for frequency-domain applications.

When used with the LTC6409 driver, the HMD6117J-T differential diplexer provides a complete solution for applications from dc to 100 MHz *(Fig. 2)*. For time-domain applications that have essentially flat spectral power distribution, with no risk of strong interferers above about 100 MHz, this topology may be used to 200 MHz—or beyond 200 MHz if the spectral power distribution rolls off with frequency.

The differential diplexer can be used in a similar manner with the LTC6417, a unity-gain differential buffer amplifier, and possibly with other feedback amplifiers. For applications requiring as much SNR as possible, the HMD6117J-T differ-

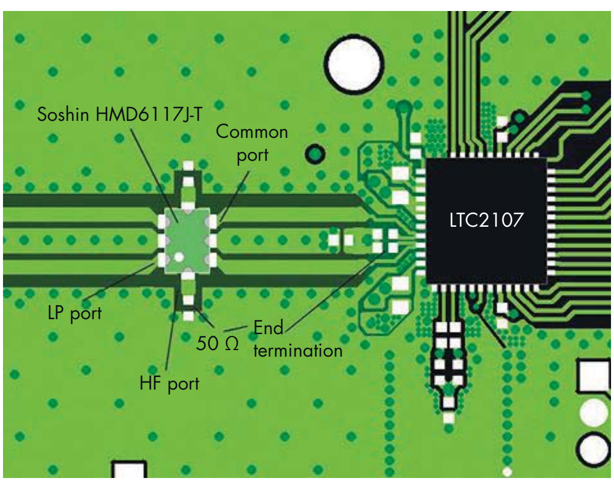
> "The diplexer may also be used following a transmission-line balun to improve an input network's high-frequency behavior, as well as reduce the noise bandwidth of an RF gain block."

ential diplexer can also be used after an absorptive bandpass filter to improve return loss at high frequency, which simplifies the filter, makes the layout less critical, simplifies the choice of inductors, and reduces the number of required high-quality RF termination resistors.

The diplexer may also be used following a transmission-line balun to improve an input network's high-frequency behavior, as well as reduce the noise bandwidth of an RF gain block *(Fig. 3)*. The LTC2107 digitizer and a number of other direct-sampling ADCs do not perform well if driven by a transmission-line transformer in close proximity to the ADC. If the transmission-line transformer is placed more than 6 in. from the LTC2107, performance may be sufficient, but the additional space required on a printed-circuit board (PCB) may not be acceptable.

The adverse effects of many transmission-line transformers are in part due to asymmetry in the construction of the Guanella balun, unequal line lengths, time skew between the lines in the twisted pair running through the binocular core, and undesired coupling between successive passes through the core. These factors can produce return reflections as well as asymmetry in the returned products. Common-mode transients translated to differential form by asymmetrical returns will degrade SFDR. The diplexer will hide this asymmetry from the ADC, allowing use of a single-ended absorptive filter or a single-ended drive amplifier prior to a balun, and enabling these to be closer to the ADC.

The diplexer might provide a greater degree of freedom for using flux-coupled transformers that have poor impedance



3. The artwork here represents circuitry that can be fabricated for the HMD6117J-T/LTC2107 combination devices.

balance above 400 MHz. Transformers with extended low-frequency response often have too much interwinding capacitance to perform well with high-speed ADCs. Other thin-film baluns that do not behave well at high sample rates may be aided by the diplexer, too. Note that the diplexer does not act as a balun. Drive signals must be amplitude- and phase-balanced in the passband, as well as being at least nominally absorptive in the region below 500 MHz.

Use of the diplexer may be advisable if the ADC's drive signals originate on the other side of a PCB, where it may prevent the complexity of the transmission path through the vias from coming into play, or compensate for generally poor impedance control of PCB traces. Producing a 50-Ω transmission line through a viahole requires a large relief around the viahole, as well as a significant collection of viaholes defining the barrel for conducting ground current. The internal layers must not have annular rings at each copper layer, and should have a minimal ring at the surface.

In any case, the abrupt change of direction at the surface produces a pair of impedance discontinuities; in a thick PCB, these are not close enough to each other to cancel. All of the traces between the driver and ADC should be "controlled impedance" 50-Ω lines. The 50-Ω terminators may be some distance away if those traces are well-controlled 50-Ω lines. Poor impedance control requires that they be close in proximity to the diplexer.

The pair of 50-Ω resistors on the highpass ports required should be 1% edge-trimmed high-frequency resistors or terminators, rather than 0.1% precision trimmed resistors, which can be poor at high frequency. The diplexer measures 3.2 × 2.5 mm.

Achieving full performance in high-speed, direct-sampling ADCs requires attention to signal integrity in all ports involved in the devices, which means essentially every pin. The analog input is simply the most demanding, followed closely by the clock.

The differential LTCC diplexer developed by Soshin Electric and Linear Technology largely resolves issues with reflections in the analog-input paths, whether they originate from impedance discontinuities, poorly controlled trace impedance, layer changes, connectors, less than optimal return loss (S_{22}) at high frequency from amplifiers and transformers, and/or low self-resonant frequency of inductors. Use of this device may help mitigate radio-frequency interference (RFI) issues, and could very well provide other benefits beyond the scope of this article. mw

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EM Analysis Guides WLAN PA Design

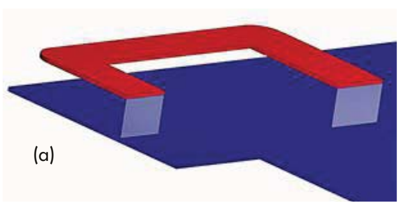
This power amplifier module, which was designed with the help of EM simulation and analysis, is well-suited for WLAN applications from 4.9 to 5.9 GHz.

Power amplifiers (PAs) for wireless local-area networks (WLANs) in the industrial-scientific-medical (ISM) band at 2.4 GHz are enabling high-speed wireless data communications in a wide range of locations, including homes, offices, and airports. WLAN radios working at ISM frequencies have provided data-transmission speeds to 54 Mb/s, and this frequency band is becoming more and more crowded with the ever-growing number of users.

To avoid loss of bandwidth and bit rates at 2.4 GHz, the unlicensed national information infrastructure (UNII) band at 5 GHz provides an alternative frequency range for WLAN radios. This higher-frequency band features 12 non-overlapping channels and can support data transmissions at 10 times the rates possible at 2.4 GHz. In support of 5-GHz WLANs, a power amplifier module (PAM) was developed with the aid of electromagnetic (EM) analysis techniques and broadband matching theory. It provides better than 1 W of saturated output power from 4.9 to 5.9 GHz while operating on +3.3-V dc bias.

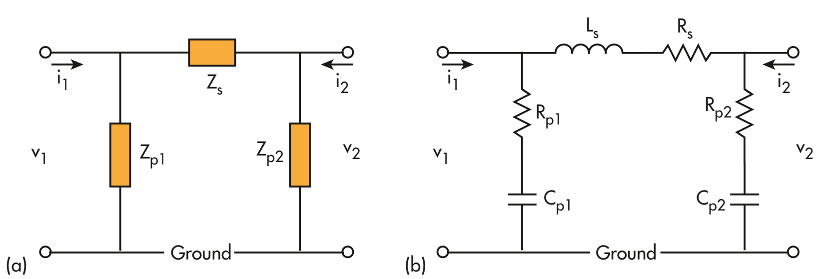
The IEEE has defined requirements for 5-GHz UNII-band WLANs by its IEEE 802.11ac standard.[1] For PAs, the standard poses challenging requirements for vector-error-magnitude (EVM) performance for all operating conditions and flat gain across the band.[2] At higher frequencies, implementing a PA that meets these requirements becomes difficult due to excessive characteristic capacitance and inductance of the PA circuit elements. However, by using EM analysis and wideband impedance matching, a high-output PAM was developed for WLAN applications. The amplifier achieves better than +29-dBm output power at 1-dB compression from 4.9 to 5.9 GHz.

The PAM consists of two parts: an InGaP/GaAs heterojunction-bipolar-transistor (HBT) monolithic-microwave-integrated-circuit (MMIC) amplifier device and a high-frequency circuit laminate. The laminate was simulated by means of three-dimensional (3D) EM models and EM analysis techniques. In the analysis of the EM models of inductors on the laminate or capacitors in the InGaP/GaAs HBT MMIC, some parasitic parameters are extracted to create simple equivalent circuits for the design of the broadband matching network. The laminate's inductors consist of microstrip lines or bonding wires. Any parasitic capacitance from these

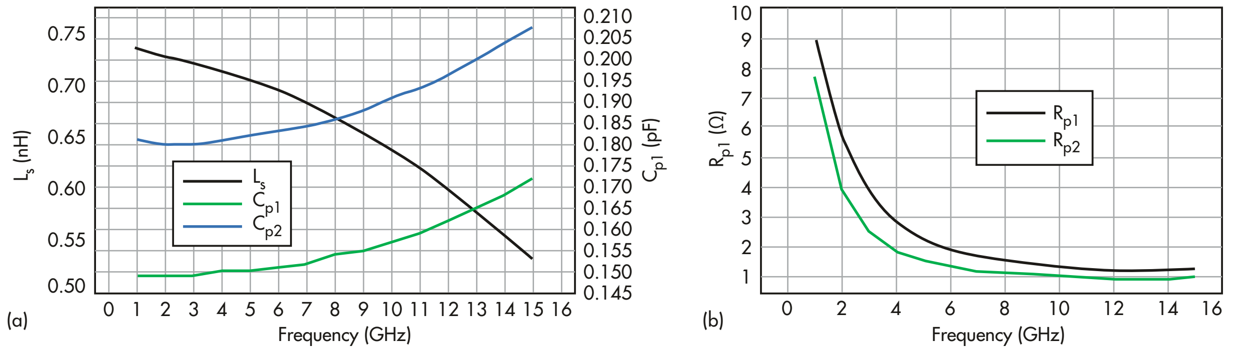


(b)

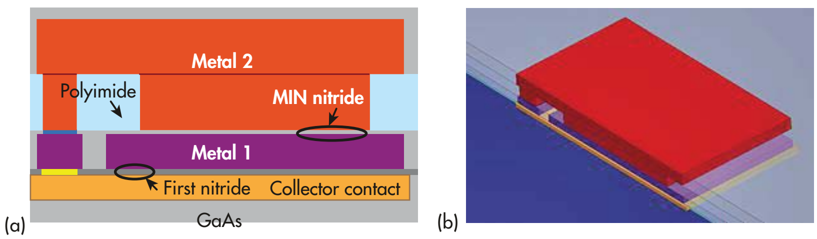
1. These images portray (a) the output impedance-matching inductor and (b) the power bias inductor on the laminate of the PAM.



2. These equivalent circuits represent (a) the inductors in Fig. 1(a), and (b) the equivalent-circuit parameters.



3. These curves show the dependence of the circuit parameters of Fig. 2(b) for (a) the effective inductance, L_S, and (b) resistances added by the parasitic capacitances.



4. This is (a) cross-sectional view of a stacked capacitor and (b) an EM model of a stacked capacitor.

inductors will complicate the creation of an impedance matching network for the PAM, since this capacitance will be part of the matching network.

Figure 1 shows several 3D EM models—for the microstrip of an output matching network on the laminate in (a), as well as a bond wire and microstrip serving as the bias power inductance in (b). This microstrip transmission line serving as an inductor is different from an ideal inductor: It exhibits distributed capacitance between the transmission line and the ground. According to a differential model of the transmission line,[3] an equivalent circuit was proposed to describe the parasitic characteristics of the inductor in *Fig. 1(a)*; the parameters of this circuit can be extracted from EM simulation results. Equivalent circuits for *Figs. 1(a) and (b)* are shown in *Figs. 2(a) and (b)*.

The inductor in *Fig. 1(a)* can be considered a two-port network. Using EM analysis, the network's S- and Y-parameters can be found over a wide frequency range. The parameters of the equivalent circuit in *Fig. 2(b)* also can be found through EM simulation.

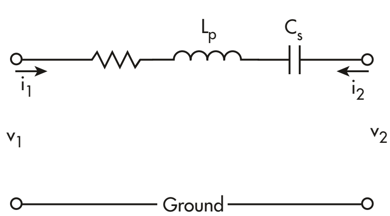
The inductor in *Fig. 1(a)* can be regarded as a two-port network. Using the EM techniques described above, the S-parameters and Y-parameters of this network can be obtained over a wide frequency range. After the electromagnetic simulation, the parameters of the equivalent circuit in *Fig. 2 (b)*—which describe the frequency characteristic of the inductors—can be calculated from the Y parameters. According to the definition of Y-parameters, Eq. 1 can be obtained from *Fig. 2(b)*, and the parameters in *Fig. 2(b)* can be calculated using Eqs. 1 and 2:

$$\begin{pmatrix} i_1 \\ i_2 \end{pmatrix} = \begin{pmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{pmatrix} \begin{pmatrix} v_1 \\ v_2 \end{pmatrix} \quad (1)$$

$$\begin{cases} Z_s = R_s + j\omega L_s = \dfrac{-2}{Y_{12} + Y_{21}} \\ Z_{p1} = R_{p1} + \dfrac{1}{j\omega C_{p1}} = \dfrac{1}{Y_{11} + Y_{12}} \\ Z_{p2} = R_{p2} + \dfrac{1}{j\omega C_{p2}} = \dfrac{1}{Y_{22} + Y_{21}} \end{cases} \quad (2)$$

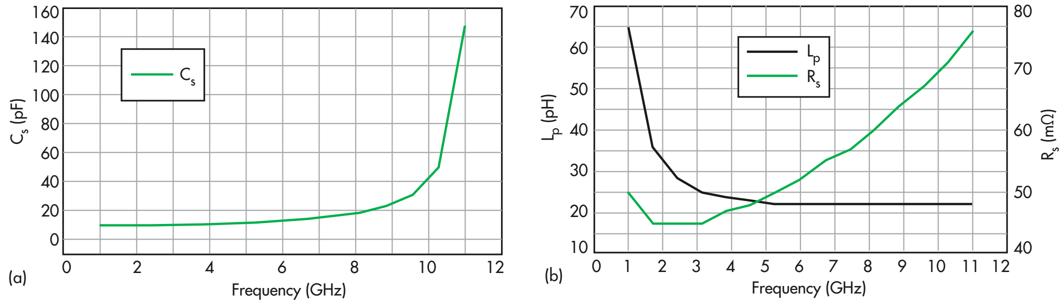
The parameters in *Fig. 2(b)* for the inductor of *Fig. 1(a)* are shown from 1 to 15 GHz in *Figs. 3(a) and (b)*. The effective inductance, L_s, decreases and the parasitic capacitances C_{p1} and C_{p2} increase with increasing frequency, which demonstrate that the frequency-dependent parasitic characteristics of inductors should be taken into account in the high-frequency range. The frequency-dependent parasitic characteristics of the power bias inductor in *Fig. 1(b)* also can be evaluated by the equivalent circuit in *Fig. 2(b)* following EM simulation.

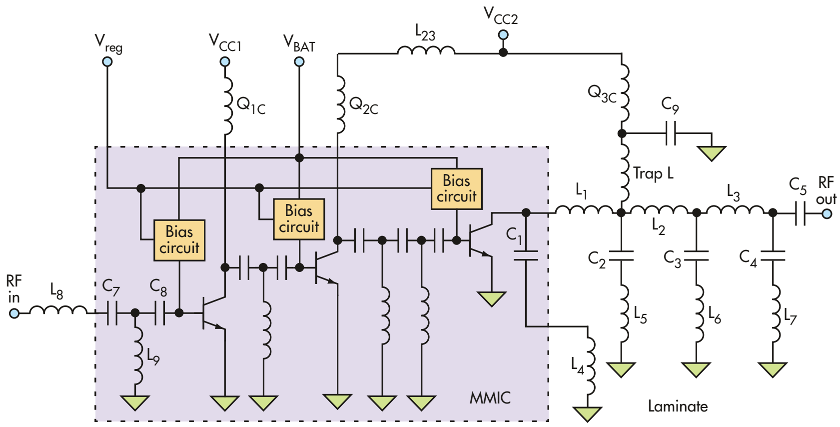
The capacitor in the MMIC contributes to parasitic circuit elements in the PAM, too. *Figure 4(a)* shows a cross-sectional view of a stacked capacitor in the InGaP/GaAs HBT MMIC while *Fig. 4(b)* details its 3D EM model. At frequencies below 1 GHz, the parasitic capacitance of this capacitor can be ignored since the effective low-frequency capacitance of this circuit element is the same as its dc capacitance.



5. This is an equivalent-circuit model for the stacked capacitor component in Fig. 4(b).

6. The plots show the dependence of the parameters in Fig. 5 of the capacitor in Fig. 4(b) from 1 to 11 GHz for (a) parasitic capacitance and (b) parasitic inductance.





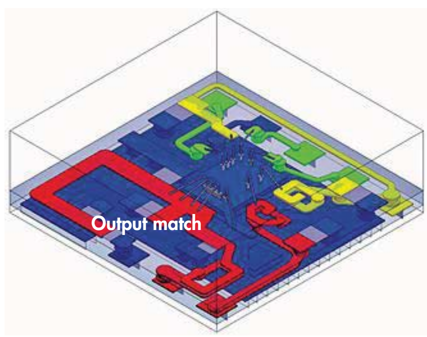
7. This is a schematic circuit diagram representing the three-stage PA on the MMIC.

Based on EM simulation, the effective capacitance of this component increases in the UNII band. When the frequency exceeds the cutoff frequency of the capacitor, it works like an inductor. *Figure 5* offers a simple equivalent circuit for the component in *Fig. 4(b)*. *Figure 6* shows the values for the circuit elements in this equivalent circuit from 1 to 11 GHz, based on EM simulation.

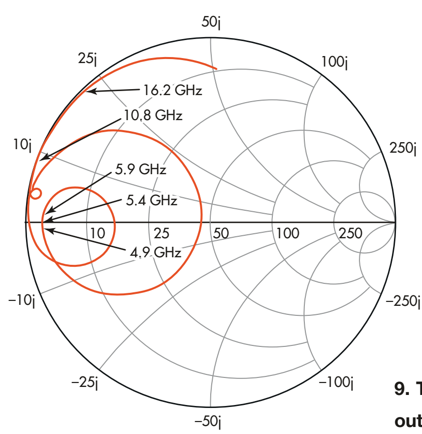
The dc capacitance of the capacitor component in *Fig. 4(b)* is 9 pF in this InGaP/GaAs HBT process, as confirmed by many designs below 1 GHz. The effective capacitance increases to about 11 pF at 5 GHz, according to the EM simulation results in *Fig. 6(a)*. When the frequency increases to 8 GHz, the effective capacitance is about 30 pF since parasitic inductor L_s dominates at these higher frequencies. The value of L_s is almost the same from 4 to 11 GHz—about 20 pH.

In addition, the electrical connections to the capacitor of *Fig. 4(b)* add more parasitic inductance, making implementation of a matching network more difficult. However, this complexity can be solved through the use of EM analysis techniques. EM analysis makes it possible to account for the parasitic elements of the various passive components in the PAM's matching networks in great detail.

Figure 7 offers a schematic circuit diagram of a three-stage PA with inductors and capacitors not having high-frequency parasitic characteristics. Without the high-frequency parasitic characteristics, the schematic circuit diagram serves only as a guideline for the design parameters of each circuit element. More precise values can be obtained by means of EM analysis.



8. The EM model represents the laminate without the surface-mount capacitors.



9. This is the EM-simulated impedance of the PA's output matching network.

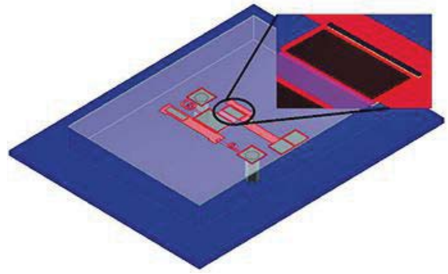
ACHIEVING THE AMPLIFIER

For 5-GHz WLAN use, the PAM was designed for operation from 4.9 to 5.9 GHz; its 1-GHz bandwidth will satisfy the requirements of the IEEE 802.11ac standard. To obtain low EVM, the output 1-dB compression point should be suitably high and the power gain should be flat, with minimal phase distortion to the 1-dB compression point. In this design, diode-based linearizing bias techniques[4-6] have been used to improve linearity. With +3.3-V dc bias, the impedance of the output matching network must be low enough over the 1-GHz bandwidth to achieve saturated output power[7] greater than 1 W. The output matching network is designed on the laminate according to *Fig. 7* using EM techniques.

Figure 8 shows the EM model of the laminate without surface-mount capacitors, but with the addition of high-

frequency parasitic characteristics. *Figure 9* offers the EM-simulated impedance of the output matching network to the HBTs; the fundamental impedance is about 2.5 Ω from 4.9 to 5.9 GHz, a low-enough value to attain the desired saturated output power for the PAM. The insertion loss of the output matching network is also less than 0.5 dB across the 1-GHz bandwidth.

The input matching network and interstage matching networks were designed on the MMIC to save area on the laminate.

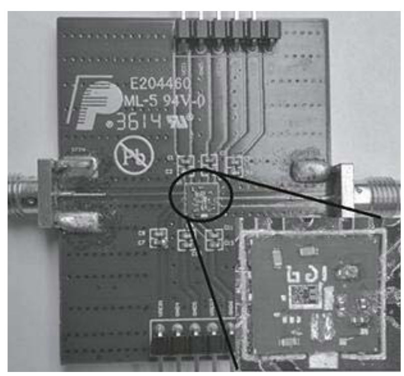


10. This is an EM model of the interstage matching network between the three-stage PA's middle and outer stages.

They consist of several L-type transformers to ensure a bandwidth of 1 GHz. The dc capacitances of the capacitors on the MMIC are less than the guidelines set in *Fig. 7*. In conjunction with the parasitic inductances produced in or around the actual capacitors, the effective capacitance in *Fig. 7* is obtained in the high-frequency range, according to EM analysis. With this design approach, the dc capacitance of the capacitors in the MMIC can be determined from EM simulation results.

Figure 10 shows an EM model of an interstage matching network between the PAM's middle and output stages in the MMIC; the simulated function is the same as the matching network in *Fig. 7*, but the dc capacitances of the capacitors in *Fig. 10* are less than the effective capacitances in *Fig. 7*.

Figure 11 shows the fabricated PAM. It consists of a PA MMIC, several surface-mount capacitors, and bond wires on a microwave laminate. The InGaP/GaAs HBT MMIC measures 1000 × 700 μm. The emitter area of the output stage is 4,800 μm^2 and the emitter areas of the first- and second-stage HBTs are 960 and 480 μm^2, respectively. The input matching network consists of two capacitors,



11. The photograph reveals the fabricated power amplifier module on the test board.

HIGH POWER

5 - 500 WATTS PRODUCTS

POWER DIVIDERS RoHS

Model #	Frequency (MHz)	Insertion Loss (dB) [Typ./Max.] ◊	Amplitude Unbalance (dB) [Typ./Max.]	Phase Unbalance (Deg.) [Typ./Max.]	Isolation (dB) [Typ./Min.]	VSWR (Typ.)	Input Power (Watts) [Max.] ◦	Package
2-WAY								
CSBK260S	20 - 600	0.28 / 0.4	0.05 / 0.4	0.8 / 3.0	25 / 20	1.15:1	50	377
DSK-729S	800 - 2200	0.5 / 0.8	0.05 / 0.4	1 / 2	25 / 20	1.3:1	10	215
DSK-H3N	800 - 2400	0.5 / 0.8	0.25 / 0.5	1 / 4	23 / 18	1.5:1	30	220
P2D100800	1000 - 8000	0.6 / 1.1	0.05 / 0.2	1 / 2	28 / 22	1.2:1	2	329
DSK100800	1000 - 8000	0.6 / 1.1	0.05 / 0.2	1 / 2	28 / 22	1.2:1	20	330
DHK-H1N	1700 - 2200	0.3 / 0.4	0.1 / 0.3	1 / 3	20 / 18	1.3:1	100	220
P2D180900L	1800 - 9000	0.4 / 0.8	0.05 / 0.2	1 / 2	27 / 23	1.2:1	2	331
DSK180900	1800 - 9000	0.4 / 0.8	0.05 / 0.2	1 / 2	27 / 23	1.2:1	20	330
3-WAY								
S3D1723	1700 - 2300	0.2 / 0.35	0.3 / 0.6	2 / 3	22 / 16	1.3:1	5	316
4-WAY								
CSDK3100S	30 - 1000	0.7 / 1.1	0.05 / 0.2	0.3 / 2.0	28 / 20	1.15:1	5	169S

◦ With matched operating conditions

HYBRIDS RoHS

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

◊ In excess of theoretical coupling loss of 3.0 dB

COUPLERS RoHS

Model #	Frequency (MHz)	Coupling (dB) [Nom]	Coupling Flatness (dB)	Mainline Loss (dB) [Typ./Max.]	Directivity (dB) [Typ./Min.]	Input Power (Watts) [Max.] ◦	Package
KFK-10-1200	10 - 1200	40 ±1.0	±1.5	0.4 / 0.5	22 / 14	150	376
KDS-30-30	30 - 512	27.5 ±0.8	±0.75	0.2 / 0.28	23 / 15	50	255 *
KBS-10-225	225 - 400	10.5 ±1.0	±0.5	0.6 / 0.7	25 / 18	50	255 *
KDS-20-225	225 - 400	20 ±1.0	±0.5	0.2 / 0.4	25 / 18	50	255 *
KBK-10-225N	225 - 400	10.5 ±1.0	±0.5	0.6 / 0.7	25 / 18	50	110N *
KDK-20-225N	225 - 400	20 ±1.0	±0.5	0.2 / 0.4	25 / 18	50	110N *
KEK-704H	850 - 960	30 ±0.75	±0.25	0.08 / 0.2	38 / 30	500	207
SCS100800-10	1000 - 8000	10.5 ±1.5	±2.0	1.2 / 1.8	8 / 5	25	361
KBK100800-10	1000 - 8000	10.5 ±1.5	±2.0	1.2 / 1.8	8 / 5	25	322
SCS100800-16	1000 - 7800	16.8 ±1.5	±2.8	0.7 / 1.0	14 / 5	25	321
KDK100800-16	1000 - 7800	16.8 ±1.5	±2.8	0.7 / 1.0	14 / 5	25	322
SCS100800-20	1000 - 7800	20.5 ±2.0	±2.0	0.45 / 0.75	12 / 5	25	321
KDK100800-20	1000 - 7800	20.5 ±2.0	±2.0	0.45 / 0.75	14 / 5	25	322
KEK-1317	13000 - 17000	30 ±1.0	±0.5	0.4 / 0.6	30 / 15	30	387

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

Unless noted, products are RoHS compliant.

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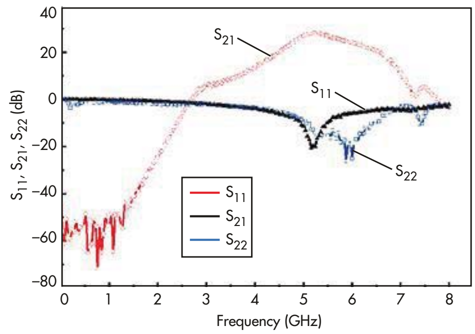
an inductor in the MMIC, a bond wire, and microstrip transmission lines on the laminate. The output matching network is formed by four bond wires and several surface-mount capacitors connected to inductors on the laminate.

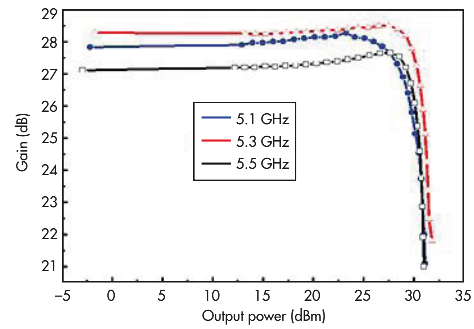
Figure 12 presents the measured S_{11}, S_{21}, and S_{22} parameters for the PAM, measured with continuous-wave (CW) signals. The peak value for S_{21} is about 28.3 dB at 5.3 GHz. The small-signal gain for the PAM fluctuates within a 2-dB window across the frequency range, while S_{22} is less than −10 dB from 4.9 to 5.9 GHz.

Figure 13 depicts the dependence of the power gain on the output power of the PAM at +3.3-V dc bias at 5.1, 5.5, and 5.7 GHz. The saturated output power is greater than +31 dBm and the power gain is greater than 27 dB at all three frequencies. The saturated output power is greater than +30 dBm at 4.9, 5.7, and 5.9 GHz. The measured dependence of power added efficiency (PAE) on output power at 5.1, 5.3, and 5.5 GHz is plotted in *Fig. 14*, where PAE reaches 26.5% at 5.3 GHz. mw

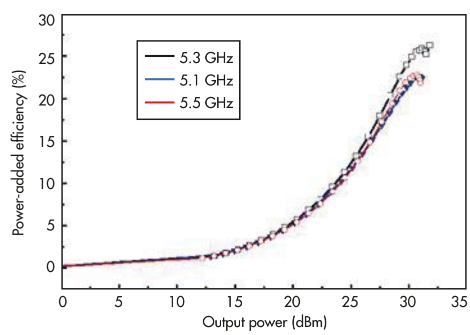
Note: For references, see the online version of this article at mwrf.com.



12. The plots show measured S_{11}, S_{21}, and S_{22} for the PAM.



13. The plots show the measured dependence of the power gain on the output power of the PAM at 5.1, 5.5, and 5.7 GHz



14. These plots reveal the measured dependence of PAE on the PAM's output power at 5.1, 5.5, and 5.7 GHz.

JACK BROWNE | Technical Contributor

Programming the Right Simulator

Software simulation tools are available with a wide range of functions, from simple filter design tools to integrated suites of linear and nonlinear circuit simulators and EM simulators.

Simulation and modeling have become ways of life for many RF/microwave design engineers, with designers choosing to predict performance changes in design iterations on a computer screen rather than building and testing different versions of a prototype circuit. In fact, the wide variety of RF/microwave commercial software simulators currently available allows designers to experiment with many different possibilities, such as mixers with different diodes or low-noise amplifiers (LNAs) with different types of transistors. Whether modeling at the device, component, or system level, modern software simulation tools help fuel the design imagination while also paying for themselves after just a few design cycles, taking the place of building and testing several different prototypes.

A recent trend in high-frequency computer-aided-engineering (CAE) software has been the integration of multiple functions, such as linear circuit simulation, nonlinear circuit simulation, and electromagnetic (EM) simulation, into common platforms. Still, some designers prefer the focus and simplicity of "single-purpose" CAE software programs, e.g., simulators for designing filters or amplifiers.

The popular S/FILSYN program from ALK Engineering (www.alkeng.com), for instance, is devoted to the design of RF/microwave filters. The S/FILSYN software is capable of designing, synthesizing, and analyzing both active and passive low-frequency and high-frequency filters, helping to create all major filter types, including lowpass, highpass, band-reject, and bandpass filters. The software can design infinite-impulse-response (IIR) and finite-impulse-response (FIR) filters, and is available (in different versions) for mainframe computers and PCs.

ALK also offers the PCFILT filter design program with many built-in functions and reference designs to use as starting points to help speed the filter design process. For example, it can scale normalized reference designs to create filters that are closely matched to a software user's set of requirements. The PCFILT software can also perform fast analysis, using Fourier analysis in the time domain, and import filter files from S/FILSYN and other design software programs for analysis.

Similarly, MultiMatch was developed as a dedicated amplifier design program by the South African software-development firm AMPSA Ltd. (www.ampsa.com). The company eventually collaborated with AWR Corp. (www.awrcorp.com) (which would eventually be acquired by National Instruments) to integrate MultiMatch as a design function module into the Microwave Office suite of CAE design tools. MultiMatch allows designers to work with different transistors and impedance-matching networks, both lossy and without loss, to create power amplifiers with targeted performance parameters.

The amplifier design software simplifies matters for users by largely automating the creation of circuit schematic diagrams and layouts. It can also automatically transfer designed amplifier networks into the Microwave Office program for further analysis and optimization, or even design interaction with other designed RF/microwave components, such as attenuators and filters, that might be connected to a power amplifier in a high-frequency system. The program was developed as a departure to the tedious approach of using Smith Charts to find matching elements and impedance networks for different transistors along the way to creating the input and output matching networks needed for a power amplifier.

KEEPING PACE

As high-frequency circuits have grown in complexity and integration, simulation software has kept pace by expanding the number of models and modeling functions that can be handled under one platform, with probably the two most widely used suites of simulation programs being Microwave Office from National Instruments (NI) AWR and the Advanced Design System (ADS) suite of simulation software tools from Keysight Technologies (www.keysight.com). It is not a coincidence

for the Task

that both suites of software tools are backed by companies with considerable expertise and experience in the design of high-frequency test equipment and measurement techniques. Measurements and simulations go hand in hand, with measurement tools providing the test data to build new device and component models, and simulation accuracy judged by how it compares to actual measurements of a design prototype represented by those simulations.

The suppliers of these two leading software simulation suites allow a user to specify the amount of simulation power required for a facility, adding software modules (e.g., EM simulation) as needed and operating with only as much modeling power as desired by a company. The modular architecture of these software platforms enables them to model a wide range of devices, components, and circuits, including analog and digital circuits, and even to progress to system-level simulations as needed. These two software suites have grown through the years by means of internal development as well as through acquisition, with one example being APLAC Corp. and its analog and radio-frequency-integrated-circuit (RFIC) circuit simulators being acquired by AWR.

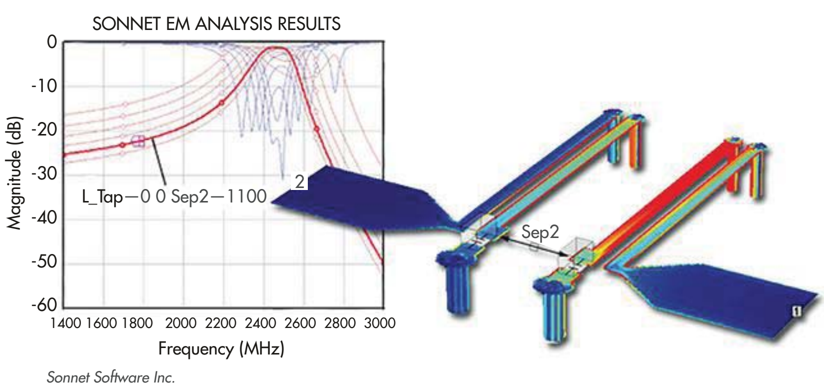
Both software simulation platforms are quite accurate and quite capable of modeling circuits from RF through millimeter-wave frequencies, with ample support for other software programs in terms of links and the compatibility of saved files. Perhaps the simplest comparison of tradeoffs between single-function programs like a MultiMix and a suite of CAE tools such as Microwave Office or ADS is that as simulation power and complexity grows, so too must the memory size and processing power of a PC or mainframe computer (along with the computer simulation time needed to solve a problem).

Accurate models are extremely important to the success of any RF/microwave circuit simulator. Although not a supplier of a commercial CAE simulator, Modelithics (www.modelithics.com) holds a strong position in the area of high-frequency circuit and system simulation with its large complement of active and passive device and component models for numerous different simulators, including ADS and Microwave Office. Modelithics even offers substrate libraries for simulating circuits and studying the effects of different commercial PCB materials, with available substrate libraries for Keysight Genesys, Keysight ADS, and NI/AWR Microwave Office.

DO THE MATH

While many engineers rely on suites of simulation tools such as ADS and Microwave Office, many have also found that the EM simulators within these suites, as well as standalone EM simulators, are quite useful for modeling different circuit phenomena, especially for passive circuit elements. EM simulators were once considered more or less scientific curiosities because of their large memory and computer processing requirements compared to linear circuit simulators. But with advances in the software and the computer themselves, EM simulators are very much now mainstream circuit simulation tools for RF/microwave designers, and have proven to be quite versatile modeling tools for high-frequency simulations.

Mathematical analysis programs such as MATLAB have been used as circuit simulators capable of predicting different circuit parameters, such as the scattering (S) parameters for impedance matching of input and output ports for active and passive cir-



The free-of-charge SonnetLite EM simulation software was used to design this edge-coupled microstrip bandpass filter. *(Courtesy of Sonnet Software)* cuits and components. Mathematical modeling is also the basis for the versatile MapleSim physical modeling system offered by Maplesoft (www.maplesoft.com).

For engineers involved in studying structures in which the physical composition is as important as the electrical behavior, such as waveguide sections, MapleSim can quickly create models for physical structures and automatically generate equations for those models that can be used in other software programs, such as MATLAB or LabView from National Instruments.

To simplify simulations, MapleSim includes a library of functions for dynamic system modeling, including frequency responses and time responses. The MapleSim software can be used to compute such things as LaPlace transforms, transfer functions, and frequency-domain representations of high-frequency component and circuit functions, such as mixer frequency translations. It is suitable for modeling different physical systems and interacting with system-level software to provide models for those system simulators.

CHOOSING THE RIGHT SIMULATION TOOL

As commercial applications incorporate RF/microwave circuits at ever-higher frequencies, such as the microwave and millimeter-wave radar systems used in commercial automobiles for collision-avoidance and protection purposes, the economy provided by modeling with CAE software tools, especially EM simulators, becomes invaluable. Because of the complexity and the small-scale dimensions of the circuits employed in these higher-frequency radar systems, EM simulators provide effective tools for studying the interaction of different circuit components with transmission lines, such as various microstrip and stripline structures. The software can also model the effects of different dielectric PCB materials on those transmission-line structures, especially as the dimensions of the transmission lines and the interfaces with the dielectric materials become more critical at millimeter-wave frequencies.

EM simulators are available within the leading CAE software simulation suites, but also as standalone software tools such as the Sonnet Suites of 3D planar EM simulation software tools from Sonnet Software (www.sonnetsoftware.com). Sonnet's EM simulation software provides an effective means of modeling different high-frequency circuit structures in microstrip, stripline, and coplanar-waveguide transmission-line formats *(see the figure)*. It can even account for the thickness of metal conductors on PCBs and the surface roughness of the conductors, as well as how these variables affect circuit performance. The EM simulator has been used to design a wide range of passive components and structures, including spiral inductors, branchline couplers, filters, resonators, and stub tuners.

Although it is a standalone EM simulator, the Sonnet Suites also feature straightforward interfaces to other leading high-frequency CAE tools, including ADS, Microwave Office, and Virtuoso from Cadence Design Systems. The EM simulator can also import and export files in standard file formats, including .DXF, Gerber, and GDSII file formats. Sonnet offers model extraction for simulation results in both time- and frequency-domain formats, and can produce S-, Y-, and Z-parameter files in Touchstone, Cadence, and Keysight MDIF formats for use in different simulators.

Sonnet Software also provides a painless introduction to EM simulation through its SonnetLite feature-limited version of its Sonnet Suites collection of EM simulation tools, available for free download from the company's website. The free software can be used to design planar high-frequency circuits from 1 MHz past 1 THz, albeit with only a fraction of the features and flexibility of the Sonnet Suites. In fact, SonnetLite can be used to view any project developed with the "full-strength" version of Sonnet planar EM simulation software. It is easy to learn and can be freely integrated with ADS and Microwave Office.

The CST Studio Suite of EM simulation software from Computer Simulation Technology (www.cst.com) is another powerful collection of EM simulation tools for the 3D time-domain EM simulation of passive circuits and components, including antennas, filters, and couplers. The software suite includes the CST Microwave Studio EM simulator; the CST EM Studio software for the design and analysis of static and low-frequency applications such as motors, sensors, and actuators; the CST Cable Studio for the EM analysis of cable assemblies; and the CST PCB Studio software for the EM analysis of PCBs.

Remcom's (www.remcom.com) XFdtd EM simulation software, another powerful EM simulation tool, is available in a free trial version from the company's website. The firm recently posted an excellent white paper on the use of EM simulation software for modeling microwave and millimeter-wave automotive radar systems: "Benefits of Time-Domain Electromagnetic Simulation for Automotive Radar." It explores the modeling of such phenomena as the ground-plane current distribution within these automotive radar systems at 25 and 77 GHz, and the effect of an automotive radar radome on the performance of a PCB-based radar system at 77 GHz. The white paper also points out the need for large amounts of computer RAM for processing more complex problems with an EM simulator, and longer run times for more complex circuit analysis. The XFdtd FDTD algorithm is efficient for EM analysis, but requires large amounts of computer memory and long run times for more complex problems.

Of course, this is but a fraction of the software tools available for simulation of different device, component, and circuit functions at RF and microwave frequencies. Many more software programs, for example, are commercially available for EM simulation as well as for system-level simulation. The wide array of available software tools simply points out the growing dependence that high-frequency designers have placed on the act of simulation and on using the computer and software to save the time and expense of multiple prototyping cycles. mw

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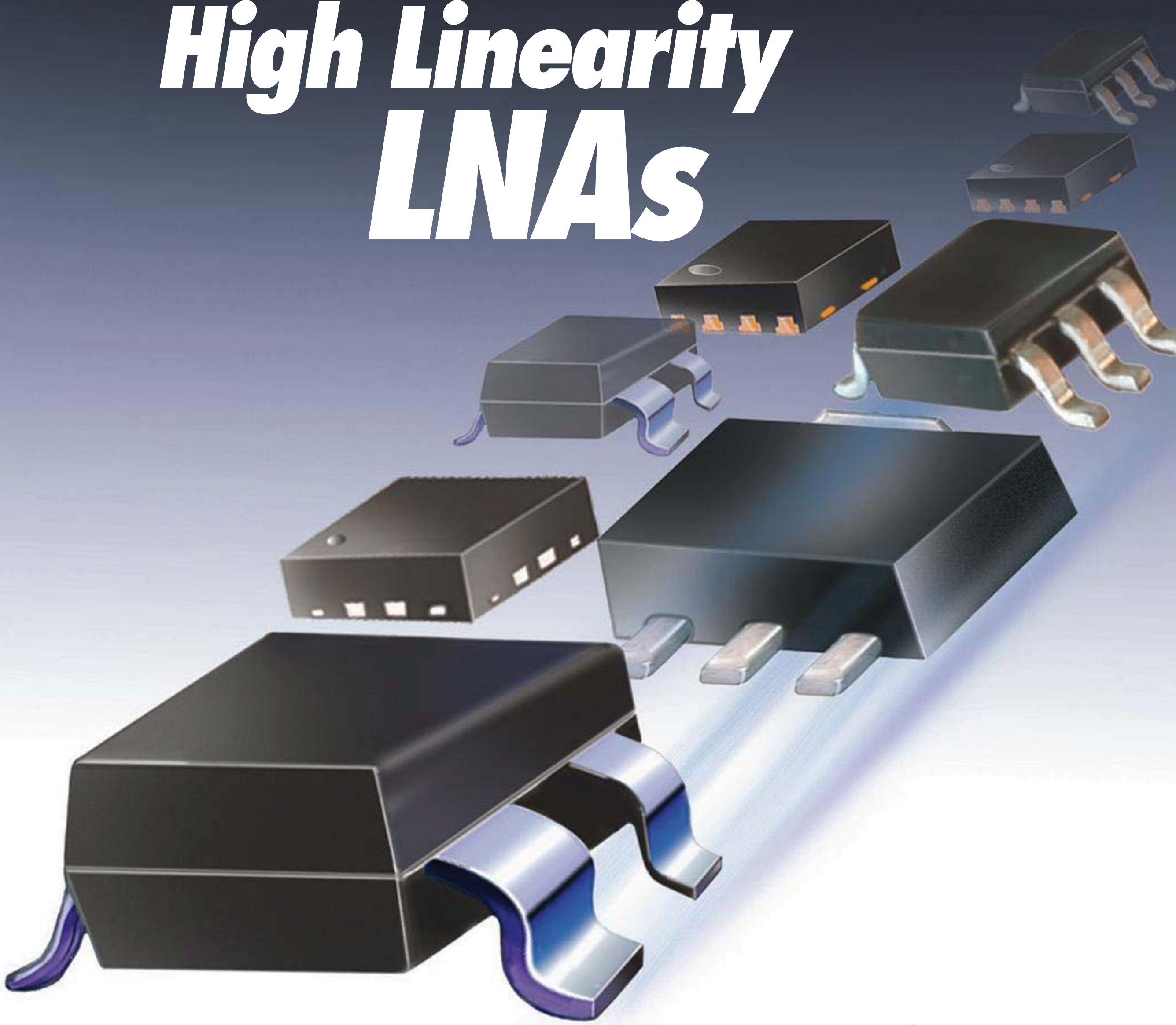

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PMA-5452+	50-6000	14.0	**0.7**	**34**	18	40	1.49
PSA4-5043+	50-4000	18.4	**0.75**	**34**	19	33 (3V) 58 (5V)	2.58
PMA-5455+	50-6000	14.0	**0.8**	**33**	19	40	1.49
PMA-5451+	50-6000	13.7	**0.8**	**31**	17	30	1.49
PMA2-252LN+	1500-2500	15-19	**0.8**	**30**	17	41 (3V) 57 (4V)	2.87
PMA-545G3+	700-1000	31.3	**0.9**	**34**	22	158	4.95
PMA-5454+	50-6000	13.5	**0.9**	**28**	15	20	1.49

Model	Freq. (MHz)	Gain (dB)	NF (dB)	IP3 (dBm)	P_{out} (dBm)	Current (mA)	Price $ (qty. 20)
New! PMA2-43LN+	1100 – 4000	19	**0.46**	**33**	19.9	51	3.99
PGA-103+	50-4000	11.0	**0.9**	**43**	22	60 (3V) 97 (5V)	1.99
PMA-5453+	50-6000	14.3	**0.7**	**37**	20	60	1.49
PSA-5453+	50-4000	14.7	**1.0**	**37**	19	60	1.49
PMA-5456+	50-6000	14.4	**0.8**	**36**	22	60	1.49
PMA-545+	50-6000	14.2	**0.8**	**36**	20	80	1.49
PSA-545+	50-4000	14.9	**1.0**	**36**	20	80	1.49
PMA-545G1+	400-2200	31.3	**1.0**	**34**	22	158	4.95
PMA-545G2+	1100-1600	30.4	**1.0**	**34**	22	158	4.95
PSA-5455+	50-4000	14.4	**1.0**	**32**	19	40	1.49

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Weighing the Options for

Sorting through different RF/microwave circuit materials educed comparisons of performance improvements and cost hikes, although some materials may save processing expenses.

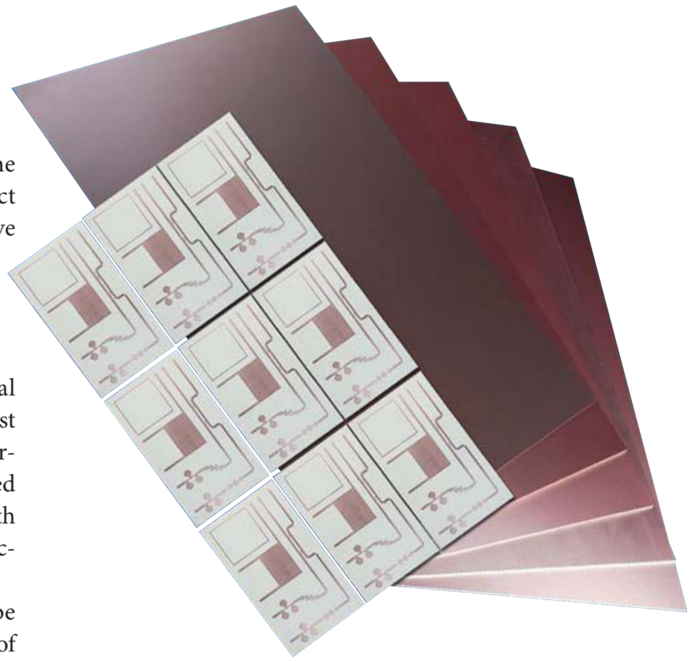
Circuit materials form the foundations for high-frequency designs, from the semiconductor to system levels. These materials tend to be taken for granted, though, in spite of the fact that the choice of a printed-circuit-board (PCB) material can impact the ultimate performance achievable with an RF/microwave circuit design. Hopefully, this quick review of some of these building-block materials used in high-frequency circuits and components can help designers better match a particular material to a design goal, even at the highest frequencies.

Extracting the most performance from a PCB material involves choosing the right material and then applying the best PCB production process with the least errors and tightest tolerances. A PCB manufacturing facility with carefully monitored and controlled processes often delivers better performance with low-cost circuit materials than one with lower-quality manufacturing processes and higher-cost circuit materials.

The choice of a PCB manufacturing facility should not be made casually. Considerations to factor in include the types of circuits to be manufactured, the required circuit tolerances, the number of component and device placements, and even the volume of PCBs to be manufactured.

Before that choice can be made, though, it's necessary to sort through a variety of circuit materials to find a suitable starting point for a PCB. High-frequency PCBs were once mostly single-sided constructions based on rigid, ceramic-based dielectric boards or more flexible, dielectric materials often based on polytetrafluoroethylene (PTFE) materials. Modern circuit-board materials are typically composites, often blending woven glass with a dielectric base material to achieve strength and consistency.

Sorting through current, commercially available PCB materials is a matter of comparing different key material characteristics and how a given material's behavior can be expected to support an application of interest. Frequency range, RF/microwave power levels, and operating-temperature range will help determine which PCB materials are likely candidates from the many materials available on the market.



1. The 4835 circuit material maintains a typical dielectric constant of 3.48 in the z-axis at 10 GHz, with outstanding dielectric constant tolerance of ±0.05. *(Courtesy of Rogers Corp.)*

Key circuit materials to compare include relative permittivity or dielectric constant (also known by the abbreviation of ε_r), dissipation factor, thermal conductivity, glass transition temperature (Tg), loss tangent, dielectric breakdown voltage, and material thickness and thickness tolerance. Material selection should entail a process of comparing multiple material parameters, since they tend to be inter-related.

For example, a material with a high dielectric constant enables miniaturized circuits; but, in the case of a power amplifier, it may lack the thermal conductivity to effectively dissipate excess heat from the active circuitry. Furthermore, a circuit material with dielectric constant that exhibits a wide frequency variation may serve a narrowband design, but not work all that well for broadband circuitry. In addition, a material with some favorable parameters may fall short in other areas, such

RF/MW Circuit Materials

as the ability to withstand the rigors of lead-free (RoHS) circuit processing. One should consider as many circuit parameters as possible when comparing the various PCB parameters for a particular application.

DIELECTRIC DECISIONS

Circuit designers typically start with dielectric constant when sorting through different PCB materials. The dielectric constant of a PCB will determine the dimensions of the transmission lines fabricated on that PCB for a given frequency or frequency range, with higher dielectric-constant values translating into smaller circuits and transmission-line dimensions. The dielectric constant is a measure of a material's capability to store charge, as in a capacitor fabricated on that material. Higher dielectric constants denote greater charge-storing capacity for a given voltage.

The "relative" dielectric constant of a material is relative to the value of a vacuum (unity) or dry air (close to unity), and can be measured with a proper test fixture and a microwave vector network analyzer (VNA). Dielectric-constant values listed by different manufacturers for their PCB materials derive from these measurements, and the measurement method and particular conditions, including frequency, are usually listed along with the dielectric-constant values.

Some manufacturers will list typical values of dielectric constant while others may list multiple values of dielectric constant for different frequencies. And, as materials specifiers should be aware, the value of a material's dielectric constant does change with frequency as well as with temperature. Also, when choosing a material for an application at a specific frequency, dielectric-constant values should be compared for test conditions as close as possible to that frequency of interest.

It should also be noted that circuit materials are anisotropic in terms of dielectric constant, with different values of dielectric constant in the x, y, and z axes of the material. Comparisons of different materials should match axes for axes. PCB dielectric constant will also vary according to variations in a material's thickness. For applications that require tight control of dielectric constant, such as in impedance matching of transmission lines and other circuit structures, PCB thickness should also feature tight tolerance.

Modern computer-aided-engineering (CAE) software simulation programs *(see p. 60)* may contain models for particular brands and models of PCB materials based on the published values of dielectric constant at particular frequencies. Or, they may allow a user to enter values of dielectric constant at different frequencies when calculating the performance of a designed circuit on a particular PCB material. Some PCB suppliers, such as Rogers Corp. (www.rogerscorp.com), will even supply dielectric-constant values that it terms as "Design Dk" values, which are measured at different frequencies and conditions for use with a commercial CAE program to obtain optimum simulation results.

TAKING THE TEMPERATURE

Thermal conductivity in a PCB is important for higher-power circuits—high thermal conductivity translates into effective heat flow from a power source to a heat sink. It's determined by a number of material factors, including the type of dielectric material, the area of heat flow, the thickness of the copper conductor, any type of plating finish used with the copper conductor, and even the surface roughness of the copper conductor.

Thermal conductivity will be less of a consideration when choosing PCB materials for small-signal, lower-power applications, which typically generate less heat. Still, even in small-signal applications, the high density of modern circuit applications can result in "hotspots" throughout a circuit board, and good thermal conductivity can contribute to the long-term reliability of even a small-signal circuit design.

A PCB material's glass transition temperature (Tg) refers to the temperature at which a dramatic change takes place in the material's coefficient of expansion, or its tendency to expand with increasing temperature. Because a material's expansion is limited in the x and y axes due to the large volume of material in those axes, most of the expansion above Tg will occur in the z axis or thickness of the material. This will cause stress on plated through holes and viaholes in a PCB material above Tg, since the dielectric material will expand while the plated metal (copper) will not expand.

The Tg of a PCB material is a consideration not only for operational temperatures, but during any manufacturing processes (e.g., soldering operations) that may yield high temperatures and failed circuit boards. Another critical temperature parameter for PCBs is the decomposition temperature (Td), which is essentially the temperature at which the material begins to melt.

A PCB can suffer electromagnetic (EM) signal loss due to both its dielectric and conductor materials. The conductors, for example, can lose energy as a result of propagation reflections that occur at impedance mismatches at circuit interfaces, such as transmission-line junctions.

Signal loss may also occur from absorption of EM energy by the dielectric material, otherwise known as the material's loss tangent. Dielectric breakdown voltage simply refers to the highest short-term voltage that a circuit material can survive without damage. While this circuit parameter is more commonly a concern for designers of digital circuits, it can come into play for any circuits that encounter high voltages.

These are just some of the parameters used to characterize PCB materials. While not a complete picture, they provide a good starting point when comparing different commercial materials for a given application.

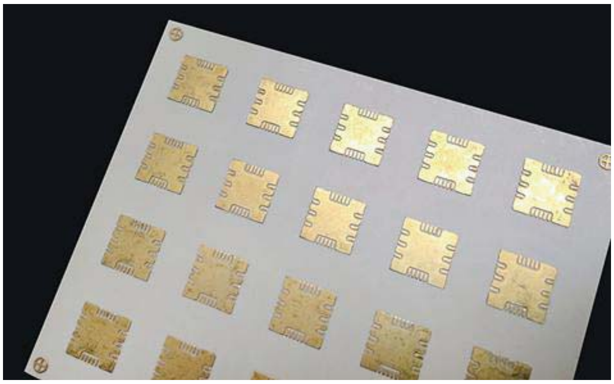
FACTORING IN COST

Cost, of course, is another key parameter, and it may dictate which circuit material will be used for an application. Low-cost FR-4 circuit materials, for example, are often used as a reference to specify circuit materials for RF/microwave applications. However, they tend to be limited in terms of their capabilities when compared to newer (and more expensive) circuit materials developed for higher-frequency applications.

FR-4 circuit materials consist of woven fiberglass covered with epoxy. They exhibit high loss, but are often used for mixed-signal, analog, and digital circuits through about 3 GHz. These rigid materials aren't meant to be flexible, and can handle temps to about +120°C before melting, so manufacturing processes must be maintained at lower temperatures accordingly.

Though FR-4 materials are popular from a cost perspective, they lack the stability and consistency of dielectric constant available from more expensive PCB materials. G10 FR-4 materials are a variant of standard FR-4 materials, developed to handle higher temperatures and higher moisture environments.

More-flexible, though higher-cost, PTFE-based circuit materials often will be used for higher-frequency applications that are less tolerant of loss. Unlike FR-4, PTFE has several special circuit-board processing requirements, including preparation of viaholes through a circuit board to create plated through holes for multilayer circuits. For those in need of additional details on how FR-4 and PTFE materials compare, Isola (www.isola-group.com) provides the white paper "FAQs for Selecting PCB Materials for RF/MW" as a free download from its website (http://www.isola-group.com/news/faqs-of-selecting-pcb-materials-for-rfmw/).



2. The ULTRALAM 3850HT circuit laminate exhibits a typical dielectric constant of 3.14 in the z-axis at 10 GHz. *(Courtesy of Rogers Corp.)*

HOW DO THE LATEST MATERIALS STACK UP?

Some newer, higher-performance circuit materials were evaluated as examples of how parameters might compare for different circuit materials. One of these, Rogers Corp.'s 4835 circuit material *(Fig. 1)*, has a typical dielectric constant of 3.48 in the z-axis at 10 GHz, held to a tolerance of ±0.05 across the board. It features a dissipation factor of 0.0037, also through the z-axis at 10 GHz.

This high-performance material is compatible with lead-free processes, and can be fabricated with standard FR-4 processes, although the material shows some impressive thermal characteristics. It offers a Tg of better than +280°C and a Td of +390°C, with a thermal coefficient of dielectric constant of +50 ppm/°C in the z-axis from –100 to +250°C. Its low thermal conductivity of 0.66 W/m/K makes this material a serious candidate for high-power amplifiers and phased-array radar systems. It suits critical, high-volume applications, such as collision-avoidance millimeter-wave radar systems in the automotive arena.

The ULTRALAM 3850HT circuit laminate from Rogers Corp. *(Fig. 2)* also features a low typical dielectric constant of 3.14 in the z-axis at 10 GHz. The material has a dissipation factor of 0.0037, which is once again through the z-axis at 10 GHz. Thermal conductivity is a low 0.2 W/m/K. The ULTRALAM 3850HT is well-suited for mobile applications that require both high flexibility and low moisture absorption.

As noted earlier, cost can be a key parameter when choosing a PCB material for an application. But when also considering performance and achieving higher yields from a production process (especially when higher temperatures are required), the higher initial costs of some circuit-material types may deliver higher yields and lower final costs than materials such as FR-4, which save on cost from the outset. mw

CORRELATE MEASUREMENTS BETWEEN PORTABLE AND BENCHTOP INSTRUMENTS

MICROWAVE MEASUREMENTS TRADITIONALLY have involved transporting a device under test (DUT) into a test laboratory for study by the appropriate test instruments. But rapid improvements in portable RF/microwave test equipment have made it possible to bring any number of measurements to a DUT in the field.

Of course, the test results from benchtop and portable test instruments must be properly correlated. Fortunately, Keysight Technologies offers a terrific primer for doing so, courtesy of a 12-page application note titled "Correlating Microwave Measurements between Handheld and Benchtop Analyzers."

Measurements are compared for the firm's MXA benchtop signal analyzer and FieldFox portable signal analyzer. Measurements are maintained as consistently as possible where controllable, such as using the same video bandwidth (VBW) and resolution bandwidth (RBW) for each instrument's set of measurements on a DUT and differing in test parameters, such as sweep speed, when those parameters were inherent functional differences of the different instruments.

Details are provided for comparing instrument specifications from data sheets, which tend to provide performance levels under a variety of different operating conditions, such as across a temperature range and/or only at room temperature or a narrow range of temperatures around room temperature (+25°C). The literature emphasizes the importance of correlating measurements made on different test platforms since a DUT may be analyzed across a number of different test instruments during its lifetime, from a prototype stage to in-field installation. The application note does not attempt to steer readers toward using either a portable or a benchtop instrument for a particular measurement but, rather, provides enough information to achieve the most consistent, accurate results with each type of test tool, and results that can be trusted across a variety of operating conditions. For anyone considering the addition of a portable test instrument such as an MXA signal analyzer to a lineup of benchtop instruments, this application note serves as an excellent introduction to using both types of test instruments together, with optimum accuracy and effectiveness.

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SIZING UP SPECIFICATIONS FOR MICROWAVE DIVIDERS AND COUPLERS

COMBINING AND DIVIDING high-frequency signals is often necessary when processing signals in multiple-channel systems, and power combiners and dividers are essential component-building blocks for this purpose. These components are available from a wide range of suppliers with different performance specifications and features and in many package styles, from miniature drop-in housings to large waveguide components. An eight-page application note from Marki Microwave, "Microwave Power Dividers and Couplers Tutorial," provides an overview of RF/microwave power combiners and dividers and how to correlate different performance specifications and features to the requirements of different applications.

Power dividers and couplers are usually reviewed with almost identical figures of merit, with some small differences. The splitting power of a coupler or divider is usually such that the input power is equally distributed among the output ports. Consequently, a divider with a two-to-one output-to-input relationship will provide output levels that are each 50% that of the input power level, and a divider with a three-to-one output-to-input relationship will provide output levels that are each about 33% that of the input power level. Power dividers and coupler circuits also can be designed with phase-shift differences between two output signals of 0, 90, or 180 deg. as needed. The units with 0-deg. phase differences in outputs usually are the easiest to design and the most common.

Power dividers and combiners are evaluated by a number of other parameters. The isolation or separation between output ports, for example, is generally related to the bandwidth of a power divider or combiner, with isolation generally dropping as the bandwidth of a component increases. For components with octave bandwidth, for example, isolation of 15 deg. is considered quite good, although for a multioctave-bandwidth power divider, such as DC to 40 GHz, isolation of 6 dB may be considered high.

The application note sizes up the different performance specifications for power dividers and couplers and the various tradeoffs that are necessary for reaching different performance goals, such as broadband versus narrowband coverage. It includes an easy-to-follow tabular review of different power dividers and couplers, as well as a short list of references with additional reading on understanding dividers and other components, such as filters, in high-frequency systems.

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JEFF SANDS | Product Manager

Mercury Systems Inc., 201 Riverneck Rd., Chelmsford, MA 01824; (866) 627-6951, (978) 256-1300, www.mrcy.com

The RFM-1R1S18K-L1-VXS downconverter/tuner separates its 1.5-GHz bandwidth into four IF outputs, each with 375-MHz bandwidth centered at 745 MHz.

MICROWAVE TUNERS Show OpenRFM Flexibility

This "building block" approach to an open-system test instrument architecture provides a great deal of measurement capability and flexibility across the traditional 2-to-18-GHz EW bandwidth.

MICROWAVE SYSTEMS AND TEST SOLUTIONS rarely have enjoyed the benefits of any form of standards to govern the design and manufacture of integrated microwave assemblies (IMAs). As a result, an IMA from one manufacturer invariably will be different in size, interfaces, and many other aspects from an IMA supplied by another manufacturer. Nor has there been any seamless integration between RF and digital subsystems in a common form factor.

To rectify this, Mercury Systems last year proposed a standardized open-system architecture based on a "building block" approach. Called OpenRFM, the approach brings RF and microwave technology into the realm of systems-level standards such as OpenVPX, VME, and VXS commonly used by digital embedded systems for electronic-warfare (EW) and other defense electronics applications. In its continuing support of the proposed standard, the company introduced the Ensemble RFM-1RS18 tuner available in four configurations that cover the 2-to-18-GHz frequency range commonly associated with electronic-warfare (EW) applications.

The four configurations include the single-channel models RFM-1R1S18K-L1-VXS and RFM-1R1S18K-1875-L1-VXS downconverter/tuners, as well as the RFM-1T18K-1875-L1-VXS and RFM-

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*GVA-62+ may be used as a replacement for RFMD SBB-4089Z
†GVA-63+ may be used as a replacement for RFMD SBB-5089Z
See model data sheets for details.

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Model	Freq. Range (MHz)	Gain (dB)	P_{OUT} (dBm)	Price $ ea. (Qty. 20)
*GVA-62+	10-6000	15	18	0.99
†GVA-63+	10-6000	20	18	0.99

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Model	RFM-1R1S18K-L1-VXS	RFM-1R1S18K-1875-L1-VXS	RFM-1T18K-1875-L1-VXS	RFM-1T1S18K-1875-L1-VXS
Description	Single-channel downconverter/tuner with synthesizer	Single-channel downconverter/tuner with synthesizer	Single-channel transmit upconverter/tuner	Single-channel transmit upconverter/tuner with synthesizer
Operating frequency range	2 to 18 GHz			
Outputs	4	1	1	1
IF center frequency	745 MHz	1.875 GHz	1.875 GHz	1.875 GHz
Instantaneous IF bandwidth	1.5 GHz total, 375 MHz/channel	1.0 GHz		
Minimum tuning step size	3 Hz	3 Hz	N/A	3 Hz
1-dB compression point	+6.5 dBm typical, +5 dBm minimum	+6.5 dBm typical, +5 dBm minimum	+25 dBm	+25 dBm
Nominal gain	10 dB	10 dB	26 dB	26 dB
Noise figure	24 to 28 dB	24 dB	30 dB	30 dB
Gain control, manual	Two sets: 15.5 dB each, 0.5-dB step size		15 dB, 1-dB step	15 dB, 1-dB step
Power consumption	~70 W	~70 W	~40 W	~70 W
Form factor	6U VXS	6U VXS	6U VXS	6U VXS
Weight	~3 lb.	~3 lb.	~3 lb.	~3 lb.

1T1S18K-1875-L1-VXS transmit upconverter/tuners *(see the figure)*. The downconverter/tuners convert signals from 2 to 18 GHz to a lower-frequency intermediate frequency (IF) for processing. The complementary transmit upconverter/tuners accept an IF that is converted to a user-selectable frequency in the 2-to-18-GHz range.

All four units are composed of as many as three OpenRFM modules—a wideband front-end, an IF converter, and, in three of the models, a fast-switching direct-digital synthesizer (DDS) for maintaining precise signal coherence. Each instrument packs broadband capabilities into a single-slot 6U VXS form factor. Whether employed as standalone units or paired together, these new models offer excellent performance and flexible capabilities to meet EW needs.

Model RFM-1R1S18K-L1-VXS offers 1.5-GHz instantaneous bandwidth, which is three times the industry standard. The 1.5-GHz instantaneous bandwidth split into four IF outputs each with a 375-MHz bandwidth centered at 745 MHz. By dividing the full 1.5-GHz instantaneous bandwidth into narrower swaths of bandwidth, the instrument is capable of very high signal fidelity in the digital-conversion process, as the highest resolution (that is, greater effective number bits) and dynamic range are afforded by analog-to-digital converters (ADCs) with lower sampling rates and bandwidths.

Consequently, the 375-MHz segments of bandwidth at each of the four outputs can be much more precisely processed than if the entire 1.5-GHz bandwidth was digitized and processed as a whole.

Dramatically reducing bandwidth also results in less data to be processed at each output, and can thus be searched more rapidly for signals of interest and analyzed with less formidable processors or signal processing workstations. The Ensem-

> "All four units are composed of as many as three OpenRFM modules—a wideband front-end, an IF converter, and, in three of the models, a fast-switching DDS for maintaining precise signal coherence."

ble RFM-1R1S18K-1875-L1-VXS unit differs from the model RFM-1R1S18K-L1-VXS since it has a single output with 1 GHz of instantaneous bandwidth centered at 1.875 GHz. This unit is designed to take advantage of higher sampling ADCs and is well-suited for applications working with digital RF memories (DRFMs) when paired with either of the transmit tuners.

Models RFM-1T18K-1875-L1-VXS and RFM-1T1S18K-1875-L1-VXS are both single-channel, single-output tuner/upconverters that accept 1 GHz of instantaneous bandwidth centered at 1.875 GHz. The 1T1S18K contains a DDS, while the 1T18K does not. The RFM-1T18K-1875-L1-VXS can be paired with the RFM-1R1S18K-1875-L1-VXS, sharing the DDS capabilities of the receive unit and ensuring locked tune frequencies.

The RFM-1T1S18K-1875-L1-VXS can be used as a stand-alone transmitter tuner or is able to be paired with the RFM-1R1S18K-1875-L1-VXS to provide an RF transmit/receive solution with independent tuning capabilities in both transmit and receive path.

All of the units provide manual gain control to optimize noise figure and other performance parameters. The *table* provides a brief summary of the major performance specifications for all four subsystems.

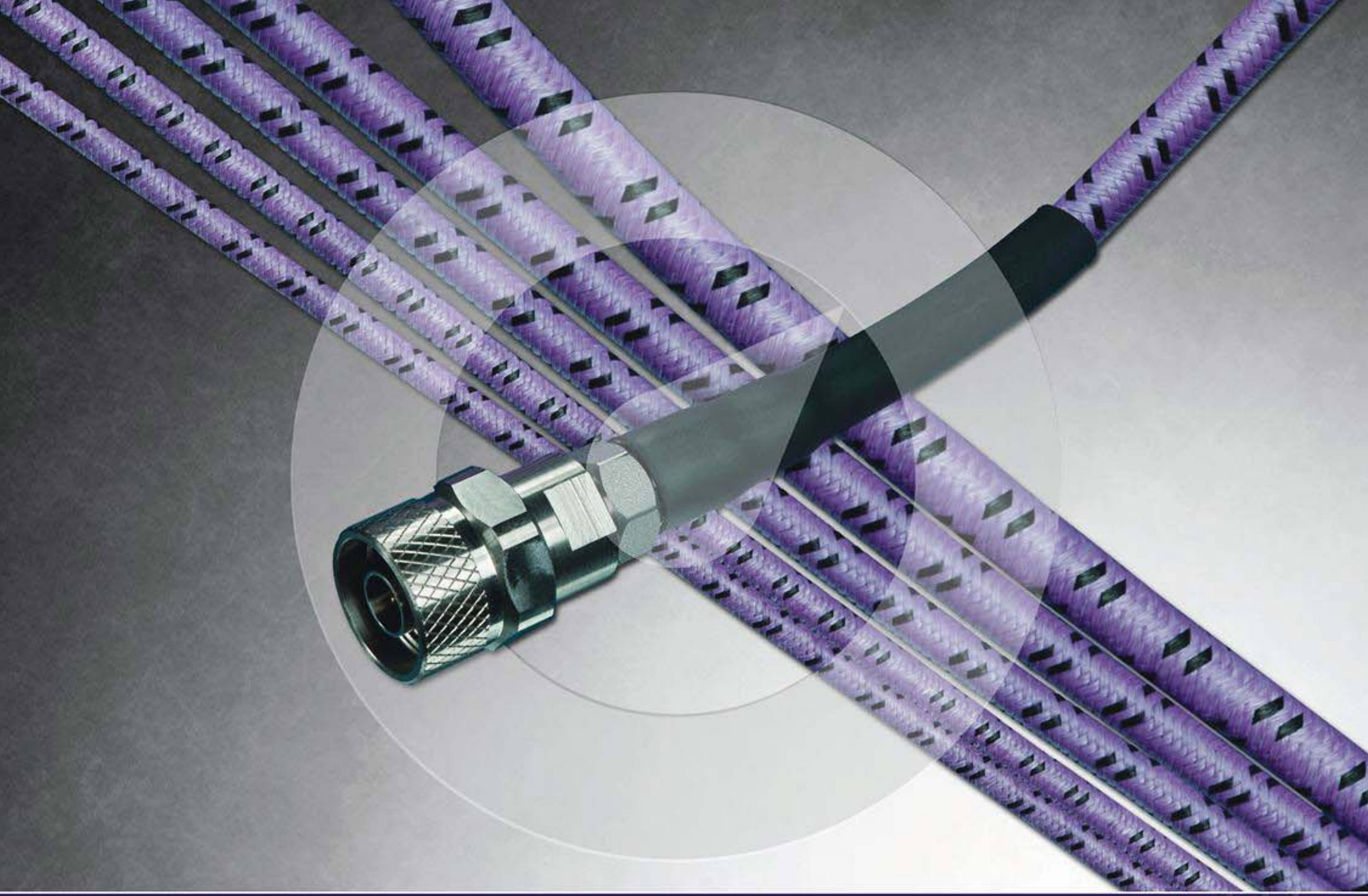
OpenRFM offers the flexibility to provide customer specific products quickly. For instance, the RF transmit and receive capabilities described could easily be integrated with the DDS synthesizer module to provide an RF only product. Likewise, any of the four products described could quickly be migrated to an OpenVPX form factor to offer the advantages of that platform.

This is typical of what can be achieved by the OpenRFM approach. It illustrates how subsystems can be built to meet specific customer requirements in a small fraction of the time and at much less cost when compared to current microwave industry practice. Modules can simply be interchanged and as OpenRFM's control plane, interfaces, and other features remain the same regardless of the modules used. Only minor adjustments are required to accommodate new hardware.

OpenRFM also allows "technology refresh" to be achieved easily over multiple platforms as components with greater performance—such as ADCs and digital-to-analog converters (DACs)—become available.

As Mercury and (hopefully) other manufacturers adopt the OpenRFM approach, the result will be a large library of single- and multiple-function blocks that can be interchanged, no matter the manufacturer, to dramatically reduce the amount of time required to build a subsystem or modify it down the road. mw

MERCURY SYSTEMS INC., 201 Riverneck Rd., Chelmsford, MA 01824; (866) 627-6951, (978) 256-1300, *www.mrcy.com*



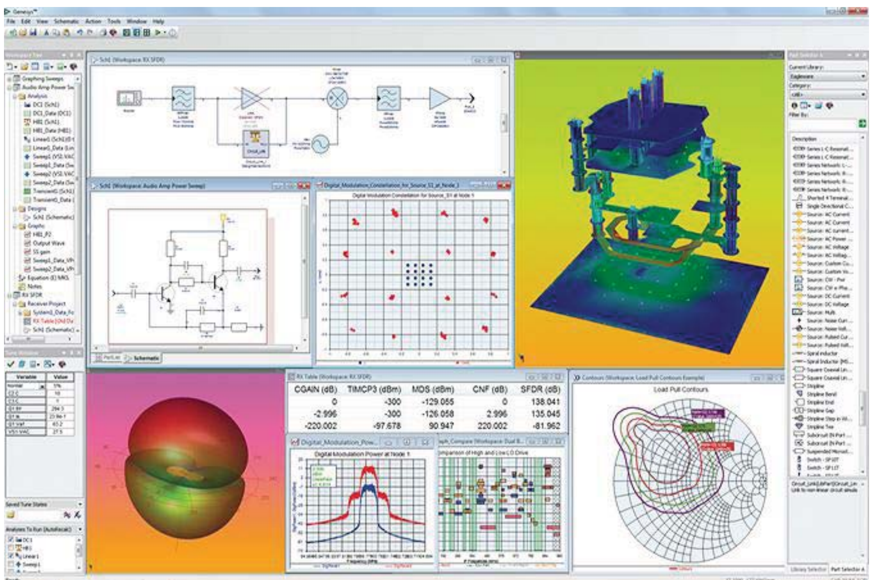
JACK BROWNE | Contributing Editor

Simulators Predict System-Level Behavior

System-level simulators provide the next step up from circuit simulation tools, modeling and predicting the joint performance of RF/microwave components and devices.

COMPUTER SIMULATION SOFTWARE fueled by RF/microwave models is usually tasked with predicting the performance of different component-level designs. When many different components are connected, however, a system-level software simulator is required, with the capabilities of analyzing the interactions of devices, components, integrated circuits (ICs), and the choice of printed-circuit-board (PCB) material. Over the years, such system-level simulators have grown quite sophisticated, with the capabilities to analyze the effects of different components and operating conditions on the performance of a communications system, radar, or almost any kind of system relying upon electromagnetic (EM) energy.

The increased availability of EM software simulation tools has boosted the effectiveness of modern system simulators and given their operators an invaluable tool for understanding how to achieve a desired level of system performance. Software simulators save the time and expense of assembling an actual system, providing simulated performance results that come strikingly close to the measured results from actual assembled prototype systems.



1. Genesys is a circuit design and layout tool that works within the ADS suite of design software in support of system-level simulations when needed. ***(Graphics courtesy of Keysight Technologies)***

For many design engineers, software simulation tools are a natural starting place for a design—for example, simulating the performance of a communications receiver or transmitter by combining a number of individual component models for amplifiers, filters, antennas, and the various other components employed in a full system design. Two of the leading suites of software design tools are the Advanced Design System (ADS) suite of programs from Keysight Technologies (www.keysight.com) and the Microwave Office design tools from National Instruments Applied Wave Research (www.awr.com).

System simulators offer the chance to explore the many possibilities of different design choices within a system without having to fabricate hardware and prototypes. Optimization capability has become an essential function in many system-level simulators, allowing designers to have their mainframe or personal computer (PC) run a series of algorithms in pursuit of the best performance possible from a component or set of components.

Newer suites of system-level simulation software offer EM simulation tools that are particularly useful in analyzing passive circuit and component structures, as well as to apply optimization functions for improved performance over an initial design. In many ways, the integration of a software tool such as an EM simulator within a system simulator can simplify the use of the former, minimizing errors due to file translations between numerous individual software programs, in addition to maintaining the models and design files in common formats.

Simulation software suites such as ADS and Microwave Office allow specifiers to add optional functionality as needed. They actually add what are complete simulation programs such as SystemVue to the ADS group of programs, along with "companion" software programs like linear and nonlinear circuit simulators and EM simulators. While a system simulator such as SystemVue is a powerful modeling tool on its own, it is the capability to apply those other simulators that makes the simulation software suite so effective. The ease of moving design files from one simulator to another has greatly simplified what was once a difficult (if not impossible) task: transferring a simulation file from one manufacturer's software program to another.

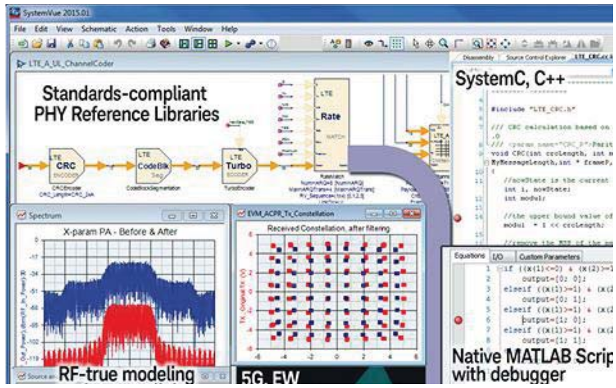
For example, ADS also incorporates the Genesys circuit-level synthesis and simulation software for creating subsystem circuit boards to be part of a larger system. Genesys in and of itself is a full-featured simulator with extended capabilities, including nonlinear circuit simulation in the DC, time, and frequency domains; modulated RF circuit analysis; 3D planar EM simulation; and even basic RF system layouts and analysis. Core building blocks include the capabilities to create schematic diagrams and circuit layouts.

When creating a layout with Genesys *(Fig. 1)*, a 3D viewer provides numerous tools—including interactive zoom, rotation, and vertical stretching functions—to verify that a layout geometry is as close to optimum as possible before commencing fabrication of a design. The software can import and export the masks and drill files needed to create a layout, using the standard PCB file formats.

The Genesys program includes a function known as Testlink, which serves as an interface between commercial test instruments and the simulation software. As expected, the software supports leading Keysight instruments, but actually works with more than 140 instruments from a total of 14 different manufacturers. For many system designers, a program like Genesys is a starting point for a design such as a transmitter or a receiver, since it accepts component files (such as filters and amplifiers) that may have been previously created.

By operating in SystemVue *(Fig. 2)*, ADS software users can take full advantage of a system-level vantage point on a design, while still employing the full power of the linear and nonlinear circuit simulators and EM simulation tools within ADS. SystemVue is an effective tool for predicting the interaction of analog and digital components and subsystems, including data converters, digital-signal-processing (DSP) ICs, and even field-programmable gate arrays (FPGAs), with a wide range of commercial, industrial, and military systems.

Similarly, Microwave Office contains numerous programs, such as linear and nonlinear circuit simulators and 3D planar EM simulation software, that work in support of the main system simulation tool, Visual System Simulator (VSS). VSS is based on the Unified Data Model architecture also employed in Microwave Office. It can be targeted towards simulating specific wireless standards, such as the VSS for Long-Term Evolution (LTE) software, for simulating components and system assemblies intended for that wireless communications standard.



2. SystemVue is the system-level simulation engine within the ADS suite of software programs that can simultaneously perform simulations with circuit and EM simulators within the suite.
(Graphics courtesy of Keysight Technologies)

The software allows an operator to simulate all the performance levels detailed in the LTE standards, including data download rates of 50 Mb/s and as fast as 100 Mb/s; a variety of different modulation formats, such as quadrature-phase-shift-keying (QPSK) and 64-state quadrature-amplitude-modulation (64QAM) formats; scalable network carrier bandwidths, from 1.4 to 20.0 MHz; and even the effects of different levels of error vector modulation (EVM) distortion on LTE communications system performance.

For working with test instruments and measurement data, VSS features plug-and-play support for such software as LabVIEW, MATLAB, and C++ code, and links readily with NI AWR's LabVIEW and TestWave measurement programs for ease of connection of simulations with commercial measurement equipment. The combination of hardware and software can even perform some high-level system analysis on a communications system such as an LTE wireless network, including adjacent channel interference (ACI) analysis.

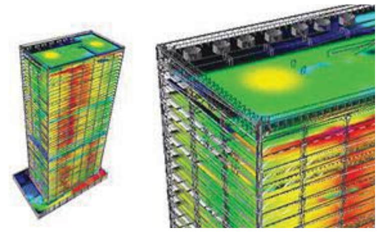
KEY ROLE OF MODELS

As with circuit simulators, models are essential to the success of a system-level simulator, and simulators such as SystemVue and VSS are supplied with a wide range of models typically based on measurements with the software developer's test equipment. Most of the models are at the component level, such as analog RF/microwave components including amplifiers, antennas, filters, and mixers to simplify the design of receivers and transmitters.

But some models also address the needs of digital designers, including models of data converters. System simulators make it possible to "exercise" digital components under different system operating conditions—e.g., different clock frequencies, bit levels,

and noise levels. Effective system simulators can provide a prediction of the overall system performance, as well as a close-up view of interactions between components (such as the effects of impedance mismatches between a low-noise amplifier and a frequency mixer in a receiver].

System-level software suites are designed for performing co-simulation with different software simulation engines running at the same time. In the case of the LNA and mixer connection, a number of different simulation tools may be operating simultaneously—with changes of impedance between the two components between studies with linear and nonlinear circuit simulators, and by EM and system-level simulators—to study simple effects such as changes in gain and noise figure. They also study more complex effects such as the generation of second-, third-, and higher-order intermodulation distortion within the two components and how the distortion levels will affect a system parameter, such as receiver sensitivity and range.



3. It is often necessary, once communications systems are assembled, to evaluate how well they perform in a particular operating environment—such as inside a building. *(Graphics courtesy of iBwave)*

Of course, with the capabilities of a system simulator, many variations must be considered. Changes to any component or junction within a receiver block diagram can affect performance, right down to the circuit-board level. Thus, the capability to perform co-simulation within a suite of simulation programs makes it possible to predict the effects of literally thousands of variables and the results on system-level performance.

SystemVision software from Mentor Graphics (www.mentor.com) is a powerful system simulation tool that provides a straightforward user interface to a multidiscipline collection of simulation tools for modeling analog, digital, and mixed-signals circuits and subsystems. It is available with the SystemVision conneXion (SVX) capability for connection to other software tools, like Simulink from MathWorks (www.mathworks.com) and LabVIEW, and provides an effective means for modeling specific types of communications networks.

For budget-conscious users, Arden Technologies (www.ardentech.com) recently introduced the latest version of their versatile system simulator, SysCalc6, which has been applied quite effectively over the years by both military and commercial communications users. For a fraction of the cost of the software suites, this dedicated system simulator can provide all the major system-level parameters while running on a PC. The software can save the most complex designs in flexible XML files, and provides a straightforward user interface that simplifies simulations setups. Impedance matching between system modular stages can be entered directly into a simulation and fine-tuned to experiment with different effects and operating conditions, and achieve an optimum design layout.

In some cases, simulation of system performance may rely heavily on the propagation environment. Design software such as iBwave Design (Version 6.6) from iBwave (www.iBwave.com) models the performance of wireless communications transmitters and receivers within a building. The software can plot the performance of multiple-carrier systems operating with voice and data transmission capabilities by using a proprietary propagation algorithm to predict the effects of the physical environment on the transmission and reception of high-frequency modulated radio waves.

The software has helped with the installation of wireless communications equipment within buildings, including the number of required antennas and the optimum placement of those antennas, plus the selection of different components for the system.

Similarly, the HERALD Professional software from Radio Engineering Services (www.radioengineering.it) provides simulation of radio links, such as point-to-point radio connections, and makes it possible to predict the effects of changing weather and atmospheric conditions on the transmission and reception of high-frequency radio waves. Such system-level programs represent the next step after a software suite such as ADS or Microwave Office has eased the way for the development of the various hardware components required for an in-building wireless communications network.

In terms of learning more about system simulators, integrated-circuits (ICs) innovator Maxim Integrated Circuits (www.maximintegrated.com) offers white papers on design on its website. These include the recent "Next Generation Power Modules Further Simplify Power Design." With references to the NI AWR and Keysight system simulators, the white paper notes that the integration of such tools as nonlinear circuit simulators and 3D EM simulators has made system simulators considerably more effective in modeling complex systems. mw

JACK BROWNE | Contributing Editor

Software Streamlines 3D Semiconductor Design

The latest version of this semiconductor-process modeling software boosts speed, accuracy, and capabilities all in a simpler, easier-to-use package.

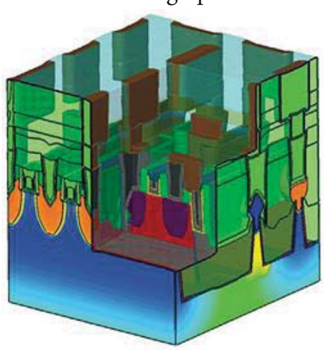
USE OF THREE-DIMENSIONAL (3D) semiconductor structures has become commonplace within many markets, and in turn, semiconductor-process technologies continue to advance in support of higher-speed, denser active devices. For example, Coventor (www.coventor.com) stays at the forefront with new and updated tools that predict the performance of different 3D semiconductor designs.

Case in point: the company's fifth generation of its SEMulator3D 5.0. The simulation software adds features for new process capabilities, and simplifies the learning process for using the software. It's a powerful platform for predicting the effects of different process parameters on semiconductor and microelectomechanical-systems (MEMS) devices.

Processes for analog, digital, and optical functionality all can be modeled with SEMulator 3D, including silicon CMOS processes with features as fine as 7 nm. Device designers use it to predict the effects of different process parameters on the performance of 3D memory structures, computer hard-disk read-heads, optical sensors, and high-frequency MEMS switches.

The software is especially useful when evaluating a new semiconductor process or manufacturing equipment or new design approaches, using what the firm refers to as "virtual fabrication" of advanced manufacturing processes. In other words, different variables and conditions can be understood before actually undergoing manufacturing-process time and costs to fabricate a prototype circuit or device.

The SEMulator3D program includes a flexible layout editor to speed and simplify the design process. It also connects to the Cadence Virtuoso software from Cadence Design Systems (www.cadence.com) for design and simulation of advanced integrated circuits (ICs). SEMulator3D can also directly import design details in the form of GDSII layout data. The 3D process simulator and its virtual process capabilities will automatically generate virtual process masks. As a result, designers are able to experiment with the effects of adjustments to the shapes of those semiconductor masks without having to endure the time and expense of a semiconductor-process cycle.



The fifth-generation SEMulator3D process simulation software uses "virtual fabrication" techniques to model semiconductor processes. The results will help better understand the effects of different variables before running the process.

Version 5.0 of this powerful software tool features a new graphical user interface (GUI) for the software's process editor, which simplifies how to use the software and speed the process of learning how to use its many features and capabilities. This version of the software also increases the number of supported interfaces. For example, a wide range of parameter-extraction tools helps speed the analysis and development of different semiconductor device/process models.

This version of SEMulator3D also boasts enhanced capabilities—process improvements for modeling semiconductor dopants include new process models for ion implantation, thermal diffusion, and *in situ* doped deposition and epitaxy. An update to the SEMulator3D Viewer provides visualization of different dopant concentrations, showing how these dopant parameters can affect another semiconductor structure's performance *(see the figure)*.

SEMulator3D 5.0 makes it possible to create accurate physics-based process models. It's invaluable for accelerating the development of advanced semiconductor structures and MEMS devices for a wide range of markets, including automotive, commercial, industrial, and military. The straightforward visualization of process parameters helps find problems quickly, and the simple GUI enables many different groups across a company to achieve consistent results with the software. mw

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TIM GALLA | Product Engineer
Pasternack Enterprises, 17802 Fitch, Irvine, CA 92614; 866-727-8376, www.pasternack.com

Noise Sources Deliver High Outputs to 18 GHz

These amplified noise sources serve test and system applications through 18 GHz that require healthy output-power levels as high as 32.5 dB.

NOISE SOURCES have long served as practical test tools for evaluating different aspects of communications systems. In fact, additive white Gaussian noise (AWGN) sources helped establish many early wireless communications channels, allowing system architects to evaluate mechanical, electrical, and environmental effects on noise signal levels sent through a channel to be tested.

However, the growing complexity of wireless systems, from simple analog channels to more elaborate digitally modulated channels, demanded more complex test sources. Most notably, they had to emulate such effects as signal fading, multipath distortion, interference, and other propagation impediments.

The model PE8504 amplified noise source has a frequency range of 12 to 18 GHz with a 15.5-dB ENR output.

Still, the noise source remains an inexpensive component for many test applications, such as modeling the noise in a communications channel, or testing a satcom link's signal quality. To serve all of these applications, Pasternack Enterprises recently introduced a series of coaxial AWGN noise sources covering frequencies from 2 to 18 GHz with a number of different noise output levels.

A noise source can be as simple as a packaged or unpackaged diode or an amplified diode in a compact housing with coaxial connectors, or as complex as a microprocessor-controlled, noise-generating instrument with additional capabilities. Pasternack's initial noise components represent the former type, in small aluminum enclosures with BNC or SMA connectors, built to survive the handling on a test bench and in multiple types of measurement systems.

The product line includes 10 models *(see table)*. Noise sources come in frequency ranges of 1 to 2 GHz, 2 to 4 GHz, 4 to 8 GHz, 8 to 12 GHz, and 12 to 18 GHz. Medium- and high-power versions are available, offering excess-noise-ratio (ENR) output levels of 15, 30, or 32.5 dB. Such high output noise levels suit common test applications like BER and noise-figure measurements.

The ENR values also correlate well with standard calibration points of noise-figure meters and RF/microwave spectrum analyzers. The versatile 15-dB ENR models can measure both low and high noise figures, while the 30- and 32.5-dB models target high-noise-figure test scenarios. The noise sources exhibit VSWRs of either 1.20:1 or 1.35:1, and feature rise/fall times of 1 µs or better. All models are rated to operate from –55 to +85°C and require 25-mA current at a bias voltage of +28 V dc. ■

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

SIZING UP THE NOISE SOURCES

Model	Frequency range (GHz)	Noise output, ENR (dB)	Noise flatness (dB)	Calibration frequency increments (GHz)	DC input connector (output connectors—SMA male)
PE8500	1 to 2	15.5	±0.5	0.5	BNC
PE8501	2 to 4	15.5	±0.5	1.0	BNC
PE8502	4 to 8	15.5	±0.5	1.0	BNC
PE8503	8 to 12	15.5	±0.5	1.0	BNC
PE8504	12 to 18	15.5	±0.5	1.0	BNC
PE8505	1 to 2	32.5	±1.0	0.5	SMA female
PE8506	2 to 4	32.5	±1.0	1.0	SMA female
PE8507	4 to 8	32.5	±1.0	1.0	SMA female
PE8508	8 to 12	30.0	±1.0	1.0	SMA female
PE8509	12 to 18	30.0	±1.0	1.0	SMA female

All models have 50-Ω impedance with rise/fall times of 1 µs or better, bias requirements of +28 V dc at 25 mA, maximum noise output versus voltage of 0.1 dB/%V dc, and an operating temperature range of –55 to +85°C.

JACK BROWNE | Contributing Editor

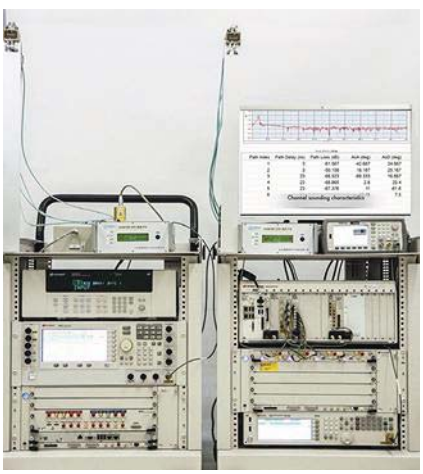
Modular Tester Performs 5G Channel Sounding

By employing modular test instruments, this measurement system packs many instruments and a great deal of functionality for evaluating the propagation capabilities of 5G wireless systems.

MODERN COMMUNICATIONS CUSTOMERS are driving for continual advances in wireless-communications system technology and performance, demanding the erection of fifth-generation (5G) wireless systems. But first, effective means of testing those 5G systems are needed.

Keysight Technologies has developed a test system for channel sounding, with the capability of generating the different waveforms and measuring propagation effects that will represent the performance levels experienced by 5G waveforms. The 5G Channel Sounding Reference Solution test system incorporates a number of multichannel wideband PXI and AXIe test-instrument modules to optimize speed and accuracy.

The 5G Channel Sounding Reference Solution *(see figure)* blends advanced signal-generation resources with high-resolution analysis capabilities to study Doppler shifts, channel loss and distortion, and other propagation effects. It packs both PXI and AXIe function modules into a mainframe enclosure, including a model M9703A AXIe wideband digitizer and model M9362A PXI quad downconverter module.



The 5G Channel Sounding Reference Solution test system incorporates PXI and AXIe measurement modules, along with flexible signal generation and analysis software, to tackle the challenges of characterizing 5G communications network channels.

The several PXI and AXIe instrument modules within the 5G Channel Sounding Reference Solution provide full-sized performance levels in a fraction of the size of conventional benchtop instruments. For example, the model M9703A AXIe receiver/digitizer processes input signals from dc to 2 GHz at sampling rates to 3.2 Gsamples/s. The eight-channel digitizer features 12-b resolution, armed with four Virtex-6 field-programmable gate arrays (FPGAs) from Xilinx (www.xilinx.com).

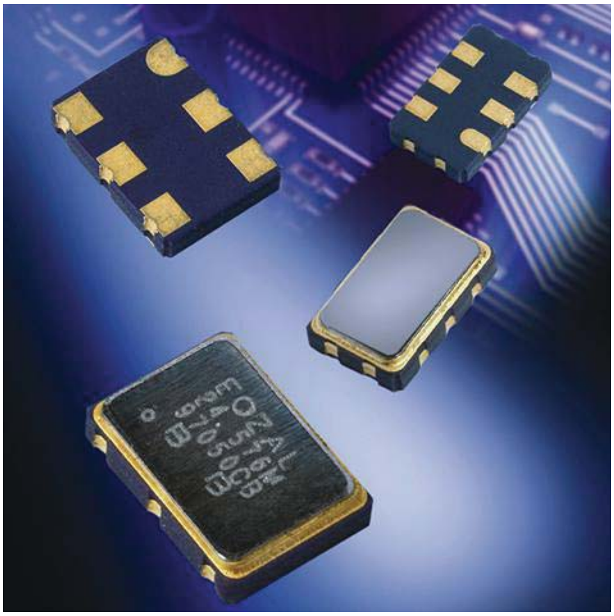
The digitizer, which is well-suited for analyzing multiple-input, multiple-output (MIMO) channels and components, is scalable to more channels. It can process real-time bandwidths as wide as 1 GHz.

The model M9362A PXI quad downconverter module operates from 10 MHz to 26.5, 40.0, and 50.0 GHz. The model M8190A arbitrary waveform generator provides 14-b resolution at sampling rates to 8 Gsamples/s and 12 b resolution at sampling rates to 12 Gsamples/s. It can operate at sampling rates from 125 MSamples/s to 8 or 12 Gsamples/s. It provides a spurious-free dynamic range (SPDR) of typically –90 dBc and harmonic distortion of typically –72 dBc.

The channel sounder also includes an N5183B MXG microwave analog signal generator and E8267D PSG 100-kHz-to-44-GHz vector signal generator (VSG), with a generous assortment of measurement software, including the model 89600 VSA software and the model M9099 Waveform Creator software. With its collection of signal sources, the test system can handle generation and analysis of systems with wide channel bandwidths at carrier frequencies to 44 GHz.

The M9099 Waveform Creator is a modular software application that employs a drag-and-drop graphical user interface (GUI). It creates the complex baseband and vector signals that will be used 5G. Engineers can also use Keysight's SystemVue simulation software platform to calculate channel parameter estimations and perform link-level simulations and validation of new 5G designs with the imported channel models *(see p. 75 for more information)*. mw

KEYSIGHT TECHNOLOGIES, 1400 Fountaingrove Pkwy., Santa Rosa, CA 95403; (707) 577-2663, *www.keysight.com*



VCXOs Maintain Consistent Timing

OSCILLATORS FOR TIMING PURPOSES should maintain their frequency over time, temperature, and various changing environmental conditions. The G326 series of voltage-controlled crystal oscillators (VCXOs) from Saelig Company Inc. (www.saelig.com) ranges in frequency from 1 to 50 MHz with outstanding timing consistency, measured in terms of integrated phase jitter of typically only 200 fs. These miniature crystal oscillators suit phase-locked loops (PLLs) and applications that depend on precise timing, including SONET systems and wireless-communications equipment.

The G326 series differs from conventional fixed-frequency oscillators since they can be tuned by 50 to 200 ppm in frequency for applications requiring dynamic changes to system clock frequency. The frequency is tuned by varying a control voltage feeding a varactor tuning diode within the oscillator package. The VCXOs come in a six-pad surface-mount packages measuring just 3.2 × 2.5 × 1.0 mm. Supply voltages include +1.8, +2.5, +3.3, and +5.0 V dc, and outputs are CMOS or two-gate transistor-transistor-logic (TTL).

The clock oscillators achieve rise/fall times of 6 ns or better with startup time of 10 ms and current consumption of 10 to 45 mA, depending on frequency. They are designed for 50 ± 10% duty cycle (with ±5% tolerance available to order) and provide linearity of 10% or better, and typically 5%. The G326 series, manufactured by Euroquartz, handle commercial operating temperatures from –10 to +70°C and industrial operating temperatures from –40 to +85°C.

SAELIG COMPANY INC., 71 Perinton Parkway, Fairport, NY 14450; (585) 385-1750; fax: (585) 385-1768; e-mail: info@saelig.com, *www.saelig.com*

IDAS Unit Blends Combiner, Duplexer

DESIGNED TO HELP boost the efficiency and performance of the Icom Digital Advanced System (IDAS), the model 16A3BJ integrated duplexer and three-way power divider features multiple ports at different frequencies. IDAS, developed by Icom UK (www.idasuk.co.uk), is a two-way radio system for business and industry with 6.25-kHz channel spacing. The system, with radios that can receive both digital and analog signals on a single channel, uses advanced noise-cancelling functions to achieve high-quality audio performance. It offers high-speed data management over its narrow channels, and as a result achieves excellent bandwidth efficiency.

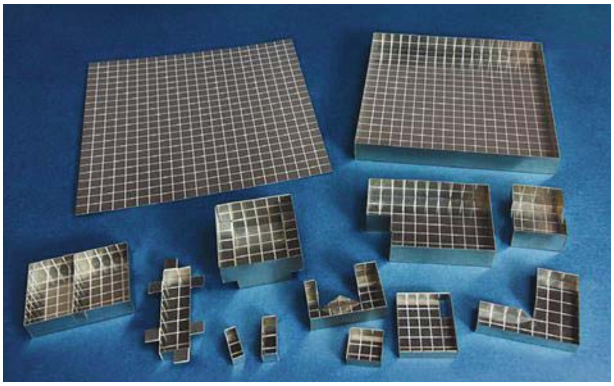
The 16A3BJ unit provides reasonable isolation between ports with low loss. It includes three ports for each frequency, with ports J1, J2, and J3 at 1900 MHz and ports J4, J5, and J6 at 2300 MHz. The assembly exhibits maximum insertion loss of 6.25 dB for all ports. Minimum isolation is 50 dB between ports covering different frequencies and better than 15 dB between ports covering the same frequency. The power divider/duplexer offers power-handling capability of 20 W CW per port over a –30 to +60°C range. It measures 6.50 × 3.74 × 1.00 in., and weighs 1.5 lbs.

RENAISSANCE ELECTRONICS AND COMMUNICATIONS, LLC, 12 Lancaster County Rd., Harvard, MA 01451; (978) 772-7774; fax: (978) 772-7775; e-mail: sales@rec-usa.com, www.rec-usa.com

Sheets Form Fast PCB Shields

ELECTROMAGNETIC-INTERFERENCE (EMI) shielding can be quickly added to a printed-circuit board (PCB) via Tech-Etch's (www.tech-etch.com) Protoshield shielding sheets, which can be easily cut into a required shape and size. A pair of scissors and a straight-edge tool are all that's needed to form the shape needed to add shielding.

The ProtoShield sheets are depth-etched with a checkerboard pattern and come in two sizes—0.25-in. squares and in a metric version with 5-mm squares. The shielding sheets feature nickel-silver composition for good corrosion resistance and ease of soldering, without requiring additional finishing or plating. A prototype formed with the shielding sheets can be directly soldered to a PCB for ease of assembly.



Free samples of the shielding sheets are available upon request from the supplier. Standard versions measure 0.10 in. thick with nickel-silver composition and CDA770 alloy material, in an overall size of 5.5 × 5.5 in. in 0.25-in. increments. The metric version features 0.254-mm-thick nickel-silver composition and incorporates CDA770 alloy material. Overall size of the metric version is 1.25-mm square, with 5-mm grid increments. **TECH-ETCH INC.,** 45 Aldrin Rd., Plymouth, MA 02360; (508) 747-0300; e-mail: sales@tech-etch.com, *www.tech-etch.com*

Demod/Mod Unit Runs 400 to 3600 MHz

THE MODEL PV5870, a compact quadrature demodulator/modulator developed by ParkerVision, is now available with support from supplier RFMW Ltd. The direction-conversion quadrature demodulator/modulator is designed for use in communications systems requiring excellent linearity while also operating with extremely low power consumption, across an input range of 400 to 3600 MHz.

The miniature demodulator/modulator comes in a 20-lead QFN package measuring only 4 × 4 mm and draws just 23-mA current from a +3-V dc supply. It's designed to maintain excellent linearity while consuming only one-tenth or less of the power of demodulations with similar functionality. Even with the low power consumption, however, the model PV5870 offers low noise figure with an approximate 6-dB improvement over competing devices covering a similar frequency range.

The demodulator controls amplitude and phase control across a frequency range of 400 to 3600 MHz as a demodulator, allowing for adjustment of second- and third-order demodulation products through controls and adjustments. The unit contains fully differential RF, local oscillator (LO), and baseband interfaces, with baseband output ports designed for direct connection to baseband filters or amplifiers.

The unit achieves sideband suppression of better than –40 dBc and carrier leakage of better than –40 dBm for 900-MHz applications. It can operate from a +1.8-V dc power supply while providing an output third-order-intercept point of +21 dBm and an output second-order-intercept point of +60 dBm. It also boasts +7.5-dBm output power at 1-dB compression at 900 MHz.

RFMW LTD. (ParkerVision stocking distributor), 188 Martinvale Lane, San Jose, CA 95119; (408) 414-1450; e-mail: info@rfmw.com, *www.rfmw.com.*

SSPA Is Bidirectional from 4.4 to 5.0 GHz

THE TTRM1008 HIGH-LINEARITY GaAs FET bidirectional solid-state power amplifier (SSPA) is suitable for use with any type of modulation and signal. It's commonly used in unmanned-aerial-vehicle (UAV) data links and long-range point-to-point coded-orthogonal-frequency-division-multiplex (COFDM) video links, and developed initially for applications from 4.4 to 5.0 GHz.

An on-board complex programmable logic device (CPLD) on the model TTRM1008 coordinates high-speed transmit/receive (T/R) switching and sequencing of the unit's power amplifier (PA), low-noise amplifier (LNA), and switch driver circuitry. As a result, the timing of switching functions can be adjusted in firmware based on system requirements.

The compact unit's transmit section produces over 25 W of binary-phase-shift-keying (BPSK) power, with more than 5 W of 64-state quadrature-amplitude-modulation (64QAM) output power. There's a manual digital gain setting and three-color status LED on the front panel that shows if the SSPA is in transmit or receive mode, or if there's an alarm condition. Its weatherproofed housing is per IP66 guidelines. The unit can also be specified for other frequency bands, including 5.0 to 5.3 GHz and 5.3 to 5.9 GHz.

TRIAD RF SYSTEMS INC., 180 Tices Lane, Building A, Suite 107, East Brunswick, NJ 08816; e-mail: sales@triadrf.com, *www.triadrf.com*

Free Handbook Explains Digitizers

DIGITIZERS ARE VERSATILE test instruments that serve as valuable companions, and at times replacements for, digital oscilloscopes on a test bench. But selecting and using a digitizer requires a good understanding of these devices. Fortunately, test-instrument developer and supplier Spectrum published a 120-page handbook on digitizers, explaining how to specify a digitizer and when the instrument can replace an oscilloscope. The digitizer handbook is available free of charge via the firm's website at *www.spectrum-instrumentation.com.*

Major digitizer product features are covered, with explanations of the different terms. It also makes comparisons to other test instruments, including digital oscilloscopes and spectrum analyzers. The handbook offers examples to help optimize performance. It details the effects of signal conditioning and how digitizers can be used with different probes and sensors for the best measurement results.

It also reviews software and how different code works with measurement speed and accuracy, and the ways different programming languages, such as Visual C++, Borland C++, Gnu C++, and Visual Basic, can be used to create device drivers for digitizers. The handbook reviews how debugging tools can be employed to test different test hardware and check data-transfer speeds.

SPECTRUM SYSTEMENTWICKLUNG MICROELECTRONIC GMBH, Ahrensfelder Weg 13-17, 22927, Grosshansdorf, Germany; +49 (0) 4102 6956-0; fax: +49 (0)4102 6956-66; e-mail: Info@spec.de, *www.spectrum-instrumentation.com*

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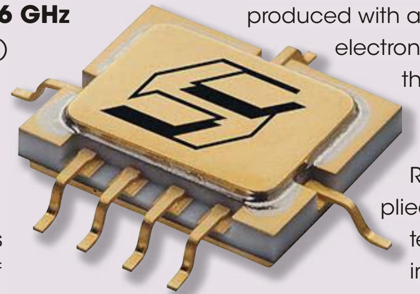
GaAs IC Switch Channels DC to 6 GHz



WIDEBAND GAAS integrated-circuit (IC) switch model ISO13316 is a single-pole, single-throw (SPST) switch with low loss and high isolation from DC to 6 GHz. The hermetic switch, which is suitable for high-reliability space, satellite, and defense applications, provides 45-dB isolation at 2 GHz with low loss of 1.1 dB at 6 GHz. Isolation ranges from typically 57 dB through 2 GHz, 51 dB through 3 GHz, and 30 dB through 6 GHz, while insertion loss is typically 0.6 dB through 3 GHz and 0.78 dB through 6 GHz. The switch is produced with a GaAs pseudomorphic-high-electron-mobility-transistor (pHEMT) process that has been shown to be radiation tolerance to 100 krad. The switch, with typical 10%/90% and 90%/10% RF switching speed of 5 ns, is supplied in a seven-lead surface-mount-technology (SMT) package measuring 0.385 × 0.345 × 0.065 in.

ISOLINK, a subsidiary of Skyworks Solutions, 880 Yosemite Way, Milpitas, CA 95035; (408) 946-1968; fax: (408) 946-1960; e-mail: sales@isolink.com, *www.isolink.com*

Waveguide Couplers Reach 110 GHz

FOR APPLICATIONS through 110 GHz, a line of ridged-waveguide directional couplers is available in waveguide sizes from K-band WR-42 through W-band WR-10. Suitable for use in communications systems, radars, and test applications, the product line includes 28 models spanning 18 to 110 GHz. The couplers are available in standard waveguide and split-block waveguide, as well as in E- and H-bend designs. The directional coupler line features 10- or 20-dB coupling with typical directivity of 30 dB and insertion loss as low as 0.6 dB in some models. The waveguide directional couplers are constructed using high-quality brass copper that is gold plated for added precision and accuracy.

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

Terminations Tackle 10 W to 4 GHz

A LINE of compact coaxial loads/terminations with 4.1/9.5 (mini-DIN) connectors serves wireless bands through 4 GHz. The 50-Ω loads are supplied with male connectors and feature low VSWRs of typically 1.10:1 through 2 GHz and 1.20:1 through 4 GHz. As an example, model TMDM1-3 operates from dc to 3 GHz with 1.10:1 typical VSWR through 1 GHz and 1.25:1 typical VSWR through 3 GHz. It handles 1 W average power and 2 kW peak power (a 5-μs pulse at 0.05% duty cycle). It is fashioned with PTFE virgin-grade insulators and handles operating temperatures from –55 to +85°C. The coaxial termination is 1.58 in. in length with 0.92-in. diameter and weighs 1.20 oz.

MECA ELECTRONICS INC., 459 East Main St., Denville, NJ 07834; (973) 625-0733; *www.e-MECA.com*

Transmit-Band Filters Serve Satcom Systems

THE 19172 and 19173 series of bandpass filters (BPFs) are designed to isolate the upper portion of the X-band satellite-communications (satcom) frequency range from the lower portion. The 19172 series filters pass 8.25 to 8.40 GHz while the 19173 series filters feature a passband of 7.09 to 8.05 GHz. The 19172 series filters exhibit maximum insertion loss of 0.8 dB with maximum VSWR of 1.30:1 across the passband. The filter has maximum passband power-handling capability of 200 W continuous-wave (CW) power. Rejection of out-of-band signals is at least 80 dB at 8.05 and 8.70 GHz. The filters, which also provide deep rejection of receive-band signals from 7.25 to 7.75 GHz, weigh 1.4 lb. The 19173 series filters offer similar performance across a passband of 7.09 to 8.05 GHz. Both series of X-band BPFs are designed for operating temperatures from –40 to +60°C.

MICROWAVE FILTER CO. INC., 6743 Kinne St., East Syracuse, NY 13057; (800) 448-1666, (315) 438-4700; e-mail: mfcsales@microwavefilter.com; *www.microwavefilter.com*

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www.minicircuits.com   P.O. Box 350166, Brooklyn, NY 11235-0003   (718) 934-4500   sales@minicircuits.com

VCO Cuts Phase Noise at 3650 MHz

MODEL CVCO55CC-3650-3650 is a voltage-controlled oscillator (VCO) designed to operate at 3650 MHz with a control voltage range of +0.5 to +4.5 VDC. It delivers +7 dBm typical output power at that frequency with typical phase noise of –108 dBc/Hz offset 10 kHz from the carrier. The VCO, which is suitable for use in digital radios and satellite-communications (satcom) systems, is supplied in an industry-standard 0.5 × 0.5 in. surface-mount package. Current consumption is typically 35 mA at a supply voltage of +8 VDC. Second-harmonic suppression is typically –15 dBc. Pulling and pushing are 1.0 MHz and 0.2 MHz/V, respectively.

CRYSTEK CORP., 12730 Commonwealth Dr., Fort Myers, FL 33913; (800) 237-3061, (238) 561-3311; fax: (239) 561-1025; *www.crystek.com*.

Transmitter Combiners Tackle 806 to 960 MHz

Ferrite power combiners have been designed as economical alternatives to cavity filter combiners for applications from 806 to 960 MHz. Models are available in two-, three-, and four-way configurations with power-handling capabilities per channel reaching 50 W. As an example, model 2TC-900A-20N is a two-way combiner with 20-W power-handling capability from 806 to 960 MHz and 3.9-dB typical insertion loss. It achieves at least 50-dB isolation between transmitters and at least 25-dB isolation between transmitter and antenna. When more robust power-handling capability is needed, model 2TC-900A-50N provides 50-W capability with very much the same electrical performance across that frequency range. All of the combiners are designed for operating temperatures from –20 to +60°C.

MICROWAVE FILTER CO., INC., 6743 Kinne St., East Syracuse, NY 13057; (800) 448-1666, (315) 438-4700, e-mail: mfcsales@microwavefilter.com; *www.microwavefilter.com*

Spectrum Analyzer Reads Signals to 85 GHz

THE R&S FSW85 high-performance signal/spectrum analyzer covers a wide frequency range from 2 Hz to 85 GHz in a single sweep. Suitable for studying continuous-wave (CW) and pulsed signals in a wide range of applications areas, from automotive radar to commercial communications systems, the signal/spectrum analyzer simplifies the measurement of high-frequency signals including

harmonic signals. It can be equipped with an optional internal analysis bandwidth as wide as 500 MHz for measurement flexibility when analyzing broadband signals in commercial and defense applications. The analyzer is equipped with a large touchscreen and simple control menu structure for ease of use and clarity in viewing results.

ROHDE & SCHWARZ USA, INC., 6821 Benjamin Franklin Dr., Columbia, MD 21046; (410) 910-7800; fax: (410) 910-7801; *www.rohde-schwarz.com*.

Limiters Handle High Power Levels to 6 GHz

A PAIR of robust RF/microwave limiters handle power levels of 100 W from 10 MHz to 4 GHz and 60 W from 10 MHz to 6 GHz. Model GG77317-04 is the lower-frequency limiter, with only 0.5 dB typical insertion loss from 10 MHz to 3 GHz, while model GG77317-04 has typical insertion loss of 0.7 dB and typical VSWR of 1.80:1 from 10 MHz to 5 GHz. The PIN-diode-based limiters, which are equipped with female SMA connectors, are designed to meet or exceed MIL-STD-883 environmental requirements. Both limiters can handle 1000 W peak (shorted pulsed) RF power with typical recovery times between 1.5 and 2.0 μs.

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

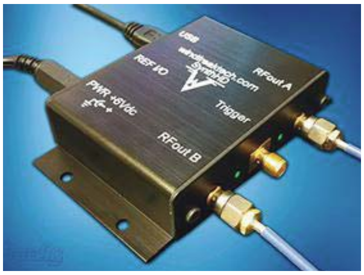
Pulsed GaN Transistors Power Circuits to 1 GHz

A LINE of high-voltage gallium-nitride-on-silicon-carbide (GaN-on-SiC) power transistors has been developed for applications below 1 GHz. Capable of operating on drain voltages of +75 V dc and higher, the pulsed power transistors can deliver better than 80% efficiency with stable gain of 27 dB and more at P-band frequencies from 420 to 450 MHz. The high-power devices are capable of output-power levels to 250 W or more in switched-mode circuits, making them ideal both for foliage- and ground-penetration terrestrial or space-based radar systems. The firm has worked with GaN devices capable of breakdown voltages exceeding +600 V dc, which enables devices operating to +150 V dc and more.

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

Dual-Channel Generator Tunes 54 MHz to 13.6 GHz

THE SYNTHHD low-cost, dual-channel signal generator can be controlled by means of a Windows- or Linux-compatible personal computer (PC) with a Universal Serial Bus (USB) connection. It also can be run as a standalone signal source. The signal generator tunes from 54 MHz to 13.6 GHz in steps as small as 0.1 Hz, and with a much as +22-dBm output power across the frequency range. It features tight control of phase and amplitude between the two channels—0.01 deg. and 0.01 dB, respectively—and the two channels can be configured to run at two different frequencies. The signal generator is based on a 32-b ARM processor and generous on-board nonvolatile memory for ease and reliability of programming. The signal source, which measures just 2.75 × 2.15 in. excluding mounting flanges, offers a dynamic range of –50 to +20 dBm and a wide range of modulation formats, including amplitude modulation (AM), frequency modulation (FM), and frequency modulation continuous wave (FMCW) pulsed chirps. It is well suited for antenna beam steering, radar testing, and communications systems testing.



SAELIG COMPANY, INC., 71 Perinton Pkwy., Fairport, NY 14450; 1-888-7SAELIG, (585) 385-1768; fax: (585) 385-1750; e-mail: info@saelig.com, *www.saelig.com*

Digital Phase Shifter Adjusts 2 to 18 GHz

MODEL NO. PS-255-2G18G-8B-SFF is an 8-b digital phase shifter capable of adjusting phase from 0 to 255 deg. across a frequency range from 2 to 18 GHz. Phase resolution is as fine as 1 deg. The phase shifter exhibits typical VSWR of 2.50:1 with typical insertion loss of 18 dB. It typically draws 200 mA current from a supply of +12 to +15 V dc. The phase shifter, which is supplied with SMA female connectors, is housed in a compact package measuring 2.0 × 2.1 × 0.5 in. It is designed for operating temperatures from –40 to +85°C.

PLANAR MONOLITHICS INDUSTRIES, INC., 7311-F Grove Rd., Frederick, MD 21704; (301) 662-5019; fax: (301) 662-1731; *www.pmi-rf.com*

Power Transistor Flies at 960 to 1215 MHz

MODEL TAN250A is a common-base high-power bipolar transistor capable of 250 W pulsed output power for avionics applications from 960 to 1215 MHz. The +50-V dc device offers 7-dB typical gain with 20-μs pulsed signals and achieves collector efficiency of typically 40%. It is rated for minimum collector-to-emitter breakdown voltage of +60 V dc. The rugged bipolar power transistor has a load mismatch tolerance equivalent to a 5.0:1 VSWR at 1090 MHz. It runs as a maximum operating temperature of +200°C and is supplied in a low-thermal-resistance package.

MICROSEMI CORP., 3000 Oakmead Village Dr., Santa Clara, CA 95051-0808; (408) 986-8031; (800) 713-4113; e-mail: RFMWMOD@microsemi.com, *www.microsemi.com*

Amplifier Module Includes Satcom Filter

DESIGNED FOR various satellite-communications (satcom) receiver applications, model SKY65709-81 is a front-end module (FEM) that combines a low-noise amplifier with filter circuits. In the GLONASS range (about 1592 to 1610 MHz), for example, the FEM achieves typical gain of 1.45 dB and typical noise figure of 1.9 dB. It runs on supply voltages from +1.8 to +3.6 VDC and is supplied in a six-pin multi-chip-module (MCM) package measuring 1.7 × 2.3 mm. The FEM is designed for BeiDou Satellite Navigation System/Global Positioning System/Global Navigation Satellite System (BDS/GPS/GNSS) receiver applications.

SKYWORKS SOLUTIONS INC., 20 Sylvan Rd., Woburn, MA 01801; (781) 376-3000; *www.skyworksinc.com*

EM Switches Channel DC to 33.5 GHz

ELECTROMECHANICAL (EM) switches in the ASPDT series offer long-life operation (better than one million switching operations) from dc to 33.5 GHz with low loss and high isolation. The EM switches, which are available in single-pole, double-throw (SPDT) through single-pole, 10-throw (SP10T) configurations, are also available in normally open, failsafe, and latching actuator architectures. All models can be specified with or without indicators and transistor-transistor-logic (TTL) drivers. The switches, which feature low passive intermodulation (PIM), exhibit typical insertion loss of 0.5 dB at 18 GHz with 60 dB or better isolation. Maximum VSWR is 1.50:1 through 18 GHz. Switching time ranges from 15 to 30 ms. The switches are designed for operating temperatures from –25 to +65°C. A range of transfer switches also is available.

ATLANTECRF, 40A Springwood Dr., Braintree, Essex CM7 2YN, England; +44 (0) 1376 550220; fax: +44 (0) 1376 552145, *www.atlantecrf.com*

Amplifier Chip Gains DC to 50 GHz

MODEL MAAM-011109-DIE is a broadband amplifier integrated circuit (IC) for applications from DC to 50 GHz. It is designed and manufactured by MACOM Technology Solutions and available from Richardson RFPD, Inc. It features typical small-signal gain of 15.5 dB from 2 kHz to 40 GHz and 12 dB at 50 GHz. The noise figure is typically 3.5 dB from DC to 40 GHz. The RoHS-compliant, broadband amplifier chip provides as much as +21 dBm output power at 1-dB compression across most of the frequency range and +15 dBm output power at 1-dB compression at 40 GHz. The amplifier draws 190 mA at +5 VDC with typical return loss of better than 15 dB. A gain trim control provides 15-dB gain control range with voltages from 0 to 1 V. The chip measures 1.97 × 1.30 × 0.1 mm.

RICHARDSON RFPD INC., 1950 S. Batavia Ave., Ste. 100, Geneva, IL. 60134; (630) 262-6837; *www.richardsonrfpd.com*

Adapters Simplify Scope Current Testing

A PAIR of test probes has been introduced to speed and simplify current measurements with commercial oscilloscopes. The model TPA10 TekProbe Probe Adapter adapts a variety of voltage and current probes from test equipment supplier Tektronix to test equipment from Teledyne LeCroy. The model CA10 Current Sensor Adapter is designed to adapt a number of commercial current-measurement devices to Teledyne LeCroy test equipment. Both adapters work with the Teledyne LeCroy ProBus probe interface, which is present on most of the firm's oscilloscopes. The TPA10 TekProbe Probe

Adapter supports single-ended active probes and high-voltage differential active probes from Tektronix.

TELEDYNE LECROY, 700 Chestnut Ridge Rd., Chestnut Ridge, NY 10977; (845) 578-6120; *www.teledynelecroy.com*

200 MS/sec Rugged Portable RF/IF Signal Recorder Slims Down

THE TALON RTR 2726A rugged portable recorder from Pentek implements a portable housing measuring weighing less than 30 lb. Enhanced capability permits up to eight recording and playback channels configurable with the right combination for a specific mission or application. At the heart of the recorder are Pentek Cobalt Series Virtex-6 software radio boards featuring A/D and D/A converters, DDCs, DUCs and complementary FPGA IP cores. The rugged workstation is reinforced with shock absorbing rubber corners and an impact-resistant protective glass for its high-resolution 17-in. LCD monitor. The hot-swappable SSD array is available in 1.9 to 15.3 TB configurations and supports RAID levels 0, 1, 5, or 6. The SSDs exhibit high immunity to shock and vibration for full operation in ground vehicles, ships and aircraft. Available I/O includes VGA video, six USB 2.0 ports, two USB 3.0 ports, and dual Gigabit Ethernet connections. The RTR 2726A has many uses for wideband signal recording and playback in signal intelligence and RF testing communities. Optional GPS time and position stamping is available.

PENTEK, 1026 Fourth Ave., Coraopolis, PA 15108; 888-873- *6835; www.pentekusa.com*

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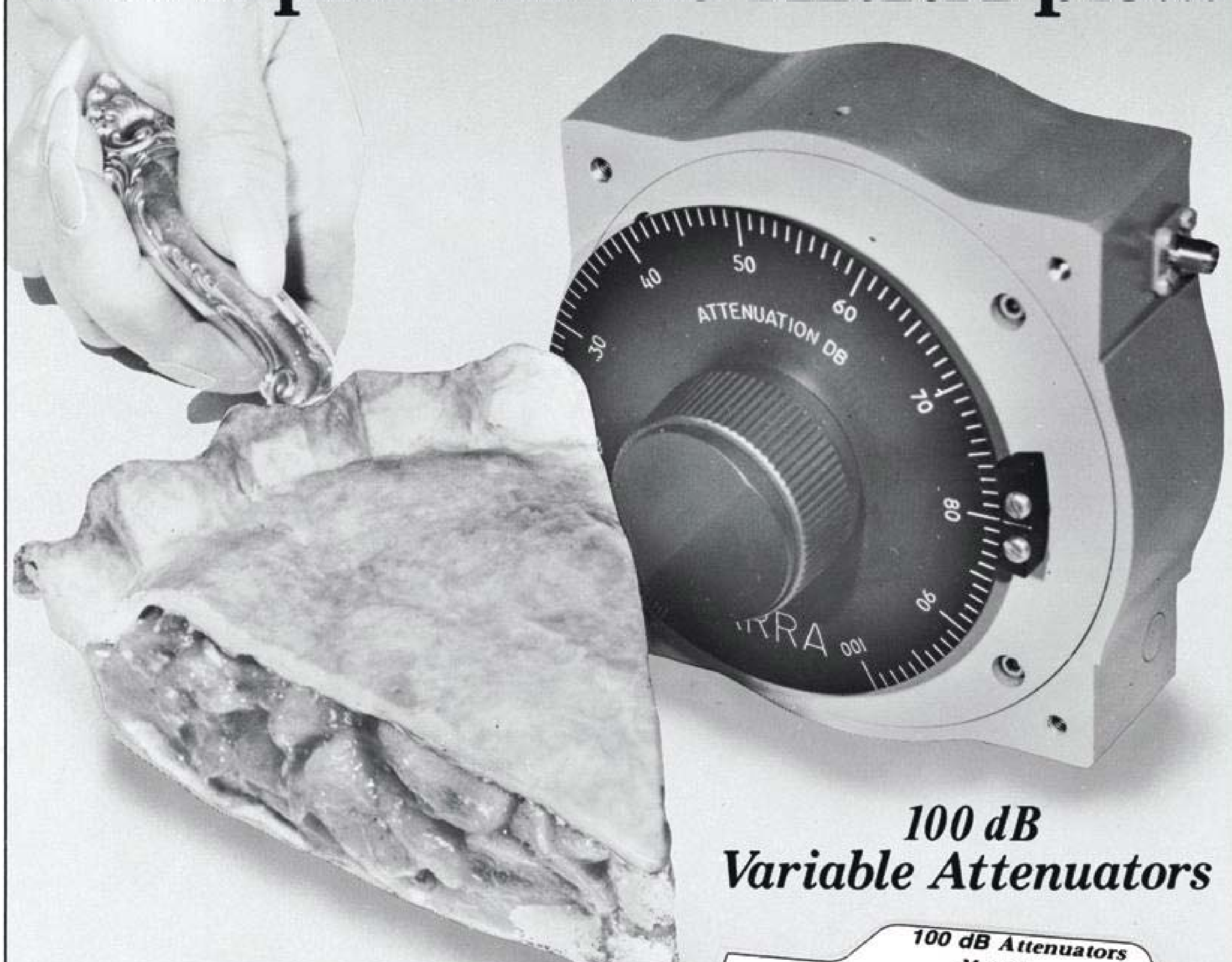

100 dB
Variable Attenuators

100 dB Attenuators
Mmmm....

Freq Range	Atten vs Freq dB	Model #
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1000 - 2000 MHz	1.5	3952 - 100X
2000 - 4000 MHz	1.5	4952 - 100 X
4000 - 8000 MHz	1.5	5952 - 100X

Insertion loss - 6 dB
VSWR - 1.5
Power - 15 cw
Temperature -30 to +120 C

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