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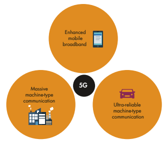

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Insertion Loss	2.8 dB Max. – Measured 2.54 dB
RF Input Power	20 Watts CW Max – Tested to 25 W CW
Switching Speed	100 ns Max – Measured 61.6 ns
Temperature	-55 ºC to +85 ºC Operating

Package Size: 1.20” x 1.00” x 0.50”
Connectors: SMA (F)
DC Voltage: +5 VDC @ 45 mA

Model: P2T-500M10G-60-R-515-SFF-10WCW

Frequency	0.5 to 10.0 GHz
Isolation	60 dB Min - Measured 88 dB
VSWR	2.0:1 Max - Measured 1.6:1
Insertion Loss	2.5 dB Max - Measured 1.15 dB
RF Input Power	10 Watts CW Max - Tested at 10 W CW
Switching Speed	100 ns Typ – Measured 86 ns
Temperature	-54 ºC to +85 ºC Operating

Package Size: 1.20” X 1.00” X 0.50”
Connectors: SMA (F)
DC Voltage: +5 VDC @ 43 mA
-15 VDC @ 38 mA

Model: P2T-500M18G-80-T-515-SFF-4W

Frequency	0.5 to 18.0 GHz
Isolation	70 dB Min - Measured 75.21 dB
VSWR	2.0:1 Max - Measured 1.86:1
Insertion Loss	3.5 dB Max - Measured 3.14 dB
RF Input Power	4 Watts CW Max - Tested at 4 W CW
Switching Speed	200 ns Max - Measured 60 ns
Temperature	-40 ºC to +85 ºC

Package Size: 1.00” X 1.00” X 0.50”
Connectors: SMA (F)
DC Voltage: +5 VDC @ 116 mA
-15 VDC @ 144 mA

Model: P2T-6G18G-40-R-570-TFF-1D6KW

Frequency	6.0 to 18.0 GHz
Isolation	40 dB Min - Measured 40 dB
VSWR	2.0:1 Max - Measured 1.99:1
Insertion Loss	2.2 dB Max - Measured 2.04 dB
RF Input Power	100 Watts CW / 1.6 KW Peak - Tested to 130 Watts CW
Switching Speed	200 ns Max - Measured 165 ns
Temperature	-40 ºC to +85 ºC

Package Size: 2.00” sq X 0.50”
Connectors: TNC (F)
DC Voltage: +5 VDC @ 265 mA
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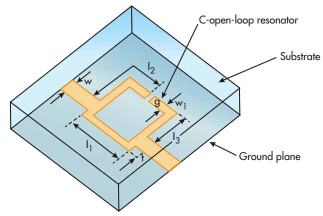

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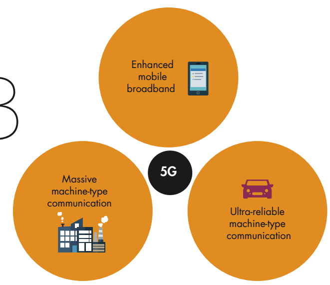

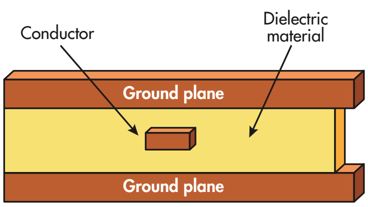

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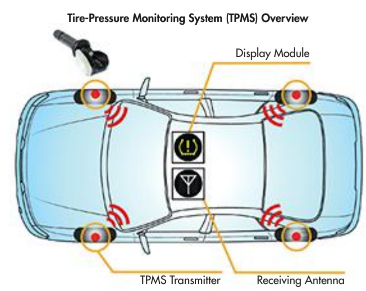

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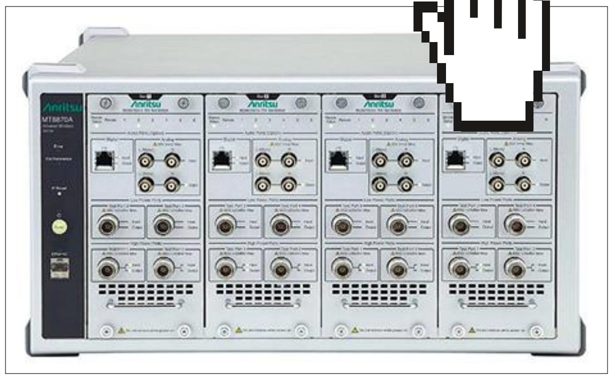


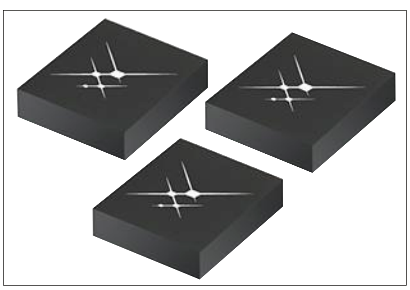
THE 2016 WIRELESS STANDARDS WALL CHART HAS ARRIVED

http://mwrf.com/wireless-standards-2016

New for this year, the Wireless Standards Wall Chart is now available to all *Microwaves & RF* readers. Featuring updated standards for cellular communication, GNSS, and wireless communication, the chart can be downloaded for free by clicking on the *Microwaves & RF* website.

AMPLIFIERS HEIGHTEN PERFORMANCE TO SATISTY THE NEXT WAVE

http://mwrf.com/active-components/amplifiers-heighten-performance-satisfy-next-wave



The pressing needs of today's applications are prompting amplifier suppliers to deliver new products to meet current high-frequency demands. One specific area that is now driving a significant amount of product development is small-cell infrastructure, which is a growing market. As many are turning to small cells to drive wireless networks, amplifier suppliers are launching new products in support of this need.

TEST SOLUTIONS CLEAR THE WAY TO CONSUMER-READY IoT DEVICES

http://mwrf.com/test-measurement/test-solutions-clear-way-consumer-ready-iot-devices

As the Internet of Things (IoT) continues to emerge, so do demands for efficient testing of the wave of products arriving into this arena. No question, the IoT encompasses a wide range of industries that utilize various wireless technologies. Needless to say, then, that IoT device testing requirements are also great in scope.

ACCURACY IS VITAL WHEN TESTING MATERIAL QUALIFIES

http://mwrf.com/materials/accuracy-vital-when-testing-material-qualities

Circuit materials, like those based on polymers and resins, serve as foundations for high-frequency circuits. They are characterized by various parameters that describe electrical and mechanical properties. Proven measurement methods are crucial for ensuring accurate results of material measurements, as well as for making valid comparisons of material parameters from different suppliers.

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Editorial

CHRIS DEMARTINO
Technical Editor
chris.demartinol@penton.com

NIWeek Has Something for Everyone

I recently had the opportunity to attend the 2016 edition of NIWeek, which occurred in Austin, Texas, from Aug. 1-4. It goes without saying that National Instruments (NI) goes the extra mile to make sure this event is noteworthy—and even fun—for those who attend. From the keynote presentations and technical sessions to the exhibition, everyone had the chance to learn something. A large number of industries were represented, demonstrating that NI's technology spans far and wide.

A full schedule of demos, keynote addresses, and tech sessions kept NIWeek attendees busy and engaged.

During the keynote presentations, a wide variety of topics was discussed. Of course, LabVIEW was one of the main points of interest. The latest version, LabVIEW 2016, was on display. LabVIEW 2016 has a new feature called channel wires, which are asynchronous wires that connect two parallel sections of code without forcing an execution order.

Charles Schroeder did the honors of highlighting the new second-generation vector signal transceiver (VST). The new VST, which achieves 1-GHz of instantaneous bandwidth, covers a frequency range of 9 kHz to 6.5 GHz. Furthermore, NI has developed a patented technology called "spectral stitching," which combines several synchronized VSTs to extend the bandwidth beyond 1 GHz.

No question, 5G was discussed throughout the entire event, allowing attendees to have the opportunity to learn about the latest developments. For example, massive multiple input, multiple output (MIMO)—which is a 5G candidate technology—was one of the topics explored during the keynote presentations. Later, I had a chance to sit down with James Kimery alongside my colleague Lou Frenzel from *Electronic Design*. One interesting point Kimery made during the conversation is that he believes 5G's modulation scheme may just simply be orthogonal frequency division multiplexing (OFDM).

It goes without saying that the Internet of Things (IoT) was also a prime topic. During a conversation, it was mentioned how there are too many wireless IoT technologies to count. Some believe that Narrowband-IoT (NB-IoT) may emerge as a winner.

In addition to the keynote presentations and technical sessions, the exhibition featured something for everyone. A large number of interesting demos were conducted that spanned many areas. If you could not attend NIWeek this year, I would encourage you to make the effort to attend next year. NI is actually making a change, as next year's event will take place in May. mw

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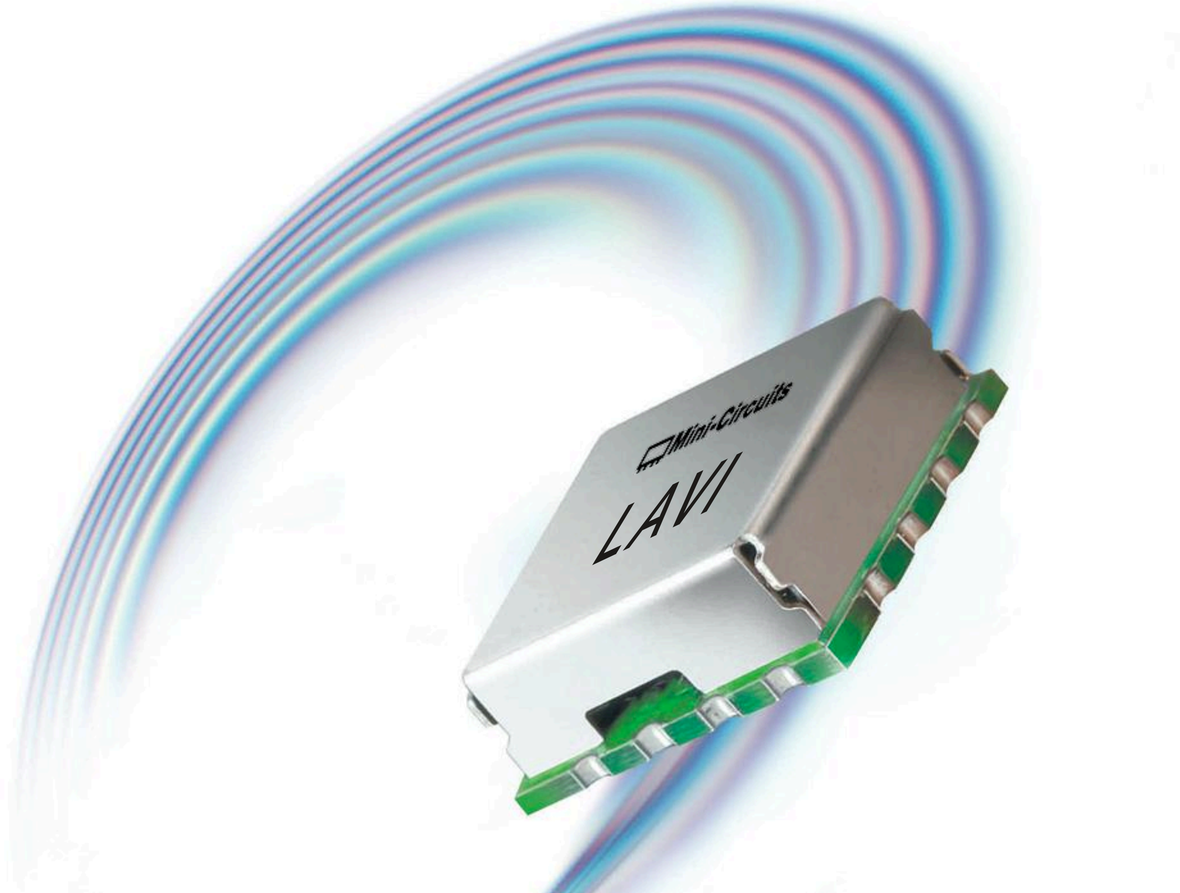
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STILL A NEED FOR TRADE SHOWS?

In reading your magazines and websites, I am somewhat bewildered by the amount of coverage devoted to trade shows such as the IEEE's International Microwave Symposium (IMS) in San Francisco earlier this year. I can understand the need for such events 20 to 25 years ago, when there was no internet and no such thing as e-mails or social media. But haven't such things as smartphones and texting and the ease of communicating by wireless means rendered electronic industry trade shows passé?

Why spend a week away from a business at a show where people walk around all day and "catch up on old times" when so much more effective communications could be conducted electronically? Aren't we in an electronics industry?

HARRY C. DOLAN

EDITOR'S NOTE

While Mr. Dolan makes some valid points, and some readers without the time or resources to travel to trade shows may agree with his opinions, trade shows such as the annual IEEE IMS are very important to this and many other industries. Every industry has its own set of trade shows. Even within the electronics industry, there are many different events devoted to different portions of it—for instance, battery power, military electronics, and even geographic markets, such as the European Microwave (EuMC) show.

At times, there may seem to be too many shows to keep up with. But each serves a purpose, and each provides an invaluable opportunity to meet present and future customers face to face. For present customers, it offers the reassurance of knowing that your company is there for them when they need you. For future customers, it is the chance to try to learn more about your company and product lines, and to do it by means of "the human touch"—e.g., through conversations and watching body language and reactions to certain questions that no electronic media can provide.

Finally, with their combinations of technical sessions and exhibition booths, trade shows provide an excellent educational arena packed into a few days. And the health of this industry's many trade shows is one sign that more than a few companies are willing to swear by the effectiveness of these events.

JACK BROWNE
TECHNICAL CONTRIBUTOR

News

CHINA LAUNCHES QUANTUM SATTELITE to Experiment with Hack-Proof Communications

The communications satellite that China launched from the Gobi Desert late last month is unlike any other system in orbit, eliciting more scrutiny from cybersecurity experts than the wireless engineers that usually design the communications payloads in satellites.

It is the world's first quantum satellite, equipped with transmitters that send messages by exploiting the mysterious laws of quantum theory. The method is vastly different from traditional communications, which send signals either with radio waves or visible light.

The satellite is called the Quantum Experiments at Space Scale, or Quess. After reaching an altitude of 310 miles, it will orbit earth every 90 minutes, according to a report by China's state news agency Xinhua.

The world's first quantum satellite was launched by China last month in the Gobi Desert.

The scientists behind the project will attempt to beam messages to the ground taking advantage of the "quantum entanglement" between photons, or particles of light. The aim is to connect two ground stations, according to the Xinhua report. If successful, the link would extend over 1,200 kilometers between Shanghai and Beijing.

Inside the quantum satellite is a crystal that produces pairs of entangled photons that remain inextricably linked even when one is transmitted over a long distance. According to an article about the Chinese satellite published in the journal *Nature* in July, messages can be sent by manipulating one of the photons, which will cause changes in the other particle.

The quantum technology is not expected to send signals faster than today's communications. One of the project's major concerns is "to boost the rate of data transmission using single photons from megabits to gigabits per second," according to the *Nature* article.

But if the technology works, the transmission would be extremely secure, impervious to hacking or wiretapping. Any interference with transmission would be detectable, the Nature article said, allowing people to communicate "safe in the knowledge that any eavesdropping would leave its mark."

Quantum scientists have already tested the new communications over the air and inside fiber optic cables. But the photons are usually bounced, absorbed, or interfered with in the process, limiting the technology's range. In trials, scientists have only been able to transmit data over 300 km, and the idea is that space will present fewer obstacles to quantum communication. ■

SKYWORKS BUYS OUT Panasonic's Filter Division

SKYWORKS SOLUTIONS, one of the largest makers of wireless analog chips, has taken outright control of Panasonic's filter division, giving it more firepower to handle the growing number of frequency bands used to connect smartphones and other devices.

In August, the company said that it was buying Panasonic's remaining interest in the filter business, which the companies formed into a joint venture more than two years ago. In 2014, Skyworks paid $148.5 million for two-thirds ownership of the business.

The arrangement gave Skyworks access to Panasonic's entire filter division, from the manufacturing equipment to more than 400 filter patents and applications. The business and its 590 workers developed a wide range of high-performance filters, including surface acoustic wave (SAW) and temperature-compensated SAW (TC-SAW) devices. The joint venture was headquartered in Osaka, Japan.

Now Skyworks is paying another $76.5 million for the remaining third of the venture.

In smartphones and other mobile devices, filters are responsible for tuning into specific frequency bands and blocking interference from other signals. With enough filters, devices can simultaneously communicate over Wi-Fi, Bluetooth, and cellular bands used in 3G and 4G networks. As wireless technology breaks into higher frequency spectrum, the number of filters inside smartphones is steadily rising.

"Given the proliferation of frequency bands, the addition of LTE capabilities and market demand for always-on connectivity, the need for filters has never been higher," said Liam K. Griffin, president and chief executive officer of Skyworks, in a statement.

Smartphone makers like Apple and Samsung are packing filters into devices as quickly as new frequency bands are opened. They are also gravitating toward higher-performance filters, including bulk acoustic wave (BAW) and TC-SAW devices, which better shut out interference. Multiple chipmakers are placing an emphasis on filters with low insertion loss and distortion that can be produced in large quantities.

Skyworks is betting that Panasonic's business will help it compete with large companies like Qualcomm and Qorvo, which are investing in the filter market, and smaller ones like Resonant, which are testing out potentially game-changing filters that can switch between multiple frequency bands.

Last year, Skyworks completed a 405,000-square-foot facility in Osaka to increase the joint venture's filter output. The business has produced more than two billion filters total, according to Skyworks estimates.

RAYTHEON TAKES CONTRACT for Scalable Aircraft Carrier Radars

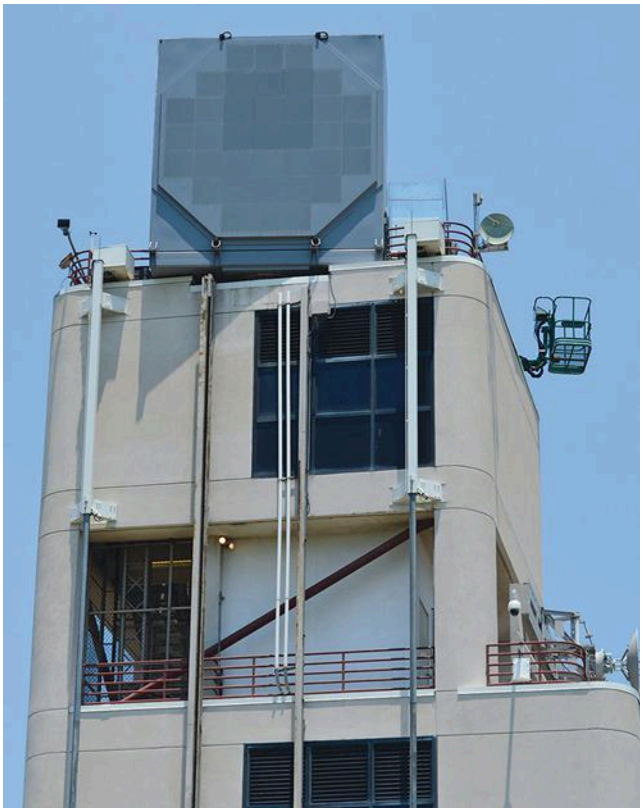
AT $92 MILLION, the contract that Raytheon signed in late August to build new aircraft carrier radars is just another drop in Raytheon's bucket of $23 billion in annual revenue.

But it stands out as the latest vote of confidence for inexpensive radars that can be linked together in bunches and customized for different ships. The new radar will replace several older radar systems that were designed to work alone.

Under the United States Navy contract, Raytheon will build the so-called Enterprise Air and Surveillance Radar, which will be used for sensing airplanes, missiles, and other ships from the deck of carriers. According to the Massachusetts-based company, the radars will detect objects at longer distances and better avoid surrounding clutter, like birds.

The Navy is planning to install the radar on Ford-class aircraft carriers, a new series of extremely large ships that are known as "supercarriers." In addition, older ships will be backfitted with the new radars.

The retrofitting will be simpler than installing standalone radars, thanks to the scalable nature of Raytheon's design. The defense contractor is building the system around its Air and Missile Defense



Raytheon's Air and Missile Defense Radar is comprised of individual modules, which can be stacked to control aperture size. *(Image courtesy of Raytheon)*

Radar, or AMDR, arrays. Each one is comprised of individual building blocks called radar modular assemblies, which can be stacked to control aperture size.

Raytheon's design is another example of the modular radar systems that other defense companies are testing out. Competing for the same contract, Northrop Grumman has also built a scalable radar system, following blueprints it had drawn for ground and fighter jet radars. Lockheed Martin's DART radar is also modular and can be plugged into older systems to help lower power consumption and increase reliability.

The EASR system will not be first to employ Raytheon's scalable radars. The company used the technology in its SPY-6(V) radar, which will be installed on the DDG 51 Flight III destroyer in 2019. That version will contain 37 radar modules spread over four arrays, making it sensitive enough to detect an object half the size at twice the distance of the destroyer's current radar, Raytheon said.

It is advanced in other ways. The radar uses gallium-nitride components, which have higher power density and efficiency than ones based on gallium arsenide, for transmitting and receiving radio waves. It also employs digital beamforming and data processing to steer signals through cluttered environments.

Raytheon first started working on the EASR contract in 2013 with a roughly \$386 million contract. The system will replace the rotating SPS-48 and SPS-49 radars on older ships, as well as expensive Dual-Band Radars that Raytheon also developed.

The Dual-Band Radar can function over two frequency bands (S-band and X-band) simultaneously. It is an active electronically-steered array that Raytheon built to track targets in a wide range of altitudes and weather conditions. According to military news site Defense News, the Navy has scaled back its plans for the dual-band system because it is too expensive.

NEW GEOSTATIONARY Weather Satellites Prepare for Launch

A NEW WEATHER satellite designed to monitor hurricanes and other severe weather more accurately than earlier technology is being prepped for launch at a testing facility in Florida.

The satellite is the first hatchling in the Geostationary Operational Environmental Satellite R Series, or GOES-R, program. The satellite will carry equipment for tracking severe weather and helping to improve warning times for things like tornados and storms. It will also use specialized instruments to measure solar activity on the sun

(continued on page 24)

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* Heat sink must be provided to limit base plate temperature. To order with heat sink, remove "X" from model number and add $50 to price.

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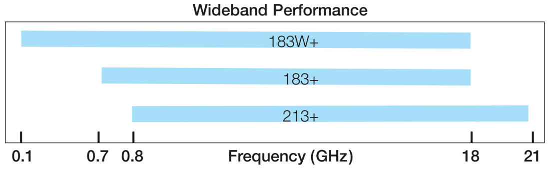

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The Geostationary Operational Environmental Satellite R Series will carry equipment for tracking severe weather and helping to improve warning times for tornados and storms. *(Image courtesy of NASA)*

Weather Satellites

(continued from page 22)

and the concentration of particles and magnetism in the space around earth.

The satellites were designed by Lockheed Martin, which shipped the first model to its Astrotech Space Operations facility in Titusville, Fla., in late August. There, the company will run through the final tests before launch, which is scheduled for early November at the Cape Canaveral Air Force Station.

A United Launch Alliance Atlas V rocket will take the satellite into geosynchronous orbit. Once it starts running, the National Oceanic and Atmospheric Administration will collect data from the sensors and put them into weather models. The aim is to sooner predict storms and other severe weather before it happens.

The satellite's Advanced Baseline Imager handles the lion's share of data collection. It is a radiometer—a device for measuring the power of electromagnetic radiation—which probes Earth's atmosphere using 16 different frequency channels. That represents more than three times the number of spectrum bands used by the current generation of GOES satellites.

The GOES-R satellites will also have four times the spatial resolution and more than five times faster temporal coverage than the current system, according to NASA, which oversees the project with NOAA officials. These capabilities will be useful for monitoring things like cloud formation, ocean currents, volcanic eruptions, air quality, and plant health on Earth's surface.

The new satellites are part of recent efforts to improve weather forecasting satellites. The NOAA is also updating its Joint Polar Satellite System, a satellite array that gathers atmospheric data with microwave scanners. Last year, NASA began testing a series of eight microsatellites that redirect GPS signals to track the evolution of hurricanes.

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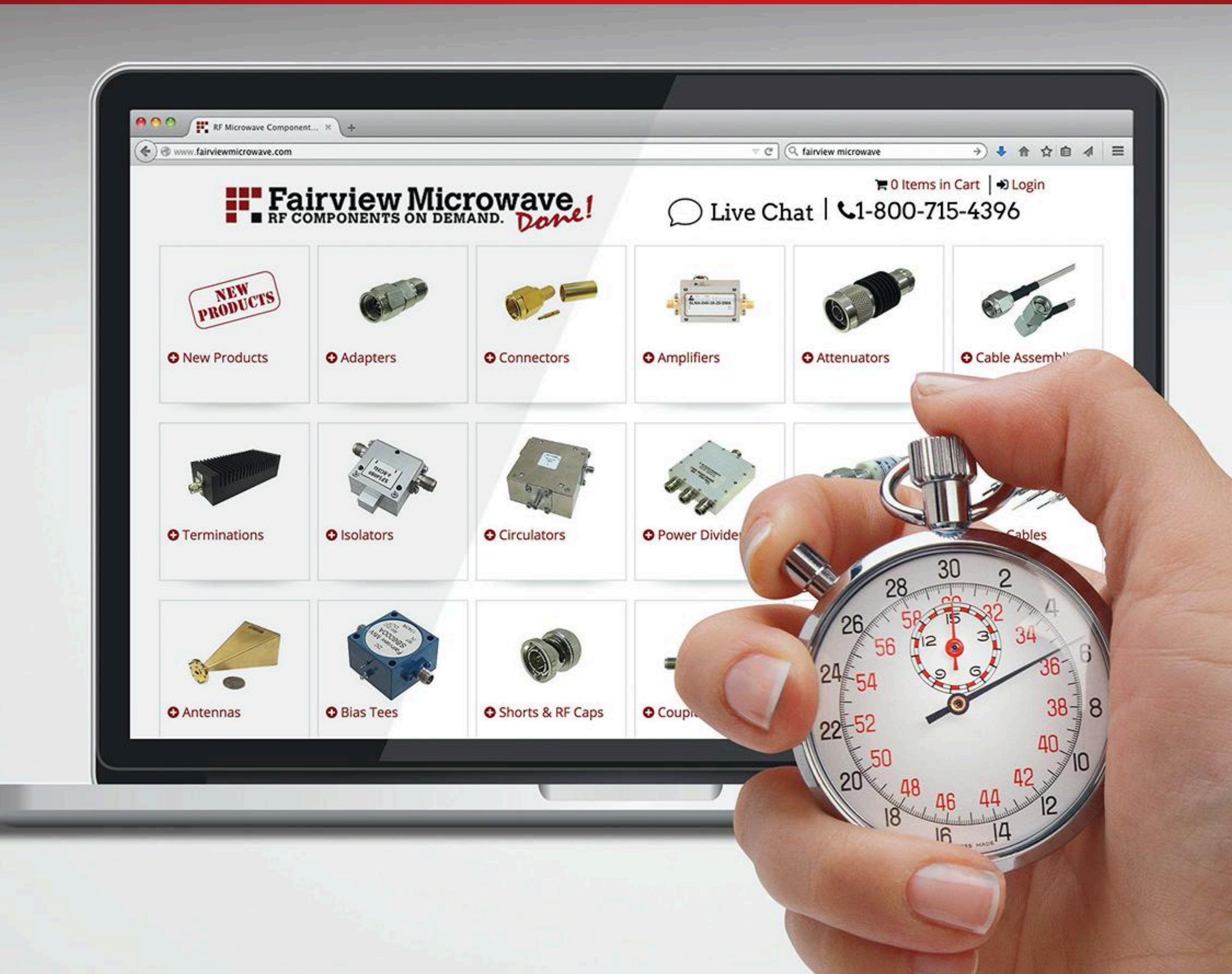

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METAMATERIALS SHOW PROMISE FOR RF CIRCUITS

ARTIFICIALLY CREATED COMPOSITE materials, also known as metamaterials, promise behavior beyond what is normally found in nature, such as dielectric materials with negative permeability and permittivity. In search of potential circuit applications for metamaterials, researchers from Australia's Queensland University of Technology and Malaysia's Universiti Kebangsaan Malaysia investigated the use of microstrip transmission lines and dual-star, split-ring resonators (DSSRRs) fabricated on metamaterials to achieve circuit sizes much smaller than normally dictated by quarter- and half-wavelength structures. They explored left-handed (LH) and right-handed (RH) metamaterial media to better understand some potential capabilities of metamaterials for RF and microwave circuits.

The researchers designed a DSSRR with metallic rings on top of a metamaterial substrate. Two opposite rings were formed, with a small gap to obtain a negative resonance. The bandwidth of the resonator can be enhanced by gap tuning. A DSSRR is fabricated in microstrip technology by etching the rings just below the surface of the substrate. The performance of this periodic unit-cell resonator was measured by vector network analysis and S-parameters. The first resonance was detected at 8.9 GHz, and the second—at about 16 dB less in amplitude—at 10 GHz. The same period unit-cell DSSRR was fabricated on commercial circuit material with dielectric constant of 10.2, RT6010 laminate from Rogers Corp. (www.rogerscorp.com), so as to verify the basic performance of the resonator.

The experimenters closely matched their numerical predictions with measured results as part of a study to better understand the properties of composite right-handed/left-handed (CRLH) metamaterials as microwave substrates. It confirmed a great deal of metamaterial theory as applied to RF/microwave circuits.

See "Making Meta Better," *IEEE Microwave Magazine*, Vol. 17, No. 8, August 2016, p. 52.

DIGITAL TECHNIQUES ENHANCE DOHERTY AMPLIFIER EFFICIENCY

DOHERTY AMPLIFIERS ARE widely employed in cellular base stations and other wireless communications systems. Typically, they consist of two parallel amplifiers—one biased for Class AB operation (the carrier amplifier) and the other for Class C bias operation (the peaking amplifier)—along with power splitters and combiners to divide input signals, and then recombine them at the outputs of the two amplifiers.

Though simple in design, these amplifiers suffer from inefficiency due to the different bias schemes for the two amplifier sections. Digital methods have been applied to improve the efficiency, including synthesizing a digitally controlled signal-distribution profile that adaptively distributes the input power between the two amplifiers for less wasted power. Other approaches have involved the use of dual input ports to attempt to drive the two amplifiers closer to saturation and at higher gain levels.

A concern with all efficiency-enhancement methods applied to Doherty power amplifiers is the compromise in linearity due to phase offsets in the signal paths. But as reported by a trio of Canadian authors from the University of Calgary, linearity can be improved while also enhancing efficiency by using some straightforward techniques, including carefully choosing the electrical length of the series transmission lines at the inputs of the two amplifier sections. The phase mismatches in these input transmission lines can result both in nonlinear performance and loss of power and efficiency.

To overcome these performance limitations, the authors developed a demonstrator prototype amplifier that uses a power-indexed lookup table for dynamic phase alignment between the carrier and the peaking amplifiers in a Doherty amplifier. The open-loop approach is executed by applying digital predistortion (DPD) at the input of the peaking amplifier signal path. With DPD, the amplitude-modulation/phase-modulation (AM/PM) response of the peaking amplifier becomes relatively constant. Therefore, any residual phase differences between the two transmission-line paths can be corrected by adding a constant phase shift at the input of the phase-lagging signal path.

The researchers reviewed various Doherty amplifier efficiency-enhancement approaches and found that the adaptive power-distribution approach was suitable for improving efficiency for both narrowband and wideband signal applications. They concluded that with improved and affordable digital-signal-processing (DSP) components, the use of digital techniques can improve output power by as much as 2 dB, and efficiency up to 20%.

See "Doherty Goes Digital," *IEEE Microwave Magazine,* Vol. 17, No. 8, August 2016, p. 41.

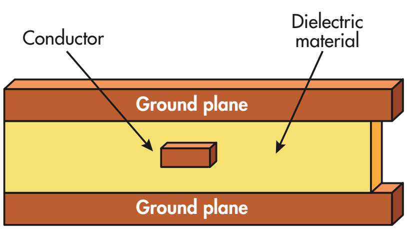
JACK BROWNE | Technical Contributor

What's the Difference Between MICROSTRIP AND STRIPLINE?

The two most popular RF/microwave transmission-line formats—microstrip and stripline—have distinguishing characteristics that designers need to know.

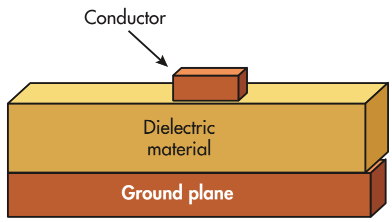
Circuit designers choose transmission-line technologies based on a number of factors, including expected high-frequency performance and ease of implementation. Although transmission-line choices include some more exotic varieties, such as coplanar-waveguide (CPW) technology, the decision often boils down to either microstrip or stripline. Recognizing the differences between the two technologies can help nail down the best option.

The two high-frequency transmission-line technologies date back to the early 1950s. Stripline was first developed by Robert Barrett of the Air Force Cambridge Research Center in the '50s as a circuit-based transmission-line alternative for waveguide and coaxial cables. It is essentially a center conductor surrounded by dielectric material with top and bottom metal ground planes (*Fig. 1*). Stripline is often described as a coaxial cable that was run over by a truck, with its outer ground planes, inner conductor, and isolating dielectric material between the three metal layers.



1. Stripline incorporates top and bottom ground planes with dielectric insulator material surrounding a center conductor in a balanced configuration.

Microstrip is a somewhat simpler structure, with a single ground plane, a conductive trace, and a dielectric layer separating the signal conductor and ground plane (*Fig. 2*). Stripline conductors are well isolated by the surrounding dielectric material. As a result, they do not radiate and are described as being nondispersive. Because of this, transmission lines in stripline circuits can be closely spaced and densely packed, lending themselves to miniaturization at microwave frequencies. However, with the additional layers, they are more difficult to assemble and manufacture than microstrip circuits with their top-layer conductors.



2. Microstrip is a relatively simple circuit configuration with top conductor, dielectric layer, and bottom ground plane. It is easy to manufacture and place components.

MANUFACTURING METHODOLOGY

Typical approaches to manufacturing microstrip circuits start with a commercial circuit laminate with metallized top and bottom layers using a highly conductive metal, such as copper. The top layer is etched to remove unwanted metal, leaving the traces that form the microstrip circuitry and transmission lines. The bottom metal layer remains as a ground plane.

For stripline circuits, a circuit laminate, prepared in the manner of a microstrip circuit, is usually combined with a prepreg material that has similar dielectric constant (Dk) value—one side is bare dielectric and the other is metallized. Since multilayer circuits may contain many different circuit functions, including RF/microwave and power supply and distribution, multilayer stripline circuits may involve dielectric layers with different materials, selected for the best combination of price and performance for the various functions.

For both microstrip and stripline transmission lines, dimensional tolerances must be tightly controlled. Many high-frequency circuits have to be maintained at 50 Ω, which requires control of a number of factors—including the width and thickness of the conductor, the thickness of the dielectric material, and the Dk value of the dielectric material.

The conductor's spacing from the two ground planes in stripline is not as critical for maintaining impedance as the

> Typical approaches to manufacturing microstrip circuits start with a commercial circuit laminate with metallized top and bottom layers using a highly conductive metal, such as copper. ”

spacing of the conductor from the single ground plane in a microstrip circuit. With two ground planes, the width of a conductor for a given impedance in stripline will be narrower than the width of a microstrip conductor for the same impedance. Stripline's thinner conductors require tighter manufacturing tolerances than microstrip conductors, as well as tighter tolerances in a circuit material's Dk values.

Because of the second ground plane, the width of a 50-Ω (or any given impedance) line in stripline will be narrower than for a conductor with the same impedance in microstrip. While the inherently thinner lines support greater circuit densities, they also require tighter fabrication tolerances, as well as substrate materials with extremely consistent dielectric constant across a board. For a single-ended (unbalanced) transmission line in microstrip, dielectric losses (defined by a substrate's dissipation factor) will be less than for stripline, since some of the field lines in microstrip are in air where the dissipation factor is negligible.

The tradeoff for the simplicity of microstrip is its dispersive nature: It tends to radiate wherever there is an impedance transition or discontinuity. Whereas stripline is considered to exhibit fully transverse-electromagnetic (TEM) propagation, microstrip transfers energy by not quite TEM modes. Rather, it uses quasi-TEM modes of propagation in which dispersion occurs as functions of frequency and transmission-line length, compared to the dispersion-free and frequency-independent TEM propagation of stripline transmission lines.

Microstrip also tends to radiate more with increased spacing between transmission lines and ground plane. As a result, microstrip has long been a favored transmission-line format for radiating structures, such as miniature microstrip patch antennas.

DIELECTRIC DIFFERENCES

Designers must be aware of one key difference in the electrical behavior of the two transmission lines—the Dk value. Since the conductors in stripline are completely surrounded by dielectric material, when modeling stripline transmission lines, the Dk of the circuit material is the numerical value that can be applied to a model. In some stripline designs, such as multilayer circuits, several types of dielectric materials may be used in a circuit assembly. Thus, the Dk value for a given stripline conductor will be a combination of the Dk values for the insulating materials above and below the conductor.

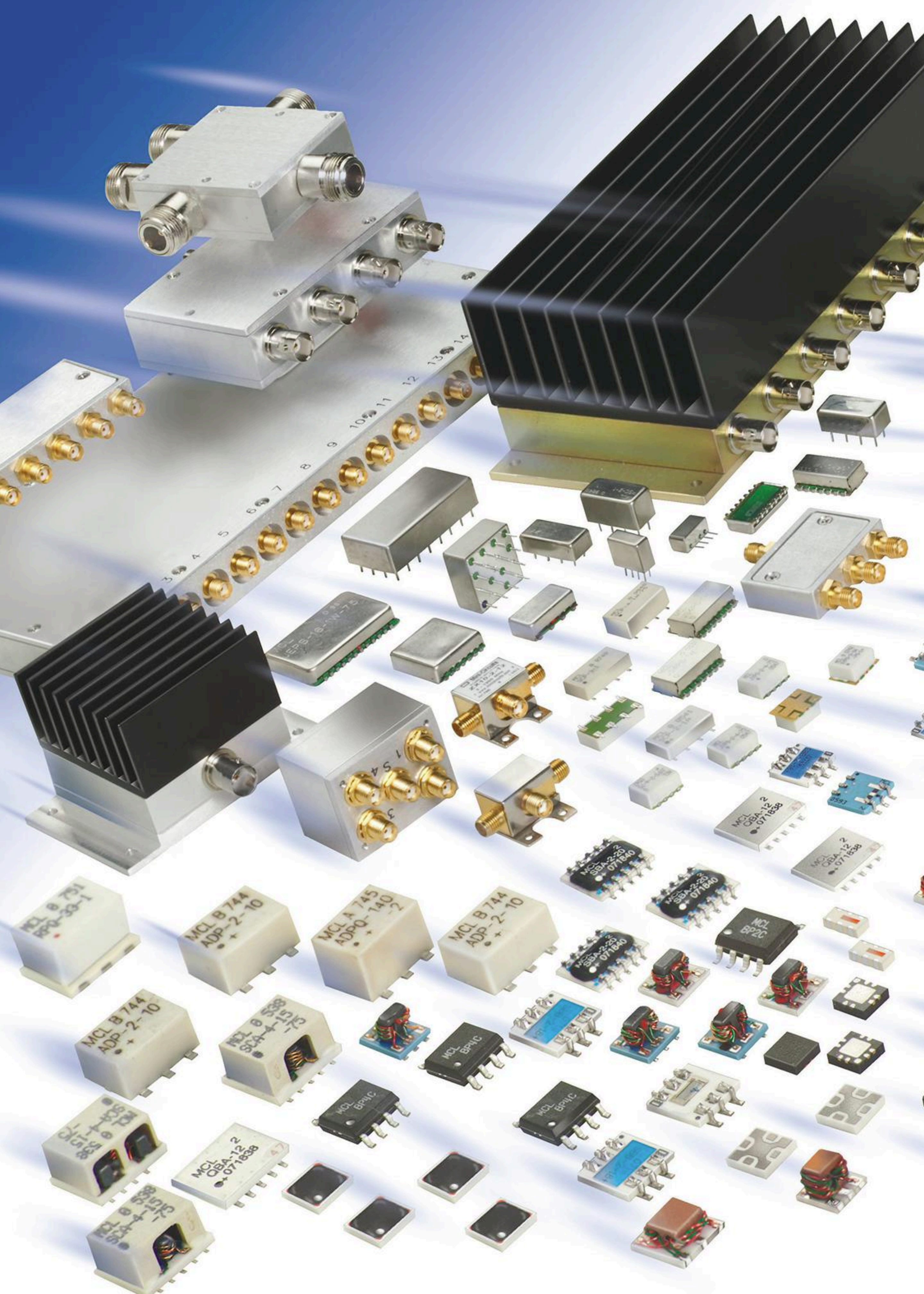
For microstrip transmission lines, the electromagnetic (EM) waves propagate through the conductors and circuit material, as well as through the air above and around the microstrip circuitry. In turn, the low Dk value of air (approximately unity or 1) impacts the effective dielectric constant that influences a microstrip circuit's modes or propagation.

Consequently, many suppliers of RF/microwave circuit-board materials provide "design Dk" values for their materials, so that designers have a more accurate value of Dk to use for microstrip circuit designs. Since microstrip propagation occurs partially in (lossless) air, dielectric losses in microstrip will be less than those in stripline circuits, although commercial circuit materials are available with almost negligible dielectric losses.

With its embedded conductors, stripline is well-suited for multilayer circuits since signals can be easily routed between layers via plated through holes (PTHs). Designing and assembling multilayer stripline assemblies requires some care, however, since uneven spacing between the top and bottom ground planes in any part of the stripline assembly can lead to unwanted propagation modes, such as a parallel-plate mode. Such a mode enables propagation not just near the signal conductor, but in any areas where the two ground planes can support propagation, creating unwanted signal coupling and interference in densely packed circuits.

Both microstrip and stripline are "well-worn" RF/microwave transmission-line technologies, having been in use for more than 60 years. As manufacturing capabilities have improved with time, so too have the formulations of circuit laminates and prepreg materials, allowing circuits with both transmission-line technologies to be designed and fabricated with high performance through millimeter-wave frequencies.

In fact, some circuit material suppliers, such as Rogers Corp. (*www.rogerscorp.com*), offer excellent educational tools. Rogers' "ROG Blog" includes comparisons of different microwave transmission lines, including microstrip and stripline. On top of that, modern computer-aided-engineering (CAE) software programs have made it possible to achieve the performance benefits of stripline and the design and manufacturing simplicities of microstrip with first-pass success. mw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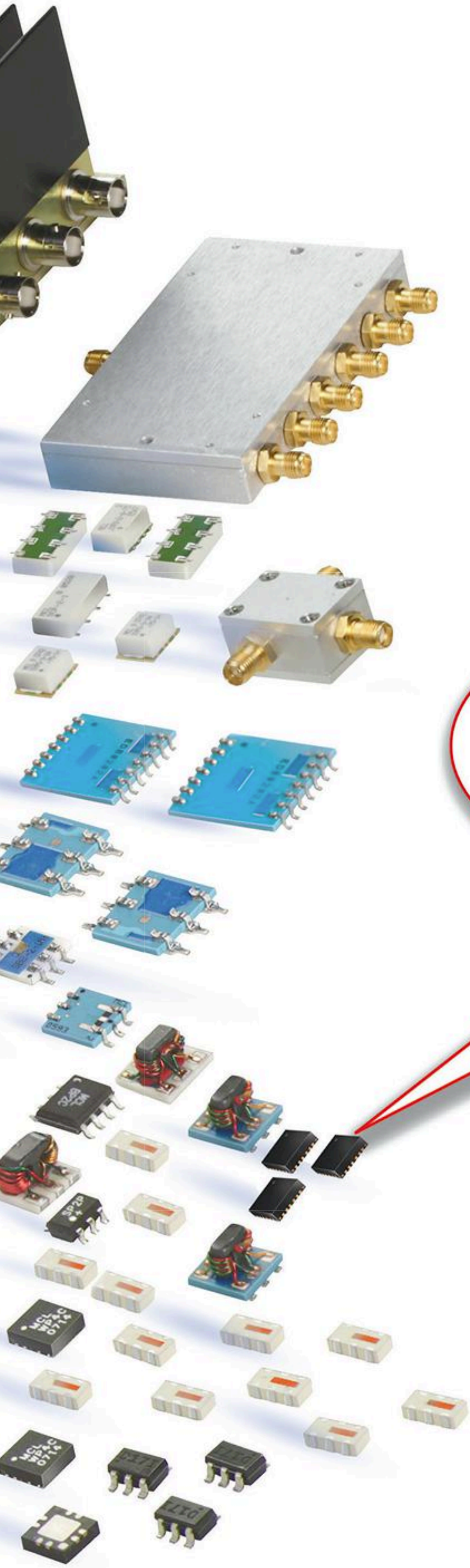


CHRIS DEMARTINO | Technology Editor

GaN, Open Systems, Low-SWaP Platforms Transform the Military Sector

To meet the needs of today's military, the RF/microwave industry is coming up with flexible, cost-effective solutions that push the technology envelope.

TO SUPPORT CURRENT aerospace and defense systems, technology has moved beyond traditional constructs and iterations to completely new approaches and solutions. The RF/microwave industry faces the task of providing ever-advancing electronic-warfare (EW) solutions while meeting size, weight, and power (SWaP) constraints. A further example of this advanced technology revolves around next-generation radar systems—a number of them are being powered by active electronically scanned arrays (AESAs) based on gallium nitride (GaN), providing capabilities not possible with older systems.

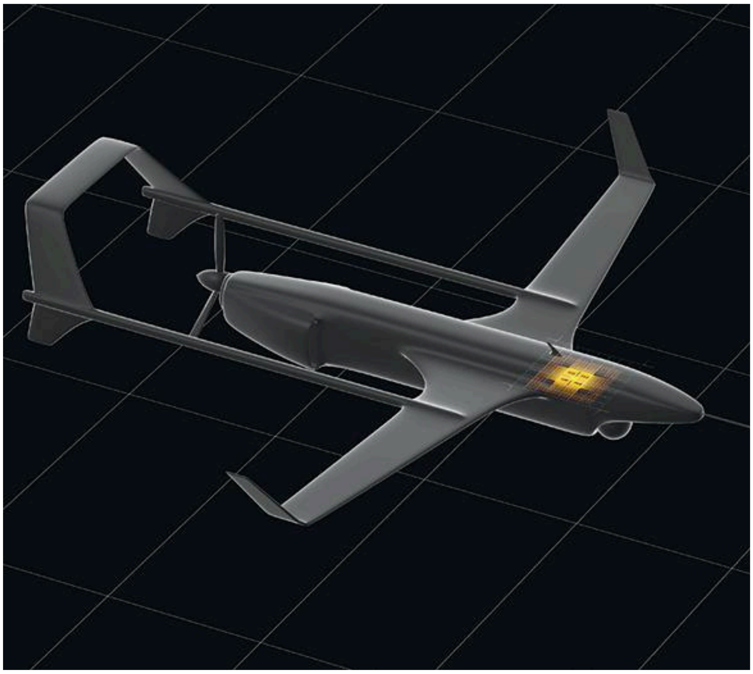
Another critical component within today's defense sector is the introduction of an open-systems architecture for RF/microwave assemblies. Open systems, which bring a standards-based approach to the RF/microwave industry, represent a significant change when compared with traditional approaches to building assemblies. Taking all of this into consideration, it is important to understand the roles these latest developments play in present-day military technology.

AN OVERALL PERSPECTIVE

At BAE Systems *(www.baesystems.com)*, for example, a focus on RF microelectronics research and development is enabling receivers and transmitters with lower SWaP for military systems *(Fig. 1)*. According to Scott Sweetland, director of advanced microwave products at the company, "Today's war-fighters are facing airspace crowded with signals from commercial and military sources—and enemy threats are evolving. We must be able to identify these threats and respond with effective jamming responses on the fly."

Sweetland adds, "Hardware needs to evolve. Custom radio application-specific integrated circuits (ASICs) can't be easily reconfigured once they're in the field. The next step is developing new general-purpose solutions that limit obsolescence and can be updated with software, as well as helping get working prototypes into the field faster."

Technological advances made by BAE Systems can be seen in its AN/ASQ-239 EW suite, which provides advanced EW capabilities to the F-35 Lightning II fighter jet. The AN/ASQ-239 system is equipped with offensive and defensive EW options for the pilot and aircraft. It provides fully integrated radar warning, targeting support, and self-protection to detect and overcome both surface and airborne threats.



1. Today's EW system designers need to consider the SWaP constraints of smaller-form-factor platforms. *(Courtesy of BAE Systems)*

2. This PA delivers 10 W of output power across a frequency range of 225 MHz to 2.6 GHz. *(Courtesy of NuWAves Engineering)*

EEW's scope is not limited to only fighter jets. "EW isn't just the domain of advanced fighter aircraft," Sweetland explains. "Increasingly, there's a need for man-portable radios and radios for unmanned aerial systems (UASs), which have SWaP constraints. These are all things that RF developers need to keep in mind as they create communications, EW, and signal-intelligence (SIGINT) systems for the future."

UNMANNED AERIAL SYSTEMS

RF communication systems do play a vital role when it comes to UASs, enabling communication between an aircraft and its operators. As Sweetland also notes, SWaP constraints pose a challenge in this arena.

One company in the RF/microwave space that supports the UAS market is NuWaves Engineering *(www.nuwaves.com)*. Recently, the firm introduced the NuPower 11B02A and 12A03A power amplifiers (PAs), which are well-suited for UASs *(Fig. 2)*. Both PAs, leveraging GaN technology, have been designed with SWaP constraints in mind, as the NuPower 11B02A and 12A03A boast form factors of 1.95 and 1.3 in.3, respectively. The company says the NuPower 12A03A's small size allows for its integration into some of the smallest UASs flying today. In addition, it consumes only 0.85 A of current with a +28-V dc supply voltage, further demonstrating its applicability to SWaP-constrained systems.

AESA SYSTEMS BASED ON GaN

No doubt, GaN technology is having a dramatic impact on the military sector. GaN monolithic microwave integrated circuits (MMICs) are being used to build AESAs, opening up numerous advantages that simply are not possible with systems based on older technology. "AESAs that are built with GaN MMIC technology are at the core of next-generation radar systems," says Scott Behan, senior product marketing manager at Qorvo *(www.qorvo.com)*. "AESAs offer a host of advantages over other legacy implementations, including jam resistance, frequency agility, and superior radiating and receiving functionality. They also offer the potential for multi-function operation, including jamming, electronic-countermeasures (ECM), and communications."

He continues, "GaN MMICs facilitate these functions, offering significant performance enhancement when compared with both historical mechanically scanned radar systems based on vacuum electronic devices (VEDs) and relatively recent solid-state systems using gallium-arsenide (GaAs) MMIC technology. The advantages are numerous, and together help improve the performance, reliability, and availability of AESA systems."

Higher-temperature performance is one of the advantages achieved with GaN MMICs. "GaN MMICs enable significantly increased power output at higher temperatures," adds Behan. "This achievement is due in part to their enhanced thermal-transfer characteristics and their capability to operate at elevated junction temperatures above 200°C."

AESA systems based on GaN technology can also operate longer than previous-generation systems. "Because GaN MMICs also operate at a significantly lower voltage than historical VED-based systems, they allow use of simpler and more reliable low-voltage system power supplies," Behan explains. "In addition, GaN MMIC mean time between failures (MTBF) exceeds 10 million hours at junction temperatures above 200°C. These factors enable GaN-based AESA systems to operate reliably for seven-plus years longer than traditional technologies. GaN MMICs do not require periodic maintenance and checkout, and are not subject to degradation due to storage or disuse. They are ready 'whenever, wherever,' and can exist indefinitely in an unpowered state and power up instantly when needed."

Lastly, GaN technology facilitates the ever-present goal to reduce both size and cost. "Perhaps the most important features of GaN-based AESAs are reduced size and weight along with cost-savings," notes Behan. "Above all, this is what makes GaN technology so central to the ongoing development of advanced radar systems to connect and protect. More compact, cost-effective systems enable platforms to be

3. A new ingredient in the RF/microwave industry's technology mix is an open-systems architecture.
(Courtesy of Mercury Systems)

photo courtesy of the
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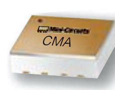

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New	CMA-82+	DC-7	15	20	42	6.8	5	6.45
New	CMA-84+	DC-7	24	21	38	5.5	5	6.45
	CMA-62+	0.01-6	15	19	33	5	5	4.95
	CMA-63+	0.01-6	20	18	32	4	5	4.95
	CMA-545+	0.05-6	15	20	37	1	3	4.95
	CMA-5043+	0.05-4	18	20	33	0.8	5	4.95
	CMA-545G1+	0.4-2.2	32	23	36	0.9	5	5.45
	CMA-162LN+	0.7-1.6	23	19	30	0.5	4	4.95
	CMA-252LN+	1.5-2.5	17	18	30	1	4	4.95

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OPEN-SYSTEMS ARCHITECTURE

GaN is certainly not the only technology innovation making an impact on today's military electronics. Another is an open-systems architecture for RF/microwave technology, which brings a standardized approach to building integrated microwave assemblies (IMAs) *(Fig. 3)*.

"For RF and microwave manufacturers serving the defense sector, the biggest trend by far is the gradual adoption of open architectures from the subsystem to system levels," says Lorne Graves, chief technologist at Mercury Systems *(www.mrcy.com)*. "This is obviously a major paradigm shift for manufacturers of microwave subsystems—IMAs—for whom every design is different, proprietary, resistant to insertion of new technology, and created to meet the needs of one platform rather than many.

"The same approach just won't work in the future, as adversaries move rapidly to challenge the superiority of U.S. defense technology," he adds. "Both new and upgraded systems must be able to be deployed in months rather than years."

The advantages of an open architecture are numerous. Graves continues, "The rationale for open architectures is simple: If employed broadly throughout the Department of Defense (DoD), a modular, well-defined, and scalable architecture would increase transparency and competition by allowing multiple vendors to participate in the initial design as well as upgrades throughout the life of the platform. It would also simplify and speed technology insertion and allow commonality between systems of the same type, such as EW and radar systems. Best of all, from the DoD's perspective, lifecycle costs would be dramatically reduced."

While other technologies have taken advantage of open systems, RF/microwave technology has yet to travel the same route. "Open systems have been de rigueur in digital, board-level products for decades," adds Graves. "The addition of RF and microwave technology, an essential and sometimes the essential ingredient in many types of systems, is the only missing link in making truly open systems possible."

Although the RF/microwave industry's approach to building subsystems has remained relatively unchanged,

> "Open-systems architectures have been debated for many years, but this time the initiative has breadth and depth. It has significant support at all levels of DoD and even in Congress, where several bills have been introduced to mandate open architectures wherever possible."

Graves believes that open systems represent the future. He notes, "Open-systems architectures have been debated for many years, but this time the initiative has breadth and depth. It has significant support at all levels of DoD and even in Congress, where several bills have been introduced to mandate open architectures wherever possible. As the microwave industry has been designing subsystems the same way since World War II, it could take many years for open architectures to be fully adopted. But make no mistake: Having so many advantages, especially in today's fiscally constrained defense budget environment, they are surely here to stay."

Open systems are still in the very early stages in the RF/microwave arena. However, Mercury Systems has introduced OpenRFM, which supports EW platforms with its creation of a set of open, standardized technologies. Last year, the company introduced the Ensemble RFM-1RS18 tuner—it comes in four configurations, each comprised of as many as three OpenRFM modules.

This report provided insight into some of the technology being utilized in the military arena. Tough SWaP requirements are prompting companies to deliver more compact solutions than ever. GaN technology is clearly a driving force, enabling the next-generation of radar systems. And the introduction of an open-systems architecture—though still in its infancy—has the potential to significantly impact the defense sector. Clearly, the RF/microwave industry is driving a large amount of change that is transforming military electronics. And plans are to continue to meet those critical needs—both today and tomorrow. mw

LOU FRENZEL | Contributing Editor

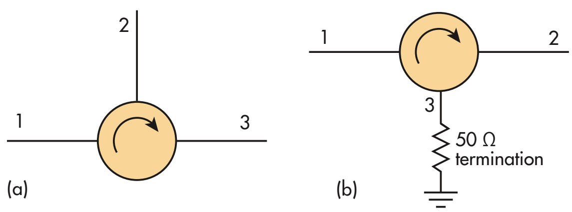
A Primer on Circulators and Isolators

These essential devices help direct the flow of microwave signals in RF equipment and systems. Here's what you need to know about them.

CIRCULATORS AND ISOLATORS are three-port passive electronic devices that help direct the flow of microwave signals in RF equipment and systems. A port is defined as a connection point for either an input signal, output signal, or termination. *Figure 1a* shows the standard schematic symbol for a circulator. The arrow indicates the unidirectional flow of any signals from port to port.

HOW A CIRCULATOR WORKS

Figure 1a shows a circulator, where any port can be an input or an output. A signal applied to port 1 will be passed to port 2 with minimum attenuation. A signal input to port 2 will pass to port 3, but not back to port 1. An input to port 3 will pass to port 1, but not in reverse to port 2. The amount of insertion loss from port to port is typically in the 0.2- to 0.75-dB range.



1. Shown are (a) the common schematic symbol of a circulator and (b) the schematic symbol of an isolator.

If one of the ports is terminated in a resistance equal to the impedance of the port, usually 50 Ω, the circulator becomes an isolator (*Fig. 1b*). An input signal at port 1 will pass to and exit port 2 if port 2 is properly matched to 50 Ω. If there is a mismatch at port 2, any reflected signal will be passed to port 3 and absorbed by the load.

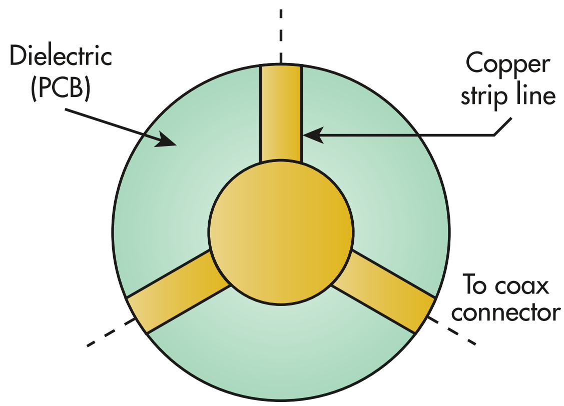
CONSTRUCTION

A circulator is typically a Y-shaped section of microstrip or stripline transmission line on a printed circuit board or other dielectric (*Fig. 2*). The line impedance is 50 Ω. The ports, spaced 120 deg. apart, are commonly terminated with SMA or N-type coaxial connectors.

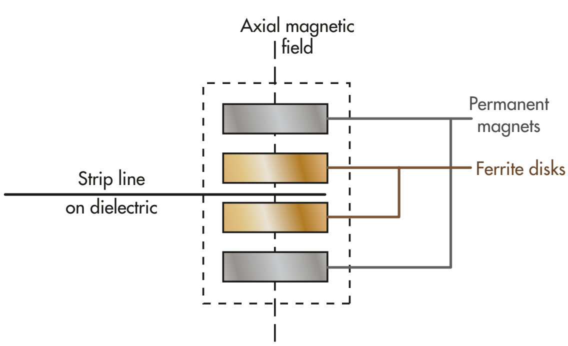
The Y-junction assembly is then sandwiched between two layers of ferrite material (*Fig. 3*). Two permanent magnets are positioned on either side of the ferrite disks. The magnets send a strong magnetic field axially through the ferrite disks. The ferrite material supports and focuses the magnetic field around the Y-junction. The axial magnetic field is called the bias.

When a signal is applied to one of the ports, an electromagnetic field is set up in the strip line. This field then interacts with the applied bias magnetic field, causing the signal to rotate in one direction to the next adjacent port.

The assembly made up of the Y-junction and the ferrite disks forms a dielectric resonator that has a resonant frequency.



2. The Y-shaped strip line circuit is the heart of the circulator.



3. This common construction of a circulator shows a Y strip line, ferrite disks, and magnets. There is no spacing between actual disk components as shown here.

Operation takes place in regions above or below this frequency, where attenuation is minimal.

APPLICATIONS

The most common application of a circulator is as a duplexer. A duplexer allows the transmitter and receiver in a radio or radar unit to share a common antenna. The transmitter output is applied to port 1 and will pass to port 2, where the antenna is connected. The receiver input is connected to port 3. A signal received by the antenna is passed to port 3, but not back to port 1. The transmitter output is not passed to the receiver input. The key effect is to prevent the typically high transmitter power from damaging the receiver input circuits.

The isolator is connected between a signal generator and some device under test (DUT). If all impedances are matched, the signal passes freely to the DUT. If there is a mismatch at the DUT or if the DUT is disconnected, it creates a high-voltage standing wave ratio (VSWR), causing a large reflected signal. The circulator absorbs this signal, protecting the signal generator.

The attenuation of an isolator in the reverse direction is typically in the 20-dB range. If greater attenuation is needed, two isolators can be cascaded. The result is a four-port device that can boost attenuation to about 40 dB or so.

SPECIFICATIONS

When specifying or buying a circulator or isolator, the most important characteristics to consider are:

Frequency of operation and bandwidth: Circulators and isolators generally operate over a range from about 700 MHz to 20 GHz. When operating above resonance, lower frequencies are better accommodated over narrower bandwidths. Below resonance operation usually allows for wider bandwidths.

Insertion loss: This is the attenuation from port to port in the forward direction. It usually ranges from 0.1 to 0.75 dB.

Isolation: This is the attenuation in the reverse flow direction. It is typically in the 17- to 35-dB range.

VSWR: This value indicates the maximum mismatch and reflected power from output port to input port. The usual range is 1.1:1 to 1.4:1.

Power: This is the average maximum power that the device can handle. Forward and reverse (reflected) power levels are usually given. Typical power ratings range from 1 to 1,000 W.

Temperature range: This is important as ferrite characteristics and magnetic field strengths vary with temperature. A common maximum range is –50 to +100°C.

Impedance: The characteristic impedance of the ports is virtually always 50 Ω.

MARK MURPHY | Marketing, RF Energy, MACOM

GaN: From Esoteric Tech to Market Mainstay

Ascending from its nascent potential, gallium nitride is now a mainstream technology as evidenced by its adoption into more commercial applications.

The evolution of gallium nitride (GaN) from research and development to commercial deployment is the single largest technology disruption impacting the RF/microwave industry today. GaN has had a clear and profound effect on system performance, size, and weight across numerous RF applications, enabling system-level solutions that couldn't be achieved with legacy semiconductor technologies. Still, GaN's market potential has only just begun to be realized.

Today, GaN is positioned for mainstream adoption in commercial RF applications spanning from wireless base stations to RF energy and beyond *(see figure)*. Its trajectory has hinged on a wide range of factors coming into alignment, though.

For example, GaN's performance benefits were once prohibitively expensive. However, a number of recent advances have distinguished GaN as the cost-competitive successor to gallium arsenide (GaAs) and laterally diffused metal-oxide semiconductor (LDMOS) technology for most RF applications. These advances include GaN-on-silicon (GaN-on-Si) technology, supply-chain optimization, device packaging techniques, and manufacturing efficiencies.

A better perspective on where GaN technology is today and where it's headed in the future can be drawn by reflecting on its origins and development roadmap. In many respects, GaN's evolution is an example of history repeating itself.

THE FORMATIVE YEARS

The U.S. Department of Defense (DoD) played a pivotal role in the development of GaAs-based monolithic microwave integrated circuits (MMICs) some 20+ years ago via the Microwave/Millimeter-Wave Monolithic Integrated Circuits (MIMIC) and Microwave Analog Front-End Technology (MAFET) programs. The DoD was equally instrumental in the early development of GaN by way of the Defense Advanced Research Projects Agency's (DARPA) Wide Bandgap Semiconductor Technology

Gallium nitride (GaN) is positioned for mainstream adoption.

(WBST) initiative. Officially launched in 2001, this initiative sought to fulfill the military's need for compact, high-power RF devices, building in part on the early success demonstrated by GaN for blue-spectrum LED lighting.

Aimed at fast-tracking GaN's use in military systems, the WBST initiative chartered program participants to cultivate MMIC fabrication processes for reproducible GaN devices with predictable performance characteristics and failure rates. As with the MIMIC and MAFET programs that preceded it, the WBST initiative was heavily skewed toward military applications that required performance at any cost. However, it would ultimately ensure the government's access to increasingly affordable, high-performance RF components as compound semiconductor providers honed their process disciplines.

For GaAs, the catalyst for mainstream commercial adoption was the explosion in consumer demand for wireless handsets, which drove strong economies of scale. Compound semiconductor providers led the industry toward the establishment of robust, reliable, and scalable GaAs supply chains, investing hundreds of millions of dollars in large-scale GaAs fabs. Making that move enabled GaAs' transition from specialized military technology to commercial mainstay.

GaN's commercial adoption commenced primarily in the cable TV (CATV) industry, driven by operators' desire to increase bandwidth while simultaneously reducing operating costs via improved energy efficiency. Despite GaN-on-silicon-carbide's (GaN-on-SiC) price premium compared to GaAs, price pressures for CATV infrastructure were more relaxed than those for wireless handsets, and the operating cost savings overrode the jump in acquisition cost. But the volume benefits of the commercial CATV market would be counterbalanced by steepening price-erosion curves, which intensified efforts to cultivate cheaper alternatives to GaN-on-SiC.

The performance gap between GaN-on-SiC and GaN-on-Si has narrowed considerably since the early stages of CATV adoption, yielding cost-effective GaN-on-Si power transistors that now have similar power efficiency and thermal attributes to GaN-on-SiC. MACOM's fourth-generation GaN-on-Si (Gen4 GaN) exemplifies this trend, delivering greater than 70% peak efficiency and 19-dB gain for continuous-wave (CW) operation from 2.45 to 2.7 GHz.

In the wireless base-station market, this performance profile has enabled GaN to challenge LDMOS' multi-decade dominance in base-station power amplifiers (PAs). Such a shift has profound implications for base-station performance and operating costs. The clear technology advantages provided by GaN position it as the natural successor to LDMOS for next-generation base stations (particularly for cellular bands above 1.8 GHz).

PERFORMANCE ADVANTAGES

When assessing GaN's technology trajectory and market potential, one must of course weigh the baseline technical merits that distinguish GaN from legacy semiconductor technologies. The performance attributes of both GaAs and LDMOS—measured in power, efficiency, bandwidth, and thermal stability—were adequate for their target applications. But among their most noteworthy shortcomings were GaAs being limited to a power output below 50 W and LDMOS limited to frequencies below 3 GHz.

While the power and frequency capabilities of GaAs and LDMOS are compromised, GaN demonstrates exceptional performance across both of these metrics in addition to offering several other technical benefits *(see table)*. GaN delivers considerably higher raw power density than GaAs and LDMOS technologies, with the capability of scaling the device technology to high frequency. GaN technology has allowed device designers to achieve broad bandwidths while maintaining high efficiency.

COMPETING ON COST

GaN's performance benefits are well known to all involved with the RF/microwave industry. But its historical cost structure

MACOM GaN THERMAL PERFORMANCE

	LDMOS	MACOM GaN on silicon	Benefits
Power amp efficiency ">2%"	-	> 10% improvement	Lower operating costs, simpler cooling
Power density	1-1.5 W/mm	4-6 W/mm	Smaller footprint and lower costs
Matching	Difficult	Easy	Time-to-market and smaller footprint
Supply chain	8″	6″ and 8″	Capacity and surge capability
Cost	Silicon	Silicon	Competitive bill of materials
Linearity	DPD-friendly	DPD friendly	Competitive bill of materials
Support all ISM bands	Limited to 2.45 GHz	Can be used > 2.45 GHz	Broader choice for applications

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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made it prohibitively expensive, which slowed its mainstream adoption. This is no longer the case, though, and customers' perceptions and expectations for GaN are evolving accordingly.

Taking into account the inherent power-density advantage and scalability to 8-in. substrates, Gen4 GaN is expected to yield GaN-based devices that are more cost-effective than LDMOS in absolute dollars-per-watt before even considering the benefits at a system level. Gen4 GaN provides significantly lower cost than comparably performing, but more expensive, GaN-on-SiC wafers at volume production levels.

What's more, the industry's ability to support commercial-scale production of GaN-on-Si, maintain inventories, and accommodate surges in demand is now firmly established. Thus, concerns about supply scarcity have diminished—concerns that will continue to linger with GaN-on-SiC given its cost- and time-intensive fabrication process.

The parallel advances in the GaN technology roadmap and GaN supply chain have enabled the manufacturing scale and cost structures necessary to allow GaN to accelerate its penetration into commercial domains. For customers evaluating where GaN does and doesn't fit based on performance and cost metrics, Gen4 GaN has changed the equation considerably.

PACKAGING VALUE

GaN packaging options are an essential part of its value proposition, with implications for product performance and cost, as well as manufacturing efficiency. Ceramics remain the packaging option of choice for GaN devices that must be hermetically sealed in order to ensure reliable operation over very long lifecycles. GaN in ceramic devices are also capable of managing high-power dissipation levels. The downside of leveraging GaN in ceramic components is the high cost of the package and their cumbersome assembly processes.

The GaN device market shifted radically with the introduction of GaN in plastic power transistors, which offer a cost-effective alternative to GaN in ceramic devices and are key to enabling a new generation of high-power, ultra-compact power modules. Plastic-packaged, high-power GaN devices allow designers to adopt conventional surface-mount manufacturing approaches and their associated manufacturing efficiencies. In this way, the adoption of GaN in plastic further drives a roadmap for supply-chain cost reduction.

THE PROMISE OF RF ENERGY

The intersection of GaN performance with silicon cost structures is going to

accelerate innovation across the RF domain, and open massive new market opportunities. Chief among them will be RF energy applications, which use controlled electromagnetic (EM) radiation to heat items or drive all kinds of processes. Today, magnetron tubes commonly generate this energy. Tomorrow, it will be generated by an all-solid-state RF semiconductor chain.

Solid-state RF energy offers numerous benefits unavailable via alternate solutions: low-voltage drive, semiconductor-type reliability, smaller form factor, and an "all-solid-state electronics" footprint. Perhaps its most compelling attributes are fast frequency, phase, and power agility complemented by hyper-precision. Collectively, the technology's attributes yield an unprecedented process-control range, even energy distribution, and fast adaption to changing load conditions.

RF energy is proving to be a highly efficient and precise heat and power source for a wide range of commercial applications, including microwave ovens, automotive ignition, and lighting systems, as well as industrial, scientific and medical (ISM) applications. The RF devices that underpin these systems must strike an optimal balance of performance, price, power efficiency, small size, and reliability—and GaN-on-Si does just that. Rugged, plastic-packaged Gen4 GaN power transistors capable of up to 300-W power output have emerged as a compelling and cost-effective solution.

EXPONENTIAL MARKET GROWTH

The wireless base-station market will continue to drive significant growth in the GaN market in the near term. Furthermore, now that GaN has crossed the threshold for mainstream adoption, it's opening the door to another opportunity.

The total addressable market for RF energy applications is enormous in scope. Consider the market for microwave ovens as just one example. MACOM estimates that more than 70 million microwave ovens are sold globally each year. With transmit powers for consumer units ranging from approximately 600 to 1,500 W, the total RF power demand for microwave ovens is in the 42- to 105-GW range. At current mainstream semiconductor price structures, the corresponding microwave-oven market revenue opportunity is approximately \$4 to 9B.

GaN's rise to the forefront of the RF/microwave industry is now complete. Its cost structure has come into alignment with legacy semiconductor technologies, and whenever cost parity is achieved between competing technologies, the higher-performing technology always wins.

The major investments made by companies like MACOM in this once burgeoning technology, and in its supply-chain ecosystem, set the stage for GaN's mainstream commercial adoption. It will have a transformative impact on our industry and others for decades to come. mw

Need Cool Efficient GaN?

Qorvo's 50V GaN gives you unparalleled advantages

- Operating Efficiency
- System Cost Savings
- True 50V Operation
- MRL 9 Trusted Source
- Highest Reliability

Part Number	Psat (W)	Freq (GHz)	Output Power (P3dB)	PAE (%)	SS Gain (dB)
QPD1008	125	DC-3.2	51	70	18
QPD1008L	125	DC-3.2	51	70	18
QPD1015	65	DC-3.7	48	70	20
QPD1015L	65	DC-3.7	48	70	20
QPD1009	15	DC-4	42	72	24
QPD1010	10	DC-4	40	70	25

qorvo

Design Feature

AHMED BOUTEJDAR | Doctor-Scientist Researcher
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Develop a BPF from a Compact DGS LPF

This technique provides a "two-for-one" design strategy, creating a miniature bandpass filter from a compact lowpass filter with low insertion loss and broad stopband.

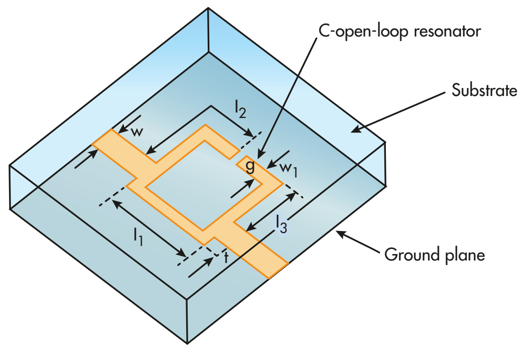
Wave propagation in periodic structures has been studied for some time as part of applied physics investigations.[1,2] Recently, periodic structures, such as photonic-bandgap (PBG) structures and defected ground structures (DGS) for planar transmission lines, have drawn wide interest in applications for microstrip filters, antennas, and millimeter-wave circuits.

A DGS is realized by etching away a defected pattern from a circuit ground plane.[3-12] The etched defect disturbs the shield current distribution in the ground plane. This disturbance can change transmission-line characteristics, such as line capacitance (C) and inductance (L), possibly giving rise to the effective C and L of a transmission line, respectively. Thus, an LC equivalent circuit can be used to model the proposed DGS loop circuit. A C-shaped loop resonator consists of two arms—a short continuous arm and a long arm with a gap (g) near the middle. Simple relations will be used to obtain the equivalent-circuit parameters utilizing the simulation response of the DGS.[13-16]

To explore the capabilities in lowpass filters (LPFs) and bandpass filters (BPFs), DGS design methods were employed with the aid of commercial computer simulations. The first filter design, a compact multilayer LPF, employs a single suspended C-shaped open-loop resonator. The second filter, a BPF, is extracted from the first, adding a feed-discontinuity, in-state-compensated patch capacitor. Both filters feature compact size, high sharpness factor, wide stopband response, and flexibility in design. Measured S-parameters indicate high performance levels, with good agreement between simulations and measurements.

LEVERAGING THE BANDSTOP FILTER

The building block of a proposed LPF is a C-shaped open-loop bandstop filter; it employs a single microstrip stepped open-loop resonator that is directly connected with two feed lines *(Fig. 1)*. The high-impedance line between the two feed lines has a constant width corresponding to an impedance of 75 Ω. The

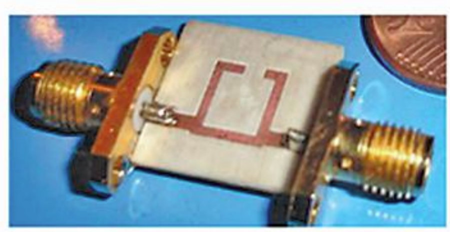


1. This diagram shows the basic layout of a C-open-loop resonator, which is used as a building block for the lowpass and bandpass filters.

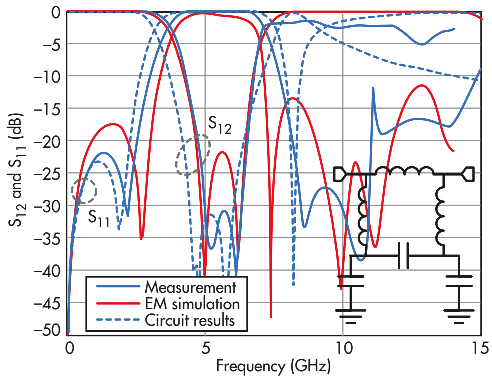
bandstop filter was designed at a center frequency of around 5.6 GHz, and simulated and fabricated on circuit material with relative dielectric constant(ε_r) of 3.38 and thickness of 0.813 mm.

The dimensions of the proposed filter are as follows: l_1 = 8 mm, l_2 = 7.6 mm, l_3 = 4.08 mm, w = 1.92 mm, w_1 = 1 mm, g = 1 mm, and t = 2 mm. The two feed lines have a characteristic impedance of 50 Ω. *Fig. 2* shows the fabricated cell (a single bandstop filter).

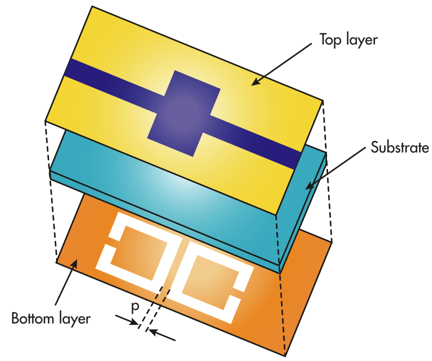
The results of electromagnetic (EM) simulation, equivalent-circuit simulation, and measurements are shown in *Fig. 3*. Good agreement among them demonstrates the validity of the equivalent-circuit model for the proposed bandstop filter. The insertion loss is less than 0.5 dB from dc to 3 GHz, while the return loss is less than −22 dB in the passband. The stopband rejection levels are more than 20 dB from 4.7 to 6.7 GHz. The proposed filter exhibits a sharp



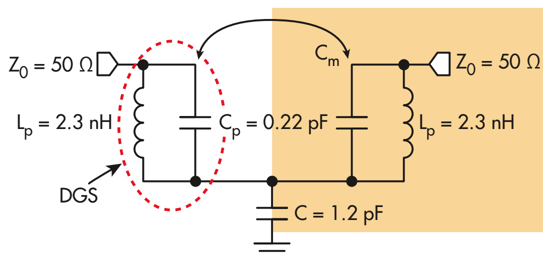
2. This photograph shows a C-open-loop resonator fabricated on commercial circuit laminate.



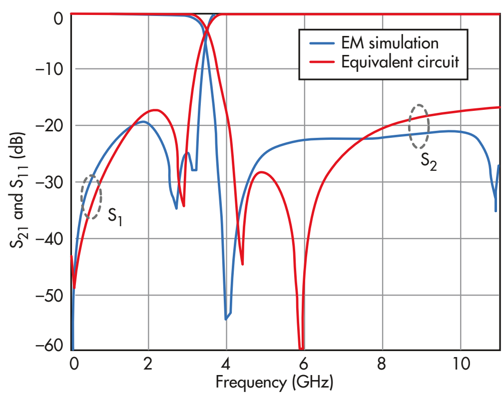
3. These measured and simulated S-parameters show the characteristics of a C-open-loop resonator used as the basis for a bandstop filter.



4. Shown is a three-dimensional (3D) view of the DGS-based lowpass filter.



5. The equivalent circuit contains values for the circuit elements in the DGS-based lowpass filter.



6. Simulations of the LPF, using circuit- and EM-based software tools, match closely.

cutoff, dropping from less than –0.5 dB to almost –44 dB within 1.5 GHz. The proposed bandstop filter measures 7 × 7 mm^2 *(Fig. 2, again)*.

Designing a LPF with large reject band and high transition domain, based on a C-shaped, open-loop DGS cell required the use of two cascaded C-shaped open-loop DGS resonators *(Fig. 4)*. This LPF consists of one compensated microstrip line on the top layer and two coupled C-DGS slots. Both C-DGS slots are etched next to each other on the metallic ground plane of a printed circuit board (PCB). The close proximity results in electric coupling between the resonators.

To verify the response of the proposed microstrip LPF, a simple structure was simulated and optimized on RO4003 circuit material from Rogers Corp. *(www.rogerscorp.com)*, with thickness of 0.815 mm and ε_r of 3.38 *(Fig. 4, again)*. The LPF was designed with a cutoff frequency of 3.5 GHz and passband insertion loss of less than 0.3 dB. It has a transmission of zero near the passband edge at 4.1 GHz, which gives a very sharp slope (S) response in the transition domain. This filter also has a wide rejection band, to 7.5 GHz.

The width of the microstrip line was chosen to be 1.9 mm for a characteristic impedance (Z_0) of 50 Ω. Other structural parameters are: p = 4 mm, a = 4 mm, and b = 8 mm. The proposed LPF structure was simulated via an equivalent-circuit model *(Fig. 5)* in a commercial software circuit simulator.

The top compensated open-stub capacitor is connected to both 50-Ω feed lines. *Fig. 6* provides a comparison between EM and equivalent-circuit simulations of the LPF. As can be seen, the circuit model simulation agrees closely with the EM simulation results except at the attenuation pole frequency. The main reason for the discrepancy is an ideal model has been adopted in circuit simulation and for the substrate without accounting for radiation. The equivalent circuit corresponding to the proposed DGS can be extracted by S-parameters and Eq. 1 for capacitor C_p and inductor L_p:

$$C_p = \frac{1}{200}\left[\frac{f_c}{\pi\,(f_0^2 - f_c^2)}\right]F,\; L_p = \left[\frac{0.25}{C\,(\pi f_0)^2}\right]H \quad (1)$$

The corresponding equivalent-circuit model for a three-pole LPF was developed to account for the mutual coupling between the DGS slots. A three-pole stub-type LPF with DGS slot was adapted from a reference source.

As is well known, coupling depends on the distance between resonators, as well as from the attenuation pole location, which corresponds to the resonance frequency. The coupling between the two resonators can be used to improve the filter characteristics, particularly the rejection bandwidth. However, it is not always simple to define the ideal coupling distance.

For the current design, the effective distance between the two resonators (p) = 3 mm, which is the value of the coupling coefficient between two DGS resonators, was determined through a MATLAB (from MathWorks;, *www.mathworks.com*) interpolation program and using an empirical method. The use of two coupled DGS C-shaped resonators combined with a top patch compensated capacitor facilitates the design of a wide-rejection-band LPF *(Fig. 6)*:

$$f_e = \frac{1}{2\pi\sqrt{(C_p + C_m)\,L_p}} \qquad f_m = \frac{1}{2\pi\sqrt{(C_p - C_m)\,L_p}} \quad (2)$$

$$k_M = \frac{f_e^2 - f_m^2}{f_e^2 + f_m^2} = \frac{C_m}{C_p} \quad (3)$$

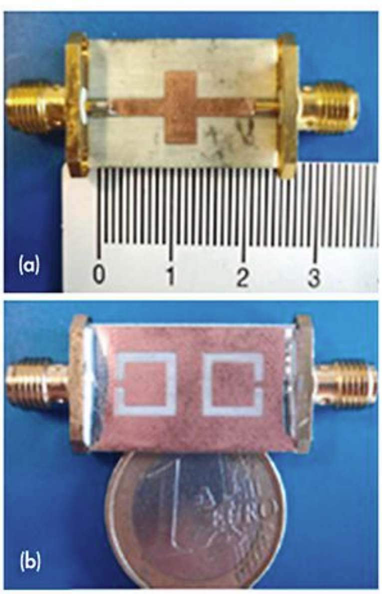
The LPF was designed and fabricated on a 0.813-mm-thick commercial circuit laminate with ε_r of 3.38 (Rogers RO4003). The value of coupling coefficient p was extracted using the Microwave Office full-wave EM simulator from AWR Corp. (*www.awrcorp.com*; *www.ni.com*) and MATLAB mathematical analysis software.

The simulated and measured results show that the passband insertion loss is less than 0.1 dB over the whole passband, and the attenuation level is less than –20 dB within a very broad stopband to about 8 GHz. *Fig. 7* shows the fabricated microstrip filter with uniform metal-loaded slots etched in the ground plane, while *Fig. 8* compares measured and simulated results, which are in good agreement. The filter achieves wide stopband, sharp transition band, and enhanced passband performance.

FROM LPF TO BPF

To realize the transformation of the LPF to BPF without using additional components, a J-inverter gap is etched in the middle of the 50-Ω feed line on in the top layer of the conventional structure *(Fig. 9)*. The proposed structure consists of two open-loop C-shaped resonators, which are etched in the ground plane. Placement of the two DGS elements ensures that they have magnetic coupling rather than electric coupling as before.

The modified structure is similar to the cascaded filter described earlier, with a simple modification to the exciting feed line on the upper layer *(Fig. 9, again)*. This DGS topology has been found to improve filter performance while significantly reducing the total size of the structure. The gap distance (q) between both microstrip feed lines can be defined by either the coupling matrix method or empirical method.



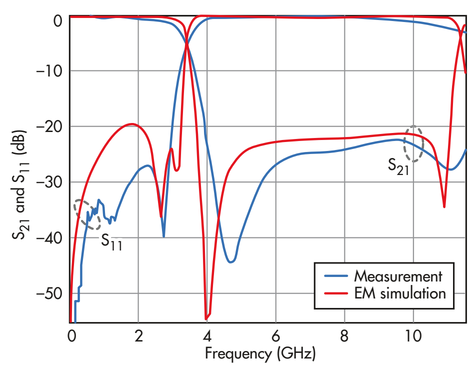
7. The small size of the fabricated LPF is shown in reference to the coaxial connectors and the coin.

By using the coupling matrix method, the coupling spacing can be exactly calculated. The disadvantage of this method is the complicated way to define the required values. The empirical process is simpler, but the disadvantages are the long duration of the process and inaccurate results.

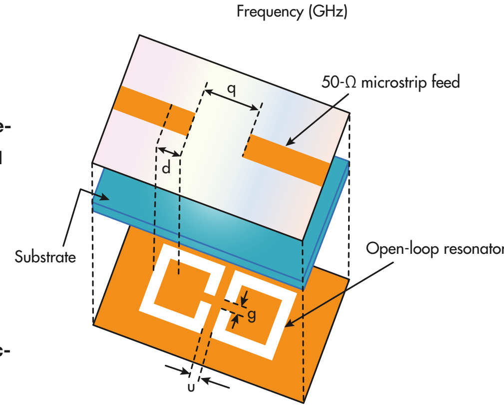
The filter was simulated on a substrate with a relative dielectric constant of 3.38 and thickness of 0.813 mm. With consideration of d, several simulation results of this filter are shown in *Fig. 10*. To study the features of this structure, different investigations were carried out on gap length. As Fig. 10 shows, if p and g are fixed and, at the same time, d is varied, passband frequency and insertion loss can be controlled. This means that the gap length significantly affects the insertion loss, as well as the quality factor Q and rejection band of the structure.

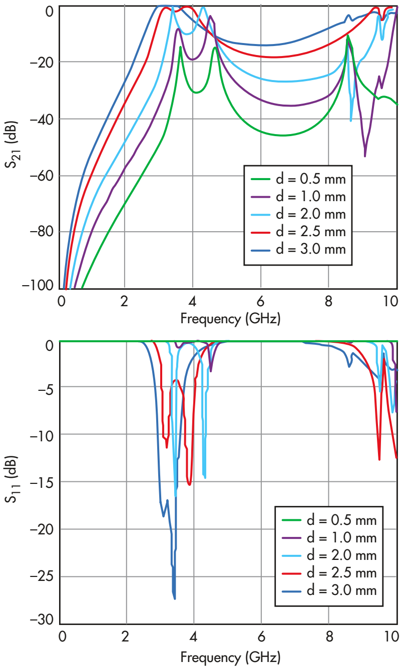
In the second step, d and g are fixed, while the effects of variations in u are studied empirically. The dimensions of the extracted filter shown in Fig. 9 are g = 1 mm, u = 1 mm, d = 0.5 to 3.0 mm, and q = 5 mm. The DGS BPF was simulated using Microwave Office software. Simulation results are given in Fig. 10, which shows the characteristics of a bandpass filter with wireless-local-area-network (WLAN) features. At d = 2.5 mm, the filter has a 3-dB cutoff frequency (fc) and resonance frequency (f_0) of 3.0 and 3.65 GHz, respectively.

8. The simulated and measured responses of the DGS LPF agree closely over the frequency range.



9. This three-dimensional (3D) view shows the extracted DGS BPF along with critical spacings.





10. The plots show the effects of the feed-line "d" distance on filter response: (top) insertion loss and (bottom) return loss.

A coupling matrix method was used to improve the performance of the previously described BPF illustrated in Figs. 9 and 10. *Fig. 11* shows the topology of the N × N matrix assembling the values of the mutual couplings between the nodes of the network. There are three variations to consider:

1. If the coupling is between sequentially numbered nodes ($M_{j,\ j+1}$), it is referred to as a direct coupling.

2. The elements, which are placed on the main diagonal ($M_{j,\,j}$) are self-coupling.

3. The other remaining couplings between the nonsequentially numbered nodes are known as cross-couplings.

Because of the reciprocity of the passive network, $M_{i,\,j} = M_{j,\,i}$, the matrix symmetrical about the main diagonal and generally all entries may approach zero, but remain nonzero. Any additional resonator or variation in the coupling values with frequency (dispersion) can lead to a change of the coupling-matrix structure.

The n + 2 normalized coupling matrix (M) provides a full description of all coupling paths in a filter, where n + 2 is the order of the matrix M and n is the filter order. All elements of the symmetrical matrix M will be designated as $m_{ij} = m_{ji}$. The input and output connections are included, thus the n + 2 coupling matrix is extended. This extension corresponds to the "+2" term. *Fig. 5* explains the n + 2 coupling matrix in more detail for the folded topology.

To realize a coupling matrix, which conforms to a chosen topology, it is necessary to first give the specifications of the filter. The desired parameters will subsequently be extracted by using an optimization-based scheme.[17, 18] The coupling coefficient and quality factor curves[19, 20] are then used to realize the obtained coupling coefficients. In our case, the second-order filter is with a bandwidth BW = 1 GHz, return loss R_L = 20 dB, and center frequency f_0 = 3.3 GHz. The coupling matrix obtained from the optimization scheme is:

$$M = \begin{bmatrix} 0 & 1.178 \\ 1.178 & 0 \end{bmatrix} \quad (4)$$

and the external quality factors are $q_1 = q_2 = 0.9136$. Using the (denormalized) coupling matrix (M), external quality factors (q_i), and normalized coupling matrix and scaled quality factors Q_i, the required fractional bandwidth (FBW), the actual (denormalized) coupling matrix, and the scaled external Q can be calculated by Eqs. 5-9:

$$BW = f_2 - f_1 \quad (5)$$

$$FBW = \frac{BW}{f_0} = 30.3\% \quad (6)$$

$$m = FBW \times M \quad (7)$$

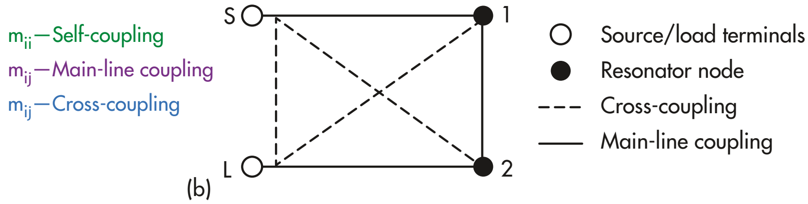
$$m = \begin{bmatrix} 0 & 0.357 \\ 0.357 & 0 \end{bmatrix} \quad (8)$$

$$Q_i = q_i \ / \ FBW \quad (9)$$

11. This is a two-degree example of (a) the folded matrix coupling network form and the (b) coupling and routing schematic diagram.

	S	1	2	L
S	m_{SS}	m_{S1}	m_{S2}	m_{SL}
1	*	m_{11}	m_{12}	m_{1L}
2	*	*	m_{22}	m_{2L}
L	*	*	*	m_{LL}

(a)

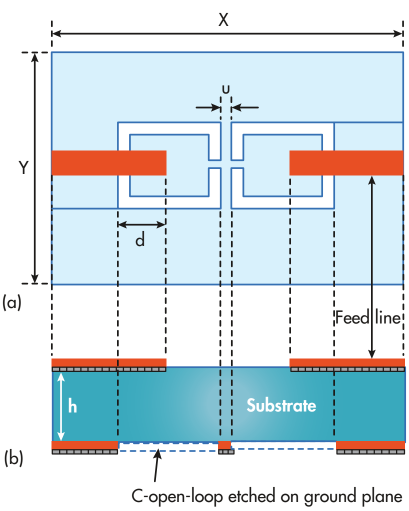


(b)

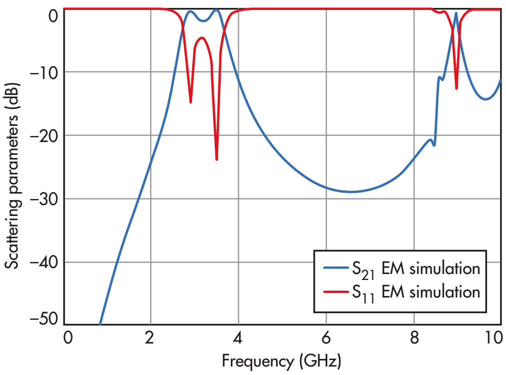
Based on these calculated values of the coupling coefficients m_{ij} and using the coupling coefficients curve, the coupling distance was selected as u = 0.75 mm.

As has been shown in earlier works,[17-20] the external Q can be easily determined through f – 90°, f + 90°, and center frequency f_0, as well as the relationship (empirical curve) between the external quality factor (Q_i), with i = 1, 2, and coupling distance (d). Using the coupling curve, the optimal value for Q_i leads to a value of coupling distance d. In this case, $Q_1 = Q_2 = 3$ and d = 2.8 mm *(Fig. 12)*.

Figure 12 shows two-dimensional (2D) views of the proposed bandpass filter. The coupling distance between the cascaded DGS resonators (u) and the coupling distance between the feed and the first DGS resonator (d) can be seen in Figs. 9 and 12. To verify the performance and the efficiency of the filter, the structure was designed, simulated, and



12. These views illustrate (a) the top and (b) the side of the extracted DGS BPF.



13. These simulations of insertion loss and return loss result after using the coupling-matrix method.

optimized. Fig. 12 shows a design of the DGS bandpass filter. The total area of the filter is:

$$(0.202\lambda_g \times 0.101\lambda_g$$

where $\lambda_g = 49.5$ mm. The simulation results of the optimized bandpass filter are located in the frequency range from dc to 8 GHz as shown in *Fig. 13*. Using the coupling matrix method, an improved BPF has been achieved by extraction from the LPF.

The bandpass filter has sharp edge steepness in its passband-stopband transition regions. The useful signal's second unwanted harmonics at twice the center frequency is suppressed, leading to a large reject band until under –20 dB to 4 GHz. mw

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Design Feature

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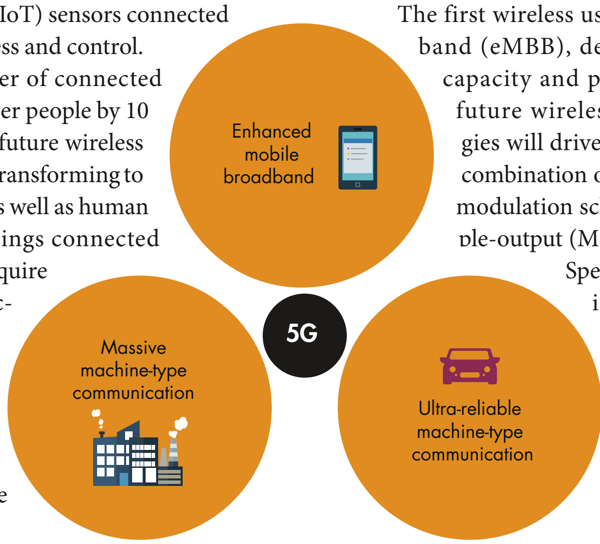
THE EVOLVING WIRELESS WORLD Requires a New Test Approach

Modular instrumentation and FPGA-enabled user programmability are key ingredients in measurement solutions for present-day and enhanced future wireless communications equipment.

Wireless technology is ubiquitous, providing the means for communicating voice, data, and video around the world. It is quickly expanding from just human users to machine-to-machine (M2M) communications and Internet of Things (IoT) sensors connected to the internet for full-time access and control.

Within a decade, the number of connected devices is projected to outnumber people by 10 to 1. As a result, emerging and future wireless communications standards are transforming to address cases involving things as well as human users. The large number of things connected by wireless technologies will require new instrumentation and effective measurement approaches to meet future demands of a wirelessly connected world. The modular PXI instrument approach provides the capability and flexibility to meet those future wireless device measurement needs.



1. These represent three examples of use cases for 5G technology.

The vision of the International Telecommunication Union (ITU) for International Mobile Telecommunications in 2020 (IMT-2020) outlines one of the clearest requirements for the range of use cases in future wireless standards. This foresight, designed as a framework to communicate the technical requirements of Fifth-Generation (5G) cellular communications, outlines three distinct wireless use cases (*Fig. 1*). Although these use cases specifically define the requirements of future mobile communication standards, they reflect the changing requirements for technologies like IEEE 802.11ad, IEEE 802.11ax, Bluetooth 5.0, near-field communications (NFC), and more.

USE CASES LOOK TO THE FUTURE

The first wireless use case, Enhanced Mobile Broadband (eMBB), defines the evolution in network capacity and peak data rates expected from a future wireless technology. eMBB technologies will drive higher peak data rates through a combination of wider bandwidths, higher-order modulation schemes, and multiple-input/multiple-output (MIMO)/beamforming technologies. Specifically for 5G, the eMBB use case is designed to deliver as much as 10-Gb/s downlink throughput, which is 100× the capability of single-carrier Long Term Evolution (LTE) cellular communications systems.

The second use case, Massive Machine-Type Communication (mMTC), is designed to deliver wireless access to more devices in more locations at low cost. By linking together more devices in more locations, mMTC technology will connect traffic lights, automobiles, and even highways in a smart, wirelessly connected city. In the short term, the need to cost-effectively connect more devices in more Industrial IoT (IIoT) applications is driving new mobile technologies, such as LTE for M2M communications and narrowband IoT (NB-IoT).

> "Within a decade, the number of connected devices is projected to outnumber people by 10 to 1."

The third and final use case is Ultra-Reliable Machine-Type Communication (uMTC). In this scenario, two key requirements of a wireless connection are latency and packet error rates. One example is a doctor performing remote surgery using a robot connected via wireless link. Another example is an automobile avoiding a massive traffic pileup and delays by communicating the existence of a vehicular wreck on the road ahead of it. In both applications, the reliability of the wireless communications link is not just a convenience, but a lifesaver.

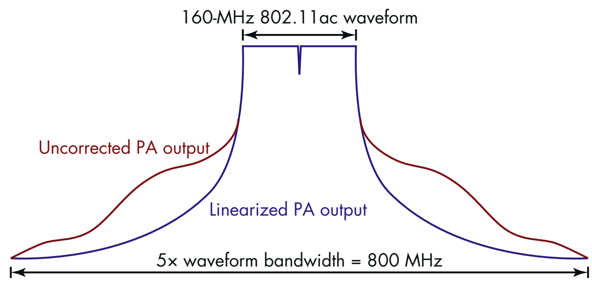
The requirements of tomorrow's wireless technology are not only driving new wireless standards like NB-IoT, 5G, and IEEE 802.11ax, but are also changing the way engineers design and test mobile devices. For example, wider bandwidths in future standards such as 5G require wider-bandwidth RF/microwave instruments. In addition, multiple-antenna technologies like MIMO and beamforming produce a need for modular and flexible instrumentation that can scale from testing single-antenna devices to 8 × 8 MIMO devices and beyond.

On top of that, lower-cost radios also require lower-cost approaches to wireless test. In a scenario where future wireless radios cost only 20% of today's prices, next-generation test equipment must be capable of much increased throughput, using faster and more parallel test approaches.

MODULAR TEST APPROACH

The PXI Vector Signal Transceiver was introduced by National Instruments in 2012 as a modular alternative to traditional "one-box" test solutions. The VST combined a 6-GHz RF signal generator, 6-GHz RF signal analyzer, and user-programmable field-programmable gate array (FPGA) in a single PXI module. It provided performance suitable for both research and development (R&D) and manufacturing test, with a user-programmable FPGA that made it possible to change the functionality of the VST for applications ranging from measurement acceleration to channel emulation.

Because of the continuing evolution of wireless technology, a second-generation VST was needed to address future requirements, one with wider bandwidth, extended frequency range, and a larger FPGA in an even smaller form factor than the first-generation instrument (*see "RF Measurement Modularity Redefined" at mwrf.com*). The second-gen VST not only addresses some of today's most challenging wireless test needs, but also offers the flexibility to address tomorrow's wireless test requirements.



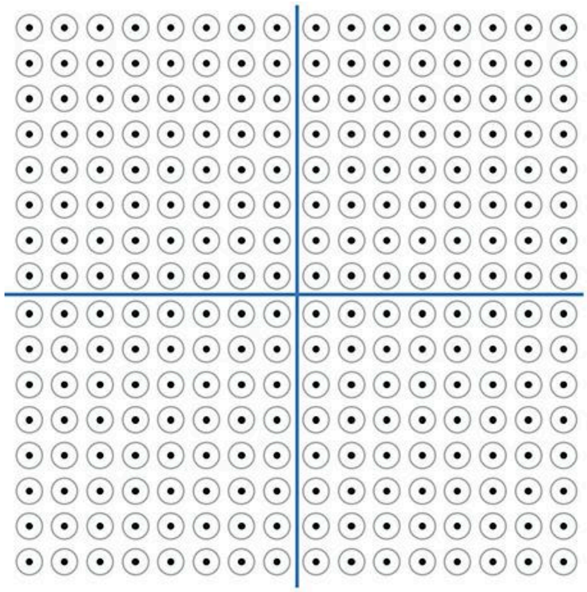
2. The new IEEE 802.11ax standard uses higher-order modulation schemes like 1024QAM.

Over the past decade, wireless standards have evolved to use significantly wider bandwidth channels to achieve higher peak data rates. For example, since 2003, Wi-Fi has advanced from 20 to 40 MHz to 160 MHz in modern IEEE 802.11ax applications. Mobile communication channels have evolved from 200 kHz in Global System for Mobile Communications (GSM) cellular systems to 100 MHz in modern LTE-Advanced (LTE-A) technology. Future wireless technologies such as LTE-Advanced Pro (LTE-A Pro) and 5G will drive this trend even further.

The bandwidth of a signal analyzer should exceed that of a device under test (DUT), especially when testing semiconductor devices. For example, when testing RF power amplifiers (PAs) using digital predistortion (DPD) to improve linearity, the test equipment must extract a PA model, provide corrections for nonlinear behavior, and then generate a corrected waveform. Advanced DPD algorithms often require three to five times the RF signal bandwidth of the DUT (*Fig. 2*). As a result, instrument bandwidth requirements can be as much as 500 MHz for LTE-A (for a 100-MHz signal) and 800 MHz for IEEE 802.11ac/ax (for a 160-MHz signal).

One of the most significant enhancements of the second-generation VST is its wider instantaneous bandwidth of 1 GHz. Due to its wider bandwidth, engineers can tackle challenges with this second-generation VST that simply can't be solved with less-available analysis bandwidth.

Numerous applications besides wireless test demand wideband instruments. For example, wideband radar systems often require as much as 1 GHz of signal bandwidth to acquire pulsed signals. Also, in spectrum monitoring systems, the bandwidth of the instrument can dramatically improve the scan rate. Finally, wide signal bandwidth is an essential requirement for many advanced research applications.



3. The new IEEE 802.11ax standard uses higher-order modulation schemes like 1024QAM.

TESTING MUST KEEP PACE WITH STANDARDS

A second critical requirement of test equipment for next-generation wireless standards is providing sufficient measurement accuracy to evaluate the enhanced specifications of these emerging standards. With higher-order modulation schemes and wideband multicarrier signal configurations, the RF/microwave front ends currently employed in wireless communications devices will need much better linearity and lower phase noise to support the more complex modulation schemes of emerging systems.

4. A single PXIe chassis can be configured as an 8 × 8 MIMO test system with eight VSTs.

For example, when assessing the error-vector-magnitude (EVM) performance of a wireless device, an RF/microwave signal analyzer should typically deliver EVM performance that is at least 10 dB better than that of the DUT. Modern IEEE 802.11ac devices need EVM performance of –32 dB when generating the required 256-state quadrature-amplitude-modulation (256QAM) scheme. As a result, the test analyzer must achieve EVM performance of –42 dB or better. In the future, the IEEE 802.11ax 1024QAM scheme will likely push device EVM limits to –35 dB, with corresponding instrument EVM requirements of –45 dB (*Fig. 3*).

To achieve superior EVM performance for wideband signals, the second-generation VST leverages advanced, patent-pending, in-phase/quadrature (I/Q) calibration techniques. In addition, PXI modularity enables engineers with the most demanding EVM performance requirements to further improve on the VST's native performance. Using an external PXI local oscillator (LO), systems based on the second-generation VST achieve EVM performance of better than –50 dB.

DEALING WITH MIMO TEST

Modern communications standards ranging from Wi-Fi to mobile systems and equipment use sophisticated multiple-antenna technology. In these systems, MIMO configurations provide a combination of either higher data rates through more spatial streams or more robust communications through beamforming techniques. Because of these MIMO benefits, next-generation wireless technologies such as IEEE 802.11ax, LTE-A Pro, and 5G will use more complex MIMO schemes with as many as 128 antennas on a single device.

Not surprisingly, MIMO adds substantial design and test complexity. It not only increases the number of ports on a device, but also introduces multichannel synchronization requirements. To evaluate a MIMO device, RF/microwave test equipment must be able to synchronize multiple signal generators and signal analyzers. Test equipment form factors and synchronization methods are critical to achieving practical solutions for such measurement requirements.

The second-generation VST is compact enough to enable the installation of as many as eight VSTs in a single 18-slot PXI chassis, with one slot reserved for a PXI controller (*Fig. 4*). The VST offers a range of technologies to tightly synchronize it either with other VSTs or other PXI modules. For example, the patented T-Clock technology developed by National Instruments can synchronize as many as eight VSTs to within 1 ns of channel-to-channel skew. In addition, the LOs of each VST can be shared with one another to conduct completely phase-coherent RF signal generation and acquisition.

> "One of the most important features of the VST is that it is part of a complete hardware and software platform."

GET WITH THE PROGRAMMABILITY

Software programmability is a key requirement for next-generation wireless test systems. Advanced wireless test applications increasingly require engineers to tailor the behavior of the instrument's firmware. In these applications, engineers can significantly improve instrument performance simply by moving closed-loop control, measurement acceleration, real-time signal processing, or synchronous DUT control on the instrument itself.

Historically, the only way to customize an instrument's firmware was to negotiate a nonrecurring-engineering (NRE) fee with the test vendor, which was usually expensive. In contrast, having the FPGA programmability of the VST allows users to attain all of the benefits of custom firmware. Users can also make their own modifications in test programs rather than hiring a costly expert in VHDL or Verilog code for the task.

One application that software-designed instrumentation can uniquely solve is radar prototyping. In this application, customers are able to use the FPGA as a complete target simulator. In radar applications, a radar system detects a "target," such as an automobile, airplane, or other object, by sending a stimulus signal and then waiting for the response. Attributes of the stimulus' reflection off the target, such as the delay and frequency shift, indicate both the distance and velocity of the target. The combination of the VST's wide bandwidth and user-programmable FPGA makes it well-suited for target emulation (*Fig. 5*). In addition, engineers can easily customize the FPGA to modify the types of targets they need to simulate.

Another application that reaps significant benefits by modifying the user-programmable FPGA is measurement acceleration. When performing measurements such as EVM or adjacent-channel-power (ACP) testing on wireless devices, the total measurement execution time is dominated by the measurement algorithm. For these measurements, it is possible to reduce measurement time by moving the measurement algorithm to the FPGA.

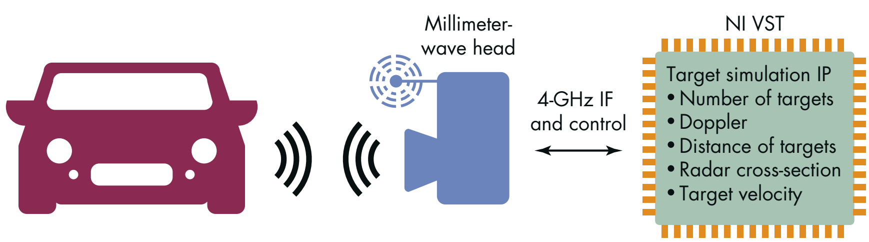
In addition, many of these measurements are often made under DPD conditions. In these cases, engineers can also use the FPGA to develop their own custom, real-time DPD implementations. The faster FPGA-based DPD implementation saves critical test time, and allows engineers to embed highly protected FPGA algorithms. By delivering an FPGA bit file to prospective customers instead of source code, organizations are better able to protect their DPD intellectual property (IP).

HW + SW

One of the most important features of the VST is that it is part of a complete hardware and software platform. In the current era of smart, connected devices and ICs, modern test instrumentation has transitioned from discrete instruments to highly integrated test systems. As a result, meeting the latest measurement challenges like envelope-tracking PA test and radar prototyping requires a platform of instruments that can be synchronized, customized, and easily controlled with software.

The VST is an example of how modular hardware and open software are increasingly being used to developer smarter, more efficient test systems. With more than 600 PXI products currently on the market, ranging from dc through millimeter-wave frequencies, these instrument modules achieve high-throughput data flows using Gen 3 PCI Express bus interfaces and sub-nanosecond synchronization with integrated timing and triggering. By leveraging intuitive software tools, a vibrant ecosystem of partners, add-on IP, and applications engineers working on practical solutions for current and emerging standards, it is possible to dramatically lower the cost and time required for testing wireless communications standards using this platform-based approach.

Although the next wave of wireless technologies, from 5G to IEEE 802.11ax, will introduce significant design and test challenges, the second-generation VST was created explicitly with the performance flexibility to address them. With wider bandwidth, a smaller form factor, excellent RF performance, and software customizability, the VST is scalable to meet the most difficult test challenges today and tomorrow. mw



5. Commercial automotive radar simulators can be designed using the second-generation VST in conjunction with a millimeter-wave head.

Design Feature

NICOLAS HENRIET | Senior RF Engineer
Sensata Technologies, www.sensata.com

Improve TPMS Design Flow with CIRCUIT DESIGN SOFTWARE AND EM VERIFICATION

To meet the latest performance requirements for tire-pressure monitoring systems, designers are turning to high-frequency design software.

Automobile safety concerns are increasing worldwide, which has led many countries to issue legal mandates that encourage a variety of car safety features. One such system, the tire-pressure monitoring system (TPMS), offers a very effective way of reducing single-car accidents caused by insufficient tire pressure. TPMS systems not only actively measure actual tire pressure, but many also sense temperature and can wirelessly report sensor data to the automobile's computer.

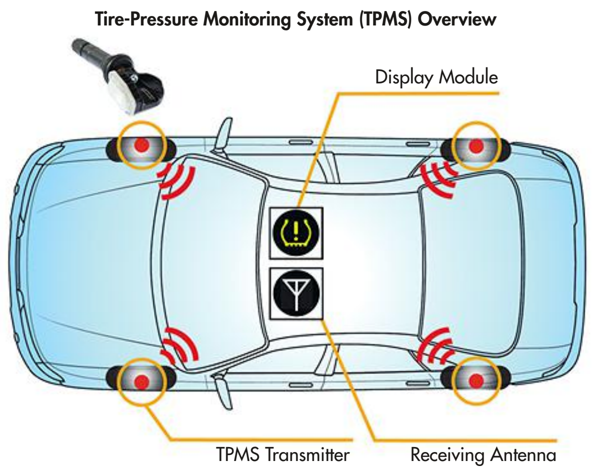
As performance demands on car electronics intensify, integrated design environment tools can enable more efficient and robust designs. Sensata Technologies, a sensing and controls company in Attleboro, Mass., employed RF/microwave circuit design software to meet the performance and optimization challenges for its TPMS system.

This article describes how the design team used Microwave Office circuit design software, as well as the AXIEM 3D planar electromagnetic (EM) and Analyst 3D finite-element method (FEM) simulators, to enhance the design process and optimize the system's performance. Planar EM simulation, Monte Carlo analysis using load-pull techniques, parametric optimization with component swapping, and EM environmental disturbance analysis were all performed within the single integrated environment.

TPMS DESIGN CHALLENGES

Active TPMS technologies must be installed and operate on, or within, the tire. The latest active TPMSs are wireless devices that can monitor several critical tire conditions and provide timely updates to the car's computer (*Fig. 1*).

Being located on or within the tire, a TPMS will be subjected to adverse weather conditions, corrosion, physical obstructions, and dirt/grime from road and car conditions. Therefore, TPMS systems must be extremely rugged and reliable. They must also continue to operate for several years after installation. Most TPMS must rely on non-replaceable battery power, which requires very low standby current drain and low-power sensing/transmission to extend the battery life. The extremely wide temperature, pressure, and physical forces in which the TPMS must operate often significantly impact circuit behavior and performance. For TPMS to meet rigorous quality standards, the design must perform within specification over –40 to 125°C.



1. This is an overview of a tire-pressure monitoring system.

From an EM perspective, the constant rotation of the wheel, the metallic wheel structure, electromagnetic interference (EMI), radio-frequency interference (RFI), and a non-ideal antenna structure are all factors that will negatively impact the performance of an active TPMS using RF communication technology. Additionally, to meet worldwide RFI and EMI regulations, the TPMS must be designed to avoid any harmful or disturbing radiation. This requires complying with over 30 RF regulations, which puts a burden on the harmonic filtering and circuit design.

These factors place a high standard and burden on TPMS circuit design, component choices, impedance matching, and optimization. Size, weight, power, and cost (SWaP-C) must all be very low to avoid impacting the wheel balance and reduce

> Active TPMS technologies must be installed and operate on, or within, the tire.

automobile production costs. Because yield contributes to the profitability of a manufacturing process, these devices must also take production variations into account.

Component parasitics, as well as physical characteristics of the PCB and components, aren't negligible in a TPMS. Thus, the design tools used to select and optimize circuit components must account for the EM behavior and circuit simulation behavior under an expanse of conditions. This requirement demands design tools that are both sophisticated and highly reconfigurable/customizable in order to enable refined adjustments and detailed analysis techniques.

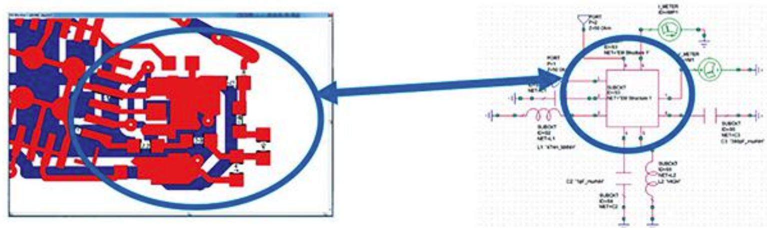
PCB ANALYSIS

The size and weight constraints of a TPMS require a small printed-circuit-board (PCB) area; however, cost structures limit the use of custom technologies. Furthermore, TPMS systems are completely contained, along with onboard power, in a single sealed device embedded with the pressure valve in a tire. Therefore, careful design of the sensing, control, and RF electronics is often implemented using standard surface-mount-technology (SMT) in highly compact layouts.

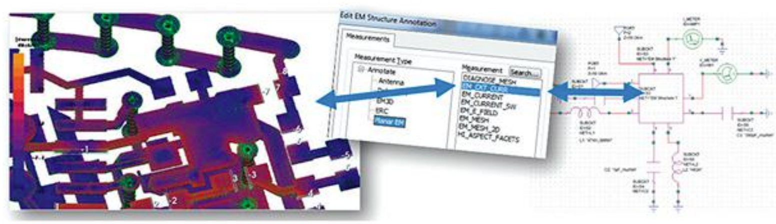
However, the parasitics introduced by the close-knit PCB traces will affect the component parameter optimization and RF performance. Hence, the PCB trace leads must be carefully modeled and accounted for before selecting optimal inductor, capacitor, and resistor components.

To overcome these challenges and begin the optimization process, Sensata's engineers imported a DXF file of the PCB traces into the circuit design software. The PCB traces were imported as a subcircuit component (*Fig. 2*), which was then simulated in a virtual testbench that provided flexibility in probing voltages and currents using AXIEM.

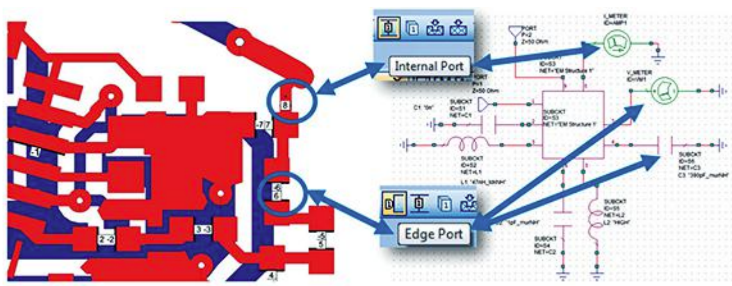
Once inside the tool, planar simulation was used to visually analyze current densities within the EM structure (*Fig. 3*). Additionally, edge ports were created in the EM simulator that revealed voltages between different circuit sections, currents along specified PCB tracks, and component locations that would later require optimization (*Fig. 4*). The designers were able to ensure a proper meshing of the geometry using a built-in "snap-to-grid" function (*Fig. 5*). This solved the predominantly high



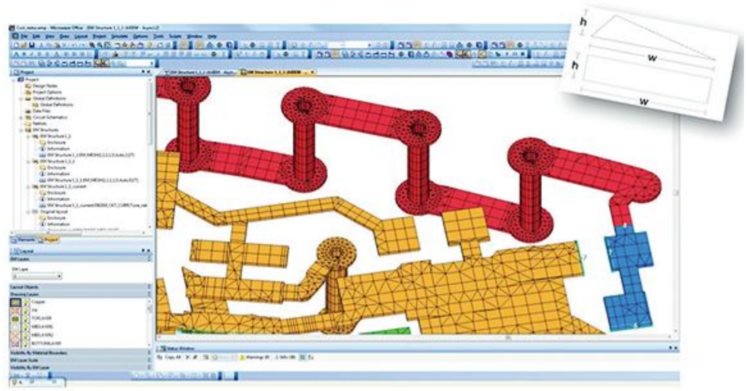
2. The printed-circuit-board's physical model was imported as a subcircuit in the circuit design software.



3. Planar electromagnetic simulation allowed current densities to be visualized.



4. Edge ports were created to monitor components and voltages/currents throughout the circuit.



5. The "snap-to-grid" feature can help solve traditionally time-consuming, complex meshing issues.

aspect ratio meshing issues with only negligible modification of the geometries of the PCB traces.

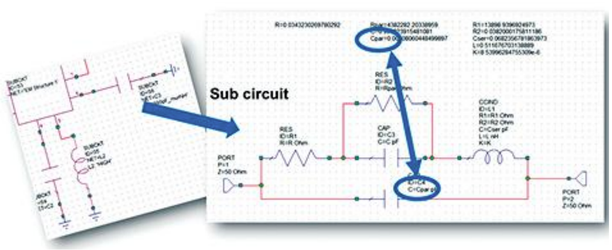
Along with the TPMS PCB optimization, the EM simulator was used to optimize the design of the TPMS antenna. The antenna size, weight, and efficiency were an extremely delicate balance in this design. The engineers used shape modifiers and optimization routines in the simulator, allowing the optimum structure for the antenna to be designed while still meeting impedance, radiation pattern, and efficiency goals.

RF CIRCUIT SIMULATION

Once the simulator contained a complete PCB trace structure with port assignments, the external components were modeled and values were optimized to meet design specifications. Intent on leveraging a detailed Monte Carlo analysis, the engineers modified each component internally to enable the statistical analysis.

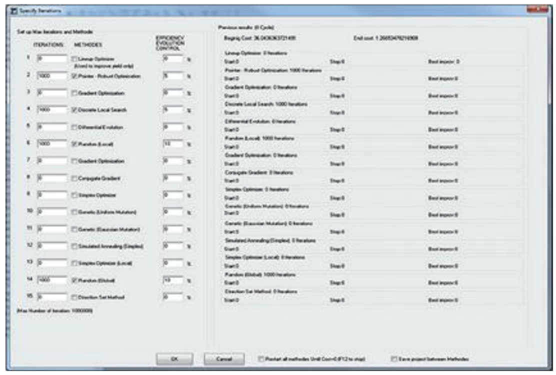
While many applications may not require the level of optimization depth that was employed in this design, the reliability and robust operating requirements of a TPMS sensor in an automotive environment demand a design that can perform in a wide range of environmental factors and up to 10 years on a single battery. Therefore, the multilevel component selection, optimization, and analysis phases were necessary to meet quality and reliability standards.

The designers used optimization features in the Microwave Office software to avoid the painstaking task of running a batch of simulations with a wide range of component values from different manufacturers. These features enabled the designers to swap components among a full library containing detailed performance data for each component (*Fig. 6*). In applications that need very precise impedance matching, power transfer, or filtering, this feature has the potential to dramatically reduce design times and parts sourcing challenges during prototyping.



6. The circuit design software is able to import component models, which can be modified to enhance the performance of the circuit.

However, out of the box, the Microwave Office optimizer was only able to tune the RF network with discrete optimization methods. Because the designers were interested in a rigorous statistical approach, the team built models that could sweep component values continuously, while maintaining the parasitic elements.



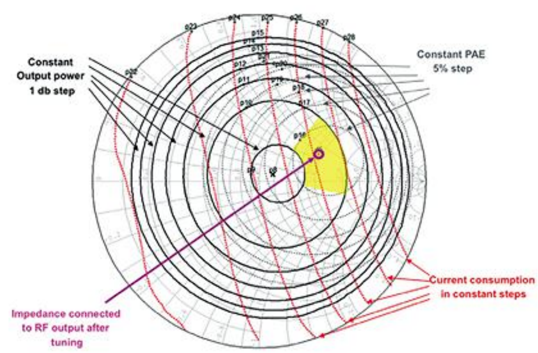
7. A custom Visual Basic script was created that automatically cycled through different methods and controlled the optimization iterations.

To further enhance the optimization, the designers leveraged the script automation capability of the optimizer and built a visual basic (VB) script that automatically cycled through different optimization methods and control iterations (*Fig. 7*). This approach circumvented time-consuming and error-prone guess-and-check, as well as increasing the number of optimization configurations that could be explored.

MONTE CARLO ANALYSIS

Understanding the full spread of the circuit's operational dynamics helps lead to a maximally efficient end design. Most TPMS have non-serviceable batteries and rely on highly efficient designs to prevent the constant need of replacing the component, making power consumption and transmitter efficiency among the utmost concerns in this design. Accurate simulations of power-added efficiency (PAE) and current consumption at various output power levels of the optimized impedance-matching circuit cut the number of prototypes and tests needed to verify the design.

A Monte Carlo analysis was performed for spread and stability assessment and improvement using a load-pull measurement technique (*Fig. 8*). The statistical variation of the SMT



8. Monte Carlo analysis of the load-pull measurements of a matching network can demonstrate performance over a wide range of parameters.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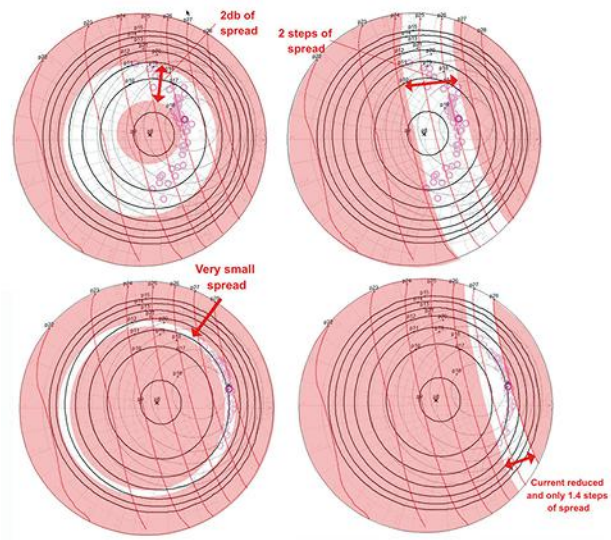
component values could have led to non-optimal performance if the circuit design wasn't robust. Thus, the Monte Carlo analysis might have revealed the need to redesign or identify component combinations that should be avoided in manufacturing. Ultimately, this approach increased the yield and overall reliability of the end product.

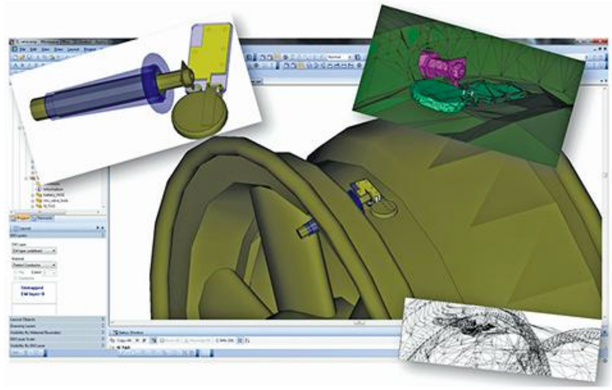
The analysis was performed both with and without optimized network matching as a control experiment to justify the investment in enhancing the design processes with such a sophisticated optimization process (*Fig. 9*). The end results of the optimized impedance matching were a decrease of roughly 1.5 dB in the ideal transmitted power and almost two steps of current-consumption reduction as compared to the ideal component values. The Monte Carlo analysis also revealed a decrease of 0.6 steps of current consumption spread and a decrease of over 1 dB of output power spread over the full range of statistical variation. These results indicate greatly improved overall power efficiency over statistical component variations, which directly impacts the lifetime of the TPMS.



9. The custom method approach leveraging optimization substantially improved the current and impedance spreads over the range of analysis parameters.

ENVIRONMENTAL DISTURBANCES ANALYSIS

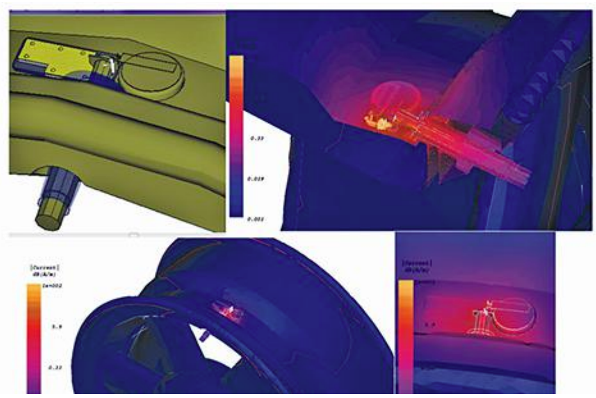
The external environmental parasitics introduced in a final assembly also can significantly affect TPMS efficiency and performance. Though the impedance-matching circuitry optimization revealed substantial internal enhancements, the designers went a step further and simulated a car wheel and TPMS model in the Analyst simulator to explore environmental effects (*Fig. 10*). The simulation results revealed current patterns, antenna radiation patterns, and even component physical-body effects on PCB trace performance.



10. Finite-element method simulation was utilized to demonstrate the effects of several environmental factors.

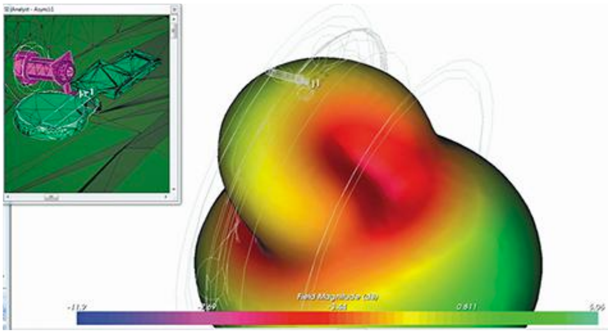
A physical model of the complete TPMS assembly installed within a wheel was used to analyze the current distribution during TPMS transmitter operation. The simulation showed significant current on the inside of the wheel rim that would most likely affect the transmitter performance and radiation pattern of the valve antenna (*Fig. 11*).

The impact of the wheel body and rim on the antenna radiation pattern is observed as a 3D intensity map in the simulator (*Fig. 12*). A tandem window display shows the physical model's orientation and interaction alongside the antenna radiation pattern to help understand the implications of the wheel's EM influence.

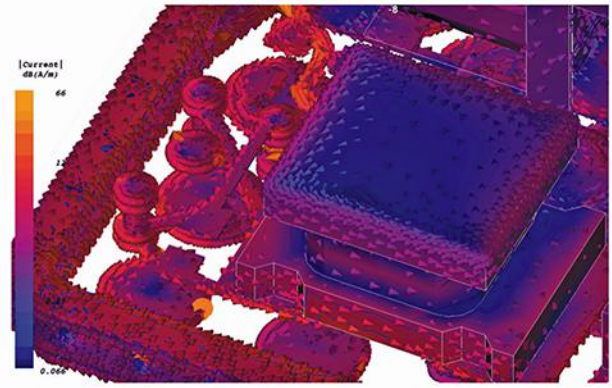


11. The close proximity and metallic nature of the wheel rim introduce reflections and disturbances that must be gauged to ensure design requirements.

The analysis reveals that only a small portion of the wheel body and rim impact the TPMS sensor behavior. A smaller parametric shape subsection of the wheel and TPMS assembly were used for more detailed simulations. Otherwise, the computational resources for the rather large wheel assembly would limit the resolution of the simulation. This is especially important when analyzing the effect of SMT component bodies when



12. 3D mapping of the antenna radiation pattern offers insight into how well the car receivers pick up the tire-pressure monitoring system transmissions.



13. 3D modeling of the physical components takes into account the packaging parasitic effects.

installed on the PCB tracks. Unpredicted current losses from parasitics could be identified and designed around that, helping prevent undesirable inefficiencies and internal interference (*Fig. 13*).

CONCLUSION

The use of a single integrated design environment, inclusive of circuit design software and EM planar and 3D FEM simulators, was critical in streamlining the design flow and enhancing optimization of the Sensata TPMS system. The software also allowed customized scripts to be utilized, enabling the designers to tweak the circuit components for even greater optimization. As the safety legislation and mandates continue, automobile manufacturers across the globe will need better performing TPMS. High-frequency software will become increasingly necessary to overcome the intensive design challenges introduced by the automotive industry. mw

SIMULATION SOFTWARE FOSTERS NEW WIRELESS STANDARDS

WHEN THE NEED for a new wireless standard has been established, a technical committee will discuss and negotiate a preliminary proposal. All of the proposal's elements—including its scope, key definitions, and content—are then negotiated. Simulation software is increasingly being used to study new technologies, helping to speed the development of standards while reducing hardware implementation costs.

For example, the 3rd Generation Partnership Project (3GPP) recently standardized Narrowband-IoT (NB-IoT), a cellular-based narrowband technology targeted for the Internet of Things (IoT). In a new white paper, *"NB-IoT System Modeling: Simple Doesn't Mean Easy,"* Keysight Technologies discusses a method for modeling and evaluating an NB-IoT system in a combined multi-domain simulation environment.

Some objectives of the NB-IoT standard include improving indoor coverage, increasing support for a vast amount of low-throughput devices, and enabling extremely low device costs. NB-IoT has been designed with three different operation modes: standalone, in-band, and guard-band. Standalone operation replaces GSM carriers with NB-IoT carriers. In-band operation utilizes resource blocks within a normal LTE carrier, while guard-band operation uses the LTE carrier's guard-band.

The white paper discusses possible NB-IoT receiver architectures, with both zero-IF and low-IF architectures noted as potential solutions. A generic low-IF architecture is presented, as well as a low-IF simulation model that takes into account various effects of non-ideal hardware.

Keysight Technologies, 1400 Fountaingrove Pkwy., Santa Rosa, CA 95403; (707) 577-2663; www.keysight.com

An RF and baseband cross-domain simulation technique is presented. The baseband signal is generated using Keysight's SystemVue LTE-A library, which supports both single-tone and multi-tone transmission. The baseband signal is filtered by two digital filters and enters a modulator. A power amplifier (PA) then amplifies the signal. The receiver demodulates the amplified signal to determine the error-vector-magnitude (EVM). EVM versus the PA's 1-dB compression point (P1dB) is simulated to evaluate how the PA's nonlinearity affects the quality of the transmission signal. The simulation results demonstrate that the PA's nonlinearity has little effect on the EVM for single-tone subcarrier spacing. However, it does negatively affect the EVM for multi-tone transmissions.

ZIGBEE 3.0 SHOWS ITS POWER

WITHOUT QUESTION, A large number of wireless technologies are associated with the Internet of Things (IoT), including Wi-Fi, Bluetooth, and ZigBee, among others. In the white paper, *"The Power of ZigBee 3.0,"* Qorvo examines ZigBee 3.0, that technology's latest specification. The white paper delves into some of the features of ZigBee 3.0, as well as some of its advantages.

The paper begins by discussing different wireless technologies, specifically the new low-power Wi-Fi standard IEEE 802.11ah. The Bluetooth standard also gets a mention, with further discussion of Bluetooth Mesh.

The white paper points to Wi-Fi, ZigBee, and Bluetooth as the three accepted core IoT radio technologies and then details them. Wi-Fi is used for familiar content distribution; ZigBee can enable sentroller (sensor/controller) networks like smart homes; and Bluetooth is utilized for connectivity, personal area networks (PANs) around a smartphone, and wearables. Furthermore, a variety of crossover products are available from various suppliers, demonstrating how these three standards truly are at the core of the IoT.

Qorvo Inc., 2300 NE Brookwood Pkwy., Hillsboro, OR 97124; (844) 890-8163; www.qorvo.com

ZigBee 3.0 is then explained. Specifically, ZigBee RF4CE is discussed in greater detail, as its latest version (ZRC 2.0) is fully integrated with the ZigBee application library. Initially developed in the consumer electronics space to replace infrared (IR) remote controls with radio-based versions, ZigBee RF4CE has since advanced significantly. ZRC 2.0 is well-positioned for the expectation of continued overlap between the consumer electronics and smart-home spaces in the future. Backwards compatibility and low latency are two key aspects of ZigBee RF4CE.

ZigBee Green Power, which is also included in ZigBee 3.0, was developed as an ultra-low-power wireless standard to support energy-harvesting devices. One common energy-harvesting application is the light switch, whereby flipping the switch generates the energy to send a communication package through the air and to the lamp. Green Power is also an effective option when using battery-power devices, as it enables years of battery operation.

JACK BROWNE | Contributing Editor

MATERIAL KNOWLEDGE Shapes Advanced Antennas

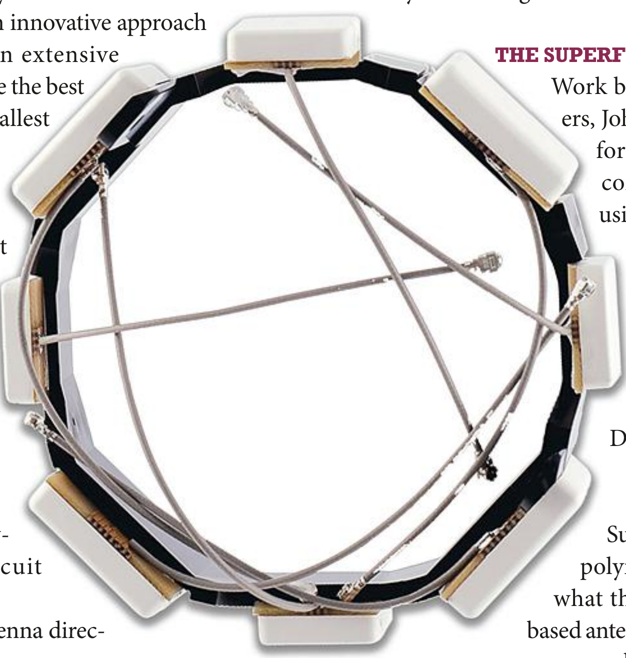
By combining a geometric approach using polymer-based dielectric materials, one company is literally changing the face of high-frequency antenna design.

ANTENNAS WILL BE needed everywhere if a Fifth-Generation (5G) future unfolds with "wireless everywhere." To help meet the present and future demands for compact antennas at RF/microwave frequencies, the aptly named Antenna Company is poised and ready with an innovative approach to antenna design, drawing on extensive knowledge of materials to achieve the best antenna performance in the smallest footprints possible.

Compact printed-circuit-board (PCB) antennas are traditionally based on resonant transmission-line circuits, such as microstrip, which are straightforward to fabricate and test. Microstrip patch antennas based on circuit materials with low dielectric constant, for example, are capable of developing the fringing fields needed for good directivity using relatively small circuit structures.

Consistent and repeatable antenna directivity is a function of the consistency of the dielectric constant across the antenna substrate material, as well as the mechanical tolerances of the microstrip transmission lines in the resonant circuitry. Recent work with advanced composite materials, often referred to as metamaterials, has shown their potential in terms of performance enhancements.

In this vein, engineers at Antenna Company sought ways to develop high-performance, form-fitting antennas that can be designed into modern wireless communications equipment (rather than simply adding them to a system). Their research culminated in the creation of dielectrically loaded polymers and an efficient computational approach to the design of 2D and 3D shapes to be used as form-fitting single-band and multiple-band wireless antennas. These new materials make it possible to produce smaller and lighter antennas with high performance, essentially reinventing dielectric resonator antennas (DRAs).



1. The ring shape of this Wi-Fi directional AP/router antenna was made possible through the use of SuperShape technology.

THE SUPERFORMULA...

Work by one of the company's founders, Johan Gielis, and his Gielis Superformula allows the calculation of complex radiating circuit shapes using a simplified set of computational parameters. Gielis serves as VP of research/materials for the firm, founded in 2013. He is joined on the management team by CEO David Favreau, CTO Dr. Diego Caratelli, and Dr. Thomas Wilhelm, VP of manufacturing.

By combining the Gielis Superformula with the company's polymer expertise, the end result is what the company calls a "geometry-based antenna technology." The technology ultimately delivers smaller antenna form factors with extended frequency coverage and improvements in gain, efficiency, directivity, and polarization. Through detailed system-level computer simulations, the company works with customers to determine optimal antenna placement and orientation for the best possible radiation patterns for a given application, whether in a fixed or mobile system.

...LEADS TO THE SUPERSHAPE

The company's SuperShape DRA antennas (SDRAs) replace the ceramic materials of traditional DRAs with a proprietary polymer material that can be shaped according to the Gielis

Superformula to achieve excellent electrical performance within defined mechanical limits. Use of polymer technology allows for simple, cost-effective integration of SDRA solutions into embedded applications, where size and cost are important considerations. Measurements have shown that SDRA systems are capable of stable radiation patterns over wide frequency ranges. In addition, they achieve high isolation, enabling systems with closely spaced multiple antenna structures without interference.

The SuperShape Antennas represent examples of the new design approach, constructed as form-fitting shapes for indoor and outdoor wireless communications applications like Wi-Fi routers and public access points (APs). Wi-Fi networks, whether using public gateways or in-home systems, are notoriously guilty of lost coverage due to blind spots and interrupted service, requiring a reset of the wireless device to regain internet access.

Some wireless connectivity problems stem from antennas with low gain and efficiency that fail to provide the required system signal strength due to propagation losses and reflections from walls and other barriers. Unwanted coupling between multiple antennas in a mobile device can also lead to interference and disruption of service.

By developing highly directional antenna reference designs (*Fig. 1, ring*) for multiple-input, multiple-output (MIMO) system configurations from 2 × 2 to 8 × 8 in array size, Antenna Company improved Wi-Fi antenna performance, such as increased coverage areas under line-of-sight (LOS) and non-LOS conditions. On top of that, it dramatically reduced the size of the antenna arrays compared to conventional microstrip technologies.

ANTENNA APPS SHAPE UP

In addition to outdoor wireless hotspots, the antennas (*Fig. 2*) are finding good fits within wirelessly connected homes and in increasingly miniaturized mobile electronic devices, such as notebook computers.

2. SuperShape technology was instrumental in creating the unique shape of this Wi-Fi directional outdoor router antenna.

The "smart home," for example, is expected to contain any number of Internet of Things (IoT) sensors that almost instantly provide data on temperature, humidity, etc., using wireless links to a centralized gateway with internet access. Antennas of many different shapes and sizes will be needed to make these smart homes a reality. For the home's connected devices, key antenna design requirements include small size and low power consumption (for "always on" access). To meet those needs, Antenna Company developed small on-board antennas that offer excellent coverage and performance while minimizing output power.

For mobile-computing applications, the company crafted a polymer-based DRA for high-performance IEEE 802.11ac MIMO notebook designs. The antenna is designed for reliable mechanical integration into the notebook hinge location while covering dual IEEE 802.11ac frequency bands with high gain, high efficiency, and high isolation (more than 20 dB) between antennas. The DRA features a more than 40% reduction in size compared to laser-direct-structured (LDS) antenna designs. As mobile devices evolve, the reduced antenna size will prove crucial to the further integration of other wireless technologies. mw

JACK BROWNE | Technical Contributor

Smaller Synthesizers Strive for Greater Stability

Frequency synthesizers continue to integrate more functionality into ever-smaller packages with lower power consumption.

FREQUENCY SYNTHESIZERS HOLD the key to dependable communications networks that so many users depend on each day. Whether as part of the network infrastructure equipment, in portable handheld products, or in test equipment to qualify their performance, RF/microwave frequency synthesizers come in many shapes and sizes and exploit multiple technologies. All are designed with a common goal: to generate stable frequencies with the lowest noise possible.

A number of parameters are used to qualify frequency synthesizers, with phase noise usually high on the list. But many other parameters help evaluate a synthesizer's quality—such as frequency range, switching speed, tuning resolution, and power consumption. Low phase noise enables high sensitivity when a synthesizer is employed as a local oscillator (LO) in a receiver, and stable transmit signals in a transmitter.

As wireless markets expanded, synthesizer designers faced a trend common to many RF/microwave components—making frequency sources smaller and more power-efficient. The industry has responded in recent years with products that pack some impressive performance levels into perpetually smaller housings.

Some of the tiniest frequency synthesizers are based on integrated-circuit (IC) semiconductor technology, which allows for integration of oscillators, phase-locked loops (PLLs), and other synthesizer components within a single chip. There is no best frequency synthesizer architecture, with various approaches based on analog and digital circuits such as phase-locked voltage-controlled oscillators (VCOs) and direct-digital-synthesizer (DDS) circuits, respectively. As with many high-frequency component technologies, each approach has its own set of benefits and tradeoffs. For that reason, some synthesizer suppliers offer products based on a number of technologies.

1. Here's an example of a modular frequency synthesizer, for use from 8 to 20 GHz, in a metal case measuring 6.125 × 4.375 × 1.50 in. *(Courtesy of Virginia Diodes)*

POTPOURRI OF SYNTHESIZERS

One such firm is Analog Devices *(www.analog.com)*, with its different types of PLL-based analog synthesizer ICs, as well as DDS sources based on conversion of digital inputs to analog outputs through a digital-to-analog converter (DAC). The company's model ADF4350 is a wideband frequency synthesizer with integral VCO that can be used as a fractional-N or integer-N synthesizer to produce phase-locked output signals from 137.5 to 4400.0 MHz.

The ADF4350 operates on supplies of +3.0 to +3.6 V dc and exhibits typical phase noise of –110 dBc/Hz offset 100 kHz from the maximum output frequency of 4.4 GHz. Spurious levels stand at –70 dBc. The PLL synthesizer measures a mere 5 × 5 mm in a lead-frame chip-scale package (LFCSP).

Another supplier of IC-based frequency synthesizers is Linear Technology *(www.linear.com)*, which was recently acquired by Analog Devices. Two recent product introductions—models LTC6946 and LTC6948—are integer-N and fractional-N PLL frequency synthesizers, respectively, with on-board VCOs.

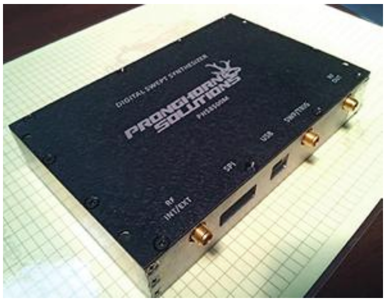
This combination of PLL circuitry with on-board VCOs is also the basis for high-performance frequency synthesizers from Skyworks Solutions *(www.skyworksinc.com)*, including its model SKY73121-11. Rather than integrating components into a single IC, however, this frequency synthesizer uses a multichip-module (MCM) approach to combine a VCO, PLL, and switch within a compact housing.

The fractional-N synthesizer, which tunes from 1,805 to 1,890 MHz, is well-suited for cellular radio base-station transceivers, achieving typical phase noise of –126 dBc/Hz offset 200 kHz from the carrier. The signal source is supplied in a 38-pin MCM housing measuring 9 × 12 × 1.7 mm. It offers switching speed of typically 208 μs to settle to within ±2 kHz of a new frequency.

MORE INNOVATIVE CONCEPTS

Synergy Microwave Corp. *(www.synergymwave.com)*, which offers extensive lines of PLL-based frequency synthesizers in coaxial and surface-mount packages, made news last year *(see "Novel ASIC Helps Sources Silence Noise" at mwrf.com)* by unveiling a line of single- and dual-loop frequency synthesizers with outputs from 100 MHz to 15 GHz in SMT packages as small as 1.00 × 1.25 in.

The synthesizers feature a novel ASIC with PLL circuitry that allowed the use of different oscillators, including VCOs and dielectric resonator oscillators (DROs), as the synthesizer's tunable source. As an example of the ASIC's capabilities, a synthesizer with bandwidth of 2.2 to 2.7 GHz achieves phase noise as good as –118 dBc/Hz as close as 1 kHz from the carrier. The synthesizer draws no more than 100 mA current from a +5-V dc supply.



2. This integer-N PLL synthesizer tunes from 0.7 to 18.0 GHz with 0.01-Hz resolution. *(Courtesy of Pronghorn Solutions)*

In terms of frequency switching speed, VCO-based PLL frequency synthesizers such as the model WSN-4G+from Mini-Circuits *(www.minicircuits.com)* are fast, with only DDS sources being faster. The WSN-4G+ tunes from 700 to 4000 MHz with worst-case frequency tuning speed of 30 μs (and typically 15 μs in a surface-mount package measuring just 1.25 × 1.75 × 0.22 in.). Ideal for jammers, the source exhibits phase noise of typically –106 dBc/Hz offset 1 kHz from a 1-GHz carrier.

3. A recent addition, this YIG-based frequency synthesizer is supplied as a single-slot PXI unit for test and system applications. *(Courtesy of Micro Lambda Wireless Inc.)*

Virginia Diodes, *(www.vadiodes.com)* offers modular frequency synthesizers that were dramatically reduced in size by re-engineering their power-supply circuitry *(Fig. 1)*. In its 6.125- × 4.375- × 1.50-in. housing, the synthesizer tunes from 8 to 20 GHz in 100-kHz steps and settles to within 20 Hz of the final frequency in less than 50 μs. It achieves phase noise of –100 dBc/Hz offset 10 kHz from the carrier and –115 dBc/Hz offset 100 kHz from the carrier. The source delivers healthy +16 dBm output with only –50 dBc spurious content and consumes 50 W power.

A relative newcomer to frequency synthesizers, Pronghorn Solutions *(www.pronghorn-solutions.com)* offers sources based on both fractional-N PLL and integer-N PLL synthesizers. The model PHS8500 *(Fig. 2)* represents the latter, with low phase noise from 0.7 to 18.0 GHz (and options for lower and higher frequencies). It tunes with 0.01-Hz resolution and provides phase-continuous and phase-coherent switching speed of 100 μs in list mode. Benchtop, modular, and handheld configurations are available.

Synthesizers functioning like self-contained subsystems or test instruments are found in Micro Lambda Wireless' (www.microlambdawireless.com) MLMS series. Based on the company's low-noise YIG oscillator technology, they add power and control circuitry to compact single-slot PXI modules *(Fig. 3)*. The line includes standard models covering 2 to 8 GHz, 6 to 13 GHz, and 8 to 16 GHz.

JACK BROWNE | Technical Contributor

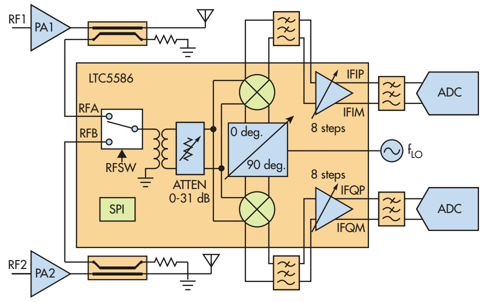
I/Q Demodulator Processes 1-GHz Bandwidths to 6 GHz

This zero-IF in-phase/quadrature demodulator provides the RF and IF bandwidths needed for the next generation of wideband-modulated wireless communications applications.

DEMODULATION OF wideband communications systems becomes more challenging with the arrival of every new wireless standard and every next generation of cellular communications system. Fortunately, the model LTC5586 in-phase/quadrature (I/Q) demodulator from Linear Technology *(www.linear.com)* helps mitigate the situation by providing the demodulation bandwidth necessary to satisfy emerging wideband requirements.

With a frequency range of 500 MHz to 6 GHz (and 300 MHz to 6 GHz by adding an external matching capacitor), this zero-intermediate-frequency (zero-IF) demodulator features an IF bandwidth of dc to 1 GHz with amplitude flatness of ±1 dB. Its wide bandwidth and high-performance analog signal processing ease the requirements for analog-to-digital converters (ADCs) at the demodulator's I and Q output ports, supporting practices such as digital predistortion (DPD) to improve transmitter linearity. The demodulator essentially has what it takes to design receivers for next-generation wireless communications systems, including Fifth-Generation (5G) cellular infrastructure systems.

The LTC5586 is a densely packed integrated circuit (IC) supplied in a surface-mount-technology (SMT) housing. Since it uses quadrature demodulation, wideband modulation can be achieved within its 1-GHz IF bandwidth without requiring extensive digital signal processing (DSP) of demodulated I and Q outputs to maintain signal linearity. As a result, the demodulator can be paired with lower-cost DSPs and field-programmable gate arrays while still maintaining excellent performance with wideband carriers through 6 GHz.



1. The dense circuit configuration of the LTC5586 includes amplification and attenuation for handling a wide range of input signal levels, as well as on-chip calibration for enhanced image rejection.

SUBSYSTEM ON A CHIP

The LTC5586 incorporates I and Q mixers; I and Q IF amplifiers with eight gain settings and maximum gain of 7.7 dB at 1.9 GHz; an RF attenuator with as much as 31-dB attenuation, adjustable in 1-dB steps; and a two-channel single-pole, double-throw switch with 40-dB isolation and 100-ns switching speed for selecting input signals *(Fig. 1)*. In addition, the demodulator provides a serial peripheral interface (SPI) to control the local-oscillator (LO) input to any frequency band from 300 MHz to 6 GHz without external matching components. The demodulator's I and Q outputs can drive filters and external ADCs when terminated with external 100-Ω differential impedance.

The wideband demodulator achieves typical –70-dBc image rejection at 3.5 GHz. The extremely linear device features output third-order-intercept (OIP3) performance of typically +35 dBm and output second-order-intercept (OIP2) performance of typically +70 dBm, both measured at 3.5 GHz.

The LTC5586, housed in a 5- × 5-mm plastic 32-lead QFN package, is designed to maintain consistent, reliable performance over operating temperatures from –40 to +105°C. To ensure optimum results, the demodulator includes on-chip calibration of the amplitude and phase responses of its I and Q channels. Calibration and other functions are controlled via the SPI connection. mw

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

JACK BROWNE | Contributing Editor

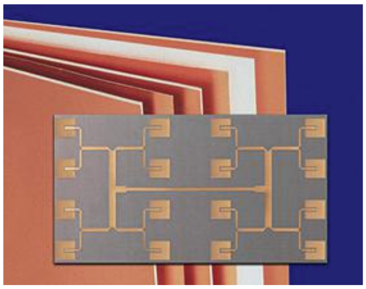
Laminates Lay Foundation for 5G Antenna Circuits

These evolutionary circuit laminates represent cost-effective solutions for low-loss antennas and active antenna arrays.

ANTENNAS ARE THE SEEN and unseen components within every wireless communications link. Some populate large cellular towers on hillsides. Others receive and transmit signals within buildings as microcell printed-circuit-board (PCB) antennas. All require a careful blend of dielectric and conductor materials to minimize intermodulation and to give low-level wireless signals every chance of getting through.

For printed-circuit antenna designers seeking the lowest possible passive intermodulation (PIM) levels, that optimum blend of materials may just be found by way of the RO4730G3 94 V-0 antenna-grade laminates from Rogers Corp. *(www.rogerscorp.com)*. Featuring a dielectric constant of 3.00 maintained to a tolerance of ±0.05 through the z axis (thickness) of the material, these laminates are capable of PIM levels of –160 dBc for almost negligible intermodulation distortion for 4G and 5G base transceiver stations (BTS) and microcells, as well as Internet of Things (IoT) wireless hubs.

The outstanding PIM performance was measured with two test tones of +43 dBm at 1.9 GHz for a 0.060-in.-thick laminate under test. RO4730G3 antenna-grade laminates *(see figure)* consist of ceramic hydrocarbon dielectric materials with low-profile LoPro copper foil to minimize PIM. Both the dielectric and conductor materials exhibit low-loss behavior. The laminates are 30% lighter than most polytetrafluoroethylene (PTFE) circuit materials traditionally used to achieve low-loss performance at microwave frequencies, assuming a comparison of materials of equal thickness.



RO4730G3 circuit materials are 94 V-0 antenna-grade laminates engineered to handle the processing steps and provide the low-loss microwave performance. needed for wireless BTSs and small cells.

NEXT-GEN LAMINATE

The antenna-grade RO4730G3 circuit materials are actually an evolution of Rogers' RO4000 circuit materials. They combine ceramic hollow spheres and an organohalogen flame-retardant additive with low-loss, high-linearity LoPro copper conductor metal to achieve enhanced performance for antenna applications.

That combination improves the material's rigidity over traditional PTFE laminates, enabling it to handle the conditions of automated-assembly manufacturing and lead-free-solder processes while being flame-retardant per Underwriters' Laboratories (UL) requirements of UL 94 V-0.

In terms of material characteristics, RO4730G3 laminates are well-suited to the requirements of present and emerging wireless-communications antennas. The dielectric constant (Dk) of 3.0 is measured in the z axis (thickness) at 10 GHz. The dielectric loss or dissipation factor (Df) in the z axis is quite low within the range of frequencies used for wireless communications—just 0.0023 at 2.5 GHz, rising to a still-low 0.0029 at 10 GHz.

In addition to impressive Dk tolerance of ±0.05 at room temperature, RO4730G3 material exhibits little change of Dk with temperature, as evidenced by a low thermal coefficient of dielectric constant of +26 ppm/°C in the z axis across a wide temperature range of –50 to +150°C. The circuit materials are formulated for high reliability over wide temperature extremes, as measured by coefficient of thermal expansion (CTE) that is relatively close to the 16.6 ppm/°C of copper.

RO4730G3 laminates exhibit a CTE of 13.7 ppm/°C in the x axis, 14.7 ppm/°C in the y axis, and 30.3 ppm/°C in the z axis, from –55 to +288°C. The z-axis value is of particular importance for multilayer designs and circuits with plated through holes (PTHs), so that copper and dielectric material exhibit similar changes with temperature.

Whether for active antenna arrays in BTS infrastructure or microstrip PCB antennas in microcells, these materials provide high performance with ease of processing. mw

ROGERS CORP., 100 S. Roosevelt Ave., Chandler, AZ 85226-3416; (480) 961-1382, www.rogerscorp.com

JACK BROWNE | Contributing Editor

Flexible Radios Deliver High-Speed IoT Data Links

These 900-MHz radio solutions provide fast data throughput and several serial ports for transferring IoT sensor data to the internet, across line-of-sight distances to 40 miles.

SENSORS EVERYWHERE: THAT'S one possible vision of the future, made all the more plausible with Internet of Things (IoT) devices providing the means to remotely control just about anything electronic. But getting the volume of data from these sensors to the internet for "anytime access" has long been the challenge—using available bandwidth to still achieve high-enough data rates to make all of that sensor data usable.

The answer may have just arrived in the form of the ZumLink 900 family of 900-MHz serial radios from FreeWave Technologies. With user-selectable transmit power, these radios can transmit data from Ethernet, USB, and RS-232 ports at high data rates (depending on serial interface) over line-of-sight (LOS) distances as far as 40 miles.

FreeWave, of course, made news earlier this year with the introduction of its dual-band WavePro WP201 radio solution, covering 2.4- and 5-GHz bands in one compact unit (*see "Short-Haul Solution Covers Two Bands" at mwrf.com*). The ZumLink 900 family of radios represents an addition to the company's lines of radio products for its Sensor-2-Sensor (S2S) wireless access-layer strategy, to transfer voice, video, and data, including in machine-to-machine (M2M) and IoT applications.

According to Scott Allen, FreeWave's CMO, "By combining amazing radio performance with an intelligent platform, ZumLink enables customers to tailor their IoT communications to whatever they need, commercial or industrial, and also provides the ability to develop custom software applications for their future technology requirements."

The ZumLink 900 Series initially includes four platforms: two radio modules, a board-level radio that can be embedded into system designs, and a fully enclosed radio, all operating in the unlicensed 900-MHz radio band from 902 to 928 MHz. The Z9-T radio module incorporates transistor-transistor-logic (TTL) data interfaces, while the Z9-C radio module provides RS-232 interfaces.

The board-level Z9-PC radio features two Ethernet and two serial data ports, and the enclosed Z9-PE radio (*see figure*) includes a single Ethernet port and two serial ports. The firm offers numerous options with the radios to meet specific customer requirements.

The ZumLink radios all operate at 900 MHz with user-adjustable transmit power (which will affect the LOS range) from 10 mW to 1 W. Link data rates currently range from

The ZumLink 900 Series high-data-rate wireless radios include the Z9-PE radio in a compact enclosure with multiple serial data interfaces.

115.2 kb/s to 4 Mb/s. Depending on the serial data connection to the radio, the radios can achieve link throughput as high as 850 kb/s with an RS-232 connection, and as high as 2 Mb/s with an Ethernet or TTL connection (at a link rate of 4 Mb/s).

The transmitters, which use Gaussian frequency shift keying (GFSK) and 8-ary FSK modulation, offer channel sizes of 115.2, 345.6, 691.2, 1382.4, and 3225.6 kHz. The radios employ frequency-hopping techniques to avoid the "RF clutter" created by the large number of wireless devices operating in the 900-MHz band, with as many as 111 frequency-hopping channels and up to 16 hopping patterns, at hopping rates of 25, 50, 100, 200, and 400 ms.

The receiver sensitivity is a function of RF data rate, with sensitivity of –106 dBm at 115.2 kb/s. With their modulation and hopping techniques, the radios achieve 136-dB system gain.

To preserve and protect data, the radios employ cyclical-redundancy-check (CRC), forward-error-correction (FEC), and automatic-repeat-request (ARQ) error correction and 128-b advanced-encryption-standard (AES) data encryption. They operate on supplies of +3 to +5 V dc with low current consumption: 1230 mA at +3 V dc and 680 mA at +5 V dc.

Each radio has built-in diagnostics capabilities and is designed for operating temperatures from –40 to +85°C. The modules each measure 2.0 × 1.4 × 0.3 in. With their flexibility and capabilities, especially the long LOS range, these radios can truly make "remote sensing" a reality. mw

FREEWAVE TECHNOLOGIES Inc., 5395 Pearl Pkwy., Ste. 100, Boulder, CO 80301; (866) 923-6168, *www.freewave.com*

Product Feature

JACK BROWNE | Technical Contributor

Software Models 3D Device Processes

This physics-based simulation software models physical, chemical, and electrical effects of semiconductor and MEMS fabrication processes, and can trace defects to a source.

PREDICTING THE OUTCOME of advanced processes, such as those for fabricating semiconductors or microelectromechanical-systems (MEMS) devices, can be extremely complex. The calculations are not made any easier as device features continue to shrink. However, a new 3D simulator from Coventor *(www.coventor.com)*, SEMulator3D, can perform like a virtual foundry.

SEMulator3D helps evaluate new semiconductor or MEMS designs before performing expensive experiments with a foundry process. The recently announced sixth generation of this modeling tool builds on previous versions by combining structural modeling with sophisticated electrical analysis capabilities; adding new features; and allowing users to expand the program at any time with an add-on software module for resistance and capacitance parameter extraction.

Variations exist within any semiconductor material, no matter the wafer size. Further variations occur with each process step used to fabricate a MEMS device or semiconductor, such as a field-effect transistor (FET). The SEMulator3D 6.0 software (*see figure*) uses physics and 3D voxel (cube-based) modeling technology to analyze device structures and predict outcomes of complete process flows for analog and digital devices.

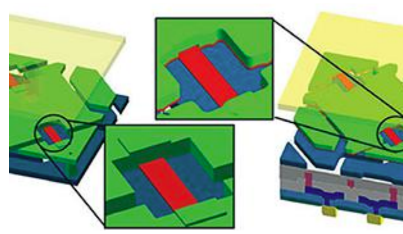
In the world of 3D imaging, a voxel or volume element is a type of building block, like a pixel in a two-dimensional (2D) environment. SEMulator3D also features surface-evolution modeling that predicts the effects of changes in surface features during different process steps.

This physics-based software evaluates device design and fabrication as a function of the process flow, analyzing a semiconductor or MEMS fabrication process as a series of unit process steps that can be understood and optimized. Typical fabrication steps involve different types of etching; deposition of layers; epitaxial and other means of growth; and functions such as lithography, implantation, and diffusion.

A user can enter geometrical and physical parameters for each process step to experiment with known or unknown process variations and to better understand how the different device process steps interact with each other when producing the final device. The software helps analyze devices such as NAND flash memory, DRAM, FinFETs, nanowires, and MEMS devices.

WHAT FUNCTIONALITY WAS ADDED?

This latest software version allows for random insertion and placement of defects as part of enhanced process diagnostics. In this way, a user can trace a known defect back to an originating process step or the tool that might have caused it. The new version also enables users to export meshes to additional file formats, as might be needed for analyzing dopant concentrations in a 3D finite-element-analysis (FEA) software program.



The sixth-generation SEMulator3D process simulation software adds new features and analysis capabilities, including resistance and capacitance solvers, but maintains its ease of use thanks to a straightforward GUI.

Perhaps one of the strongest new capabilities of the software is the Electrical Analysis module. It allows users to better understand how device and process variations translate into resistance and capacitance effects for a given design. The software solves for resistances and capacitances without requiring time-consuming meshing or data export to mathematical analysis tools.

In spite of its sophistication, the software is easy to use thanks to a straightforward graphical user interface (GUI). Ease-of-use was further enhanced through a new environment for the Analysis Editor. Analysis steps—e.g., metrology, structure search, and parasitic extraction—are now separated from the process sequence to make it easier to apply input data and understand the results of modifications. The simulation software can also import design data such as GDSII layout data or OASIS layouts.

Furthermore, the base virtual fabrication software offers the means for visualizing various ion implantations, dopant concentrations, epitaxial processes, etching, and DSA processes as part of fabricating a device or an IC. mw

COVENTOR INC., 1000 Centregreen Way, Ste. 200, Cary, NC 27513; (919) 854-7500, e-mail: sales@coventor.com.

Miniature Hybrid Spans 0.5 to 1.0 GHz

MODEL 2164-90 is a miniature 90-deg. hybrid designed for use from 500 MHz to 1 GHz. It provides 25-dB minimum isolation between ports with maximum VSWR of 1.25:1 and maximum insertion loss of 0.25 dB. The hybrid coupler, which is supplied with SMA female coaxial connectors, measures just 3.25 × 1.19 × 0.50 in., but can handle 100 W average power and as much as 5 kW peak power.

ARRA, INC., 15 Harold Ct., Bay Shore, NY 11706-2296; (516) 231-8400, *www.arra.com*

Attenuator Has 60-dB Range from 6 to 12 GHz

MODEL PD-VAN-6012-60-8 is an 8-b programmable PIN diode attenuator with 60-dB total attenuation range and 0.25-dB step resolution from 6 to 12 GHz. The maximum insertion loss is 2.8 dB, with more typical measured insertion loss of 2.13 dB. The VSWR is 2.0:1 or better and typically 1.70:1. The attenuator is rated for as much as +20 dB continuous-wave (CW) output power and can survive surges as high as 1 W (+30 dBm). Attenuation flatness is better than ±0.7 dB at 10-dB attenuation, better than ±1.5 dB at 40-dB attenuation, and better than ±1.6 dB at 60-dB attenuation. The compact attenuator, which is supplied with SMA female connectors and 15-pin subminiature-D male connectors and 8-b transistor-transistor-logic (TTL) control, measures just 2.00 × 1.80 × 0.50 in. It draws a maximum of 150 mA from +12 to +15 V dc and a maximum of 75 mA from −12 to −15 V dc.

PMI, 7311-F Grove Rd., Frederick, MD 21710; (301) 662-5019, e-mail: sales@pmi-rf.com, *www.pmi-rf.com*

Benchtop Scope Doubles as Portable Tester

MODEL DSC-5300 is a general-purpose, low-frequency digital storage oscilloscope (DSO) that is equally at home on a benchtop or in the field. The two-channel instrument features a 50-MHz bandwidth and operates with single-channel real-time sampling rates to 500 MSamples/s. It provides 32 kpoints of memory and shows signal waveforms on a 7-in. color liquid-crystal-display (LCD) screen. As many as 10 waveforms and as many as 20 scope settings can be saved to internal memory, and a built-in Universal Serial Bus (USB) allows control and data transfer with an external computer. P&A: stock; $349.

GLOBAL SPECIALTIES, 22820 Savi Ranch Pkwy., Yorba Linda, CA 92887; (800) 572-1028, *www.globalspecialties.com*

High-Q MLCCs are Stable with Temperature

THE H SERIES of high-quality-factor (high-Q) multilayer ceramic capacitors (MLCCs) provide stable performance in high-temperature, high-frequency circuits. The tiny components feature an extended operating temperature range of −55 to +150°C. They are available in a wide range of values and case styles, including 0603 and 0805 packages. The capacitors, which are suitable for impedance matching and DC blocking, are designed for long, reliable operating lifetimes in applications with wide operating temperature ranges, such as automotive electronics and small cellular base stations.

SYFER TECHNOLOGY LTD. (PART OF KNOWLES CAPACITORS), Old Stoke Rd., Norwich NR14 8SQ, UK; +44 1603 723300, e-mail: SyferSales@knowles.com, *www.syfer.com*

Variable Attenuators Pad 0.4 to 18.0 GHz

A LINE of coaxial voltage-variable attenuators (VVAs) offers as much as 60-dB attenuation from 400 MHz to 18 GHz. Ideal for communications systems, test equipment and electronic-warfare (EW) systems, the attenuation levels of these PIN-diode-based VVAs are set by varying an analog voltage on the input control line. The product line includes six models rated for CW input power to +23 dBm. The unit with the broadest bandwidth is model PE70A2900, which operates from 500 MHz to 18 GHz with 0 to 60 dB attenuation. It exhibits 3.5-dB insertion loss and is supplied with field-replaceable female SMA connectors. All models meet MIL-STD-202 environmental requirements.

PASTERNACK, 17802 Fitch, Irvine, CA 92614; (949) 261-1920, *www.pasternack.com.*

Rack-Mount Amplifier Powers 6 to 18 GHz

MODEL BME69189-20 is a Class AB linear solid-state amplifier module capable of 20 W output power from 6 to 18 GHz in a housing measuring just 6.56 × 3.50 × 0.84 in. and weighing 1.4 lb. It achieves more than 41 dB gain (and typically 45 dB gain) at 20 W output power, reaching 3-dB compression output power with +10 dBm input power. The gain flatness is within ±4 dB. Second harmonics are better than –15 dBc, while third harmonics are less than -25 dBc; spurious content is less than -60 dBc. The amplifier module is powered by +28 V dc and is designed for operating temperatures from –40 to +55°C. It is supplied with SMA female field-replaceable connectors.

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

Coaxial Adapters Keep PIM Under Control

A LINE of coaxial adapters well suited for distributed antenna systems (DAS) is available for use with 7/16 DIN, SMA, Type N, and 4.1/9.5 standard and bulkhead connectors. With passive intermodulation (PIM) performance of typically –165 dBc or better, these adapters help minimize intermodulation in wireless base stations as well as in-building wireless communications infrastructure systems, including for Fourth-Generation (4G) and Fifth-Generation (5G) cellular communications equipment.

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

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