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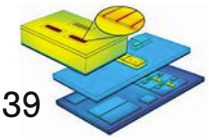

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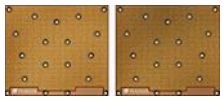


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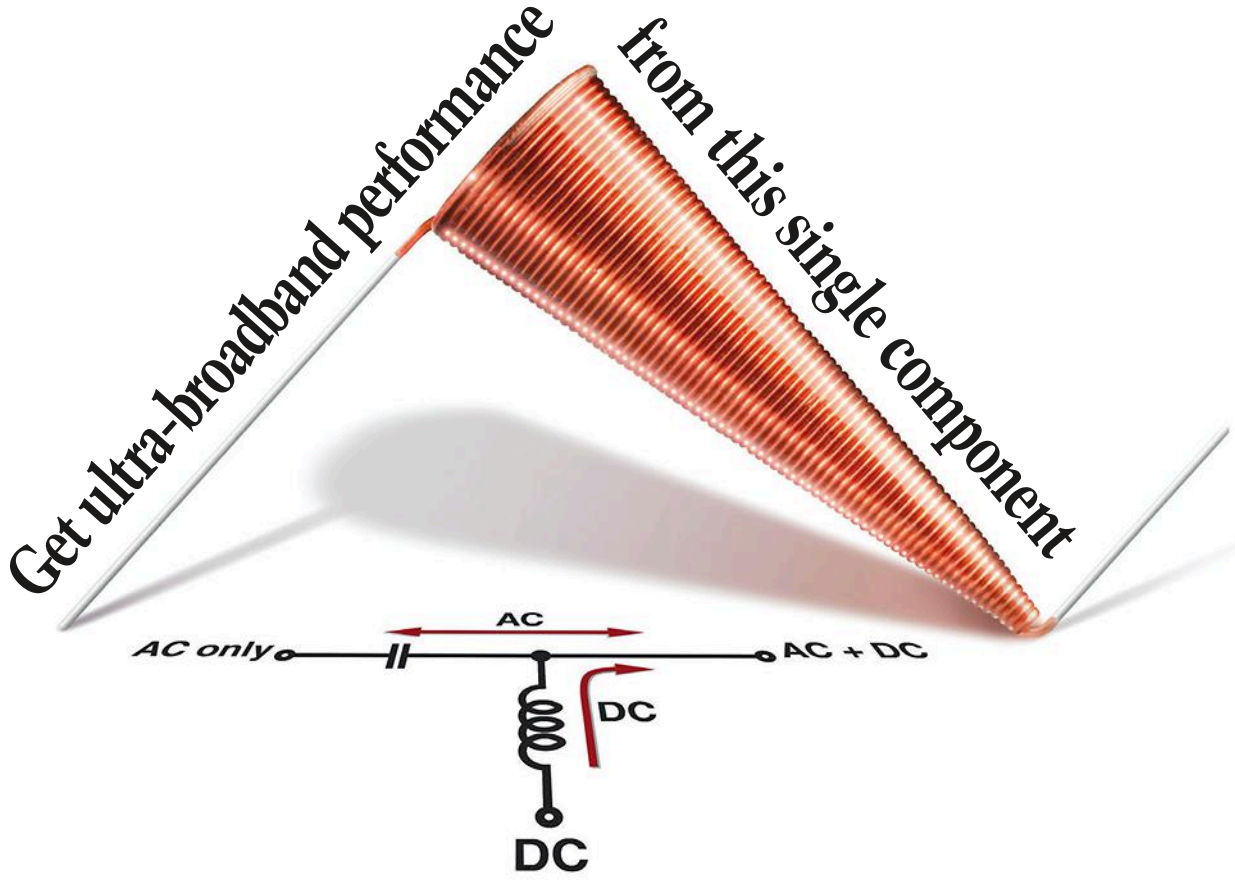


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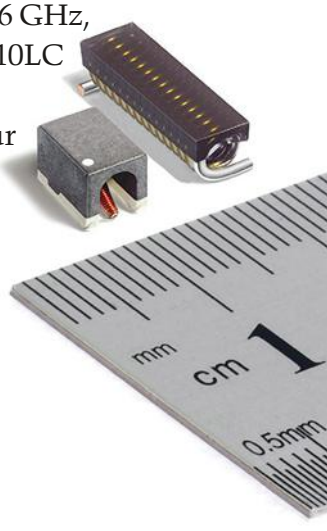


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|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2.5 GHz | 6.0 GHz | 2.5 GHz | 6.0 GHz | 2.5 GHz | 6.0 GHz | | |
| CG2163X3 | SPDT | 6.0 | 0.40 | 0.50 | 40 | 31 | +33 @ P1.0dB | +32 @ P1.0dB |  | (1.5 x 1.5 x 0.37) |
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| CG2176X3 | Absorptive SPDT | 6.0 | 0.45 | 0.55 | 30 | 22 | +37.5 @ P0.5dB | +37.5 @ P0.5dB |  | (1.5 x 1.5 x 0.37) |
| CG2179M2 | SPDT | 3.0 | 0.45 | N/A | 26 | N/A | +30 @ P0.1dB | NA |  | (1.25 x 2.0 x 0.9) |
| CG2185X2 | SPDT | 6.0 | 0.35 | 0.40 | 28 | 26 | +29 @ P0.1dB | +29 @ P0.1dB |  | (1.0 x 1.0 x 0.37) |
| CG2214M6 | SPDT | 3.0 | 0.35 | N/A | 25 | N/A | +30 @ P0.1dB | NA |  | (1.1 x 1.5 x 0.55) |
| JUST ADDED CG2409M2 | SPDT | 3.8 | 0.45 | N/A | 27 | N/A | +37.5 @ P0.1dB | NA |  | (1.25 x 2.0 x 0.9) |
| JUST ADDED CG2409X3 | SPDT | 6.0 | 0.40 | N/A | 26 | N/A | +37.5 @ P0.1dB | |  | (1.5 x 1.5 x 0.37) |
| CG2415M6 | SPDT | 6.0 | 0.35 | 0.45 | 32 | 26 | +31 @ P0.1dB | +31 @ P0.1dB |  | (1.1 x 1.5 x 0.55) |
| CG2430X1 | SP3T | 6.0 | 0.50 | 0.60 | 28 | 25 | +28 @ P0.1dB | +28 @ P0.1dB |  | (1.5 x 1.5 x 0.37) |

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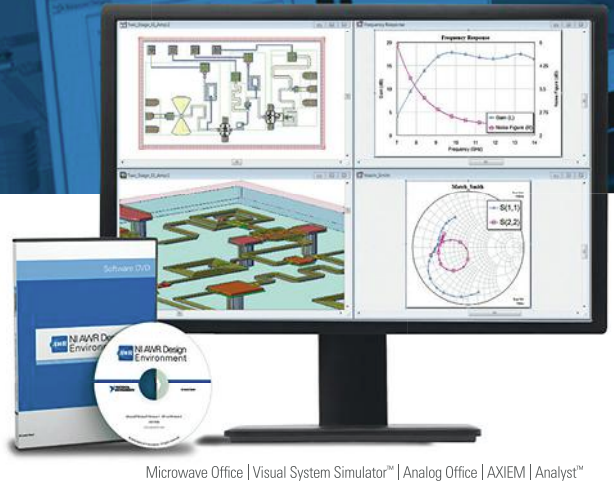


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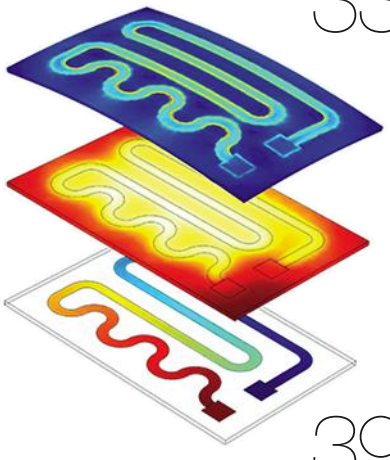



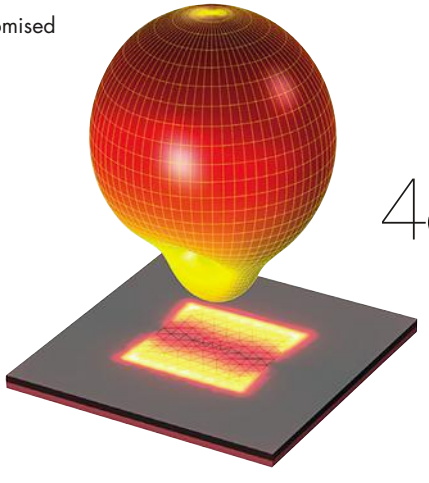



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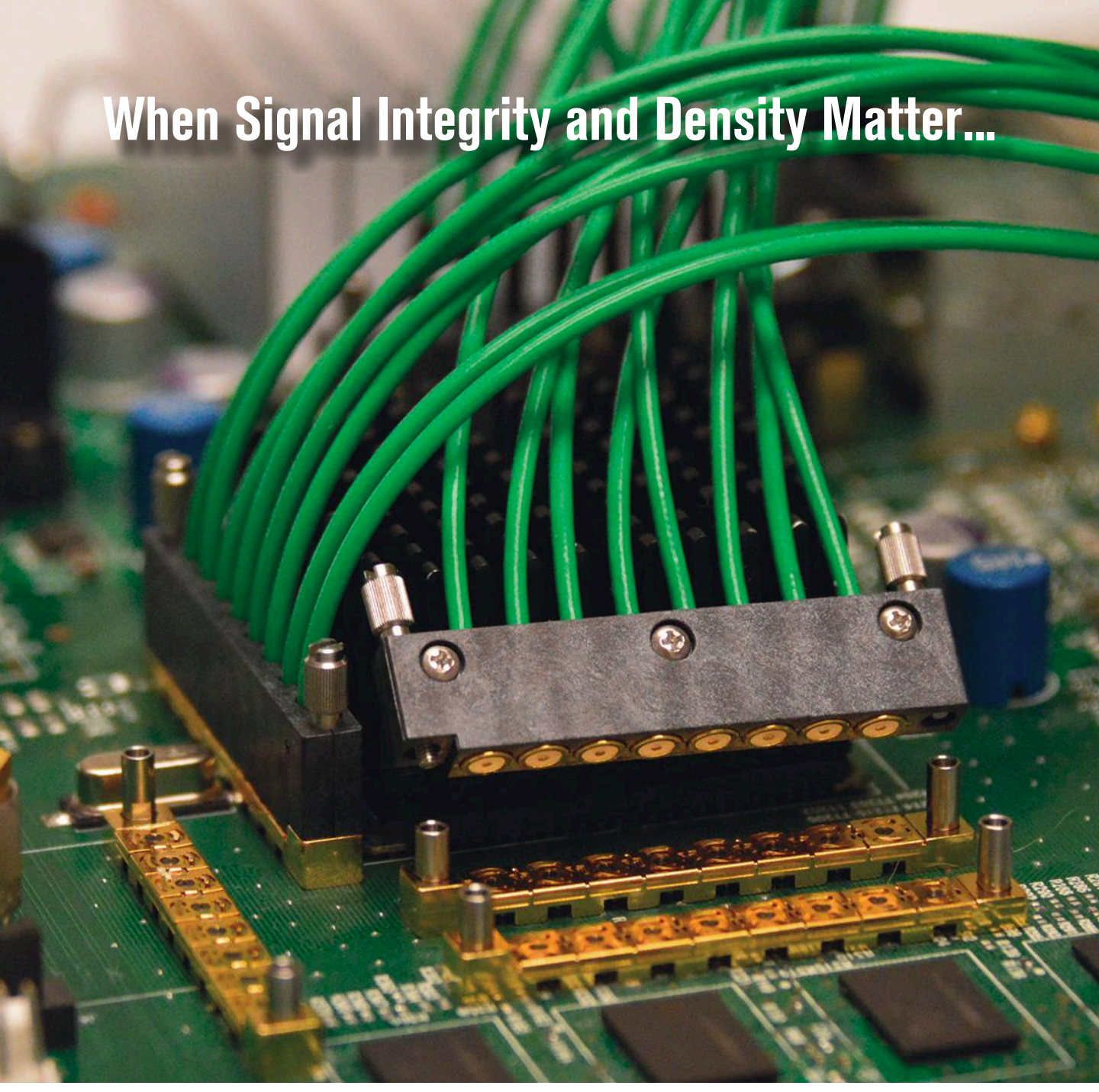


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*http://mwrf.com/systems/microwave-energy-aims-improve-health*

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## WIRELESS TECHNOLOGY CONNECTS INTERNET TO THINGS

*http://mwrf.com/systems/wireless-technology-connects-internet-things*

The billions of electronic devices that will comprise the Internet of Things (IoT) universe may one day tell us at a glance all we need to know. While some communications systems operate with physical cables, such as landline telephone networks, cable-television (CATV) systems, and power utilities, most IoT devices and IoT networks will rely on wireless technology. Thus, the choice of said technology will have a great deal to do with the success of these IoT networks.

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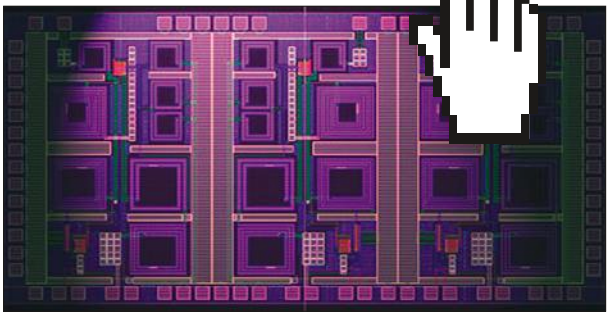


## EM SIMULATION TECHNOLOGIES SUPPORT RFIC DEVELOPMENT

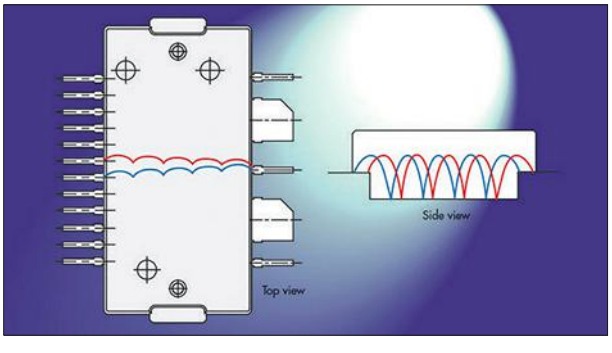
*http://mwrf.com/software/em-simulation-technologies-support-rfic-development*

RF integrated circuits (RFICs) employ a variety of different interconnect and passive component geometries. Each requires specialized electromagnetic (EM) technology to provide accurate modeling in a reasonable amount of simulation run time. For example, a transistor feed network may consist of a complex network of short traces, best modeled using quasi-static techniques for parasitic extraction. On the other hand, electrically longer structures require planar or 3D EM simulation to capture full-wave behavior.

## LDMOS RFICs GAIN GROUND IN SMALL CELLS

*http://mwrf.com/analog-semiconductors/ldmos-rfics-gain-ground-small-cells*

Cellular wireless-communications-link handsets and their users throughout the world are often located by large base stations, and transmissions from those base stations are typically powered by discrete silicon LDMOS RF/microwave power transistors. But with increasing use of smaller cells to provide wireless coverage at the edges of large cells—in shopping centers, airports, and other public places—LDMOS RF integrated circuits (RFICs) are supplying the transmission power rather than discrete devices.



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## Editorial

CHRIS DeMARTINO
Technical Editor
chris.demartino@penton.com

# Narrowband-IoT Proves Its Worth

One of the more talked about wireless communication technologies for the Internet of Things (IoT) is Narrowband-IoT (NB-IoT). If you don't already know, NB-IoT is a cellular-based narrowband technology that uses licensed spectrum.

Although it is integrated in the LTE standard, NB-IoT is actually a new air interface. It was standardized by the 3rd Generation Partnership Project (3GPP) as part of Release 13 this past June, but development is not expected to stop there. And applications for the technology will likely span a broad range, from smart metering and smart cities to agriculture and white-goods monitoring.

For the most part, today's cellular networks are not intended for applications that transmit small amounts of data—this is where NB-IoT steps in. NB-IoT is intended to be simple and efficient, with objectives that include improving battery life and lowering device costs. Another goal is improvement of coverage areas. Locations that cannot be reached easily, such as those deep within buildings, should reap the benefits of NB-IoT.

One company deeply involved with NB-IoT technology is u-blox *(www.u-blox.com)*, as evidenced by its SARA-N2 series of modules. The series is comprised of three modules—the SARA-N200, SARA-N201, and SARA-N210—each covering a different NB-IoT band.

On another front, Nokia recently conducted an IoT trial in Finland using NB-IoT technology. Nokia utilized NB-IoT to enable communication over Sonera's (a Finnish operator) 4G network in Helsinki. In addition, a roaming device was connected over the network using NB-IoT.

Nokia base-station technology, operating in the 800-MHz frequency band, was used by the Sonera network—speeds reached as high as 200 kb/s. The trial results clearly proved the significant potential possessed by NB-IoT technology in terms of supporting the IoT.

It goes without saying that many wireless technologies are currently in play for the IoT. Although time will reveal how it all plays out, NB-IoT is surely one to keep close tabs on. MW

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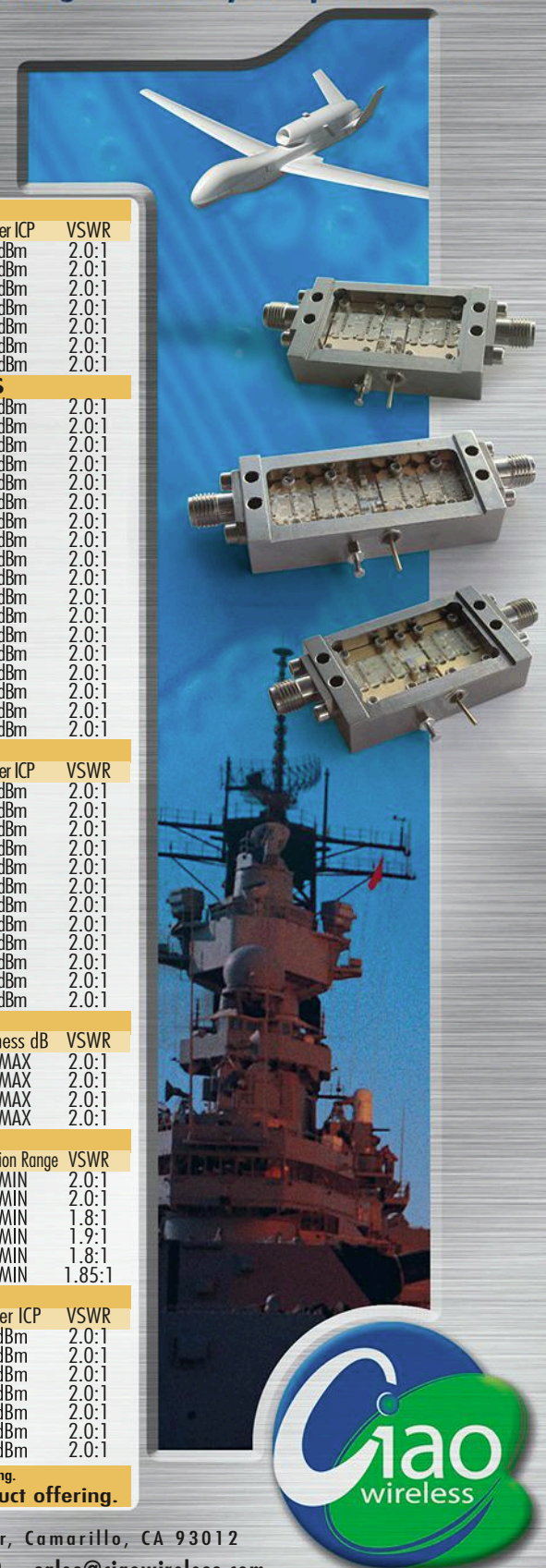

### OCTAVE BAND LOW NOISE AMPLIFIERS

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

### NARROW BAND LOW NOISE AND MEDIUM POWER AMPLIFIERS

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

### ULTRA-BROADBAND & MULTI-OCTAVE BAND AMPLIFIERS

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

### LIMITING AMPLIFIERS

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

### AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

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

### LOW FREQUENCY AMPLIFIERS

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

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## WHICH CAME FIRST: MEASURE OR MODEL?

The editorial in your November issue ("Will Your Design and Test Flow Soon Be Obsolete?") made some interesting points about designing and testing. It referred to changes about to take place in the way RF/microwave products are developed, especially with the impact of the Internet of Things (IoT) market and its potential billions of items sold each year. Whether at the design stage or in production, these mixed-signal devices must be modeled and then tested. As someone much wiser than me once said, "Time is money," especially in terms of modeling and measuring high-frequency electronic products.

I wanted to remind readers that this industry has already experienced at least one "transformation" in the design and test flow, when it embraced cellular communications in the early 1990s. Designers were faced with much faster design cycles than had been typical of military and aerospace applications. Design engineers came to lean more on simulation software to create the circuits necessary for wireless communications.

Today, the use of software is almost taken for granted as part of the design process, and comparisons are often made between simulated and measured performance when prototype circuits are assembled. The device and component models contained in commercial CAE programs are quite good, but this is a belief based on practice and experience. How is it possible to know is a software program's models are accurate? Aren't measurements critical to developing a model and don't they have to come first?

*Donald Shortell*



## EDITOR'S NOTE

Measurements are indeed vital to any model, and any effective design and test flow hould incorporate ongoing measurements to enhance the accuracy of established models.

It might be easier to understand the interaction between modeling and measuring in an article on thermal modeling elsewhere in this issue. While most RF/microwave engineers may be familiar with EM simulation software, not quite as many may use thermal modeling software. Models may be first created based on physics, but then measurements are needed to see how close the equations come to reality. The goal in any design and test flow is to narrow the gap between the modeled and the measured curves for a design. When there is only one curve, the goal has been met.

*Jack Browne*
*Technical Contributor*

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Photo of TR5048 in use at CERN.
*Photo courtesy of Daniel Valuch.*

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# News

# Built to Help Computers Understand Hand Gestures,

## Tiny Radars Now Identify Objects

*(Image courtesy of Infineon Technologies)*

Radars are not known for having a keen sense of detail. They shoot out radio signals and measure the reflections, rendering an object's location as a series of digital coordinates or a pulsating dot on a radar display. Cameras or laser scanners are generally better equipped to determine an object's shape or size.

But in recent years, new advances have improved radars to the point where they can generate rough images of the physical world. Several companies are making radars that help drones and autonomous cars avoid obstacles using specialized materials and software.

Now researchers in Scotland have further enhanced what radars can do—using radar to instantly recognize objects like metals and body parts and distinguish between them, according to a paper presented at the Symposium on User Interface Software and Technology.

To build the classification system, the researchers used a miniature radar chip that Google unveiled at its I/O developer's conference in 2015. The chip, called Soli, had been designed to track slight finger movements, so that people can use hand gestures to control computers and smartphones.

But the researchers at St. Andrews University found that the radar chip can recognize slight variations in the surface and composition of objects placed against it. The radar signals reflect off objects and materials in unique ways, creating something like a digital signature.

The system, also known as Radar Categorization for Input & Interaction or RadarCat, trains itself with machine-learning algorithms to read those signatures and assign them to an object. It has been shown to instantly identify things like sponges and smartphones, differentiate between copper and steel, and tell if a glass of water is empty.

The researchers demonstrated the system in a video accompanying the paper. RadarCat can be used to create an object dictionary, allowing shoppers to compare the nutrition information of different fruits or the specs of different smartphone models. The researchers also suggest using it to speed up checkouts at supermarkets or separate recycling.

They also showed that the system could recognize body parts, allowing smartphones or other devices to use them like hot keys. They explained that touching the radar on the back of your wrist could open a watch app. Placing the radar against your stomach might launch a food-delivery app like Uber Eats.

Meanwhile, the Soli radars are several months from being put on the market. Infineon, which partnered with Google to build the chip, has said that it expects samples to be available in the first half of 2017 and production devices to go on sale in the second half. ■

## QUALCOMM TEASES A Prototype Spectrum-Sharing Radio

**A PROTOTYPE RADIO** is using new technology to gain access to large swaths of wireless spectrum that are not being used to their full potential. Built by Qualcomm, it is the latest attempt to communize the wireless spectrum used by billions of smartphones, tablets, and other devices.

The company recently teased the new radio, which has been built to flip between licensed and unlicensed spectrum utilizing a technique known as spectrum sharing. With it, the radio listens into different frequency bands, finds the fastest ones, and subsequently allows smartphones and other devices to pluck signals from them.

Efficiently sharing spectrum could help address the explosive demand for mobile data spurred by new technologies like virtual reality and sensor networks in factories. In the view of Qualcomm executives, it could also form a central part of the next generation of wireless technology, also known as 5G.

The 5G New Radio, as the prototype is called, searches up and down the wireless spectrum for potential openings. The radio can broadcast on frequency bands below 6 GHz, where most of today's devices send communications, and then leap into higher bands in the millimeter-wave range.

The concept of sharing spectrum faces uncertain regulatory hurdles, though. Wireless carriers pay billions for exclusive rights to thin slices of radio spectrum, and many might not want to surrender those rights. The government, for its part, will likely have to keep a database of different spectrum bands, a kind of traffic report, that devices will review before picking a channel. The database would also keep track of which bands are off-limits or used by the military.

One of the biggest concerns, however, is that sharing spectrum might cause interference. Qualcomm has endorsed an array of controversial technologies that break from their prescribed frequency bands to increase download speeds. A technology known as LTE in the unlicensed spectrum, or LTE-U, has been at the epicenter of the controversy, accused for barnstorming the same spectrum used by Wi-Fi and interfering with its signals.


*(Image courtesy of Thinkstock)*

There have been attempts at compromise. Many companies have agreed to conduct tests that could shed light on what the industry has dubbed a "peaceful coexistence." But Qualcomm has argued that the compromises are inherently biased against LTE-U, and that the technology is being asked to provide unnecessary protections for Wi-Fi that it won't reciprocate.

Qualcomm says that it has installed fail-safes, including what is known as listen-before-talk technology. Like knocking before opening a bathroom door, it checks Wi-Fi channels for traffic before allowing smartphones to send messages or stream video over the same spectrum. Qualcomm's prototype is said to have the same technology.

The prototype is based on the sub-gigahertz and millimeter-wave radios that Qualcomm unveiled earlier this year. It will be used for technology development in 2017, Qualcomm said in a statement. It will start field trials after that, though the company didn't specify when. ■

# AN ANTENNA That Tethers Cars to Their Surroundings

**ETHERTRONICS HAS TAKEN** a well-thumbed page from the wireless industry's playbook.

The chipmaker announced that it would start selling an antenna that tethers cars wirelessly to things like traffic lights and other vehicles, recycling technology it first created for threading wireless signals inside and out of smartphones.

The San Diego-based company says it has shipped around 1.4 billion antennas for linking smartphones and myriad other devices to cellular networks. But the announcement pushes it deeper into the hot market for automotive chips. New systems are being developed to upload driving data to the cloud and send automatic software updates to cars.

Over the last few years, wireless companies like Ethertronics have enshrined automotive electronics as the next big thing. Qualcomm and Skyworks Solutions, who blossomed making the intestines of smartphones, have also repurposed their wireless chips for cars.

The new antenna, which debuted at the electronica trade show in Munich, Germany, is capable of what is called active steering. It plots out multiple paths over which information can travel. An algorithm samples and switches between them, picking the fastest and most reliable one out of the bunch.

It is designed for vehicle-to-everything—also known as V2X—communication devices that give cars a more detailed and instantaneous view of their surroundings. The hardware allows cars to broadcast their position and speed to almost everything, like construction equipment and smartphones in pockets of people walking on the sidewalk, and vice versa.

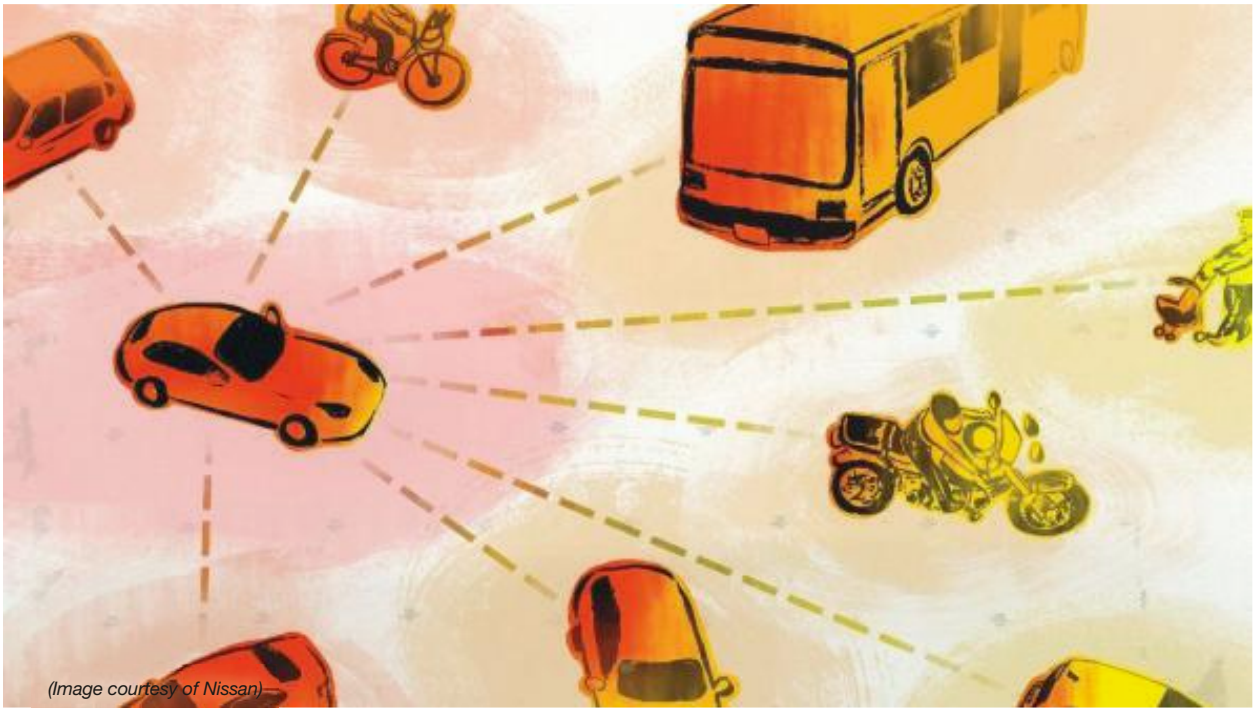
That includes connecting cars with other vehicles on the road. Such systems could allow vehicles to detect cars around corners or hidden in a snowstorm that a human driver would not see. V2X is considered a vital part of autonomous cars, which depends on a combination of cameras, lasers, and radar sensors to drive without human intervention.

Ethertronics said that its antennas can cycle between wireless signals every few milliseconds, eliminating blind spots in coverage and better navigating crowded networks. The technology also helps the antenna hit devices on the fringes of a network or hidden behind walls.

The company has embedded the same technology inside antennas for smartphones, home routers, and sensors. Founded in 2000, the company has signed deals with manufacturers as large as Samsung and as small as Switzerland's Sirin Labs, the maker of the $17,000 smartphone.

The new antenna is designed to be mounted on the exterior of the vehicle. The EtherDSRC—which nods at the dedicated short-range communications being tested for connected cars—exhibits 5-dB peak gain and is controlled digitally from a single radio cable.

It is capable of transmitting data over the spectrum that the United States and Europe reserved for V2X devices. The company has also developed an embedded version of the chip, which operates over the same frequency bands and features a 4-dB maximum gain. ■



*(Image courtesy of Nissan)*

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## WITH ACQUISITION, Analog Devices Continues Move Toward IIoT

**FOR YEARS, ANALOG DEVICES** has been shifting toward chips that manage power and condition sensors inside cars and factory equipment. Now, the Norwood, Mass.-based chipmaker is moving deeper into technology for sharing information between devices.

The company has acquired Innovasic, a maker of Ethernet chips that act like tiny switchboards inside large networks of devices, such as factory robots or security cameras. The financial terms of the deal were not disclosed.

Innovasic, which was founded in 1992, started out making replacement chips for products no longer manufactured by companies like AMD and Intel. The New Mexico-based company focused on creating products with long lifetimes, since industrial equipment is not typically updated as often as consumer electronics.

It still does that work, but now it also creates its own unique microcontrollers for coordinating robotic arms in an assembly line or connecting sensors inside a vehicle's gas tank with the fuel gauge. It also makes the software for processing all that data in real time.

"In environments such as automotive manufacturing, where teams of robots are working in tandem in harsh and noisy conditions, our automation customers demand robust, synchronized, network technology," said Kevin Carlin, general manager of Analog Devices' automation business, in a statement.

Innovasic is mostly known for its Fido networking chips, which shift real-time software capabilities into hardware. That makes them useful in applications where precise timing is important, like deploying airbags or filling soda bottles in a factory. Innovasic sells the chips to companies like Rockwell Automation and Schneider Electric.

Ensuring that an entire network can make split-second decisions has become an increasingly vital part of industrial chips. Intel's new Atom processors, the E3900, include what the chipmaker calls time-coordinated computing, which synchronizes an entire network of connected devices to achieve timing accuracy within a microsecond.

Innovasic will be folded into Analog Devices' Industrial Automation Business unit. "With this acquisition, ADI is now able to offer its customers a path forward from the sensor to the connected future of Industrial IoT," said Carlin. ■

## RAYTHEON ENHANCES GaN for the USAF

**RAYTHEON CO. RECENTLY** received a $14.9 million contract from the United States Air Force Research Laboratory and the Office of the Secretary of Defense to further enhance its process for fabricating discrete devices and monolithic integrated circuits (ICs) based on gallium-nitride (GaN) semiconductor materials. These wide-bandgap materials are capable of producing high signal power levels at microwave through millimeter-wave frequencies with relatively high efficiency.

The new contract agreement follows a previous GaN Title III contract, completed in 2013, with the additional investment intended to improve performance, reliability, and yield of the high-power microwave semiconductors. The high-power GaN devices are used in a wide range of defense circuits and systems, including radars as well as the U.S. Navy's Air and Missile Defense Radar and Next Generation Jammer.

Colin Whelan, vice president of advanced technology in Raytheon's Integrated Defense Systems business unit, explains: "We have only scratched the surface when it comes to harness-

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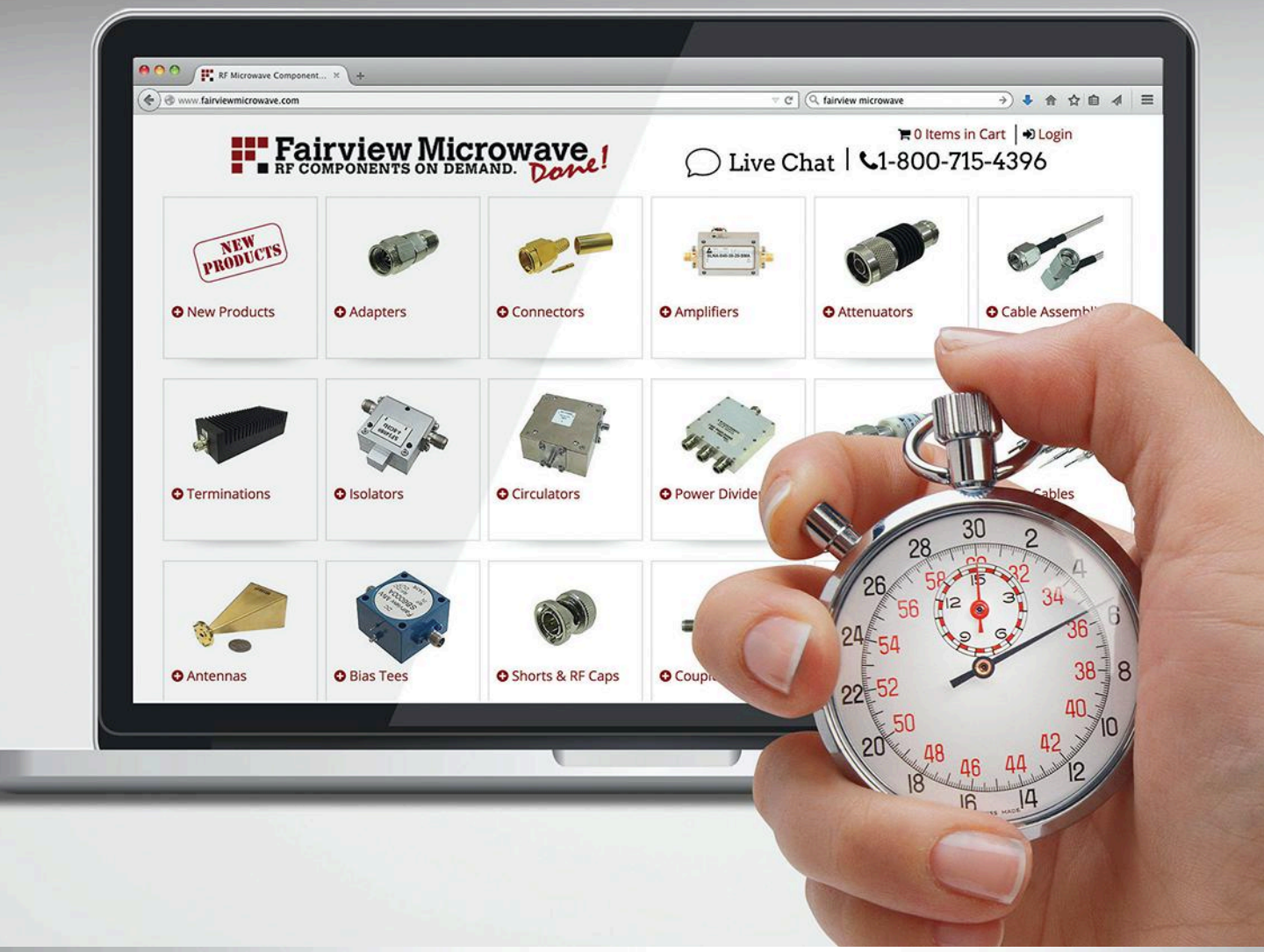


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ing the game-changing power that gallium-nitride technology can bring to military applications." For the progress that the new contract now makes possible, he notes: "This contract will build on the 17-year, $200-plus million investment Raytheon has made in maturing GaN. Over the next two years, we will further refine our GaN process to push the limits of radio frequency performance while maintaining or increasing yield and reliability."

The first demonstrator of this technology will be incorporated into Raytheon Space and Airborne Systems' Next Generation Jammer program, which is scheduled for low-rate initial production in 2018. ■

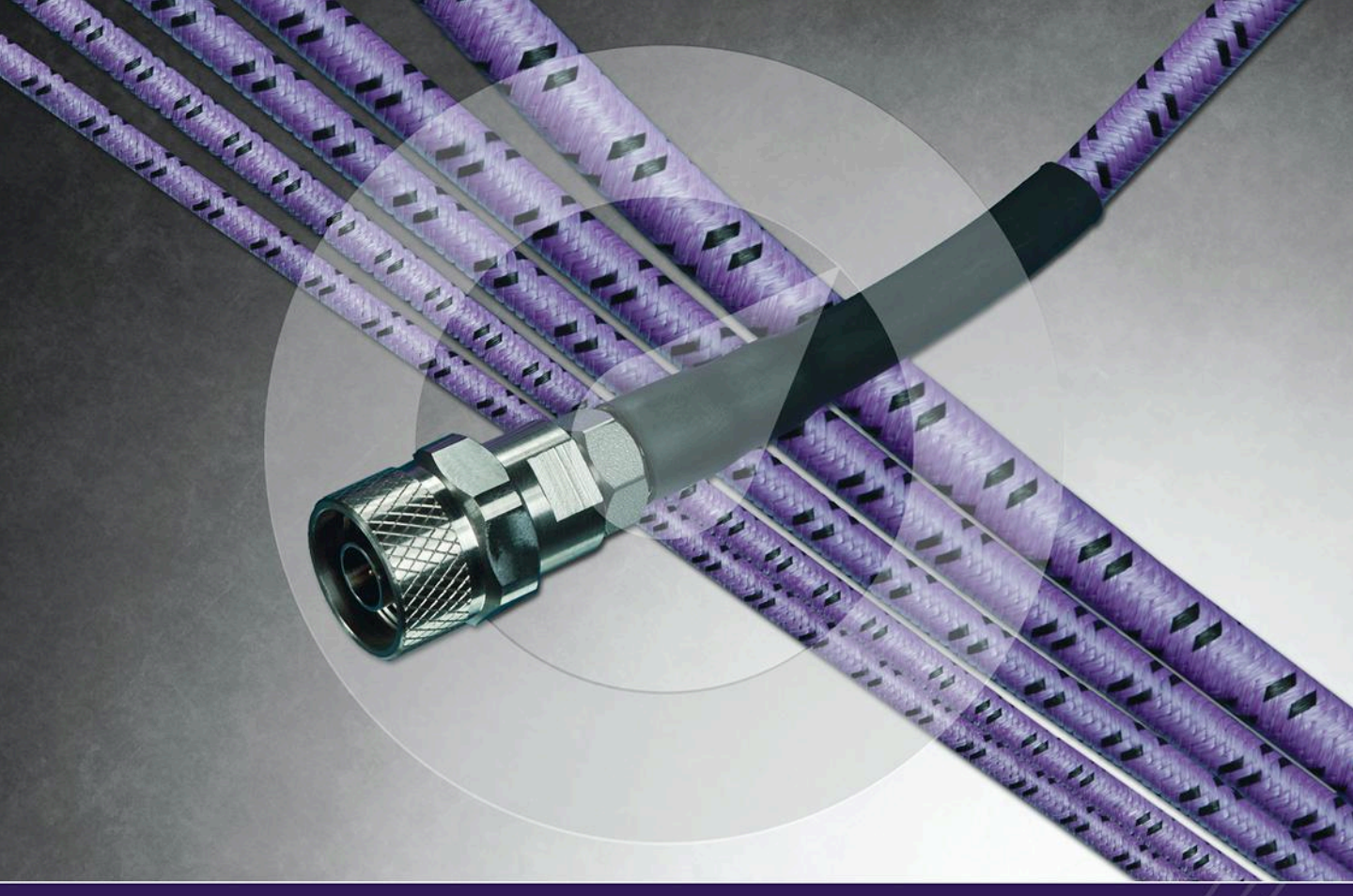


## CANADA STRENGTHENS AIRBORNE Communications

**THE CANADIAN DEPARTMENT** of National Defense (DND) will be enhancing communications capabilities onboard its fleet of CP-140 Aurora long-range patrol aircraft by way of several of its equipment suppliers. The MDM9000 satellite modem, designed and manufactured by Newtec, has been selected by General Dynamics Mission Systems-Canada for use on the Canadian Aurora fleet as part of its Aurora Incremental Modernization Project Block IV upgrades.

The CP-140 Aurora aircraft are used over land and sea for a wide range of applications, including intelligence, surveillance, and reconnaissance (ISR) and search-and-rescue (SAR) missions. The fleet, which helps patrol Canada and North America, will be improved through the addition of the MDM9000 ruggedized airborne modems. These are capable of high-data-rate (HDR) and beyond-line-of-sight (BLOS) communications between an aircraft and the DND ground network using DVB-S2X and S2 waveforms.

The modems are compliant with DO-160 and MIL-STD-810E standards and will contribute to superior communications capabilities on Wideband Global Satcom (WGS) satellite constellations. They operate at L-band transmit and receive frequencies and can achieve rates to 133 Mbaud. An airborne MDM9000 modem communicates with a similar unit on the ground. ■



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# REMOTE WAKE-UP SYSTEM SAVES STANDBY POWER

**INCREASING NUMBERS OF** electronic devices implies increasing amounts of consumed electrical power and a greater need to conserve power in electronic devices. For that reason, Faycel Fezai, a hardware engineer with Thales Air Systems, France, and co-researchers from various locations throughout France, propose an efficient RF-based energy-transfer system and RF-to-dc conversion circuit and switch with the ability to "wake up" commercial and industrial electronic devices as needed. The technology employs an integrated emitter and receiver working in the industrial-scientific-medical (ISM) frequency range from 2.40 to 2.48 GHz.

The researchers set an energy-consumption limit at 1 mW for electronic devices. They based their system solution on antennas with easily tuned radiation efficiency and a receiver without a direct power supply that has a rectifying circuit optimized for low RF power levels. In addition, the solution is coupled to a self-maintained switch. The system's intent is to be able to wake up an electronic device from a distance of 5 m by means of some form of remote-control device.

The emitter is based on a commercial transceiver from Texas Instruments *(www.ti.com)* used with a lithium-polymer (LiPo) battery. The transceiver's output is connected to a commercial power amplifier with 29-dB gain and then to an antenna.

Although the amplifier normally exhibits power consumption of 600 mA, the RF emissions for the transceiver system are based on a 10% duty cycle consisting of a 20-ms burst repeated three times during a 200-ms period. The researchers note that this particular amplifier and duty cycle were chosen for the benefits of gain, energy consumption, and cost in a commercial marketplace, with an expected operating lifetime of two years.

A parasitic-element antenna was developed for the transceiver using the same commercial printed-circuit-board (PCB) material as the transceiver circuitry. Adding surface-mount-technology (SMT) components to the PCB tuned the antenna pattern; then, commercial computer-aided-engineering (CAE) software programs, such as MATLAB from MathWorks *(www.mathworks.com)* and CST Microwave Studio from Computer Simulation Technology *(www.cst.com)*, were used to design and optimize the antenna. The compact antenna aided the wake-up circuit's effectiveness by means of a maximum gain of 5.75 dBi across a 200-MHz bandwidth from 2.4 to 2.6 GHz in the main radiated direction of interest (0°).

See "Reducing Electronic Device Standby Power Using a Remote Wake-Up System," *IEEE Antennas & Propagation Magazine,* Vol. 58, No. 5, October, 2016, p. 66.

# MICROWAVE PHOTONICS ENHANCES RADAR PERFORMANCE

**RADAR SPATIAL RESOLUTION** is essential when trying to identify more than one radar target simultaneously. To enhance the spatial resolution of a radar system, designers can apply waveform processing or use multiple antennas in multiple-input, multiple-output (MIMO) techniques. As an alternative approach, Moshe Mizrahi of the Department of Electrical and Computer Engineering, Bar-Ilan University, Ramat-Gan, Israel, and the Department of Electrical and Electronic Engineering, Ariel University, Israel, and fellow researchers based in Israel developed a technique that draws upon optical imaging.

In their approach, the size of the optical imaging lens is the same as the aperture of the radar antenna. The new method provides improved radar spatial resolution through frequency coding—various parts of the radar target are illuminated with different microwave frequencies using a transmission antenna array.

The array transmits the full frequency spectrum of interest, but portions of the frequency spectrum are used to illuminate different parts of the radar target. The received signals are processed to identify the different parts of the illuminated target with improved spatial resolution. The optical sensor works in collaboration with the frequency techniques, with the number of pixels in the optical sensor equivalent to the number of different frequency channels used for the radar detection.

Modeling performed with commercial electromagnetic (EM) simulation software showed the effectiveness of the new approach in detecting and differentiating four separate metallic targets in an experimental test setup. It was compared against a standard radar, which had difficulty in simultaneously detecting three different targets over the same test range. For radar experiments performed over a bandwidth of 4 GHz, the frequency-selective, optically aided process shows great promise as a means of improving the spatial resolution of radar systems for both one-dimensional (1D) and two-dimensional (2D) radar target data.

See "Improving Radar's Spatial Recognition," *IEEE Microwave Magazine*, Vol. 17, No. 10, October 2016, p. 28.

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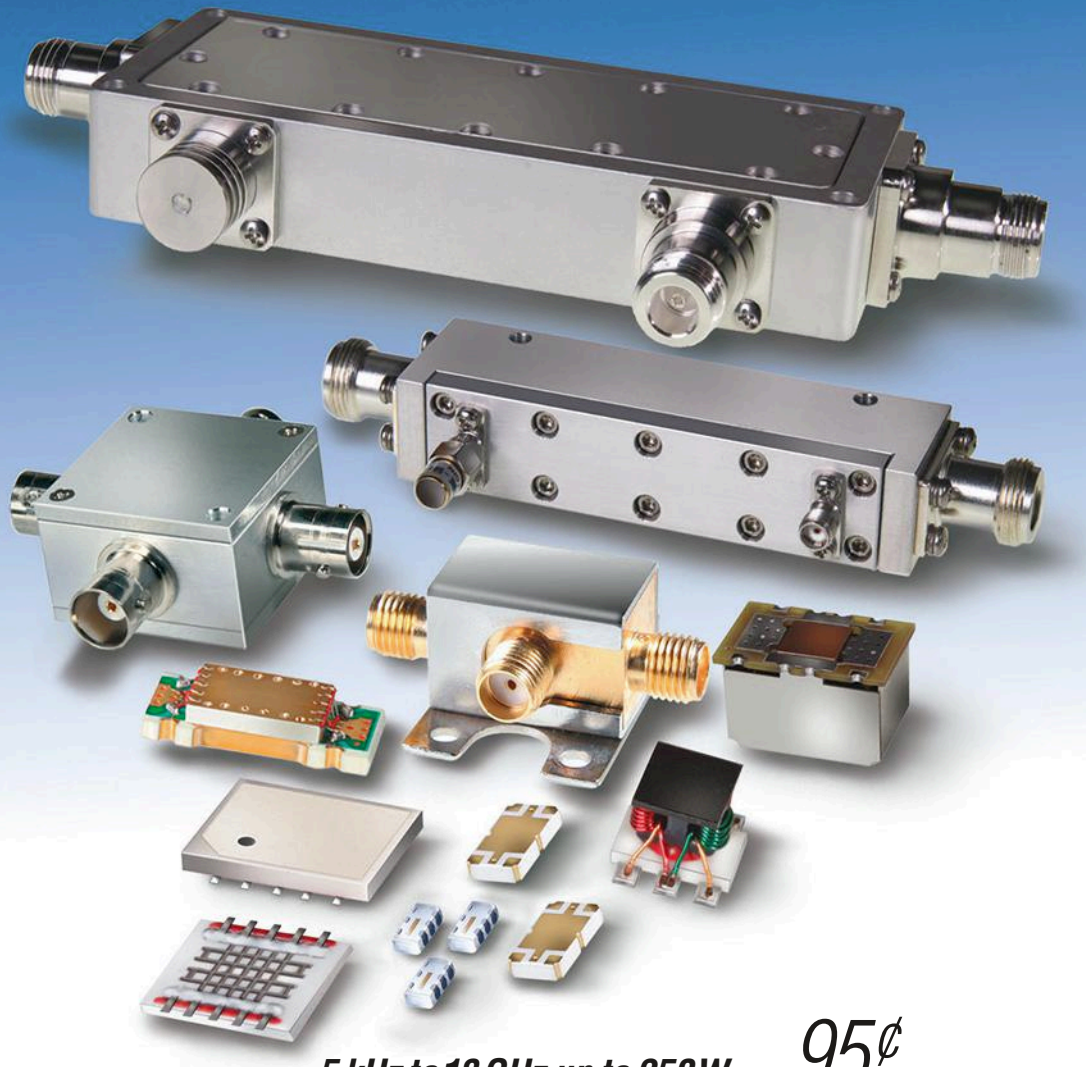

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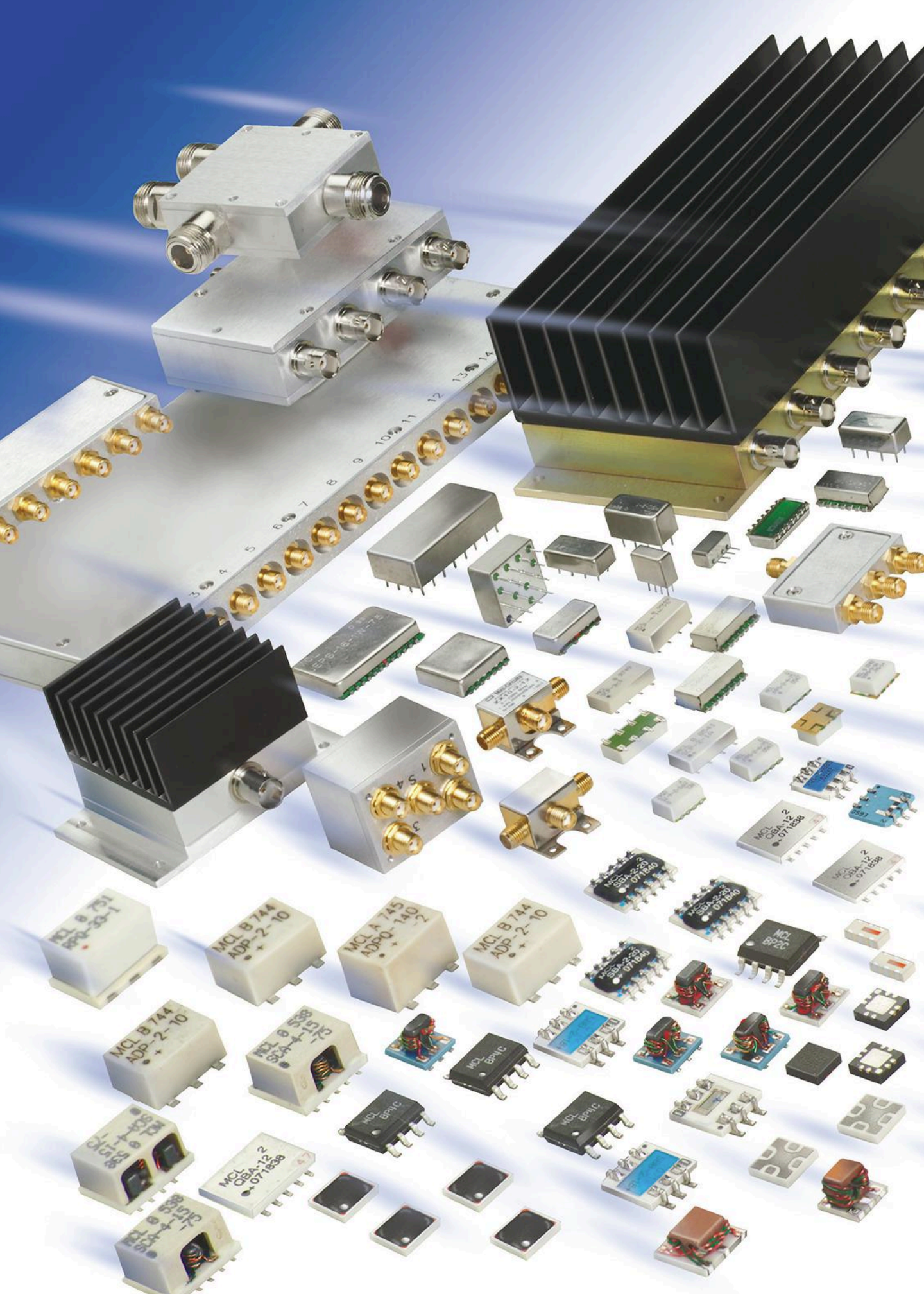

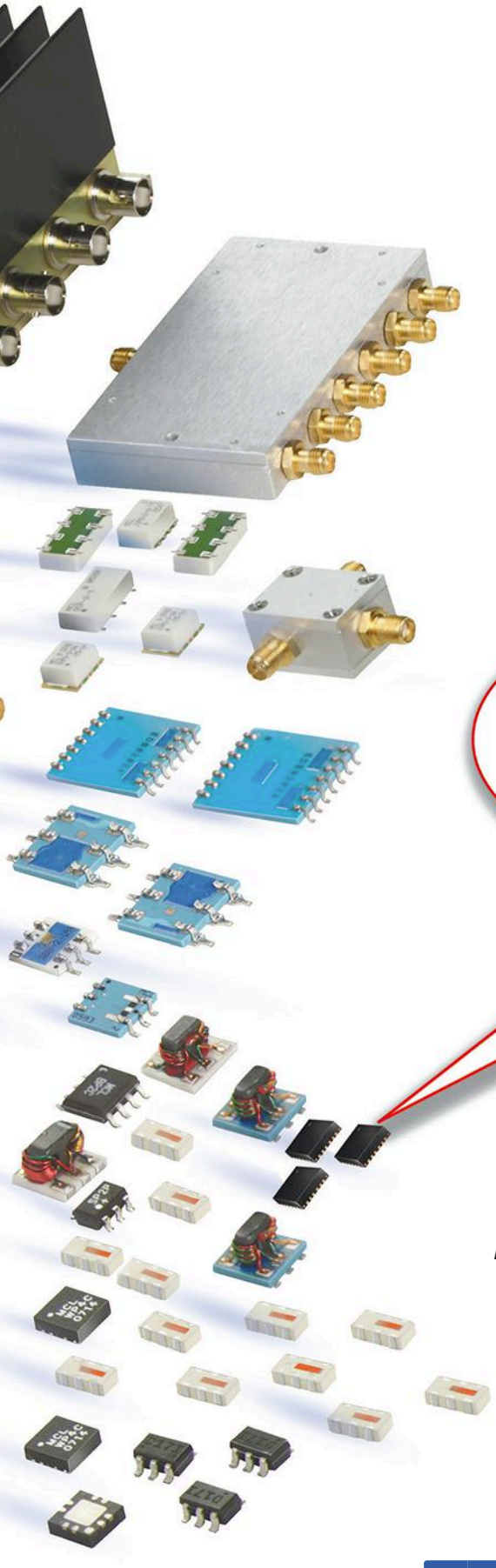

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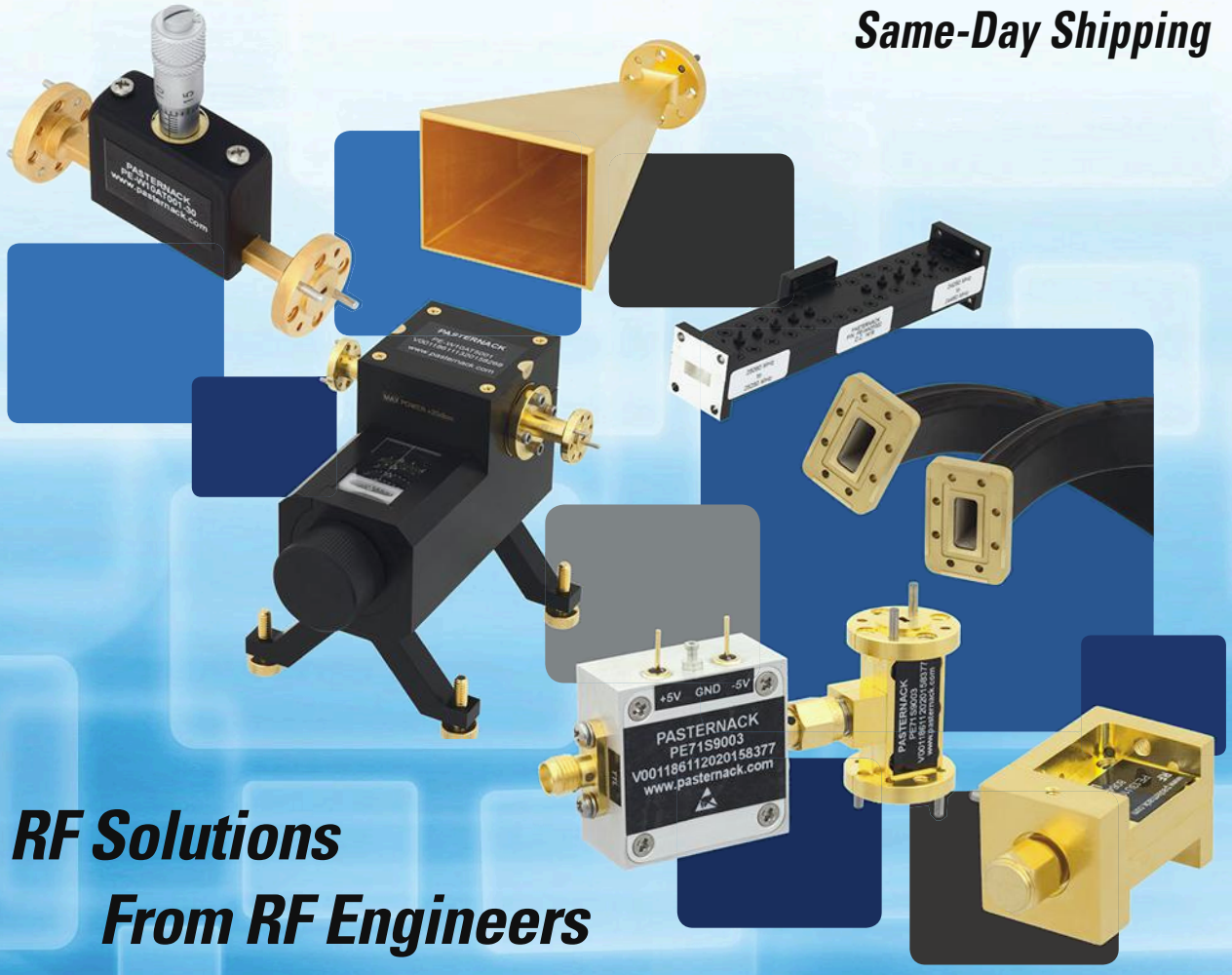


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# 5 Talking Points in Test & Measurement

**To support advancing technology, suppliers of test-and-measurement equipment are delivering solutions that reach even greater heights.**

**AS WIRELESS TECHNOLOGY** continues to invade our lives, suppliers of test-and-measurement equipment must keep up by offering the proper test solutions to meet today's needs. And the same suppliers must also think in terms of the future, with 5G obviously being on the minds of many. 5G and other applications are clearly setting the stage for even higher-frequency test solutions, which is currently a major focus of several suppliers. Today's other trends include compact, portable instruments that allow for flexibility while still delivering quality performance. Moreover, some other developments are worthy of attention as well.

With all of that being said, here are five recent—and potentially future—developments to take note of when it comes to high-frequency test and measurement:

**1. This VSG can generate signals at frequencies as high as 40 GHz.** *(Courtesy of Rohde & Schwarz)*

## 1. HIGHER-FREQUENCY TEST SOLUTIONS

Delivering higher-frequency test solutions is clearly a high priority of a number of suppliers of test-and-measurement equipment today. There is no question that 5G is a major reason for this activity, with millimeter-wave frequencies being linked to 5G. However, other applications besides 5G are utilizing these higher frequencies, too. Automotive radar and IEEE 802.11ad, for example, both operate at millimeter-wave frequencies. Therefore, with the growing usage of millimeter-wave technology, test solutions must be available that can effectively satisfy higher-frequency requirements.

One company that is focused on providing millimeter-wave test solutions is Rohde & Schwarz *(www.rohde-schwarz.com)*. The company is at the forefront of 5G development, as proven by instruments like the SMW200A vector signal generator (VSG) and the FSW85 signal and spectrum analyzer *(Fig. 1)*.

The SMW200A can generate signals at frequencies as high as 40 GHz. It can also deliver modulated signals with bandwidths as high as 2 GHz, when external in-phase/quadrature (I/Q) signals are provided. The FSW85 covers frequencies ranging all the way to 85 GHz. Recently, both the SMW200A VSG and FSW signal and spectrum analyzer were successfully used for 5G signal generation and analysis based on Verizon's 5G specifications.

In addition, Rohde & Schwarz recently unveiled its NRPM over-the-air (OTA) power measurement solution, which covers frequencies ranging from 27.5 to 75 GHz. The NRPM OTA measurement solution is intended to test 5G, IEEE 802.11ad, and IEEE 802.11ay signals.

Beamforming is a technique used to control the direction of radiation. When utilizing beamforming, the transmitted power must be measured over the air. In addition, the actual beamforming performance needs to be verified. The NRPM measurement solution is designed to calibrate the transmit antenna output power and test the beamforming function.

The NRPM power measurement solution includes the NRPM-A66 single-polarized antenna module and the NRPM3 three-channel sensor module. The NRPM-A66 is a Vivaldi antenna with an integrated diode detector, which allows for power measurements. The NRPM3 processes the measured values from as many as three NRPM-A66 modules, and is connected to a PC by an interface cable.

For its part, Anritsu *(www.anritsu.com)* is also delivering higher-frequency test solutions. For instance, the company's MS2840A signal analyzer and MA2808A waveguide mixer can be used together, enabling measurements to be performed at E-band frequencies. This combination yields a phase noise at 79 GHz of -100 dBc/Hz at 10-kHz offset, making it well suited for automotive radar applications.

## 2. BETTER -PERFORMING AWGS

Recently introduced arbitrary waveform generators (AWGs) are offering increased functionality, as suppliers are striving to meet a wide range of needs. For example, RIGOL Technologies *(www.rigolna.com)* recently expanded its DG1000Z series of function/arbitrary waveform generators by introducing the new DG1022Z model *(Fig. 2)*. The DG1022Z provides users with a number of features, including eighth-order harmonic generation, support of various modulation types, and much more. "With the DG1022Z's built-in harmonic generation capability, engineers are able to test a wide array of filtering techniques," says Daniel Monforte, applications engineer at RIGOL Technologies.

The DG1000Z series utilizes RIGOL's SiFi technology, which allows true point-to-point arbitrary waves to be created. Monforte notes, "With our SiFi sampling technology, the DG1022Z creates complex arbitrary functions with ease and high signal fidelity, whether the goal is injecting a specific spectral noise profile or emulating baseband data. When paired with a RIGOL DSG3000 series RF source, the DG1022Z can be used to generate long series' of in-phase/quadrature (I/Q) modulated signals on a carrier. Hence, the DG1022Z enables testing of low-frequency RF modulation and emulation applications."

In addition to the new DG1022Z, the DG1000Z series consists of the DG1032Z and DG1062Z models. The DG1022Z has a maximum output frequency of 25 MHz for sine waves and square waves. Additionally, the DG1000Z series supports a number of modulation types, including amplitude modulation (AM), frequency modulation (FM), phase modulation (PM), amplitude shift keying (ASK), frequency shift keying (FSK), phase shift keying (PSK), and pulse-width modulation (PWM). The DG1000Z generators also contain a large number of built-in waveforms, allowing quick access to predefined signals.

Earlier in the year, Tektronix *(www.tek.com)* introduced its AWG4000 series waveform generation platform, which has two operation modes. The first is Basic mode, in which the AWG4000 operates as a two-channel arbitrary function generator (AFG). In this mode of operation, sine waves can be generated at frequencies as high as 600 MHz. In Advanced mode, the AWG4000 functions as an AWG with both analog and digital channels for complex waveform generation.

## 3. USB-BASED SPECTRUM ANALYZERS

The spectrum analyzer has traditionally been a benchtop instrument. While traditional spectrum analyzers are not going to disappear anytime soon, several suppliers are now offering compact USB-based spectrum analyzers that possess their own advantages. Such instruments are particularly beneficial to meet the needs of the Internet of Things (IoT).

"The IoT is a primary driver in microwave and RF design today, and by extension a key driver in test-and-measurement instrumentation," says Matthew Maxwell, product manager of spectrum analyzers, Tektronix. "With the IoT comes exponentially increasing numbers of devices from thousands of manufacturers and a proliferation in wireless standards and proprietary protocols—more than 20 currently.

"We're seeing a growing need for engineers to have RF design experience—and the time-to-market windows keep shrinking," he adds. "Systems are being designed and built for a broad range of products, so test instrumentation versatility is vital."

Simply put, the increasing amount of IoT devices requires companies to have a larger number of test instruments. More test instruments obviously come at a large cost. However, Maxwell believes that USB-based spectrum analyzers can remedy the situation. In comparison to traditional instruments, USB-based instruments are a cost-effective solution for today's needs.

"Traditionally, RF experts shared expensive high-end equipment," he explains. "This was because few organizations could afford to buy more than one or two high-end instruments, and low-end signal analyzers lacked the necessary capabilities. This situation is now changing with the recent introduction of USB-based spectrum analyzers. USB-based RF test instruments possess fundamental advantages over their traditional desktop equivalents. In addition to signal capture circuitry, desktop spectrum analyzers


**2. This waveform generator can generate eighth-order harmonics.** *(Courtesy of RIGOL Technologies)*

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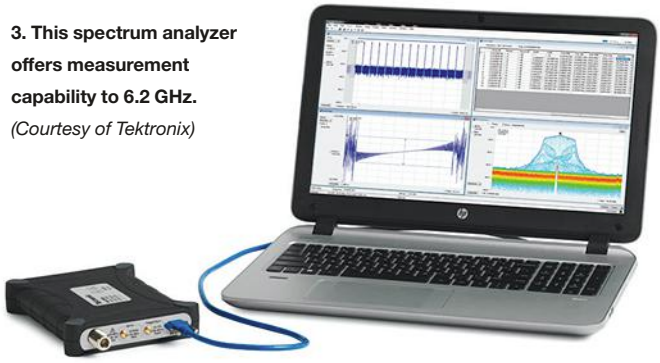
must also include a full PC, adding considerable cost and complexity to the instrument.

"In contrast, the USB-based spectrum analyzer eliminates this cost from the instrument itself and simply takes advantage of the processing power sitting on the lab bench of every engineer or spectrum manager. USB-based instruments are controlled from PC-based software, and offer full real-time capture and advanced analysis capabilities in a compact package. In terms of price, organizations can now afford to buy 10 to 20 USB-based spectrum analyzers for the same price as one $50,000 or $100,000 instrument—and get similar analysis capabilities."

Among the USB-based spectrum analyzers currently offered by Tektronix is the RSA306B *(Fig. 3)*. The RSA306B covers a frequency range of 9 kHz to 6.2 GHz and has an acquisition bandwidth of 40 MHz. Its portable package makes it well suited for use in the field, as well as factories and academic institutions.



**3. This spectrum analyzer offers measurement capability to 6.2 GHz.** *(Courtesy of Tektronix)*

### 4. PXI

PXI has been adopted by a number of manufacturers, allowing them to build scalable test systems. Of course, National Instruments (NI; *www.ni.com)* is one company that is associated with PXI. Earlier this year, NI made headlines by unveiling its second-generation vector signal transceiver (VST), which offers as much as 1 GHz of instantaneous bandwidth.

Other players in the PXI space include Pickering Interfaces *(www.pickeringtest.com)*, which offers a range of RF/microwave PXI switch modules that cover frequencies as high as 65 GHz. The company recently introduced its new 60-104 two-slot chassis, which can support one or two 3U-high PXI switching modules. And earlier in the year, the company expanded its line of RF multiplexers with the introduction of the 40-760 series. This series of multiplexers covers frequencies ranging to 600 MHz.

### 5. A NEW WORKFLOW

One additional point to take note of is not actually a trend in terms of current test-and-measurement equipment, but rather a potential change in regard to how test and design will be integrated in the future. According to Jack Sifri, MMIC/module design flow specialist at Keysight Technologies *(www.keysight.com)*, "A dramatic shift is underway in the electronics design and test industry. Traditionally, a design flow has been pretty linear: Measure components and create models; use the models to design and simulate a circuit; then test the prototype. Each stage is separate and distinct."

As technology advances, Sifri believes the traditional workflow will change significantly. He adds, "We are headed toward a revolution, moving from the traditional flow toward one that will require an entirely new level of integration to design and verify the new systems of the future.

"The world is changing right in front of our eyes," he continues. "We see it in 5G, IoT, and modern radar systems. Instead of single channels, or even simple multiple input, multiple output (MIMO) configurations, the world is moving to massive phased array systems. Bandwidths have exploded from a few tens of MHz to multiple GHz. Carrier frequencies have moved from RF and low microwave to well into millimeter-wave. These technologies will change the way we work. Design and test are moving to an entirely new level of integration. These factors combine to break the traditional 'model, simulate, measure' flow that has served us so well in the past."

Sifri believes that test will increase in complexity as the systems themselves become more complex. As a result, test-and-measurement will be more interwoven with the actual design process. He explains, "The most powerful compute farms simply will not have the horsepower to model the systems. As the systems become more complex, the tests that are needed to verify performance also become more complex. Applying modern computer science to this problem will dramatically reduce that time. Instead of designing test sequentially (and redundantly), simulation and measurement configurations will be driven by common databases. Thus, design will be even more inextricably connected with test. Our design/simulation software and test equipment provide a full solution for the engineering community to embrace this new design and test workflow."

### CONCLUSION

To summarize, test-and-measurement suppliers are clearly focused on delivering new solutions to ever-advancing requirements. No doubt, delivering higher-frequency test solutions is a primary objective of some suppliers. 5G is playing a large role in these efforts, but other applications are utilizing higher frequencies as well. Both USB- and PXI-based instruments are heavily counted on, offering various benefits like cost, portability, and scalability. Lastly, technology advances have the potential to impact the overall role of test in future workflows. With all of this being said, it is clear that we can expect to continue seeing innovative test-and-measurement solutions. mw

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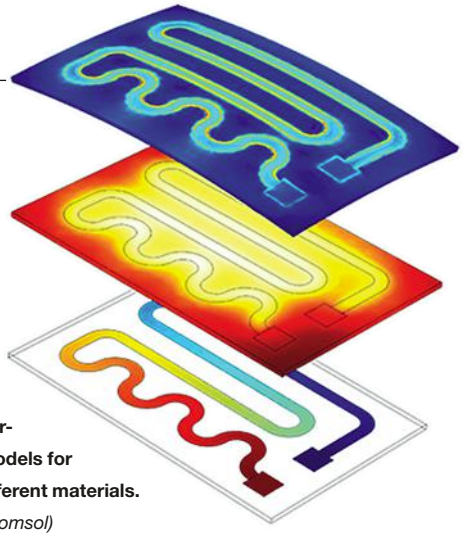
# Tracking Effects of Temperature

**Thermal modeling of high-frequency electronic circuits must take into account the thermodynamic differences among circuit-board materials, their components, and the packages that hold them.**



**1. The COMSOL Multiphysics suite of design software tools includes a thermal module with models for more than 2,500 different materials.** *(Image courtesy of Comsol)*

**THERMAL MODELING IS** becoming a more important part of the electronic design process, especially with increasing efforts to pack more power into smaller electronic devices. Quite simply, power = heat. Where power is generated or transferred, any form of loss will result in the production of heat. For the preservation of an electronic design, the heat must be efficiently removed. Thermal modeling is a way to predict where the heat comes from, how much must dissipated, and where it will go.

Dissipating heat has long been an essential requirement in high-power systems, such as radar and communications transmitters. High-power components like amplifiers and antennas are usually surrounded by robust heat sinks made of thermally conductive metals to draw heat away from a source, such as a traveling wave tube (TWT) in a vacuum amplifier or the transistors in a solid-state amplifier.

Thermal management for these larger systems has relied on tried-and-true methods and heat sinks with well-established thermal profiles based on their material compositions. Metals like stainless steel and copper have the excellent thermal conductivity needed to provide a low-thermal-resistance path for the flow of heat away from the source, preventing the buildup of potentially damaging "hotspots" on the thermal source.

However, as the general trend in electronics is leading toward packing higher power levels into smaller package sizes, thermal management becomes more challenging, and thermal modeling becomes a more valuable tool in the design process. For example, with the increase of active devices based on gallium nitride (GaN) and GaN on silicon-carbide (GaN-on-SiC) transistor technologies, more high-frequency solid-state devices are available with higher power densities. This requires a combination of imaginative thermal modeling and precise thermal measurements to better understand how heat can best be removed from such high-power-density sources.

Heat can be removed from a source via three modes of heat transfer: radiation, convection, and conduction. Heat radiation from an area of high thermal energy to an area of lower thermal energy in an electronic design benefits from good air flow, often aided by a fan (although this is not a practical solution for miniature designs). Convection of heat involves the movement of fluids to transfer heat, such as in an automotive radiator. For smaller electronic designs, conduction—the flow of heat through solids—is the main method of removing heat from a source.

Developing thermal models for electronic circuits, devices, and their packages requires fundamental knowledge of the thermal resistances of the different materials used in these components, as well as other parameters related to thermal behavior. The latter includes the coefficients of thermal expansion (CTE) for different materials used in electronic design.

Printed-circuit-board (PCB) materials suppliers, for example, have invested significant time in understanding the thermal properties of the various dielectric materials that comprise their circuit materials, such as ceramic, fiberglass, and polytetrafluouroethylene (PTFE) materials, along with the thermal conductivities of metallization (such as copper) used to form the circuit traces on the PCBs. At higher power levels and densities, accurate knowledge of the thermal properties of each material, along with stress points at junctions between different materials, can provide insights into the behavior of the circuit materials over time and temperature.

In addition, since the dielectric constant of PCB materials

changes as a function of temperature, circuit material developers typically model and measure their materials to precisely track the behavior of dielectric constant with temperature. Doing so enables circuit designers to incorporate that knowledge as part of their own circuit simulations.

Semiconductor-device developers have also investigated the thermal properties of the metal and semiconductor materials that comprise high-power-density devices, such as GaN and silicon-carbide (SiC) transistors. Special attention is paid to any material interfaces where thermal stresses may occur, since these interfaces can determine the ultimate reliability and lifetime of a semiconductor device at high power levels and densities.

## TAKING THE TEMPERATURES

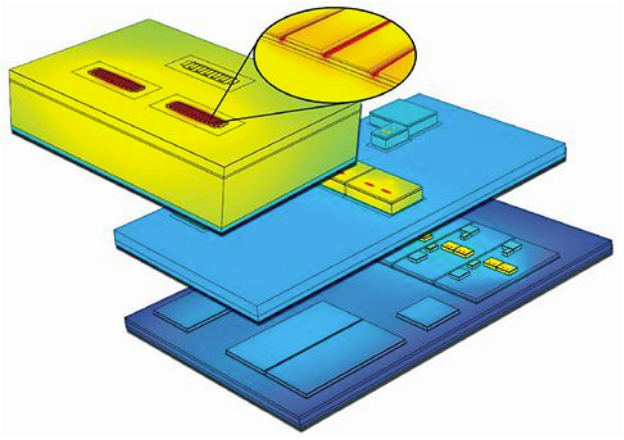
Before a thermal model can be developed for any material or combination of materials, it is useful to know the amount of heat that will result under different operating conditions, which requires reliable thermal measurements. As electronic dimensions to be measured shrink in size, researchers grappling with developing thermal models face the challenges of performing accurate thermal measurements on micron-sized component features (e.g., transistor gates, drains, and sources).

The temperatures of electronic devices and circuits can be measured by contact or noncontact methods, although noncontact methods are usually preferred. Device developers have also incorporated built measurement tools into their designs, such as temperature-sensing diodes, to provide readings of temperature at or near the active device. However, external thermography systems are generally employed for reading the temperature of an active device and examining the effectiveness of circuit junctions, heat sinks, and packaging used along with that device to dissipate heat.

For example, infrared (IR) thermography can provide images of thermal gradients across the surface of a circuit or device, although it typically lacks the resolution needed to study hotspots in micron-sized areas. For thermal measurements on device-sized dimensions, Raman scattering has been widely used. In this process, the temperature of a micron-sized surface is studied by irradiating the surface with monochromatic light, and then gauging the temperature by amount of shift in the irradiated light reflected from the thermal source.

Software tools for analyzing thermal effects have included 3D finite-element-analysis (FEA) electromagnetic (EM) simulation tools with thermal software modules, as well as dedicated thermal-analysis tools. Software using FEA predicts the mechanical effects of heat and thermal transfer on mechanical structures, including semiconductor-scale structures. Although FEA and thermal-analysis programs are sometimes considered competitive approaches to thermal analysis, they are complementary tools that can work well together to analyze thermomechanical stresses in electronic circuits and devices.

Some of the leading suites of RF/microwave design programs,



**2. The SYMMIC thermal-analysis software provides templates for quick design of PCBs.** *(Image courtesy of CapeSym)*

such as the Advanced Design System (ADS) software from Keysight Technologies *(www.keysight.com)* and CST Microwave Studio from Computer Simulation Technology *(www.cst.com)*, have been used in different ways for thermal analysis (e.g., analyzing current densities in active and passive components), although they lack nominal thermal-analysis programs.

One of the better-known software solutions for thermal analysis on the FEA side is FloTHERM from Mentor Graphics *(www.mentor.com)*, which is readily integrated with electronic-design-automation (EDA) software tools for simultaneous modeling of circuit and device performance with thermal analysis. It clearly shows where different objects are connected in a design as well as all of the thermal interfaces, and includes an extensive device database. The thermal-modeling software can be used to predict thermal effects at the device, circuit, and system levels.

Long-time suppliers of high-frequency simulation tools like ANSYS *(www.ansys.com)*, known for its FEA-based HFSS EM simulation software, have also developed software-analysis tools for thermal modeling. ANSYS' Icepak can perform electronics cooling simulation and thermal analysis at chip-scale-package, circuit, and system levels. Like FloTHERM, Icepak is based on computation-fluid-dynamics (CFD) technology and simulation of heat flow according to fluid motion.

The CFD modeling approach is quite effective at predicting heat flow within a circuit or device, and how heat can be transferred from a thermal source. Icepak can provide thermo-mechanical stress analysis of active devices in different styles of packages, and can link to EM simulation software tools such as HFSS to study thermal effects on RF/microwave performance and EM behavior. EM analysis is combined with thermal analysis to predict reliability parameters—e.g., mean time to failure (MTTF).

COMSOL Multiphysics *(www.comsol.com)* is a suite of software simulation tools that includes a heat-transfer module for modeling thermal transfers in solids and fluids *(Fig. 1)*. Users gain the benefit of an extensive database of solids and fluids,

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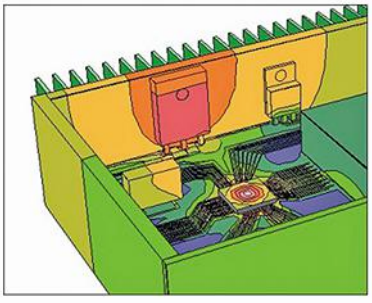

**3. The Sauna thermal-modeling software can analyze thermal effects for individual components as well as full PCBs.** *(Image courtesy of Thermal Solutions Inc)*

with data or algebraic solutions for more than 2,500 different solid materials for thermal modeling. Users can also import thermodynamic and other material data from spreadsheets for creating their own thermal models. The Master RF Design Suite from CAD Design Software *(www.cad-design.com)* allows users to customize their combination of PCB software design tools, including a thermal-modeling module.

Developed specifically for thermal modeling, SYMMIC thermal-analysis software from CapeSym *(www.capesym.com)* is an easy-to-use program for the design-stage thermal analysis of high-power RF/microwave components. It can be used to analyze the heat generation and dissipation from individual transistors, as well as from complete monolithic microwave integrated circuits (MMICs). The SYMMIC software can be integrated with popular commercial RF/microwave simulators like Microwave Office from AWR Corp. *(www.awrcorp.com)* and the Advanced Design System (ADS) software from Keysight Technologies.

SYMMIC starts with predefined templates of active and passive devices in different circuit configurations that can be reconfigured to match a desired circuit layout *(Fig. 2)*. The templates are based on 3D FEA heat-transfer studies and can be readily modified for the thermal analysis of many different MMIC parameters.

Thermal modeling and analysis need not be costly, as evidenced by the accessibility of the Sauna thermal-modeling software package from Thermal Solutions *(www.thermalsoftware.com)*. Although the simple-to-use software is ideal for performing fast thermal analysis on circuit components such as heat sinks, it can also be used for thermal modeling of full PCB representations of a design on FR-4 and other circuit materials *(Fig. 3)*.

Sauna includes a library of different standard pin and drop-in packages and package pad layouts, and allows a user to create custom packages for thermal modeling. The software contains 3D modeling capability to create any of the geometries and multilayer PCBs needed for transient thermal analysis, steady-state analysis, or thermal studies based on specific on/off duty cycles. mw

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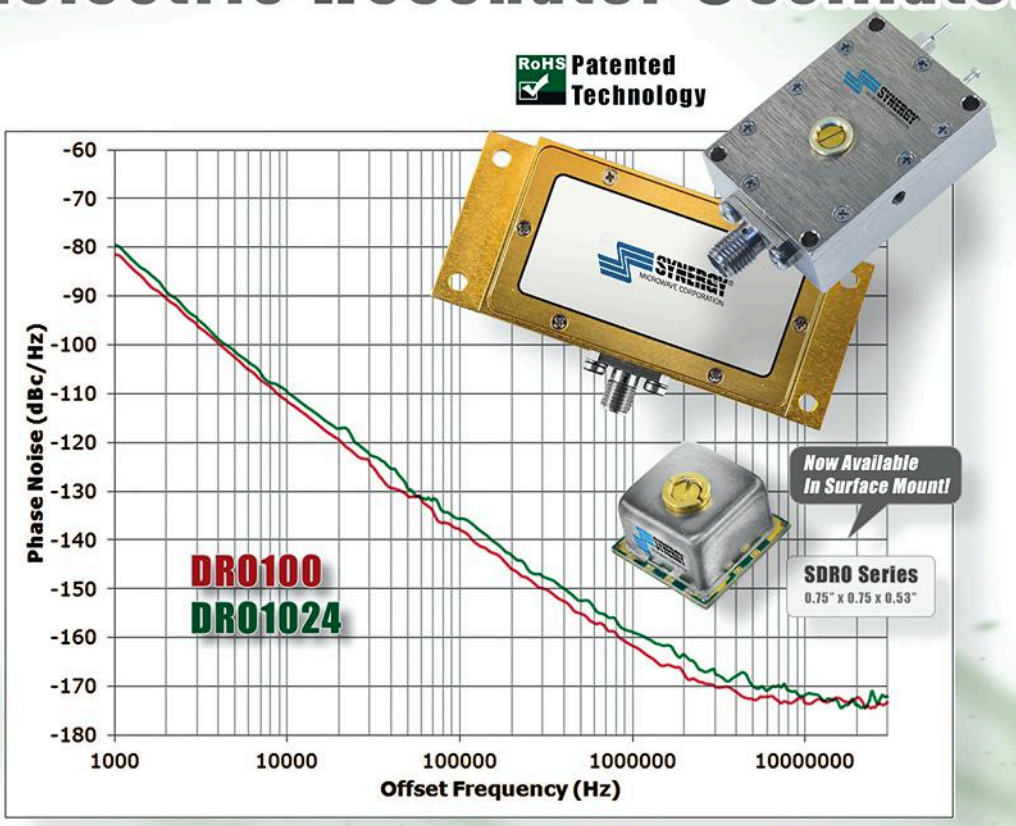


| Model | Frequency (GHz) | Tuning Voltage (VDC) | DC Bias (VDC) | Typical Phase Noise @ 10 kHz ( dBc/Hz ) |
|---|---|---|---|---|
| **Surface Mount Models** | | | | |
| SDRO1000-8 | 10 | 1 - 15 | +8 @ 25 mA | -107 |
| SDRO1024-8 | 10.24 | 1 - 15 | +8 @ 25 mA | -111 |
| SDRO1250-8 | 12.50 | 1 - 15 | +8 @ 25 mA | -105 |
| **Connectorized Models** | | | | |
| DRO100 | 10 | 1 - 15 | +7 - 10 @ 70 mA | -111 |
| DRO1024 | 10.24 | 1 - 15 | +7 - 10 @ 70 mA | -109 |

| Model | Center Frequency (GHz) | Mechanical Tuning (MHz) | Supply Voltage (VDC / Current) | Typical Phase Noise @ 10 kHz ( dBc/Hz ) |
|---|---|---|---|---|
| **Mechanical Tuning Connectorized Model** | | | | |
| KDRO145-15-411M | 14.5 | ±4 MHz | 7.5 V / 90 mA (Max.) | -88 |

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# Direct-Synthesis Software Approach Facilitates Filter Design

## Design software that incorporates the direct-synthesis technique can be highly beneficial to those involved with designing customized filters.

**RF/MICROWAVE SIMULATION SOFTWARE** has become an increasingly important aspect of today's design process. Anyone tasked with designing RF/microwave filters knows how critical software is in meeting design goals, especially in terms of customization. Today, a variety of software tools is available to help achieve those filter-design objectives.

One effective approach is the direct-synthesis technique, which enables a designer to manage the location of transmission zeros. As a result, filters are able to be designed with customized rejection responses.

This article discusses how Genesys software from Keysight Technologies *(www.keysight.com)* can be used to design filters with the direct-synthesis technique. A lowpass filter example is also presented to illustrate the software's capabilities.

### TRANSMISSION ZEROS

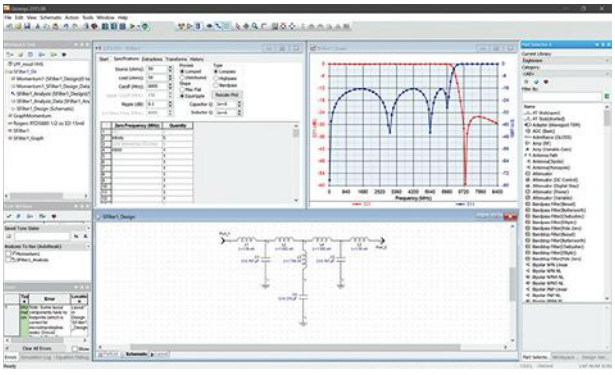
Transmission zeros are frequencies in which there is no signal transmission. A lowpass filter has transmission zeros at infinite frequency, while a highpass filter has transmission zeros at dc. A bandpass filter contains transmission zeros at both dc and infinite frequency.

Finite-frequency transmission zeros (FTZs) are transmission zeroes at frequencies aside from dc and infinite frequency. They can be incorporated into a filter to reject signals at specific frequencies. In other words, FTZs allow unwanted frequencies to be "notched out." FTZs essentially shape a filter's stopband response.

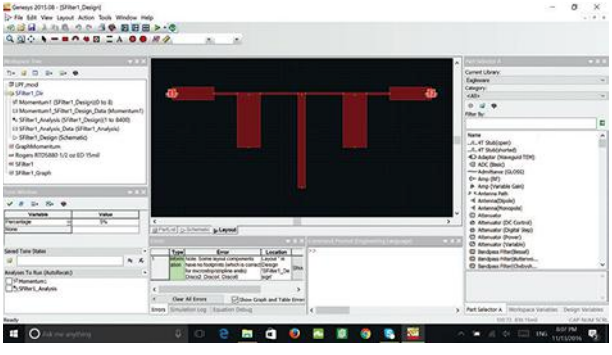
### S/FILTER SYNTHESIS PROGRAM

Genesys software can be applied to create both lumped-element and distributed filters. Users can design classic filter types, such as Butterworth, Chebyshev, etc., as well as filters beyond those traditional methods.

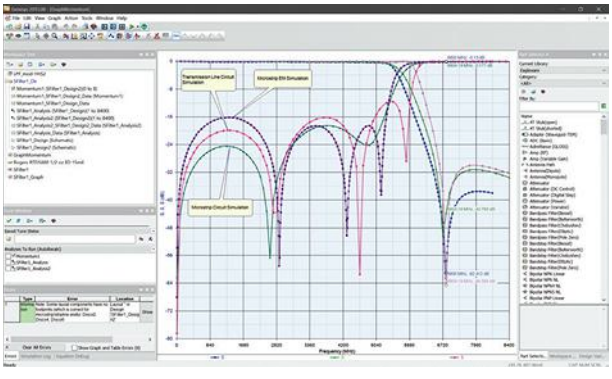
Specifically, Genesys contains the S/Filter synthesis program, which utilizes the direct-synthesis technique. When using S/Filter, a designer can place FTZs at specific frequencies



**1. Users can enter FTZ frequency values by clicking on the Specifications tab.**



**2. This lowpass filter is designed on a 15-mil-thick Rogers RT/duroid 5880 laminate.**



**3. These simulation results reveal that the lowpass filter achieves greater than 60 dB of rejection at 6.8 GHz.**

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to obtain the desired filter stopband performance. This capability allows for custom filter design, as frequency responses can be shaped to meet the needs of a specific application. Direct synthesis is particularly effective in practical scenarios, such as when a certain amount of rejection is needed at a given frequency or frequencies.

S/Filter accommodates design of lowpass, highpass, and bandpass filters. Its operation is simple: Click on the *Specifications* tab in the user interface to enter the desired FTZ values *(Fig. 1)*. Then, once the criteria are entered, the software directly synthesizes custom filter schematic solutions. Users can click on the Extractions tab to cycle through all of the schematic extractions that satisfy their criteria.

The white paper, *"Genesys S/Filter Software Synthesizes Custom RF, MW and Analog Filters for Realization,"* discusses S/Filter in greater detail. The paper, written by How-Siang Yap from Keysight Technologies, also includes a bandpass-filter design example. This filter has a passband from 300 to 350 MHz, and is designed with one FTZ initially set to 400 MHz and then varied.

## DESIGN EXAMPLE

Now let's take a look at the design of a simple lowpass filter using S/Filter. This filter has a passband to 5.2 GHz, and an FTZ at 6.8 GHz.

After the criteria were entered, a lumped-element schematic was chosen from among the several extracted schematics. Subsequently, this lumped-element filter was converted to a distributed filter via lumped-to-distributed transformations. The filter is designed on a 15-mil-thick Rogers RT/duroid 5880 laminate. The layout is presented in *Fig. 2*.

*Figure 3* shows the electromagnetic (EM) simulation results. As can be seen, the filter has a passband response to 5.2 GHz, with less than –16-dB return loss across the entire band. It also achieves more than 60 dB of rejection at 6.8 GHz. In comparison, approximately 37 dB of rejection occurs at 7.6 GHz, demonstrating the effect of placing an FTZ at 6.8 GHz. Of course, some optimizations were performed to obtain the desired results. In summary, this lowpass filter—though relatively simple—was modeled in a very short amount of time with S/Filter.

Those who wish to further explore the topics discussed in this article should consider obtaining a copy of Randall Rhea's book, *Filter Synthesis Using Genesys S/Filter.* The book serves as a practical guide for RF/microwave filter design, covering the design of lumped-element, distributed, and resonator-based filters using Genesys software. MW

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# Our 5G Future: In the Fast Lane with Numerical Simulation

## The latest simulation tools seek to enable the design of next-generation wireless communication systems.

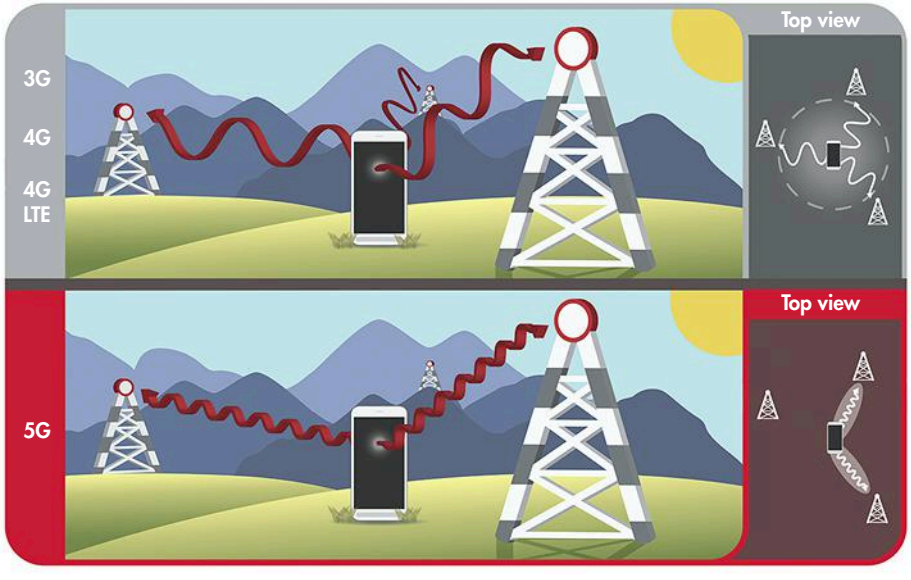
5G and the Internet of Things (IoT) are among the hottest topics being discussed in the RF and microwave industry. Everyday activities and technological advancements depend more than ever on reliable and fast data communication. Designers are now faced with their biggest challenges, having been tasked with bringing real-time data usage and availability to the next level. This requires access to the best design tools, along with significant advances in signal processing, device-centered communications, and evolving technical standards.

### FROM 4G LTE TO 5G

It's expected that 5G will need to utilize higher-frequency spectrums in the millimeter-wave range when deploying active electronically scanned arrays (AESAs), which enables multi-beam multiplexing and massive multiple-input, multiple-output (MIMO) technologies *(Fig. 1)*. Researchers working on the frontlines of forging this ultra-fast and high-bandwidth successor to 4G LTE are relying on modeling and simulation tools to optimize product development and test cycles.

Simulation supports designers throughout the design cycle by allowing them to virtually evaluate several design ideas and implement physical prototypes based on the most promising concepts. Another advantage lies in the possibility of investigating different boundary conditions. In this case, simulation allows an engineer to efficiently measure and test several scenarios—including extreme temperature variation, structural deformation, and chemical reactions—without damaging a prototype.

The goal of simulation specialists is to mimic the real world as closely as possible, so that the prototype is based on numerical results that achieve the expected performance in fewer design and test iterations.




**1. An isotropic radiation pattern was preferred before the 5G era (top). Antennas that generate a higher gain (directivity) radiation pattern are required for 5G millimeter-wave communications to compensate for the path loss in free space (bottom).**

Supplied with the right tools, designers working on 5G implementation can freely collaborate and complement their skills with those of their colleagues and collaborators who specialize in physics and numerical analysis.

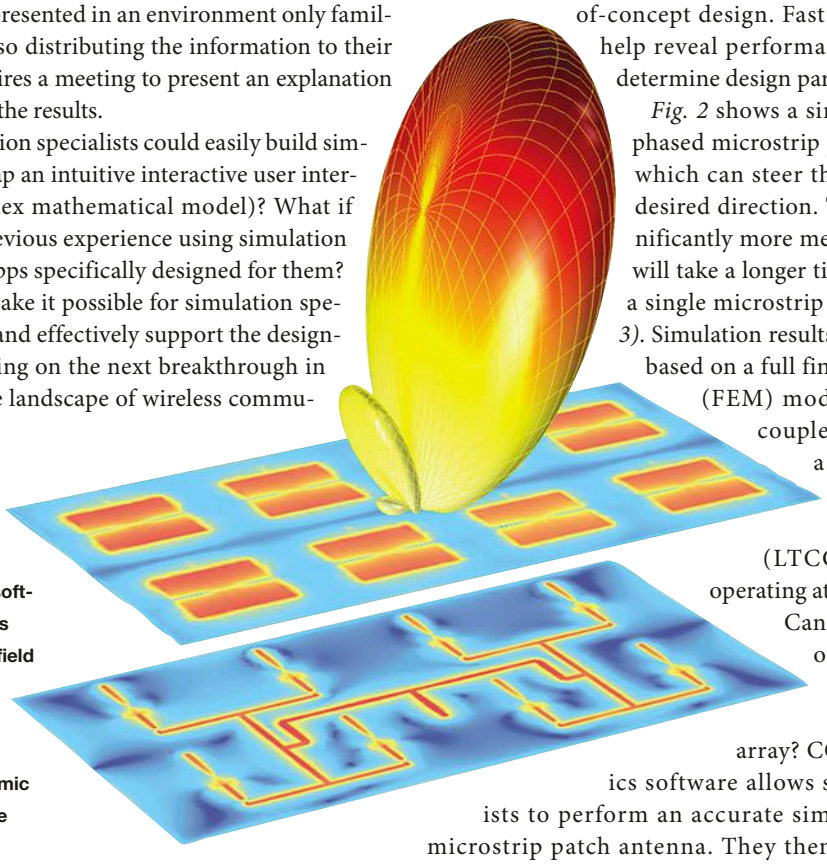
## DESIGNERS JOIN FORCES WITH SIMULATION SPECIALISTS THROUGH APPS

In preparation for the 5G rollout, designers are working through a number of obstacles, including frequency choices, propagation, reliability, battery life, and interference. Each of these challenges is represented by a unique blend of physics that require a simulation specialist in that specific area—one who is equipped with the right tools to set up the underlying mathematical model properly. The symbiosis between designers and simulation specialists needs to be perfect in order to deliver the right product at the right time.

Simulation experts are typically the only ones who can safely provide the input data needed to get a useful output from a model. They therefore have to be involved in the iteration process every time there is a new request or change to be made in the device being simulated. Additionally, results or outputs are often presented in an environment only familiar to the specialist, so distributing the information to their colleagues often requires a meeting to present an explanation and interpretation of the results.

But what if simulation specialists could easily build simulation apps (i.e., wrap an intuitive interactive user interface around a complex mathematical model)? What if users without any previous experience using simulation software could run apps specifically designed for them?

Simulation apps make it possible for simulation specialists to efficiently and effectively support the designers relentlessly working on the next breakthrough in the ultra-competitive landscape of wireless communication. Supplied with the right tools, designers working on 5G implementation can freely collaborate and complement their skills with those of their colleagues and collaborators who specialize in physics and numerical analysis.



**2. This figure shows a 4-×-2 phased microstrip patch antenna modeled using COMSOL Multiphysics software. The top plot shows the logarithmic electric field norm on the patch and the 3D far-field radiation pattern. The lower plot depicts the logarithmic electric field norm on the feed line planes.**

## WHAT SIMULATION APPS CAN DO FOR WIRELESS COMMUNICATION DESIGN

Let's take the example of AESAs, or phase antenna arrays. They have become popular for military use in radar and satellite applications and are now occupying a conspicuous position for commercial purposes due to the growing needs of higher data rates in communication devices. The size of a simple component can easily exceed tens of wavelengths, making its numerical analysis very memory-intensive.

As a result, models take a very long time even when approximated values would be sufficient to evaluate a proof-of-concept design. Fast prototyping would help reveal performance tendencies and determine design parameters quickly.

*Fig. 2* shows a simulation of a 4-×-2 phased microstrip patch antenna array which can steer the beam toward the desired direction. This example is significantly more memory-intensive and will take a longer time to compute than a single microstrip patch antenna *(Fig. 3)*. Simulation results shown in Fig. 3 are based on a full finite-element method (FEM) model of a single slot-coupled microstrip patch antenna built on low-temperature co-fired-ceramic (LTCC) layers, initially operating at 30 GHz.

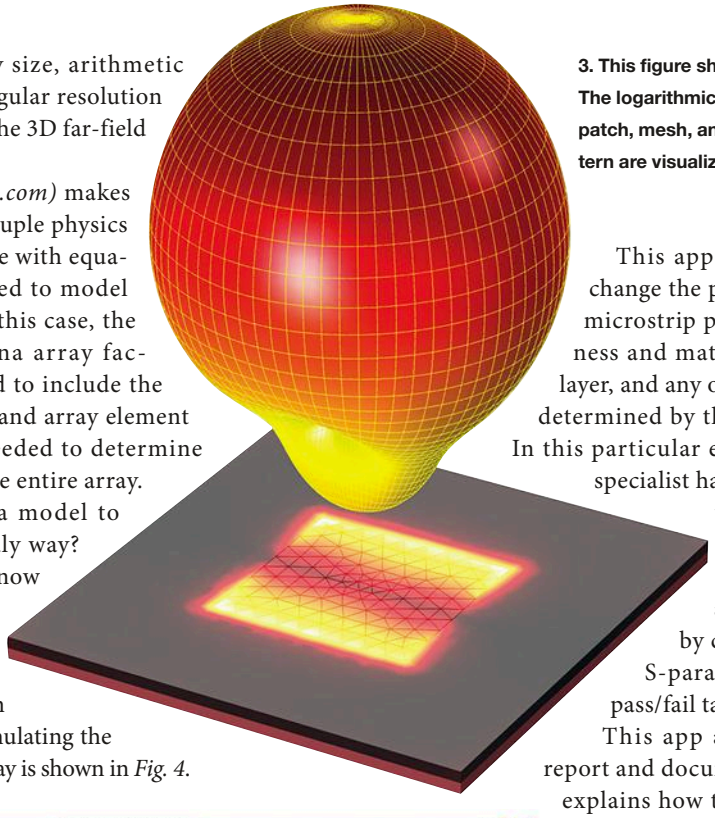
Can we use the analysis of a single antenna to describe the behavior of the entire array? COMSOL Multiphysics software allows simulation specialists to perform an accurate simulation of a single microstrip patch antenna. They then take into account

Apps can also be easily deployed to colleagues and collaborators through a local installation of the COMSOL Server product, which allows authorized users to access apps through COMSOL Client or a major web browser.

user inputs such as array size, arithmetic phase progression, and angular resolution to describe (for example) the 3D far-field of the entire array.

COMSOL *(www.comsol.com)* makes it easy for specialists to couple physics interfaces already available with equations or algorithms needed to model a specific application. In this case, the two-dimensional antenna array factor has been implemented to include the translational phase shifts and array element weighting coefficients needed to determine the radiation pattern of the entire array.

Can we present such a model to designers in a user friendly way? Simulation specialists are now provided with an intuitive workflow to create custom user interfaces based on their multiphysics simulation model. An app built for simulating the aforementioned antenna array is shown in *Fig. 4*.

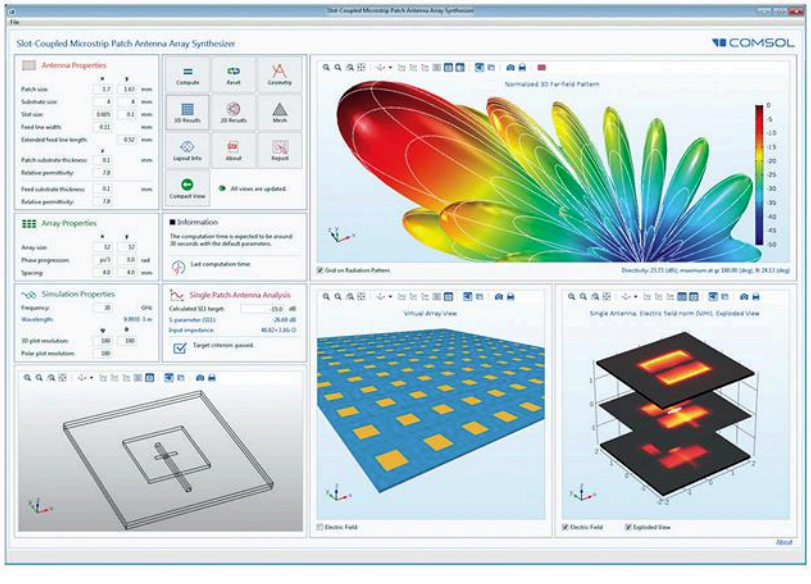


**3. This figure shows a single-patch antenna. The logarithmic electric field norm on the patch, mesh, and 3D far-field radiation pattern are visualized.**

This app allows the designer to change the physical size of the single microstrip patch antenna, the thickness and material properties of each layer, and any other relevant parameters determined by the simulation specialist. In this particular example, the simulation specialist has included an interactive user experience by indicating whether the chosen design parameters are appropriate or not by comparing the computed S-parameter ($S_{11}$) value to the pass/fail target criterion.

This app also includes a results report and documentation that concisely explains how the app is working. This last feature can be used in a variety of practical ways, from building reports to stakeholders and management, to use as a training tool for new hires in the company. Apps can also be easily deployed to colleagues and collaborators through a local installation of the COMSOL Server product, which allows authorized users to access apps through COMSOL Client or a major web browser.

We have a lot of work ahead of us before 5G is unveiled to the public. When designers are equipped with the right set of tools, they can freely collaborate with colleagues throughout their organization and beyond. Working cross-departmentally will be key to competing and succeeding in the 5G race. mw




**4. The user interface of the Slot-Coupled Microstrip Patch Antenna Array Synthesizer simulation app was built using the Application Builder tool in COMSOL Multiphysics.**

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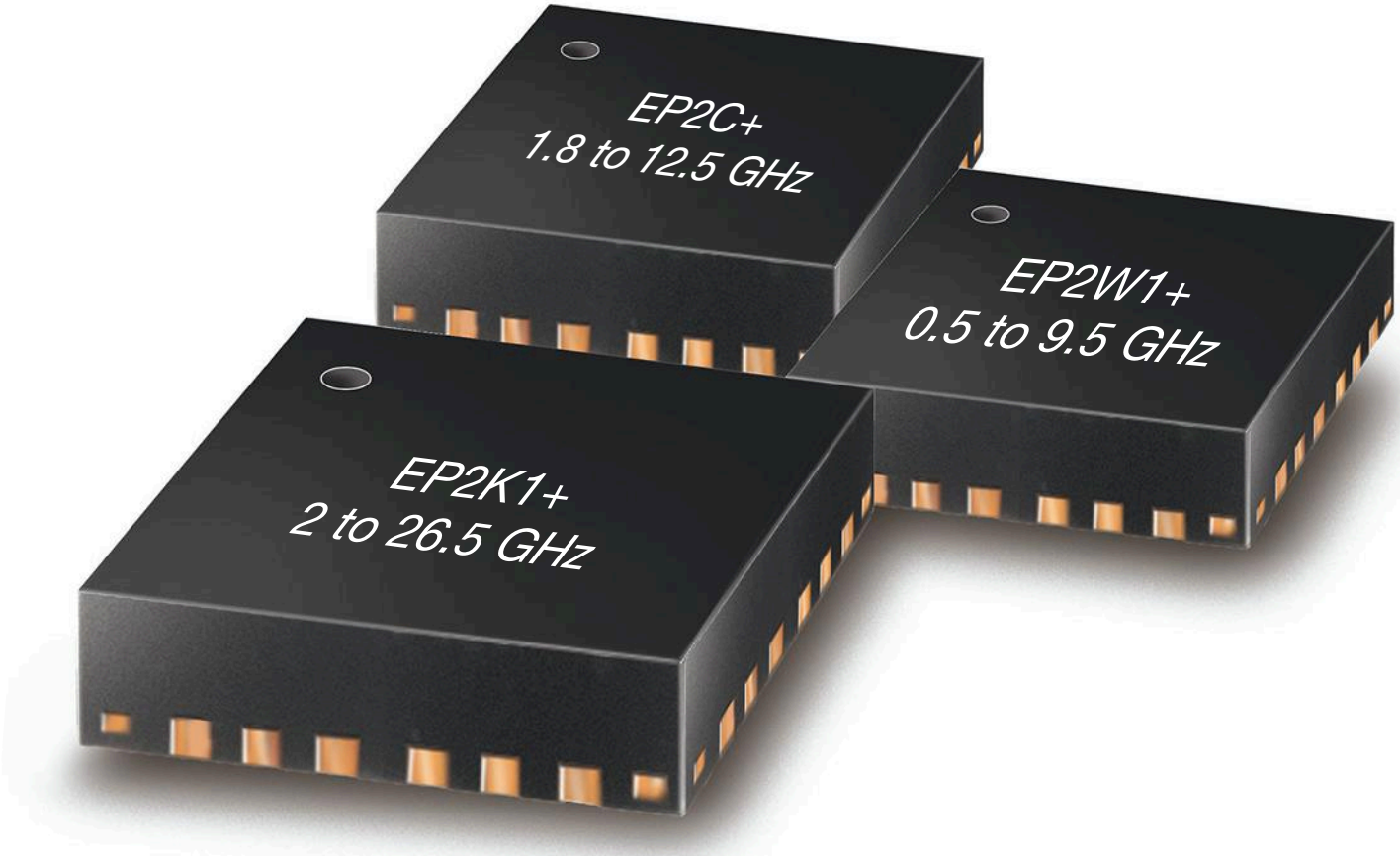


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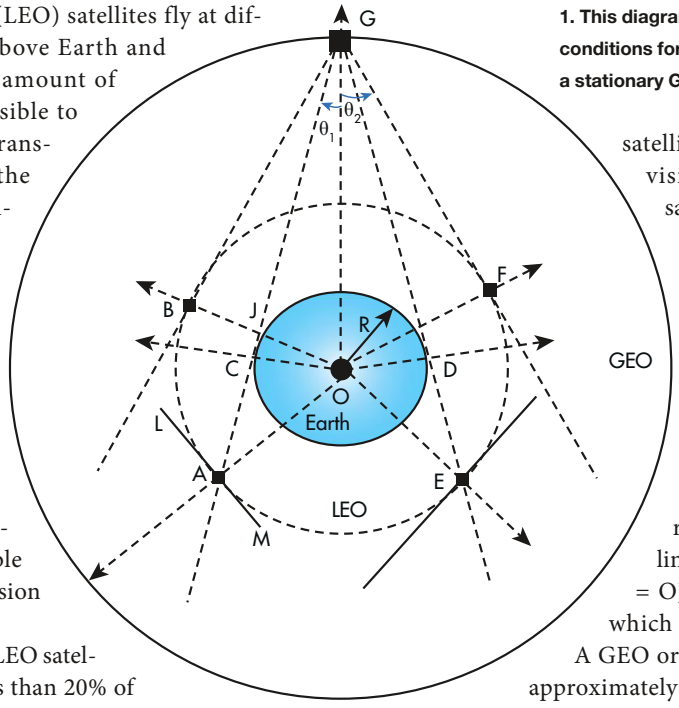
# Extend LEO Downlinks with GEO Satellites

**The data downlinking capability of a LEO satellite can be increased by using GEO satellites in a configuration of multiple satellites that relays data to earth.**

Low-Earth-orbit (LEO) satellites fly at different heights above Earth and can vary in the amount of time they are visible to a ground station (GS) to transferring data to and from the GS. For a typical LEO satellite in orbit 600 km above Earth, visibility to a GS may be less than 20 minutes per orbit, limiting the amount of data that can be exchanged. By recruiting a geosynchronous-Earth-orbit (GEO) satellite as part of the overall data link, however, it can be possible to increase the available LEO satellite data-transmission time (and amount of data).

Since the percentage of a LEO satellite's visibility to a GS is less than 20% of the satellite's orbital period, the time to download data in a satellite-communications (satcom) system is limited. To increase the imaging data capability and capacity of a remote-sensing LEO satellite, the imagery data must be stored onboard the satellite and downloaded at a higher data rate during such a limited visibility period. Furthermore, a greater number of networked GS sites around the Earth must be used.

Most of Earth's surface is covered by water, so accomplishing this task would require that a large number of "ground" terminals be located on ships—at prohibitive cost. However, a GEO satellite is visible to a LEO spacecraft for more than one-half of the LEO satellite's orbit, as a possible component in a data relay system. In theory, two widely spaced GEO satellites can provide continuous visibility/coverage for a LEO satellite.




**1. This diagram attempts to illustrate the conditions for visibility of a LEO satellite from a stationary GEO satellite.**

*Figure 1* depicts the visibility of a LEO satellite from a GEO satellite and antenna tracking ranges. A GEO communications satellite is considered to be at point G in the GEO equatorial orbit, with zero inclination. Earth's center is represented by point O, with line segments OC = OD = OH = OJ = R, the radius of Earth, which is approximately 6,380 km. A GEO orbit is represented by HG, at approximately 36,000 km. The height of a LEO satellite orbit is represented by HI (about 600 km for a typical remote-sensing satellite).

In the satellite diagram of *Fig. 1*, line segment OC is perpendicular to line segment ACG (where ACG is tangential to Earth at point C) and line segment OB is perpendicular to KBG (with KBG tangential to the LEO orbit at point B). The satellite at point G in the GEO orbit can have a maximum line-of-sight (LOS) visibility to point A or point E in the LEO satellite orbit. Arc ABIFE represents the maximum arc of the LEO satellite in which a GEO satellite can have LOS visibility with the LEO satellite. Angle BGF is the maximum angle a GEO satellite can have a LOS with the LEO satellite.

Wide-beam antennas are not practical onboard LEO or GEO satellites because of the need for the high gain required

TABLE 1: TRACKING DETAILS OF A LEO SATELLITE WITH RESPECT TO A GEO SATELLITE

| Visibility condition for steering LEO satellite antenna | Maximum range (km) | Maximum angle GEO antenna to track (°) | Maximum angle LEO antenna to track (°) | Percentage of coverage (%) |
|---|---|---|---|---|
| Limited visibility (±90°) tracking | 42,950 | ±9.35 | ±90 | 44.8 |
| Maximum visibility tracking | 45,700 | ±9.35 | ±113 | 63.3 |

in support of transmitting signals at high data rates in excess of 100 Mb/s. The high-gain data links from LEO to GEO satellites call for antennas with narrow beam widths. In addition, to maintain LOS between satellites, the beams of LEO satellite antennas as well as GEO satellite antennas must be steered. An antenna on the LEO satellite intended for LOS with the GEO satellite must be mounted on the face of the satellite opposite the Earth's surface.

The steering angle range of the antenna on a LEO satellite with respect to a GEO satellite is 180° or the angle denoted by OAG in *Fig. 1*. This indicates that an antenna on a LEO satellite shall have a beam-scanning capacity of more than ±90° while a GEO satellite antenna shall be able to scan over the angle represented by ±OGB in *Fig. 1*. *Table 1* presents details for two typical LEO scenarios, with a LEO satellite in orbit 600 km above Earth and a GEO satellite for relaying data.

## ENHANCING VISIBILITY

In principle, 100% visibility of a LEO satellite can be obtained by using two GEO satellites positioned 180° apart in GEO flight patterns. This calls for two ground stations (GSs) on opposite sides of Earth. The ground stations must be networked so that data is transferred to the required GS.

Two satellites separated, for example, by about 100° in GEO can be controlled by a single GS, with both satellites transferring data to the single GS. With these two GEO satellites separated by 100°, steering the LEO antenna by ±90° can cover the majority of its orbit. By steering the LEO antenna by about ±113° for maximum LEO satellite visibility, 100% of its orbit can be covered.

Such steering capability is not routine, however. The antenna on the LEO satellite must track over an angular range of ±XAG as represented in *Fig. 1*, which is more than 90° on either side of LOS contact with the GEO satellite from points A and E on the orbital map. Although this can provide maximum visibility of the LEO satellite to the GEO satellite, this can make the design of the LEO satellite's antenna very complicated. That's because it requires sufficient clearance from the satellite body to achieve a large field of view (FOV), and an antenna with a large boom.

Steering a beam either by dual-gimbal-controlled, high-gain antenna or by spherical phased-array antenna over ±90° is possible with minimum impact on the satellite. An alternative means of achieving the maximum possible visibility area is by employing such an antenna design as a quadrifilar helix antenna to provide a wide beam (±120°) with sufficient FOV of the LEO satellite and its antenna.

As an example, two stationary GEO satellites at 34° E and at 134° E (100° separation) can be controlled from a GS in India. Two types of antennas can be used on each satellite. A horn antenna with a relatively wide beam width of 18.7° can provide about 16 dBi gain. Alternatively, a higher-gain antenna with narrower beam width can be used, although it must be steered over a range of ±18.7° in elevation and 360° in azimuth. To better understand the results expected from the use of such different antennas, link analyses were performed with a LEO imaging satellite in 600-km-high orbit catering to low data rates of less than 10 kb/s, as well as payload data at rates to 150 Mb/s.

For the analyses, C- and Ku-band frequencies were not considered since these frequency bands are fully occupied. Rather, the use of links between satellites was considered for cases with bands specified by the International Telecommunications Union (ITU) at S-, X-, or Ka-band frequencies.

For intersatellite communications, when GEO tracking is limited to LEO arc FIB in *Fig. 1*, rain attenuation is not a concern since the radio links will not pass through the atmosphere. Under such conditions, 20/30-GHz Ka-band frequencies would be popular choices for intersatellite communications. However, for maximum visibility between satellites, the LOS between the GEO and LEO satellites will pass through Earth's atmosphere; Ka-band frequencies are not well-suited due to rainfall attenuation.

In addition, for maximum visibility, the required antenna structure becomes complex. More than 85% orbital coverage is possible with a configuration of two satellites separated by 100° in the GEO satellite and antenna tracking limited to ±90° on the LEO satellite, As a result, Ka-band frequencies at 30 GHz were chosen as the operating range for a high-bit-rate link between LEO and GEO satellites.

Spectra at X-band frequencies (8025 to 8400 MHz) and Ka-band frequencies (25.5 to 27 GHz) were allotted for space-to-Earth data transmissions. Either of these bands can be used for high-bit-rate links from GEO satellite to GS. A link at X-band will be less affected by rain than one at Ka-band frequencies, but a Ka-band link can be used to transfer high-bit-rate data from a GEO satellite to a GS by adopting rain-loss mitigation techniques. By designing in sufficient link margin; using adoptive modulation, data-rate, and coding techniques; and using spatial diversity, it is possible to

minimize the effects of rainfall attenuation on link performance.

For lower-rate telemetry, tracking, and control (TTC) data, S-band frequencies can be used as a link between a GS and the GEO satellite since this link will be not be impacted by rainfall attenuation. When using a wide-beam antenna on a LEO satellite, almost 100% coverage can be obtained with two GEO satellites placed at 34° elevation and 134° elevation locations. S-band frequencies can also be employed for GEO-LEO and LEO-GEO inter-satellite communications. Alternatively, low-bit-rate data can be communicated to a GEO satellite from a GS using S-band frequencies and translated onboard the GEO satellite to Ka-band frequencies for transfer to a LEO satellite.

TABLE 2: COMPARING OPTIONS FOR SATCOM LINKS

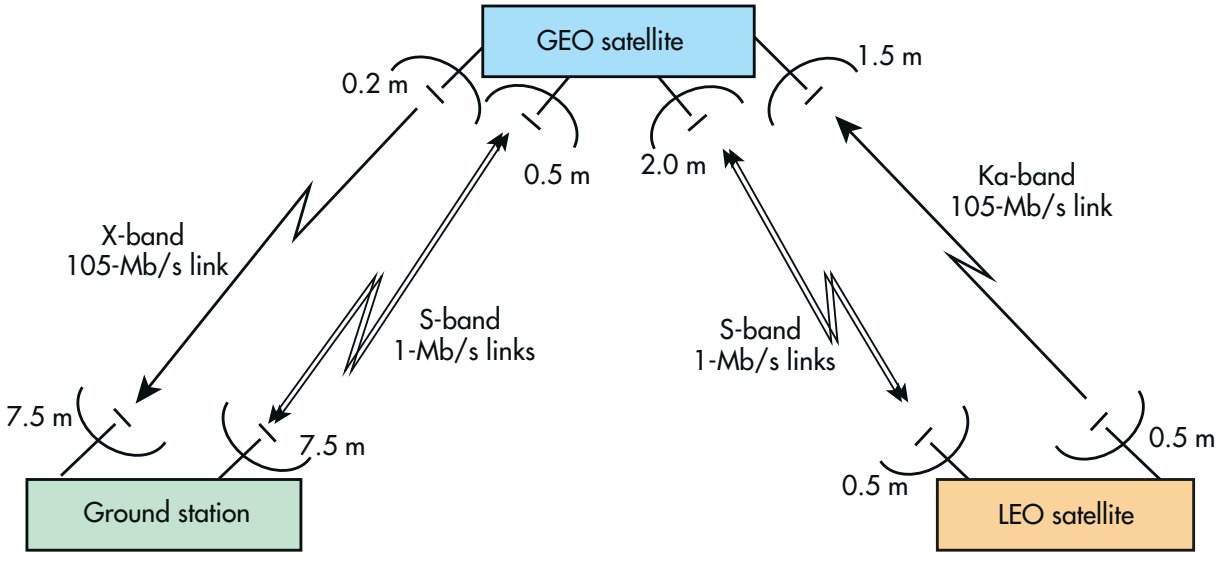
| Forward link Frequency: 2000 to 2100 MHz Data rate: 1 Mb/s | | | | | | |
|---|---|---|---|---|---|---|
| | GEO | | | LEO | | |
| | Transmit antenna | Transmit power | EIRP | Receive antenna | G/T | Margin (coding gain of 9 dB) |
| Option 1 | 2.0 m | 20 W | 42 dBW | 0.5 m | –12 db/°K | 2 dB |
| Option 2 | 5.6 m | 250 W | 62 dBW | Wide-beam antenna –2 dBi | –32 dB/°K | 2 dB |
| **Return link Frequency: 2200 to 2300 MHz Data rate: 1 Mb/s** | | | | | | |
| | LEO | | | GEO | | |
| | Transmit antenna | Transmit power | EIRP | Receive antenna | G/T | Margin (coding gain of 9 dB) |
| Option 1 | 0.5 m | 20 W | 30 dBW | 2.0 m | 1 dB/°K | 2 dB |
| Option 2 | Wide-beam antenna –2 dBi | 250 W | 21 dBW | 5.6 m | 9 dB/°K | 2 dB |

EIRP = effective isotropic radiated power; G/T = gain-to-noise temperature

## MAKING THE CASE VIA LINK ANALYSIS

To better understand the workings of inter-satellite communications, link analysis was performed for three possible cases, with various options. Each case assumed that high-bit-rate data was being communicated from a LEO satellite to a GEO satellite to a GS. The link from the LEO satellite to the GEO satellite occurred at Ka-band (30 GHz), while the link from the GEO satellite to the GS took place at Ka-band (26 GHz) or X-band (8.2 GHz).

In the first case, a wide-beam antenna was used on the LEO satellite with a high-gain antenna on the GEO satellite. The LEO antenna gain was 0 dBi with transmit power of 100 W. The GEO receive antenna had a diameter of 5 m and an antenna gain-to-noise-temperature (G/T) value of 31.5 dB/°K. This case was found to be capable of supporting a maximum data rate of 200 kb/s with about 3-dB link margin. It would not be practical to provide more transmit power to the LEO antenna, and a complicated mechanism was required for steering the 5-m antenna on the GEO satellite. As became evident, it is not easy to achieve a high-bit-rate data link with an omnidirectional, wide-beam antenna on the LEO satellite.




**2. Shown are the various links between two different types of satellites and an Earth-based ground station (GS).**

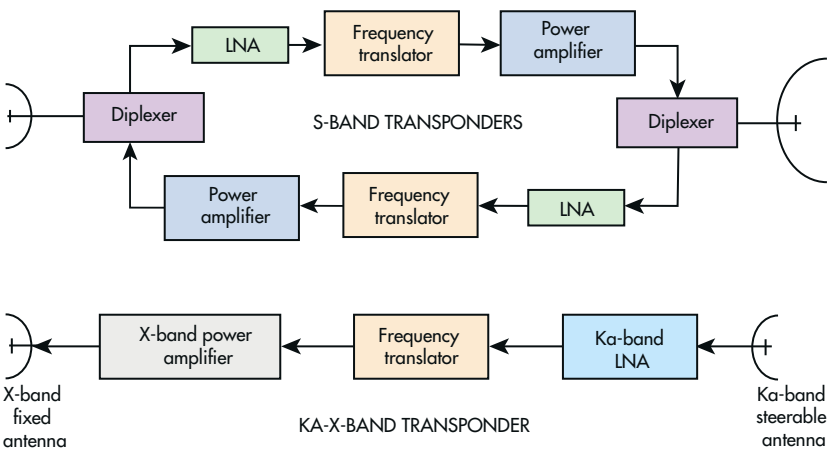
In the second case, a narrow-beam horn antenna with 18.7° beam width and 16-dBi gain was used on the GEO spacecraft to eliminate antenna steering. To send 100 Mb/s at 100 W Ka-band transmit power, a steerable parabolic antenna larger than 5 m in diameter would be needed on the LEO satellite, which is not very practical. For sustainable, high-speed data links, even the GEO satellite must be steerable and capable of high gain in this case.

In the third case, to transmit data at 100 Mb/s between satellites, quadrature-phase-shift-keying (QPSK) modulation with 7.5-dB coding gain was used at Ka-band (30 GHz). A 0.6-m-diameter transmit antenna was incorporated on the LEO satellite with 40 W transmit power and effective isotropic radiated power (EIRP) of 57 dBW. A 1.5-m-diameter receive antenna was used on the GEO satellite with G/T of 21 dB/°K and a LEO-to-GEO-link carrier-to-noise ($C/N_0$) ratio of 90 dBHz.

Several options were considered as part of these three satcom systems for analysis. For option 1, a link between the GEO satellite and the GS was assumed at Ka-band (26 GHz). The GEO satellite transmit antenna was 0.2 m in diameter with 20 W transmit power and 43.5 dBW EIRP. The receive antenna on the GS was 7.5 m in diameter with G/T ratio of 37.5 dB/°K. The downlink $C/N_0$ level was 95 dBHz with an overall $C/N_0$ of 88.8 dBHz. For 100-Mb/s data transfer with 10-6 bit-error-rate (BER) performance that maintains 7.5-dB coding gain, this setup provides about 3.5-dB margin for a clear sky.

For option 2, the link between the GEO satellite and GS was at X-band (8.2 GHz) using a 0.2-m-diameter GEO satellite transmit antenna with 40 W transmit power and 36 dBW EIRP. The receive antenna on the GS was 7.5 m in diameter with a G/T ratio of 32 dB/°K. The downlink $C/N_0$ level was 92 dBHz with an overall $C/N_0$ of 88 dBHz. For 100-Mb/s data transfer with 10-6 BER and 7.5-dB coding gain, this setup provides about 3.0-dB margin for a clear sky.

Suggested system configurations for achieving a Ka-band high-bit-rate data link from the LEO satellite to the GEO satellite requires a LEO satellite with a 0.5-m-diameter dual-gimballed antenna (DGA) that features 1.4° beam width and better than ±0.01° tracking accuracy. To achieve a better than 56 dBW EIRP, a 40-W Ka-band traveling-wave-tube amplifier (TWTA) is needed onboard the LEO satellite. For the GEO satellite, a DGA with 1.5-m diameter and 0.47° beam




**3. This block diagram represents the basic components of a GEO satellite system.**

width can be used. It should have a G/T ratio of 21 dB/°K and better than ±0.04° tracking accuracy.

For the third case with option 1, Ka-band could be considered from the link from the GEO satellite to the GS if the satellite carries Ka-band payload transponders and the onboard antenna can be shared. To overcome at least 10-dB rainfall attenuation, a Ka-band antenna of at least 0.5 m in diameter should be used. The GS antenna should be 7.5 m in diameter with G/T performance of 37.5 dB/°K.

For the third case with option 2, less rainfall attenuation will occur when using an X-band link from the GEO satellite to the GS. To achieve an EIRP of 36 dBW from the GEO satellite to the GS, the GEO satellite should have a 0.2-m-diameter fixed antenna with 40-W-output TWTA or solid-state power amplifier (SSPA), or a 0.5-m-diameter antenna with 10-W-output-power SSPA. The GS should be 7.5 m in diameter with a G/T of 32 dB/°K. For low-bit-rate data links to 1 Mb/s at S-band, coding gain of about 9 dB is possible with turbo/LDPC coding.

For data links from the GS to the GEO satellite, a forward link from 2.0 to 2.1 GHz is possible by maintaining GS EIRP of 50 dBW via a 7.5-m-diameter antenna with 10 W transmit power and a GEO satellite with 0.5-m-diameter antenna and G/T of 13 dB/°K. For the return link from 2.2 to 2.3 GHz, the GEO satellite should have a 0.5-m-diameter antenna with 10 W transmit power and 27 dBW EIRP, as well as a GS with 7.5-m-diameter antenna and 12 dBW EIRP.

For data links from the GEO satellite to the LEO satellite (forward link) from 2.0 to 2.1 GHz, the GEO satellite should have a 2-m-diameter antenna with 50 W transmit power and EIRP of 47 dBW. The LEO satellite should have a 0.5-m-diameter antenna with G/T of –12 dB/°K. For the return data link from the LEO satellite to the GEO satellite, at 2.2 to 2.3 GHz, the LEO satellite should have a 0.5-m-diameter antenna with 50 W transmit power and the GEO satellite should have a 2-m-diameter antenna with G/T of +1 dB/°K. Analysis has shown that the link cannot be sustained with an omnidirectional or wide-beamwidth antenna on the LEO satellite. For optimum high-bit-rate data communications at Ka-band, high-gain steerable antennas should be used on the LEO and GEO satellites.

*Table 2* details the various options for the low-bit-rate forward and return links. For option 1, the antennas on the GEO satellite and on the two LEO satellites will be steered. For option 2, beamsteering is eliminated for the LEO satellites, but requires transmit power to be increased by 250-W power amplifiers (PAs) on the GEO satellite as well as on the LEO satellites, and a steerable 5.6-m antenna on the GEO satellite. Each 250-W PA requires more than 400 W dc power. Such added power consumption is difficult to justify in LEO satellites.

Since steering antennas on the GEO and LEO satellites is not a problem, option 1 is a more viable solution than option 2. *Figure 2* shows a suggested satellite configuration, and *Fig. 3* illustrates a block schematic of a GEO satcom system.

As this analysis has shown, the downlink data capacity of a LEO satellite can be enhanced by using GEO relay satellites. A single ground station can control the percentage of visibility with two satellites in GEO separated by about 100°, and enhance the data-transfer period to about 85% of the total orbital period of a LEO satellite. mw

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# Choosing Between CW and Pulsed Power Amps

**The electrical and mechanical design approaches taken with high-power RF/microwave amplifiers depend on whether they are intended for pulsed or CW applications.**

Power amplifiers (PAs) for RF/microwave use come in various shapes and sizes, at many different performance levels, and based on numerous technologies. Differences in capabilities separate one PA from another as a better fit for a particular system. But one key difference perhaps stands apart from the rest: Has the PA been designed for continuous-wave (CW) or pulsed amplification, such as in communications or radar systems, respectively. Furthermore, what characteristics can help make an amplifier a good fit for either a CW or pulsed application?

Whether based on vacuum tubes or solid-state semiconductor devices, PAs must be designed for either CW or pulsed operation—not for both modes. One reason is that the active devices within an amplifier are typically biased in such a way as to satisfy a blend of performance tradeoffs, including gain, linearity, efficiency, and output power for a target frequency or band of frequencies.

For example, if a CW amplifier with gallium-nitride (GaN) high-electron-mobility-transistor (HEMT) semiconductor devices is biased to generate 50 W output power with a 0-dBm input signal, it cannot simply be fed a short pulsed input signal at +3 dBm (or even a CW signal at that level) with the expectations of doubling the output power.

An amplifier that is not specifically designed for pulsed signals in general, or signals with a specific pulse width and pulse duration, can leave "traces" of itself on the output signal. These can be critical for defense-related applications, such as radar systems. For example, an amplifier that adds pulse traits such as ringing, overshoot, and droop to a boosted signal also makes a particular radar signal easily identifiable by an adversary due to those pulse characteristics. But by designing an amplifier for pulsed signals and adjusting its bias levels for minimal pulse distortion, a radar's transmitted pulses can remain undecipherable to an adversary's receivers.

On the other hand, it may be possible for an amplifier nominally designed as a CW component to perform with pulsed signals. However, the power levels of the pulsed input signals cannot overload the CW PA's active devices and the attempted pulsed output-power levels cannot exceed the thermal-management capabilities of the CW PA.


**Thermal protection is built into this pulsed GaN PA, which provides 200 W output power from 8.5 to 9.6 GHz. The amplifier's manufacturer emphasizes that the component must be used with a heat sink.** *(Courtesy of CTT Inc.)*

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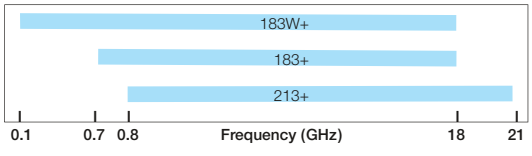


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Many performance parameters are comparable between CW and pulsed PAs, such as frequency range, small-signal gain, gain flatness, input and output VSWR, and bias voltage and current.

Of course, for a CW amplifier with bias that is designed to be always on, operating with pulsed input signals that are on for a fraction of the time may ease the total amount of heat generated by the active devices. But, it will lack the power efficiency of a pulsed PA designed with bias that switches on and off as needed by the pulsed input signals.

## KEEPING IT COOL

Pulsed and CW amplifiers are designed and assembled much differently in terms of thermal management. Quite simply, extremely high-power pulsed amplifiers are not designed for CW operation. In fact, many pulsed amplifiers would overheat if operated with CW signals at their rated output-power levels.

Whether in commercial, industrial, or military applications, PAs are typically designed with heat sinks that are not overly large, but sized to dissipate the amount of excess heat generated by the PA. The amount of heat is a function of a number of different factors, including active device gain, output power, and amplifier power-added efficiency (PAE).

A pulsed amplifier may operate at higher output-power levels than a CW amplifier, but it also generates heat for a fraction of the time of a CW PA, which is continuously amplifying signals and generating heat. Even for an amplifier with a typically high PAE rating of 50%, one-half of the dc power supplied to the amplifier converts to heat, which must be dissipated.

For challenging PA thermal-management cases, a heat sink is typically only part of the solution. Usually some additional form of heat dissipation, such as fan-driven forced-air cooling, is needed to maintain a PA's active devices within a safe operating temperature range. Without proper cooling, those active devices can quickly rise above their maximum allowable operating temperature, such as +85°C, leading to device damage or destruction and almost always to degraded device reliability.

For PAs with healthy output-power levels, whether CW or pulsed, the heat sink is usually a good part of the total package. Because of system requirements for smaller size, amplifier designers will usually try to integrate the smallest-possible heat sink that can still dissipate the amount of heat expected to be generated at maximum output-power levels.

Take, for example, a 100-W pulsed PA with active devices that are 50% efficient, but it has a short duty cycle of 1% and is only on 1% of the time. A heat sink capable of dissipating that pulsed PA's heat during normal operation would be severely undersized if the amplifier was operated at a 100-W output-power level but on 100% of the time. Ideally, the timing of the pulsed bias is synchronized with the timing of the pulsed signal conditions, such as pulse width, pulse repetition frequency (PRF), and pulse duty cycle, so that amplifier power is on only when the pulse is being processed.

## A TALE OF TWO SPEC RANGES

Specifying an amplifier for a CW application is somewhat simpler than sorting through the operating parameters required of a pulsed PA for a radar or EW application. A CW amplifier is always on, so the current draw will be continuous for a given supply voltage, although the amount of current will vary according to the amplifier's load, input-signal level, and maximum output power.

Many performance parameters are comparable between CW and pulsed PAs, such as frequency range, small-signal gain, gain flatness, input and output VSWR, and bias voltage and current. However, pulsed PAs have their own specifications regarding pulsed operating conditions, and these specifications are often defined for very specific applications.

As an example, model AGN/096-5364-P is a solid-state pulsed PA from CTT Inc. *(www.cttinc.com)* based on GaN semiconductor technology *(see figure)*. It provides 200 W pulsed output power from 8.5 to 9.6 GHz when operating with a 100-µs pulse width at a 10% duty cycle and 0-dBm input power. It features extremely high gain of 64 dB or more and worst-case gain flatness of ±3 dB, with worst-case input/output VSWR of 2.0:1. Specifications differ from a CW PA in terms of time-related parameters that help establish the pulsed performance. Using transistor-transistor-logic (TTL) on/off control, the pulsed GaN PA achieves on and off switching speeds of 250 ns.

For its high output-power rating, this is a fairly compact amplifier, measuring 6.08 × 4.49 × 0.72 in. and weighing 500 g. It draws 2.5 A from a +40-V dc supply and 0.5 A from a +12-V dc supply. The amplifier includes temperature protection to keep its metal case from rising above a safe upper limit of +70°C. The manufacturer stresses that a heat sink is "absolutely required" with this PA to maintain safe thermal operating conditions, and offers guidance on the proper selection of a heat sink for this or any of the company's other PAs. mw


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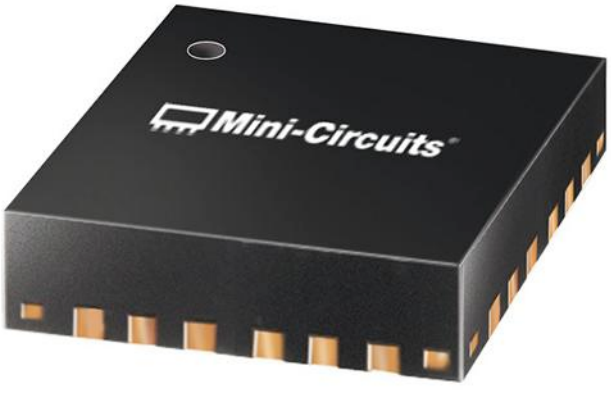
# Deciding Between Mixers and Muliplers/Dividers

**Frequency translation is essential to communications and other electronic systems, and can be achieved in a number of ways with or without an additional signal source.**

Many applications translate frequencies higher or lower in various ways, such as via frequency mixers, frequency multipliers, and frequency dividers. These components take different approaches to transform the frequencies of signals and their modulation content from their inputs to their outputs, but are they interchangeable? When does it make more sense to use a mixer rather than a multiplier or divider?

The main functional difference between the components involves how frequency conversion is achieved: A frequency mixer requires a second input signal, adding and subtracting the two signals to achieve a desired result. On the other hand, a frequency multiplier or divider works with the first input signal alone, extracting the final result from harmonic or subharmonic signal components.




**1. Frequency-translation components such as this surface-mount frequency multiplier achieve miniaturization through integration.** *(Courtesy of Mini-Circuits)*

Frequency mixers and multipliers/dividers both rely on the nonlinear behavior of semiconductors, such as diodes and transistors, to translate frequencies from input to output ports. Schottky diodes and GaAs field-effect transistors (FETs) have been long-time choices for RF/microwave mixers. Meanwhile, newer mixers take advantage of monolithic-microwave-integrated-circuit (MMIC) technology to include supporting circuits, such as filters and amplifiers, in compact circuits that fit into surface-mount-technology (SMT) or drop-in packages.

Frequency mixers are three-port circuits that can upconvert input signals to higher frequencies and downconvert input signals to lower frequencies, depending on how the signals are fed to the ports. The three ports in a conventional mixer are the radio-frequency (RF), local-oscillator (LO), and intermediate-frequency (IF) ports; the traditional component symbol for a frequency mixer is a circle with "x" inside. The input signal mixes with the LO signal to achieve the sum (f1 + f2) or difference (f1 – f2) of the two signals.

When the incoming signal is fed to the RF port, a downconverted, lower-frequency signal appears at the IF port. When the incoming signal is applied to the IF port, an upconverted, higher-frequency signal is available at the RF port. Receivers typically employ downconversion, while transmitters require upconversion.

Frequency translation in a mixer can be defined in two ways. In single-sideband conversion, only the sum or difference of the two input signals is available at the mixer output port (and the unwanted signal product suppressed

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within the mixer). For double-sideband conversion, both the sum and the difference of the two input signals are available at the output and the user filters out the unneeded signal product.

## MULTIPLYING AND DIVIDING

Translation to higher frequencies can also be achieved by means of frequency multipliers, as with translation to lower frequency using frequency dividers. In a frequency multiplier, the output signal's frequency is an integer multiple of the input signal's frequency: $f_{out} = nf_{in}$. Output power drops with higher values of n, but high-frequency multiplication is possible by cascading multipliers together. Schottky-barrier or varactor diodes are often the nonlinear semiconductors of choice for frequency multipliers or dividers, with PIN or step-recovery diodes used when the need arises for higher-order multiplication.

Ideally, multiplication would occur with no degradation in the output signal's spectral purity. In reality, noise occurs with any frequency-translation process, including with multipliers and dividers. A frequency multiplier will increase the phase noise of the source because it is a phase/frequency multiplier, and it will multiply the phase deviations as well as the input signal's frequency. Similarly, a frequency divider, often comprised of semiconductor prescalers, will contribute additive phase noise to its lower-frequency, divided outputs.

A frequency multiplier will cause a change in the carrier-to-noise ratio (CNR) of an input signal, or ΔCNR, according to the relationship ΔCNR = 20log n, where n is the multiplication factor. As a result, a doubler (n = 2) will cause a degradation of 6 dB in an input signal's CNR, a quadrupler (n = 4) will raise the noise level by 12 dB, and so forth. However, when multiplying signals from a low-noise source, such as a 10-MHz reference oscillator with low phase noise, it is possible to achieve RF/microwave signals with low phase noise even when using high multiplication factors.


**2. Additional programmability and functionality in turn required a larger package for this analog/digital frequency divider.** *(Courtesy of Valon Technology)*

## SIZING UP SPECIFICATIONS

Frequency mixers, multipliers, and dividers are characterized by somewhat different parameters, although they can be compared in terms of frequency-conversion loss/gain or conversion efficiency across their applicable bandwidths. The bandwidths of the different components are usually designed according to the requirements of a particular communications or radar system, with models available for narrow, moderate, and wide bandwidths as needed.

Conversion loss (or conversion gain in an active mixer) is a key performance parameter for RF/microwave mixers, with isolation between ports and the 1-dB compression point being important performance details. The conversion loss of a frequency mixer, in general, is considerably less than that of a frequency multiplier or divider. However, the mixer will also

Modern frequency mixers and multipliers benefit from the miniaturization possible with integrated-circuit (IC) processes and SMT packaging.

require an LO for a particular frequency range and output-power level, and some of the LO's energy will be lost as part of the frequency-translation process.

When specifying a mixer for a required downconversion or upconversion frequency range, the LO's performance is as important as that of the mixer circuitry. LO characteristics like phase noise, spurious content, and harmonic content will contribute to the content of the upconverted or downconverted signal, so the choice of LO must be made according to final signal performance requirements.

Some frequency mixers, such as the SIM mixers from Mini-Circuits *(www.minicircuits.com),* are designed for broadband frequency coverage (a total frequency range of 100 kHz to 20 GHz) while maintaining low conversion loss and high port-to-port isolation, even with flexible LO requirements. These mixers, based on low-temperature-cofired-ceramic (LTCC) substrates for commercial, industrial, and military applications, are available with LOs at different power levels: +7, +10, +13, and +17 dBm (often referred to as Level 7, Level 10, and so on). The diversity of models simplifies the task of specifying a mixer for an application, since broadband models can be used for multiple applications.

Modern frequency mixers and multipliers benefit from the miniaturization possible with integrated-circuit (IC) processes and SMT packaging *(Fig. 1)*. The usual tradeoff for miniature size is power-handling capability. But, following the trend of increased circuit density in system designs, the small sizes of these components allow for additional circuit functionality in limited space.

For example, GaAs heterojunction-bipolar-transistor (HBT) semiconductor technology is the basis for Mini-Circuits' CY2-143+ wideband frequency doubler, which comes in a MCLP housing measuring just 4 × 4 × 1 mm. The multiplier provides outputs from 4 to 14 GHz when fed input signals from 2 to 7 GHz. It works with input signal levels from +12 to +18 dBm, and yields output levels to about +6 dBm as a result of 12-dB typical conversion loss across the frequency range. This compact multiplier exhibits good suppression of spurious and fundamental-frequency signals, thus simplifying requirements for additional filtering at the system level.

In applications where frequency translation must be programmable or performed according to a certain protocol, signal and control interfaces may require that a frequency multiplier or divider be housed in a somewhat larger package. As a sophisticated example, the model 3010 programmable frequency divider from Valon Technology handles inputs from 5 to 2000 MHz at RF power levels from –20 to +20 dBm. It also provides multiple 50-Ω coaxial RF and +3.3-V CMOS/TTL-compatible lower-frequency outputs as might be needed for laboratory or test applications.

The 3010 employs a cascade of internal dividers to achieve its broad bandwidth. It allows operators to select from 16 division ratios spanning 1 to 32 by means of hardware jumpers. In exchange for the larger size and power consumption (about 150 mA from +4 to +7 V dc) compared to miniature components, this frequency divider *(Fig. 2)* provides a wide input dynamic range (typically –20 to +13 dBm) and flexible programmability. MW

# RF INNOVATION ARISES TO ENABLE 5G

**FIFTH-GENERATION (5G)** networks represent the future of wireless technology. 5G environments are expected to be more complex and require more components, such as filters. Other aspects of 5G likely include more complex multiple-input, multiple-output (MIMO) antennas, new and adaptable waveforms, and improved interference mitigation. In a new white paper from Resonant, *"RF Innovation and the Transition to 5G Wireless Technology,"* an overview of 5G is first provided. The white paper then delves into additional topics, with a focus on 5G RF filter requirements.

The white paper discusses how 5G is expected to dramatically improve performance in terms of network capacity, mobile connections, latency, cost, data rates, and coverage. It also describes the range of devices that will connect to the 5G network, such as mission-critical, Internet of Things (IoT), and next-generation mobile devices. In addition, several key factors that could help meet the targeted goals for 5G are explained: higher frequencies, massive MIMO, interference mitigation, and new and adaptable waveforms.

5G RF front ends are also examined, as the complexity associated with 5G could impact RF front-end development in a number of ways. These front ends will be driven by cost, power efficiency, and available space within a unit, according to the white paper. In essence, 5G RF front ends will need to be small, highly efficient, and manufactured in large quantities to meet global demands.

**Resonant Inc.,**
**110 Castilian Dr. Ste. 100,**
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Filter requirements for future 5G networks are discussed, as a number of filtering challenges are mentioned. One of these challenges is complex multiplexing, which will be required as a result of carrier aggregation (CA). And because an increased number of filters will be required, their size and cost must continue to decrease. Additionally, higher frequencies will require filter technologies other than the current acoustic wave filters used in mobile devices. The white paper concludes with a description of Resonant's Infinite Synthesized Networks (ISN) technology, which the company says is well suited to meet 5G requirements.

# BEAMFORMING TECHNOLOGY EMBARKS ON THE NEXT GENERATION

**BEAMFORMING ANTENNA ARRAYS** are expected to play a significant role in 5G networks. These antenna arrays allow for increased capacity of cellular networks, as signal-to-interference ratio (SIR) can be improved by directly targeting user groups. In the white paper, *"Millimeter-Wave Beamforming: Antenna Array Design Choices & Characterization,"* Rohde & Schwarz provides an overview of beamforming technology. The white paper then discusses antenna array simulation techniques, as an antenna array is first simulated with ideal antenna elements and then with actual measured element radiation patterns.

A phase coherent signal is a requirement for all beamforming architectures, as phase coherency can allow a main lobe to be steered in the desired direction. A few methods of generating phase coherent signals are mentioned. Moreover, the document explains how multipath fading and delay spread can significantly reduce a cellular network's capacity. The white paper states that modern beamforming architectures can help mitigate these problems by adapting to the channel.

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Three different beamforming architectures are described. The first one is an analog beamforming transmitter architecture, which consists of an RF chain and multiple phase shifters. Next, the digital beamforming architecture is presented. While analog beamforming is generally restricted to a single RF chain, digital beamforming can theoretically support as many RF chains as there are antenna elements. Lastly, the hybrid beamforming architecture is described. This solution combines advantages of both analog and digital beamforming architectures.

Linear antenna arrays are then theoretically explained. The white paper notes that the radiation pattern of a linear antenna array can be approximated by multiplying the array factor with the element radiation pattern. This element radiation pattern is considered equal for all elements—assuming the array is large enough. Illustrations demonstrate the effect of varying the number of antenna elements, as well as the distance between them. Next, linear antenna array simulations are performed using omnidirectional antenna elements. Simulations are then executed with measured element radiation patterns instead of omnidirectional data to help increase accuracy.

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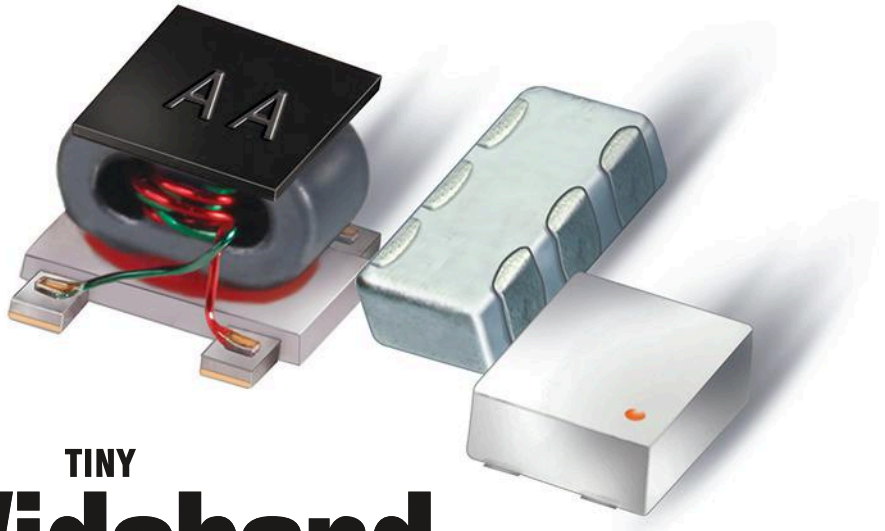

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Product Feature

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# The Year's Top New Products

## Even as the high-frequency industry looks to robust commercial growth promised by markets for 5G and IoT applications, military and aerospace demands remain strong.

**STRONG FUTURE DEMAND** looms over the RF/microwave industry, in the form of potentially huge, global commercial markets such as for Fifth-Generation (5G) wireless communications networks and Internet of Things (IoT) products. Even so, 2016 was a year of balanced business opportunities for many high-frequency companies.

Customers came with requirements for hardware, software, and test equipment to serve commercial, industrial, and military markets, while at times broaching new opportunities in medical and automotive electronics areas. To recognize a dozen of the innovative product solutions developed to meet these needs during the year, *Microwaves & RF* presents our picks for the Top New Products of 2016—a listing that combines value and performance, technology and design, and comes from companies large, small, established, and new alike.

A number of these new products demonstrate impressive performance levels for their respective technologies through tight control of microscopic device features. On the electrical side, the model ADC32RF45 dual-channel analog-to-digital converter (ADC) from Texas Instruments enables direct sampling of S-band radar receiver signals by means of its 3 GSamples/s per channel sampling capabilities. It can digitize modulated input signals from dc to 1.25 GHz, such as in-phase (I) and quadrature (Q) signal components, with high, 14-b resolution and can process input signals to 4 GHz.

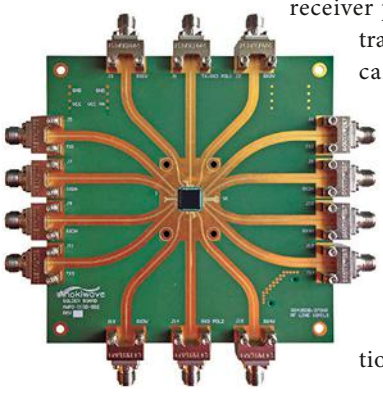
On the mechanical side, several companies brought microelectromechanical-systems (MEMS) technology to the forefront with quite accessible, commercial products. For example, Analog Devices introduced its ADGM1304 and ADGM1004 single-pole, four-throw (SP4T) MEMS switches with true dc-coupled operation to 14 GHz. To make things simple, each MEMS switch is packaged with a low-voltage TTL/CMOS-compatible switch driver.

MEMS technology is also the basis for a line of silicon timing oscillators from SiTime, with clock frequencies of 1 to 220 MHz and differential outputs as high as 700 MHz. The Elite Platform MEMS oscillators are a fraction of the size and power consumption of the temperature-compensated crystal oscillators (TCXOs) and oven-controlled crystal oscillators (OCXOs) they replace. The MEMS oscillators follow the industry's trend of circuit densification with miniaturization, fitting a pair of SiTime's Dual-MEMS MEMS resonators—one for timing and one for temperature sensing—in a miniature package with a mixed-signal silicon CMOS IC.


**1. The AD9371 direct-conversion receiver works without an LO, handling channels as wide as 100 MHz from 300 MHz to 6 GHz.** *(Courtesy of Analog Devices)*

Analog Devices also made progress in traditional semiconductor IC technology with their RadioVerse AD9371 direct-conversion transceiver. It packs the functionality and performance needed for 4G and 5G wireless networks with multiple radios on a single device *(Fig. 1)*. The transceiver doesn't require a local oscillator (LO) since the IC contains multiple voltage-controlled oscillators (VCOs) and three fractional-N phase-locked loops (PLLs) for stable frequency generation.

The AD9371 has a frequency range of 300 MHz to 6 GHz with channel bandwidths as wide as 100 MHz, offering total control of two independent transmitter paths and two independent receiver paths. The differential transmitters and receivers can be programmed for frequency-division-duplex (FDD) and time-division-duplex (TDD) operation for use in current and future wireless communications networks. Broadband amplification is essential for many



**2. Developer kits such as this simplify the evaluation of advanced ICs fabricated on different semiconductor processes.** *(Courtesy of Anokiwave)*

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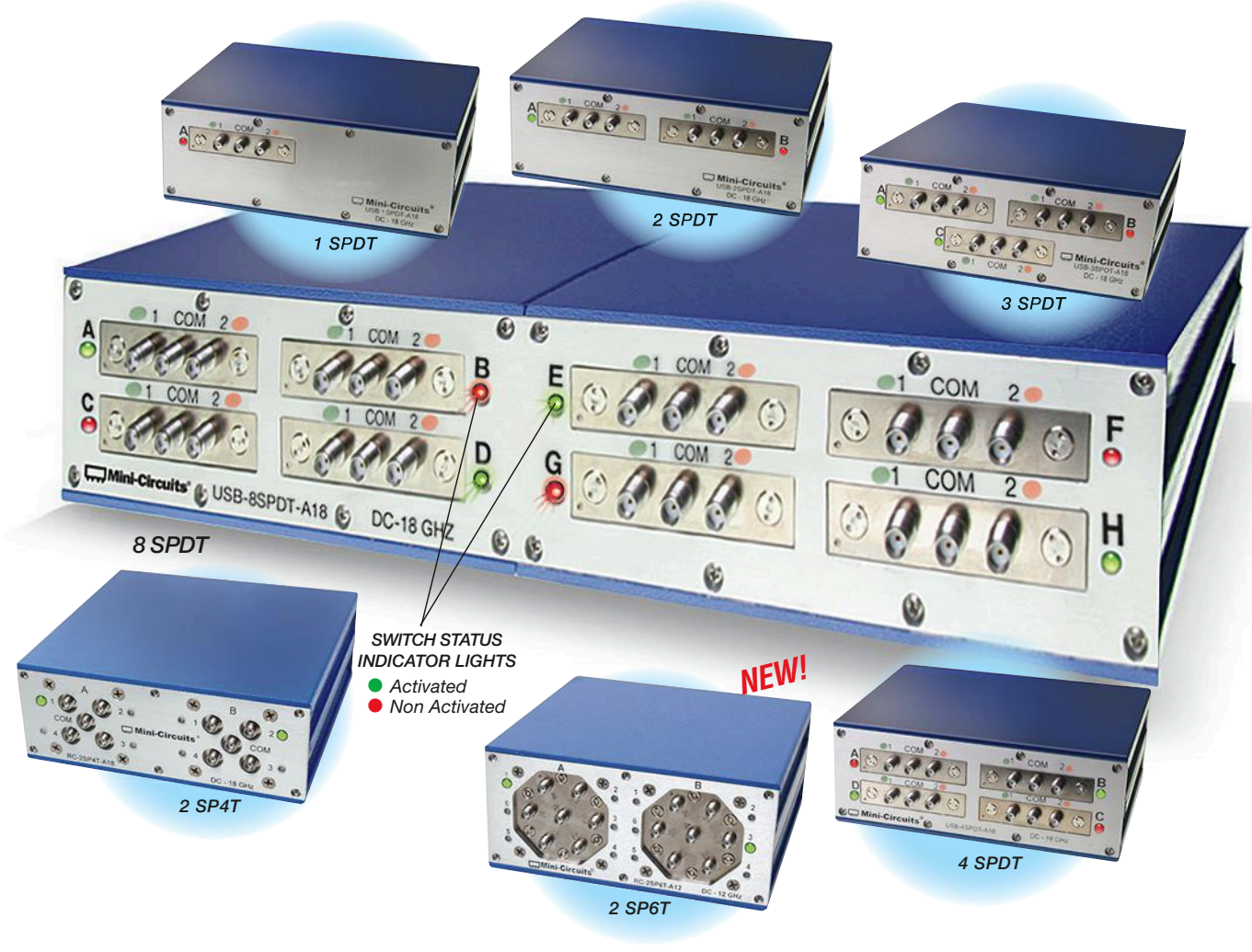


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communications networks, and RF/microwave system designers have come to terms with the gradual drop in signal gain that comes with increasing frequency—all except broadband amplifier designers at Custom MMIC. The company's BroadRange distributed amplifiers cover a total frequency range of dc to 22 GHz with a unique positive gain slope, allowing system designers to overcome losses from passive components elsewhere in a communications or even electronic-warfare (EW) system.

To fill the growing need for compact printed-circuit-board (PCB) antennas for the current Fourth-Generation (4G) and coming 5G wireless communications networks, circuit-material-supplier Rogers Corp. created its RO4730G laminates. These are 94 V-0 antenna-grade laminates well suited for printed-circuit antennas in wireless base-transceiver station (BTS) and microcell applications.

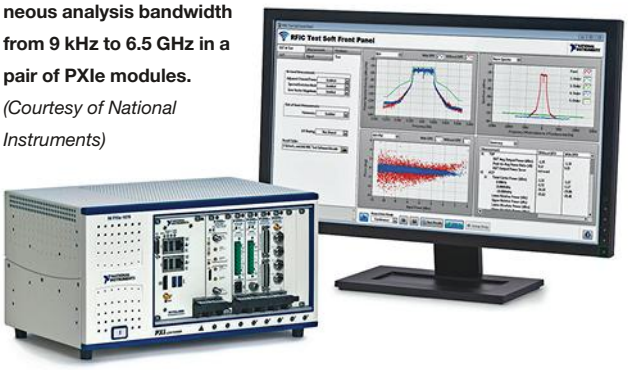
## MAKING WAVES

As wireless services and products continue to consume bandwidth, designers look to higher frequencies to place communications channels—and even to millimeter-wave frequencies. Anokiwave is attempting to bring millimeter-wave technology to the masses by matching a semiconductor process to a function, such as gallium arsenide (GaAs) for low-noise amplification, silicon CMOS for logic, and gallium nitride (GaN) for high-frequency power amplification.

The firm has developed a number of different ICs, including quad-core transceivers with electronically steerable antenna arrays operable to 30 GHz, GaAs-based low-noise amplifiers (LNAs) for bands from 71 to 86 GHz, and GaN-based power amplifiers (PAs) to 86 GHz, that are available as part of test circuit boards in Developer Kits (*Fig. 2*; 40GFIG2).

The industry move toward more practical millimeter-wave solutions was also echoed by Peregrine Semiconductor with its UltraCMOS silicon-on-insulator (SOI) semiconductor process and a pair of switches capable of operation from 9 kHz to 60 GHz. The reflective switches feature 8-ns switching speed, and one is designed for extended operating temperatures.

New test equipment occupies a healthy portion of our picks for 2016. The industry trend toward achieving smaller size with higher density was certainly not absent among designers of test gear. In response to the growing need of mobile communications networks for better high-frequency measurements in the field, the RSA500A and RSA600A Series battery-powered spectrum analyzers from Tektronix represent a dramatic miniaturization of the portable spectrum analyzers the company once offered.



**3. This versatile vector signal transceiver provides a 1-GHz instantaneous analysis bandwidth from 9 kHz to 6.5 GHz in a pair of PXIe modules.** *(Courtesy of National Instruments)*

**4. The FieldFox portable analyzer line was extended to real-time analysis bandwidths as wide as 10 MHz from 9 kHz to 50 GHz.** *(Courtesy of Keysight Instruments)*

With frequency coverage as wide as 9 kHz to 7.5 GHz and analysis bandwidths as wide as 40 MHz, the compact instruments keep essential analysis functions in the box and move command, control, and display functions to a PC via USB cable. These analyzers measure just 11.78 × 10.68 × 2.65 in. (299.1 × 271.3 × 67.3 mm) and weigh just 6.6 lb. 2.99 kg) with rechargeable lithium-ion battery.

National Instruments continued its "mastery over the modular" by introducing its PXIe-5840R vector signal transceiver (VST). In what would have once occupied multiple spaces in a 19-in.-wide instrument rack, this software-driven modular test system fits within a pair of PXIe modules. These miniature modules *(Fig. 3)* include a fast switching signal generator and wideband signal analyzer along with a user-programmable field-programmable gate array (FPGA) and high-speed digital interface for rapid transfer of test data.

They combine for a 1-GHz instantaneous analysis bandwidth spanning 9 kHz to 6.5 GHz. The modules combine the essential functions of an RF/microwave test instrument with a PC. The modular instrument can be commanded and controlled with a PC running the company's LabVIEW design and test software.

Keysight Technologies did its part for improved in-field RF/microwave measurements in 2016 with its latest additions to its FieldFox portable signal and spectrum analyzer product line *(Fig. 4)*. Available with optional real-time-spectrum-analysis (RTSA) capability, the instruments can test real-time analysis bandwidths as wide as 10 MHz across a frequency range as wide as 9 kHz to 50 GHz.

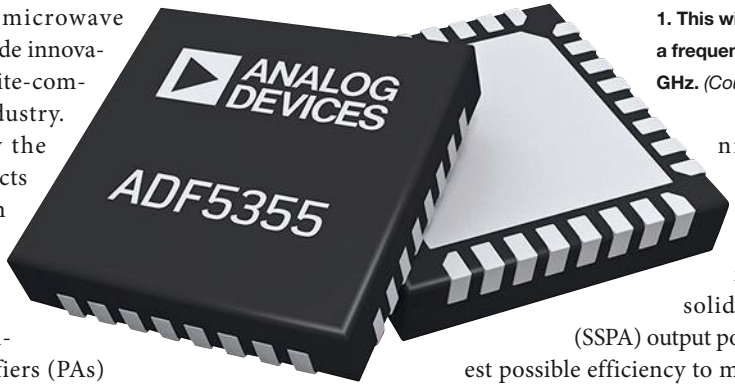
The compact battery-powered instruments provide the measurement capabilities for testing across a wide range of markets and applications, with spectrum analyzers, vector network analyzers (VNAs), and cable and antenna testers (CATs) along with built-in power meters, frequency counters, and even GPS receivers for precise location information of detected signals. They measure just 11.5 ×7.4 × 2.8 in. (292 ×188 × 72 mm) with a 6.5-in. diagonal thin-film-transistor (TFT) display. mw

CHRIS DeMARTINO | Technical Editor

# Satcom Trends Span Higher Frequencies, GaN, and Integrated Solutions

## Today's satcom applications benefit from the latest cutting-edge technology offered by the RF/microwave industry.

**NO QUESTION, THE** RF/microwave industry continues to provide innovative solutions to the satellite-communications (satcom) industry. This is demonstrated by the number of Ka-band products being introduced, as satcom applications are utilizing these higher frequencies. Moreover, performance enhancements being realized include power amplifiers (PAs) with improved efficiency, low-noise amplifiers (LNAs) with very low noise figures at millimeter-wave frequencies, and more compact solutions. Smaller sizes are due partly to the utilization of highly integrated products.




**1. This wideband synthesizer covers a frequency range of 54 MHz to 13.6 GHz.** *(Courtesy of Analog Devices)*

In addition, while the benefits of gallium-nitride (GaN) technology have been well documented, it is worth noting how the technology is specifically enabling satcom applications. Gallium-arsenide (GaAs) technology previously dominated the satcom realm, and although GaAs has by no means disappeared, GaN has now clearly assumed a prominent role. Taking all of this into account, one should be aware of the latest technology developments that are impacting the satcom arena.

### ONE COMPANY'S PERSPECTIVE

BAE Systems *(www.baesystems.com)* is heavily involved in developing RF/microwave technology solutions to support today's satcom requirements. "The two major trends we see—more capability/throughput from traditional large satellites and small satellites with low target cost—call for optimal use of available resources in an extremely power-constrained environment," says Phillip Smith, the company's chief engineer of advanced microwave products. "This includes moving to higher frequencies like Ka-band and beyond for available bandwidth, coupled with bandwidth-efficient modulation (BEM) techniques that maximize spectrum use—but dictate enhanced linearity. "Other developments include increased solid-state power amplifier (SSPA) output power levels with the highest possible efficiency to minimize required prime power," adds Smith. "And robust high-sensitivity receivers are enhancing link margin and easing requirements for transmitted power from crosslinks or ground terminals. Reconfigurability and multi-functionality are also in high demand, with phased-array implementations becoming more attractive as microwave integrated circuits (MICs) become ubiquitous."

To support satcom applications, BAE Systems is developing solutions based on both GaAs and GaN technologies. GaAs technology is being utilized to build low-noise amplifiers (LNAs) with sub-2-dB noise figures at millimeter-wave frequencies. And the company is taking advantage of GaN technology to offer high-power solutions.

"We provide GaAs- and GaN-based monolithic-microwave-integrated-circuit (MMIC) technologies that are well-suited for satcom requirements," explains Smith. "Our space-qualified GaAs technologies include pseudomorphic-high-electron-mobility-transistor (pHEMT) and metamorphic-high-electron-mobility-transistor (mHEMT) technologies.

"Extremely low noise figures at frequencies from 10 to 200 GHz (e.g., under 2 dB at 80 GHz) are being achieved by 50-nm gate-length mHEMT LNAs," he continues. "Current four-inch GaN wafers have produced MMIC PAs with 10 to 15 W of output power and 30% power-added efficiency (PAE) at Ka-band."

GaN technology can help to meet space-lifetime require-

ments. Smith notes, "GaN reliability meets demanding space-lifetime requirements—the process exhibits a mean time to failure (MTTF) of 10 million hours at channel temperatures of +200°C when operating at a $V_{ds}$ of 30 V. GaN is currently being scaled to six-inch wafer sizes (with planned release to production in 2017) to enhance chip affordability, repeatability, and foundry capacity."

One point Smith brought up is the move to Ka-band frequencies. A number of companies are developing products that operate at this frequency band. For example, MACOM *(www.macom.com)* recently launched the MAAP-011289, which is a 3-W PA that covers a frequency range of 28.0 to 30.5 GHz.

In addition, Anokiwave *(www.anokiwave.com)* unveiled the AWMF-0109 and AWMF-0113 models earlier this year. The AWMF-0109 and AWMF-0113 are Ka-band integrated solutions that should find their way into satcom transmit applications. The intent of both devices is that they can be easily installed in planar phased-array antennas. The AWMF-0109 supports four dual polarization radiating elements, while the AWMF-0113 supports eight single polarization radiating elements. Both devices operate from 27.5 to 30.0 GHz.

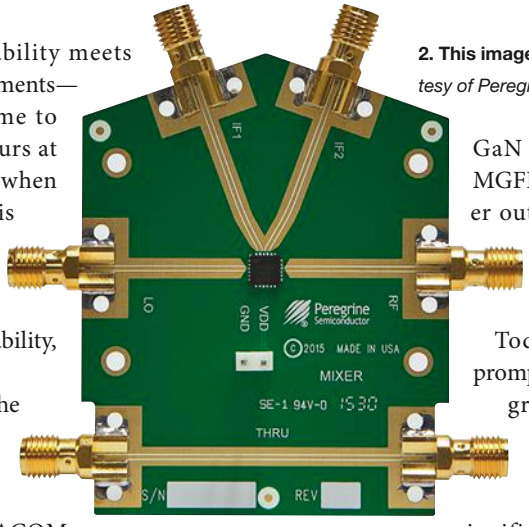
## MORE ON GaN TECHNOLOGY

GaN technology offers other benefits, too, such as allowing for smaller packages. David Schnaufer, technical marketing manager at Qorvo *(www.qorvo.com)*, elaborates: "The demand for high-performance semiconductor products in small package styles is increasing. Small-packaged devices are particularly important in satellite communications and must be able to withstand harsh environments on land, in the air, and at sea.

"GaAs technology has long been the norm for RF devices in these spaces," says Schnaufer. "But with the demand for smaller form factors, and the extreme heat, cold, and damp conditions of satcom systems, GaN is the new best choice. GaN is more reliable, fits in a smaller package, and operates at higher temperatures than GaAs. Our recent breakthroughs in GaN device and packaging technology allow for smaller packages while offering environmental protection."

Qorvo currently offers a number of GaN products in support of satcom applications. One example is the TGM2635-CP PA, which was announced earlier this year. This 100-W PA covers a frequency range of 7.9 to 11 GHz, and is well-suited for X-band satcom systems.

Several other suppliers are also providing GaN-based solutions for satcom applications. Among them is Mitsubishi Electric, which recently expanded its lineup of Ku-band GaN devices with two new models. The MGFK50G3745 and MGFK48G3745 deliver output power levels of 100 and 70 W, respectively.




**2. This image-reject mixer operates to 19 GHz.** *(Courtesy of Peregrine Semiconductor)*

## INTEGRATED SOLUTIONS

Today's satcom requirements are also prompting suppliers to develop highly integrated solutions. "A nearly insatiable demand for bandwidth and the desire to get more value from current levels of investment are two trends driving significant growth in the satellite market," says Greg Henderson, vice president, RF/microwave business at Analog Devices *(www.analog.com)*. "Continuing success in the industry will come through developing high-performance, highly integrated silicon solutions.

"We are replacing large multi-technology signal chains with monolithic, fully integrated, silicon direct-conversion transmit (Tx) and receive (Rx) solutions," continues Henderson. "We're using an antenna-to-bits portfolio for applications up to 100 GHz. We believe customers want complete signal-chain capability, including complementary functions such as clocks and phase-locked loops (PLLs). Looking ahead, by leveraging design and millimeter-wave integration IP, significant improvements in performance (as much as 10× greater throughput than current solutions)—with 30% lower power consumption and a reduced footprint of more than 10×—are possible."

One product from Analog Devices that fits this description is the ADF5355, which is a wideband synthesizer with an integrated voltage-controlled oscillator (VCO) *(Fig. 1)*. The company says this product is being designed into Ka-band receivers. The frequency range of the ADF5355 spans 54 MHz to 13.6 GHz.

Additional suppliers of integrated solutions include Peregrine Semiconductor *(www.psemi.com)*. Earlier this year, the company introduced the PE41901 image-reject mixer, which is suitable for Ku-band satcom applications *(Fig. 2)*. The PE41901 contains two mixers, a local-oscillator (LO) path 90-deg. coupler, and RF port baluns on a single die. The integration of this functionality allows the required board space to be minimized. The PE41901 covers an RF frequency range of 10 to 19 GHz.

This article discussed some of the latest developments in the satcom space. Clearly, Ka-band solutions are one focal point, as this frequency band is highly crucial for today's satcom applications. Of course, high-power GaN products will continue to power the next-generation of satcom. Furthermore, suppliers are reaching new levels of innovation with highly integrated products, leading to a number of performance enhancements. mw

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# MODULAR INSTRUMENTS Extend Capabilities

New instruments and repair/calibration services reinforce one company's dedication to achieving accurate measurements from dc through millimeter-wave frequencies.

**MODULAR TEST EQUIPMENT** provides a compact architecture for performing many different types of measurements. By plugging the appropriate module into a chassis, a function can be added to a test system, in the total size once required for a traditional single-function instrument, such as a spectrum analyzer or a vector network analyzer (VNA).

Modern test instruments are available in a variety of modular formats, such as PXI and AXIe modules. These are increasingly being used with traditional benchtop measurement systems, often with multiple chassis holding the many modules needed for complex measurement functions—e.g., evaluating antenna arrays and multiple-input, multiple-output (MIMO) communications systems.

For those faced with trying to decide whether to move to modular instruments or which modular format is better, Keysight Technologies *(www.keysight.com)* recently reinforced its support for AXIe and PXI formats. The company offers a series of modular test instruments in both formats featuring calibration and repair services that can be applied not only to their own modular and benchtop instruments, but to test instruments from most instrument makers around the world.

Modular instruments typically save space in a rack by using a PC for common display and control purposes, enabling essential measurement capabilities to be contained within a universal module that can slide into a rack-mountable chassis. Consequently, the chassis space once occupied by a single analyzer can now hold five or six instrument functions. Whether in PCI or AXIe format, Keysight recently showed its support for modular instruments with a host of introductions, including wideband PXIe and AXIe digital receivers, an AXIe embedded controller, and a PXI M9421A vector signal transceiver (VST).

**1. Model M9203A is a PXIe digitizer/digital receiver with instantaneous bandwidths to 2 GHz and sampling rates to 3.2 GSamples/s.**

The M9203A digitizer/wideband digital receiver is a compact dual-slot 3U PXIe measurement receiver *(Fig. 1)* with two channels operating at 12-b sampling rates to 3.2 GSamples/s.

**2. Model M9537A is an embedded controller in the AXIe modular format that is equivalent to a powerful Windows 7 personal computer.**

It provides instantaneous analog bandwidths of DC to 2 GHz. In spite of the small size, it features on-board digital processing and 4-GB of DD3 acquisition memory to capture and record the most exotic waveforms. The digital receiver leverages a Virtex-6 field programmable gate array (FPGA) from Xilinx *(www.xilinx.com)* for impressive digital processing power.

For those preferring the AXIe modular instrument format, the M9703B high-speed digitizer/wideband receiver also captures signals across an analog input bandwidth of DC to 2 GHz but with eight acquisition channels. It fits on a single-slot AXIe card and operates at sampling rates to 1.6 GSamples/s per channel. By interleaving two channels, sampling rates to 3.2 GSamples/s are available on as many as four channels for instantaneous bandwidths to 1.4 GHz.

The model M9537A embedded controller *(Fig. 2)* is also in the AXIe format. It is based on an i7-6820EQ 2.8-GHz quad-core microprocessor from Intel *(www.intel.com)* and includes a front-removable 240-GB solid-state drive and 8-GB DDR4 random-access memory (RAM). The Gen 3 PCIe link to the AXIe backplane provides as much as 16 GB/s data bandwidth. It includes four USB 3.0 ports and two USB 2.0 ports.

The M9421A vector signal transceiver (VST) is a four-slot PXIe instrument *(Fig. 3)* available with bandwidths of 60 MHz to 3.8 GHz or 60 MHz to 6 GHz. It offers standard analysis bandwidth to 40 MHz with options that can extend the analysis bandwidth to 80 or 160 MHz. It is supported by software for analysis of analog demodulation formats and noise figure measurements.

This is just a small sample of the recently introduced AXIe and PXIe instrument modules, which also included a source-measure unit (SMU) for precise current/voltage measurements and a multiple-channel bit-error-rate tester (BERT) capable of data rates to 16 GB/s. mw

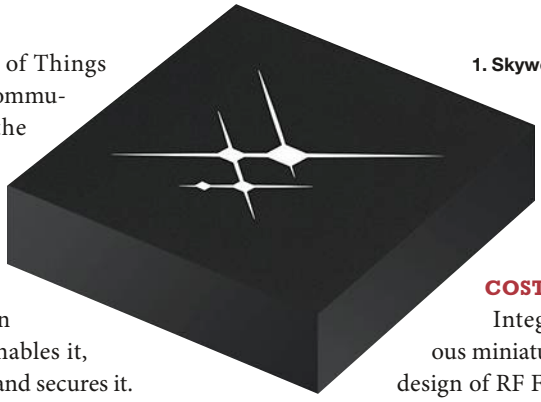
KEYSIGHT TECHNOLOGIES, Inc., 1400 Fountaingrove Pkwy., Santa Rosa, CA 95403; (707) 577-2663, *www.keysight.com*

**3. Model M9421A is a vector signal transceiver (VST) in a four-slot PXIe module capable of operating to 6 GHz.**

STEFAN FULGA | Director of Marketing for IoT, Skyworks Solutions Inc.

# Front-End Modules Make Smart Connections for IoT

**The integration of RF/microwave functionality in highly integrated front-end modules paves the way for smaller, lower-power, cost-effective IoT solutions for a wide range of applications.**



**1. Skyworks Solutions' SKY66112-11 RF front-end module provides Bluetooth 5, Thread, and ZigBee compatibility, and provides four times the range of an IoT SoC radio alone along with a 7-dB increase in receiver sensitivity.**

**THE BASIC IDEA** of the Internet of Things (IoT) may seem simple: wireless communications between sensors and the Internet. But for engineers faced with designing its component parts, such a simple description is much less than the tip of the iceberg. Challenges are presented by every component within an IoT product, the software that enables it, and the network that coordinates and secures it.

One of the more daunting challenges is the need for unprecedented levels of functional integration to reduce the size, design complexity, and cost of IoT devices. Radio-frequency (RF) front-end modules (FEMs) could very well offer a solution, as they are designed to provide performance and functionality in miniature packages with low power consumption.

Projections for the global acceptance of IoT technology predict billions, even trillions, of these devices operating in many different applications, and no single design solution will serve all purposes. In some cases, sensors will remain almost continuously in a sleep mode, coming to life only briefly either when externally instructed, on a schedule programmed into it, or when it detects trouble in the device to which it is connected. In these environments, wireless-enabled sensors should be able to operate for up to 10 years on a coin cell or cells.

In other applications, IoT sensors will be partially or continuously operational, requiring access to mains power or biasing from energy harvesting or wireless power transfer. The multitude of IoT applications may be diverse, but one core requirement remains the same: the need to make every element of an IoT device extremely small, highly integrated, efficient, and frugal with power. Studies project that the cost of IoT devices may have to drop 10 to 100 times and power consumption from milliwatts at present to microwatts or even nanowatts in the future.

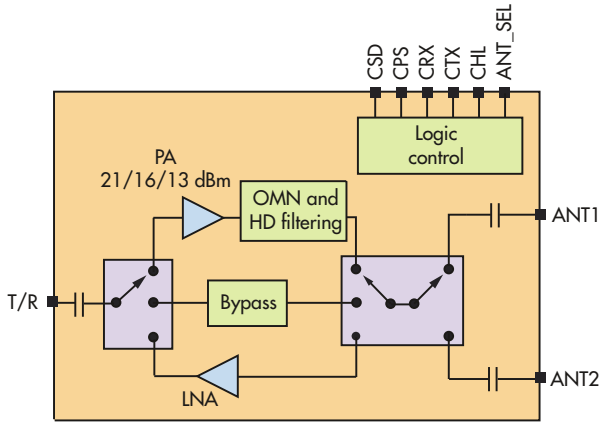
## COST-EFFECTIVE MINIATURIZATION

Integration is the key to achieving serious miniaturization in IoT applications, with the design of RF FEMs including as many functions as possible within a single package. Aided by system-on-chip (SoC) devices that perform analog-to-digital conversion, baseband functions, and overall subsystem control, RF FEMs can deliver a cost-effective solution for IoT applications, with very high performance in a very small footprint. Ever-increasing integration of IoT functions means more functionality will be included in smaller system-in-package (SiP) devices, allowing IoT capabilities to squeeze into even smaller, cost-effective, lower-power solutions.

Digital circuitry scales smaller in size with advancing technology. For SoCs, the semiconductor technology of choice has been silicon CMOS, with minimum feature sizes shrinking from 250 nm to about 22 nm during the past 25 years, allowing for smaller digital electronic circuitry in IoT solutions. Expectations are that it will drop to about 5 nm by 2025.

RF/microwave circuitry does not scale down in size so easily—the RF/microwave portion of an IoT design can account for 60% of the circuit-board area. While the digital circuitry continues to benefit from reductions in CMOS geometry, the size reduction of RF circuitry can be accomplished by further integration of RF functions on the same die, or by employing advanced packaging technologies.

For IoT applications, integrated RF FEMs offer advantages in smaller size, lower power consumption, and lower cost compared to IoT designs based on discrete devices. The benefits of FEMs over discrete implementations also include reduced design time as a result of components that have been




**2. The SKY66112-11 integrates all transceiver functions in a module measuring only 3.5 × 3.0 × 0.96 mm.**

**THE SKY66112-11 AT A GLANCE**

| Parameter | Value |
|---|---|
| Frequency range | 2400 to 2500 MHz |
| RF output power | To +22 dBm |
| LNA noise figure | 2 dB |
| Maximum RF input power in receive mode | +15 dBm |
| Transmit/receive switching speed | 800 ns |
| Operating voltage | 1.2 to 3.6 V dc |
| Sleep-mode current | Less than 1 µA |
| Package style | 22-pin MCM, 3.5 × 3 × 0.96 mm |

proven and tested together as a single module, compared to mixing and matching separate components. With RF FEMs, the main interconnections are to the SoC. Since RF FEMs are fully tested, turnkey components, they avoid (for the most part) design validation and minimize compliance testing.

## SKYWORKS FEM UPS THE OUTPUT

Yet another benefit of RF FEMs is compatibility with multiple wireless standards, such as a single RF module for Bluetooth, Thread, and ZigBee wireless connectivity. As an example, the SKY66112-11 RF FEM *(Fig. 1)* from Skyworks Solutions will serve Bluetooth 5 upon release of that latest version of the short-range wireless standard, as well as next-generation Thread and ZigBee wireless networking protocols. When paired with an SoC platform, the result is an extremely efficient IoT solution with long battery life and extended transmission range by means of high RF output-power levels.

This FEM produces as much as five times the RF output power (+20 dBm) of the SoC radio alone. It eliminates the need for further transmit-side amplification, and can increase receive sensitivity by more than 7 dB to more than double the receive range of an IoT device. It also handles RF input-power levels to +15 dBm to allow the receiver to function in the presence of high-power collocated Wi-Fi access points, which is likely to be a common scenario in many IoT environments. In addition, the SKY66112-11 reduces total system current ($I_{cc}$) by as much as 38% when compared to an SoC alone delivering the same transmit output power.

The SKY66112-11 provides integrated interstage matching, harmonic filtering, and digital control compatible with CMOS logic levels *(Fig. 2)*. It operates on supply voltages from +1.2 to +3.6 V dc, making it a good fit for battery-powered applications. The FEM is being incorporated in SoC reference designs from all leading SoC suppliers for multimode ZigBee/Thread/BLE systems.

Since the SKY66112-11 will be compatible with Bluetooth 5, its high RF output power will be well-suited to that standard's enhanced connection range. Bluetooth 5 is expected to be rapidly adopted in new devices beginning in the first half of 2017. Not surprisingly, many of Bluetooth 5's new features are dedicated to IoT. While Bluetooth is appealing for many IoT applications, it is limited in range, messaging capacity, and networking capability. This latest version should bring the ubiquitous wireless protocol to the forefront of IoT connectivity.

Although complete specifications are expected at year's end, range should be about 1,000 feet, a best-case value achievable only in unobstructed, line-of-sight conditions, but greater than its predecessor. The range extension makes Bluetooth more than a personal area network for the first time and cost-effective to implement as it requires no infrastructure (access points) and uses far less power.

Bluetooth 5 is also expected to have twice the speed of its predecessor and more than enough speed for almost all IoT applications. The Bluetooth Special Interest Group (SIG) says it will have eight times the data broadcasting bandwidth, which makes the use of Bluetooth beacons far more interesting for retailers and other organizations.

Widespread acceptance of IoT devices and technology will depend on reasonably priced IoT products that can operate for as long as a decade on a battery and communicate over considerable distances in the presence of stronger signals (such as from Wi-Fi systems). While these are not insignificant economic and technological challenges, it should be possible to overcome them thanks to increasing levels of integration and advances in packaging technologies. No doubt RF FEMs will play a significant role. MW

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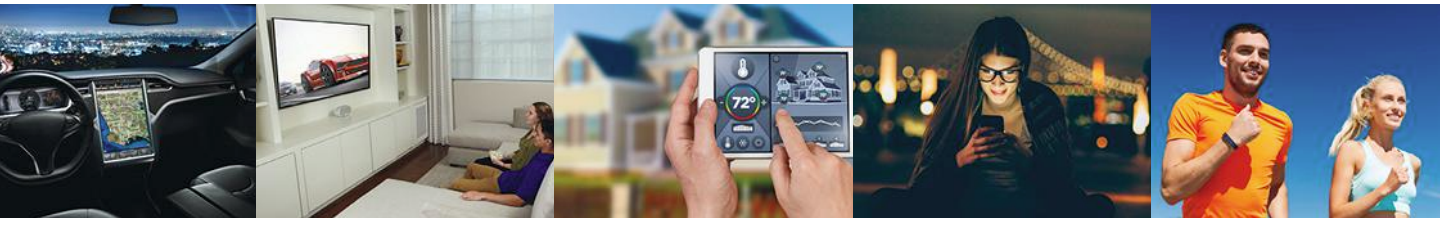


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Product Feature

JACK BROWNE | Technical Contributor

# System Analyzes Antennas Without Anechoic Chamber

## Measuring radiation patterns from wireless designs with antennas normally requires a rack of test gear, but this system does the job in a moderate-sized room without an anechoic chamber.

**RADIATION PATTERNS DESCRIBE** the coverage possible with a particular antenna and its associated wireless circuitry, but such patterns are not easy to generate. They typically are generated by a test signal generator, receiver, broadband receive antenna and many necessary test accessories such as a turntable to rotate a device under test (DUT) while testing. One other not inexpensive "accessory" that is usually part of the test system is an anechoic chamber, to prevent interference from radio sources that might be present in the frequency band of interest.

Fortunately, the RMS-0740 MegiQ Radiation Measurement System from MegiQ BV provides everything for making three-axis radiation pattern measurements, except the anechoic chamber. It is designed to work without the chamber, delivering accurate radiation pattern measurements from 0.7 to 4.0 GHz *(see figure)*.

The radiation pattern measurement system consists of a dual-channel receiver (with option for a signal generator), a dual polarization antenna, a stepper-motor-driven turntable for mounting an antenna under test, software, and interconnecting power and control cables, including a Universal Serial Bus (USB) cable for connection to a personal computer (PC). The system rotates a DUT on the turntable and makes three-axis radiation pattern measurements using one turn of the turntable per axis. When necessary, the turntable can be rotated manually, without using the stepper motor.

The test system features an antenna designed for minimum reflections in compact test areas. The system, which is ready for use without calibration, is designed for accurate results in moderate test spaces, such as only 4 × 4 × 3 m. It can be used in even smaller test spaces, although careful positioning of some absorbing materials may be required to minimize reflections. The test system can measure multiple frequencies at the same time and, with its optional test signal source, can generate horizontal and/or vertical test signals for evaluating a DUT in receive mode. The height of the system's measurement antenna can be set from 100 to 170 cm, and the measurement antenna and receiver are designed for use at measurement distances of 0.8 to 3.0 m from a DUT.

The system can be supplied with a standard-sized turntable measuring 28 × 28 cm and holding DUTs as large as 7.5 kg or an optional heavy-duty turntable measuring 100 × 50 cm and accommodating DUTs weighing as much as 30 kg. The stepper motor spins the turntables at 30 s per rotation during radiation pattern measurements, although the turntables can also be rotated manually as needed for special radiation pattern measurements.

**The MegiQ Radiation Measurement System performs three-axis antenna radiation-pattern measurements from 700 MHz to 4 GHz without need of an anechoic chamber.**

The measurement software supplied with the test system simplifies the measurement setup with functions for rotational control of the turntable, data storage and processing, graphing, and report generation. The software provides three-dimensional (3D) representations of test results, processing data that the test antenna and receiver have collected by measuring the radiation patterns in the x, y, and z axes of a DUT mounted on the rotating turntable. The software can produce standard radiation patterns and calculate statistics related to the performance of the DUT.

Radiation pattern measurements often require the assistance of a shielded environment, such as an anechoic chamber or a Faraday cage, which can represent a considerable investment. When the space and the funds are short but the need for radiation pattern measurements is quite real, the compact , the RMS-0740 MegiQ Radiation Measurement System provides accuracy approaching that of much larger systems and test chambers, in a practical measurement solution covering many of the commonly used wireless frequency bands. mw

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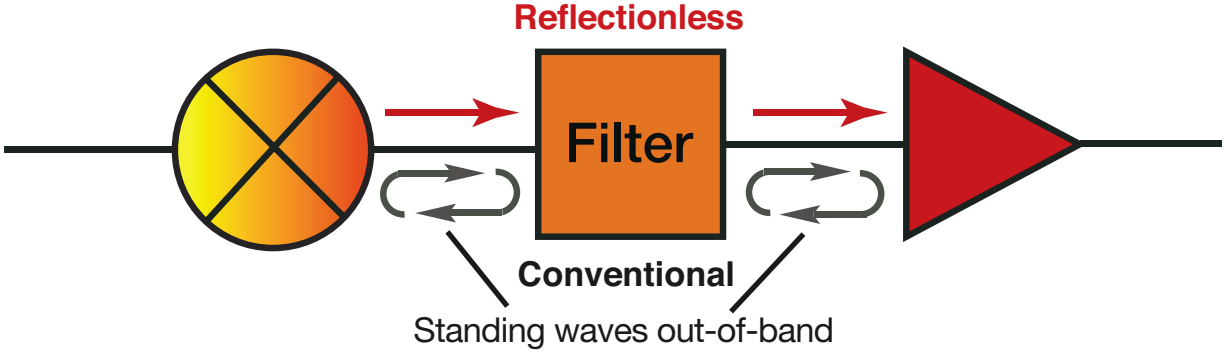


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- ✓ Absorbs stopband signal power rather than reflecting it
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- ✓ Intrinsically Cascadable[3]
- ✓ Passbands from DC – to 21 GHz[4]
- ✓ Stopbands up to 35 GHz

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[1] Small quantity samples available, $9.95 ea. (qty. 20)
[2] See application note AN-75-007 on our website
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[4] Defined to 3 dB cutoff point



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Product Feature

JACK BROWNE | Technical Contributor

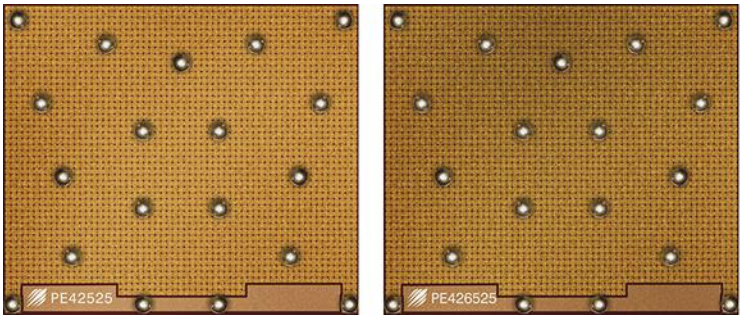
# SOI SWITCHES Tackle 60 GHz

## Silicon is not often associated with millimeter-wave frequencies, but these switches operate to 60 GHz thanks to an advanced silicon CMOS semiconductor process.

**FAST SWITCHES ARE FINDING** places in test instruments and communications equipment at higher and higher frequencies, with applications such as automotive safety systems and even backhaul links in Fifth-Generation (5G) wireless communications networks reaching millimeter-wave frequencies. To provide those switching functions, a pair of UltraCMOS silicon-on-insulator (SOI) single-pole, double-throw (SPDT) flip-chip switch die from Peregrine Semiconductor (www.psemi.com) offer electrical performance from 9 kHz to 60 GHz with 8-ns switching speed.

The switches, models PE42525 and PE426525, are similar in physical configuration and performance. The one exception is that the PE426525 is designed to operate over an extended temperature range for use in hostile environments, including oilfields and in military applications.

The two reflective millimeter-wave switches *(see figure)* provide the low loss and high port-to-port isolation desirable in any broadband switch, especially for a bandwidth approaching 60 GHz. For both switches, the insertion loss is typically 0.9 dB at 100 MHz, 1.3 dB from 100 MHz to 26.5 GHz, 1.7 dB from 26.5 to 45.0 GHz, 1.9 dB from 45 to 50 GHz, and 2.6 dB from 50 to 60 GHz. Typical isolation is 76 dB at 100 MHz, 44 dB from 100 MHz to 26.5 GHz, 39 dB from 26.5 to 45.0 GHz, 38 dB from 45 to 50 GHz, and 38 dB from 50 to 60 GHz. Typical return loss is 20 dB at 100 MHz, 18 dB from 100 MHz to 26.5 GHz, 22 dB from 26.5 to 45.0 GHz, 20 dB from 45 to 50 GHz, and 12 dB from 50 to 60 GHz.




**The PE42525 (left) and PE426525 (right) SPDT switches are supplied as flip-chip die, and have similar specs except for operating temperature range.**

Die size is usually 2495 × 2149 µm. The SPDT switches are fabricated on silicon wafers that are customarily 200 µm thick. In addition, the flip-chip switch die are fabricated with a tight 500-µm bump pitch to minimize performance variations resulting from different bond wire lengths. Short interconnections also contribute to excellent time-domain performance, with typical switching speed of 8 ns and rise/fall time of 4 ns. The settling time is generally 40 ns from 50% of the control signal to within 0.05 dB of the final switched signal.

### POWER-FRIENDLY

The switches provide linear operation at moderate power levels. The PE42525 has typical recommended high-level marks of +26 dBm at 100 MHz and +27 dBm at 26.5 GHz for continuous-wave (CW) signals, and +28 dBm at 100 MHz and +29 dBm at 26.5 GHz for pulsed signals. The PE426525 has typical recommended high-level marks of +24 dBm at 100 MHz and +25 dBm at 26.5 GHz for CW signals and +26 dBm at 100 MHz and +27 dBm at 26.5 GHz for pulsed signals. They are rated for maximum signal levels of +30 dBm at 100 MHz and +31 dBm at 26.5 GHz.

The switches achieve a typical 1-dB compression point (P1dB) of +33 dBm at 40 GHz and a third-order intercept point (IIP3) of +48 dBm at 13.5 GHz. Second-harmonic rejection is typically –74 dBc for an input frequency of 1.0 GHz and –78 dBc for an input frequency of 1.9 GHz.

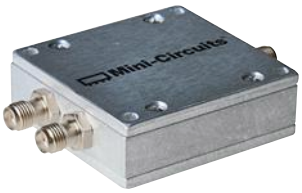
These miniature millimeter-wave switches provide healthy electrostatic-discharge (ESD) protection of 2 kV, per the human body model (HBM). They operate with typical control current of 450 nA, a high control voltage of +3.0 V dc, and a low control voltage of –3.0 V dc. Model PE42525 is designed for operating temperatures from –40 to +105°C and model PE426525 for the wider range of operating temperatures from –55 to +125°C. P&A: $40 for the PE42525 and $48 for the PE426525 (1,000 qty.) mw

PEREGRINE SEMICONDUCTOR CORP., 9380 Carroll Park Dr., San Diego, CA 92121; (858) 731-9400, www.psemi.com.

## Connectorized 50/75Ω Matching Transformer


Mini-Circuits' Z7550-FFSF+ connectorized matching transformer supports a wide range of applications from DC to 2500 MHz where 50 to 75Ω matching is required and minimizing overall signal loss is a priority. It provides 0.5 dB insertion loss, 1.7:1 VSWR, and 1W RF input power handling. The transformer is housed in a rugged, compact case (1.25 x 1.25 x 0.75") with F-female (75Ω) to SMA-female (50Ω) connectors.

## Connectorized 2-Way 0° Splitter/Combiner Handles up to 35W, 500 to 10500 MHz




Mini-Circuits ZN2PD2-14W+ is a connectorized 2-way 0° splitter/combiner providing power handling up to 35W as a splitter (1W as a combiner) for a wide range of applications from 500 to 10500 MHz. This model provides 1.0 dB insertion loss, 1.15:1 VSWR, 20 dB isolation, 0.1 dB amplitude unbalance, and 2° phase unbalance. It is also capable of passing up to 600mA (300mA each port) from input to output. Its outstanding combination of high power handling and low loss make it an ideal choice for applications requiring excellent power transmission from input to output. The splitter/combiner comes housed in a rugged, aluminum-alloy case measuring 4.5 x 2.5 x 0.67" with SMA connectors.

## Low-Cost Solid State SP10T Absorptive Switch with SPI Control, 1 to 6000 MHz


Mini-Circuits SPI-SP10T-63 is a high-speed, solid state SP10T absorptive switch supporting applications from 1 to 6000 MHz. This model features control and power supply via a digital snap fit connector and is operated using a 3-wire SPI interface compatible with TTL and LVTTL voltages, allowing connection of up to 50 units in series to the same control line in "daisy chain" configuration. The RF switch provides 80 dB isolation, fast switching time of just 6µs, and power handling up to +27 dBm. It comes housed in a rugged, aluminum alloy case (3.395 x 4.58 x 0.45") with SMP connectors.

## Surface-Mount Diplexer Splits DC – 50 MHz and 950 to 2150 MHz Channels


Mini-Circuits RDP-50-2R15+ is a 50Ω surface-mount diplexer with a low passband from DC to 50 MHz and a high passband from 950 to 2150 MHz. This model is suitable for a wide range of applications including SatCom modems, air traffic control, and other multiband radio systems. It provides 0.5 dB passband insertion loss, high stop band rejection (32 – 74 dB), and RF input power handling up to 1W. The unit comes in a miniature, 16-lead, shielded package measuring only 0.5 x 0.5 x 0.18" with wraparound terminations for excellent solderability.

## Coaxial 50/75Ω Matching Transformer, DC to 2500 MHz


Mini-Circuits' SFMP-5075+ is a coaxial 50/75Ω matching transformer covering the DC to 2500 MHz frequency range, supporting impedance matching in a wide range of systems including CATV, broadband networks, and more. This model is ideal for 50/75Ω matching in systems where minimizing overall signal loss is a priority. The transformer handles RF input power up to 1W and is capable of passing DC current up to 350mA. Measuring only 2.22 (l) x 0.67" (dia), the transformer comes housed in a rugged, nickel-plated brass case with SMA-F (50Ω) to F-Type-M (75Ω) connectors.

## Connectorized Low Noise Amplifier, 400 to 1100 MHz


Mini-Circuits' ZX60-112LN+ is a connectorized low noise amplifier with a unique combination of low noise (1.2 dB), high gain (27 dB), and high IP3 (+30 dBm) over the 400 to 1100 MHz band. This model also provides excellent reverse isolation of 52 dB, making it usable as a buffer amplifier and minimizing interaction with adjacent circuits. It provides ±1.0 dB gain flatness, +1.65 dBm P1dB and good matching with 1.4:1 input VSWR and 1.3:1 output VSWR. It operates on a single +5V supply and comes housed in a rugged, unibody case (1.2 x 0.75 x 0.46") with SMA connectors.

JACK BROWNE | Technical Contributor

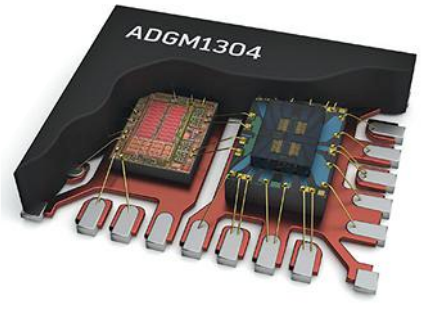
# Tiny MEMS Switches Route DC to 14 GHz

## This pair of MEMS switches offers SP4T functionality in miniature components that feature companion low-voltage switch drivers for ease of installation and application.

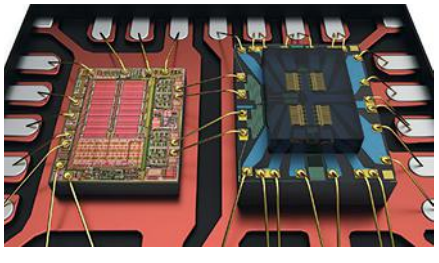
**ELECTROMECHANICAL SWITCHES AND** relays have been a part of RF/microwave circuits and systems design for some time. They can handle reasonable input power levels for their small sizes, but are typically slower and larger than solid-state switches.

Edging closer in speed to solid-state devices, a line of microelectromechanical-systems (MEMS) switches from Analog Devices *(www.analog.com)* targets RF/microwave signal switching in a fraction of the size and power consumption of electromechanical relays while promising considerably faster switching speeds and much greater reliability. The first two switches in the MEMS product line—single-pole, four-throw (SP4T) models ADGM1304 and ADGM1004—offer similar wideband performance from dc to 14 GHz, with the latter also incorporating electrostatic-discharge (ESD) protection.

Analog Devices is no stranger to designing and fabricating MEMS devices, supplying MEMS accelerometers for airbags in motor vehicles since 1991.The two new RF/microwave switches, manufactured in the company's own MEMS foundry, come in compact packages with silicon caps that provide hermeticity *(Fig. 1)*. Each package includes an electrostatically activated MEMS switch die and a low-current, low-voltage driver IC *(Fig. 2)*. The integrated driver is TTL/CMOS compatible for parallel interfaces; having the driver within the same miniature package as the MEMS chip simplifies circuit design and saves space on printed circuit boards (PCBs).




**1. This cutaway view of the ADGM1304 SP4T MEMS switch shows the driver and switch circuitry side by side inside an LFCP measuring 5 × 4 × 0.95 mm.**



**2. Each of the packaged MEMS switches also contains a low-voltage TTL/CMOS switch driver for ease of use.**

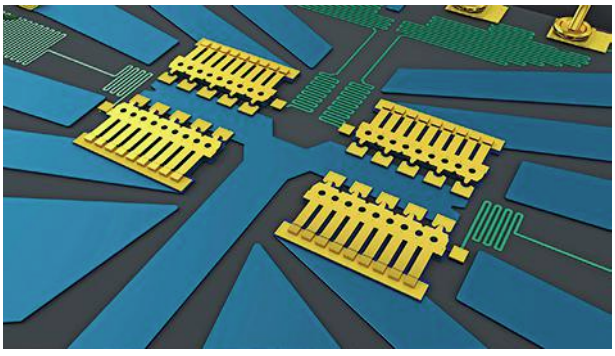
The two switches meet MIL-STD-883 requirements. Thus, they are well-suited for automatic-test-equipment (ATE) applications with high circuit density and in portable circuits and test applications where power is limited power (such as from a rechargeable battery).

The MEMS switches are not capacitive, but rather dc-coupled for a wide range of broadband applications. They are designed for use with nominal supply voltages of +3.1 to +3.3 V dc. The devices use spring force for actuation and de-actuation *(Fig. 3)*, with very little wear on the contacts after an almost inconceivable number of switching cycles. In fact, both switches are rated for operating lifetimes of billions of switching cycles. They are evaluated with the same reliability testing used by Analog Devices for its semiconductor devices to ensure consistency in lifetime testing. The two MEMS switches are capable of operating lifetimes 10× longer than electromechanical relays.

### SWITCH SPECS

In terms of performance, the model ADGM1004 SP4T MEMS switch has a 2.5-kV ESD rating per the human-body model (HBM); the ADGM3004 doesn't include ESD protection. These miniature switches feature extremely low on-resistance of 1.8 Ω. Both are usable from dc to 14 GHz, with typical insertion loss of 0.45 dB at 2.5 GHz and 0.63 dB at 6.0 GHz. The return loss is at least 14 dB at typically 17 dB from dc to 6 GHz. Isolation is customarily 24 dB at 2.5 GHz and 19 dB at 6.0 GHz, from the control to an RF output port. Crosstalk is typically 30 dB measured at 2.4 GHz.

Although these are mechanical devices, they provide impressive switching speed, with 30 µs typical on switching



3. This close-up of the MEMS switch illustrates how different switch states are achieved through spring force on the cantilever structure.


4. The ADGM1304 SP4T MEMS switch (top) occupies a fraction of the board space as a conventional drop-in high-frequency relay (bottom).

time and 5 µs typical off switching time. The settling time for the rising edge of a switched signal is generally 40 µs and typically 8 µs for the falling edge. Both switches offer excellent linearity, with typical input third-order-intercept point (IIP3) of +69 dBm. The non-ESD-protected model ADGM1304, even with its compact size *(Fig. 4)*, is rated for maximum input power to +36 dBm. It is quite capable of maintaining high signal integrity throughout its frequency range, with second harmonics of typically –90 dBc and third harmonics of typically –85 dBc.

Model ADGM1004 and its ESD protection come in a 24-lead lead-frame chip-scale package (LFCP) measuring 5 × 4 ×1.45 mm, complete with TTL/CMOS driver. Model ADGM1304 is housed in a LFCP measuring 5 × 4 × 0.95 mm. Both switches are frugal on power consumption, requiring only 1 µA current during sleep mode.

These two switches are the first in what promises to be an extensive line of miniature high-speed MEMS switches for commercial and industrial applications, as well as in ruggedized versions for the harsh environments encountered in defense and aerospace applications. With their performance levels and operating lifetimes, they should provide service to those applications without need of replacements. mw

ANALOG DEVICES INC., One Technology Way, P. O. Box 9106, Norwood, MA 02062-9106; (781) 329-4700, www.analog.com.

Product Feature

JACK BROWNE | Technical Contributor

# VERSATILE TESTERS Emulate Satellite-Communications Links

These sources provide the advanced signal processing to generate test signals with delays, fading, and noise as found in modern satellite-communications systems.

**SATELLITE-COMMUNICATIONS SYSTEMS REACH** to orbiting satellites to provide reliable communications on Earth. They are subject to interference from the planet and other impairments that can challenge the performance and reliability, but regular testing helps avoid problems.

Testing a satellite-communications (satcom) system, however, requires a special kind of test instrument, one capable of recreating the signal path between a satellite and ground station. Addressing that need is a trio of Satellite Link Emulators (SLEs) from dBm Corp., which can recreate the multiple paths, noise, and distortion common to satcom systems, along with a choice of three bandwidths to suit most testing needs.

Designed for testing at satcom intermediate frequencies (IFs), models SLE9072, SLE90125, and SLE90250 are available, respectively, with 1-dB bandwidths of 72 MHz centered at either 70 or 140 MHz, 125 MHz centered at 140 MHz, and 250 MHz centered at 1200 MHz.

These satellite link emulators *(see figure)* are well-suited for testing Earth terminals and satellite payloads, as well as mobile transceivers. The firm offers both optional internal frequency converters for L-band coverage and compact external frequency converters to translate signals from the emulators to higher-frequency signals at L-, C-, S-, X-, Ku-, and Ka-bands.

The satcom testers use a combination of analog and digital components to achieve different signal effects. To create desired signal effects, such as Doppler shifts, added noise, and fading, signals on each channel are first demodulated into in-phase (I) and quadrature (Q) components. They are transformed into digital signals by means of a high-performance 12-b analog-to-digital converter (ADC).

It is in the digital realm where a digital signal processor (DSP) performs its magic, achieving Raleigh and Rician fading with as many as six paths per channel, precise amounts of additive white Gaussian noise (AWGN), and Doppler shifts.

The digitally processed signals are then converted back to the analog realm through a high-resolution, 16-b digital-to-analog converter (DAC), with I and Q modulation restored, noise removed through filtering, and frequency offsets added by means of a high-speed direct-digital synthesizer (DDS). Upconversion is applied to return the signals to their original IFs.


**The SLE line of Satellite Link Emulators features a touchscreen front panel for ease of use, along with a modular design that allows from one to four channels to be installed for flexible satellite link emulation.**

Each instrument includes generous internal flash memory to store digital representations of different signal scenarios. An Ethernet connection provides the means to download data files for signal emulation. Data files can run at playback rates from 1 to 1,000 Hz—whether in single steps, continuous loops, forward, or reverse—to emulate the many different conditions encountered in satcom systems.

The SLE instruments accept IF input signals at a maximum power level of 0 dBm, producing delayed and processed output signals

**The software, which runs on a standard PC or mobile computing device running Windows XP, 7, 8.1, or 10, can model signals for as many as eight transceivers for each channel. It is able to simulate signal conditions for fixed earth terminals, mobile vehicular transceivers, aircraft transceivers, and maritime satellite transceivers.**

at the same 0 dBm. The instruments will operate in static mode, where signal conditions are fixed, or in dynamic mode, with time-varying conditions according to programmed limits.

The typical noise floor for each instrument is −141 dBm/Hz. For the maximum bandwidth (250 MHz), the peak-to-peak amplitude ripple is typically 1.0 dB. For narrower bandwidths, the amplitude ripple is typically better than 0.5 dB.

The instruments provide delay ranges depending on bandwidths, with delays of 15 µs to 1,400 ms for a 72-MHz bandwidth and delays from 10 µs to 890 ms for 125- and 250-MHz bandwidths. Delays can be set with 0.1-ns resolution in static mode and with 0.5-ps/s resolution in dynamic mode. Frequency offsets are able to be set for a range of ±3 MHz with 0.01-Hz resolution.

Phase offsets can be added from 0 to 180 deg. with 1-deg. resolution and better than 1-deg. accuracy, while attenuation is adjustable from 0 to 70 dB with 0.1-dB resolution and ±0.2 dB accuracy. The attenuation can be varied over time, with a slew rate of greater than 70 dB/ms.

These are just a fraction of the capabilities of these three satellite link emulators. Modeling all characteristics of a satellite signal path is certainly not trivial. But the SLE line of emulators, with straightforward, touchscreen-based front panels—in combination with the firm's SATGEN II satellite modeling software—can significantly cut the time required to create the test signals required for satcom system measurements.

The software, which runs on a standard PC or mobile computing device running Windows XP, 7, 8.1, or 10, can model signals for as many as eight transceivers for each channel. It is able to simulate signal conditions for fixed earth terminals, mobile vehicular transceivers, aircraft transceivers, and maritime satellite transceivers. The software can model any satellite orbit, and orchestrate the creation of data files for delays, path losses, Doppler shifts, and even atmospheric signal losses as a function of frequency, humidity, and temperature. MW

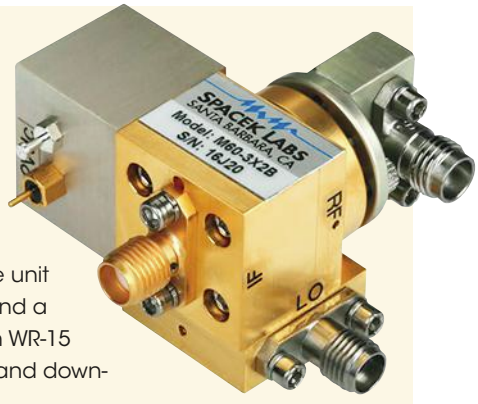
DBM CORP., 32A Spruce St., Oakland, NJ 07436; (201) 677-0008, www.dbmcorp.com

### 10-kW Amplifier Powers L-Band Radar Transmitter

**FOR TRULY HIGH** pulsed output power in radar applications, model 2185 is a rack-mount high-power amplifier (HPA) capable of 10 kW peak output power from 960 to 1,215 MHz. It features nominal gain of 74 dB and operates with pulse widths from 1 to 25 µs, duty cycles from 0.1 to 5.0%, and pulse repetition frequencies (PRFs) from 1 to 25 kHz. The robust HPA achieves its rated output power with input power levels of just –2 to +2 dBm. It exhibits low spurious levels, at typically –70 dBc, with second harmonics of nominally –12 dBc and third harmonics of nominally –16 dBc. The amplifier has built-in forced-air cooling along with a host of protection functions, such as input overdrive protection, output-power limiting, and thermal management. The flexible rack-mount amplifier is well-suited for radar component testing, research, and system development, as well as for tactical applications such as identify friend or foe (IFF), tactical air navigation (TACAN), and surveillance radar systems. It measures 19.00 × 5.25 × 22.00 in. and weighs 450 lb. It has a factory-configured serial RS-232 or RS422 interface and front-panel touchscreen display.

**EMPOWER RF SYSTEMS INC.,** 316 W. Florence Ave., Inglewood, CA 90301; (310) 412-8100, *www.EmpowerRF.com*

### Frequency Converter/Mixer Tackles 57 to 64 GHz



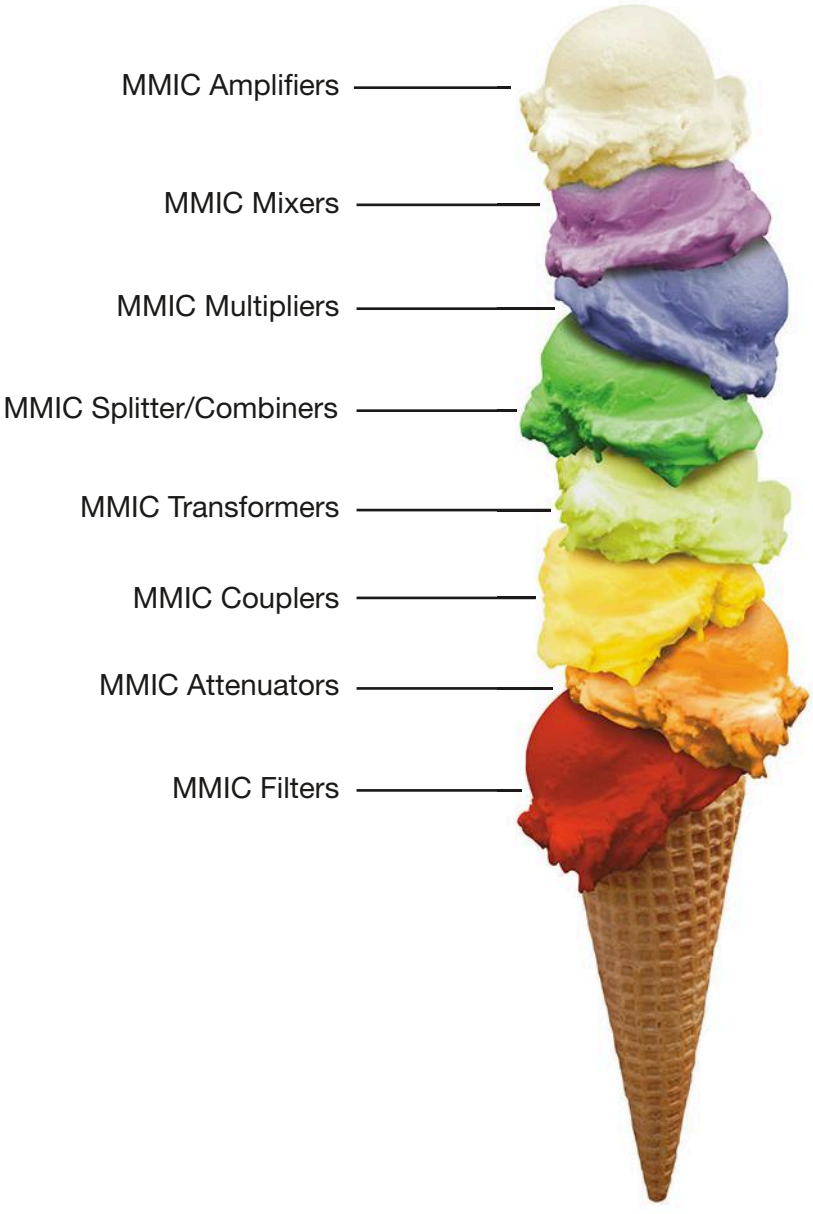

**IN ANTICIPATION OF** the coming millimeter-wave backlinks in Fifth-Generation (5G) wireless networks, the model M60-3X2B frequency converter/mixer provides translation of V-band signals from 57 to 64 GHz. It works with a local-oscillator (LO) frequency range of 28.5 to 32.0 GHz (using an integral ×2 multiplier) and an intermediate-frequency (IF) range of 10 MHz to 7 GHz. Conversion loss is typically 6 dB and no more than 8.5 dB when fed with input signals at typically 0 dBm. The component draws 10-mA current from a -12-V dc supply. The unit is equipped with a female 2.92-mm coaxial connector on the RF and LO ports and a female SMA connector on the IF port, although the RF port can be configured in WR-15 waveguide. The frequency converter/mixer can be used for both upconversion and downconversion.

**SPACEK LABS INC.,** 212 E. Gutierrez St., Santa Barbara, CA 93101; (805) 564-4404, *www.spaceklabs.com*


### Waveguide Bends Channel 90 GHz

**A LINE OF WAVEGUIDE** bends includes models covering 12 frequency bands from 5.85 to 90 GHz (C-band to W-band frequencies). Available in waveguide sizes from WR-12 through WR-137, these bends are suitable for instrumentation, radar, satellite communications (satcom), and telecommunications systems in commercial and radar applications. They feature 90-deg. bends with VSWR as low as 1.08:1 and low insertion loss. The bends are constructed with gold-plated, oxygen-free hard copper (OFHC) or painted copper alloy, depending on the model. The bends are also offered with either a CPR-style flange or a UG-style flange per the military standard. Most models are RoHS-compliant. One of the waveguide bends, the WR-15 model SMF-15EB-001, operates from 50 to 75 GHz with worst-case VSWR of 1.10:1 and typical insertion loss of 0.17 dB

**FAIRVIEW MICROWAVE,** (972) 649-6678, *www.fairviewmicrowave.com*

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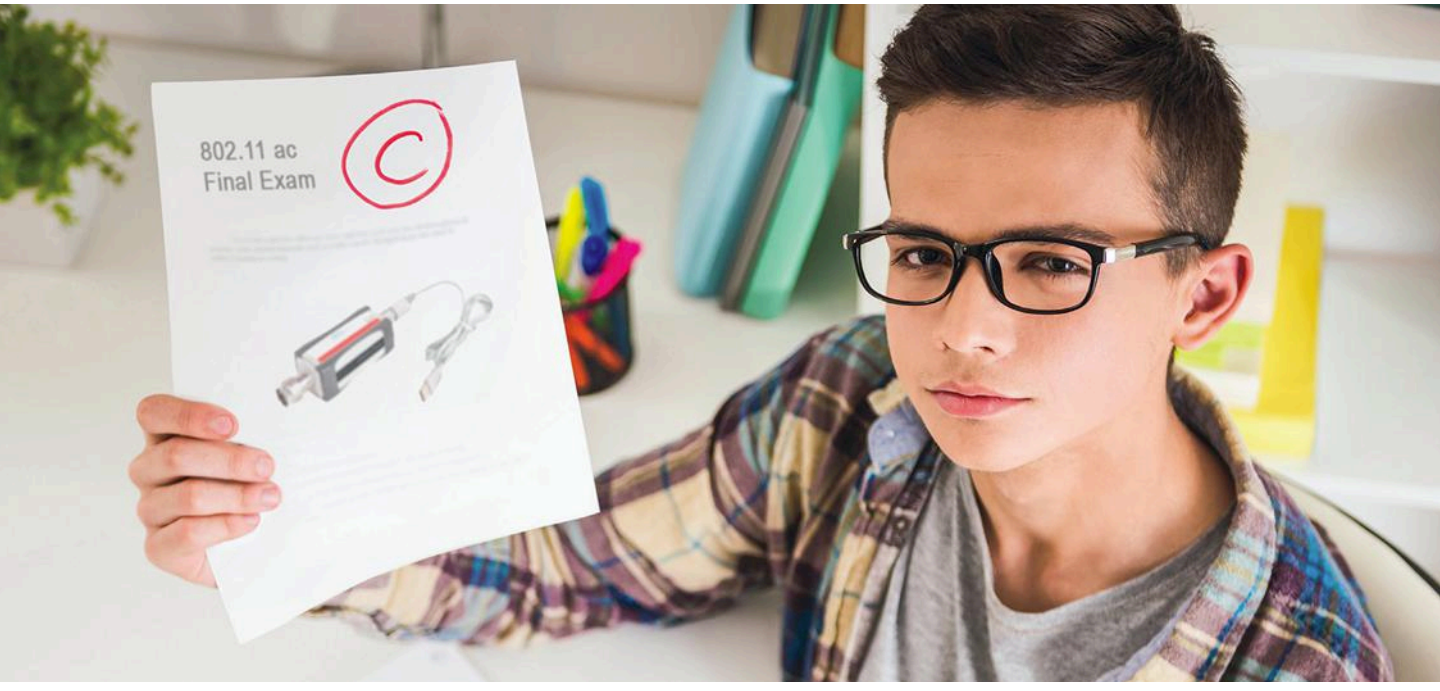


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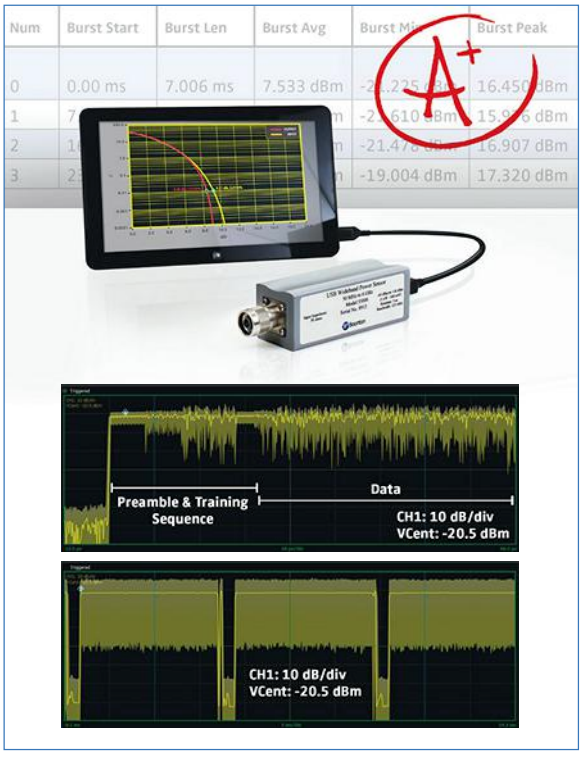


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