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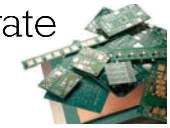

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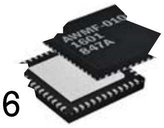

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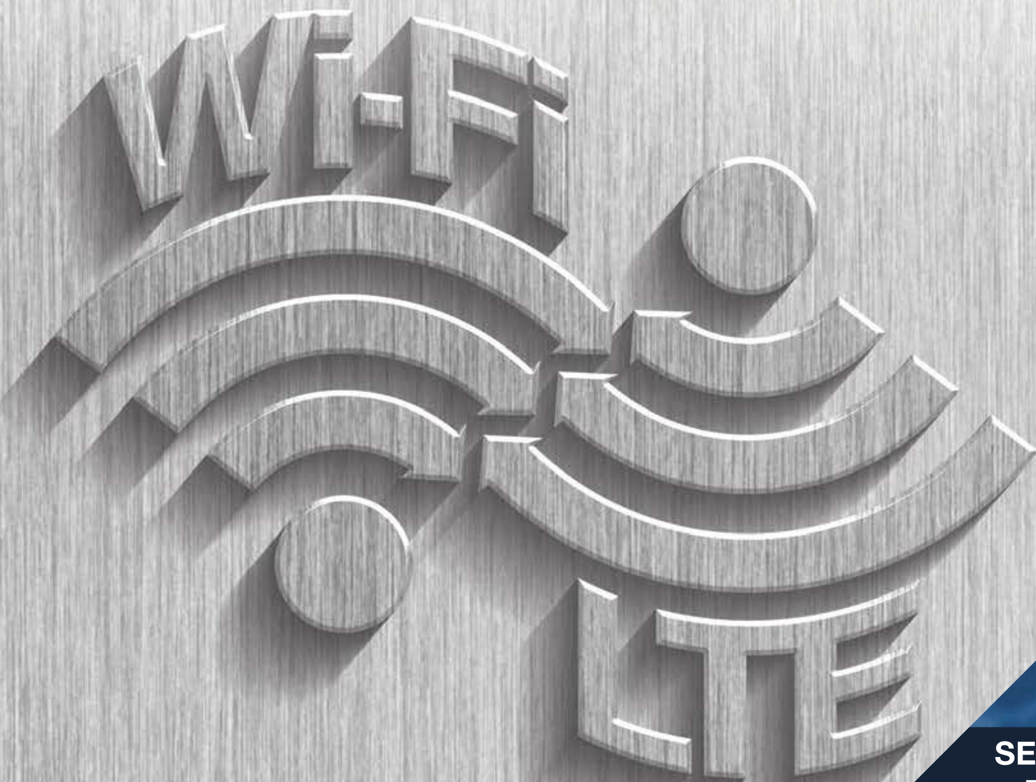
WIRELESS TECHNOLOGIES ISSUE

Forging a Peaceful Coexistence p|35



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A-2D-001040-15-13P	0.1-4	23	1.5	1.5	2.0 / 2.0	+13	90
A-3D-001060-17-13P	0.1-6	33	1.5	1.7	2.0 / 2.0	+13	135
A-3D-001080-19-13P	0.1-8	32	1.5	1.9	2.0 / 2.0	+13	150
A-3D-001100-20-13P	0.1-10	31	1.5	2.0	2.0 / 2.0	+13	150
A-3D-001120-21-13P	0.1-12	27	1.5	2.1	2.0 / 2.0	+13	150
A-4D-001180-25-10P	0.1-18	30	2.0	2.5	2.5 / 2.0	+10	150
A-4D-001200-28-10P	0.1-20	28	2.0	2.8	2.5 / 2.5	+10	150
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A-2D-005060-16-13P	0.5-6	23	1.5	1.6	2.0 / 2.0	+13	90
A-3D-005080-18-13P	0.5-8	33	1.5	1.8	2.0 / 2.0	+13	150
A-4D-005180-24-10P	0.5-18	30	2.0	2.4	2.2 / 2.0	+10	150
A-4D-005200-27-10P	0.5-20	28	2.0	2.7	2.3 / 2.3	+10	150
A-4D-005220-30-10P	0.5-22	25	2.0	3.0	2.3 / 2.3	+10	150
A-5D-005265-40-08P	0.5-26.5	24	2.0	4.0	2.5 / 2.5	+8	200
A-3D-020120-20-13P	2-12	27	1.5	2.0	2.0 / 2.0	+13	150
A-3D-020180-23-10P	2-18	22	1.5	2.3	2.2 / 2.0	+10	150
A-4D-020180-23-10P	2-18	30	1.5	2.3	2.2 / 2.0	+10	150
A-4D-020200-26-10P	2-20	28	1.5	2.6	2.2 / 2.2	+10	150
A-4D-020220-29-10P	2-22	26	1.5	2.9	2.2 / 2.2	+10	150
A-4D-020265-39 -08P	2-26.5	19	2.0	3.9	2.5 / 2.5	+8	150
A-4D-200265-30-08P	20-26.5	24	1.0	3.0	2.0 / 2.0	+8	150
A-4D-265330-35-10P	26.5-33	23	1.5	3.5	2.0 / 2.0	+10	180
A-4D-300330-35-08P	30-33	23	1.5	3.5	2.0 / 2.0	+8	180
A-4D-340360-35-08P	34-36	23	1.5	3.5	2.0 / 2.0	+8	180
A-4D-300400-40-08P	30-40	23	1.5	4.0	2.5 / 2.5	+8	180
A-4D-180400-40-6P	18-40	20	2.5	4.0	2.5 / 2.5	+6	180
A-5D-260400-38-10P	26-40	30	2.5	3.8	2.5 / 2.5	+10	250

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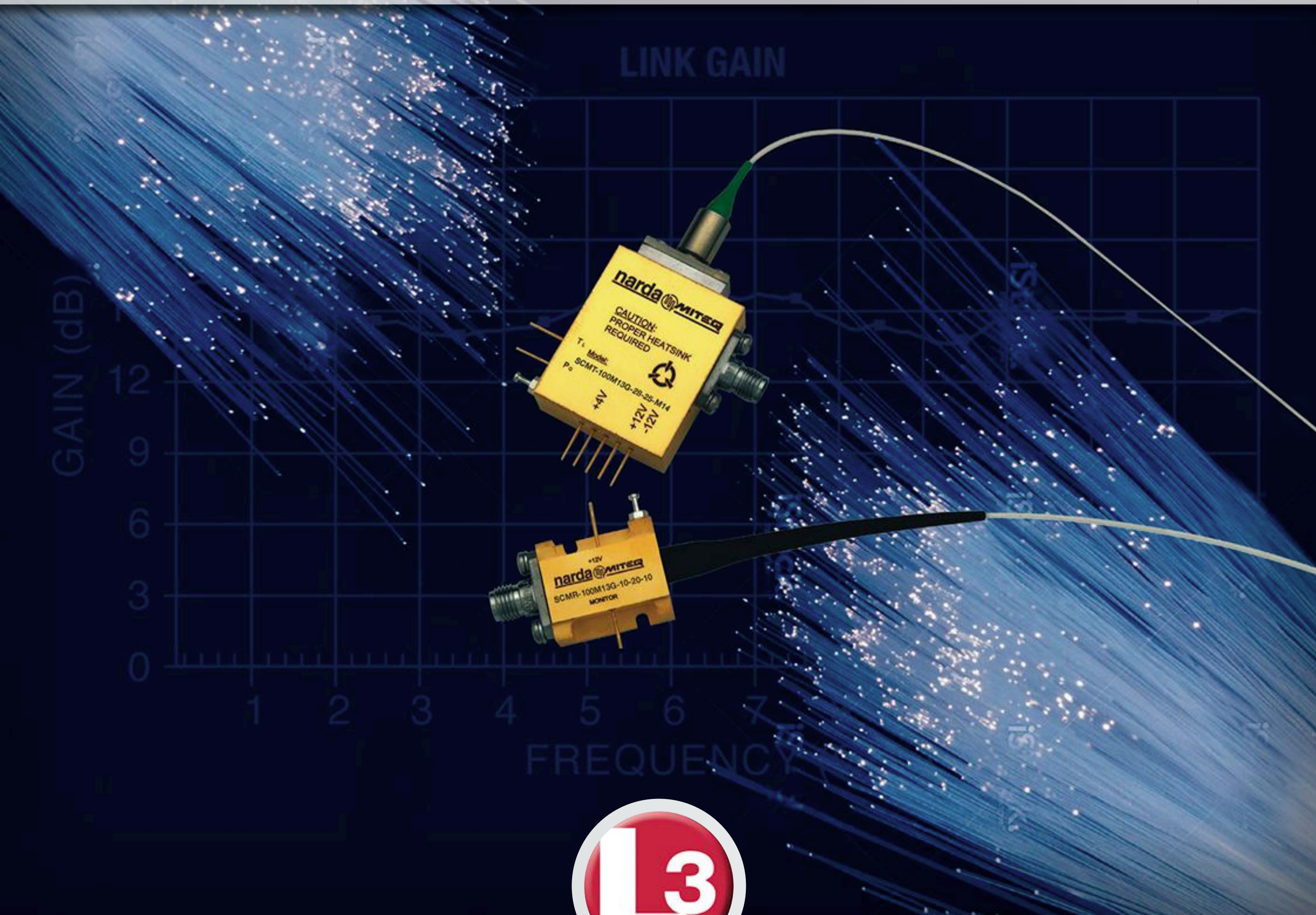

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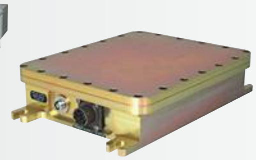


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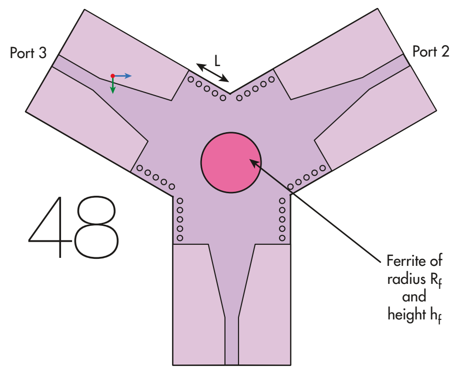

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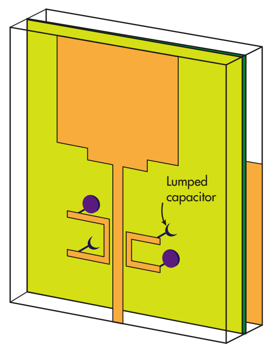

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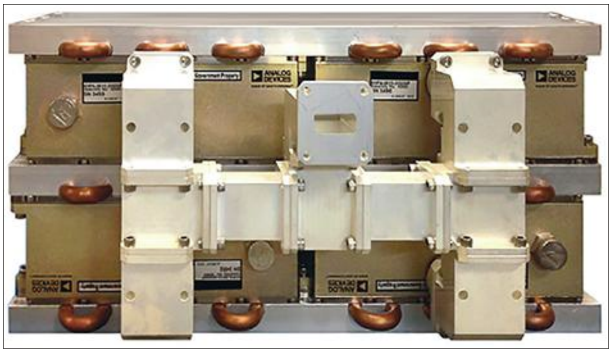
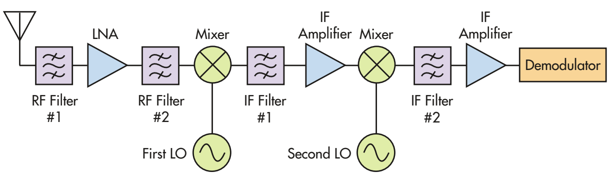


GaN BREAKS THROUGH PERFORMANCE BARRIERS

http://mwrf.com/active-components/gan-breaks-through-performance-barriers

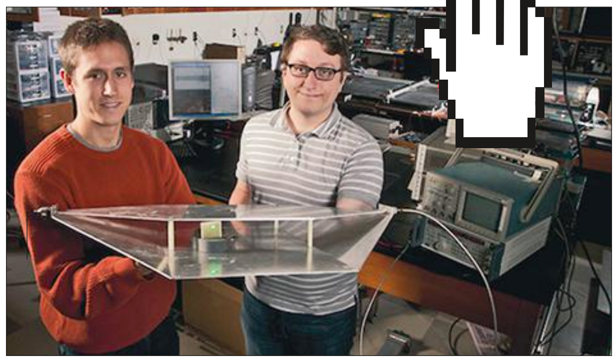
Gallium-nitride (GaN) technology has officially arrived, as applications ranging from defense to commercial cellular exploit its performance benefits—benefits that are simply unavailable with older semiconductor technology like gallium-arsenide (GaAs). Today, a number of different suppliers offer an array of GaN devices. And GaN shows no signs of slowing down, as it will likely find its way into more future applications.



THE DIFFERENCES BETWEEN RECEIVER TYPES, PART 2

http://mwrf.com/active-components/differences-between-receiver-types-part-2

This two-part series examines various types of receiver implementations, focusing in on the roles played by receivers, as well as some of the characteristics that describe their performance. Part 1 analyzed both the direct-conversion and superheterodyne implementations. In Part 2, we take a deeper look into the dual-conversion superheterodyne receiver, as well as discuss the newer direct RF-sampling technique.



CUTTING-EDGE TECHNOLOGIES PRIMED FOR THEIR MOMENT

http://mwrf.com/materials/cutting-edge-technologies-primed-break-out

Microwave components and systems have long depended on developments within many different technology areas to sustain the evolution of the industry as a whole. Take gallium arsenide (GaAs). For many years, it was viewed as "the semiconductor technology of the future" for its capabilities in broadband, high-gain field-effect transistors (FETs). But because engineers by nature are always striving for better ways to do things, new technologies are constantly under the microscope.

WIRELESS STANDARDS ENSURE CONNECTIVITY

http://mwrf.com/systems/wireless-standards-ensure-connectivity

So pervasive has wireless communications become in daily life, most people take for granted the effective operation of multiple wireless devices each day (including their cellular telephones and Internet-connected computers). But bandwidth is limited, and without wireless standards to set limits and guidelines, all of these different wireless devices would be competing for their "wireless space." And only the highest-level signals would make the connection.

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CHRIS DeMARTINO
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RF/Microwave Symposium Returns to Long Island

On April 14, the IEEE hosted the Long Island RF/Microwave Symposium in Hauppauge, N.Y. Prior to this year, a symposium such as this had not been held on Long Island since the 1980s, so it was nice to see the event return. This region has long had a major impact on the RF/microwave industry, proven by names like MITEQ, General Microwave, and Airborne Instruments Laboratory (AIL), among others. Today, a number of RF/microwave companies make their home on Long Island, including L3 Narda-MITEQ (www.nardamiteq.com), Geosync Microwave (www.geosyncmicrowave.com), Comtech PST (www.comtechpst.com), and Agile Microwave Technology (www.agilemwt.com).

The symposium welcomed the presence of three IEEE fellows who spoke at the event. A keynote address was given by Jesse Taub. Several lectures were presented, with topics that included reflectionless filters, digital pre-distortion (DPD), and switchable/tunable ferroelectric devices. Another lecture, "RF Aspects of Magnetic Resonance Imaging," was presented by Dr. Robert Caverly from Villanova University.

In addition to the presentations, a number of companies participated in the exhibition. A good variety was seen, as the various exhibitors represented different segments of the RF/microwave industry. While the exhibition obviously was not on the same scale as the International Microwave Symposium (IMS), it was nice to see companies participate in an exhibition in a much smaller setting.

Manufacturers of test-and-measurement equipment had a strong presence, with companies like Keysight Technologies (www.keysight.com), Tektronix (www.tek.com), Pickering Interfaces (www.pickeringtest.com), and Copper Mountain Technologies (www.coppermountaintech.com). Pickering Interfaces, which recently introduced its new 40-760 series of PXI RF multiplexers, demonstrated its modular switching capabilities. Of course, companies like Keysight and Tektronix always have much to present, and this event was no exception.

Long Island had some its own companies participate in the exhibition, such as L3 Narda-MITEQ and Geosync Microwave. L3 Narda-MITEQ presented a full table of products, while Geosync Microwave displayed its dual-conversion synthesized frequency converter. Some of the other companies that were present included Mini-Circuits (www.minicircuits.com), KCB Solutions (www.kcbsolutions.com), Amplifier Research (www.arworld.us), and HXI (www.hxi.com). Mini-Circuits displayed a large number of its products, while Amplifier Research showcased a 10-W power amplifier (PA).

Overall, the event had something for anyone who is a part of the industry. Those who did not attend will have another opportunity, as the event is being planned again for next year. mw

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EDITORIAL

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TAKING SOME HEAT ABOUT "STANDARD" NOISE TEMPERATURE

Dear Mr. DeMartino,

I have just read Part 1 of your series of "Differences Between" articles on receivers, "The Differences Between Receiver Types *(see Microwaves & RF, March 2016, p. 60)*, and have one small quibble. I think a footnote is in order in regard to the noise temperature of the noise source. It can be substantially higher than 290 K due to atmospheric, man-made, or solar noise, and can be substantially lower if your antenna is looking at a cool region in space. This can be complicated by high-frequency (HF) propagation modes and by antenna patterns.

Yours truly,

Ralph Gaze
RF Engineer

EDITOR'S NOTE

We appreciate your interest in Chris DeMartino's article on receivers and in the magazine. It can sometimes be difficult to explore technical topics on many levels simultaneously so that readers of all educational levels can draw some value. Chris has provided a tutorial-level view of different receivers while also trying to provide explanations of what can limit the performance, such as the impact of noise on sensitivity. Most engineers think of noise as the familiar "kTB" value that factors in Boltzmann's constant and bandwidth. Noise is produced as a function of temperature, notably at temperatures above absolute zero, or 0 K.

As Chris noted, noise is usually referenced to room temperature, or 290 K, which is a somewhat vague term because "room temperature" is a relative value unless specified as a precise value. You are correct in pointing out that what is taken as a reference temperature for a noise source can vary a great deal due to atmospheric and other effects. As with any measurements and the calibrations of the instruments used to perform them, agreement on a reference or starting point is essential to achieving agreed-upon results. We appreciate that you have taken the time to point out that 290 K is not an absolute value for standard noise-source room temperature, and that meaningful measurements require such attention to details.

Jack Browne
Technical Contributor

Microwaves & RF welcomes mail from its readers. The magazine reserves the right to edit letters appearing in "Feedback." Address letters to:

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News

GRAPHENE FILTERS Could Unlock Ultra-Fast Wireless Speeds

Buried in the wilderness between microwaves and infrared light is part of the electromagnetic spectrum known as the terahertz gap. The term comes from the relative lack of wireless technology that is capable of transmitting or receiving these ultra-high-frequency bands.

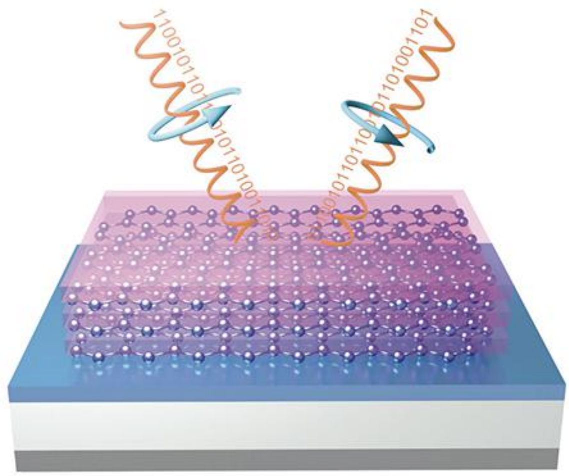
Now, researchers from the Ecole Polytechnique Federale de Lausanne (EPFL) and University of Geneva have invented a graphene filter that could make terahertz antennas more efficient and practical. The new microchip blocks out rogue signals that interfere with wireless transmissions, clearing the way for antennas up to 10 times faster than current technology.

The microchip, which was described in the journal *Nature Communications*, is also known as an optical isolator. These components prevent signals and other noise from leaking into antennas. That noise impacts the quality of the transmission—introducing static to a phone call or blurring a video stream, for instance.

The new device helps compensate for reciprocity, or the natural property of antennas to transmit and receive signals over the same path. When antennas open to let signals out, signals bouncing off walls and other obstacles can get inside the antenna. As the antennas become more efficient, they grow more susceptible to this kind of interference.

Isolators are widely used in current mobile devices, which transmit data in the megahertz or gigahertz range. But scientists have struggled to build isolators and other components that can manipulate terahertz waves, which are notoriously difficult to transmit, detect, and modulate. Further research could have a huge payoff, considering terahertz waves send data at blisteringly fast speeds.

In this case, the researchers found that graphene, an extremely thin lattice of carbon molecules, could be configured to let only certain frequencies inside the antenna. The graphene is either "transparent" or "opaque," depending on the vibration and direction of incoming signals. The researchers compared the new isolator to polarized sunglasses, which absorb horizontal light waves, while allowing vertical waves to pass through. In the same way the sunglasses eliminate glare, the graphene isolator dispels interference.



The filter developed by EPFL scientists is either "transparent" or "opaque," depending on the vibration and direction of incoming signals. In that way, it helps to dispel wireless interference. ***(Image courtesy of EPFL)***

The advance marks another step forward for research into terahertz radiation, which has begun to accelerate over the last few years, spurred by the demand for faster networks and additional wireless spectrum. The new microchip could help to unlock speeds achieved earlier this year in Japan. Researchers used terahertz waves to transmit data at 100 Gbits/s, the fastest wireless transmission in the world.

"Our graphene-based microchip is an essential building block for faster wireless telecommunications in frequency bands that current mobile devices cannot access," Michele Tamagnone, an EPFL scientist, said in a statement. ■

(Image courtesy of Scyther, Thinkstock)

QORVO ACQUIRES IoT Chipmaker Greenpeak Technologies

QORVO RECENTLY AGREED to purchase Greenpeak Technologies, a fabless semiconductor company that builds low-power, short-range wireless chips. The deal is the latest example of large wireless companies buying out smaller competitors that target smart homes.

Greenpeak builds controller chips based on Bluetooth and ZigBee, a wireless standard for creating networks that are only large enough to cover a house or apartment. The company designs chips and integrated software for remote controls, lighting, heating, access control, and security in smart homes. In 2015, the company announced it had shipped 100 million ZigBee chips.

Bluetooth Smart, the low-power version of the standard, has begun to shift toward the Internet of Things (IoT). Earlier this year, developers gained the ability to build internet gateways with Bluetooth, making it possible for sensors and other devices to relay data to the cloud. That feature would allow anyone to monitor and control Bluetooth sensors from a remote location, like turning your house lights off while on vacation.

The acquisition helps Qorvo "expand its customer offering to include highly integrated RF solutions and systems-on-a-chip for the connected home and the rapidly growing Internet of Things," the company said in a statement.

The terms of the deal were not announced. Based in the Netherlands, Greenpeak Technologies will become part of Qorvo's Infrastructure and Defense Products division. Both companies expect the transaction to close this quarter.

The deal is the latest sign that large wireless companies are turning to acquisitions to expand into the IoT quickly. Last year, Silicon Labs closed deals to buy Telegesis (a supplier of mesh ZigBee modules) and Bluegiga Technologies (a company that develops Bluetooth Smart modules). Synopsys, which makes electronic-design-automation software, last year purchased the intellectual-property assets of Bluetooth Smart chip designer Silicon Vision.

In the battle for the smart home, ZigBee and Bluetooth are also competing with Thread, a rival standard developed in part by Google's NEST smart home division. Thread's protocol places an emphasis on mesh networking, or skipping wireless data from one node to another. Greenpeak chips, however, are network-agnostic, meaning that they can support Thread if developers abandon ZigBee or Bluetooth. ■

COMPETITION CALLS FOR Innovative Designs Using Simulation Software

ALTAIR ENGINEERING, a developer of computer-aided design software, is holding a competition for students to design antennas and other wireless systems using electromagnetic simulation software. The FEKO Student Competition is now accepting projects that leverage Altair's FEKO Hypervision software.

Because simulation software is widely used in engineering, it has also become a familiar tool for students. Companies that make the software often have licenses with universities, giving students access to electronic-design-automation (EDA) programs for electrical engineers and modeling software for mechanical engineers.

For wireless engineers, too, "it has become popular to simulate antennas in electromagnetic simulation software," John Dunn, technical marketer for AWR Design Software, wrote in a blog post. "Even to more experienced circuit designers, antennas can be mysterious entities, not obeying the laws of normal circuit theory."

Part of the problem is that the environments surrounding antennas can be complicated. In biomedical devices, for instance, the bone and muscle inside the human body can affect the radiation pattern of the antenna. The other problem is that antenna types and electromagnetic requirements vary widely based on where antennas are placed on structures.

FEKO software is capable of analyzing antenna locations, simulating the antenna's interaction with electrically complex environments and large structures, like ships and planes. It can also simulate other wireless components like filters, couplers, isolators, and circulators.

Ting-Yen Shih, a graduate student from the University of Wisconsin-Madison, won last year's competition. Using FEKO's characteristic mode configuration, he developed a method to improve the bandwidth of high-frequency antennas in platform mode. The resulting bandwidth was higher than what is possible with standalone antennas.

The deadline for this year's competition is Sept. 30, 2016. Altair has released a free version of its Hyperworks software, which includes the FEKO electromagnetic field simulation software, for students to download for the competition. ■

Researchers Develop INTERFERENCE-RESISTING ANTENNA

ONE OF THE FUNDAMENTAL PROPERTIES of antennas is reciprocity, or their ability to transmit and receive radio signals with the same efficiency. That natural symmetry is not always an advantage, since it makes antennas more susceptible to noise and interference as they get better at handling radio waves.

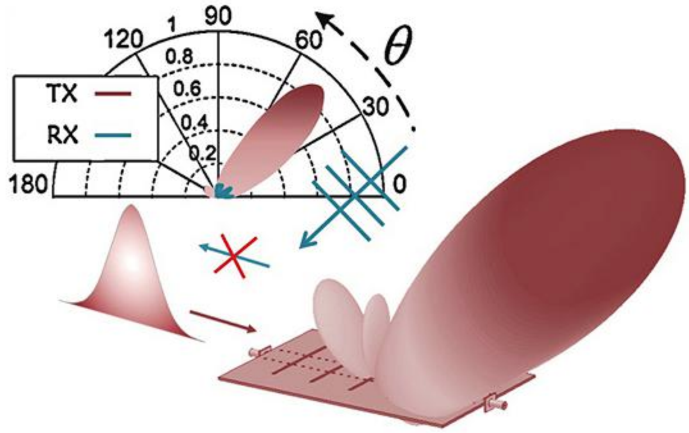
Now, researchers from the University of Texas at Austin have developed an antenna not bound by the same property. This “non-reciprocal” antenna can independently control signals entering and exiting the antenna more efficiently, and without the need for other electrical components to keep out noise.

Normally, antennas transmit and receive signals over the same path, so that when it “opens” to let signals out, rogue signals that reflect off objects or walls can leak back through the channel. Such leakage impacts the quality of the transmission—introducing static into a phone call, for instance. To combat these types of effects, special isolators are employed to prevent noise from leaking into antenna amplifiers.

The new design, however, limits the effect of those rogue signals. “We break the symmetry between transmission and reception signals, so we are able to prevent the antenna from having to listen to reflections and echoes that affect the source,” says Andrea Alu, an associate professor who led the UT Austin research team.

The findings, which were published in the journal *Proceedings of the National Academy of Sciences*, could enable faster data rates and clearer telecommunications. Keeping noise and echoes out of the antenna could also help reduce the number of non-reciprocal devices (like isolators and circulators) used in antenna systems, reducing their size and cost.

The team’s experiments involved feeding an antenna a low-frequency modulation signal while it was transmitting or receiving an RF signal. That low-frequency signal, which was temporally modulated, slowly changed the properties of the antenna, interrupting its natural symmetry.



“We break the symmetry between transmission and reception signals, so we are able to prevent the antenna from having to listen to reflections and echoes,” says Andrea Alu, an associate professor from UT Austin. ***(Image courtesy of UT Austin School of Engineering)***

The modulation signal altered how efficiently the antenna receives and sends signals. In the experiments, the researchers were able to make the reception efficiency hundreds of times smaller than normal when the antenna was sending radio signals.

Having completed these initial experiments, the researchers are looking to new applications for the technology. For instance, it might be applied to sensors used in healthcare and weather forecasting, enabling them to distill more accurate data from its surroundings. The researchers also want to find out if the same concepts apply with visible light and higher frequencies.

One of the most promising applications is thermophotovolatic cells, devices that convert heat from the sun into electricity. Like antennas, these devices are forced to emit light as efficiently as they absorb it, limiting their overall efficiency. The new antenna technology could help these devices more efficiently absorb light while reflecting less of it away. ■

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HIGHS AND LOWS Converge in Qualcomm Results

FOR EVERY SUCCESS that appeared in Qualcomm's second-quarter financial results, another question seemingly was raised about the future of its modem chip business. The company is in the middle of a large restructuring, which has been focused on tightening its grip on mobile phones and expanding into new businesses.

"This is a transition year, and we are making significant progress," said Qualcomm CEO Steve Mollenkopf in a conference call with financial analysts. *(Image courtesy of Jon Jordan, Flickr)*

Qualcomm's revenues were slightly higher than analysts had predicted, buoyed by the end of a patent dispute with LG Electronics and new licensing agreements with Chinese carriers and manufacturers. Nevertheless, the slowing smartphone market forced Qualcomm to project lower third-quarter revenues for its modem chips, which connect mobile phones to cellular networks.

"This is a transition year, and we are making significant progress," said Qualcomm CEO Steve Mollenkopf in a conference call with financial analysts. He reiterated plans to cut $1.4 billion in spending by the end of the year, which will involve cutting 15% of the company's workforce.

That restructuring is the latest evidence of the chipmaker's plans to control the intestines of the modern smartphone. The company has started to build filters, which enable mobile phones to access a certain part of the wireless spectrum, in a joint venture with TDK. It has also begun to develop power amplifiers, front-end modules, and Wi-Fi and Bluetooth chipsets. Qualcomm's latest processor, the Snapdragon 820, has already been customized into 115 designs, the company said.

Derek Aberle, president of Qualcomm Technologies, said that the company was making progress in automobiles, robotics, and networking. The company continues to work on its 5G air interface, parts of which it could license for the next generation of wireless networks. He also noted that Qualcomm was working on new wearable Snapdragon processors.

For the second quarter, Qualcomm reported $1.2 billion in profit with $0.78 earning per share. The company's revenues were $5.6 billion, down 19% from the second quarter last year and 4% from the first quarter. The revenues included $266 million from a licensing agreement that was terminated when two customers merged.

Though the results indicated slowing growth in its smartphone business, one of the more optimistic results was the company's success in China. Qualcomm has signed pat-

ent licensing deals with more than 100 Chinese companies. The chipmaker has also had more success collecting patent payments than last year, when the Chinese government launched an anti-monopoly investigation.

"We are making good progress on the licensing side in China, and this remains a key focus area for the company," Mollenkopf explained. That included a deal with the Chinese electronics conglomerate Hisense to develop 3G WCDMA, CDMA2000, and 4G devices. Chinese manufacturers are also buying new carrier-aggregation chips from Qualcomm in order to separate their products from competitors.

"In China, the transition from LTE to carrier aggregation is actually going faster [than expected]," said Christian Amon, president of Qualcomm CDMA Technologies, which develops the company's wireless chipsets. "As we continue to invest and see those technologies transition ahead of us, we feel very confident that the whole nature of the market will demand the latest," he said.

Despite new licensing agreements, Qualcomm predicted a sluggish third quarter. The company forecast revenues of roughly $5.6 billion in the third quarter, which is down from $5.8 billion a year earlier. Qualcomm expects to ship between 185 and 195 million chips over the next quarter, down from 225 million a year ago.

The reason is that Qualcomm expects one of its "biggest customers" to give orders to other wireless chipmakers. For months, analysts have speculated that Qualcomm was losing some of its business with Apple. Qualcomm supplies all 3G and 4G modems inside iPhones, including the iPhone SE.

Analysts have rumored that Intel would be supplying up to 30% of all modem chips for the iPhone 7, which is expected to be released later this year. That would be a sharp blow to Qualcomm, which has already failed to get its Snapdragon processors into Apple phones. Though Apple designs its own processors, it buys separate modems.

Mollenkopf was "assuming" that the company would lose some of its business when the restructuring began last year. As a result, there should be little impact on profit margins in its chip business, which has thrived on pairing its processors with wireless chips and other components.

"It's really a communication of a planning assumption and also confidence in us meeting our long-term trajectory," Mollenkopf said on the earnings call. "And I think it's important to make sure people understand that. We do feel very confident, though, in our position in the modem segment." ■


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Inside TRACK with James Chen,

Senior Director of Product Marketing, Quantenna

Interview by CHRIS DeMARTINO

James C. Chen, Ph.D., is the Senior Director of Product Marketing at Quantenna Communications. Throughout his career, Chen has defined and promoted Wi-Fi solutions to service providers worldwide.

CD: IEEE 802.11ac Wave 3 is a new way for Wi-Fi networks to operate. What advantages does Wave 3 have over Wave 2 and earlier technologies?

JC: Wave 3 defines a new class of access points for Wi-Fi networks to operate. As Wi-Fi usage continues to explode, 10G Wave 3 provides the flexibility and scalability to meet the growing demand for Wi-Fi capacity. Wave 3 has a number of advantages over Wave 2 and earlier technologies, starting with higher-order MIMO. In Wave 2, users are limited to 4 × 4—four transmit antennas and four receive antennas. On Wave 3, we have defined a dual-band system, where 5 GHz can go up to 8 × 8 with four additional antennas on 2.4-GHz networks, for a total of 12 unique streams of data.

The end result in the 5 GHz band is that 8 × 8 has much better maximum range than 4 × 4. Even if you live in a smaller home and don't care about ultimate range, the improvement is seen at every distance—whether near, far, or something in the middle, 8 × 8 will give you higher speeds. If you were getting a certain amount of speed at a specific location using 4 × 4, at that same position 8 × 8 will significantly increase your throughput.

CD: When do you expect to see widespread use of Wave 3 in consumer applications?

JC: We're working with service-provider and retail-market customers to launch products into consumers' hands by the end of 2016.

CD: What specific challenges are associated with developing chipsets for IEEE 802.11ac Wave 3?

JC: Wave 3 combines the best of 802.11ac and 802.11n all in a single chipset. Our Wave 3 technology enables 12

> **"Wave 3 defines a new class of access points for Wi-Fi networks to operate. As Wi-Fi usage continues to explode, 10G Wave 3 provides the flexibility and scalability to meet the growing demand for Wi-Fi capacity."**

"We're now taking the latest and greatest semiconductor process technology and designing chips with it. Every 18 months customers can pack twice as many transistors in the same area, enabling tremendous integration."

streams—maxing out what the IEEE standard has defined. The challenge is to pack all of that functionality into a single chipset, which traditionally required customers to use three or more distinct chipsets. Integrating all of that complexity down in a cohesive form also has to be carefully architected and managed in terms of size, power, and performance.

The last challenge is really about perception, since—much like when we introduced 4 × 4 in 2013—people usually don't think about the need for a chipset to transmit such high speeds using so many streams. However, our past experience in 4 × 4 showed that Wi-Fi demands continue to increase and become more stringent. We are confident that a Wave 3-type solution is needed to provide the additional reassurance that consumers will be able to experience broadband where, and when, they need it.

CD: What advances in semiconductor technology in the last five years or so have enabled these chipsets?

JC: Wi-Fi is a unique blend because it's digital and RF. All Wi-Fi uses CMOS, and in the last five years, with help from Moore's Law, it has become commonplace. We're now taking the latest and greatest semiconductor process technology and designing chips with it. Every 18 months customers can pack twice as many transistors in the same area, enabling tremendous integration—including 12 streams onto one chip!

CD: What techniques are being implemented into power-amplifier (PA) designs to meet the latest demands for stringent requirements like linearity and efficiency?

JC: Our partners, such as Skyworks and Qorvo, have benefited from many generations of PAs. They supply not only to us, but also to the greater market. We work with them to help design the most power-efficient PAs to meet Wave 3 requirements, such as eight streams at 160-MHz channel bandwidth and 1024-QAM modulation.

CD: Can you explain the adaptive multiple-input, multiple-output (MIMO) architecture?

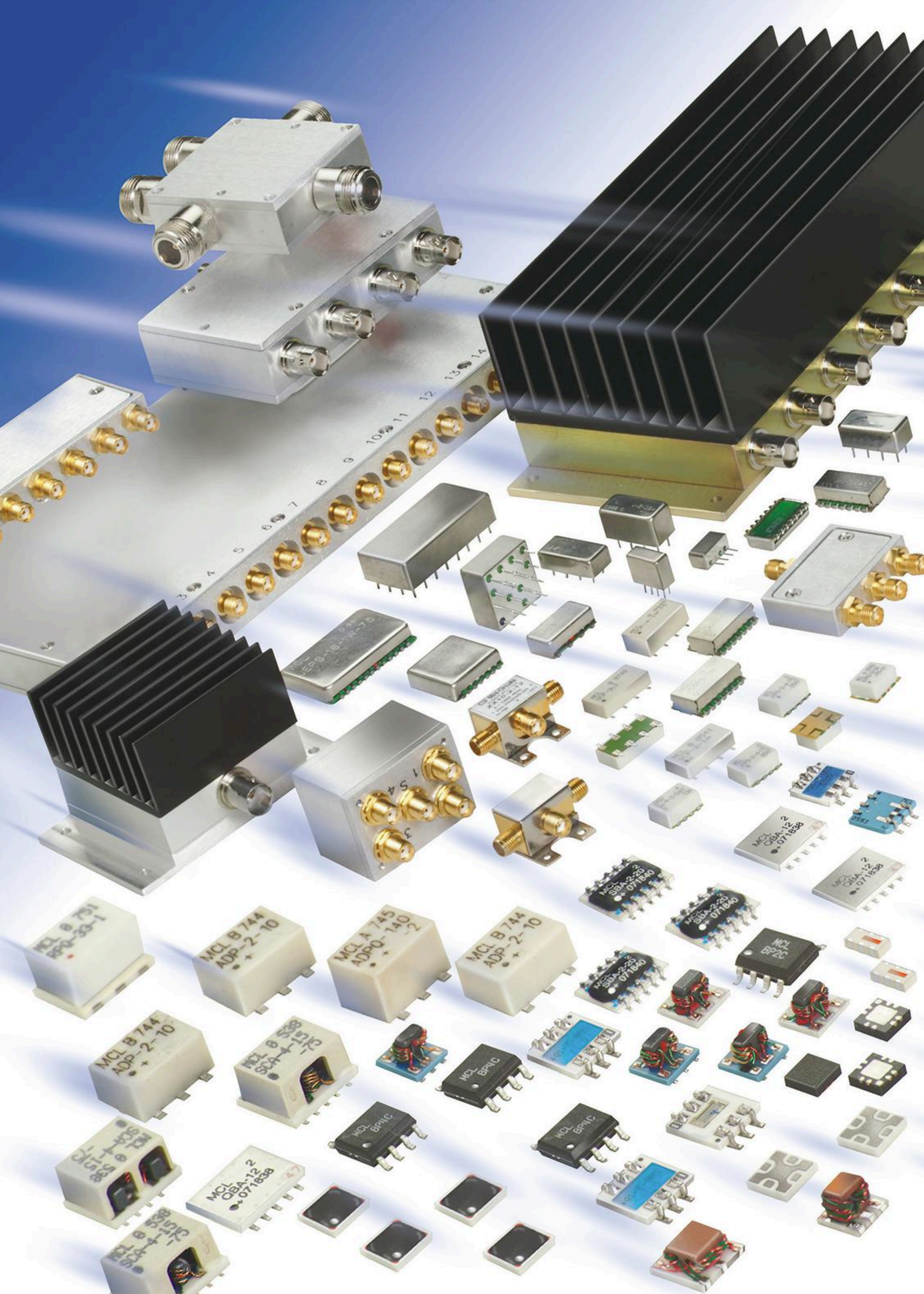
JC: Wave 3 includes support for multi-user MIMO (MU-MIMO). MU-MIMO provides the ability to support multiple clients at the same time, thus dramatically increasing the capacity of the network. This is extremely important as consumers use more services over Wi-Fi, and as the number of users increase per household. More consumers will experience the fastest, most reliable video-streaming experience, faster downloads and uploads, and better performance even at extremely long distances—in challenging high-density Wi-Fi home environments, and even outdoor applications such as Wi-Fi hotspots.

CD: How will IEEE 802.11ac Wave 3 tie into the Internet of Things (IoT)?

JC: Because we have 12 streams and not four, we can service many more clients. Think of capacity like the width of a pipe: Now we have three times the capacity for IoT clients producing thermostats, wireless door locks, alarm systems, IP video cameras, and many more smart devices. Wave 3 is critical because it makes better use of network and airtime efficiency to support the growing number of connected devices, services, and applications, which is the current trend. I have 14 devices in my home, including iPhones, an iPad, laptops, desktops, and AppleTVs. In the next four, five, 10 years, there will be even more devices, which means more capacity… and Wave 3 stands ready to support all of that.

CD: What is your vision regarding the future of wireless networking?

JC: Everything's wireless. Cars are now outfitted with LTE for web access. This was not possible just a few years ago. In the not-so-distant future, cars will also have high-speed Wi-Fi. This will be used for downloading apps, e-mail, and video for that long summer trip, as well as telemetry, traffic accident notification, and congestion avoidance. Wi-Fi will also find its way into other devices and surroundings we can't even imagine now. What we do know is that in addition to ubiquity, Wi-Fi will also enable demand management. To this end, Quantenna has introduced a solution call MAUI, which is a cloud-based Wi-Fi monitoring and self-healing service that keeps Wi-Fi networks secure, and in peak performance. mw



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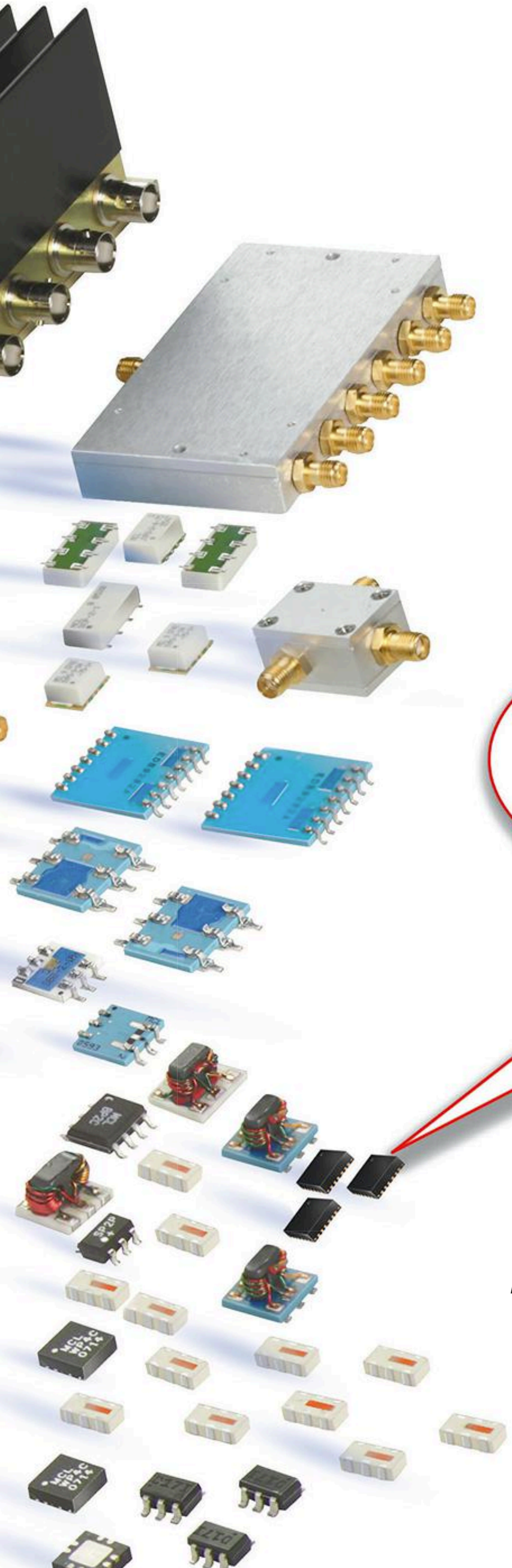

KA-BAND ANTENNAS LINK MOBILE SATCOM USERS

SATELLITE COMMUNICATIONS (SATCOM) technology is moving far beyond the simple reception of video from orbiting geosynchronous satellites and into full bidirectional mobile satcom services. To accomplish this at Ka-band frequencies, efficient antenna designs are needed for mobile satcom terminals. Researchers from the RF and Microwave Research Laboratory at the Technische Universitat Ilmenau (Ilmenau, Germany) and the Fraunhofer Institute for Integrated Circuits IIS, Design Automation Division EAS (Dresden, Germany) attempted to compare two different Ka-band antenna terminal setups for mobile satcom applications. The two antennas traded size for performance: one was a larger, high-gain antenna, the other a lower-gain, lower-profile antenna.

The researchers point out the growing interest in Ka-band frequencies at 29.5 to 30.0 GHz for uplinks and 19.7 to 20.2 GHz for downlinks because of their healthy capacity and compact terminal antennas. In emergency situations where terrestrial communications systems may not be available or reliable, the use of geosynchronous satellites can provide a means of communications. The two antenna designs explore the classic tradeoff of size for performance.

The larger of the two designs is a Cassegrain double-reflector antenna mounted on a mechanically adjusted, two-axis positioner on a carrier vehicle. The reflector diameter is 60 cm, but it provides large gain of about 40 dBi in support of high data rates for bidirectional satcom links. While moving, the antenna tracks satellite direction by means of multimode monopulse tracking. It can be mounted on large vehicles, such as pickup trucks.

The smaller antenna is designed for greater mobility, with a maximum height of only 15 cm. The smaller profile and size yields less gain, at about 20 dBi, and a correspondingly broader beamwidth. The low profile of the antenna design makes possible a compact satellite terminal outdoor unit (ODU) with a mechanical azimuth positioned that operates effectively while maintaining the aforementioned height, even when the vehicle is in motion.

The design was evaluated by means of an antenna ODU demonstrator capable of adjusting azimuth for both uplink and downlink operations. In contrast to the larger, high-gain antenna, this low-profile satcom antenna is suitable for mounting on smaller vehicles, including standard automobiles. See "Ka-Band User Terminal Antennas for Satellite Communications," *IEEE Antennas & Propagation Magazine*, February 2016, p. 76.

TRANSCEIVER ARRAY AIDS SUBMILLIMETER-WAVE RADAR

SUBMILLIMETER-WAVE RADAR SYSTEMS operating at beyond 300 GHz are effective solutions for imaging concealed weapons at security checkpoints. These fine wavelengths can detect metal objects through most clothing without the health risks posed by x-ray imaging systems.

In pursuit of a practical submillimeter-wave front end, researchers at the California Institute of Technology's Jet Propulsion Laboratory (JPL; Pasadena, Calif.), under contract with the National Aeronautics and Space Administration (NASA), developed an eight-pixel transceiver array for use in a 340-GHz imaging radar. The array was fabricated by silicon micromachining for relatively low cost and with high circuit density, with 12-mm pixel spacing in a vertically integrated waveguide configuration.

This work builds on active imaging techniques developed at JPL in the development of a frequency-modulated, continuous-wave (FMCW) radar that measures the time of flight between the system and a target by transmitting chirped tones, then demodulating received signals for determining the range to the point of focus on a target. Because the scanning speed of JPL's radar system was limited by a mechanical scanning mechanism, the authors sought an eight-pixel transceiver array capable of faster scanning frame rates.

The researchers' experiments produced a transceiver array capable of operating from 324 to 354 GHz. The transceiver provides 0.5-mW transmit power per pixel with conversion loss of 8 dB. Performance is ultimately limited by combining the receiver and transmitter paths in a 3-dB waveguide hybrid coupler with about 28-dB isolation. High isolation is required of the hybrid coupler to achieve good system sensitivity because of transmitter phase noise leakage that degrades receiver performance. The High Frequency Structure Simulator (HFSS) electromagnetic (EM) simulation software from ANSYS (www.ansys.com) was used to simulate and optimize the hybrid coupler.

Silicon waveguide structures for the transceiver array were fabricated at JPL's Micro-Devices Lab using a multi-etch-depth, deep-reactive-ion-etching (DRIE) silicon micromachining process. A tiered hard mask was employed to define all of the circuit patterns prior to silicon etching, thus avoiding spinning photoresist across a silicon wafer, as well as minimizing pits and over-etched channels in the wafer. Deep waveguide trenches were formed in an 800-μm-thick silicon wafer, with through-wafer waveguides etched from both sides of the wafer to minimize surface roughness and loss.

Experiments using a single pixel of the array have provided effective imaging of concealed weapons, even when concealed beneath thick leather jackets. See "A Silicon Micromachined Eight-Pixel Transceiver Array for Submillimeter-Wave Radar," *IEEE Transactions on Terahertz Science and Technology*, Vol. 5, No. 2, March, 2015, p. 197.

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LAA: LTE and Wi-Fi Coexistence or Convergence?

To meet future service requirements, researchers are exploring new technology solutions to share unlicensed spectrum.

Using cellular and Wi-Fi together in a mobile device has now become an expectation. Not only should they work together, but they should be enabled to work together seamlessly at the switch of a button. LTE and Wi-Fi have coexisted and been complementary for years, but researchers have recently proposed new LTE and Wi-Fi coexistence technologies to enhance the user's mobile data experience. As demand for mobile data access continues to escalate, these technologies will likely be commercialized and deployed in the near future.

LTE and Wi-Fi coexistence technologies share a common premise—using an LTE air interface in the 5-GHz unlicensed band. Cellular service providers have exclusive rights to operate networks in spectrum they purchased (in some cases for billions of dollars/euros). Wi-Fi is deployed in the 2.4- or 5-GHz (U-NII-1 and U-NII-3)[1] unlicensed bands available to anyone as long as users follow the laws that govern the spectrum.

While sharing the spectrum is an opportunity, it also presents many challenges. Thus, multiple proposals are being considered for standardization.

WHAT DOES IT MEAN TO "COEXIST"?

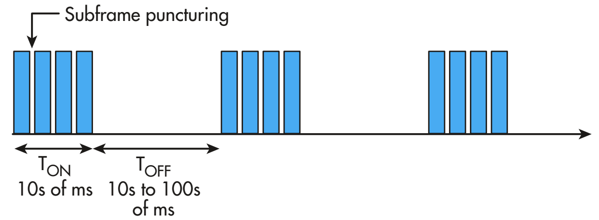
Two LTE/Wi-Fi coexistence technologies of note include LTE-Unlicensed (LTE-U) and Licensed Authorized Access (LAA). The LTE-U standard is driven by Alcatel-Lucent, Ericsson, LG Electronics, and Qualcomm Technologies Inc., who comprise the membership of the LTE-U Forum[2]—an organization committed to the adoption and proliferation of the LTE-U standard. LAA is a variation of LTE-U going through 3rd Generation Partnership Program (3GPP) standardization for inclusion in 3GPP Release 13 (March 2016).

Both LTE-U and LAA likely will be commercialized and deployed. At issue is the question of "coexistence": What does it mean to share spectrum fairly? Both LTE-U and LAA have mechanisms in place to enable sharing with Wi-Fi devices, but the actual impact will likely not be fully understood until more testing is conducted and after the first deployments.

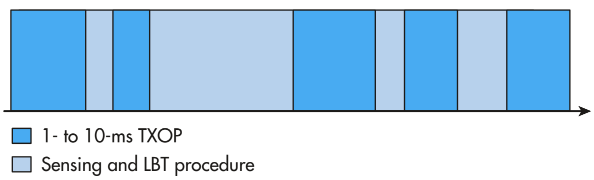
DATA SHARING—ANOTHER DIMENSION

Cellular and Wi-Fi have coexisted for over a decade, with each standard and implementation fulfilling a unique set of needs. Simply put, cellular (LTE) provides mobility and Wi-Fi addresses localized high data-rate access. In fact, cellular devices utilizing Wi-Fi offloading shouldered 55% of all mobile traffic in 2015.[3]

So, how is LTE-U/LAA different from cellular/Wi-Fi offloading? For the cellular data user, the impact is tangible. In geographic regions where Wi-Fi is not present, service operators can offer LTE over 5-GHz bands to double or triple the mobile data user experience. In your own home or a brick-



1. The LTE-U waveform has a T_{ON}- and T_{OFF}-controlled duty cycle.



2. LAA senses use of listen-before-talk (LBT), and then transmits for a predetermined amount of time.

and-mortar office building, the benefits of LTE-U/LAA are less clear. In both of these cases, the Wi-Fi access point will be known and Wi-Fi offloading can occur seamlessly.

LTE-U

LTE-U utilizes the LTE-Advanced carrier aggregation (CA) framework adopted in 3GPP Release 10, where the data streams are independent and aggregated outside the communication protocol stack. As in CA, LTE-U extends the concept of a primary or anchor cell, and one or more "data" or "secondary serving cells" (SSCs). LTE-U proposes the unlicensed band be added as a SSC used for downlink while the primary cell connection would be reserved for control and uplink.

Sharing in the unlicensed band is achieved through a carrier-sense adaptive transmission (CSAT)[4] approach. In CSAT, the Wi-Fi band is monitored over time to assess traffic patterns. This allows dynamic channel selection and adaption of the transmit duty cycle to minimize impact to incumbent devices operating in the 5-GHz band *(Fig. 1)*. Early rollout of LTE-U, as it is defined today, will be limited to countries that permit CSAT in unlicensed bands.

LAA (DOWNLINK ONLY)

As part of 3GPP Release 13,[5] LAA adopts the LTE-U CA approach. However, the channel access approach is much closer to the Wi-Fi implementation that uses a listen-before-talk (LBT) method, which is called carrier-sense multiple access with collision avoidance (CSMA/CA).

LBT ensures global compliance and should facilitate a global roll-out without changes in the regulation for unlicensed bands. Various options were considered for detection, with the result being a Wi-Fi-like system with an initial defer period and exponential back-off. An example waveform is shown *(Fig. 2)*, in which the LBT procedure is used based on energy detection to sense the channel and determine transmit opportunities (TXOP) for as many as 10 LTE subframes.

It should be noted that LTE-U and LAA include uplink and downlink. However, 3GPP Release 13 only includes LAA downlink, while uplink is scheduled to be considered for Release 14.

IS "FAIR" COEXISTENCE REALISTIC?

Assigning a common definition to the term "fair" has presented challenges. Experimental results so far have typically been directly aligned to the business interests of the publishing research group. Chip and infrastructure vendors have produced results supporting LTE-U, while Wi-Fi and cable providers generally found the technology to be problematic or inconclusive at best.

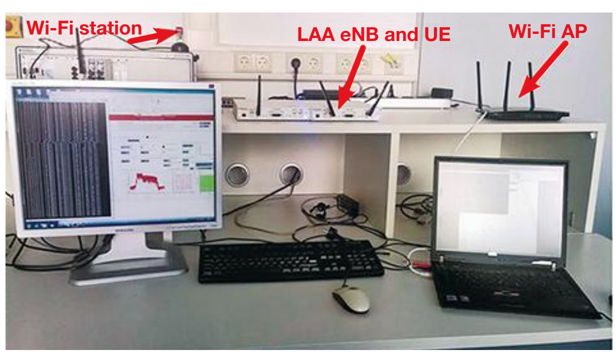
The two most debated challenges with coexistence include:

- The ability for legacy devices in the unlicensed bands to detect a free channel.
- The ability for LAA implementations to detect and avoid conflicts with the right level of aggressiveness (often tuned through energy-level threshold and backoff).

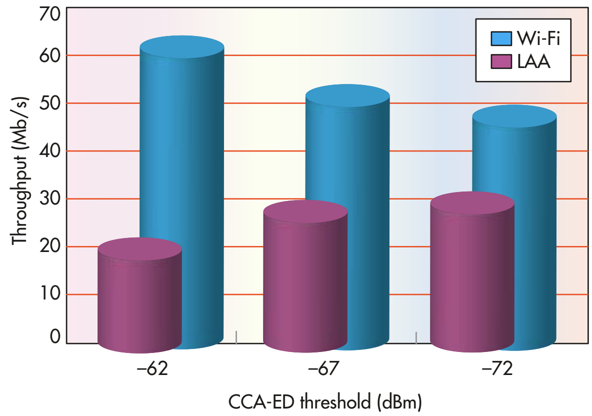
The proponents of LTE-U have shown results indicating the deployment of these networks do not significantly degrade Wi-Fi network performance.[6] However, papers like that in ref. 7 disagree, since LTE-U does not implement LBT mechanisms (such as CSMA/CA with defer period and exponential back-off as in Wi-Fi), as they believe it is critical to fair sharing of unlicensed channels.

Some regulatory regimes, such as those in Europe and Japan, require LBT in unlicensed bands. Therefore, LTE-U cannot be deployed in those regions. Due to the controversial nature of LTE-U, regulators like the FCC in the U.S., where LTE-U can be deployed without LBT, are reviewing input from the ecosystem and evaluating if further regulation is needed.[8]

Wi-Fi providers have indicated a preference for LAA over LTE-U because they can participate in the open standards process. In addition, they expect LBT design to be critical to achieve good coexistence performance.



3. The photo shows the National Instruments LTE/Wi-Fi Coexistence Test bed.



4. Throughput for Wi-Fi 802.11ac VHT40 and LAA with LBT cat 4 is shown for varying LAA CCA energy-detection thresholds.

TESTING SCENARIOS

As with any new technology, prototyping using a realistic testbed is the optimal way to truly understand the various performance tradeoffs. Given the complexity and closed nature of Wi-Fi and LTE chipsets, most trials and research up to this point have been conducted by the vendors of the devices themselves.

NI has also introduced a neutral, modifiable prototyping platform *(Fig. 3)* that is based on software-defined radio (SDR). This platform enables researchers to evaluate and compare performance tradeoffs of such algorithms in realistic environments.[9] The real-time LTE physical layer (PHY) and real-time Wi-Fi PHY can be modified in the LabVIEW Communications System Design environment to evaluate over-the-air performance of both LAA and LTE-U scenarios.

LAA experimentation requires adaptation of the standard LTE protocol for several reasons:

- Operation at a new center frequency (typically the 5-GHz Wi-Fi band).
- Enhanced PHY to incorporate discontinuous transmission (DTX).
- Enhanced PHY to incorporate listen before talk (LBT, Category 4). In the case of LTE-U, LBT is replaced by duty cycling and puncturing imposed on the LTE frame structure at the resolution of LTE subframes. Discontinuous transmission can be done to include support for LTE-U patterns.

TESTING RESULTS

The NI LTE/Wi-Fi Coexistence Testbed with LAA adaptations to the LTE PHY was used in conjunction with an off-the-shelf Wi-Fi access point. Throughput of a Wi-Fi 802.11ac waveform running in "Very High Throughput—40 MHz bandwidth mode (VHT40)" and LAA LBT Cat 4 system was analyzed with varying carrier-sensing energy-detection threshold values. Both the Wi-Fi 802.11ac access point and the LAA node observe one another with a received signal strength indicator (RSSI) of around –67 dBm *(Fig. 4)*. More experiments and results can be found in 3GPP contributions.[10,11]

CONCLUSION

It was largely believed that 4G would make Wi-Fi offloading obsolete. However, it has only increased due to higher-consumption devices and cell-phone plan data-usage fees.[1] The pivot toward LTE/Wi-Fi coexistence seems imminent, given the influence that infrastructure providers and chip vendors have in the industry. While LTE on unlicensed bands may help improve service in some scenarios, future proposals may further push LTE into unlicensed bands directly competing with Wi-Fi in other cases.

With all of these technologies, the details of the implementation will significantly impact the gains experienced in practice. As with a majority of new wireless technologies, rapid prototyping and field trials are needed to evaluate usage scenarios and maximize the user experience for both the LTE user and the incumbents.

While the field trials conducted so far have not disqualified the concept, they have not created overwhelming evidence to favor any approach. More neutral research is needed to explore how incumbent Wi-Fi devices are affected, and how this impacts other devices and scenarios in heterogeneous networks that continue to increase in density and complexity.

The first large-scale demonstrations of 5G are being aligned to the 2018 and 2020 Olympic Games. Hopefully, though, we will not have to wait that long to benefit from the enhancements brought by 3GPP Release 13, often labeled 4.5G, to be rolled out into base stations and our smart devices. mw

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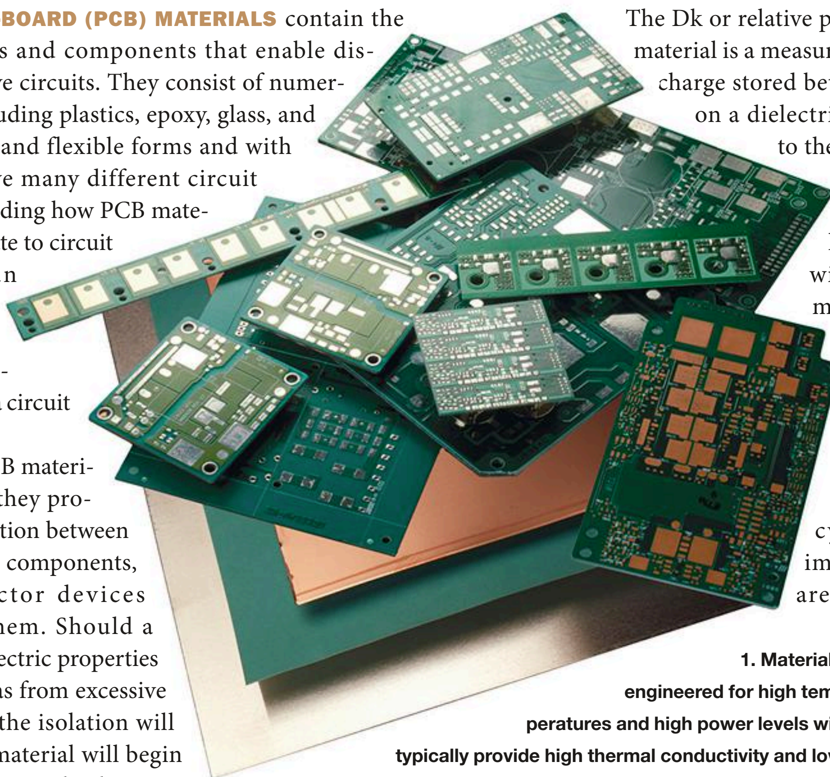
JACK BROWNE | Technical Contributor

What Substrate Material Best Fits Your High-Speed Circuits?

Sorting through the specifications helps when selecting a circuit material for microwave, millimeter-wave, and even high-speed-digital circuits.

PRINTED-CIRCUIT-BOARD (PCB) MATERIALS contain the transmission lines and components that enable discrete RF/microwave circuits. They consist of numerous materials, including plastics, epoxy, glass, and ceramics, in rigid and flexible forms and with qualities that serve many different circuit designs. Understanding how PCB material parameters relate to circuit performance can simplify the task of matching a PCB material to an application as well as to a circuit fabrication process.

Quite simply, PCB materials are insulators; they provide electrical isolation between transmission lines, components, and semiconductor devices mounted upon them. Should a PCB material's dielectric properties break down, such as from excessive power or voltage, the isolation will diminish and the material will begin to conduct electricity, to the detriment of the attached components.



1. Materials engineered for high temperatures and high power levels will typically provide high thermal conductivity and low thermal resistance. *(Courtesy of Laird Technologies)*

DETERMINING DIELECTRIC CONSTANT

PCB materials are commercially available in many formulations at numerous performance levels, with the most usual tradeoff being between price and performance. A large number of parameters describe a circuit material's performance, with dielectric constant (ε_r or Dk) probably the most popular starting point when comparing materials.

The Dk or relative permittivity of a circuit material is a measure of the capacitance or charge stored between two conductors on a dielectric material, compared to the same two conductors in a vacuum. Higher Dk values relate to higher flux densities, with the dimensions of microwave transmission lines (e.g., microstrip) diminishing with the increasing values of Dk for a particular frequency.

For a given frequency and characteristic impedance, conductors are wider for materials with lower Dk values, yielding less loss. The circuits on lower-Dk materials will have larger dimensions, but this may also mean higher yields for a particular circuit manufacturing process—all tradeoffs to consider when choosing a PCB material.

The dielectric constant of a vacuum, at 1.0, serves as the reference for other dielectric materials, such as Teflon with a dielectric constant of 2.1. Lower-Dk materials like Teflon or polytetrafluroethylene (PTFE) have often been used in RF/microwave circuits. However, the range of Dk values for high-frequency circuit materials is quite wide, from below 2.1 to

> **"Understanding how PCB material parameters relate to circuit performance can simplify the task of matching a PCB to an application as well as to a circuit fabrication process."**

above 10.0, for miniaturizing lower-frequency circuits with longer wavelengths.

The dielectric constant of PCB materials will vary with humidity and temperature. Since water has a high Dk value of about 80, any material that absorbs water in a high-humidity environment will exhibit an increase in Dk, resulting in a change in high-frequency circuit performance. Changes in ambient temperature or from heat generated by high-power circuit components can also affect Dk, characterized by a parameter known as thermal coefficient of Dk (TCDk). For stable circuit performance, lower values are preferred, over the widest operating-temperature ranges possible.

Another important material parameter related to temperature is coefficient of thermal expansion (CTE), a measure of how a material changes mechanically with temperature. Such changes are unavoidable, but ideally should be as close in value to other materials, such as copper conductors, integrated with the PCB material to minimize temperature-related stress. In automotive electronic applications, for example, where operating temperatures can cover a wide range, consideration should be given to both TCDk and CTE.

PCB materials can be specified in many sizes, thicknesses, and dielectric constants. Materials suppliers may characterize their materials in terms of dielectric constant in the z-axis (thickness of the material) and/or in the x-y plane (length and width of the material), and typically at a particular test frequency, such as 1 or 10 GHz. For circuit designs requiring channels that are closely matched in phase and/or amplitude, or otherwise needing tight performance tolerances, PCB materials can also be specified with varying degrees of ε_r tolerance across a circuit board. This helps minimize the performance variations in the transmission lines and other circuit structures fabricated on those circuit boards.

Dissipation factor (Df) or loss tangent serves as a means of comparing loss characteristics for different PCB material. It is usually determined through the thickness or z-axis of the material, and at different frequencies and ambient temperatures. Dissipation factor represents a function of frequency and rises with increasing frequency; lower values represent lower loss characteristics.

Certain types of general-purpose circuit materials, such as flame-retardant FR-4 glass-reinforced epoxy laminate or G-10 glass/epoxy composite materials, have long served a variety of analog and digital circuit applications. That's because they have simple processing requirements compared to softer materials such as PTFE. Drilling and plating holes with metal conductors, as required for plated throughholes (PTHs) in multilayer circuits, can be more complex (and costly) in such softer materials. Thus, manufacturing ease is another factor to consider when selecting a circuit material.

HANDLING THE HEAT

Above certain power levels, heat will generate and higher temperatures will occur at thermal mismatch points or at junctions, such as where a packaged component is mounted on a PCB. A PCB must be able to efficiently dissipate heat to avoid thermal stress on the material and its transmission lines and components.

Circuit materials developed for high power levels are typically low-loss laminates that might include metal backing and PTHs through the dielectric layer to facilitate thermal flow from top conductor layers to the bottom ground plane in a microstrip circuit. Additional components, such as heat sinks, can be used to enhance thermal management of high-power circuit boards, but these will also add size, weight, and cost to a design.

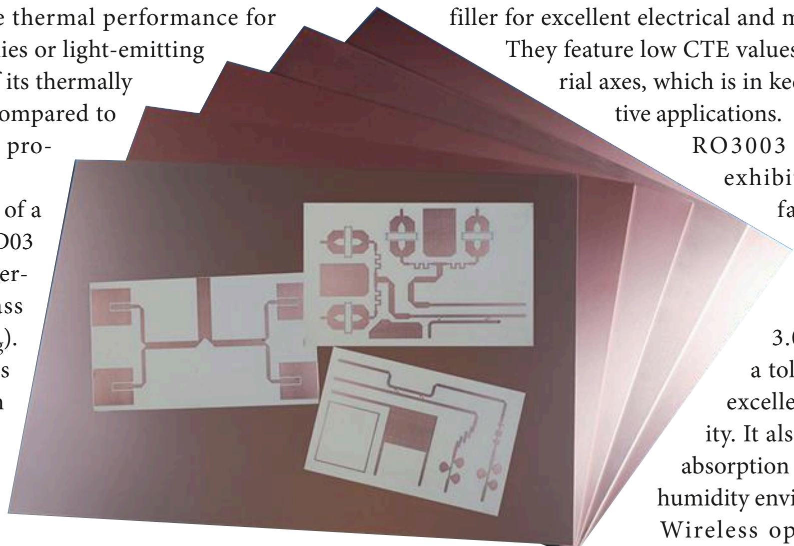
The thermal properties of a PCB material will define the limits of the material's power-handling capabilities, since high power levels generally mean high circuit temperatures. The heat may come from an applied power source, from the environment, or from a component mounted on the circuit board, such as a high-power transistor in an amplifier.

The most reliable PCBs can channel the thermal energy without damaging the circuitry or board material. This ability is summarized by a PCB's thermal conductivity, with higher values denoting lower resistance to the flow of heat. Thermal conductivity is essentially a measure of a material's rate of loss of energy as heat. Higher values of thermal conductivity translate into higher power-handling capabilities for PCB materials.

Electrical conductors, such as those formed of copper, exhibit high thermal conductivity compared to dielectric materials. However, some dielectric materials are formulated with fillers that enhance their thermal conductivity. Such differences in thermal resistance of the materials making up a PCB can lead to hot spots on a circuit board, where heat flows easily through copper conductors, but not through the surrounding dielectric material. For that reason, higher-power applications typically require circuit materials with higher values of thermal conductivity for better power handling and better heat dissipation.

As a lower-frequency example, the thermal conductivity of standard FR-4 material is typically around 0.30 W/mK, a relatively low value that warns of potential circuit hotspots at higher power levels. This value is a fraction of the thermal conductivity exhibited by a material engineered for higher-power use.

For instance, Tlam SS HTD03 thermally conductive PCB materials from Laird Technologies (www.lairdtech.com) possess a thermal conductivity of 2.2 W/mK and low thermal resistance of 0.049°C-in.^{2}/W for good heat flow *(Fig. 1)*. They consist of a copper circuit layer with high-temperature-rated dielectric material and copper or aluminum baseplate to enhance the thermal performance for circuits with power supplies or light-emitting diodes (LEDs). In spite of its thermally enhanced performance compared to standard FR-4, it can be processed in the same way.



2. Higher-performance circuit materials with extremely stable Dk characteristics will be needed for emerging millimeter-wave and high-speed-digital circuits. *(Courtesy of Rogers Corp.)*

The dielectric material of a PCB such as Tlam SS HTD03 is judged as a high-temperature material by its glass transition temperature (T_g). This parameter indicates the temperature at which a material changes from a harder state to a softer, more molten state. It is typically used to determine if a material is suitable for higher-temperature manufacturing methods, such as lead-free-solder assembly processes. Standard T_g values are typically +125°C, while higher-T_g materials have a T_g of about +145°C. T_g refers to a short-term maximum temperature and should not be considered as a top temperature for continuous use.

A safer PCB upper-temperature limit being considered for high-temperature, higher-power use is the maximum operating temperature (MOT), a parameter established by Underwriters Laboratories (UL). It refers to the maximum temperature at which a PCB can be used indefinitely without significant degradation in performance. Once a PCB is used above its rated MOT, performance can degrade and reliability may be compromised. The MOT refers to temperature and does not consider the added effects of handling high power levels and possible degradation of dielectric properties.

DELIVERING DIGITAL SPEED

Many different rigid and flexible circuit materials, with a wide range of Dk values, are available from numerous suppliers for narrowband and broadband RF/microwave circuit applications. Specifiers typically weigh performance against cost and manufacturability when selecting a material for an application, although that selection process may become more challenging with emerging applications.

For example, automotive manufacturers are increasingly offering collision-warning/avoidance systems based on millimeter-wave radar techniques. These systems require that PCB materials be capable of low-loss performance to 70 GHz and beyond, such as RO3003 circuit materials from Rogers Corp. *(Fig. 2)*.

These PTFE-based materials are fortified with ceramic filler for excellent electrical and mechanical stability. They feature low CTE values for all three material axes, which is in keeping with automotive applications.

RO3003 circuit material exhibits low dissipation factor in the z-axis (0.0010 at 10 GHz). Its dielectric constant of 3.00 is controlled to a tolerance of ±0.04 for excellent electrical stability. It also has low moisture absorption for stability in high-humidity environments.

Wireless operating frequencies are expected to skyrocket with the development of Fifth-Generation (5G) cellular communications systems, requiring cost-effective circuit materials for use at millimeter-wave frequencies (above 30 GHz). The same properties that qualify a PCB material for millimeter-wave circuits also make it suitable for high-speed digital circuits. Conversely, the excessive loss of low-cost materials such as FR-4 results in serious degradation of performance for both millimeter-wave and high-speed-digital circuits.

Circuit materials capable of high-speed-digital operation must handle signals rich in harmonic content. When the harmonic signal components of a digital signal at 10 Gb/s are considered, with third,-, fifth-, and seventh-harmonic signal components, circuit material requirements are in the same range when handling, say, analog millimeter-wave signals.

To maintain the signal integrity of input signals, a circuit must faithfully reproduce all of its essential harmonic components without distortion. In particular, material parameters related to consistency of Dk, such as TCDk, will provide insight into the material's capability to maintain transmission lines with consistence impedance characteristics—a vital factor when trying to achieve high signal integrity in high-speed digital circuits.

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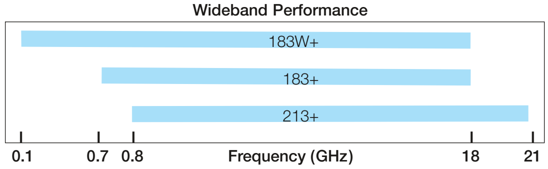
Wideband Performance



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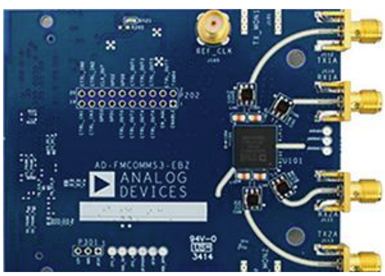
Summarizing Advances in SDR Technology

Widespread adoption of SDR technology continues throughout many markets as key mixed-signal and digital components improve in performance, even as they shrink in size and power consumption.

SOFTWARE MAY BE what defines the functionality of a software-defined radio (SDR), but hardware is still a critical part of the radio—whether it is in a smart cellular phone or a tactical radio for military use. The software can only achieve the performance levels made possible by the essential hardware components within the radio, including analog-to-digital converters (ADCs), digital-to-analog converters (DACs), field-programmable gate arrays (FPGAs), and integrated-circuit (IC) radios.

In its simplest form, an SDR feeds incoming signals from an antenna to an ADC to be digitized and passed along to a digital baseband processor. For the transmit function, data from the baseband processor is passed to the DAC and converted to analog voltages for transmission over the same antenna. But digital and mixed-signal components can only carry part of the lead in an SDR design. Additional analog components (such as amplifiers, filters, and limiters) are needed to achieve an acceptable dynamic range for real-world signals, which they achieve by generating high-enough input levels to the ADC and output levels from the DAC.



1. The AD-FMCOMMS3-EBZ is an SDR demonstration module and reference design using the AD9361 direct-conversion transceiver IC. *(Photo courtesy of Analog Devices)*

A continuing trend in the design and development of radio ICs for SDR applications is to include as many component functions as practical within a single IC, housed within a single multipin package. Such functions include analog upconversion and downconversion of frequencies, achieved by means of frequency mixers and local oscillators (LOs). The integration within a single IC simplifies the circuit-level SDR block diagram while shrinking the size of the radio hardware. Whether in discrete or integrated forms, these component functions are critical for SDR performance. As the data converters, FPGAs, and other components improve in performance, they enable improved performance from final SDR circuit boards and products.

As the model AD9361 transceiver IC from Analog Devices (www.analog.com) demonstrates, direct-conversion techniques help to simplify the amount of RF/microwave circuitry added to the data converters in a radio IC for SDR use, while also supporting wide bandwidths. Nominally developed for cellular-radio base stations, this device operates from 70 MHz to 6.0 GHz with channel bandwidths from 200 kHz to 56 MHz for flexibility. The radio's RF/microwave front end works with a mixed-signal baseband processor to enable a straightforward interface to a programmable digital processor.

The device actually contains two independent direct-conversion receivers with on-board LOs and phase-locked loops (PLLs) for processing digital modulation formats based on in-phase (I) and quadrature (Q) signal components. By changing sample rate, digital filters, and decimation, the radio IC can change channel bandwidths according to software programming. While not a complete SDR system on a chip (SoC) device, it is a flexible integrated starting point for SDR circuit-level designers, given the wide bandwidths and modulation versatility. The AD9361 is supplied in a 144-ball chip-scale package (CSP) measuring 10 × 10 mm.

For those who would prefer to get a head start on the SDR design process, Analog Devices also offers its model AD-FMCOMMS3-EBZ demonstration module and reference design, based on the AD9361 transceiver IC (*Fig. 1*). The module allows designers to quickly measure waveforms from the IC based on programming code.

The AD-FMCOMMS3-EBZ module is also available as part of the ZedBoard SDR design kit from Avnet (www.avnet.com), which incorporates the programmable Zynq-7020 SoC with integral FPGA from Xilinx (www.xilinx.com). The Zynq-7020 might be described as the combination of a microprocessor and an FPGA, providing two essential SDR functions in one pack-

2. The bladeRF transmit/receive module is a board-level SDR that operates from 300 MHz to 3.8 GHz. *(Photo courtesy of Nuand)*

aged IC, in keeping with a trend of increasing integration of components for SDRs.

The ZedBoard SDR circuitry can be programmed by means of Vivado design software from Xilinx or by using software from one of the firm's SDR reference designs; at least one of these adapts Long-Term-Evolution (LTE) standards for public-safety radios. Software for the SDR radio kit can run on numerous operating systems.

Texas Instruments (www.ti.com) also offers an SDR design kit, its TIDEPOO40 SDR reference design. Incorporating the firm's OMAP-L138 dual-core microprocessor and a Spartan 6 FPGA from Xilinx, this SDR hardware/software reference design includes source design files and a complete bill of materials (BOM) for rapid entry in the development of an SDR. The reference design is based on the MityDSP-L138F system on module (SOM) from Critical Link LLC (www.criticallink.com) and includes ARM-based graphical-user-interface (GUI) software, along with sample microprocessor software.

3. For those who need only receive functionality, the Airspy One series of SDRs offer continuous coverage from 24 to 1,800 MHz. *(Photo courtesy of Airspy)*

BUILDING A RADIO

Commercial SDR designers often employ a practical blend of ICs and discrete components, enabling them to choose component function blocks (such as FPGAs and microprocessors) with the best possible performance for their particular set of design goals. Commercial board-level SDRs like the Universal Software Radio Peripheral (USRP) B200mini Series of business-card-sized radios from Ettus Research, a National Instruments Co. (www.ettus.com), provide a good example of how available mixed-signal and digital IC components can be combined.

The compact board incorporates a model AD9364 transceiver IC from Analog Devices for front-end functions, with a Spartan-6 FPGA from Xilinx for programmability. The AD9364 matches the 70-MHz-to-6-GHz total frequency range and bandwidths of the AD9361 radio IC, with one on-chip direct-conversion receiver rather than the two receivers in the AD9361. The miniature SDR, with instantaneous bandwidth of 56 MHz, draws power from a high-speed USB 3.0 connection for streaming data to a host computer. It is meant as a building block for larger radio designs and can be synchronized with a standard 10-MHz clock reference source or pulse-per-second (PPS) time reference signal.

Another design example for SDR experimenters is the bladeRF transmit/receive board *(Fig. 2)* from Nuand (www.nuand.com), with a frequency range of 300 MHz to 3.8 GHz. The SDR module measures 5.0 × 3.5 in. with gold-plated SMA connectors. It performs independent receive/transmit sampling with the aid of a 12-b, 40-MSamples/s ADC and 16-b DAC. It also includes a general-purpose microprocessor with on-board memory as well as an FPGA from Altera (www.altera.com) for flexible programming.

The board can be configured for 2 × 2 multiple-input, multiple-output (MIMO) antenna systems and expanded for 4 × 4 MIMO systems. The SDR board is also capable of operating as a spectrum analyzer, vector signal analyzer, and vector signal generator. It features support for Windows, Mac OS, and Linux operating systems and is powered via USB 3.0 port.

For those only concerned with SDR receive functions, the Airspy One series of SDR receivers *(Fig. 3)* from Airspy (www.airspy.com) provide continuous coverage from 24 to 1,800 MHz with 10-MHz instantaneous bandwidth, including the use of tracking RF filters to reduce noise levels. It incorporates 12-b analog to digital conversion at 20 MSamples/s.

Developing control software for an SDR is obviously as important as finding the optimum blend of hardware, and software simulation tools such as MATLAB and SIMULINK from The MathWorks (www.mathworks.com) can provide modeling tools for determining the parameters to program an SDR's digital components, such as its FPGAs. Software is developed according to the Software Communications Architecture (SCA) standard derived from the early work of the U.S. military's Joint Tactical Radio System (JTRS) efforts to develop a universal radio platform for all of its branches.

One challenge facing all component developers for SDRs lies in meeting higher performance goals with lower power consumption, since the majority of SDRs will be powered by batteries, and power-hungry components can drain a radio's battery quickly. Solutions continue to be found by means of dense circuitry within compact ICs, fabricated with semiconductor processes capable of ever-smaller feature sizes.

SDR technology is certainly no longer novel, and many of the semiconductor component suppliers addressing this market are making great strides in providing higher-performance, lower-power devices to meet next-generation SDR requirements. mw

Design Feature

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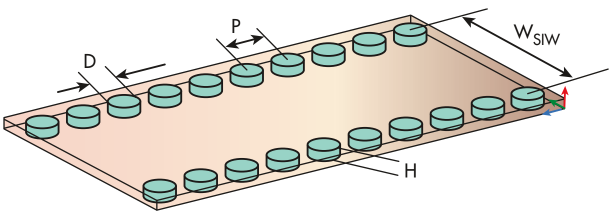
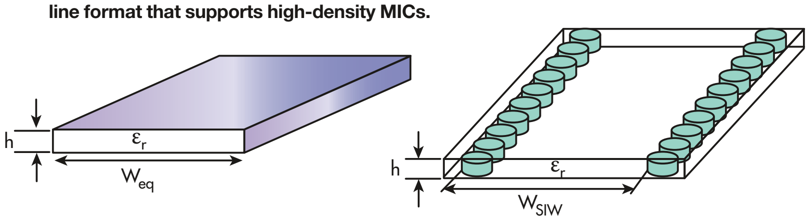
Fabricate C-Band

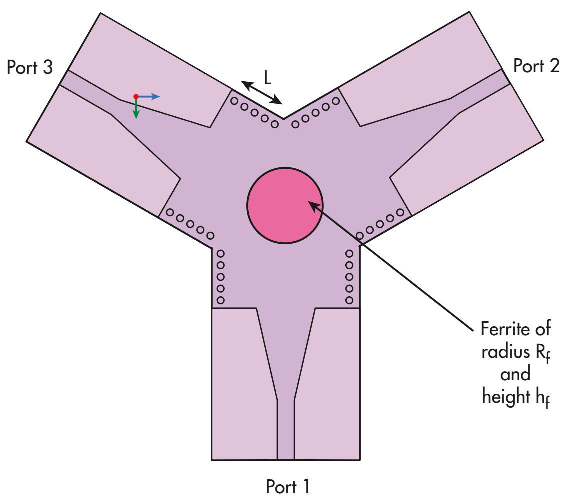
Rectangular substrate integrated waveguide is a transmission-line format that supports planar circuits capable of operating to microwave and millimeter-wave frequencies.



1. Rectangular substrate integrated waveguide (RSIW) is a transmission-line format that supports high-density MICs.



2. This is a comparison of RSIW with the structure for equivalent conventional rectangular waveguide.



3. The RSIW circulator was designed with a length (L) of 10.5 mm for use from 4.0 to 6.5 GHz.

Substrate integrated waveguide (SIW) is a high-frequency transmission line that can provide excellent high-frequency performance on low-dielectric-constant substrate materials. To demonstrate the effectiveness of the technology, rectangular SIW (RSIW) was utilized to design and fabricate a SIW power divider, circulator, and coupler for use at frequencies from 4.0 to 6.5 GHz. In SIW, these components are readily implemented as planar circuits, with measured results of prototype circuits that agree closely with computer simulations.

RSIW technology is usable through millimeter-wave frequencies and can be integrated with other planar circuits and transmission-line technologies. Compared to conventional waveguide technology at higher frequencies, RSIW can be used to fabricate a wide range of components with conventional printed-circuit-board (PCB) materials and processes to significantly reduce costs for many applications.[1]

RSIW COMPONENTS

In exploring the capabilities of RSIW technology, a number of components were modeled with High-Frequency Structure Simulator (HFSS) three-dimensional (3D) electromagnetic (EM) simulation software from ANSYS (www.ansys.com). They were then fabricated to compare measured and simulated performance. The results match quite closely in the frequency band of interest from 4.0 to 6.5 GHz.

RSIW transmission line is essentially a type of rectangular dielectric-filled waveguide that is fabricated on a planar dielectric substrate. It incorporates arrays of conductive metal via holes to realize bilateral edge walls that enable transverse-electromagnetic (TE) propagation in all different TE_{n0} modes. Integrated transitions can be formed on an RSIW substrate for

Components with Rectangular SIW

connection to other high-frequency planar structures, such as those formed with microstrip transmission lines.

RSIW components are covered by metal surfaces on both sides of the substrate, which contributes to low insertion loss, low radiation loss, and insensitivity to outside interference.[1,2] The electrical behavior of RSIW *(Fig. 1)* is similar to that of a conventional rectangular waveguide filled with dielectric of width W_{eq}.[3]

TABLE 1: COMPARING PARAMETERS FOR CLASSIC WAVEGUIDE, EXTRACTED EQUIVALENT, AND RSIW

Classic waveguide	Equivalent waveguide	RSIW
a = 43.96 mm	h = 1.5 mm, ε_r = 4.3	h = 1.5 mm, ε_r = 4.3
b = 21.98 mm, ε_r = 1	ε_r = 4.3 W_{eq} = 21.2 mm	d = 1 mm p = 2 mm W_{SIW} = 21.8 mm

TABLE 2: KEY PARAMETERS FOR THE SIW POWER DIVIDER

Parameter	Value
L_T	15.7 mm
W_T	9.4 mm
W_{mst}	2.73 mm
L	27 mm

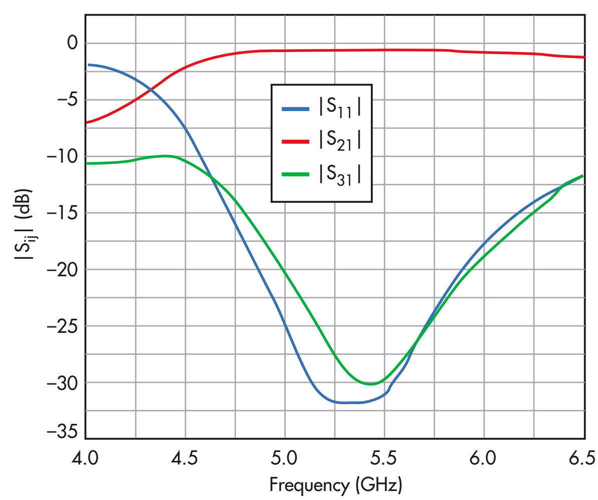
The experimental RSIW 4.0- to 6.5-GHz components employed the parameters listed in *Table 1* in comparison to conventional waveguide *(Fig. 2)*. Via-hole dimensions were obtained from closed-form expressions described in refs. 1 and 2.

The ANSYS HFSS EM simulation software[4] was used for EM field analysis of the RSIW transmission lines and the different component structures. The software made it possible to show the similarity of the EM field distribution of the TE_{10} propagation mode in the RSIW circuits and conventional waveguide technology applied to the same components and frequencies. To provide an interface to measurement equipment for analysis, tapers from RSIW to microstrip were designed, with parameters listed in *Table 2*.[6]

SIMULATION RESULTS

The three components designed for evaluating RSIW technology were a circulator, power divider, and a coupler, all for operation from 4.0 to 6.5 GHz. The circulator was designed based on guidelines presented in refs. 2-5 *(Fig. 3)*. As *Fig. 4* shows, for more than 26.78% of the frequency band, the return loss (S_{11}) is better than 15 dB while the maximum insertion loss (S_{21}) is in the range of 0.54 dB. The isolation between ports (S_{31}) is 30.16 dB.

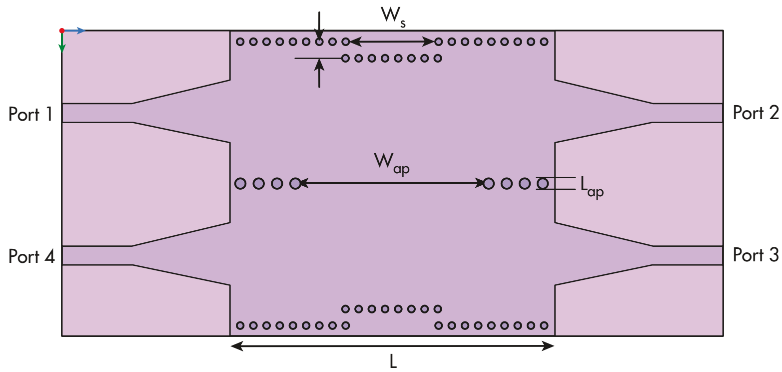
The parameters listed in Tables 1 and 2 were also applied to the design and fabrication of an RSIW power divider, based on guidance from refs. 2-5 *(Fig. 5)*. As shown in *Fig. 6*, the return



4. The plots show the S-parameters for the RSIW circulator from 4.0 to 6.5 GHz.

TABLE 3: KEY PARAMETERS FOR THE SIW DIRECTIONAL COUPLER

Parameter	Value
W_S	49 mm
L_S	14 mm
W_{ap}	2.5 mm
L_{ap}	29.2 mm



7. This diagram illustrates the layout and four ports of the RSIW directional coupler for use from 4.0 to 6.5 GHz.

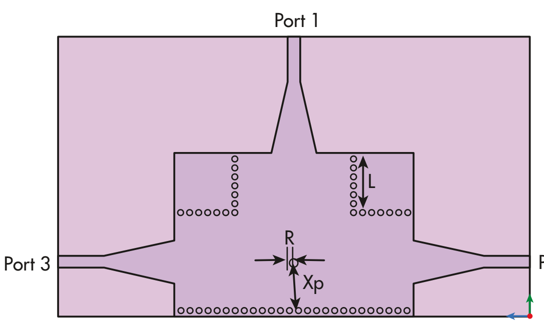
loss (S_{11}) is better than 15 dB between 4.86 and 5.78 GHz, or for more than 17.3% of the total bandwidth. The values of transmission coefficients S_{21} and S_{31} fluctuate between 3.38 and 3.67 dB across the frequency range, although these are acceptable values for a power divider for these two parameters.

The RSIW directional coupler *(Fig. 7)* was designed and simulated with ANSYS HFSS according to the parameters listed in *Table 3* for use from 4.0 to 6.5 GHz and evaluated in terms of return loss, isolation, and bandwidth.[1-5] As *Fig. 8* shows, simulated results predict reflection (S_{11}) and isolation (S_{41}) levels of better than 15 dB for more than 25% of the total bandwidth, with insertion loss (S_{21}) and coupling (S_{31}) both on the order of 3.41 dB.

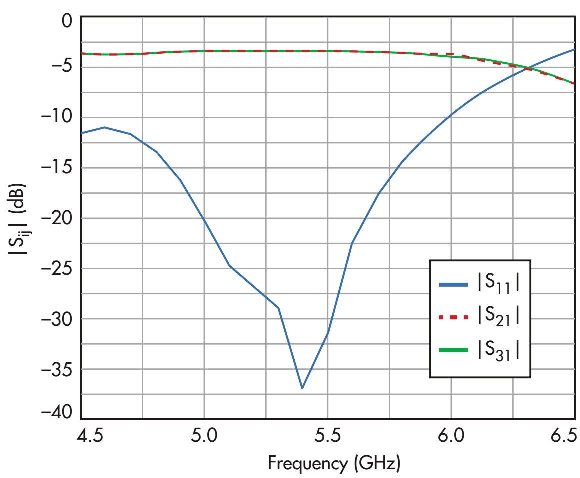
PROTOTYPE VALIDATION

To validate the RSIW technology and the predicted performance levels provided by the EM simulation software, prototypes of the RSIW power divider and directional coupler were fabricated at ECS-Lab EA 3649, ENSEA. The prototype components were characterized using a commercial microwave vector network analyzer (VNA), model E5071C from Agilent Technologies (now Keysight Technologies; www.keysight.com), with a frequency range of 100 kHz to 8.5 GHz.

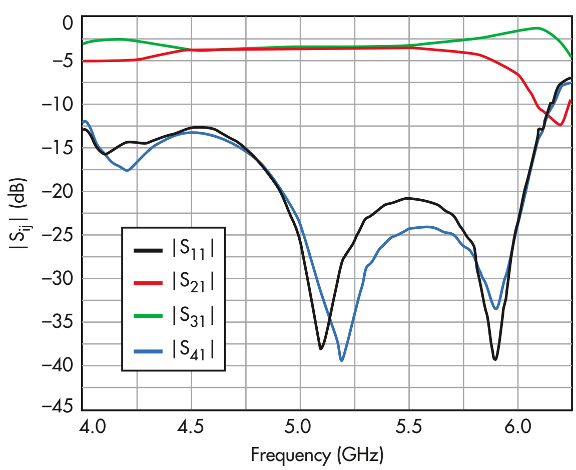
Figures 9 and 10 compare the simulated performance with the measured results for the RSIW power divider and directional coupler, respectively. In reviewing the performance of the power divider, the return loss (S_{11}) is better than 15 dB for a 16% segment of bandwidth from 4.98 to 5.849 GHz. For the S_{21} and S_{31} parameters, the value is about 3.32 dB between 5.0 and 5.74 GHz. This equates to a relative bandwidth of about 14% of the



5. The RSIW power divider was designed with L = 14 mm, r = 0.9 mm, and Xp = 10.5 mm for use from 4.0 to 6.5 GHz.



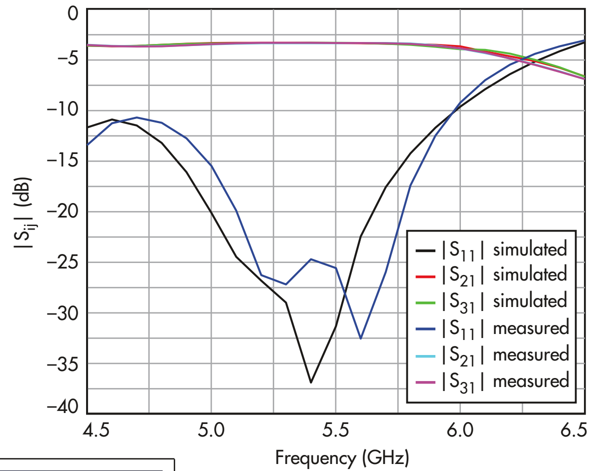
6. The S-parameters of the RSIW power divider are shown with an inductive cylinder.



8. The plots show the frequency response of the RSIW directional coupler from 4.0 to 6.5 GHz.

total measured bandwidth, if amplitude flatness of ±0.3 dB is a qualifying characteristic. This is quite acceptable for such a power divider.

The measured results for the RSIW directional coupler show return loss (S_{11}) of better than 15 dB between 4.739 and 5.500 GHz. This equates to more than 15% of the total bandwidth. The isolation between ports (S_{41}) is on the order of 33.71 dB at 5.10 GHz. Insertion loss (S_{21}) and the coupling (S_{31}) are around 3.41 dB between 4.5 and 5.5 GHz, a 1-GHz range that represents 20% of the total bandwidth.



9. The plots depict the simulated and measured frequency responses of the RSIW power divider.

All in all, the measurements show some differences with the predictions provided by the computer simulations. In general, though, the simulated and measured S-parameters are in fairly good agreement for the two components.

The differences between measured and simulated data may stem from a number of factors, assuming that a simulation can only be as good as the input data used in the simulation. For example, some of the differences in the measured and simulated results may result from substrate conductor losses (or even dielectric losses) that were not included in the simulation. Other factors include an assumed loss tangent that was applied at 10 GHz, which may not have been applied at the lower frequencies of this experiment. In addition, the VNA may not have been properly calibrated, or the calibration may not have been up to date.

To minimize the through and reflected losses in passive components, such as the RSIW power divider and directional coupler, especially with the transitions made to microstrip to facilitate the VNA measurements, the impedance matching must be optimized. In the test setup, the impedance matching must be optimized between the SMA test connector and the directional coupler's microstrip transmission lines. In addition, the taper from the microstrip transmission line is often as reflective as the RSIW component and its own transmission lines, and can significantly degrade the VNA measurement results.

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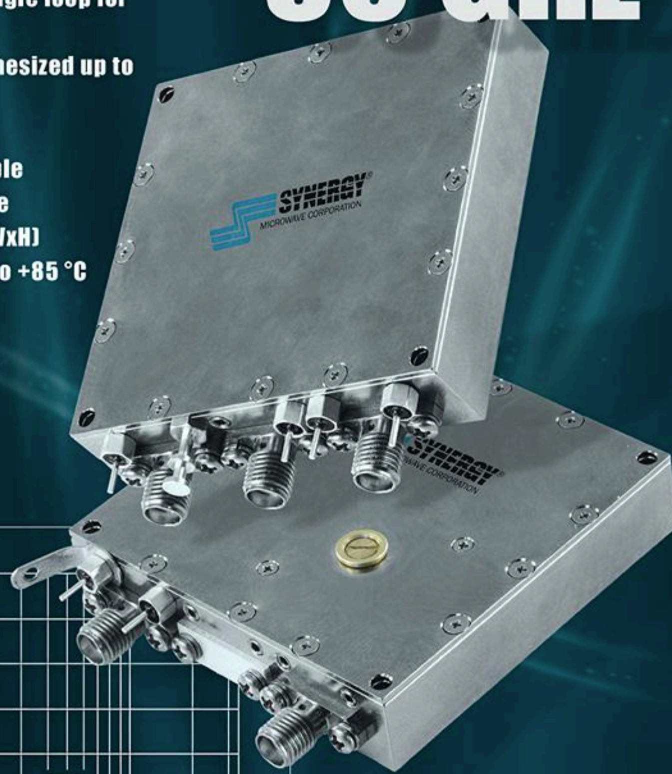

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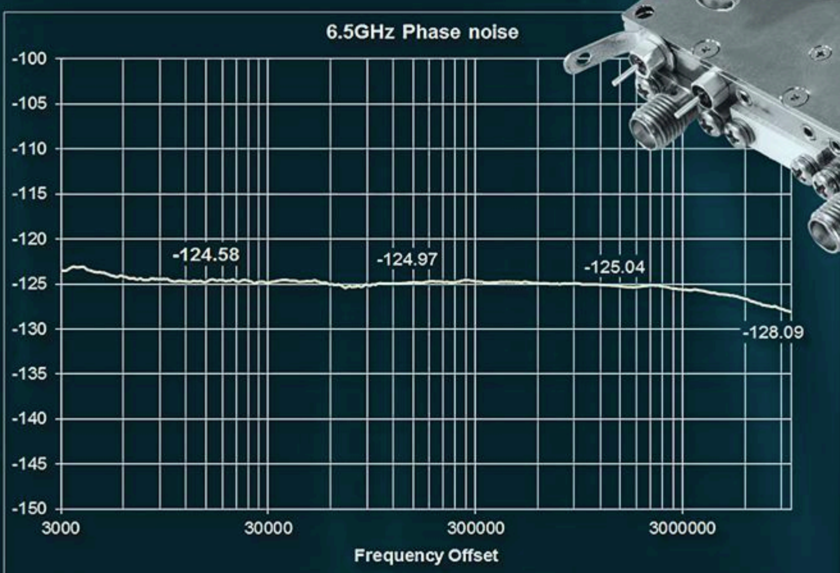

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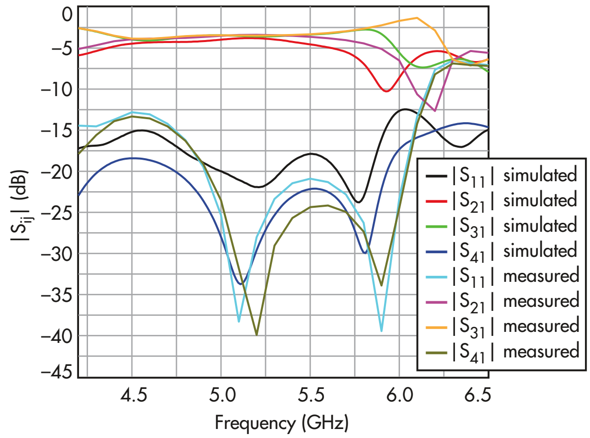

10. These plots represent the simulated and measured frequency responses of the RSIW directional coupler.

SUMMARY

In conclusion, the use of HFSS EM simulation software made it possible to design practical RSIW circuits such as the circulator, power divider, and directional coupler designed for 4.0 to 6.5 GHz. Measurements were made on two of the RSIW circuits, the power divider and the directional coupler.

The experimental results compare well with the simulations and show the validity of this transmission-line technology for designing and constructing high-density microwave integrated circuits (MICs) for both microwave and millimeter-wave frequencies.

By refining the measurement approaches and properly calibrating the test equipment, it may be possible to achieve an even closer match of simulated and measured results in the future. Ultimately, taking these steps will help to further refine the understanding of how rectangular-substrate-integrated waveguide transmission-line technology can be employed to achieve ever-higher performance levels at microwave frequencies. mw

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Design Feature

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Hybrid Technique Delivers Dual-Notch UWB Antenna

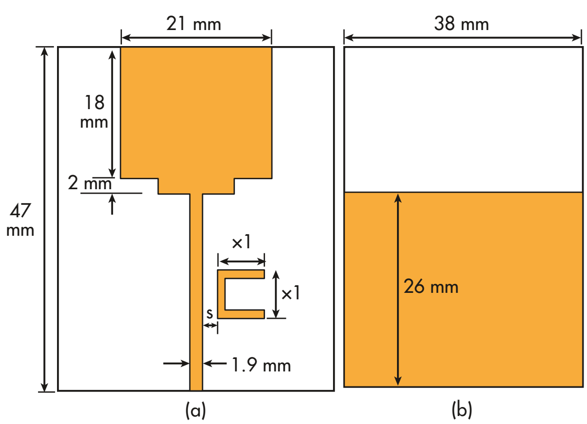
Developed for UWB communications systems, this compact printed antenna includes two notches to minimize the effects of interference from other wireless devices, such as WiMAX and WLAN systems.

As communications services extend across different frequency bands and standards, wideband components are required to match the performance requirements. In particular, ultrawideband (UWB) antennas are needed to avoid mounting multiple antennas into multiband systems. To meet these needs, a printed-circuit, UWB monopole antenna with dual-frequency-band notched characteristics was developed.

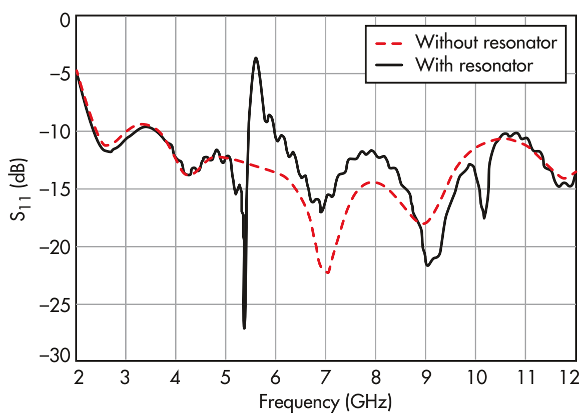
The dual-band frequency notches were achieved with open-loop microstrip resonators. For miniaturization, lumped-element capacitors were added to the microstrip resonators at the locations of maximum electric-field strength, helping to reduce the size of the resonators by more than 40% compared to resonators without the capacitors. The first notch is in the WiMAX band, from 3.3 to 3.7 GHz. The second notch is in the wireless-local-area-network (WLAN) range from 5.2 to 5.8 GHz.

The antenna design covers a total frequency range of 2.3 to 12.5 GHz with VSWR of less than 2.0:1, except within the two notches. For optimum performance, the effects of resonator length, position, and the value of the capacitors were explored through simulations to find the combinations.

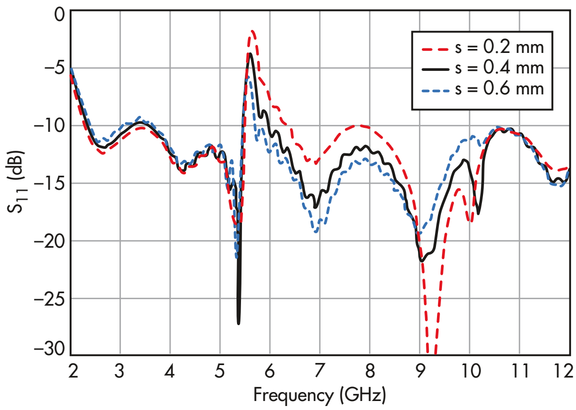
With communications systems being driven to handle higher data rates with low power consumption and simple circuit configurations, the need for UWB antennas is self-evident.[1] The Federal Communications Commission (FCC) allocated frequencies from 3.1 to 10.6 for commercial UWB communications,[2] requiring antennas capable of good impedance matching across a wide frequency range, with stable radiation patterns and linear phase characteristics.[3-5]



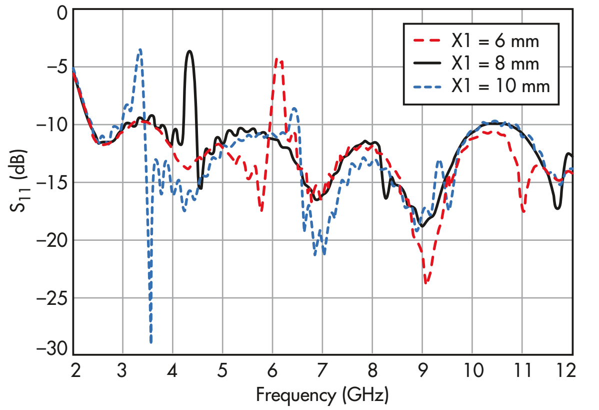
1. This figure is a two-dimensional (2D) representation of the dual-notch UWB antenna showing (a) top and (b) bottom views of the microstrip circuitry.



2. The return loss of the UWB antenna was simulated with and without a microstrip resonator.



3. The return loss of the UWB antenna was simulated with different values of coupling distance, s, with X1 = 6 mm.



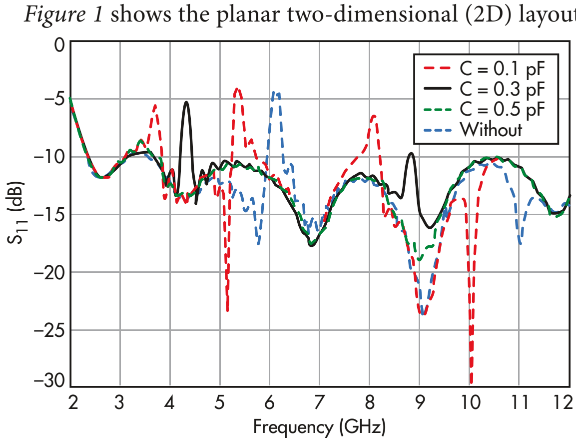
4. The return loss was simulated with different resonator length, X1, with coupling distance set at s = 0.4 mm.

To achieve these requirements, stepped impedance configurations have been suggested.[6, 7] In addition, many additional wideband antenna configurations have been investigated.[8-10]

Monopole printed-circuit UWB antennas offer numerous benefits for wireless communications applications, including ease of fabrication, small size, and low cost. Better still, they can be built on the same printed-circuit board (PCB) as other components to create compact receivers. A recent challenge for UWB antenna designers has been to incorporate band notches within the full frequency range to eliminate interference from existing wireless systems. Various antennas with band-notched functionality have been presented employing coupled resonators,[11-14] slots,[15, 16] or defected ground structures.[17-21]

To cover the UWB bandwidth while attempting to minimize interference from such systems as WiMAX and WLANs, a microstrip-fed monopole UWB antenna was designed with dual-notch characteristics. The antenna radiates from 2.3 to 12.5 GHz with notches at 3.3 to 3.7 GHz and 5.2 to 5.8 GHz. The resonators were reduced in size by adding lumped-element capacitors. The antenna was designed with the aid of CST Microwave Studio three-dimensional (3D) electromagnetic (EM) simulation software from Computer Simulation Technology (www.cst.com).

Figure 1 shows the planar two-dimensional (2D) layout of the antenna, with a view of the top in *Fig. 1a* and a view of the bottom in *Fig. 1b*. The antenna features a 50-Ω microstrip feed line. The rectangular monopole antenna is designed for fabrication on RO4003 laminates from Rogers Corp. (www.rogerscorp.com) with relative permittivity of 3.38, dielectric loss tangent of 0.00027, and thickness, h, of 0.813 mm.



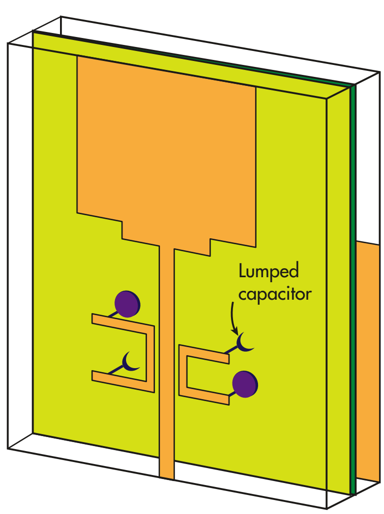
5. The reflection coefficient was simulated for different values of lumped-element capacitors.

Notches were obtained by means of a half-wave open-loop resonator coupled to the microstrip feed line *(Fig. 1a)*. The resonator will provide filtering at a certain frequency range. To obtain full antenna bandwidth, the ground-plane dimensions were optimized to 38 × 26 mm, with X1 equal to 6 mm and spacing, s, equal to 0.4 mm.

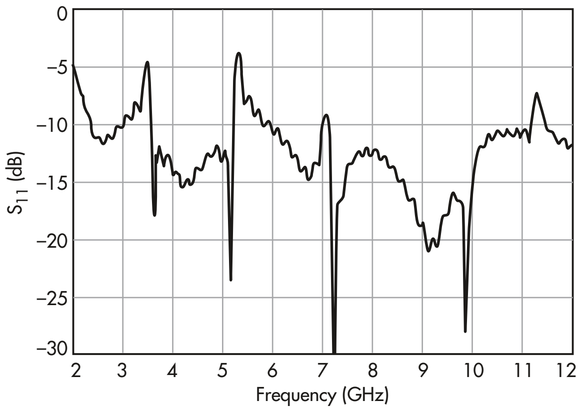
Figure 2 shows the simulated return-loss behavior with and without the microstrip resonator. Without the resonator, the return loss is –10 dB across the impedance bandwidth of 2.3 to 12.5 GHz. With the resonator, the return loss is more than –10 dB from 5.2 to 5.8 GHz for filtering purposes. As can be seen in the figure, the antenna design covers the UWB frequency range while also reducing interference from 5.2 to 5.8 GHz (the WLAN band).

Parametric analysis was carried out for different values of coupling distance, s, to find the best coupling distance from the microstrip resonator to the feed line. *Figure 3* shows simulations of different distances. The effects of the resonator on the band notch can be seen at a distance of 0.2 mm, with return loss approaching –2 dB near 6 GHz.

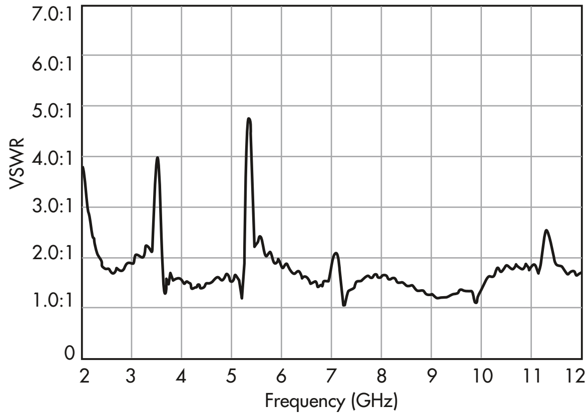
However, the range



6. This is a 3D representation of the dual-notch UWB microstrip antenna.



7. The reflection coefficient of the UWB antenna was simulated with the two resonator-based notches.



8. The plots show simulations of VSWR performance for the dual-notch UWB antenna.

from 7 to 9 GHz is also affected at this spacing distance, with return loss increased slightly more than 10 dB. The effect of the resonator on the band notch decreases as the coupling distance increases. Based on the optimization process for best antenna performance (higher reflection coefficient within the notching frequency band along with lower reflection coefficient outside the notching band), a coupling distance of 0.4 mm was chosen.

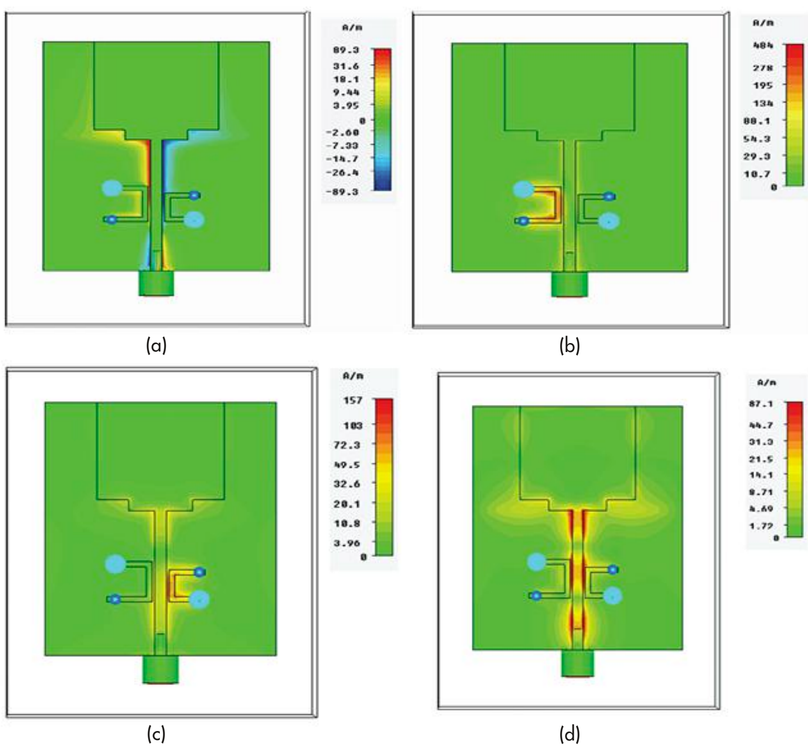
Simulations were also performed to better understand the effect of resonator length on antenna performance. It is clear that resonator length affects notch center frequency and bandwidth *(Fig. 4)*. When the resonator length increases, it decreases the band notch center frequency, and the equivalent reactive component of the resonant circuit increases which decreases the resonant frequency. The latter decreases from 6.2 to 3.5 GHz when the microstrip resonator (X1) length increases from 6 to 10 mm.

The antenna was simulated with different values of lumped-element capacitors. *Figure 5* shows the effects of the lumped-element capacitors on resonant frequency. The capacitors were inserted in the microstrip resonators in the area of maximum electric field which, in a microstrip resonator, is typically concentrated at the open end of the resonator. By inserting a lumped-element capacitor in this location, the total capacitance of the resonator increases. This leads to a decrease in the resonant frequency of the notch.

As Fig. 5 shows, the notch resonant frequency decreases from 6.2 GHz without the capacitor to 3.5 GHz when a lumped-element capacitor with capacitance value from 0.1 to 0.5 pF has been added to the resonator circuit. Thus, a lumped-element capacitor can shorten the length of the resonator.

Figure 6 shows a 3D layout of the dual-notch UWB antenna, with two microstrip resonators loaded with lumped-element capacitors. The smaller resonator rejects interference from 5.2 to 5.8 GHz; the larger resonator rejects interference from 3.3 to 3.7 GHz. Adding the lumped-element capacitors was found to be an effective way to reduce the size of the resonators.

Figure 7 shows the simulated return loss of the dual-notch antenna, with simulated VSWR in *Fig. 8*. The antenna shows impedance mismatches of greater than

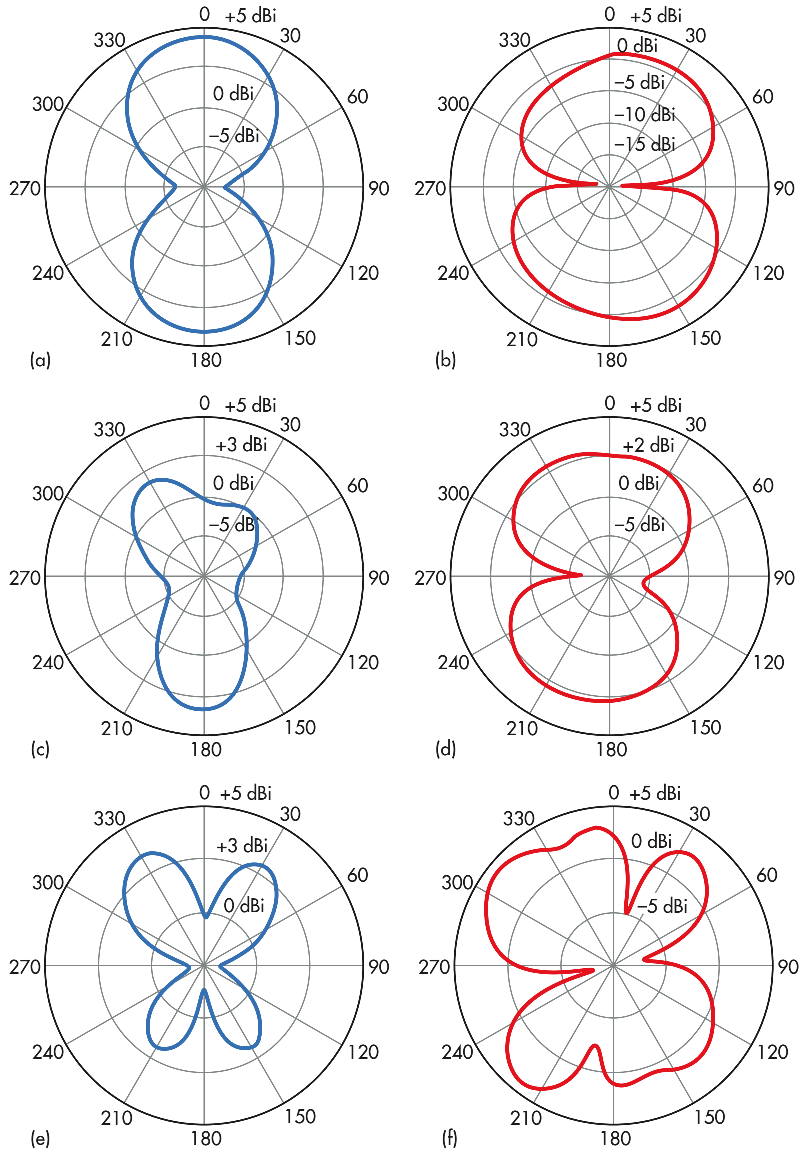


9. These simulations show the surface current distributon for the dual-notch UWB antenna at different frequencies: (a) 3.0 GHz, (b) 3.5 GHz, (c) 5.5 GHz, and (d) 9.0 GHz.

2.0:1 for the bands of 3.3 to 3.7 GHz and 5.2 to 5.8 GHz compared to the matched impedance VSWR of less than 2.0:1 for the remainder of the frequency range.

The surface-current distribution of the dual-notch antenna is shown in *Fig. 9* at 3.0, 3.5, 5.5, and 9.0 GHz. It can be seen that the displayed frequencies are considered the radiating frequencies, since the surface current flows through the microstrip feed line and radiating element and isn't concentrated at any of the resonators.

From *Figs. 9b and c*, the surface current appears concentrated around the larger resonator at 3.5 GHz, the center of the WiMAX band, while the smaller resonator, for 5.5 GHz or the center of the WLAN band, didn't radiate at either of these two bands. *Figure 10* shows the E- and H-plane radiation patterns are presented at 4.5, 6.5, and 9.0 GHz; the E-pattern appears bidirectional and the H-pattern omnidirectional. mw



10. The antenna's directive gain was simulated at different frequencies for the H- and E-planes: (a) the E-plane at 4.5 GHz, (b) the H-plane at 4.5 GHz, (c) the E-plane at 6.5 GHz, (d) the H-plane at 6.5 GHz, (e) the E-plane at 9.0 GHz, and (f) the H-plane at 9.0 GHz.

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CHRIS DeMARTINO | Technology Editor

Part 1: What are the Differences Between COAXIAL CONNECTORS?

In this first of a two-part series, we'll delve into the basics of the often overlooked—but vitally important—coaxial connector.

Although often taken for granted, coaxial connectors are a key aspect of any RF/microwave application. While they may receive less attention than other components, connectors nonetheless must provide adequate performance to avoid any system degradations. Therefore, anyone tasked with selecting coaxial connectors for any given application should clearly understand the parameters that define connector performance.

This article, Part 1, provides a general overview of coaxial connectors. The important parameters that define performance are reviewed, as is some of the terminology commonly used to classify connectors. Here, we will also begin to discuss some of the various types of coaxial connectors. Part 2, which will appear in the June issue of *Microwaves & RF*, will describe other regularly used coaxial connectors.

It should be noted that this series makes no claim to be an exhaustive list; the two articles do not cover every type that's on the market. With that being said, some of the more prevalent coaxial connectors employed throughout the RF/microwave industry will be found here.

1. The UHF connector can still be purchased from some manufacturers today.

INTRODUCTION TO CONNECTORS

Today's designers can select from a large array of connectors available from various suppliers. This wide assortment is in direct contrast to the early days of connectors—back in 1940, the UHF connector was the only choice.

However, as demands of high-frequency applications steadily increased throughout the years, the variety of connectors also grew in scope. Specifically, new connectors were developed to handle progressively higher-frequency operation. Today, connectors can be used at frequencies as high as 100 GHz and beyond.

Choosing a proper coaxial connector requires an understanding of its characteristics—both electrical and mechanical. Obviously, a connector's physical size is an important aspect. Furthermore, multiple performance characteristics, such as frequency range and power-handling capability, must be examined when making a selection. Other important parameters include insertion loss and voltage standing wave ratio (VSWR). And environmental characteristics, such as operating temperature, vibration, and shock, help determine if a connector is suitable for a given application. Of course, cost plays a key role, too.

Generally, coaxial connectors consist of an outer conductor contact and an inner conductor contact. These devices also must have the means to mechanically couple to another connector. Some connectors are named after the inside diameter of their outer conductor, with smaller diameters yielding higher usable frequencies.

Connectors are designed with either an air or a solid dielectric. Air-dielectric types include 3.5-, 2.92-, and 2.4-mm

> "Choosing a proper coaxial connector requires an understanding of its characteristics—both electrical and mechanical. Obviously, a connector's size is an important aspect."

connectors, among others. A good example of a connector that employs a solid dielectric is the widely used SMA connector. A solid dielectric can be implemented with either a flush or overlapping configuration; overlapping configurations are employed to prevent voltage breakdown and to handle higher power levels.

Connectors can be mounted in various ways. Those intended to mount onto printed-circuit boards (PCBs) are manufactured with either a straight or right-angle orientation. Cable-mount connectors can be attached to cables by means of either crimping or clamping. And panel-mount connectors include those with flanges, which typically have either two or four holes.

2. The Type-N connector was first introduced in the 1940s.

MATERIALS

Manufacture of coaxial connectors involves various materials, each having their own set of advantages and disadvantages. Such materials are evaluated by their electrical, mechanical, and environmental properties, and they weigh heavily in terms of connector performance and reliability.

Two of the more commonly used materials for building connector bodies are stainless steel and brass. Stainless steel is more durable than brass, but it comes at a higher cost. The highest-quality connectors are often manufactured with stainless-steel bodies. Connector contacts, on the other hand, are typically not made of stainless steel, which has a relatively low electrical conductivity. Rather they often consist of brass or beryllium copper.

To improve the quality of a connector, manufacturers will generally plate the bodies and contacts with a metal finish. For instance, connector contacts made of copper or brass are commonly gold-plated, since gold is an excellent conductor and highly resistant to corrosion. Silver is used in some instances as well.

Due to the high cost of gold, gold-plating for connectors usually comprises a very thin layer, enabling manufacturers to still reap its benefits while only using a minimal amount. However, the thin gold layer can lead to the diffusion of the base material onto the gold surface. Thus, a suitable metal—often nickel—is typically underplated beneath the gold layer. It acts as a barrier to prevent diffusion.

In addition, manufacturers utilize different forms of finishing for connector bodies, such as gold, silver, and nickel. Another alternative employed by manufacturers is white bronze. Some connectors are available with passivated body finishes as well.

CONNECTOR TERMINOLOGY

The vast majority of standard connector types have both a male and female variant, which join together to form a mated pair. Male connectors are known as plugs, and female connectors are referred to as jacks. Furthermore, the male contact is a pin, while the female contact is a socket. Genderless connectors, such as the APC-7 connector (otherwise known as the 7-mm connector), also exist.

Connector pairs are mated by several coupling techniques, such as threaded, bayonet, and snap-on coupling. Threaded-coupling connectors include SMA and Type-N. The BNC connector implements the bayonet-coupling technique, while the SMB connector takes advantage of the snap-on-coupling technique.

EARLY DAYS OF CONNECTORS

As mentioned, prior to World War II, the UHF connector was the only coaxial connector used for RF applications *(Fig. 1)*. E.C. Quackenbush of the American Phenolic Corporation (later Amphenol) developed the connector in the 1930s. It functioned reliably at frequencies as high as 300 MHz, which was considered high frequency at the time. Still manufactured today, the UHF connector, which employs threaded coupling, derives its name from the acronym for Ultra High Frequency.

Although the UHF connector was reliable for applications to 300 MHz, higher-frequency requirements soon emerged. That mandated new connector designs, since the UHF connector was not suitable at such frequency levels. Thus, a joint U.S. Army-Navy RF Cable Coordinating Committee (ANRFCCC) was established in the early 1940s to develop standards for RF cables, rigid transmission lines, and connectors for radio and radar equipment. In 1942, the ANRFCCC introduced the Type-N connector *(Fig. 2)*.

In Part 2 of this series, we'll further explore the popular Type-N connector, and describe other commonly used coaxial connectors such as the SMA and 2.4-, 2.92-, and 3.5-mm varieties. That article will also cover the characteristics of each of these, as well as other coaxial connectors. mw

NOMA, MIMO USED TO BOOST SPECTRUM EFFICIENCY

WITH MOBILE TRAFFIC expected to surge significantly over the next 10 years, demands will intensify for more efficient use of available frequency spectrum, increased network speeds, and opening of additional frequency spectrum for wireless applications. In the white paper, "Non-orthogonal Multiple Access and Massive MIMO for Improved Spectrum Efficiency," Anritsu examines 5G wireless access systems and describes two technology solutions to enhance spectrum efficiency: non-orthogonal multiple-access (NOMA) and multiple input, multiple output (MIMO).

Next-generation 5G access systems, for example, are being investigated to provide the required solutions. Proposals for 5G systems aim to increase spectrum efficiency by various methods. A NOMA implementation for 5G systems is being discussed, as it improves spectrum efficiency by extending the user multiplex domain. This implementation requires encoding and interference cancellation technologies that were considered difficult to implement in the past. However, recent central-processing-unit (CPU) performance improvements are enabling the development of these technology solutions.

NOMA can be grouped into three categories: NOMA with successive interference canceller/semi-orthogonal multiple-access (SIC/SOMA), sparse code multiple-access (SCMA), and interleave division multiple-access (IDMA). Each of these methods uses a different user multiplex domain to improve spectrum efficiency. NOMA with SIC/SOMA utilizes the new power domain, for example. The SCMA method takes advantage of the power and code domains, while the IDMA method utilizes the code domain.

Anritsu Corp., 490 Jarvis Dr., Morgan Hill, CA 95037-2809; (408) 778-2000; www.anritsu.com

MIMO is an important aspect of today's wireless-communications systems, as it achieves high throughput and reliability by using multiple antennas. Massive-MIMO technology is targeted as a solution for future 5G systems. Massive MIMO uses as many as 100 antenna elements to support simultaneous communication with multiple mobile terminals, thereby significantly improving the spectrum usage efficiency. In addition, millimeter-wave frequencies are being investigated for 5G to enable high-speed communications. However, transmission losses are greater at these higher frequencies. The white paper describes how a beamforming (BF) technique can be used with massive-MIMO antenna configurations to counter increased transmission losses.

FIND THE KEY TO BROADBAND PA DESIGN

A SIMULATION-BASED METHODOLOGY for broadband power-amplifier (PA) design can be accomplished using load-line, load-pull, and real-frequency synthesis techniques. Thus, by taking advantage of simulation software and nonlinear transistor models, the design process can be streamlined. In the application note, "A Simulation-Based Flow for Broadband GaN Power Amplifier Design," National Instruments presents the design of a Class F PA using a gallium-nitride (GaN) high-electron-mobility transistor (HEMT). The design is achieved by utilizing a nonlinear model of the transistor with the NI AWR Design Environment.

A schematic was first created to bias and stabilize the transistor. After establishing the biasing and stability conditions, initial load-line analysis and harmonic impedance tuning was performed. After determining the impedance of the fundamental frequency, the second- and third-harmonic impedances were tuned to a short circuit and an open circuit, respectively. The fundamental impedance of the input tuner was set to a conjugate match, providing maximum gain. When all impedances were tuned, a final harmonic-balance (HB) simulation was performed to confirm the desired mode of operation.

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

The application note goes on to describe a load-pull impedance extraction method, which was performed at three different frequencies: 1.8, 2.0, and 2.2 GHz. Load-pull simulations were executed to generate contours for maximum power and then for maximum drain efficiency. The maximum power and efficiency contours at the fundamental frequency were both superimposed on a Smith Chart.

By using this approach, a region of mutually acceptable power and efficiency could be determined. Load-pull simulations for the second- and third-harmonic frequencies were then performed.

The Amplifier Design Wizard (ADW) tool synthesized the broadband matching networks after determining all impedances. Both the output and input matching networks were designed and subsequently exported to the Microwave Office software. Linear, HB, electromagnetic (EM), and dc simulations were executed to fine-tune the design. The actual power amplifier was later built and tested without any bench tuning, therefore demonstrating agreement with the simulation results.

JACK BROWNE | Technical Contributor

Matching a Process to

From X-band through millimeter-wave frequencies, this fabless semiconductor company evaluates the needs of an application before deciding on the best fit for a device process.

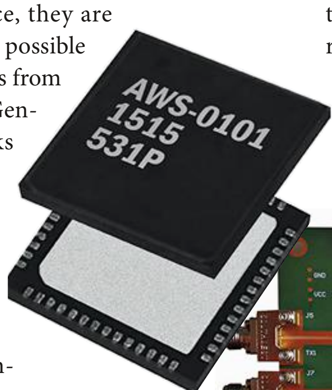
MILLIMETER-WAVE FREQUENCIES OFFER wide available bandwidth for short-range communications at high data rates. Today, due to the relentlessly increasing consumption of bandwidth for broadcast, wireless devices, and other applications at lower frequencies, millimeter-wave bands have been pushed into the spotlight. For instance, they are gaining significant footholds as possible solutions for backhaul data links from base stations in various Fifth-Generation (5G) cellular networks (still in the planning stages).

Of course, millimeter-wave radar devices are being employed in some automotive safety (collision-avoidance) systems. And many proposals for 5G point to a mass consumer-level use of frequencies once regarded as the sole realm of scientific or military applications.

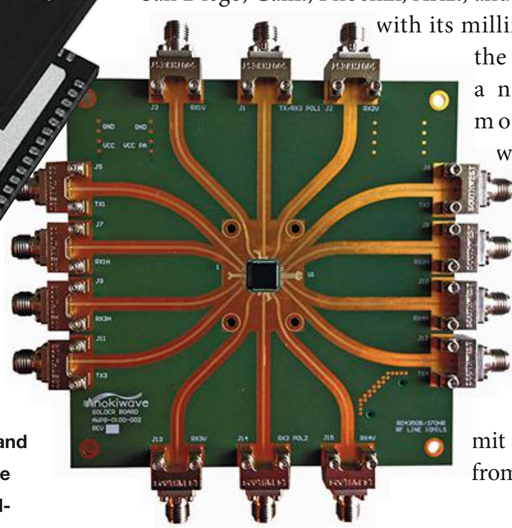
The biggest—and what's become long-term—obstacle in bringing such high frequencies (above 30 GHz) to the masses is the implementation of millimeter-wave circuits and devices at reasonable (affordable) costs. To overcome that hurdle, and open the door to possible widespread use of millimeter-wave technology, fabless semiconductor company Anokiwave adopted a flexible design approach: Devices are fabricated at outside foundries using the semiconductor process that's deemed the best fit for a particular function and application. One such example is gallium arsenide (GaAs) for small-signal, low-noise, and medium-power amplification.

Silicon-based device processes such as silicon germanium (SiGe) and silicon CMOS are an important part of Anokiwave's device process portfolio. They enable the firm to produce practical, high-performance integrated circuits (ICs) for a wide range of markets, from communications to radar systems.

The company, whose name derives from "Anoki," the Hindi word for "extraordinary" and "unique," has locations in San Diego, Calif.; Phoenix, Ariz.; and Boston, Mass. Along with its millimeter-wave devices, the firm has introduced a number of X-band monolithic microwave integrated circuits (MMICs) for active electronically steered array (AESA) applications, including the AWS-0101, a quad-core integrated circuit (IC) with transmit and receive functions from 8 to 11 GHz *(Fig. 1)*.



1. Model AWS-0101 is a quad-core transceiver based on SiGe semiconductor process technology for X-band transmit and receive functions in phased-array systems from 8 to 12 GHz.



2. The AWS-0102-DK Developer Kit helps designers quickly learn how to control and evaluate the performance of the AWS-0102 K/Ka-band receiver IC.

TARGETING X- AND K-BANDS

The AWS-0101 supports four radiating elements, each capable of dual polarization, for electronic beamsteering in phased-array radar and communications systems. Based on a SiGe semiconductor process, it provides 21-dB gain for both transmit and receive, with +15-dBm transmit output power at 1-dB compression and 3.4-dB receive noise figure.

Application Demands

For programming fast beamsteering operation, it includes 6-b amplitude control with least significant bit (LSB) of 0.5 dB and 6-b phase control with LSB of 5.625 deg. The power-efficient device consumes only 1.8 W in transmit mode and 1.8 W in receive mode when operating from a low-voltage, +1.8-V dc supply.

The X-band transmit/receive IC is ideal for commercial and weather radar systems, as well as 5G communications systems using AESAs. It comes in a 56-lead, 7- × 7-mm PQFN package with an operating temperature range of –40 to +85°C. The lead-free device is fully RoHS-compliant.

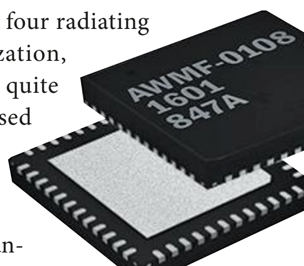
Moving higher in frequency, model AWS-0102 is another quad-core IC, designed for K-band satellite-communications (satcom) receiver systems. It also supports four radiating antenna elements, each with dual polarization, from 17.7 to 20.2 GHz. The receiver IC is quite flexible in these applications, and can be used for linear polarization as well as left-handed (LH) and right-handed (RH) circular polarization (CP).

The AWS-0102 offers 22-dB coherent channel gain with 3.4-dB noise figure. It features programmable 5-b control of phase and gain, with 11.25-deg. phase resolution and 5-deg. root-mean-square (RMS) phase error, and 15.5-dB dynamic range for gain with 0.5-dB resolution and 0.25-dB RMS amplitude error.

Also housed in a 56-lead, 7- × 7-mm PQFN package for ease of installation in planar phase-array antennas, the SiGe IC includes temperature-sensing circuitry for stable performance over a temperature range of –40 to +85°C. The device includes electrostatic-discharge (ESD) protection on all package pins. It consumes just 0.3-W power from a +1.8-V dc supply.

To help circuit designers get started with its quad-core ICs, the firm offers Developer Kits for all of its ICs, which include numerous interfaces to facilitate testing *(Fig. 2)*. Each kit contains a test circuit board that helps emulate the operation of the device in actual applications and provides high channel-to-channel isolation to view channel characteristics separately. Calibration data is also included, to subtract circuit-board and connector losses from the device itself when testing.

Each kit and board offers Serial Peripheral Interface (SPI) control via a high-speed cable, interposer board, and Universal Serial Bus (USB) interface module. In addition, drive software is included to control device functions with a personal computer (PC) during evaluation and testing. A separate cable assembly supplies dc power to the test board. Each Developer Kit features its own set of measured data to serve as reference points for users to compare their own measured results.



3. The model AWMF-0108 transceiver supports electronically steerable antenna arrays from 27.5 to 30.0 GHz. With four antenna elements in each transceiver, a 4 × 4 configuration of devices forms a compact 64-element electronically steered antenna array.

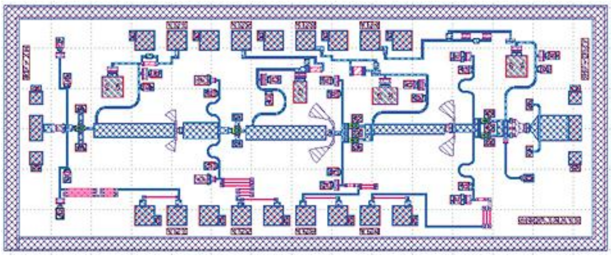
KA-BAND TRANSCEIVER

The quad-core design approach was also applied to higher frequencies, specifically in the model AWMF-0108 transceiver *(Fig. 3)* nominally for 5G antenna arrays. The Ka-band device operates from 27.5 to 30.0 GHz.

As with the AWS-0101 transceiver, the AWMF-0108 supports radiating elements in antenna arrays with healthy transmit and receive gain. The half-duplex transceiver is capable of fast beamsteering and telemetry reporting, with programmable amplitude and phase control. In a 5G system, for example, it could be used in a 4 × 4 configuration of AWMF-0108 devices as part of an AESA solution for a compact 64-element planar antenna array, with the flexibility of electronic beamsteering that eliminates the need for mechanical motion of an antenna.

The model AWMF-0108 transceiver achieves 26-dB transmit gain with +9-dBm transmit output power at 1-dB compression. It also features 31-dB coherent receive gain with 4-dB noise figure and –23-dBm receive input third-order-intercept point (IIP3). Beamsteering is performed with 5-b phase control with LSB of 11.25 deg., and 5-b gain control with 1-dB amplitude resolution.

Designed to operate from a +1.8-V dc supply, the device consumes 0.65 W power in quiescent transmit mode, 0.85 W at transmit 1-dB compressed output power, and 0.50 W in receive



4. Targeting E-band point-to-point communications, the AWP-7176 and AWP-8186 are GaN-based PAs supplied in chip form for applications from 71 to 76 and 81 to 86 GHz, respectively. Each chip measures 2.90 × 2.29 mm with on-chip, diode-based forward power detectors.

mode. The Ka-band transceiver is supplied in a 48-lead, 6- × 6-mm PQFN package with ESD protection on all pins.

REACHING E-BAND

These are just a sampling of the firm's silicon-based devices at "lower" frequencies. Anokiwave has announced many more upcoming introductions, including models AWP-7176 and AWP-8186—GaAs power amplifiers (PAs) developed for E-band point-to-point communications *(Fig. 4)*. Model AWP-7176 operates from 71 to 76 GHz, while model AWP-8186 boosts signals from 81 to 86 GHz.

Both PAs feature a five-stage circuit architecture, each capable of +25-dBm typical saturated output power across their full frequency ranges. The tiny devices (2.90 × 2.29 mm), which include on-chip, diode-based forward power detectors, offer flexible dynamic ranges of +18 to +30 dBm while drawing only 900 mA at +3.5 V dc.

With a little more power at somewhat lower frequencies, model AWP-1102 is a PA for satcom, AESA, and point-to-point-communications applications at Ka-band frequencies from 28 to 30 GHz. It provides 25-dB linear gain across the 2-GHz bandwidth with +34.6-dBm (3-W) saturated output power. The four-stage PA is fabricated in a 0.15-µm pseudomorphic GaAs high-electron-mobility-transistor (pHEMT) semiconductor process. It draws 2.9 A current from a +6-V dc supply and comes in a 28-lead, 5- × 5-mm QFN package.

For receiver applications at E-band, the firm also offers the model AWL-7186 low-noise amplifier (LNA), with better than 3.5-dB noise figure from 71 to 86 GHz. The four-stage amplifier provides typical gain of 17 dB across the 15-GHz bandwidth, with an adjustable gain range of 15 dB. Gain is controlled by applying –2.6 to –1.8 V dc in 0.2-V steps. Representing one part of the company's blend of devices based on different semiconductor processes, the LNA also leverages a 0.1-µm pHEMT process for excellent high-frequency performance. It generates +8 dBm output power at 1-dB compression and has an operating temperature range of –20 to +85°C. Supplied in die form that measures 2.90 × 1.12 mm, the LNA maintains typical current draw of 80 mA at +3.5 V dc.

As with 5G, some of these higher-frequency devices are still in the testing and evaluation stages, with near-term product availability. In general, the devices are RoHS-compliant and durable, with ESD protection and power-monitoring functions where appropriate. They provide a glimpse into the design philosophy of a company poised to embrace the challenges of affordable communications and radar functions at millimeter-wave frequencies. Moreover, it's a firm positioned to supply the devices needed for 5G systems should they incorporate data links at millimeter-wave frequencies. mw

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CHRIS DeMARTINO | Technology Editor

Wireless Technologies Flood the IoT Landscape

A number of wireless technologies will be needed to provide the increased connectivity promised by the Internet of Things.

THE INTERNET OF THINGS (IoT) continues to be a major talking point, as many look ahead to the connectivity it may bring to our world. However, an important question remains to be addressed: How will all of these IoT devices be wirelessly connected? Given the vast amount of IoT applications and requirements, it is certain that no single wireless technology by itself will be the driving force behind the IoT.

When investigating the technology options for IoT wireless connectivity, one cannot disregard cellular standards because they do figure to play a role. However, a number of other wireless technologies will likely have major involvement. In fact, vendors are already enabling IoT applications by offering products based on technologies such as ZigBee, Bluetooth, and LoRa. While we can expect to see much more wireless activity in the future as the IoT picks up steam, it is important to understand which aspects of current technologies make them such apt choices for the IoT.

ZIGBEE

At the forefront of the IoT is ZigBee, a standards-based wireless technology that is intended to meet the needs of device-to-device communications *(Fig. 1)*. ZigBee has the advantage of being low power, which means that it enables battery-operated devices to operate for several years. By using mesh-networking technology, it also eliminates single points of failure. Another benefit of ZigBee is the standardization at all levels of the network, which allows devices from different vendors to work together seamlessly. ZigBee operates in the 2.4-GHz frequency band.

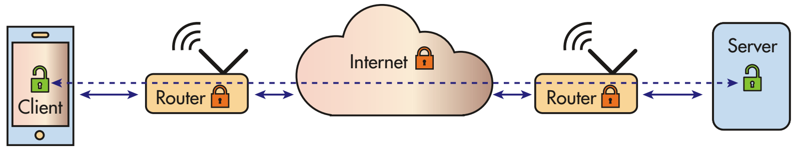
1. ZigBee is enabling applications like smart homes and connected lighting.

The ZigBee Alliance, which was established in 2002, is responsible for creating ZigBee standards. Its members come from all types of organizations across the world.

"The ZigBee Alliance is an organization of over 425 member companies that create, maintain, and deliver specifications, standards, and solutions for the wireless IoT market," says Mark Walters, vice president of strategic development, ZigBee Alliance. "We provide and administer many different technologies ranging from simple low-cost, low-latency point-to-point technology ideally suited for consumer electronic remote controls (ZigBee RF4CE) to highly efficient and secure low-power mesh networking (ZigBee PRO) solutions to highly sophisticated and ultra-secure mesh networks based on Internet Protocols used by governments and utilities worldwide."

The latest specification, ZigBee 3.0, was ratified in December 2015. Walters adds, "Our latest release is ZigBee 3.0, which is based on our ZigBee PRO mesh network. It incorporates all previously used application profiles into a singular, interoperable solution, thus making technology selection and market selection simple. The ZigBee Alliance provides complete end-to-end solutions, including the network specification or standard, the application layer and device definition, test plans and tools, and certification programs as well as branding and logo programs. This not only provides for powerful product solutions, but for interoperable market ecosystems as well."

The large number of ZigBee-certified products includes a multitude of home-automation and smart-energy products. "ZigBee-based solutions have been in the market for more than 12 years with continuous improvement throughout that time—and ship on the order of 400 million devices a year," says Walters. "Advantages of ZigBee-based technologies/solutions include support from multiple manufacturers and suppliers."



2. A SDK for IoT can benefit project developers. *(Courtesy of Nordic Semiconductor)*

Recently, NXP Semiconductors (www.nxp.com)—a member of the ZigBee Alliance—announced its new software development kit (SDK) for ZigBee 3.0. NXP ZigBee 3.0 software is intended to be used with the company's JN5169, JN5168, and JN5164 wireless microcontrollers, which are suitable for ZigBee and other IEEE 802.15.4-based network applications. The JN5169, for example, includes a 2.4-GHz transceiver, which comprises a 2.4-GHz radio, modem, baseband controller, and security coprocessor.

BLUETOOTH

Bluetooth low energy, also known as Bluetooth Smart or BLE, is a low-energy version of Bluetooth that is ideal for IoT applications. Its power efficiency allows devices to run for long periods of time via power sources like coin-cell batteries. "The IoT is likely to be founded on several wireless technologies, including Bluetooth low energy (also known by its consumer branding of Bluetooth Smart)," says John Leonard, product marketing manager at Nordic Semiconductor (www.nordicsemi.com). "Bluetooth low energy is a proven, 'ultra-low-power' protocol based on an open standard and available from several major silicon vendors."

However, BLE has its pitfalls. Leonard notes, "Today's Bluetooth low energy suffers a significant drawback as a technology for connecting 'things' directly to the internet. To make such a connection, contemporary Bluetooth low-energy devices require the resources of a sophisticated gateway, such as a smartphone or Wi-Fi bridge. For IoT implementations—where many millions of remote sensors are likely to be deployed—that is hardly a practical solution, as such gateways are expensive, bulky, complex, and demand a great deal of power."

In the future, BLE devices may benefit from Internet Protocol version 6 (IPv6). Thus, these gateways may no longer be required. "Tomorrow's Bluetooth low-energy devices will take advantage of the Internet Protocol (IP) to make things much more practical," says Leonard. "IP defines how computers and other devices connected to the internet locate each other and exchange information. As the contemporary internet transforms into the IoT, many engineers suggest it will naturally adopt the latest version of the protocol, known as IPv6. A wireless IoT sensor supporting IPv6 will be able to communicate and exchange information with every other IPv6-enabled device without the resources of a gateway."

Leonard adds, "The Bluetooth Special Interest Group (SIG) has made IP connectivity a little easier to implement with the introduction of the Internet Protocol Support Profile (IPSP) in Bluetooth Version 4.1. Communication between devices that support IPSP is accomplished using IPv6 packets over the Bluetooth low energy transport. Nordic Semiconductor is enabling Bluetooth low-energy devices with its nRF52 Series systems-on-a-chip (SoCs), which can now communicate with any other IPv6-enabled device. The company has helped developers working on IoT projects by offering the nRF5 SDK for IoT, which is a software development kit that incorporates a Bluetooth Smart software stack with an 'IPv6 over Bluetooth Smart' adaptation layer (6LoWPAN) and a complete Internet Protocol Suite *(Fig. 2)*."

Other suppliers of Bluetooth-based products include Silicon Labs (www.silabs.com), which recently unveiled its new Blue Gecko BGM113 Bluetooth Smart module. This module incorporates a 2.4-GHz Blue Gecko wireless SoC, a chip antenna, and the company's Bluetooth 4.1-compliant software stack. Furthermore, the BGM113 delivers +3 dBm of transmit (Tx) output power and can cover a range as high as 50 meters. The BGM113 is well-suited for a variety of applications, such as smartphone accessories, wearable sports and fitness products, wireless locks, and point-of-sale devices.

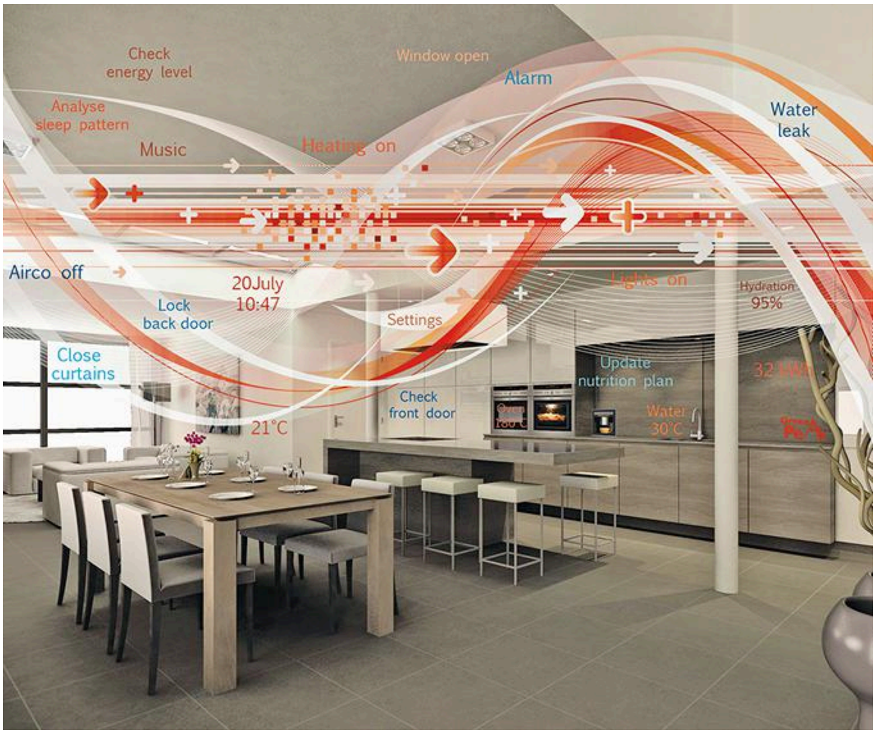
For its part, Telink Semiconductor (www.telink-semi.com) offers a BLE series of Bluetooth SoC solutions, which includes the TLSR8263, TLSR8266, and TLSR8267 chips. Each of these devices features a 2.4-GHz transceiver and a single-pin antenna interface. The TLSR8263 provides +6 dBm of Tx output power, while both the TLSR8266 and TLSR8267 deliver +7 dBm of Tx output power. The company also provides a Bluetooth low-energy SDK and can deliver turnkey hardware reference designs to support fast product development.

Also sparking interest is Cypress Semiconductor (www.cypress.com), which recently launched its new CYBLE-224110-00 module. This new module supports BLE applications and includes an onboard power amplifier (PA), low-noise amplifier (LNA), crystal oscillators, chip antenna, passive components, and Cypress' PSoC 4 technology. The CYBLE-224110-00 can deliver as much as +9.5 dBm of Tx output power while attaining a receive sensitivity of –95 dBm. Cypress Semiconductor also unveiled the CYBLE-222014-01 module to support Bluetooth Version 4.2.

LoRa TECHNOLOGY

ZigBee and Bluetooth are certainly not the only solutions that will enable the IoT, as a number of other wireless technologies are in the fray. One to keep an eye on is LoRa, which derives its name from the ability to enable "long-range" communications. LoRa is based on the chirp-spread-spectrum modulation format, which has the same low-power characteristics of frequency-shift-keying (FSK) modulation while providing increased communication range. Although the chirp-spread-spectrum technique has been used in military and space applications for a long time, LoRa is said to be the first commercial implementation.

LoRaWAN networks employ a star-of-stars topology and are designed to optimize the battery lifetime, capacity, range, and cost of low-power wide-area networks (LPWANs). These networks employ LoRa gateways, used to relay messages between the end node and the cloud-based network server. Such gateways are connected to the network server via standard IP connections, while end nodes use single-hop wireless communication to one or many gateways.



3. The connected home can be realized as a result of SoC solutions. *(Courtesy of GreenPeak Technologies)*

The LoRaWAN specification varies slightly from region to region. In North America, LoRaWAN networks operate in the industrial, scientific, and medical (ISM) frequency band from 902 to 928 MHz. In Europe, the frequency band from 867 to 869 MHz is utilized.

The LoRa product family from Semtech (www.semtech.com) consists of several LoRa transceivers along with the SX1301 digital baseband chip. The SX1272 LoRa transceiver covers a frequency range of 860 to 1,020 MHz. It has three bandwidth options—125, 250, and 500 kHz—with spreading factors ranging from 6 to 12. The SX1276 transceiver spans a frequency range from 137 to 1,020 MHz. Its bandwidth options range from 7.8 to 500 kHz with spreading factors ranging from 6 to 12.

IoT SOLUTION PROVIDERS

The aforementioned companies are not the only ones providing IoT-based solutions. GreenPeak Technologies (www.greenpeak.com; recently acquired by Qorvo) also offers technology solutions for IoT applications *(Fig. 3)*, including various ZigBee transceiver chips.

Earlier this year, GreenPeak demonstrated its GP712 SoC for ZigBee and Thread networks. By combining both protocols, the company believes this solution can optimize the cost of connected-home applications. The GP712 covers a frequency range of 2400 to 2483.5 MHz, and can deliver +7 dBm of Tx power. It is intended for printed-circuit-board (PCB) designs using only low-cost components and printed antennas. The company also offers reference designs, development kits, software libraries, and production platforms.

In addition, Texas Instruments (TI; www.ti.com) is doing its part to enable IoT applications. The company is accomplishing this by utilizing a number of wireless technologies including Wi-Fi, Bluetooth Smart, ZigBee, and more. One IoT-based product offered by the company is the CC3200 single-chip wireless microcontroller unit (MCU), which consists of an applications microcontroller, Wi-Fi network processor, and power-management subsystems.

Obviously, the IoT will require the utilization of a number of different wireless technologies. In addition to those featured here, there are others such as Z-Wave, Thread, and SIGFOX, to name a few. In addition, more variations will surely emerge in the future, such as Wi-Fi HaLow, which the Wi-Fi Alliance plans to unleash in 2018.

With all of that being said, it is clear the IoT landscape will require a number of technology solutions to satisfy the needs of so many applications. As the world becomes increasingly connected, we can expect to see more IoT devices from many suppliers with various wireless technologies being utilized. The IoT is still in the early stages, and it will be interesting to witness how everything unfolds in the weeks, months, and years to come.

JACK BROWNE | Technical Contributor

Current Analyzers Go Where No Instrument Has Gone Before

These two- and four-channel device current analyzers, along with their associated current probes, make it possible to accurately measure the lowest levels of current in analog and digital devices.

CURRENT CONSUMPTION AND energy conservation are real concerns for many present and future wireless applications, both for analog and digital devices. Measuring current has long been a task "left" to a general-purpose instrument (such as a multimeter) or to an instrument nominally designed for some other function (such as a digital storage oscilloscope or spectrum analyzer).

Unfortunately, for the low current levels expected in low-power devices for many emerging wireless applications, which must run for extended periods on battery power—like wearable electronics, embedded medical devices, machine-to-machine (M2M) devices, and Internet of Things (IoT) sensors—such measurement tools fall short of sensitivity and resolution.

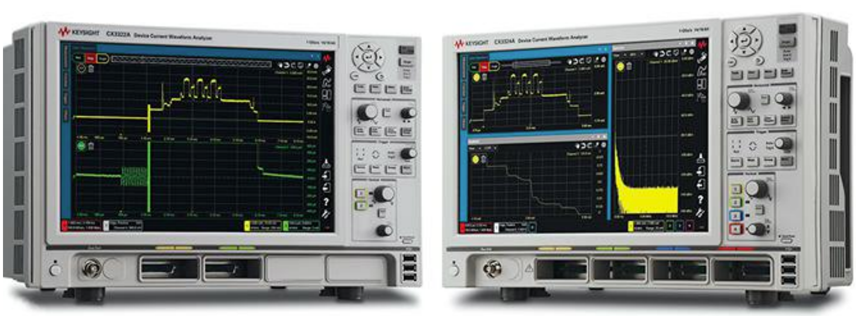
Fortunately, a series of instruments has been developed specifically for measuring low current levels, the CX3300 series of device current waveform analyzers from Keysight Technologies (www.keysight.com). When armed with the appropriate current sensor, the analyzers can characterize device currents as low as 10 pA and as large as 10 A. The current waveform analyzers receive signals from the current sensor and digitize them at a rate of 1 Gsample/s and 14- and 16-b dynamic-range settings with bandwidths of either 100 or 200 MHz, providing measurements of current levels previously undetectable and unmeasurable.

The analyzers are candidates for research laboratories; analog, digital, and mixed-signal semiconductor device designers; and semiconductor device users. They provide the analysis capability to develop that next-generation wireless device that will run almost forever on battery power.

The CX3300 series *(Fig. 1)* consists of two instruments with various options, current probes, and a variety of accessories. The benchtop instruments are the model CX3322A with two input channels and the model CX3324A with four input channels. Both perform measurements with a maximum sampling rate of 1 Gsample/s, offering 14-b resolution in high-speed mode and 16-b resolution in high-resolution mode (better than 100 dB). The current analyzers are available with a choice of analog bandwidths—50, 100, or 200 MHz—and a choice of memory depth—16, 64, or 256 Mpoints. The bandwidth and memory depth options are upgradeable for future requirements.

Although these instruments represent the first of their kind in terms of their capabilities in measuring low current levels with massive dynamic range, they will seem familiar to many users, since they adopt many of the traits of an oscilloscope. They feature intuitive graphical user interfaces (GUIs) that are relatively easy to learn and simple to use, aided by a striking 14.1-in. multitouch liquid-crystal-display (LCD) screen.

By touching a starting point on a displayed curve, for example, the instrument's "anywhere zoom" feature makes it possible with a touch of a finger to

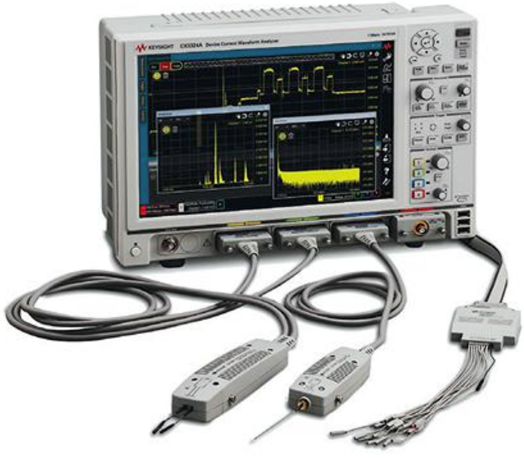


1. The CX3300 Series of device current waveform analyzers includes the two-channel model CX3322A (left) and four-channel model CX3324A (right).

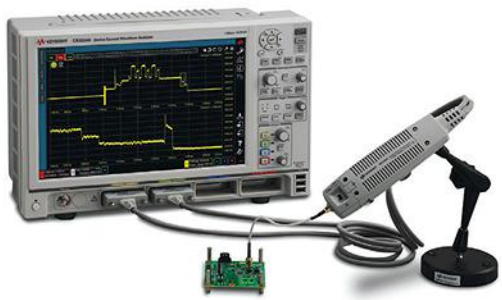
expand or shrink the view for the selected portion of a waveform. For those who prefer an "old-fashioned" display screen, a front-panel switch allows the touch function to be deactivated. As an added feature, both analyzers can function as spectrum analyzers, showing results on the full screen or on a window of the screen.

DON'T FORGET THE SENSORS

The device current waveform analyzers work with different sensors to provide a choice of measurement capabilities and measurement sensitivity. At present, three types of sensors are available for the analyzers: models CX1101A, CX1102A, and CX1103A *(Fig. 2)*. Model CX1101A is a single-channel current sensor capable of working with the highest voltages, with a maximum input voltage of ±40 V dc. It operates with 100-MHz bandwidth to measure minimum current of 40 nA and maximum current of 10 A with ±0.9% dc measurement accuracy when working with one of the device current waveform analyzers.



2. Three current sensors are available for the CX3300 series analyzers—models CX1101A, CX1102A, and CX1103A.



3. Six probe-tip connections and connector interfaces simplify measurements on many different devices under test (DUTs).

Model CX1102A is a dual-channel current sensor with 100-MHz standalone bandwidth. It operates with maximum input voltage of ±12 V dc and can measure current from 40 nA to 1 A, also with ±0.9% measurement accuracy with one of the analyzers. This dual-channel current sensor offers a great deal of flexibility—for example, studying device current at two different current settings or measurement resolutions.

For truly low-current-level measurements, the third current sensor, model CX1103A, enables measurements of current levels as low as 150 pA to a maximum current level of 20 mA, with ±0.9% measurement accuracy. This sensitive tool features a standalone measurement bandwidth of 200 MHz and can be specified with maximum input voltage of ±0.5 V dc.

Current measurements may be performed by means of coaxial connections to a test fixture or using probe-tip connection additions to the current sensors to probe device leads and other points in a circuit *(Fig. 3)*. A total of six detachable probe-tip connections are available for the sensors. These connections offer endless possibilities for experimentation—for example, to study how current changes as a result of different factors in a circuit, such as the variations in dielectric constant of a substrate material, or even the conductivity of microstrip transmission lines.

In addition, using a model CX1151A passive probe interface adapter, power consumption can also be calculated and displayed on either of the CX3300 series device current waveform analyzers. The CX1151A has a maximum input voltage rating of 100 V peak and 200-MHz bandwidth.

Neither the CX3322A nor the CX3324A device current waveform analyzer include a dedicated digital trigger input for analysis of digital devices. But the added channels in the CX3324A enable the use of one of the accessories, the CX1152A digital channel interface cable, in support of digital measurements (with maximum input voltages of ±25 V dc). The interface cable, combined with the measurement capabilities of the CX3324A, make it possible to examine the logic status of digital devices.

Both analyzers are relatively easy to use, with controls intelligently laid out for manual operation, knobs for horizontal and vertical settings, and navigation keys for ease of finding values on different parts of a captured waveform. Three Universal Serial Bus (USB) ports are including for saving and moving measurement results as needed.

For ease of analysis, the device current waveform analyzers have a number of analysis capabilities, including an Automatic Power and Current Profiler, a Power Measurement Wizard, a fast-Fourier-transform (FFT) analyzer, and Statistical Analysis functions. These built-in functions provide analysis power without adding external computers and programs. In addition, the analyzers include simple user calibration functions to allow an operator to quickly calibrate the analyzer and a connected sensor for a zero-current setting.

The CX3322A and CX3324A analyzers, along with their sensors and accessories, reach uncharted territory for engineers seeking to understand the current consumption of their circuits and devices. Their wide measurement bandwidths make it possible to capture even the briefest transient current events to fully understand device behavior. With picoampere sensitivity and better than ±1% accuracy, they provide the insights needed to understand the effects of active devices on battery power.

With the growing number of wireless devices that will depend on battery power, this is invaluable measurement data that was previously unavailable at these low current levels. mw

JACK BROWNE | Technical Contributor

Receiver Navigates Precision Time Keeping

This compact receiver works with signals from various navigation satellite systems, providing precision frequency and timing output signals for synchronization purposes.

FREQUENCY AND TIME are two ways of looking at the same time, and both require stable clocks for accuracy. The model ptf 3207A GlobalTyme2 receiver from Precise Time and Frequency is a combination frequency reference and timekeeping standard with dependably stable output signals. It operates with a choice of internal local oscillator (LO)—a temperature-compensated crystal oscillator (TCXO), for example—or oven-controlled crystal oscillator (OCXO).

The model ptf 3207A GlobalTyme2 receiver provides precise frequency and timing output signals for synchronizing test equipment, communications networks, and other systems.

The receiver incorporates circuitry to lock the LO to signals from a satellite-based navigation system, such as Global Positioning System (GPS) satellites, or Russia's version of GPS, the Global Navigation Satellite System (GLONASS). The receiver can also be equipped to operate with Galileo QZSS (in Japan), and SBAS (WAAS, EGNOS) system signals. It performs Global Navigation System (GNS) tracking on 34 parallel channels.

The ptf 3207A *(see figure)* offers various performance options depending on the precision required. In addition to TCXO and standard or low-noise internal OXCOs, it can be equipped with rubidium or low-noise rubidium oscillators. It provides 10-MHz sinewave outputs for frequency, with options for 100 kHz, 1 MHz, and 5 MHz, as well as IRIG-B and 1 pulse-per-second (PPS)/minute (PPM), pulse-per-half-hour (PHH), or pulse-per-hour (PPH) output signals for time synchronization.

A SAMPLING OF ptf 3207A RECEIVER SSB PHASE NOISE WITH DIFFERENT SOURCES

Signal source	Phase noise at offset from carrier (dBc/Hz)			
	1 Hz	10 Hz	100 Hz	1 kHz
Standard TCXO	–72	–93	–115	–126
Standard OCXO	–96	–130	–155	–162
Low-noise OCXO	–108	–125	–150	–165
Rubidium clock	–190	–130	–145	–150

The 1PPS output is accurate within 20 ns or better of the Universal Time Code (UTC). For system flexibility and redundancy, the receiver can be equipped with 1PPS, IRIG, and 10-MHz input ports as an option.

For monitoring and control, the ptf 3207A includes a front-panel membrane keypad with tactile feel for ease of programming and setup. For security, the front-panel control can be locked by means of a four-digit personal-identification-number (PIN) access code.

Frequency stability and noise performance is a function of the choice of LO for each receiver, with the single-sideband (SSB) phase noise lower at a given offset frequency for an OCXO source than for a TCXO source *(see table)*. Spurious output levels for OCXO-equipped receivers are better than –80 dBc for all offsets.

The ptf 3207 GlobalTyme2 receiver produces four individual digital outputs, with each producing a 5-V TTL/CMOS-compatible signal into a 50-Ω load. In addition, each of the outputs is able to drive multiple distributed outputs. These programmable clock outputs can be set in frequency from a high of 10 MHz to a low of 0.5960 Hz with 24-bit resolution. It is possible to tune frequency in steps as fine as 10,000,000 (for the 10-MHz reference) divided by 16,777,215 (for the 24-bit resolution).

The receiver is available in 1U and 2U rack-height versions with lengths and widths of 19 × 16 in. The receiver runs on 90 to 264 V ac or, optionally, on +18 to +72 V dc. mw

PRECISE TIME AND FREQUENCY INC., 50L Audubon Rd., Wakefield, MA 01880; (781) 245-9090, *www.ptfinc.com*

JACK BROWNE | Technical Contributor

Remote Monitoring System Resolves Interference Issues

This powerful, cloud-based system enables operators to remotely assess the health of their wireless networks from web-enabled smartphones, tablets, or computers.

WIRELESS COMMUNICATIONS NETWORKS have become essential tools for first responders and a broad range of mission-critical state, local, and federal agencies. During emergency operations, an agency's wireless network is simply too important to fail.

In the past, maintaining signaling reliability meant scheduling a technician with a handheld analyzer to search for interference and quality issues. However, with an increase in the distribution of small cells and wireless gateways, the traditional method of collecting on-site measurements has become logistically challenging, time-intensive, and costly.

Fortunately, there is a better way. By implementing a SpectrumPROFILER DS-1620S remote monitoring system from Deviser Instruments at key points throughout the wireless network infrastructure, an agency can monitor, analyze, and resolve wireless interference signals in real time—and from anywhere in the world with internet access *(see figure)*.

The SpectrumPROFILER DS-1620S remote monitoring system can perform fast frequency sweeps from 9 kHz to 3 GHz with high sensitivity to capture interference signals that might be disrupting wireless network operation.

This remote monitoring system operates from 9 kHz to 3 GHz with 1-Hz frequency resolution; resolution bandwidths (RBWs) from 1 Hz to 3 MHz; and video bandwidths from 1 Hz to 1 MHz. It features the fast sweep speed needed to capture even sporadic interference, sweeping its entire bandwidth in only 60 ms.

The DS-1620S works through a network of distributed rack-mounted management units working in unison with an array of actively monitoring self-positioning sensors. The system is accessed through the internet via a simple-yet-powerful user-interface experience (UX) from any smartphone, tablet, or personal computer (PC). By offering network operators independence from specific locations and the flexibility to access their wireless spectrum at any time, system maintenance is simplified.

The system is offered in a small-footprint 1U-high rack-mount enclosure. It can be remotely accessed using any computerized mobile communications device, laptop computer, or network operations center (NOC) computer via TCP/IP Ethernet over VPN or through an integrated web user interface. Remotely accessible features include measurement settings such as center frequency, frequency span, and reference level.

The analyzer can also measure channel power, occupied bandwidth (OBW), and adjacent channel leakage ratio (ACLR). It displays results in a number of different formats to simplify signal analysis, including in spectrograms, three-dimensional (3D) waterfall displays, received-signal-strength-indication (RSSI) plots, and field-strength displays.

Fully equipped, the DS-1620S can leverage an array of three or more geo-locating sensors that triangulate signals-of-interest, helping to precisely locate detected interference in three-dimensional (3D) space. The DS-1620S includes an impressive measurement tool, with a built-in 18-dB gain preamplifier, essential in capturing extremely low-level interference. The unit has a displayed average noise level (DANL) of –148 dBm offset 1 Hz from the carrier, without the preamplifier, and –158 dBm at the same offset with the preamplifier.

For measuring higher-level signals, the unit includes a step attenuator with 0 to 55 dB attenuation in 5-dB steps. The analyzer exhibits spectral purity of –95 dBc/Hz offset 10 kHz from the carrier. It holds frequency uncertainty to ±1 ppm, with frequency reference aging rate of ±1 ppm/year, and temperature drift of only ±1 ppm/°C for an operating temperature range of –10 to +55°C. mw

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Model	Power Measurement	Frequency MHz	Dynamic Range (dBm)	Control Interface	Price $ ea. (Qty1-4)
NEW! PWR-6LGHS	CW	50 to 6000	-45 to +10	USB	895.00
NEW! PWR-6RMS-RC	True RMS	50 to 6000	-35 to +20	USB & Ethernet	1595.00
PWR-4RMS	True RMS	50 to 4000	-35 to +20	USB	1169.00
PWR-2.5GHS-75 (75Ω)	CW	0.1 to 2500	-30 to +20	USB	795.00
PWR-4GHS	CW	0.009 to 4000	-30 to +20	USB	795.00
PWR-6GHS	CW	1 to 6000	-30 to +20	USB	695.00
PWR-8GHS	CW	1 to 8000	-30 to +20	USB	869.00
PWR-8GHS-RC	CW	1 to 8000	-30 to +20	USB & Ethernet	969.00
PWR-8FS	CW	1 to 8000	-30 to +20	USB	969.00

*Measurement speed as fast as 10 ms for model PWR-8-FS. All other models as fast as 30 ms.

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JACK BROWNE | Technical Contributor

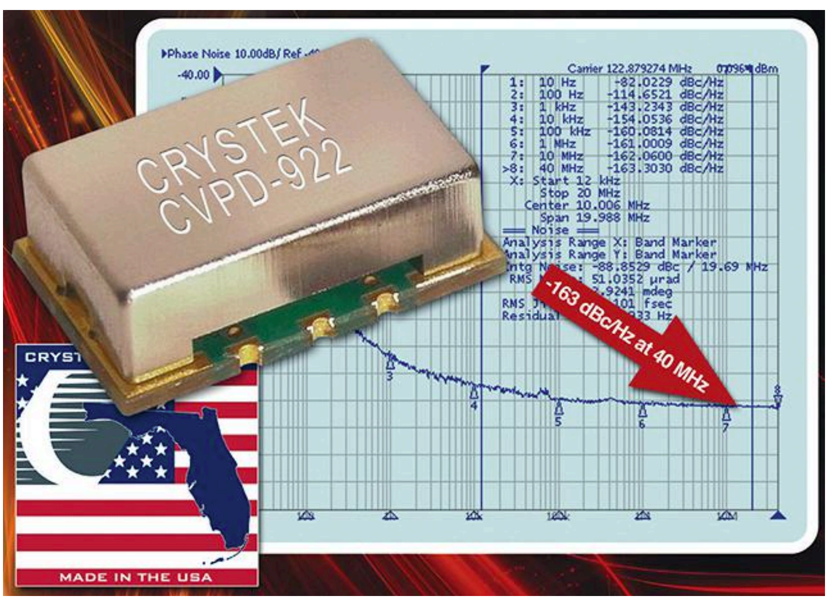
VCXOs Quiet Phase Noise to –162 dBc/Hz

These LVPECL logic-output crystal oscillators are available with outstanding short- and long-term stability, plus low-voltage operation, for output frequencies from 40 to 125 MHz.

PHASE NOISE IS one of the limiting factors in receiver and transmitter performance within communications systems. Whether for analog or digital transmissions, excessive phase noise can cause a variety of side effects, such as interference for closely spaced carriers and degradation of digital bit-error-rate (BER) performance.

To limit the phase noise at the starting point in a high-frequency signal-conversion chain—the clock oscillator—Crystek (www.crystek.com) recently introduced its CVPD-922 family of voltage-controlled crystal oscillators (VCXOs) with differential, low-voltage positive-emitter-coupled-logic (LVPECL) output signals. Available in a frequency range from 40 to 125 MHz, these "quiet" sources feature close-in single-sideband (SSB) phase noise of –85 dBc/Hz offset 10 Hz from the carrier, dropping to a noise floor of –162 dBc/Hz.

SUMMARIZING TYPICAL CVPD-922 PHASE NOISE AT 100 MHZ	
Offset from the carrier	Phase noise
10 Hz	–85 dBc/Hz
100 Hz	–115 dBc/Hz
1 kHz	–145 dBc/Hz
10 kHz	–155 dBc/Hz
100 kHz	–160 dBc/Hz
1 MHz	–162 dBc/Hz
10 MHz	–162 dBc/Hz



The CVPD-922 family of LVPECL crystal oscillators can be supplied with output frequencies from 40 to 125 MHz.

The CVPD-922 family *(see figure)* provides a new degree of freedom for designers working on high-speed ECL-based circuits. Since ECL logic circuitry is extremely sensitive to noise, these oscillators provide a noise-floor limit that enables transmission of signals with higher signal integrity and improved BERs. The oscillators' differential LVPECL outputs feature worst-case 20-to-80% rise/fall time of 1 ns and ±10% linearity in support of logic signals with sharp pulse edges.

These VCXOs offer excellent time-domain performance and low noise to help achieve high levels of signal integrity in numerous high-speed logic circuits. In the time domain, typical phase jitter is just 85 fs at 100 MHz. In the frequency domain, SSB phase noise drops steady from close to the carrier to offsets of 1 MHz and greater from the carrier *(see table)*.

(continued on p. 85)

photo courtesy of the
U.S. Military & NASA

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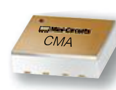
Electrical Specifications *(-55 to +105°C)*



3 x 3 x 1.14 mm

	Model	Freq. (GHz)	Gain (dB)	P_{OUT} (dBm)	IP3 (dBm)	NF (dB)	DC (V)	Price $ ea. (qty 20)
New	CMA-81+	DC-6	10	19.5	38	7.5	5	6.45
New	CMA-82+	DC-7	15	20	42	6.8	5	6.45
New	CMA-84+	DC-7	24	21	38	5.5	5	6.45
	CMA-62+	0.01-6	15	19	33	5	5	4.95
	CMA-63+	0.01-6	20	18	32	4	5	4.95
	CMA-545+	0.05-6	15	20	37	1	3	4.95
	CMA-5043+	0.05-4	18	20	33	0.8	5	4.95
	CMA-545G1+	0.4-2.2	32	23	36	0.9	5	5.45
	CMA-162LN+	0.7-1.6	23	19	30	0.5	4	4.95
	CMA-252LN+	1.5-2.5	17	18	30	1	4	4.95

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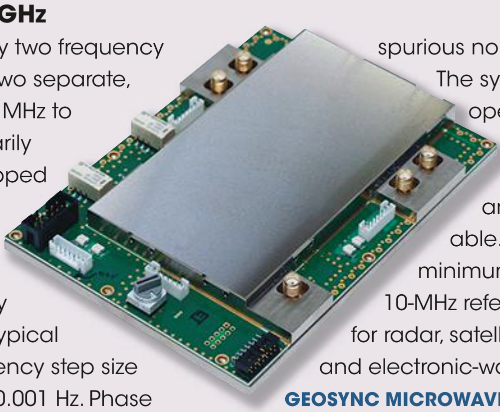


MODEL GFS-500M6G is essentially two frequency synthesizers in one. It generates two separate, programmable outputs from 500 MHz to 6 GHz. The outputs can be arbitrarily stepped, swept, or frequency-hopped over the full range or any portion thereof, with low noise characteristics. Frequencies are set via a 16-position manual switch or by RS-422/485 control, with 100-ms typical switching speed. Standard frequency step size is 1 kHz, with options as small as 0.001 Hz. Phase noise is –84 dBc/Hz offset 1 Hz from a 500-MHz carrier and –55 dBc offset 1 Hz from a 6-GHz carrier. In-band spurious noise is –65 dBc, with no harmonics. The synthesizer, which is designed for operating temperatures from –40 to +60°C, measures just 4.5 × 6.0 × 0.5 in. Higher-frequency versions and custom models are also available. The GFS-500M6G offers +13-dBm minimum output power and works with a 10-MHz reference. The synthesizer is suitable for radar, satellite-communications (satcom), and electronic-warfare (EW) systems.

GEOSYNC MICROWAVE, INC., 320 Oser Ave., Hauppauge, NY 11788; (631) 760-5567, *www.geosyncmicrowave.com*

GaN-on-SiC Devices Meet Space Requirements

HIGH-POWER GALLIUM-NITRIDE-ON-SILICON-CARBIDE (GaN-on-SiC) power transistors have been qualified through extensive testing to comply with NASA's reliability standards for satellite and space systems. The compliance applies to discrete devices as well as GaN monolithic microwave integrated circuits (MMICs). Through testing by KCB Solutions (www.kcbsolutions.com), an AS9100-certified facility with experience in Class-S and Class-K requirements, the GaN-on-SiC devices were found to meet NASA EEE-INST-002 Level 1 reliability and performance standards derived from military-grade Class C and Class K qualifications. In particular, testing was performed on GaN-on-SiC model CGH40025F and GaN model CMPA801B025F devices based on the company's 0.4-µm G28V3 semiconductor process. Model CGH40025F is a +28-V dc high-electron-mobility transistor (HEMT) capable of 25 W peak output power from DC to 6 GHz. Model CMPA801B025F is a +28-V dc GaN HEMT power amplifier capable of 25 W peak output power from 8 to 11 GHz. Both devices met or exceeded specified performance levels after all testing, including exposure to radiation exceeding 1 Mrad.

WOLFSPEED, A CREE CO., (866) 924-3645, (919) 287-7888, *www.wolfspeed.com*

Diplexer Diminishes Losses to 3.92 GHz

DIPLEXER MODEL 802857 provides passbands of 698 to 980 MHz and 1,396 to 3,920 MHz with better than 14-dB passband return loss and no more than 1.1-dB passband insertion loss. The channel-to-channel isolation is 60 dB or better. The diplexer is supplied with female SMA connectors and measures 4.0 × 2.0 × 1.0 in. and handles power levels to 25 W CW. It is designed to maintain performance levels for operating temperatures from –25 to +85°C.

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

Three-Way Divider Runs 8 to 18 GHz

MODEL P3S-12.000 is a three-way Wilkinson power divider designed for broadband applications from 8 to 18 GHz. It features low 0.7-dB insertion loss across the full frequency range with at least 20-dB isolation between ports. The typical VSWR is 1.40:1, while the amplitude balance is maintained within ±0.4 dB.

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

Terminations Trim PIM to 2.7 GHz

A LINE OF TERMINATIONS with low passive intermodulation (PIM) has been developed for cellular and wireless applications from 380 MHz to 2.7 GHz. The terminations, which are now available with 7/16 DIN, 4.3/10.0 DIN, and Type-N connectors, minimize typical PIM levels to between –160 and –165 dBc when tested with two 20-W tones at +25°C. The product line includes models with power ratings of 10, 30, 50, and 100 W usable at operating temperatures to +85°C.

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

Connector Interface Minimizes Mobile PIM

THE 4.3-10 CONNECTOR INTERFACE was developed for mobile communications applications that require exceptional passive-intermodulation (PIM) performance. Its PIM performance is superior to that of 7-16 DIN and 4.1-9.5 interfaces, with lower weight and volume than 7-16 DIN connectors. The 4.3-10 connector system is IP68-rated, will support up to 500 W at 2 GHz, and meets IEC standard 61169-54. The connector interface is a strong candidate for remote radio heads, jumpers, and antennas in wireless base stations.

RF CONNECTORS, A DIVISION OF RF INDUSTRIES, 7610 Miramar Rd., San Diego, CA 92126; (858) 549-6340, (800) 233-1728, e-mail: rfi@rfindustries.com, *www.rfindustries.com*

MEMS Foundry Offers Through-Silicon Vias

THE CAPABILITY TO FABRICATE through-silicon vias (TSVs) has been added to a comprehensive list of microelectromechanical-systems (MEMS) foundry services. The 30,000-ft.^{2} foundry, which processes wafers as large as 6 in. for high-volume production, produces surface and bulk MEMS devices as well as electrostatic and electromagnetic (EM) actuators. The conductor-filled TSVs exhibit DC resistance of less than 0.01 Ω per via and insertion loss of only 0.01 dB at 6 GHz. The TSVs can be formed with different hole diameters and depths, such as 15-μm diameter with 50-μ depth and 50-μm diameter with 250-μm depth. The foundry also offers hermetic wafer-level packaging (WLP) of customer-designed components.

INNOVATIVE MICRO TECHNOLOGY, MEMS Technology Center, 75 Robin Hill Rd., Santa Barbara, CA 93117; (805) 681-2852, *www.imtmems.com*

Kits Weatherproof Coaxial Connectors

THE IPB WEATHERPROOFING SYSTEM provides protection for coaxial connector interfaces in cable assemblies for long-term outdoor deployments, as well as for short-term mission-critical use. These weatherproofing boots are available in different interface sizes, such as Type-N and 7/16 DIN, with Type-N boots covering any connector smaller than a mini DIN connector. The protection is available, for example, for straight and right-angle male and female Type-N,

BNC, and TNC connectors and for a wide range of coaxial cables, including the firm's LMR-400 and LMR-600 cables, as well as 0.25- and 0.5-in. helically corrugated cables. The boots are IP68-, RoHS-, and REACH-compliant.

TIMES MICROWAVE SYSTEMS, 358 Hall Ave., Wallingford, CT 06492; (203) 949-8400, *www.timesmicrowave.com*

Monolithic Amplifier Drives 50 MHz to 6 GHz

MODEL PHA-1H+ is a wideband monolithic amplifier for use from 50 MHz to 6 GHz. The RoHS-compliant amplifier is matched to 50 Ω, with typical small-signal gain of 13.8 dB at 2 GHz and typical output third-order intercept point of +40.4 dBm at 2.4 GHz. The enhanced-pseudomorphic-high-electron-mobility-transistor (e-PHEMT) amplifier achieves typical noise figure of 2.6 dB to 4 GHz and 3.4 dB to 6 GHz and is supplied in a SOT-89 housing.

MINI-CIRCUITS, P.O. Box 350166, Brooklyn, NY 11235-003; (718) 934-4500, *www.minicircuits.com*

Isolators Handle 50 to 220 GHz

THE MFXXXX- SERIES of millimeter-wave isolators are smaller than Faraday isolators while still providing full waveguide-band frequency coverage. The isolators incorporate input and output ports at 11.2-deg. orientation, with excellent impedance matching. With models operating over six waveguide bands from 50 to 220 GHz, these compact isolators feature typical VSWR of 1.30:1 and no higher than 1.40:1. The isolators are available in electric-to-magnetic (E-to-H) plane, as well as E-to-E plane configurations.

MICROWAVE RESOURCES, INC., 14250 Central Ave., Ste. D, Chino CA 91710; (909) 627-4125; e-mail: sales@microwaveresourcesinc.com, *www.microwaveresourcesinc.com*

> "These VCXOs offer excellent time-domain performance and low noise to help achieve high levels of signal integrity in numerous high-speed logic circuits."

The CVPD-922 oscillators support power-efficient designs with low current consumption and fast switching between enabled/disabled logic modes (controlled by package pin number 2). They feature a maximum startup time of 2 ms, with typical startup time of only 1 ms. The oscillators' output disable time is only 200 ns. They offer typical tuning sensitivity of +25 ppm/V for a tuning range of 1.65 ± 1.65 V dc. In addition, the VCXOs provide a typical 3-dB modulation bandwidth of greater than 10 kHz.

The crystal oscillators are available with a standard operating-temperature range of 0 to +70°C and an operating-temperature range of –40 to +85°C as an option. They operate on a supply voltage of +3.3 ± 0.3 V dc with maximum current consumption of 88 mA. They are extremely stable with time, with an aging rate of less than 3 ppm during the first year of operation, and then less than 1 ppm per year after that. The oscillators conform to the applicable mechanical and environmental conditions of MIL-STD-883.

The CVPD-922 oscillators are supplied in surface-mount-device (SMD) housings measuring 0.560 × 0.360 × 0.210 in. (14.12 × 9.14 × 5.3 mm). They come in tape-and-reel packaging for automated electronic manufacturing lines. mw

CRYSTEK CRYSTALS, a division of Crystek Corp., 12730 Commonwealth Dr., Fort Myers, FL 33913; (239) 561-3311, (800) 237-3061, *www.crystek.com*

Wideband PLL Stabilizes 20 MHz to 9.8 GHz

MODEL LMX2592 is a low-noise, wideband phase-locked-loop (PLL) frequency synthesizer with integrated voltage-controlled oscillator (VCO) capable of a frequency range of 20 MHz to 9.8 GHz. It supports both fractional-N and integer-N modes, with a 32-b fractional divider allowing fine frequency selection. The PLL achieves integrated noise of 49 fs for 6 GHz output and phase noise of –134.5 dBc/Hz offset 10 MHz from a 6-GHz carrier. The device features a great deal of control, including programmable phase adjustment and programmable charge-pump current. It works with input clock frequencies to 1.4 GHz and operates on a single +3.3-V dc supply. It can be used with two differential outputs, as well as single-ended outputs.

TEXAS INSTRUMENTS, P.O. Box 655303, Dallas, TX 75265; *www.ti.com*

GaN Amplifier Module Powers 9.2 to 10.0 GHz

MODEL BPMC928109-1000 is a Class-AB linear high-power amplifier module capable of 1,000 W peak output power from 9.2 to 10.0 GHz. Based on gallium-nitride (GaN) semiconductor technology, it achieves nominal gain of 60 dB, with power gain variations held to ±2 dB across the full frequency range. The rugged amplifier module handles pulse widths from 0.25 to 100 µs at maximum duty cycle of 10%. Pulse droop is less than 0.5 dB and pulse rise/fall time is typically better than 60 ns. Input VSWR is less than 1.50:1 while output load VSWR is less than 2.0:1. Second harmonics of better than –40 dBc and third harmonics of better than –50 dBc. The power amplifier module, which is well suited for phased-array radar systems, runs on a +28-V dc supply. It is supplied with SMA input connectors and TNC connectors on the output port, with subminiature-D connectors on the DC and interface ports. The amplifier module measures 9.6 × 6.8 × 2.15 in. and weighs 5 lb. It handles operating temperatures from 0 to +55°C with no degradation in performance, and includes thermal and load-mismatch protection as well as pulse-width and duty-actor protection

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

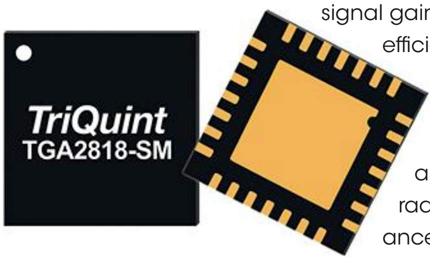
OCSO Achieves Low Noise at 3,200 MHz

MODEL LNO 3200 B3 is a low-noise oscillator with integral multiplier that offers stable output signals at 3200 MHz. The unit includes a surface-acoustic-wave (SAW) oscillator and ×10 multiplier to reach the final 3,200-MHz frequency. The oven-controlled SAW oscillator (OCSO) can be equipped with an optional phase-lock loop (PLL) for locking to an external 10-MHz reference source. The 3,200-MHz oscillator provides sinewave outputs at +5 dBm nominal output power. The frequency is calibrated at the factory within ±0.2 ppm of the final 3,200 MHz. The OCSO achieves typical phase noise of –130 dBc/Hz offset 1 kHz from the carrier and –154 dBc/Hz offset 10 kHz from the carrier, with a noise floor of –157 dBc/Hz. It measures 120.7 × 76.2 × 23.3 mm and runs on supply +10 V dc with a control voltage range of +2 to +8 V dc. The source has an operating temperature range of 0 to +50°C.

RAKON LTD., 8 Sylvia Park Rd., Mt. Wellington, Auckland 1060, New Zealand; (64) 9-573-5554, *www.rakon.com*

GaN-on SiC Amp Powers 2.8 to 3.7 GHz

RFMW HAS ANNOUNCED SUPPORT for the model TGA2818-SM S-band amplifier from Qorvo. The two-stage amplifier provides more than +45.5 dBm (30 W) saturated output power from 2.8 to 3.7 with better than 18.5-dB large-signal gain and more than 47% power-added efficiency (PAE). It is fabricated with a 0.25-μm gallium-nitride-on-silicon-carbide (GaN-on-SiC) semiconductor process. Suitable for commercial and military applications including radar systems, the amplifier is impedance matched to 50 Ω. It is supplied in a compact 6 × 6 mm QFN surface-mount package and draws 200 mA current from a +28-V dc supply.



RFMW, LTD. (Qorvo Stocking Distributor), 188 Martinvale Lane, San Jose, CA 95119; (408) 414-1450, *www.rfmw.com*

Amplifier Boosts 225 to 2,600 MHz

THE NUPOWER 11B02A MODEL NW-PA-11B02A is a power amplifier (PA) designed to deliver at least 7 W and typically 10 W output power from 225 to 2,600 W when driven with a 2-mW (+3-dBm) input signal. The PA is supplied in a rugged aluminum chassis measuring 2.34 × 11.96 × 0.620 in. and is a drop-in replacement for the firm's model NW-SSPA-MINI-10W-0-0.225-2.6 with improved switching speed. It can switch between standby and operating modes in less than 100 μs to conserve energy in power-limited applications. It can operate over a broad supply-voltage range of +11 to +32 V dc for a great deal of application flexibility, including running on battery power.

NUWAVES LTD., 132 Edison Dr., Middletown, OH 45044-3269; (513) 360-0800, *www.nuwaves.com*

PXI Multiplexers Extend to 600 MHz

A LINE OF MODULAR PXI MULTIPLEXERS now includes 18 different configurations, including a PXI two-slot, 32:1 configuration for applications through 600 MHz. The series 40-760 multiplexers can be supplied in dual, quad, and octal single-pole, four-throw (SP4T) configurations; as single, dual, and quad single-pole, eight-throw (SP8T) units; and as single and dual single-pole, 16-throw (SP16T), and single-pole, 32-throw (SP32T) units. All include versions with automatic terminations to minimize VSWR when used in test and other critical signal switching applications. Insertion loss is minimized and well matched across all signal paths. The multiplexers are compatible with standard PXI chassis and can be fitted to PXI hybrid slots in a PXIe chassis. They can also be used in the firm's LXI Modular chassis for users requiring control via Ethernet port.

PICKERING INTERFACES LTD., Stephenson Road, Clacton-on-Sea, United Kingdom; +44 (0) 1255-687900, e-mail: sales@pickeringtest.com, *www.pickeringtest.com*

Transmit-Receiver Module Fits Cellular Handsets

FLEXIBLE CELLULAR TRANSCEIVER MODULE SKY77927-11 SkyLITE is designed for quad-band GSM/GPRS/EDGE handsets. Its coverage extends to 850/900-MHz bands, 1,800/1,900-MHz bands, and more, including Long-Term-Evolution (LTE) bands 34 and 39. The transceiver measures just 5.5 × 5.5 × 0.8 mm in a 44-pin multi-chip-module (MCM) configuration complete with power amplification and switching for minimum complexity in designing a cellular telephone circuit board. Transmit harmonics are less than –40 dBc, while power amplifier efficiency is 35% or better.

SKYWORKS SOLUTIONS, INC., 20 Sylvan St., Woburn, MA 01801; (781) 376-3000, e-mail: sales@skyworksinc.com, *www.skyworksinc.com*

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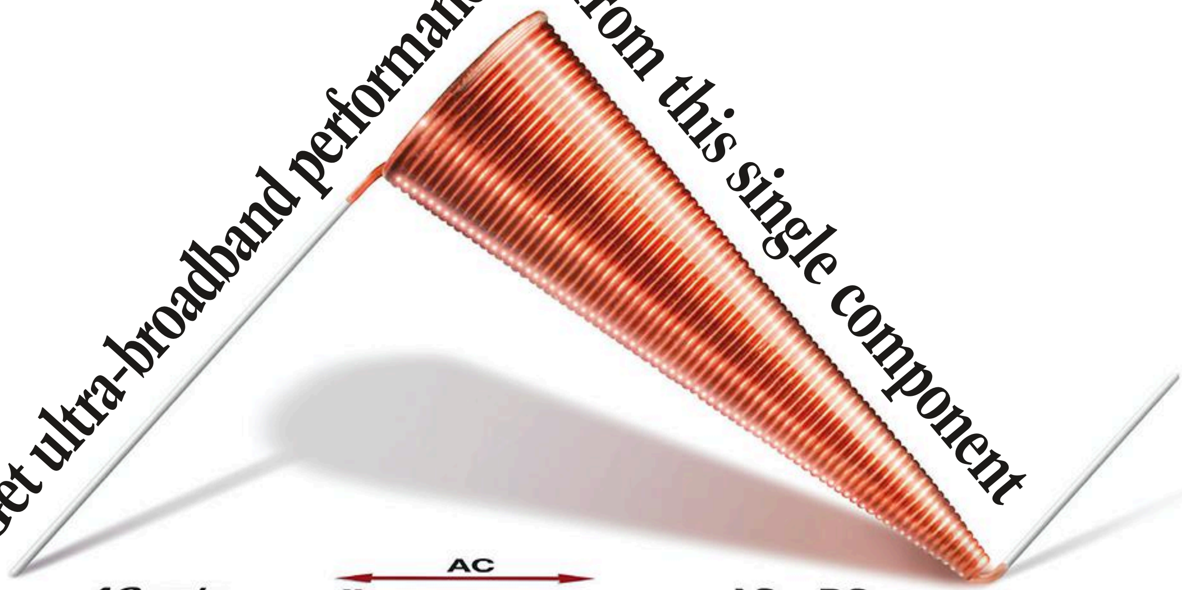
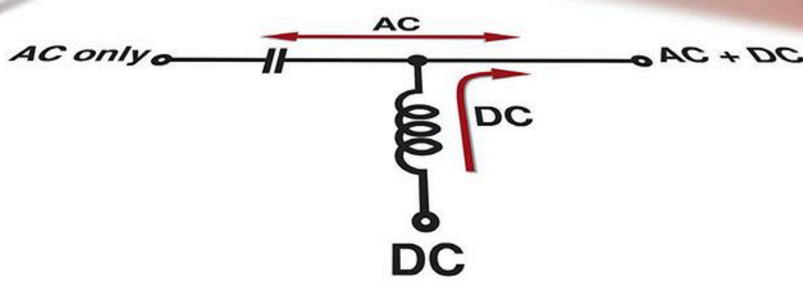




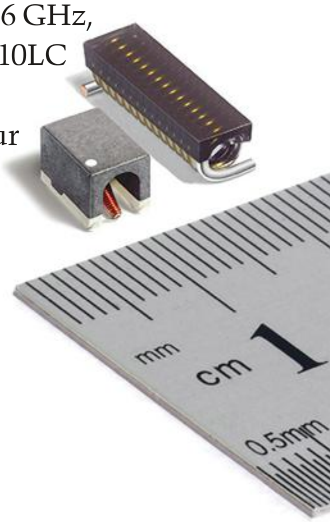
Ideal for use in Bias Tees, Coilcraft conical inductors offer flat bandwidth and high impedance to 40 GHz

Coilcraft BCL/BCR Series conical inductors operate across a frequency range of 10 MHz to 40 GHz, letting you replace a series of narrow band inductors with one part.

Both series provide excellent return loss and insertion loss. Their unique conical shape optimizes the effects of capacitance, maintaining high impedance across your frequency spectrum.

Choose from a rugged, surface mount package or our flying lead configuration. And for applications below 6 GHz, try our high current 4310LC wideband bias choke.

Learn more and order your free evaluation samples by visiting us online at: **coilcraft.com/conicals.**



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