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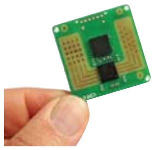

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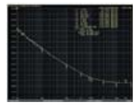

A Different View of Power Sensors | 70

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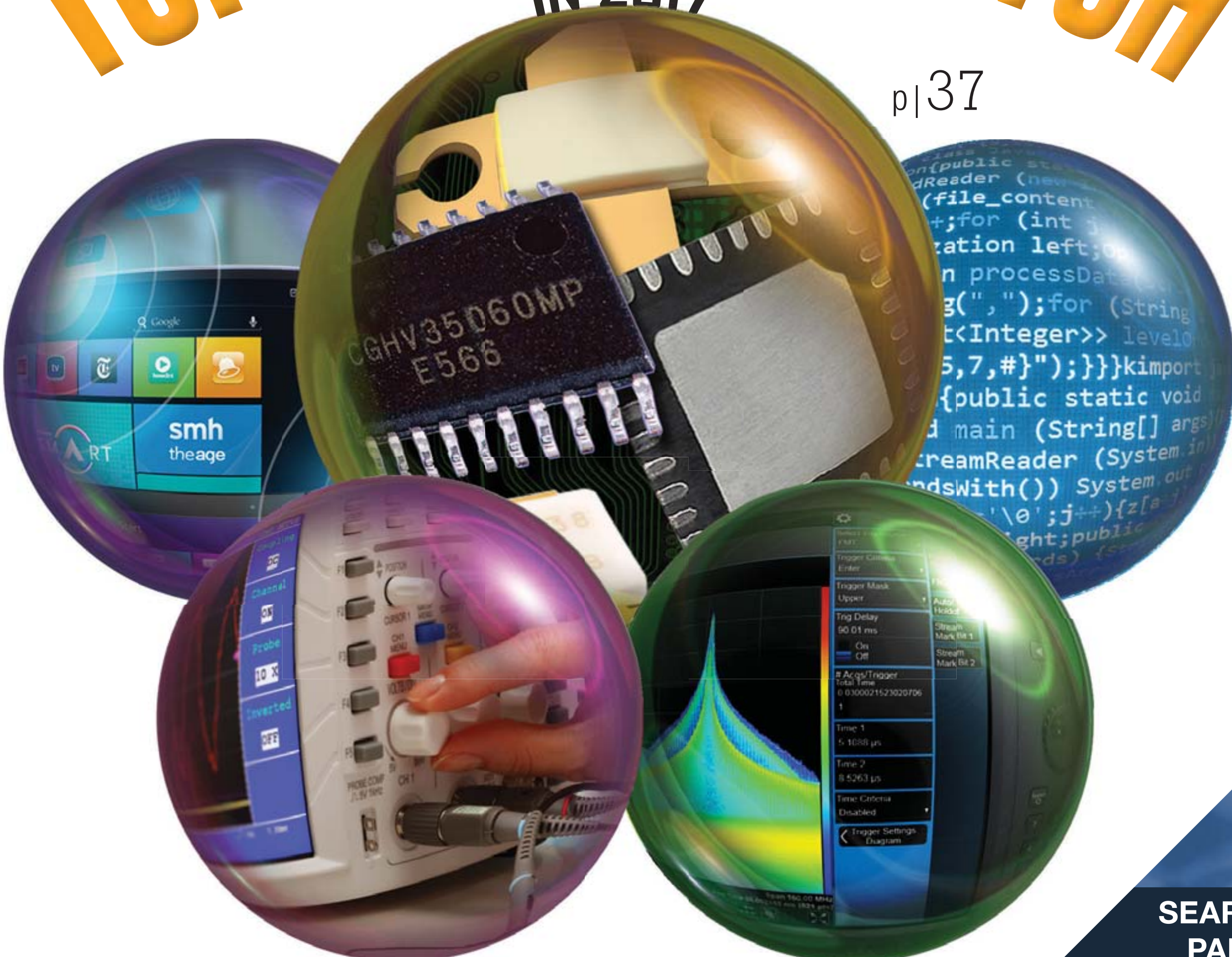

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	Doubler Power Amplifier	MAFC-011009, 28 - 30 GHz
	L-Band Power Amplifier Module	MAAP-011060, 1616 - 1627 MHz
Test & Measurement	Wideband Power Amplifier	MAAP-011247, DC - 22 GHz
	Wideband Low Noise Amplifier	MAAL-011141, DC - 26.5 GHz
	Wideband DBL BAL Mixer	MAMX-011036, 8 - 43 GHz
Aerospace & Defense	Octave Band VCO	MAOC-415000, 10 - 20 GHz
	Power Amplifier	MAAP-011232, 0.1 - 3 GHz
Industrial, Scientific & Medical	Low Noise Amplifier	MAAL-011129, 18 - 32 GHz
	Gain Block	MAAM-011206, DC - 15 GHz
Wired Broadband	Variable Gain Amplifier	MAAM-011194, 45 - 1218 MHz
	Gain Block	MAAM-011220, 45 - 1218 MHz
	Very Low Noise Amplifier	MAAL-011136, 45 - 1218 MHz

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- Couplers (Quadrature, 180° & Directional)
- Detectors – RF/Microwave
- DLVAs, ERDLVAs & SDLVAs
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- Form, Fit, Functional Products & Services
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- Switched Filter Banks
- Switches – Solid State
- Systems – Fly Eye Radars
- Threshold Detectors
- USB Products

PMI designs and manufactures a variety of coaxial monopulse compartors for beamforming antenna applications up to 26.5 GHz. Form, fit and functional designs can also be replicated to specific requirements. Standard models with various options are available at PMI's website (Link below)

http://pmi-rf.com/Products/monopulse_comparators/features.htm

Model: MPC-20R2G21R2G-CD-LNF
8 Input Monopulse Compartor with Gain

Frequency	20.2 - 21.2 GHz
Gain	0 dB, 5 dB Nom. (Selectable)
Noise Temperature /Figure	100 K / 1.3 dB Noise Figure
Phase Balance	±3° Maximum
DC Supply	+12 VDC @ 700 mA, -12 VDC @ 100 mA
Temperature	-55 °C to +85 °C

Package Size:
6.25" x Ø4.80" x 2.00"
Connectors: SMA (F)

Model: PMC-3G3D5G-6D8-SFF
4 Input Monopulse Comparator

Frequency	3.0 to 3.5 GHz
Insertion Loss	0.8 dB Max. - Measured 0.4 dB
VSWR	1.25:1 Max. - Measured 1.25:1
Isolation	23 dB Min. - Measured 25.052 dB
Amplitude Balance	±0.4 dB Max. - Measured ±0.2681 dB
Phase Balance	±5° Maximum - Measured ±3.2°
RF Input Power	Average: 11 Watt Max. Peak: 0.1 kW Max.
Temperature	-55 °C to +85 °C

Package Size:
3.23" x 3.23" x 0.43"
Connectors: SMA (F)

Model: PD-CD-001-1, 4 Way Phase Shift
Power Divider with 0°, 90°, 180°, 270° Outputs

Frequency	9.3 - 9.9 GHz
Insertion Loss	8.0 dB Max. - Measured 6.97 dB Max
VSWR	2.0:1 Max. - Measured 1.60:1 Max.
Amplitude Balance	±0.5 dB Max. - Measured ±0.2 dB Max.
Phase Balance	±7.0° Max. - Measured ±4° Max.
RF Input Power	28 W CW, 750 W Peak
Temperature	-32 °C to +77 °C Operating

Package Size:
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Connectors: SMA (F)

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VOLUME 56, ISSUE 1

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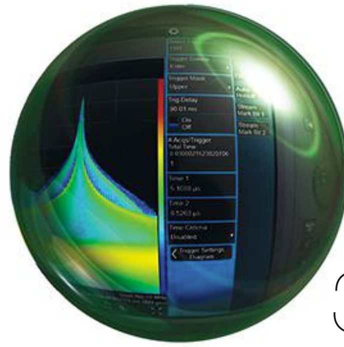

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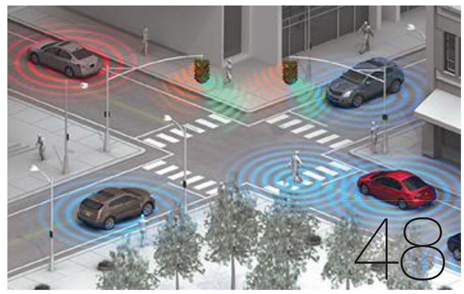

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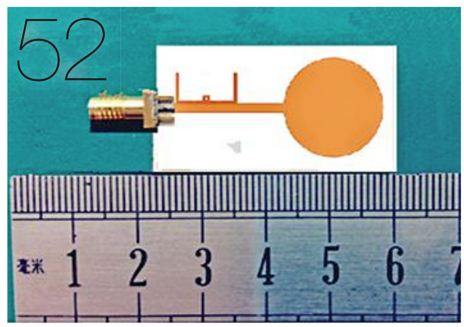

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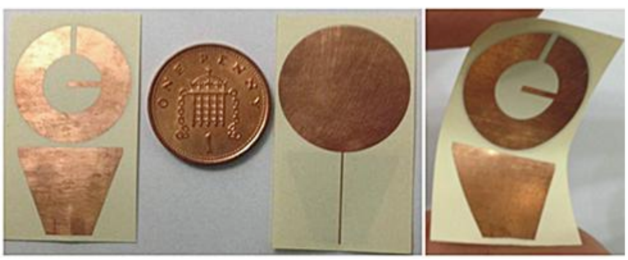

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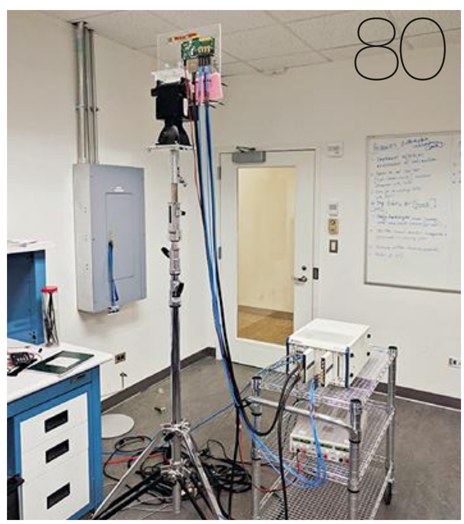

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PRODUCT TECHNOLOGY

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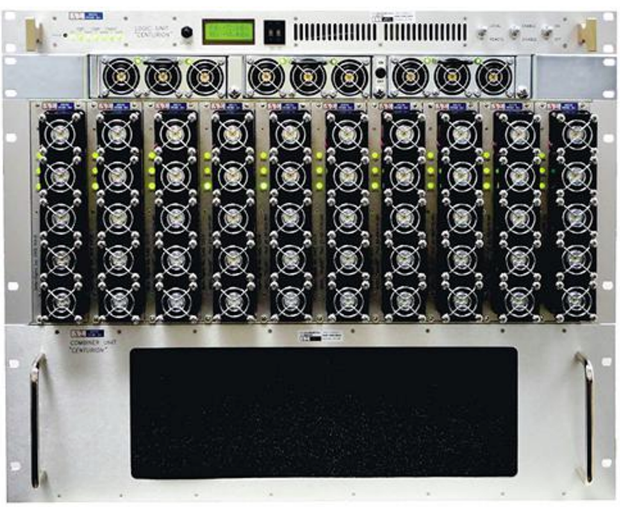
Example of conservatively-rated 150 to 218 MHz, 1 kW CW module for AM, FM, CW, or pulse applications in a ruggedized 4.1 x 2.7 x 1.2 in., 17 oz. package. Rated for altitudes to 30,000 ft. and MIL-STD-810F Method 516.5 shock and vibration.



This amplifier delivers 16 kW at a 20% duty cycle from 3.5 to 450 MHz with transmit and receive switching less than 1.5 µs with 60-dB isolation in a 24 x 19.25 x 18 in. enclosure.

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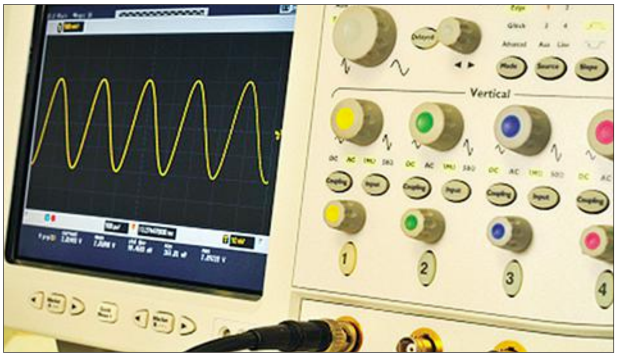
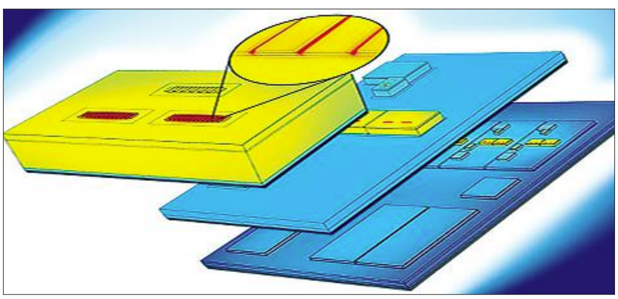


FIERCELY INDEPENDENT IN MAKING MEASUREMENTS

http://mwrf.com/blog/fiercely-independent-making-measurements

Every editor covering electronics technology dreams about having their own test laboratory—a station to provide our observations on the "published specifications" provided to us when writing stories about RF/microwave hardware. But be careful what you wish for.



TRACKING EFFECTS OF TEMPERATURE

http://mwrf.com/software/tracking-effects-temperature

Thermal modeling is becoming a more important part of the electronic design process, especially with increasing efforts to pack more power into smaller electronic devices. Quite simply, power = heat. Where power is generated or transferred, any form of loss will result in the production of heat. For the preservation of an electronic design, the heat must be efficiently removed.

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ARE YOU BEING AFFECTED BY PHASE COHERENCE?

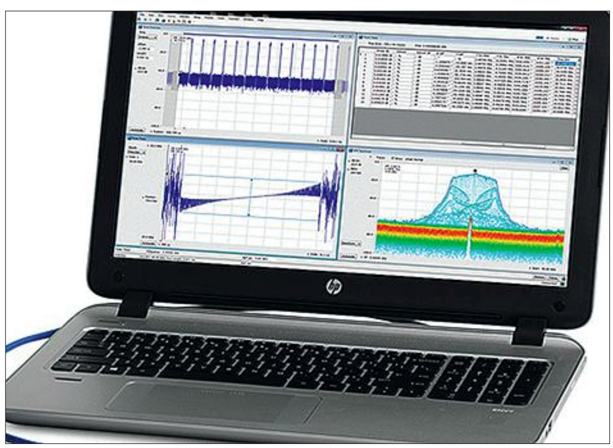
http://mwrf.com/blog/are-you-being-affected-phase-coherence

Phase coherence can be an ambiguous topic, yet one that's important for RF, electrical, and design engineers to understand. This article will set out and build upon some basic definitions, ultimately enabling you to determine if and why phase coherence is affecting your various designs and applications.

CRITICAL TALKING POINTS IN TEST & MEASUREMENT

http://mwrf.com/test-measurement-analyzers/critical-talking-points-test-measurement

As wireless technology continues to invade our lives, suppliers of test-and-measurement equipment must keep up by offering the proper test solutions to meet today's needs. And the same suppliers must also think in terms of the future, with 5G obviously being on the minds of many.



Editorial

CHRIS DeMARTINO
Technical Editor
chris.demartino@penton.com

Will 2017 Be the Year of the Engineer?

All things considered, 2017 certainly looks to be a significant year for the RF/microwave industry. Of course, we will continue to hear about 5G as it inches closer to reality. We can also expect to hear all sorts of reports concerning the Internet of Things (IoT). Driverless cars are sure to make headlines, too. The list goes on.

Whether it's texting a friend or watching a YouTube video on an iPhone, wireless technology is now clearly entrenched in our lives. It is impossible to walk around here in New York City and not see people texting on the street or looking at something on their phone while waiting for the train. We can get so distracted by a text message conversation that we become unaware of what's happening around us (I have been guilty of this myself).

Although wireless technology is such a major part of our lives, does society appreciate the engineers who are responsible for it? Are engineers more or less appreciated than, say, teachers and health professionals? Teachers should be respected—their jobs can often be difficult and stressful. I have teacher friends who can certainly attest to that. The same can be said for the nursing profession. I also know several nurses who can relate to having stressful jobs. One can make the case that teachers and nurses are seriously underappreciated (but I won't get into that here).

What about engineers? Are they appreciated? I'm not sure, but it is clear that many people—and understandably so—have no idea of the concept of RF/microwave engineering. I am positive that many of you reading this right now have experienced telling someone that you work in the "microwave" industry—or for a "microwave" company—only to wind up explaining to that same person that you don't actually work with microwave ovens. This simply underscores how wireless technology is relied upon, but not really understood.

Whether you may or may not feel appreciated, you should nonetheless feel some satisfaction today if you are a part of this industry. After all, you are creating the technology that so many people depend on—whether they realize it or not. mw

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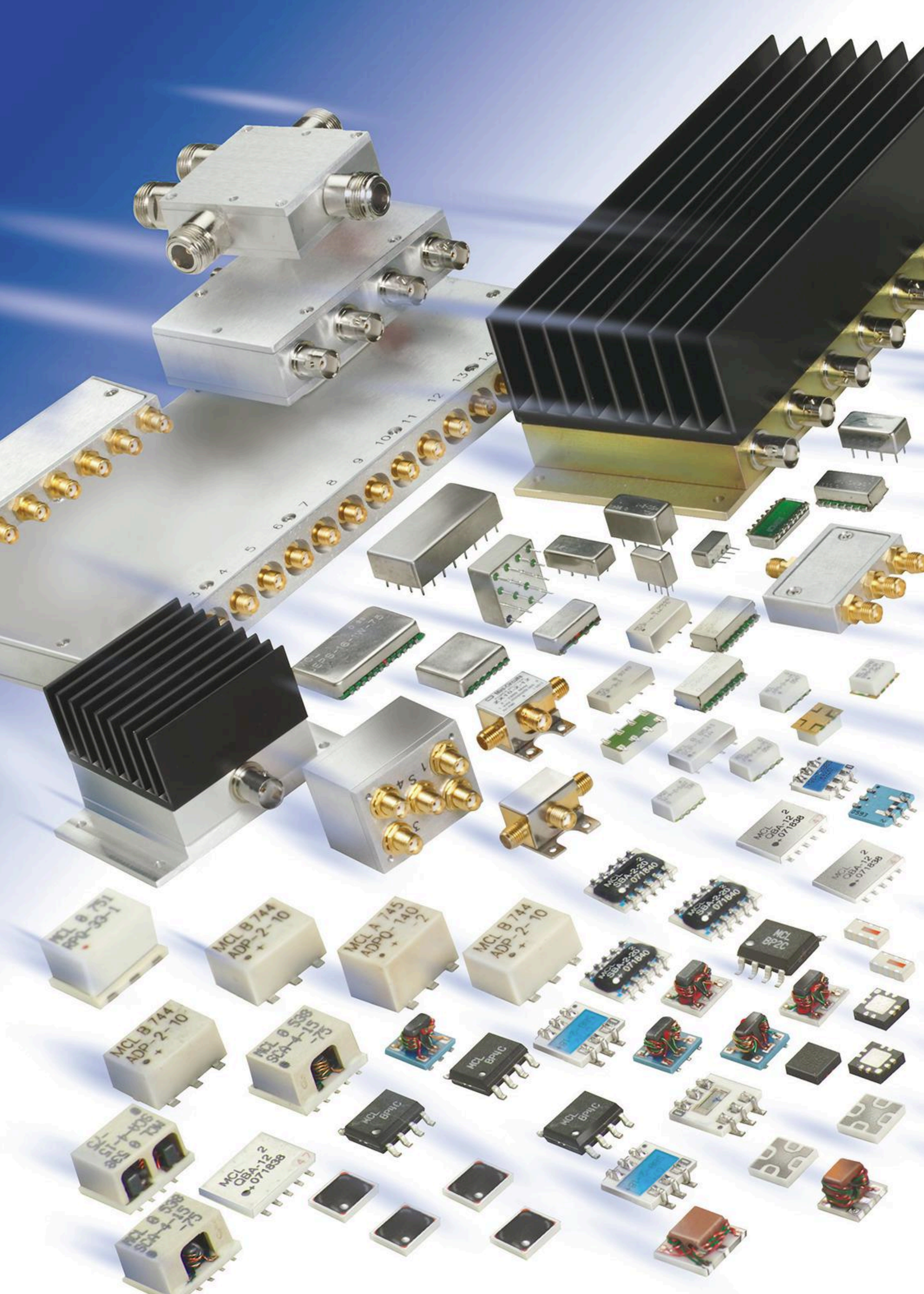

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ANOTHER PATH TO INDEPENDENCE?

I really enjoyed reading your article titled "Fiercely Independent in Making Measurements" just now (available on *mwrf.com*). Your quest to "set up a test station to provide observations on published specifications" reminded me of someone else I know: me.

I launched JitterLabs (*www.jitterlabs.com*) last year as an independent test lab for characterizing clock sources for timing noise—primarily phase noise and jitter, which as you know are hotly contested and important specifications for their manufacturers and customers. It took me years to design and create a laboratory, in which I obsessed about providing the most accurate data. I even obtained several patents, including one to remove spurs introduced by an oscilloscope. I also developed techniques to reduce artifacts introduced by baluns when measuring phase noise, something which the industry had not been aware of.

The lab's boundaries extend online, where all the test data is hosted for clock-device vendors, who use custom software to explore the data, run analyses, export results, etc. Additionally, it allows their customers to input custom specifications for clock performance (phase noise masks, jitter limits, custom filtering, etc.), and apply them to test data to create compliance statements. This way, customers can compare the performance of competing vendors' products, apples-to-apples. Any company can share their data with any other company they choose, to facilitate business. It's quite a novel business plan, which attempts to streamline traditional business processes by moving them online for greater efficiencies and cost savings.

While I can't loan you test equipment, I can provide perhaps something better—independent test data (which might be all you wanted, anyway), along with detailed documentation about how it's obtained, and software that runs in your favorite web browser to analyze the data in accordance with its intended end application.

Thanks for letting me share my experience. Please keep me in mind if I can ever help you out.

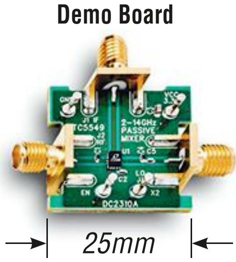
Gary Giust, Ph.D., JitterLabs

EDITOR'S NOTE

Thanks for reading, and thanks for replying. JitterLabs sounds like it could provide an invaluable "second look" at a clock, especially since the clock is so critical to the performance of so many systems—whether commercial comms or military EW. We appreciate your offer to take a look at stuff for us. Perhaps we'll be able to take you up on it down the road. For now, at least, we can help spread the word that you and JitterLabs are out there and ready.

Jack Browne, Technical Contributor


Tx
LTC5549
Rx
LTC5549


25mm

TAKING WIRELESS SENSOR Networks out of Factories and Putting Them in Cars

There are many potential stumbling blocks to using wireless technologies inside cars, including metal parts that could prove difficult for wireless signals to get through.

Inside its Silicon Valley wafer factory, Linear Technology has installed wireless sensors to monitor gas cylinders used in the manufacturing process and alert managers when to replace them. The chipmaker had little trouble selecting which sensors to buy—it designed them.

The sensors, equipped with wireless technology called SmartMesh IP, have found early success in the industrial Internet of Things, which aims to increase manufacturing efficiency by using sensor data and sharing it between machines. Linear Technology says that over 50,000 SmartMesh networks have been installed in places like GlaxoSmithKline's factory in Cork, Ireland, where they observe the drug company's water storage tanks.

But the company's engineers have a vision of pushing SmartMesh out of its industrial nest. Linear Technology recently said that it helped build a battery-management system for electric vehicles using SmartMesh chips and battery monitors. The idea was to cut out the complex and costly wiring that normally connects auto electronics.

The system paired the wireless SmartMesh devices with battery-monitoring circuits capable of tolerating lots of electrical noise and wide operating temperatures inside the battery cells of a BMW i3 electric vehicle. The devices reported the charge of each battery using a wireless technology called mesh networking, which shares wireless signals within a small community of the chips.

The battery-management system was built by Lion Smart using components from Linear Technology, which showed the BMW test vehicle at the electronica trade show in Munich, Germany in November. It stands out for using technology that was originally developed to cut costs and make it easier to add cheap sensors inside high-voltage factory environments.

The results were similar in new battery-management systems, said Erik Soule, Linear Technology's vice president of signal conditioning products, in a recent interview. The wireless chips eliminate the wires that normally deliver battery readings to a central computer, improving reliability and simplifying designs. There is a constant threat that the wires will shake loose or fail while driving.

The power required to drive electric cars is not usually contained in a single large battery. In the BMW i3, for example, two separate battery packs are located in the front and back of the vehicle. Reporting their status to a central point normally falls to wires, like the popular CAN Bus cable or a proprietary technology like Linear Technology's isoSPI cable.

SmartMesh takes the cables out of the equation, allowing engineers to install the battery packs and sensors where wiring harnesses can't fit, said Soule. Getting more data about the batteries, like current and temperature, is as simple as adding more sensors. The wireless chips are also cheaper than the cabling, he said.

There are many potential stumbling blocks to using wireless technologies inside cars, said Soule. Electric cars are not safe environments for wireless signals. There are many metal parts that could prove difficult for wireless signals to get through and the high-voltage electronics create tons of electromagnetic noise.

But SmartMesh uses both path and frequency diversity, which routes the messages around obstacles as well as dampen interference. It is also constantly watching the network so that it can hop between channels when one gets too crowded. Linear Technology boasts that SmartMesh networks are "99.999% reliable."

The system has its limitations, though. Soule cautioned that SmartMesh doesn't have the response times to stream data from critical sensors like radar or cameras that could help a vehicle automatically avoid a collision. The devices, which can synchronize their clocks to within several microseconds, were originally developed for factories and environmental sensing, prioritizing reliability and low power consumption over speed.

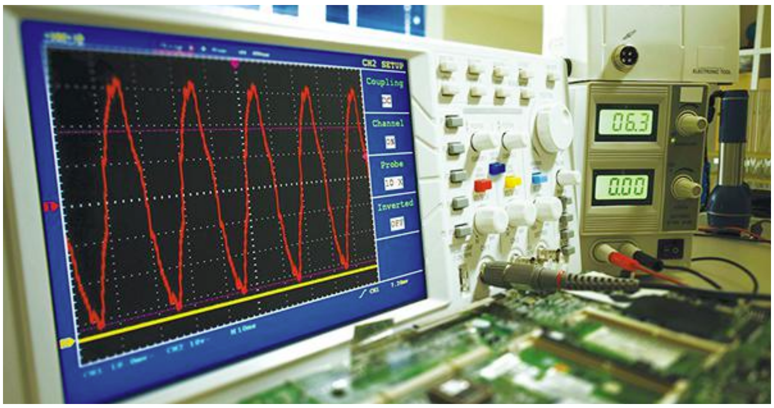
The concept of using wireless sensors inside cars also has history working against it. In 2010, researchers found that hackers could hijack the wireless pressure sensors built into the tires of some luxury vehicles. The researchers warned that criminals could exploit the vulnerability to track a vehicle or force its electronic control system to malfunction.

Soule pointed to SmartMesh's AES128 encryption as a thick insulation against hackers, but he also admits that the system is still a proof-of-concept. He said that he talked with representatives from several German automakers at the electronica demonstration. "There is huge interest," he noted.

Linear Technology acquired SmartMesh through its acquisition of Dust Networks in 2011, on the premise that its sensor networking chips could provide a wider audience for the power-management chips for which it is known. The technology has kept a low profile in the $14.7 billion deal that Linear Tech signed in May to be acquired by Analog Devices, which is increasingly courting factories and cars with its chips. ■

MODULES EXTEND FREQUENCY Range of Testers into Millimeter-Wave Territory

MILLITECH RECENTLY RELEASED a pair of wireless modules that bolt onto test equipment and extend their frequency range into millimeter waves. It represents a part of the wireless spectrum that is being plumbed for transmitting a much larger volume of information than today's low frequencies.



Millitech wireless modules link to existing testers using standard connectors, saving engineers money that would otherwise be spent on custom test setups.

The Spartan Test Modules, as they are called, extend a vector network analyzer into the 69-GHz range, also known as the V-band, and the 90-GHz or E-band range. The modules link to existing testers using standard connectors, saving engineers money that would otherwise be spent on custom test setups, the company said.

Millitech, which is based in Northampton, Mass., and is a subsidiary of Smiths Interconnect, said that the modules were designed to test radar components, like switches and filters, which must be tested over a wide frequency range. The receiver part of the module can also double as a downconverter for extending the range of spectrum analyzers.

The modules represent one of the latest attempts to make regular test equipment compatible with millimeter frequencies, which are challenging to generate and often require multiple devices. Another effort came from National Instruments, which in February 2016 revealed a radio platform to better understand the behavior and capabilities of millimeter waves, which have already been opened for communications.

In July, the Federal Communications Commission ruled to open new bands of unlicensed spectrum between 64 and 71 GHz. Many companies have already started pilots of next-generation wireless gear. Intel is testing millimeter-wave equipment at its headquarters in Austin, Texas. The company is trying out the 15- and 28-GHz bands, which like all millimeter waves, have trouble traveling far and penetrating obstacles. ■

TELEDYNE ACQUIRES
e2v Technologies in $789 Million Deal

TELEDYNE TECHNOLOGIES RECENTLY SIGNED a deal to acquire e2v Technologies, a maker of radio-frequency parts and machine-vision systems, for $789 million. Teledyne said that e2v's technology would mesh with the mixed-signal and imaging products it sells to aerospace and defense firms.

The deal is the latest evidence of Teledyne's sensitive trigger finger for acquiring new technologies and the engineers behind them to enhance growth. Teledyne, which acts like a holding company for around 70 different divisions, has focused in recently years on systems engineering, machine vision, and instrumentation in aerospace, defense, healthcare, and other markets.

e2v Technologies, which is based in Chelmsford, UK, is known for making image sensors and power components for radio-frequency applications in healthcare, factories, and wireless communications. It offers microprocessors and other chips for commercial airplanes, as well as assembly and packaging services for semiconductors. It also builds satellite parts hardened against dangerous radiation.

In September 2016, e2v released a new phase-locked loop (PLL) that can be used in satellite control systems. The PLL is based on novel silicon-on-insulator technology. In December, it claimed to have built the first digital-to-analog converter that can generate K-band signals, which are harnessed for radar and satellite communications, without a mixer.

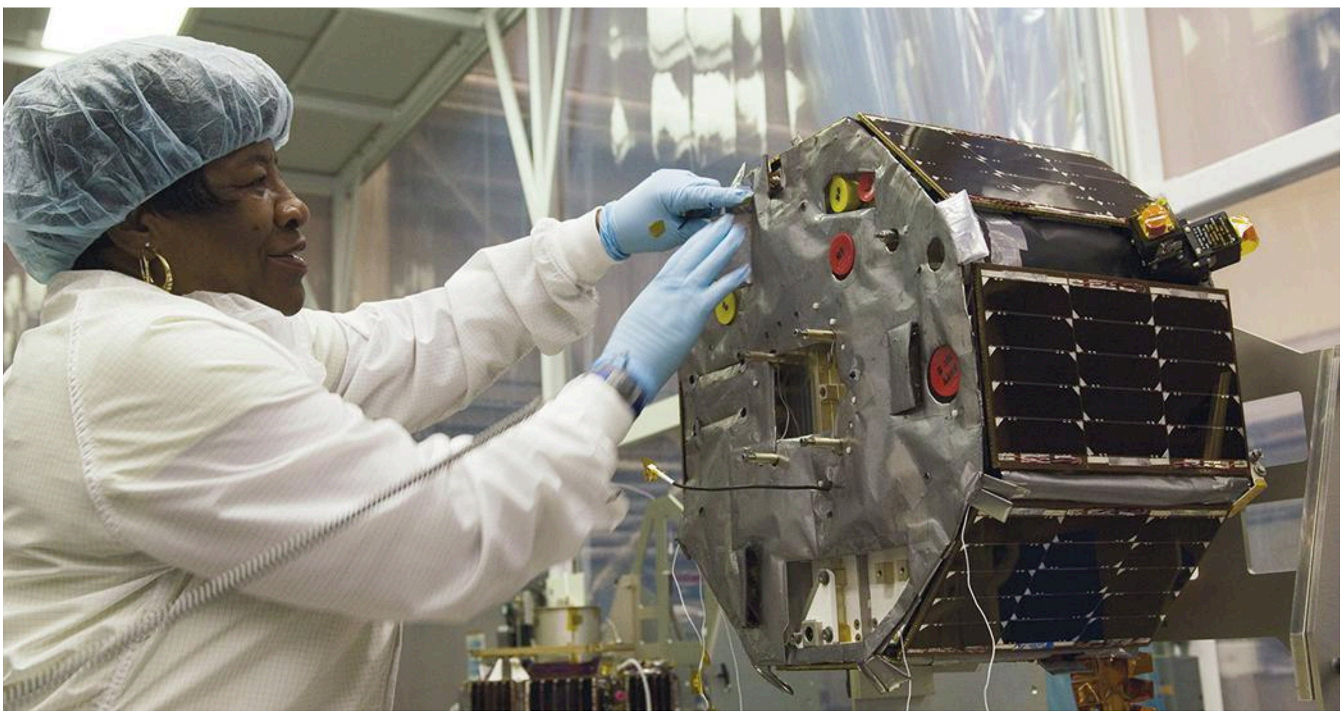
Teledyne said that these types of parts complement its microwave electronics and assemblies. "While we both provide microwave devices, e2v's largest product and market are magnetrons for cancer radiotherapy," said Robert Mehrabian, Teledyne's chief executive, in a statement. "Teledyne supplies solid-state and vacuum microwave systems, but no magnetrons, and we primarily serve defense markets such as electronic warfare, radar, and communications."

e2v has also built radio systems for specific customers like law-enforcement agencies. In 2013, the company disclosed that it was working on a system that projects radio pulses to remotely shut down the electronics in motorcycle and car engines. It creates a similar effect to an electromagnetic pulse at a distance up to 50 meters.

Neil Johnson, e2v's chairman, said in a statement that the company would benefit from "being part of a larger, complementary group with enhanced scale and a wider range of capabilities to service its key customers and management." e2v's board of directors, he said, had approved the deal.

With previous deals, Teledyne has acted like a holding company, forming subsidiaries like Teledyne LeCroy, a maker of electronic test equipment, to operate independently. Neither company said whether e2v, which employs around 1,700, would become a subsidiary or be absorbed by other Teledyne units, like its Microwave or Microelectronic Technologies divisions. Over the last year, e2v had sales of around $340 million and netted about $60 million in profit.

The deal is expected to be completed in the first half of 2017. ■



Teledyne said that e2v's technology would mesh with the mixed-signal and imaging products it sells to aerospace and defense firms.
(Image courtesy of NASA Goddard Space Flight Center, Creative Commons)

COMPOUND SEMICONDUCTOR Maker II-VI Expands Factory

II-VI INC. IS expanding a factory for compound semiconductors used in displays, laser sensors, and radio-frequency devices. The company, based in Saxonburg, Pa., expects four times the number of chips will leave the new plant by 2020.

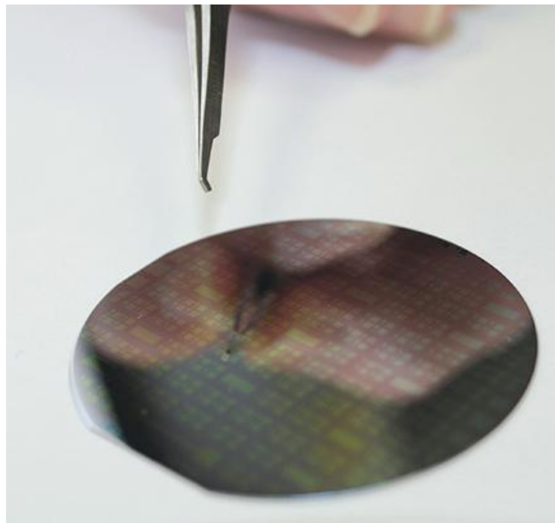
The factory under renovation is located in Champaign, Ill., and is operated by EpiWorks, a chipmaker that II-VI purchased for an undisclosed sum in February 2016. EpiWorks is known for manufacturing epitaxial chips out of extremely thin layers of semiconductors like indium phosphate and gallium arsenide. Both are critical building blocks for optical as well as wireless chips.

Before it acquired EpiWorks, II-VI built other semiconductors in the arcane field of electrical materials, including silicon carbide and zinc sulfide. Vincent Mattera, II-VI's CEO since September, has followed his predecessor Francis Kramer in laying ambitious plans for new technology.

The company is building clean rooms in Illinois for new manufacturing tools, but also a special laboratory for testing wafers. And renovating a chip factory is not to be taken lightly. The facility must be designed to be extremely clean, free of even a single speck of dust that can corrupt a chip's circuits.

After the EpiWorks deal closed, the company ordered three new specialized semiconductor machines that filled the available space in the Illinois plant, according to Quesnell Hartmann, one of the co-founders of EpiWorks, in a recent statement. "These systems have already been installed and we have now moved into the next phase of growth," he added.

The renovations are scheduled to be finished in mid-2017. In the meantime, II-VI is hiring engineers and plant managers to help run the bigger facility. The new hires will oversee the production of devices based on indium phosphate (InP) and gallium arsenide (GaAs). The products will include optoelectronic parts for data centers, semiconductor lasers, and specialized chips for 5G wireless infrastructure.



Before acquiring EpiWorks, II-VI built other semiconductors in the arcane field of electrical materials, including silicon carbide and zinc sulfide. *(Image courtesy of UCL Engineering, Creative Commons)*

While most chipmakers contract foundries to manufacture chip designs, II-VI has expanded its manufacturing operations in recent years. Before it signed the deal with EpiWorks, it also bought Anadigics, a maker of compound semiconductors for wireless chips, for $78.2 million. The deal ended a surprise bidding war between an unidentified Chinese firm and GaAs Labs, the holding company for Macom.

II-VI disclosed in a recent government filing that it had sold some of Anadigics' radio-frequency technology for around $45 million. But the company kept Anadigics' manufacturing plant in New Jersey, which had produced GaAs wafers measuring six inches. II-VI plans to build optical components known as vertical-cavity surface-emitting lasers with the old equipment. ■

QUANTENNA FOLLOWS UP with Second 802.11ax Chip

BACK IN OCTOBER, Quantenna revealed the first known chip to support an embryonic form of Wi-Fi, which will not be released until around 2019. At the Consumer Electronics Show (CES) in Las Vegas earlier this month, the company previewed its second chip based on the standard, called 802.11ax.

The new chip, QSR5G-AX, supports an early draft of the standard, which technology analysts and industry executives have painted as a significant upgrade to the latest 802.11ac version of Wi-Fi. It will not increase download speeds explicitly, but instead will improve how Wi-Fi networks share the available airwaves to reduce traffic.

The Wi-Fi Alliance has said that 802.11ax will coordinate multiple antennas to send multiple streams of data to devices. Each stream is split again with orthogonal frequency-division multiple access, or OFDMA, a variation on the technology used in modern cellular networks, creating a bigger pipeline for data. In contrast, earlier forms of Wi-Fi created multiple streams but assigned only one to each device.

The new standard aims to provide better coverage in places bursting with mobile devices and connected sensors, like apartment buildings and offices. Wi-Fi networks in your neighbor's apartment or the office below yours can cause interference. It will also provide download speeds to over 10 Gb/s.

"802.11ax is the future of Wi-Fi," said Sam Heidari, Quantenna's CEO, in a statement. The company has jumped out ahead of major rivals like Broadcom, which last year completed its $37 billion merger with Avago to form Broadcom Incorporated. And that has given Quantenna clout with investors, who gave it around $160 million in funding before it went public late last year.

The QSR5G-AX supports eight total streams for routers and set-top boxes. Four of the streams occupy the 5-GHz band and four are in the 2.4-GHz band. The 5-GHz spectrum holds more room for wireless traffic than 2.4-GHz, which is at varying degrees by earlier standards.

The new chip is a slightly lighter version than the first 802.11ax chip released by Quantenna in October, the QSR10G-AX, which supports 12 streams of data. That device is a drop-in replacement for older chips based on the company's 802.11ac chip architecture.

Both chips will be compatible with 802.11ax devices, like smartphones or computers, said the company. They will also be compatible with existing standards, like 802.11ac and 802.11n. Quantenna plans to begin sampling both the QSR10G-AX and QSR5G-AX chips in early 2017. It did not say when either chip would enter production. ■

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BOOSTING POWER WITH SILICON CMOS

SILICON CMOS SEMICONDUCTOR technology has been the basis for a wide range of analog, digital, and mixed-signal semiconductor devices. Traditionally, though, it does not fare well in high-frequency amplification applications. A different semiconductor technology, such as gallium arsenide (GaAs), is typically recruited to raise the amplitude of high-frequency signals.

In hopes of gaining more power at higher frequencies from Si CMOS, Jie Cui from the School of Electrical and Optical Engineering, Nanjing University of Science and Technology (Nanjing, China) and Purdue University (West Lafayette, Ind.), working with Sultan Helmi, Yingheng Tang, and Saeed Mohammadi from Purdue Univ., reviewed a great deal of the work already performed on increasing the operating frequencies of Si CMOS processes. In concert, they stacked on-chip transistors in different configurations to achieve higher levels of output power.

The team reviewed the performance levels of a number of different stacked CMOS PAs, operating from RF through millimeter-wave frequencies, including a number of PAs developed at Purdue. As with other researchers, they discovered that various limitations in Si CMOS must first be overcome for higher performance. For example, output power is limited by the low breakdown voltages of CMOS. In addition, limitations in frequency, efficiency, and bandwidth are caused by the parasitic elements of active and passive components in CMOS technology, including on-chip passive components with high loss (e.g., inductors, transformers, and transmission lines).

Some of the parasitic limitations can be overcome by using a substrate material with high thermal conductivity, such as aluminum nitride (AlN), in place of the standard Si-based substrates. In addition, the use of an enhanced silicon-on-sapphire (SOS) CMOS process can also minimize parasitic elements when fabricating PA circuitry for improved higher-frequency performance.

Employing an innovative interconnection scheme, the three transistors of a triple-cascode cell were fabricated and stacked using a combined layout cell with low parasitic elements. The researchers were able to achieve power outputs at frequencies approaching the performance levels of commercial GaAs PAs.

One of the designs features a stacked transistor configuration and switchable input matching network for optimizing wideband performance by dividing the total bandwidth into two portions. When the input matching switch is in the “on” state, the PA covers a bandwidth of 1.8 to 2.4 GHz; when the switch is in the “off” state, the PA operates across a bandwidth of 2.4 to 3.4 GHz. This particular design provides 6-dB gain with better than +13 dBm output power at 1-dB compression (P1dB) with better than 13% peak power-added efficiency (PAE). Fabricated with a 0.25-μm SOS CMOS process, it is a good example of the higher-frequency PA performance achievable with Si CMOS.

See “Stacking the Deck for Efficiency,” *IEEE Microwave Magazine*, Vol. 17, No. 12, December 2016, p. 55.

REGISTERING HIGH RFID ISOLATION

RADIO-FREQUENCY-IDENTIFICATION (RFID) TECHNOLOGY continues to spread as a reliable means of wireless security for many systems. These include readers that transmit signals to remotely power transceivers without batteries, which return signals to the reader at the same frequency. Effective operation requires adequate isolation between the two signals and the transmit and receive paths, which is typically achieved by two separate bistatic antennas or a single, switchable monostatic antenna.

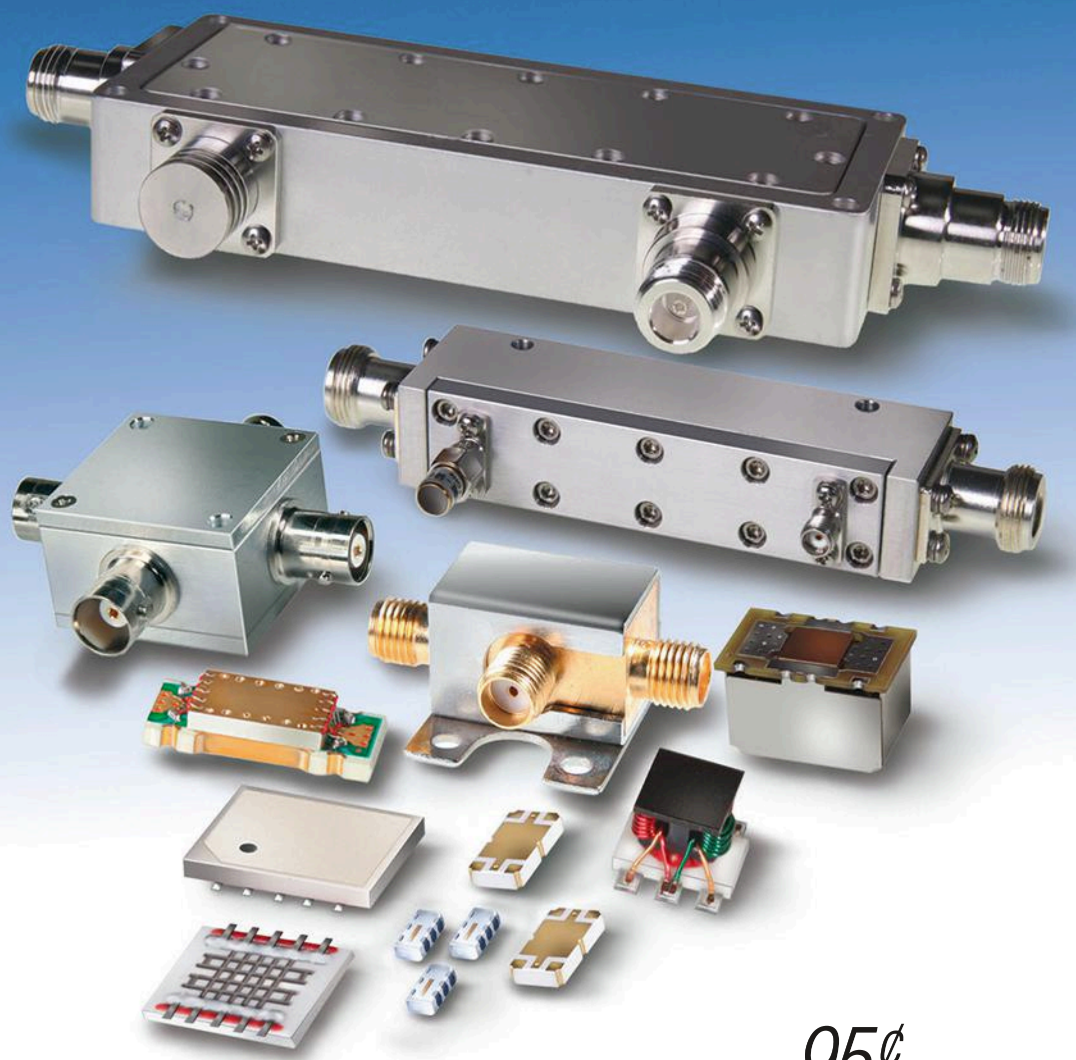
Because both approaches can suffer from leakage of transmit power into the RFID reader, researchers Alirio Boaventura, Joao Santos, Arnaldo Oliveira, and Nuno Borges Carvalho of the Instituto de Telecomunicações, Departamento de Eletrònica, Telecomunicações e Informática, Universidade de Aveiro, Portugal, explored various self-jamming cancellation techniques for commercial RFID integrated circuits (ICs), including methods currently used in radar systems.

Such factors as signal reflections; RFID tag movement and resulting modulation from RFID tag antennas; lack of isolation from passive couplers in RFID antenna connections; and interference from nearby radio systems can result in jamming of RFID systems. Without sufficient isolation, power from these different sources can leak into the RFID receiver section and cause an overload of the receiver front end.

One proven method for cancelling self-jamming signals is to use a sample of the self-jamming signal to create an out-of-phase version of the signal to cancel the interference. This classical approach involves amplitude and phase control to create a reliable self-jamming cancellation signal, leaving only the RFID information signal.

Through experimentation using baseband approaches, the researchers developed several approaches suitable for passive RFID designs based on algorithms that form lowpass filters (LPFs) and highpass filters (HPFs) for the removal of self-jamming interference in RFID systems. The approaches are meant to extend the range of passive RFID systems and, as the researchers explain, have already been adopted in a number of commercial RFID ICs. The techniques have proved effective in minimizing self-jamming effects for RFID systems even under transient operating conditions.

See “Perfect Isolation,” *IEEE Microwave Magazine*, Vol. 17, No. 11, November 2016, p. 20.



Inside TRACK with James Kimery,

for RF Communications and Software-Defined Radio (SDR), National Instruments

Interview by CHRIS DeMARTINO, Technology Editor

__JAMES KIMERY__ is the director of marketing for RF, communications, and software-defined radio (SDR) initiatives at National Instruments (NI). He is responsible for the company's communication system design and SDR strategies. Kimery also manages NI's advanced research RF/Communications Lead User program.

5G is obviously receiving lots of attention. In your own words, can you tell us why we need 5G?

There are several reasons, but I believe that there are two primary drivers. First, we all know and have experienced the transformational impact of the smartphone. Our mobile smart devices have become an indispensable part of our lives and drive our collective demand for mobile broadband data, resulting in an exponential increase in broadband data. Unfortunately, industry analysts predict the growing demand for mobile data will outstrip capacity in the not-so-distant future. To keep up with rising demand, new capacity is needed. That's where 5G comes in—5G promises significant increases in data rates as well as capacity.

Second, the concept of a network encompassing increased capacity, increased bandwidth, and perhaps even lower latency will inevitably give rise to a wealth of new applications and services that could transform our lives, once again spawning new businesses and unlocking enormous economic potential. Service operators are motivated to move 5G forward to increase revenue by offering new services for businesses and consumers beyond broadband data and voice, igniting an ecosystem of suppliers primed to deliver solutions that capitalize on these new capabilities.

To conclude, there are two primary drivers for 5G—one based on our need for faster data and more capacity than our current 4G networks, and the other rooted in the nascent wireless broadband movement but augmented by new 5G capabilities. The 5G network will enable entrepreneurs to create applications, services, and solutions that take full advantage of the network's new functionality and hopefully create tremendous business opportunities.

Millimeter-wave frequencies are clearly tied to 5G. Where do you see that going?

On July 14, 2016, the FCC moved forward with reclassifying the following spectrum bands as mixed-use, including mobile access: 28-GHz (27.5 to 28.35 GHz), 37-GHz (37 to 38.6 GHz), and 39-GHz (38.6 to 40 GHz) bands, and a new unlicensed band at 64 to 71 GHz. In total, the FCC essentially allocated almost 14 GHz of licensed and unlicensed spectrum for 5G. As such, the United States became the first country in the world to designate spectrum for 5G operation and more aggressively designated specific centimeter- and millimeter-wave spectrum as potential spectrum targets.

Although these centimeter- and millimeter-wave frequencies have been designated for 5G by the U.S., global harmonization is a challenge. The WRC—the ITU group responsible for global spectrum harmonization—noted in 2015 that the 28-GHz band cannot by allocated globally, meaning the U.S. and other countries that have available spectrum around 28 GHz may likely join together to move asynchronously forward. Without global agreement on spectrum for 5G, worldwide acceptance and adoption of 5G technologies may be challenged.

In addition, the smartphone industry today enjoys tremendous benefits from economies of scale with the harmonization of the standard and spectrum bands regionally (and also technology with few vendors dominating the global market). 5G will need this type of harmonization to maximize the impact.

Furthermore, Verizon announced a "5G Specification" and plans for fixed wireless deployment intended for "last mile access" to residential homes. Although not technically 5G, Verizon has seen the opportunity and vision to move forward with millimeter-wave technologies to address a near-term opportunity. And this move could potentially pave the wave for a broader 5G millimeter-wave deployment for mobile access.

When we met at NIWeek, you mentioned how you think 5G's modulation scheme may simply be orthogonal frequency-division multiplexing (OFDM). Do you still feel that's the case?

Yes. In fact, since NIWeek, the 3GPP has kicked off several study items related to Release 15, otherwise known as the 5G release. Because the 3GPP is a consensus-building organization, OFDM seems to be the strongest candidate for Phase 1 5G standardization. Although competing waveforms are technically still alive and viable, OFDM seems to have the broadest support—and in a consensus organization, popularity matters. Other flavors of filtered OFDM are still being considered, but the path for inclusion is not quite as straightforward or clear.

Massive multiple-input, multiple-output (MIMO) technology is something that is linked to 5G. Can you tell us a little about it?

Unlike 3G or 4G systems, massive MIMO employs hundreds of antennas at the base station to exploit the numerous degrees of freedom that these many antennas can deliver. Lund University and the University of Bristol were able to demonstrate last spring the vast potential of massive MIMO by prototyping a 128-antenna system with 22 UEs. These researchers achieved a spectrum efficiency of over 145 b/s/Hz, which is over 15× the current LTE systems. Spectrum below 6 GHz is scarce, and by using massive MIMO rather than conventional LTE, networks could increase capacity by over 15× using relatively low-cost technology.

The 3GPP is still considering massive MIMO for inclusion in Release 15, and many aspects to massive MIMO must be worked out at a system level. However, there seems to be genuine interest and motivation to work through these issues and build consensus before June 2018, which is the current scheduled date for finalization of Phase 1 of 5G.

What challenges are associated with 5G testing?

5G offers tremendous potential benefits over our current networks, and in the end, new technologies are needed to realize these systems. In order for millimeter-wave systems to be viable, it is almost certain that high-gain, phased-array antennas will be needed at the base station and at the UE to overcome the path loss at these frequencies.

These antenna beams are highly directional at such frequencies and may be packaged with the silicon, producing a module that includes the transceivers, low-noise amplifiers (LNAs), power amplifiers (PAs), and the antenna. With this type of packaging, instrument access with a cable is not possible and the specter of over-the-air testing of these modules must be considered. Over-the-air testing introduces many variables not encountered with cabled testing, and this is a research area for test-and-measurement companies.

Massive MIMO also presents challenges in that massive-MIMO base stations feature hundreds of transceiver chains and MIMO processing, and these systems differ dramatically from current 4G implementations. With massive MIMO, each individual transceiver chain can be tested individually, but a test capable of testing all transceiver chains in aggregate is surely needed to obtain error-vector-magnitude (EVM) measurements—a common method to assess the performance characteristics of a transceiver. Testing one receiver or one transmit path is not sufficient to measure EVM of the system.

To address the massive-MIMO test challenge, one could envision a signal generator with 128 or more outputs and a vector signal analyzer (VSA) with the same number. Cost-effectively delivering this type of instrument requires test-and-measurement companies to be creative.

What developments do you think will occur in 2017 that will bring 5G closer to reality?

Two really important events will happen in 2017. The work items for 3GPP Release 15 are expected to be set in March. So by March of 2017, we should have a good picture of the 5G Phase 1 specification, although there will be several months of work ahead for the 3GPP membership.

Second, I mentioned earlier the Verizon 5G specification. I believe there will be a big focus on what Verizon does in the 28-GHz band. Although Verizon may not deploy mobile access equipment, and perhaps the specification may be short of a comprehensive 5G mobile access network, the Verizon work will be the first commercial widespread deployment of centimeter-/millimeter-wave technology in the world. In some ways, the Verizon progress may be an early indicator of the success of 5G mobile access networks. In other words, if Verizon is successful with their field trials and deployments, this will bode well for future 5G millimeter-wave deployments.

Lastly, when do you expect to see the first 5G deployments?

The Korean government is pushing very hard to have 5G trial deployments in time for the 2018 Winter Olympics in Pyeoungchang, and these deployments are widely expected to be at 28 GHz. Given the timing of the specification finalization—June 2018—it is unclear whether these trial deployments will be standard-compliant. However, if both Verizon and the Korean operators such as Korea Telecom and South Korea Telecom are successful with their initial millimeter-wave deployment goals, then we may all see and experience 5G much sooner than 2020. mw

CHRIS DeMARTINO | Technical Editor

5 Technology Areas to Watch in 2017

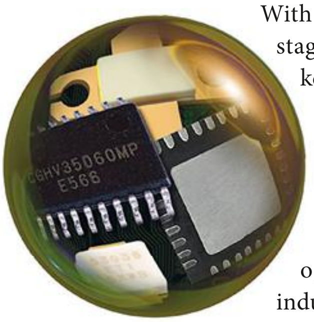
This year, expect to see the RF/microwave industry produce solutions that push technological boundaries to meet new and emerging requirements.

When forecasting what 2017 has in store for the RF/microwave landscape, it led to one concrete conclusion: The industry is primed to continue delivering its share of innovative technology solutions. Both commercial and military applications demand cutting-edge devices, components, and systems as well as the latest design software and test-and-measurement equipment. And with companies focused on making 5G a reality, the industry shows no signs of slowing down.

Speaking with those throughout the industry revealed a number of predictions for 2017. For one, size, weight, and power (SWaP) constraints will be ever-more stringent for aerospace and defense systems. Radar applications will take advantage of emerging technology to offer performance that surpasses the capabilities of older systems. Of course, gallium-nitride (GaN) technology will play a key role in all of these developments.

Moreover, mobile communication demands will lead to challenging filter requirements. Proper antenna solutions are needed, too, as more people drop cable service. In addition, providers of design software tools and test-and-measurement equipment must deliver solutions to satisfy rapidly changing needs.

With these prognostications setting the stage, here are five industry sectors to keep a close eye on this year:



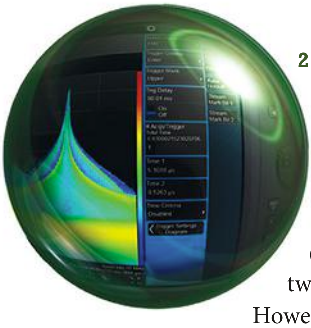
1. SEMICONDUCTOR TECHNOLOGY

By now, GaN technology's huge impact on RF/microwave technology should be apparent to all in the industry. In 2017, we can surely expect to see GaN in heavy doses. One well-documented benefit of GaN lies in the realization of smaller form factors, making it vital when it comes to meeting today's SWaP requirements.

"In 2017, we expect to see a continued push toward more stringent SWaP requirements for upgraded and next-generation aerospace and defense systems—particularly for radar applications," says Kevin Harrington, director of strategic marketing, discrete products group, Microsemi *(www.microsemi.com)*. "New power lineups based on GaN-on-silicon carbide (GaN-on-SiC) provide higher power-added efficiencies (PAEs) and smaller form factors that were not possible in older radar systems. Combining GaN-on-SiC with continued advances in thermal design packages and smart chip design for peak RF and thermal performance will help continue to push the limits of SWaP requirements.

"Monolithic microwave integrated circuits (MMICs) will continue to have a critical role in advanced electronic-warfare (EW) solutions," continues Harrington. "Mixed technology, gallium arsenide (GaAs), GaN, and silicon germanium (SiGe) each offer critical performance advantages. GaN MMICs have pushed higher power capability over wide bandwidths, while GaAs MMICs maintain higher linearity and low noise figure at lower power levels. Added functionality to standard building blocks will help system-level designers optimize the various lineups needed in EW and electronic-countermeasure (ECM) systems."

Harrington believes there will be an ongoing move to more integrated solutions. He notes, "Higher levels of integration will also be a continued trend in 2017. This will happen either through multi-chip modules (MCMs) for higher power applications using GaN, GaAs, and silicon-diode technologies, or through SiGe BiCMOS for lower power, highly integrated RF integrated circuits (RFICs). This trend is seen in many market applications, including military communications, smart munitions, avionics, and radios."



2. FILTER REQUIREMENTS

Intensifying demands of mobile communications have created a need for more advanced RF filter solutions. Firms such as Qorvo *(www.qorvo.com)* and Broadcom *(www.broadcom.com)* represent two of the major players in this space. However, newer companies like Resonant *(www.resonant.com)* and Akoustis *(www.akoustis.com)* are now making their presence felt, too.

"For 2017, band proliferation, higher data rates, and minimizing the number of smartphone models continue to drive the growth and complexity of filters," says Mike Eddy, vice president of marketing at Resonant. "Hence, the expectation is that the number of filters sold will increase to more than 45 billion in 2017, according to [market research firm] Navian."

Eddy adds, "These are the trends for filters in mobile devices, which are the largest filter market:

- **Increasing number of filters per device:** More RF paths within the device from multiple antennas and spectrum proliferation will continue to grow and require more filters. Thus, filter size and cost must continue to decrease.
- **Increasing integration:** RF front-end performance is crucial. Maximizing power-amplifier (PA) efficiency on the uplink and receiver sensitivity on the downlink will require optimization of the entire RF chain. As complexity increases, understanding the RF chain and any interactions between elements becomes crucial. For filters, optimizing the interface to the PA and the low-noise amplifier (LNA) will be required in the filter design process.
- **Complex multiplexing:** Carrier aggregation (CA) for higher data rates will drive more complex multiplexing, which in turn drives more complex filters.
- **More demanding specifications:** Isolation, loss, and power-handling requirements continue to create new challenges. Filters in the RF chain are a major contributor to loss, which is critical for total transmit (Tx) efficiency (and ultimately for the PA current draw and for battery life) as well as the total noise figure in the receive (Rx) path (and ultimately for the signal-to-noise ratio and the data rate)."

3. ANTENNA SOLUTIONS

Another key technology area that bears watching in 2017 is the antenna. Interestingly enough, the large number of people who are dropping cable service, or "cord-cutting," has led to greater demands for adequate antenna performance, according to one company. Jeff Shamblin, chief scientist at Ethertronics *(www.ethertronics.com)*, explains, "Adoption of video streaming is accelerating and the move is on to cancel cable subscriptions. The main drawback is that the local TV channels provided as part of a cable subscription are no longer available to the consumer. In 2017, we can expect around 24 million non-paying TV households."

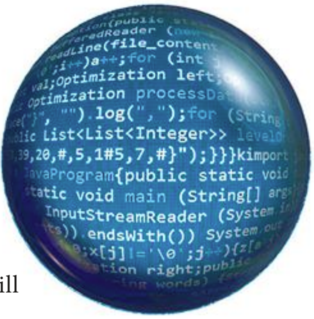
Shamblin is quick to point out how dropped cable service requires proper antenna technology. He explains, "The relevant problem to solve for cord-cutting systems is antenna selection and placement. A lot of neighborhoods with single-family homes have restrictions on placement of TV antennas outdoors. Additionally, for consumers living in apartments and condos, there are restrictions on roof access that add to the antenna siting task. The popular approach is to use a small antenna indoors to connect to the TV tuner to access over-the-air (OTA) signals.

"This current approach of placing a passive antenna at a location in a room in a home provides you the ability to sample the signal at that one location," he notes. "Since this is an indoor environment, there will be reflected signals bouncing around the room. The antenna will in reality be picking up multiple signals and coupling them into the OTA receiver. The shape of the radiation pattern and polarization of the passive antenna is fixed, i.e., one radiation pattern only per channel and a fixed polarization state of the antenna. This fixed radiation pattern will not be optimized for reception of the multiple reflected signals in the room across all of the TV channels."

According to Shamblin, utilizing an LNA in these scenarios is not the proper solution: "Attempting to improve a passive antenna by adding an LNA typically fails since the LNA will amplify noise along with the TV signal received by the antenna. As a result, the signal-to-noise ratio (SNR) is slightly lower than it is without the amplifier since the LNA has losses. LNAs are recommended when using an outdoor antenna and a long cable run, with the LNA providing the capability of boosting the signal at the antenna prior to the losses associated with the long coaxial cable leading to the TV."

Ethertronics has developed technology that can help overcome those problems. "Our Active Steering technology provides the capability of generating four or more radiation patterns from a single antenna and to dynamically change the polarization state. This dynamic 'radiation mode' capability, when coupled to an Ethertronics-supplied algorithm, allows for these multiple radiation patterns and polarization states to be sampled. The technology allows for the optimal radiation mode to be selected for use when acquiring an OTA channel for viewing. This will result in receiving a stronger TV signal in-home from an Active Steering antenna when compared to a passive antenna of equivalent size."

4. DESIGN TOOLS



Soon, 5G may transform the way that products are designed and built, with simulation software playing a key role. "In 2017, emerging 5G technologies and the increasing power of low-cost software-defined radios (SDRs) will change the way that engineers research, design, and build wireless products," says Ken Karnofsky, senior strategist, signal processing applications, at MathWorks *(www.mathworks.com)*. "These technologies are driving deep integration of RF and digital technologies to implement millimeter-wave radios, massive multiple-input, multiple-output (MIMO) antenna arrays, and flexible multi-function radios for commercial, military, and public safety systems.

"Specifically, radios operating at millimeter-wave frequencies will employ extremely compact MIMO array designs, with the RFIC integrated with the antenna elements," continues Karnofsky. "Similarly, 5G systems are expected to achieve high throughput at relatively low power by using hybrid beamforming techniques. These techniques partition the processing between RF and digital components to optimize SNR and efficiently focus transmitted signals on a specific location."

According to Karnofsky, simulation tools that support multiple domains offer a tremendous advantage. "Highly integrated devices require engineers to design across traditional silos of expertise and use domain-specific tools," he notes. "As a result, 5G and other advanced wireless-technology designers should rely on multi-domain simulation tools. By modeling the antenna, RF, and digital subsystems together, they can quickly explore alternative architectures and algorithms along with measuring the impact of design tradeoffs on system performance."

Karnfosky also expects to see increased dependence on SDR technology for wireless applications. He elaborates, "We will also see expanded use of SDR technology to meet the need for hardware prototypes and testbeds for a range of wireless applications—including 5G. System designers and research and development engineers see an opportunity to use SDR hardware to speed development of these prototypes. But they often lack the field-programmable gate array (FPGA) or system-on-a-chip (SoC) programming expertise to implement their designs on that hardware.

"They will and should increasingly turn to a model-based design workflow that uses generation of portable HDL and C code from models," says Karnofsky. "Using this workflow, they can design, prototype, and verify algorithms on a range of commercial SDR hardware and create production-ready IP for implementation on custom hardware."

5. CHANGING TEST NEEDS

New advances in wireless communications will have a major impact on test-and-measurement requirements. Several different technologies can be considered driving factors. According to Adam Smith, director of product marketing at LitePoint *(www.litepoint.com)*, "Big changes are coming to wireless. There is an explosion in new wirelessly connected products and new use models will value improvements in range, battery life, latency, and number of connected devices. Three major technologies will play a key role in these new products: IEEE 802.11ax, low-power wide-area networks (LPWANs), and millimeter-wave frequencies.

"IEEE 802.11ax is not simply the next version of Wi-Fi," explains Smith. "It represents a fundamental change in the way that Wi-Fi operates. "Simplistically speaking, Wi-Fi is borrowing from cellular by adopting techniques used in LTE. Unlike LTE, which operates in a managed, licensed spectrum, Wi-Fi operates in the unlicensed spectrum on an ad hoc, on-demand basis. A successful launch of this technology will require products to manage the chaos of the unlicensed spectrum. Verifying that these devices play by the IEEE 802.11ax rules requires smarter test equipment. Equipment needs to be 'packet aware' and support near real-time power control. New test methodologies are needed to achieve the required manufacturing economics without sacrificing product quality."

LitePoint is also offering test solutions to support LPWAN technologies. Smith notes, "LPWAN technologies, such as Sigfox, LoRa, and LTE Cat-NB1, seek to meet the emerging requirements for the Industrial Internet of Things (IIoT) market. These technologies address range, battery life, security, and quality-of-service. One challenge device makers will face is getting their products to market quickly with high quality. To make this easier, we provide 'reference designs' for test, delivering pre-validated chipset-specific solutions that accelerate product validation."

The third factor that Smith believes will impact the test-and-measurement arena is millimeter-wave technology. He says, "Millimeter-wave technology represents the next frontier of wireless with nearly 20 GHz of pristine spectrum. The physics of this spectrum drives antenna beamforming technology, which in turn drives new ways of measuring these types of signals. Test equipment needs to be able to address OTA measurements of a variety of antenna arrays, ensuring that these arrays can efficiently 'steer' the energy to the end-user."

Taking all of these potential advances into consideration, 2017 looks to be an eventful year for the RF/microwave industry. As 5G and other new technologies loom on the horizon, companies are focused on delivering the next generation of design and test solutions. Cutting-edge performance in terms of semiconductor technology will likely create headlines this year. And filter and antenna solutions will play key roles across many wireless fields in 2017. Stay tuned to *Microwaves & RF*, as we report on these unfolding developments.

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JACK BROWNE | Technical Contributor

Harvesting Energy from RF Sources

Excess energy from transmitted communications signals can be captured and transformed to dc power, perfect for a wide range of low-power electronic devices.

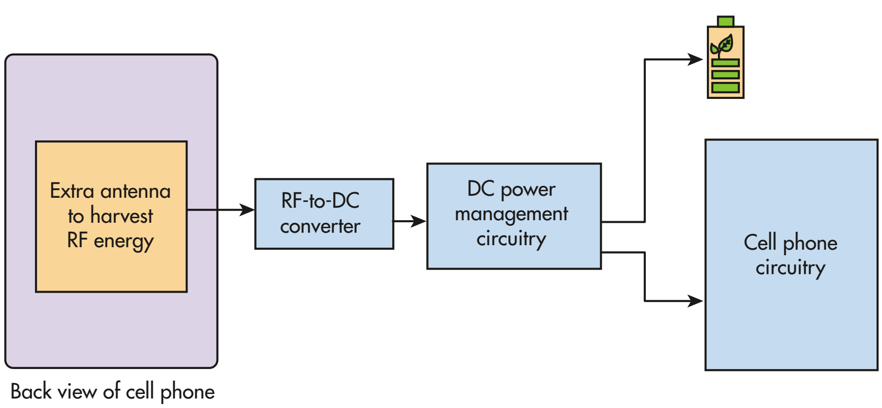
CONSERVATION OF ENERGY starts by reusing energy that has already been expended. That energy is readily available in electromagnetic (EM) form, from broadcast AM and FM radio waves to the many wireless devices that transmit signals around us, such as cellular base stations and short-distance wireless local-area networks (WLANs). The key to harvesting or scavenging this "used" energy starts with a dedicated receiver capable of receiving the available wireless signals, along with some means of converting the received signal power into a supply of electrical power.

Many leading suppliers of wireless communications products are well aware of the eventual need to conserve battery power as users became more dependent on those devices. The evolution of the cellular telephone into a personal messaging and entertainment center has meant that these portable radios can do more, but it also means that they require more power to do so. If limited to batteries as power sources, the increased current drain from the added functionality will result in less operating time per battery charge (and less billable hours for service providers).

For a while now, developers of mobile communications devices have sought to ease the load on the batteries in those devices via some form of energy recovery system. With the growing popularity of Internet of Things (IoT) and machine-to-machine (M2M) devices for automated remote control of electronic devices, IoT applications are being envisioned—for homes and factories alike—that could potentially remain powered for years awaiting a trigger. With energy-harvesting capability, such devices can literally pull energy out of the air to recharge their own batteries or harvest enough energy from the environment so that a battery may not even be required for power.

Such devices are now typically referred to as "zero-power" wireless sensors for their capability of providing sensor data directly on a wireless channel or by means of the internet, using a wireless gateway with no apparent source of energy. The "batteryless" approach has been commonly used with radio-frequency-identification (RFID) tags that transmit an identifying signal based on received power from an RFID reader's transmitted signals (as the source of power).

By harvesting power from available RF energy sources, a new generation of ultra-low-power (ULP) wireless devices, such as IoT sensors, can be developed for low-maintenance applications like remote monitoring. Energy harvesting is considered very much a "companion" technology to wireless communications, since it can enable extended battery lifetime for mobile devices and possibly battery-free operation for some electronic devices.



This is a simplified functional diagram of how RF energy can be harnessed from the environment and converted into dc power for another application. The diagram is based on a patented concept of using a cellular telephone's surface as an energy-harvesting antenna, thus reusing the electromagnetic (EM) energy from the very same cellular phone. *(Courtesy of Radient micro-tech Corp.)*

The basic concept for harvesting energy from an RF source typically involves an extra antenna to receive the desired wireless signals via a wireless product's primary receiver.

CREATING ENERGY

Energy can be harvested from a number of different sources, including light, heat, vibration, motion, pressure, magnetic fields, and RF/microwave signals. Some methods of producing energy are quite creative but practical. Enocean *(www.enocean.com)*, for example, makes wireless light-emitting-diode (LED) lamp switches that use the pressure of a user's hand on the switch as the source of energy. Pressing on the switch generates the dc power needed to transmit wireless on/off signals to an LED lamp within line of sight of the switch.

The basic concept for harvesting energy from an RF source typically involves an extra antenna to receive the desired wireless signals via a wireless product's primary receiver. Alternately, a secondary receiver may be dedicated to energy harvesting that covers the frequency range of interest *(see figure)*. Received signals are applied to some form of rectifying circuitry to convert the wireless energy to dc power.

In some cases, an antenna that incorporates the rectifying circuitry, known as a rectenna, may be used to save space. The antenna portion of a rectenna can be almost any form of antenna suitable for the frequency band of interest. Options include a monopole, dipole, or microstrip patch fabricated on printed-circuit board (PCB), along with rectifying circuitry based on nonlinear rectifying devices (such as Schottky or IMPATT diodes). The antenna will be joined to the rectifying circuitry by means of impedance-matching circuitry and filters, such as lowpass filters, to block any harmonics generated by the diodes.

Conversion efficiency is critical to any energy-harvesting solution. The antenna and receiver will determine the amount of RF signal power available for rectification, while the diodes and diode-rectifying circuitry will determine the RF-to-dc conversion efficiency. Energy-harvesting circuits have historically taken advantage of plentiful sources of RF energy, such as FM radio signals, which can be collected with simple stick antennas and basic diode-rectifying circuits.

Voltage regulation is an important part of any energy-harvesting solution, as it ensures that a stable supply of electricity is being provided to the load. For that purpose, a number of IC suppliers offer various forms of voltage converters with built-in regulation to maintain consistent voltage and current for the intended load. Linear Technology (*www.linear.com/energyharvesting*), for example, has developed a family of energy-harvesting power supplies with capabilities that target different forms of initial energy sources.

The ICs, which integrate a full-wave bridge rectifier with a buck converter, are designed for lower current operation with lower-energy sources (like thermoelectric generators and piezoelectric sources) and higher currents with higher-power sources (e.g., solar and RF energy). In fact, many IC suppliers with energy-harvesting power supplies, such as Silicon Labs *(www.silabs.com)* and Texas Instruments *(www.ti.com)*, offer reference designs to show their ICs in typical applications.

These ICs are not simple power-supply circuits, but sophisticated means of (in some cases) controlling trickle charges to a battery from a low-power energy supply. A device such as the LTC3588-1 from Linear Technology is a nanopower energy-harvesting power supply for use with high-output-impedance energy sources such as piezoelectric, solar, or magnetic transducers. It allows charge to accumulate on an input capacitor until the IC's buck converter can efficiently transfer a portion of the stored charge to a load (like a battery) at the output.

It provides four pin-selectable output voltages of 1.8, 2.5, 3.3, and 3.6 V with as much as 100 mA continuous output current to accommodate many different load or battery requirements. A larger output capacitor can be used with the IC when higher output current bursts are needed. This IC, with an input voltage range of 2.7 to 20.0 V dc, is part of a total energy-harvesting solution, along with an antenna, receiver, and rectifying element. Depending on the amount of energy available from a source, the designer of an energy-harvesting solution would select the power-supply circuitry according to the expected voltage and current range to be fed to the load.

Energy sources are all around, and RF/microwave signals are just one type of those sources. Military equipment suppliers, for example, have already experimented with circuits that extract energy from motion, such as using a soldier's walking motion to generate the power supply for recharging a portable radio system. In the medical world, where implantable devices must be powered by external power supplies, ICs are being developed with on-chip antennas and the capability to draw power from radio waves in a patient's environment. The rapid growth of IoT devices and applications will be creating increasing demand for energy-harvesting solutions that can free many future wireless devices from their dependences on batteries. mw

JACK BROWNE | Technical Contributor

Driving the Future of Vehicular Technology

Electronic technologies, from basic temperature sensors to millimeter-wave radars, are playing more prominent roles in new car models.

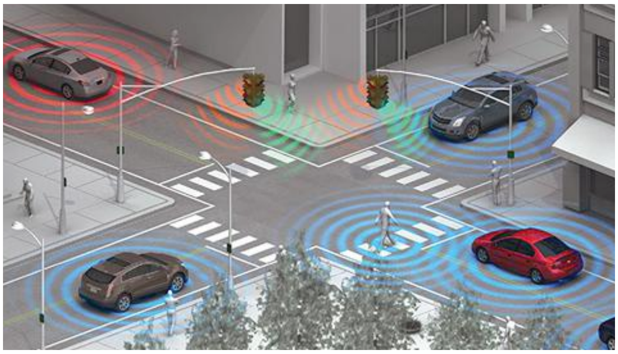
AUTOMOBILES ARE BEING made smarter with each model year. Electronic technologies are playing major roles in enhancing vehicular safety, and that trend will continue. Cameras and millimeter-wave radar systems in newer car models, for example, can detect objects in front and rear and send warning and trigger signals to other subsystems within a car, such as the automatic braking system (ABS), to prevent an accident.

The interest of automotive manufacturers in producing fully autonomous vehicles has been well publicized, and the overall growth of electronic content within new-model automobiles represents a heartily growing market for electronic devices such as microprocessors and wireless transceivers, as well as software that can help build the road to the "driverless" vehicle of the future. But before we can all take our hands off the wheel, a better understanding of the industry's growing electronic needs is needed.

Cars are smarter due to their growing electronics content, starting with their computer networks—among them, those based on the controller area network (CAN), local interconnect network (LIN), and FlexRay protocols. The CAN protocol, for example, allows all electronic devices in an automobile to communicate. A vehicle's electronic control unit (ECU) can communicate by means of a single CAN interface, as opposed to utilizing separate analog and digital interfaces for different electronic components to save weight and complexity. The CAN protocol was first developed for automotive applications, but has been adopted by other industries (e.g., medical electronic equipment manufacturers) because of its reliability and effectiveness.

As vehicles gain more electronic content, an efficient communications and control protocol such as CAN is essential for orchestrating the sequences of messages among the networked devices. All devices on a CAN system first receive all transmitted messages from the ECU, then decide whether a message is relevant or should be filtered. Every message has a priority, and the device node with the higher priority has the opportunity to respond first. A CAN system includes cyclic redundancy code (CRC) that is used for error checking.

In addition to this communication of electronic devices within a vehicle's own network, future vehicles will also communicate with each other by means of wireless vehicle-to -vehicle (V2V) communications. A recent proposal by the U.S. Department of Transportation (DoT) outlined the benefits of V2V communications and a timeframe for its implementation in new model cars (by 2023). The proposal is under review by a number of other organizations, including the U.S. Federal Highway Administration and the Alliance of Automobile Manufacturers.



1. The concept of vehicle-to-vehicle (V2V) communications involves a sharing of vehicular speed and location information among vehicles with V2V wireless technology, to avoid accidents as well as traffic backups. *(Courtesy of Car Talk)*

By having all vehicles communicating their locations, speeds, directions, and other parameters 10 times per second to other vehicles, all vehicles will have a 360-deg. situational awareness of the traffic volume and conditions around them (*Fig. 1*), both to avoid accidents and minimize traffic congestion. Existing vehicular electronic technologies, such as collision-avoidance systems, are seen as complementary to V2V systems and networks.

The DoT's proposal suggests that V2V technology can provide significant decreases in the number of accidents and significant decreases in the number of lives lost due to vehicular accidents. The 392-page proposal is aligned with the automotive industry's efforts to develop autonomous, "self-driving" vehicles that would employ GPS satellite receivers for position information and V2V networks for cars to "talk" to each other by means of various electronic components and devices. As a consequence, roads are made safer even with less local control exerted by human drivers.

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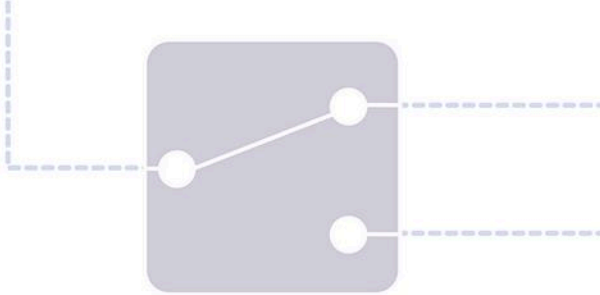

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			2.5 GHz	6.0 GHz	2.5 GHz	6.0 GHz	2.5 GHz	6.0 GHz	
CG2163X3	SPDT	6.0	0.40	0.50	40	31	+33 @ P1.0dB	+32 @ P1.0dB	(1.5 x 1.5 x 0.37)
JUST ADDED CG2164X3	DPDT	6.0	0.50	0.65	25	17	+32 @ P0.5dB	+30 @ P0.5dB	(1.5 x 1.5 x 0.37)
CG2176X3	Absorptive SPDT	6.0	0.45	0.55	30	22	+37.5 @ P0.5dB	+37.5 @ P0.5dB	(1.5 x 1.5 x 0.37)
CG2179M2	SPDT	3.0	0.45	N/A	26	N/A	+30 @ P0.1dB	NA	(2.0 x 1.25 x 0.9)
CG2185X2	SPDT	6.0	0.35	0.40	28	26	+29 @ P0.1dB	+29 @ P0.1dB	(1.0 x 1.0 x 0.37)
CG2214M6	SPDT	3.0	0.35	N/A	25	N/A	+30 @ P0.1dB	NA	(1.5 x 1.1 x 0.55)
JUST ADDED CG2409M2	SPDT	3.8	0.45	N/A	27	N/A	+37.5 @ P0.1dB	NA	(2.0 x 1.25 x 0.9)
JUST ADDED CG2409X3	SPDT	6.0	0.40	N/A	26	N/A	+37.5 @ P0.1dB		(1.5 x 1.5 x 0.37)
CG2415M6	SPDT	6.0	0.35	0.45	32	26	+31 @ P0.1dB	+31 @ P0.1dB	(1.5 x 1.1 x 0.55)
CG2430X1	SP3T	6.0	0.50	0.60	28	25	+28 @ P0.1dB	+28 @ P0.1dB	(1.5 x 1.5 x 0.37)

Wireless communications within a single vehicle has traditionally been conducted within the Industrial-Scientific-Medical (ISM) frequency band, typically from 315 to 915 MHz, although much higher frequencies are used for automotive radar systems and will be used for V2V technology. For example, in the U.S., the FCC has allocated the frequency range normally associated with wireless local area network (WLAN) equipment for V2V applications: 5.850 to 5.925 GHz. While internet providers and other wireless users are hoping to gain the use of some of this bandwidth, the automotive industry is well aware of the need for bandwidth if it is to achieve the challenging goals set for future V2V networks.

Depending upon geographic regions, the V2V standards and frequencies will vary. The U.S. V2V standard is commonly known as the wireless access for vehicular environments (WAVE) standard. Europe has the vehicular ad hoc network (VANET) standard, which is a variation on the mobile ad hoc network (MANET) standard. While the FCC that governs frequency bandwidth in the U.S., it is the European Telecommunications Standards Institute (ETSI) in Europe that sets the requirements for V2V technology. The latter governing body has created a standard known as ITS-G5, which is based on the IEEE's 802.11p wireless networking standard.

DRIVING MORE CHIPS

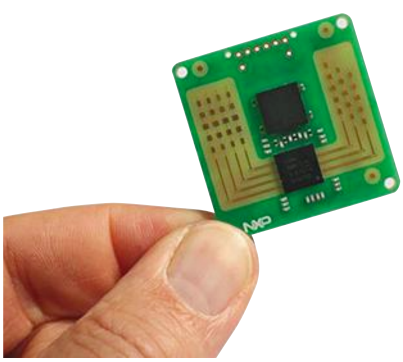
Semiconductor manufacturers have been long at work developing and supplying wireless transceivers, sensors, and other forms of integrated circuits (ICs) for automotive electronics prior to the coming of V2V technologies. The list of well-established IC suppliers for automotive electronics is long, and includes Analog Devices (*www.analog.com*), Broadcom (*www.broadcom.com*), NXP Semiconductors (*www.nxp.com*), and Infineon Technologies (*www.infineon.com*). Not only are electronic sensors helping to meet stricter emissions standards for vehicles with internal combustion engines, but they are also being used to achieve low-emissions power trains in hybrid electric vehicles (HEVs).

The operating environment for automotive ICs is not unlike the specifications set for military electronic devices, with high reliability required over wide operating temperature ranges. To be considered "automotive-grade" electronic devices, such ICs must endure stress testing according to guidelines established by the Automotive Electronics Council (AEC) in the AEC Q100 specifications. Electronic devices for automotive use are qualified according to how rigorous the conditions of their particular applications and locations within the vehicle, with grades

0 through 4 assigned for different ambient operating temperature ranges: –40 to +150°C (Grade 0), –40 to +125°C (Grade 1), –40 to +105°C (Grade 2), –40 to +85°C (Grade 3), and –40 to +70°C (Grade 4).

Through its merger with Freescale Semiconductor, NXP (which is in turn about to be acquired by Qualcomm) fortified its already strong semiconductor design and fabrication capabilities to produce some of the industry's smallest 77-GHz radar ICs (*Fig. 2*). Based on a high-frequency silicon germanium (SiGe) semiconductor process, the single-chip, multiple-channel, 77-GHz radar transceiver measures just 7.5 × 7.5 mm2 and provides high-resolution radar performance for automotive advanced driver assistance systems (ADASs). The small size of the radar IC makes it easier to integrate into multiple locations within a vehicle. The IC provides the accurate, high-resolution radar returns needed for self-driving autonomous vehicles in addition to its support of collision-avoidance systems and adaptive cruise control systems.

Infineon, a long-time supplier of automotive electronic solutions, also relies on a SiGe semiconductor process for its radar system IC (RASIC) series of 77-GHz automotive radar devices that are fully qualified to AEC-Q100 requirements. The highly integrated devices require few, if any, additional external components.



2. The high level of integration used in a SiGe semiconductor process has enabled the production of this miniature 77-GHz automotive radar chip. *(Courtesy of NXP Semiconductors)*

NXP, which supports all three automotive network protocols, also makes a number of RF-based solutions for automotive electronics applications at ISM band frequencies, including a single-chip transceiver with programmable fractional-N phased-lock loop (PLL) frequency synthesizer. These lower-frequency devices are typically used for such applications as communicating data from tire pressure monitoring systems (TPMSs) and for keyless remote entry and other telemetry applications. The firm supplies a range of sensors for such functions as monitoring gas emissions and fluid temperature monitoring (such as for antifreeze and motor oil).

All automotive radar systems are not at millimeter-wave frequencies, as Analog Devices offers a frequency-modulated-continuous-wave (FMCW) radar chip for use at 24 GHz, along with a number of different sensors based on MEMS technology. The radar chipset includes a two-channel transmitter, a four-channel receiver, and a 13-GHz fractional-N PLL frequency synthesizer. The firm recently bolstered its position as an electronics component supplier for automotive safety systems by acquiring solid-state laser-beam steering technology from the privately held Vescent Photonics, Inc. of Golden, Colo. The nonmechanical technology is a good fit for automotive LIDAR systems with higher reliability than mechanical solutions.

Between the self-contained networks within each vehicle, such as a CAN system, and the expectations of widespread V2V wireless communications capabilities in future vehicles, modern wireless communications technologies will ensure that vehicles are as well connected as their owners. Whether a driver's hands are on or off the steering wheel, hopefully the end result is a safer driving experience for all. mw

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UWB Printed Antenna Blocks Satellite and WLAN Signals

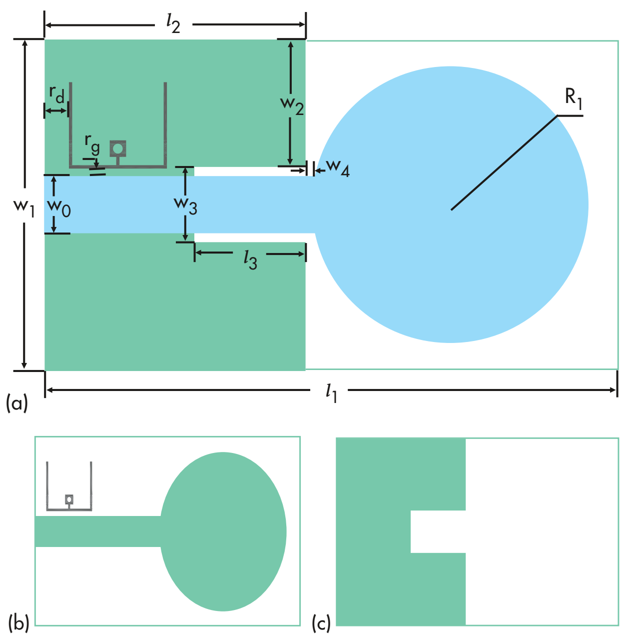
This novel monopole UWB antenna provides two notched bands for rejecting interference from 5-GHz WLAN signals and 8-GHz X-band satellite signals.

Ultrawideband (UWB) communications systems provide many times the bandwidth needed for standard communications services, such as cellular wireless communications or wireless local area networks (WLANs). One of the main benefits of an UWB component like an antenna or amplifier is that a single component can be used in a system that provides multiple communications services.

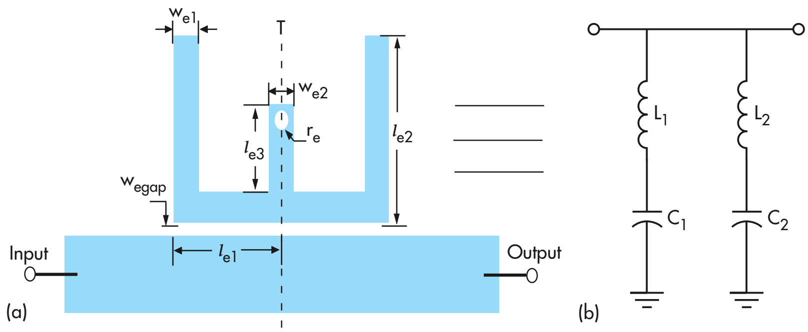
As an example, a novel printed UWB monopole antenna was developed with dual-notched frequency bands, for use in both the 5.2-GHz WLAN band and the 8.0-GHz X-band satellite-communications (satcom) band. The design couples an E-shaped structure with microstrip feedline to achieve UWB performance with band-rejection capability. The UWB antenna demonstrates omnidirectional radiation patterns across its wide bandwidth.

UWB radio technology has attracted a great deal of attention ever since the U.S. Federal Communications Commission (FCC) allocated 7.5 GHz of bandwidth (3.1 to 10.6 GHz) for unlicensed radio applications. Many applications have been developed based on UWB technology, such as short-range broadband communications, radar sensing, and body-area networks (BANs) for medical and health-care use.[1] In terms of antennas for UWB systems, planar monopole antennas present attractive features: simple structure, small size, low cost, stable radiation patterns, and constant gain over wide operating bands. Owing to these characteristics, research is increasingly being focused on planar monopoles for UWB use.[2-6]

Potential problems for UWB communications systems stem from interference from existing systems within that wide frequency range, such as 5.8-GHz signals from WLAN systems and 8-GHz signals from X-band satellite communications systems (XSCSs). As a result, a compact UWB monopole antenna with multiple reject bands can provide a practical solution to reject these unwanted interference signals.[7-13]



1. These diagrams show the layout of the UWB antenna with two notches: (a) the overall view of the antenna layout, (b) a front view of the layout, and (c) a rear view of the layout.



2. This layout and equivalent circuit represent the coupled E-shaped resonator used in the UWB antenna.

To achieve the desired band-notched performance, different-shaped slots (such as U- or V-) are usually inserted into the initial UWB monopole antenna structure. In refs. 8 and 9, however, only one notch band was created. In refs. 10 and 11, two notched bands can be achieved by means of a defected ground structure (DGS) approach. However, all these notched UWB antenna design strategies are based on the use of multilayer circuit structures that would increase fabrication costs and not be compatible with existing integrated-circuit (IC) radio devices.

To provide a practical solution for limiting the effects of interference in UWB systems, a compact UWB monopole antenna with two notch bands was developed. To start, the resonant properties of an E-shaped resonator were explored. Analysis of the resonator structure reveals that dual bandstop performance was possible based on the dual-mode resonant properties of the E-shaped resonator. By placing the E-shaped resonator structure close to the feed-line of the UWB antenna, it should be possible to achieve the two notched bands within the total UWB frequency range.

To validate the design concept, a novel planar UWB antenna with two sharply rejected notch bands centered at 5.8 and 8.0 GHz, respectively, was designed and fabricated. Computer simulations and prototype measurements show that the antenna achieves an ultrawide bandwidth ranging from 2.0 to 11.0 GHz while avoiding interference from WLAN/XSCS signals. The antenna offers an omnidirectional radiation pattern in the H-plane across its full bandwidth.

Figure 1 presents the geometry of the proposed UWB antenna with two sharp notch bands. The antenna consists of a dual bandstop filter and a conventional planar circular monopole antenna. It is fabricated on 0.508-mm-thick RO4350B circuit material from Rogers Corp. (*www.rogerscorp.com*). The circuit material exhibits a dielectric constant (relative permittivity) of 3.48 at 10 GHz in the z-axis (thickness) of the substrate. The bandstop filter (i.e., the two notch bands) is realized by coupling the E-shaped resonator to 50-Ω microstrip feedlines for the antenna.

The proposed planar UWB antenna has a circular patch with radius, R_1 , of 8.5 mm, which is fed by 50-Ω microstrip line of width w_0 = 3.5 mm. To improve impedance-matching performance, a rectangular slit is embedded in the ground plane, located under the microstrip feed line. The final optimized parameters of the planar UWB antenna are as follows: w_1=20 mm, w_2=8.05 mm, w_3=4.6 mm, w_4=0.3 mm, l_1=35 mm, l_2=16 mm, and l_3=3.8 mm.

The proposed E-shaped resonator is composed of a stepped-impedance hairpin resonator with a centrally loaded short-ended stub. *Figure 2* shows the layout of the E-shaped resonator coupled to a section of main transmission line and its corresponding equivalent circuit. The properties of the E-shaped resonator can be analyzed by the even-odd-mode analysis method. Under mode excitation, the electrical field distribution of the resonator exhibits either an even- or an odd-mode distribution property. Thus, the even- and odd-mode resonant frequencies (f_{even} and f_{odd}, respectively) can be deduced by means of Eqs. 1 and 2, respectively:

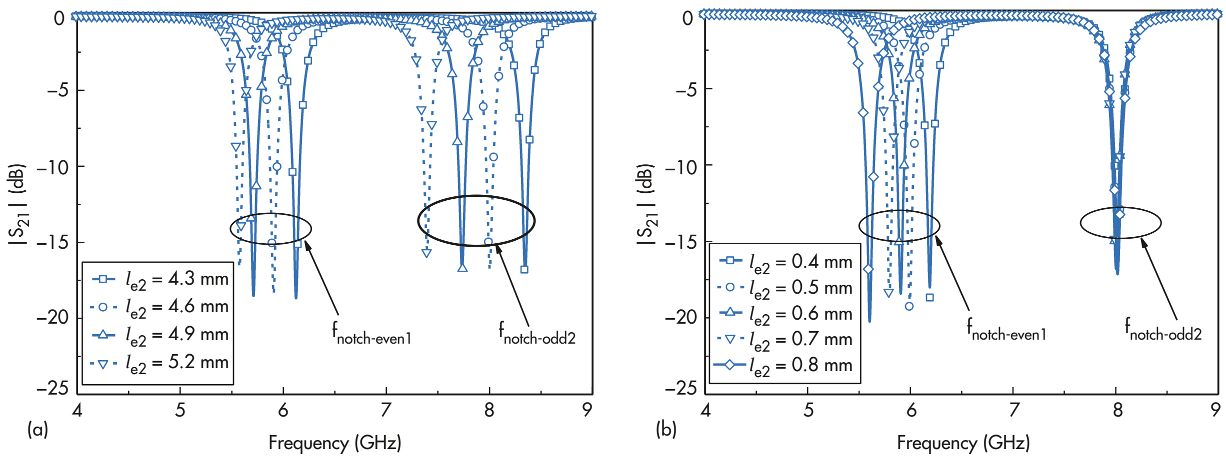
$$f_{even} = \frac{c}{\lambda_{even}\sqrt{\varepsilon_{eff}}} = \frac{c}{4(l_{e1} + l_{e2} + l_{e3})\sqrt{\varepsilon_{eff}}} \qquad (1)$$

$$f_{odd} = \frac{c}{\lambda_{odd}\sqrt{\varepsilon_{eff}}} = \frac{c}{4(l_{e1} + l_{e2})\sqrt{\varepsilon_{eff}}} \qquad (2)$$

where *f* is the center frequency of the E-shaped resonator; ε_{eff} denotes the effective dielectric constant of the substrate; and *c* is the speed of light in free space.

The dual-mode stepped-impedance resonator (SIR) can achieve dual-stopband (i.e., the two notch bands) performance when placed next to the microstrip feedline. It can be functionally equivalent to two shunt-connected series resonance circuits, as shown in *Fig. 2b*. The section l_{e1}, l_{e2} of the dual-mode SIR can be seen as the capacitance C while the section l_{e3} of the dual-mode SIR can be seen as inductance *L*. The dimensions of the E-shaped resonator were selected as follows: w_{e1} = 0.2 mm, w_{e2} = 0.2 mm, l_{e1} = 3 mm, l_{e2} = 4.6 mm, l_{e3} = 0.8 mm, and r_e = 0.2 mm.

Transfer characteristics of the coupled E-shaped resonator with various dimensions were studied to validate its two-mode resonant properties (*Fig. 3*). The frequencies of the two notch bands move down simultaneously with



3. These S-parameters were simulated for various dimensions of the coupled E-shaped resonator: (a) l_{e2} and (b) l_{e3}.

increases in the length l_{e1}. This is because the electrical fields are distributed on these two sections for both the even and odd modes.

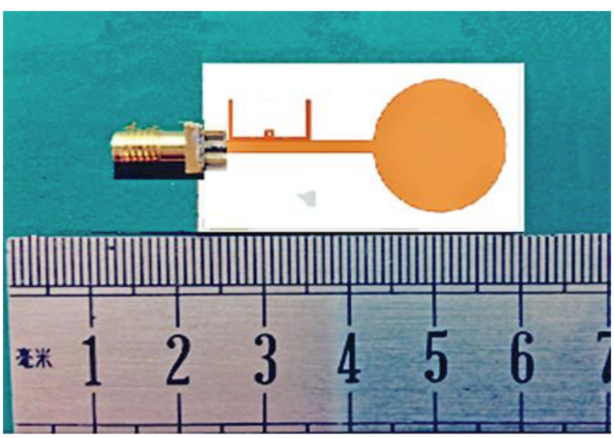
When l_{e3} is decreased, only the frequency of the first notch band moves higher. This is because there are no electrical fields distributed on the area of l_{e3} for the odd mode. Therefore, by appropriately adjusting the resonator dimensions, two notch bands can be achieved at desired frequencies.

Based on the two bandstop filters previously described, a novel planar UWB monopole antenna with two high-rejection notch bands was designed as shown in *Fig. 4*. All simulations were carried out using Version 11.0 of the commercial Ansoft HFSS finite-element EM simulation software from Ansys (*www.ansys.com*).

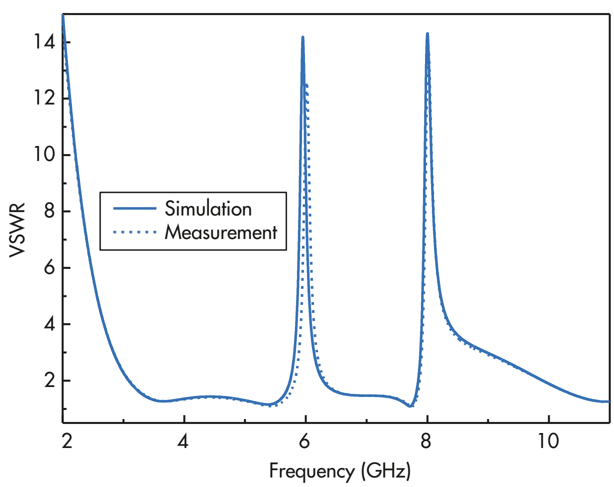
Figure 5 compares the simulated and measured VSWR for the UWB antenna. The antenna exhibits an impedance bandwidth of 2.0 to 11.0 GHz for a VSWR of less than 2.0:1, except for the notch bands of 5.5 to 6.5 GHz and 7.6 to 9.1 GHz. The center frequencies of these two notch bands are about 5.8 and 8.0 GHz, respectively.

These notch bands are well suited for rejecting 5.8-GHz WLAN signals and 8.0-GHz satellite signals. The normalized radiation patterns in the E- and H-planes were simulated at 2.5, 5.0, 7.5, and 10.0 GHz (*Fig. 6*). As the patterns show, the antenna achieves good omnidirectional radiation patterns in the H-plane. *Figure 7* plots the measured peak gain in the E-plane. The radiation patterns in the E-plane are in symmetry. Even with its dual notches, this antenna behaves very much like a typical printed-circuit-board (PCB) monopole antenna.

By controlling the parameters of the E-shaped resonator, the two notch bands can be easily tuned to the desirable



4. This is a photograph of the fabricated prototype of the UWB antenna with dual notches.

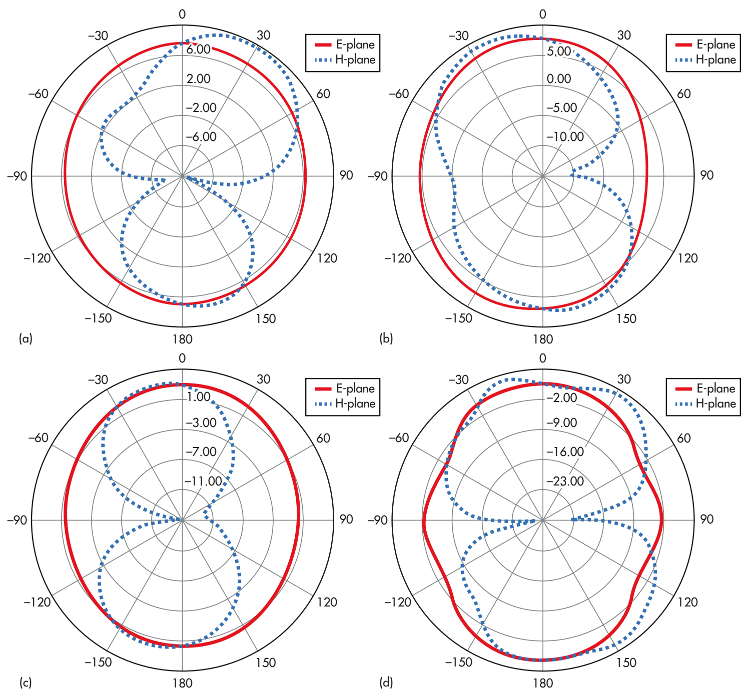


5. The measured and simulated VSWRs of the UWB antenna are plotted here.

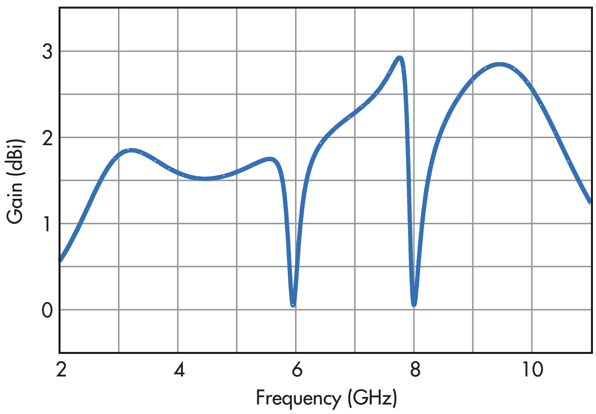
By controlling the parameters of the E-shaped resonator, the two notch bands can be easily tuned to the desirable frequency locations.

frequency locations. The antenna covers the frequency range for UWB systems, between 2.0 and 11.0 GHz, with rejection bands centered around WLAN/SCS services. With the benefit of small size, outstanding performance can be realized for broadband antennas—widely needed for UWB applications.

The measured results show good performance in terms of reflection coefficient, antenna gain, and radiation patterns. The antenna design represents a practical approach for modern UWB wireless communication



6. The measured and simulated radiation patterns for the UWB antenna are shown for the following frequencies: (a) 2.5 GHz, (b) 5.0 GHz, (c) 7.5 GHz, and (d) 10.0 GHz.



7. The measured peak gain of the UWB antenna is plotted as a function of frequency for the UWB frequency range.

systems owing to its simple topology, compact size, and excellent performance.

Editor's Note: The authors' design approach was also demonstrated in the construction of an UWB bandpass filter, using parallel U-shaped slots to achieve dual frequency notches within the full FCC-approved UWB frequency range of 3.1 to 10.6 GHz. (See *http://mwrf.com/passive-components/uwb-bandpass-filter-features-dual-notches*). mw

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Design Feature

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How Bending Affects a Flexible UWB Antenna

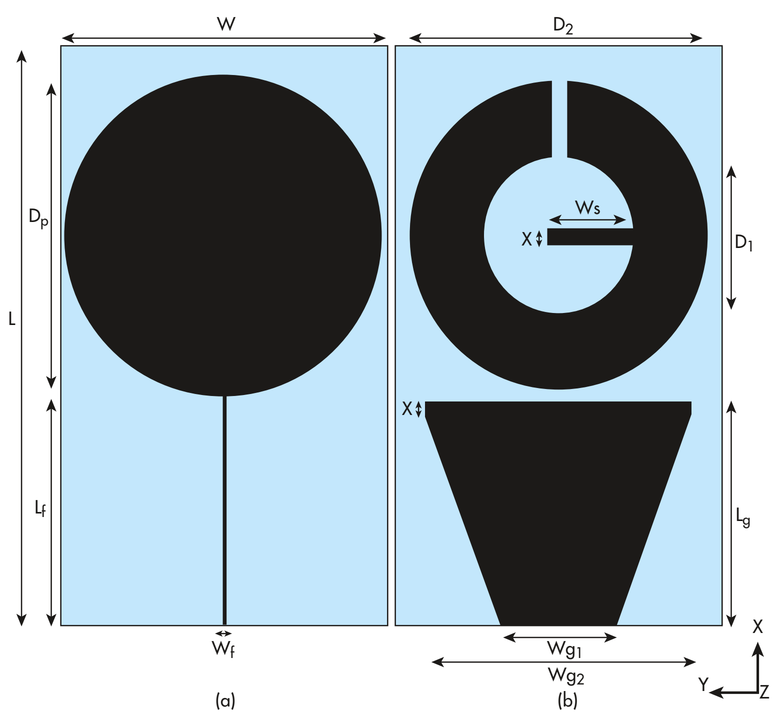
A compact antenna maintains high gain and an omnidirectional radiation pattern, even with flexing across frequency ranges complying with UWB frequency allocations in the U.S. and Europe.

Flexible antennas are important components in a growing number of wireless applications, including wearable electronics and sensor systems. However, flexing the antenna from its nominal straight configuration can impact performance, depending on the antenna design, substrate material, and other factors. To meet the need for flexibility, a robust yet compact ultrawideband (UWB) antenna was designed based on microstrip feed approach.

The antenna design measures just 38 × 22 mm[2] and is fabricated on flexible liquid crystalline polymer substrate material. It features a resonating structure, which plays a key role in the enhancement of gain across the lower part of the UWB spectrum. The design was simulated with commercial design software and a prototype was built and characterized, with good agreement between simulations and measurements for bent and straight cases.

The markets for flexible wireless devices are rapidly increasing, both with regard to wearable and implantable devices for health-monitoring systems and daily-life wireless devices (e.g., cell phones, tablets, and laptop computers). For this reason, the need for flexible printed antennas has increased in recent years, especially for biomedical applications,[1-3] wearable applications,[4, 5] and body-mounted applications.[6]

A number of flexible antenna designs have been attempted on different mechanically flexible substrate materials. Some approaches involve textile substrates,[7, 8] others use paper substrates,[9, 10] and still others employ thin, flexible dielectric substrates.[11-13] A tradeoff always exists between achieving functional conformability and low cost. In the case of circuits fabricated on flexible substrates, the circuit material must be robust and be able to endure wide temperature ranges without degradation in performance.



1. These 2D diagrams illustrate the basic geometry of the UWB antenna: (a) the top layer and (b) the bottom layer.

For flexible antennas, design goals include good radiation parameters in a compact size, with performance maintained throughout bending. In other words, it is very important requirement that they should perform effectively under various bending conditions.[14]

One application area in urgent need of flexible devices is UWB communications. The enormous bandwidth available, the capacity for high data rates, and the potential for small size and low processing power—along with low implementation costs—present a unique opportunity for UWB to become a widely adopted radio solution for future wireless home-networking technology.[15]

Such systems include wireless PC peripherals, multimedia connectivity, and wireless network access for mobile computing devices. One example of a flexible radio application is a body area network (BAN), which is becoming increasingly popular for health monitoring in medical applications.

From a frequency spectrum point of view, UWB technology employs bandwidths of greater than 500 MHz (or fractional bandwidths of greater than 20%[15]), such as 2,500 to 3,000 MHz. Depending on location, various frequency allocations have been made for UWB series.

In the United States, for example, there is 3.1 to 10.6 GHz by the Federal Communications Commission (FCC).[16] Europe has multiband orthogonal frequency division multiplexing (MB-OFDM; 3.1 to 4.8 GHz) and direct-sequence UWB (DS-UWB; 6 to 8.5 GHz) by the European Conference for Postal and Telecommunication Administrations (CEPT) Electronic Communication Committee (ECC).[17]

Antennas designed for these applications should have reasonable and constant radiation properties (such as radiation pattern type, gain, and polarization) within their operating bandwidths.[18, 19] Different planar monopole antenna structures have been widely used as UWB antennas due to their ability to provide constant omnidirectional radiation patterns and controlled input impedance parameters over the UWB frequency band. Moreover, planar antennas have simple structures and small size, and can be printed on the very same PCB circuitry as the transmitter and receiver.[20-26]

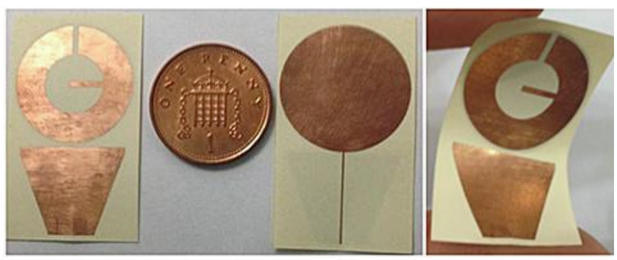
Designing flexible antennas requires thin substrates to accommodate the flexing. As a consequence, the antenna's radiation pattern properties may be degraded due to the thinness of the substrate. Care must be taken in the design of an antenna with thin substrate material to achieve an omnidirectional radiation pattern with good gain across the target operating frequency range. Examples of UWB flexible antennas in planar configurations are presented in refs. 27-31. Success in achieving good performance parameters has made flexible UWB antennas valuable components for wearable, implantable, and body-centric applications.[32-34]

By using an extremely thin substrate material, it is possible to develop a compact flexible antenna for UWB applications. The antenna is fed with a microstrip transmission line with modified monopole structure. The design was computer-simulated with a commercial full-wave electromagnetic (EM) simulation software program, with measurements of a prototype matching closely with the performance predictions made by the simulations.

The antenna design employs a microstrip-fed circular monopole with resonator at ground level, fabricated on Ultralam 3850 liquid-crystal-polymer (LCP) circuit material from Rogers Corp. (*www.rogerscorp.com*). The circuit material has dielectric constant (relative permittivity) of 3.14 in the z-axis (thickness) at 10 GHz with loss tangent of 0.0025. The substrate was 100 μm thick and the copper cladding was 18 μm thick.

Figures 1a and b show the top and bottom design geometry of the antenna, respectively. The top layer is designed as a circular monopole antenna. The monopole antenna is fed by a single 50-Ω transmission line with feed width, $W_f = 0.245$ mm. To compensate the low efficiency of an antenna fabricated on such a thin substrate, an incomplete half-disk resonator was added on the bottom of the circular patch antenna.

The additional resonator acts as an incomplete reflector, preserving moderate antenna gain without deforming the desired omnidirectional radiation pattern of the antenna. A stub was added to the resonator to compensate for any further added resonance that may affect the desired UWB bandwidth. Finally, the ground shape of the feeding microstrip transmission line was formed in the shape of a triangle to decrease the size of metal at the ends, which enhances bending functionality.



(a) (b) (c)

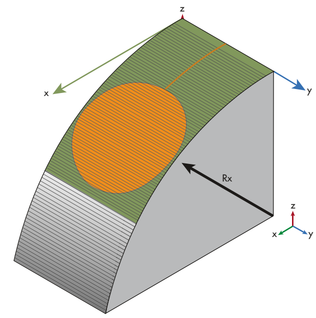
2. These photographs show the fabricated prototype antenna next to a British penny: (a) the bottom layer, (b) the top layer, and (c) the amount of bending possible with the flexible substrate.

Figure 2 compares the fabricated antenna prototype to a coin (a British penny) and in its bent form. Fabrication was performed by means of a carefully controlled photolithographic process, followed by a high-resolution chemical etching process. As can be seen in *Fig. 2c*, the antenna's thin structure and bending capabilities make it an excellent candidate for wearable wireless electronic products.

The initial design of the circular monopole diameter was set equal to the wavelength of the center frequency within the selected UWB bandwidth, which was designed as 7.5 GHz.

THE PROPOSED FLEXIBLE UWB ANTENNA AND ITS DIMENSIONS

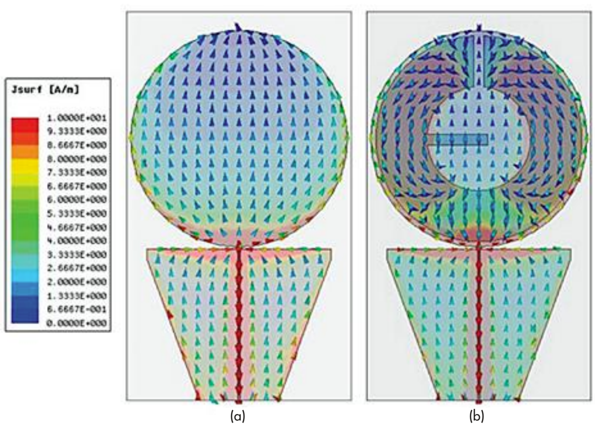
Parameters (in mm)						
Parameter	L	W	D_p	D_1	D_2	W_S
Dimension	38	22	21.2	10.2	20.2	6
Parameter	W_{g1}	W_{g2}	L_g	X	W_f	L_f
Dimension	8	18	14.8	1	0.245	15



5. The flexible antenna design was simulated for its flexed performance when bent over an imaginary cylinder with radius R_x.

The antenna was further optimized based on investigating the current flow through the antenna radiator over the full bandwidth of the UWB antenna requirements. The antenna's dimensions are listed in the *table*; it has a total area of 38 × 22 mm^2.

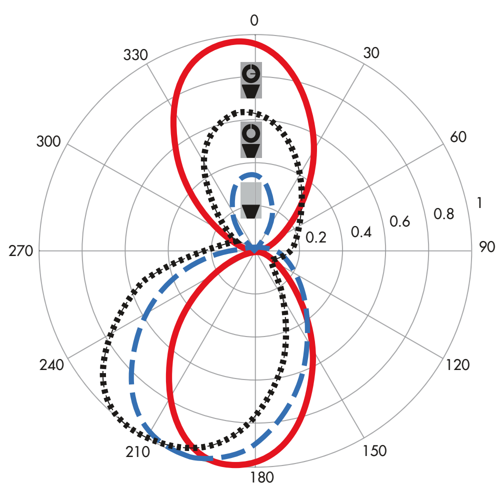
To explain the role of the additional resonator at ground, the surface current distributions are shown in *Fig. 3* with and without the resonator. It shows the direction and distribution of surface currents at 4 GHz induced by the presence of a smaller-radius, ground-resonating structure, which forces the current to coexist more on the edges of the top radiating patch. This enhances the generation of less-deformed radiation patterns at this frequency.



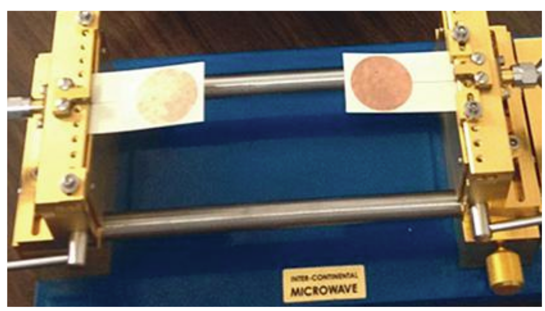
3. These simulated plots show magnitude/vector surface current distributions over the top and bottom antenna surfaces for (a) the antenna geometry without the booster at 4 GHz, and (b) the novel UWB antenna design with the bottom booster resonator at 4 GHz.

The normalized two-dimensional (2D) gain pattern in the X-Y plane of *Fig. 4* demonstrates how the initial structure without the stub resonator improves the generation of radiation in the Z+ direction. It also shows how the addition of the stub results in further enhancements to the radiation pattern in that direction.

The antenna's performance was simulated with the commercial Ansoft HFSS finite-element EM simulation software from Ansys (*www.ansys.com*). Two versions of the antenna were built and simulated: straight and bent forms. *Figure 5* shows the configuration of the bent version of the antenna, with the antenna simulated as being bent around an imaginary cylinder with radius of curvature R_x.



4. This 2D radiation pattern was simulated for the normalized antenna XZ-plane gain, for different antenna configurations, at 4 GHz.

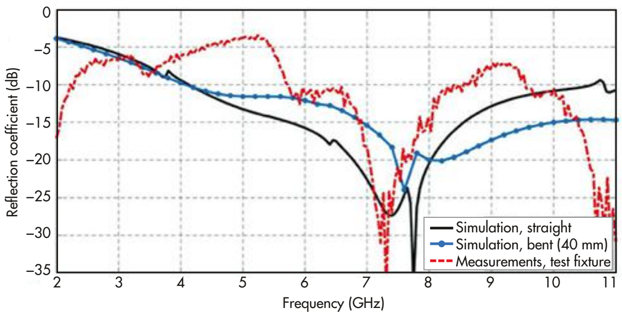


6. The photograph shows the measurement setup for the UWB antenna design, using a test fixture from Inter-Continental Microwave (*www.icmicrowave.com*).

The antenna's resonant characteristics were confirmed by measurements of the fabricated antenna prototype. *Figure 6* shows the measurement setup for antenna matching. A test fixture was used to measure antenna impedance-matching properties, since soldering a 50-Ω SMA connector to the antenna for coaxial measurements proved quite difficult due to the narrow width of the antenna's microstrip transmission lines.

Figure 7 compares the simulated reflection coefficients of the antenna for straight and bent (R_x= 40 mm) formats versus the measured reflection coefficient for the straight antenna.


Mini-Circuits
YAT



7. Simulations provided the reflection coefficients for the straight and bent (R_x = 40 mm) versions of the UWB antenna, from 2 to 11 GHz, which can be compared to measurements of the straight version of the antenna.

Both simulated results have reflection coefficients lower than –10 dB from 4 to 10.7 GHz. Also, the reflection coefficient is lower than –6 dB within the frequency band of 3 to 4 GHz. Both simulated results display a deep resonance close to 7.5 GHz with small difference in amplitude. Furthermore, the measurements show similar values over most of the frequency band of interest.

The measured reflection coefficient indicates the strong resonance near 7.5 GHz, and is lower than –6 dB at frequencies starting from 3 GHz and higher. However, despite a decrease in the simulated reflection coefficient of less than –10 dB from 4 GHz and higher, the measured reflection coefficient has a sudden increase to –4 dB in the frequency band of 4.0 to 5.3 GHz before it decreases to less than –10 dB, preserving a pattern close to that of the simulated curves.

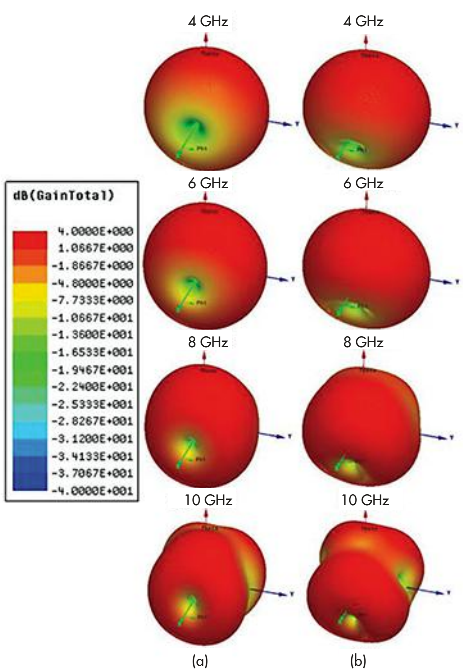
This is caused by the difficulty in making measurements due to the thin feeding microstrip line width. However, it is still apparent that the measurement and simulated results are fairly close.

To validate the antenna's far-field characteristics, three-dimensional (3D) gain radiation patterns were simulated at certain frequencies (4, 6, 8, and 10 GHz), as shown in *Fig. 8*. To validate that bending the antenna does not affect its radiation patterns, the simulated radiation patterns for the straight antenna (*Fig. 8a*) are compared to the bent antenna with R_x = 40 mm for the same selected frequencies (*Fig. 8b*). In both cases, the 3D gain patterns preserve an omnidirectional pattern , as is quite apparent at 4, 6, and 8 GHz. A small deformation in the omnidirectional pattern is noticeable at 10 GHz.

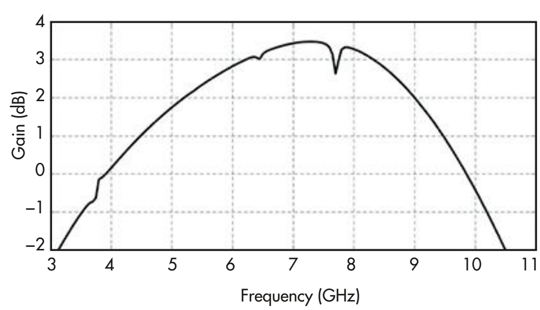
By observing the color bar of the plotted pattern, the antenna has directive gain values that range around –40 dB for nulls at x axis (feeding axis) and 4 dB for boresight direction. For more antenna radiation pattern investigation, the simulated antenna gain at the Z axis is plotted in *Fig. 9*. As can be seen, the antenna gain reaches a maximum at 7 GHz, where it is 3.5 dB, and a minimum at –1 dB for the frequency band edges within the UWB spectrum.

To analyze the antenna radiation patterns within the UWB frequency range, the current distributions were measured and plotted for the same test frequencies at 4, 6, 8, and 10 GHz (*Fig. 10*). As can be seen, the radiation pattern degrades with increasing frequency. Also, the current distribution is homogenous over the antenna's resonant band in ordered harmonics, which explains how the antenna preserves the omnidirectional pattern at these frequencies.

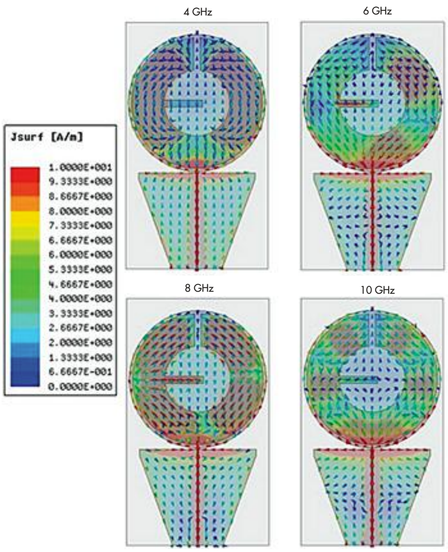
The antenna design provides near-stable performance with bending in terms of matching and radiation characteristics. The design appears suitable for use in wearable applications, although other issues must also be considered. These include the specific absorption rate (SAR), along with the thermal and dielectric properties of the substrate material when matched with human tissue for medical applications.



8. The 3D gain patterns of the UWB antenna were simulated at different target frequencies for the (a) straight and (b) bent versions of the antenna, bent over an imaginary cylinder with 4-cm radius.



9. The simulated gain of the straight version of the UWB antenna was plotted as a function of frequency.



10. The magnitude/vector surface current distributions for the UWB antenna design were simulated for different frequencies.

In short, the antenna design combines flexibility with a miniature footprint of only 38 × 22 mm^2, making it a good fit (literally) for wearable wireless applications. It is designed for use in the upper UWB frequency range from 4 to 10.6 GHz, satisfying at least 82% of the FCC's UWB frequency regulation and 100% of the ECC's DS-UWB frequency-range requirements. The antenna maintains an omnidirectional radiation pattern in both straight and bent configurations except at higher frequencies, with high gain throughout. mw

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DIVE INTO LNA DESIGN

A LOW-NOISE AMPLIFIER (LNA) is a critical component in a receiver design, as its performance heavily determines the receiver's overall performance. Those involved with designing LNAs must ensure that noise figure is minimized while also being mindful of other parameters. In the application note, "Design of a 10 GHz Low-Noise Amplifier," National Instruments presents the design of an LNA that operates over a frequency range of 10.0 to 10.7 GHz. The NI AWR Design Environment is used to design and simulate the LNA.

The LNA is designed with the NE3515S02 heterojunction field-effect transistor (HJFET). At 10.4 GHz, this transistor has a minimum noise figure of approximately 0.3 dB along with roughly 12 dB of associated gain. Furthermore, a 12-mil-thick RO4003C laminate from Rogers Corp. is used for the design.

A waveguide-to-microstrip adapter is incorporated into the input section of the LNA. This adapter was simulated with the Analyst 3D electromagnetic (EM) simulator. The next step of the design process involves the planar structures, which are the amplifier stages and bandpass filter. The LNA consists of two amplifier stages, enabling it to achieve greater than 20 dB of gain. The bandpass filter is placed at the output of the second amplifier stage to reduce out-of-band gain.

Initially, the Microwave Office software was used to simulate and optimize the amplifier stages and bandpass filter via closed-form distributed transmission-line models. Final adjustments and design verification were then achieved by using the AXIEM 3D planar EM simulator. The output transition is the final section of the overall RF design. This transition is realized with a coaxial connector that is placed perpendicular to the printed-circuit board (PCB).

The LNA's enclosure is then described in detail. A specific cover is designed to prevent potential spurious oscillations. Lastly, 10 prototypes were assembled and measured. The measurements demonstrated good agreement with the simulated results, proving that the LNA has a gain of approximately 21 dB at 10.37 GHz. In addition, noise figure is below 0.6 dB across the entire 700-MHz band.

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RECOGNIZE RF ARCHITECTURES FOR THE SMARTPHONE MARKET

THE SMARTPHONE MARKET consists of multiple categories, each having its own design goals and priorities. To meet these varying requirements, different approaches to RF front-end (RFFE) integration must be utilized. In the white paper, "RF Architecture Choices for Next-Generation Handset Designs," Qorvo discusses the differing RFFE integration requirements of two major smartphone categories: flagship and mid-tier phones. The white paper provides RFFE architecture examples of both.

Flagship phones and mid-tier (or entry level) handsets are decidedly different in terms of design priorities, price points, and development timelines. Flagship phones are premium designs that are intended for global use. They typically support six modes and more than 15 LTE bands, according to the white paper. Mid-tier handsets are intended for regional usage with some roaming capabilities. The white paper notes that a typical mid-tier phone supports five modes and between five and eight LTE bands.

Flagship phones demand a very high level of RFFE integration. To attract customers, manufacturers must pack high levels of functionality and performance into an extremely slim handset. The RFFE must support a large number of bands to allow for global use. Another requirement involves support for multiple uplink and downlink carrier-aggregation (CA) combinations.

Qorvo's RF Fusion modules are designed for flagship phones. The RF Fusion portfolio consists of three different modules to cover the low-, mid-, and high-band spectrum regions. An illustration of the RF Fusion architecture is presented in the document.

Regional mid-tier handsets have different RFFE requirements in comparison to global premium handsets. Handset price is critical in this competitive market, meaning manufacturers generally aim to only include the RF components that are needed for each target region or operator. Design flexibility is also important, as handsets must be rapidly adapted for different regions. Qorvo's RF Flex portfolio of modules is intended for mid-tier smartphone manufacturers. These modules enable manufacturers to minimize handset costs. The white paper provides an illustration of the RF Flex architecture.

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Receiver ICs Blend Mixers, Synthesizers, and IF Amps

These densely packed integrated circuits surround mixer circuitry with many of the components that once had to be added to mixers in a typical receiver front end.

WIRELESS BASE STATIONS were once contained in large, climate-controlled spaces, but now they can be mounted anywhere. As wireless network service providers attempt to achieve coverage everywhere, the pressure is on base-station component suppliers to provide more functionality in smaller packages.

A pair of integrated circuits (ICs) from Analog Devices provides a solution by redefining the meaning of "mixer" in receiver front ends. Essentially, the ICs incorporate many of the components once added to a mixer in a receiver—such as local oscillators (LOs) and intermediate-frequency (IF) amplifiers—within the mixer IC itself. They make it possible to dramatically shrink a cellular base station while also providing software-defined-radio (SDR) flexibility to handle a number of different wireless standards.

The ICs in question are the models ADRF6612 and ADRF6614, both designed for RF ranges of 700 to 3,000 MHz, LO ranges of 200 to 2,700 MHz, and IF spans of 40 to 500 MHz. They work with low- or high-side LO injection and include an on-board phase-locked loop (PLL) and multiple low-noise voltage-controlled oscillators (VCOs), all packed within a 7- × 7-mm, 48-lead LFCSP housing. This level of integration and component density is enhanced by the diversity and programmability to support a number of different wireless standards in the small volumes required by modern microcells.

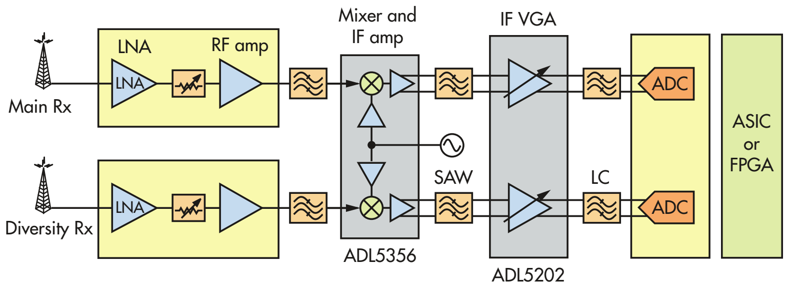
To appreciate the savings in space offered by these highly integrated mixer ICs, it may help to remember the front end of a cellular base-station receiver from around 2010 *(Fig. 1)*. The dual-mixer architecture covered a bandwidth of approximately 1 GHz, requiring multiple components to handle the then cellular frequency range of 800 to 1,900 MHz. Frequency synthesis was provided by a separate PLL and narrowband VCO module that required a unique PLL loop filter for optimum performance. Dedicated VCO modules were used for each band of interest, adding to the required circuit-board area within the base station.

In addition, these discrete components were interconnected by low-impedance transmission lines, which contributed some signal loss. As a result, generous current was needed to drive the VCO output to a sufficient level for the mixer for low phase noise and noise figure under signal-blocking conditions.

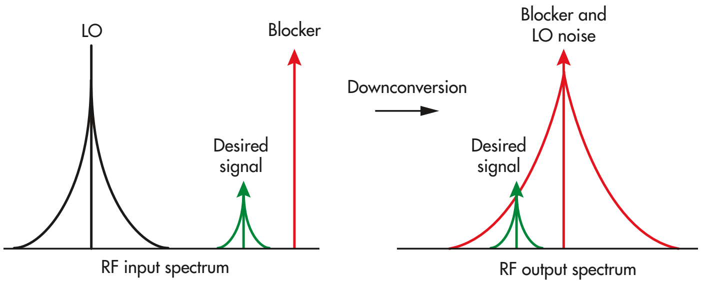
Receiver ICs with integrated VCOs are not new. But achieving the wide bandwidths and low phase-noise levels required by multiple-carrier Global System for Mobile Communications (MC-GSM) wireless networks has been a challenge. The channel reuse scheme of GSM requires that receive LOs have extremely low phase noise, particularly at an alternate-channel offset frequency of 800 kHz *(Fig. 2)*. If excessive phase noise at these alternate channels mixes with unwanted signals at the same 800-kHz offset, it can result in phase noise translated to the IF output, degrading system sensitivity.

Low VCO phase noise is typically achieved with a high-quality-factor (high-Q) tank and narrowband design. Frequency division can also reduce noise. By operating a VCO at an integer multiple of a receiver's LO frequency, a 6-dB/octave reduction in phase noise is achieved by the subsequent division *(Fig. 3)*. The phase-noise requirements for GSM in the 1,800- to 1,900-MHz band are extremely difficult—roughly twice as severe as those in the 800- to 900-MHz band.

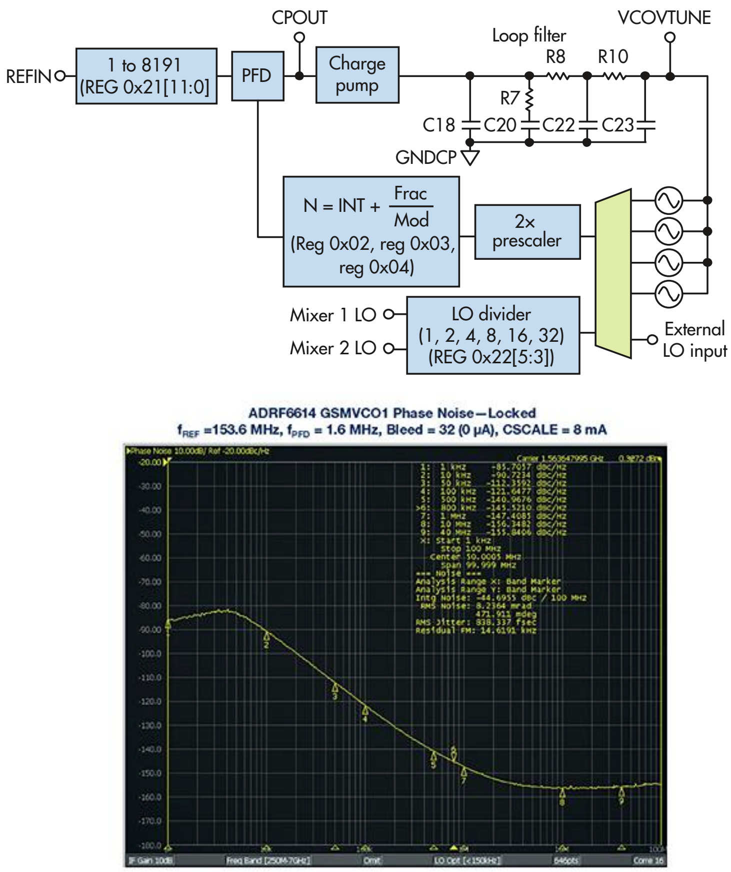
In addition to low phase noise, modern base-station receiver designs must support the many modulation schemes currently used in wireless communications networks. In addition to GSM, other modulation schemes include wideband code-division-multiple-access (WCDMA) and Long Term Evolution (LTE) systems. Receiver designs often consist



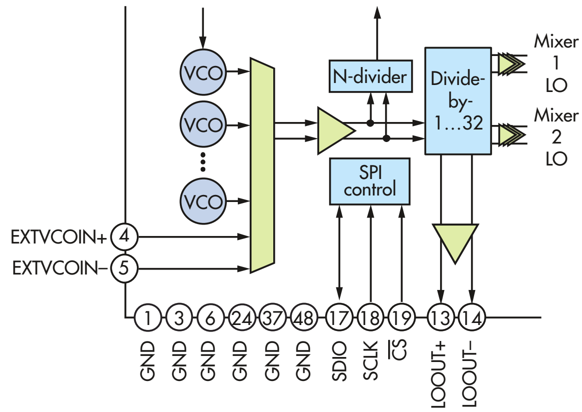
1. The block diagram represents a typical cellular wireless base station from about 2010.



2. The channel reuse scheme requires the use of wide-bandwidth VCOs with low phase noise in GSM wireless systems to avoid performance degradation due to blocking.



3. Octave bandwidths are possible with this VCO circuit configuration.



4. This LO signal chain is used in support of a wireless base-station receiver.

of a number of different VCOs with moderate phase-noise performance levels configured so that they are combined to cover an octave bandwidth within the base station.

Once a number of VCOs have been configured to generate an octave bandwidth for the highest frequencies of operation, lower LO frequencies can be achieved by binary division. This approach was used in the ADRF6612 receiver mixer, where VCO fundamental frequencies span 2.7 to 5.6 GHz and two stages of frequency division realize LO frequencies from 200 to 2,700 MHz by dividing from 1 to 32. For applications that also include MC-GSM, the ADRF6614 receiver mixer includes two additional high-performance VCO cores to provide the LO frequencies needed for the 1,800- to 1,900-MHz GSM bands.

Since modern wireless microcells may not have the benefits of climate-controlled environments, components such as these receiver ICs must provide consistent, reliable performance over wide temperature extremes. To achieve specified performance over a wide operating temperature range, the PLLs and VCOs in the ADRF6612 and ADRF6614 ICs employ a number of calibration techniques.

For wide bandwidths with low noise, each VCO core employs an 8-b capacitive digital-to-analog converter (CDAC) that automatically selects the correct band (1 of 128) for a given LO frequency. Any variations in VCO tank amplitude are carefully monitored by the system, and the amplitude is adjusted using an automatic-level-control (ALC) system for optimum output amplitude. Each IC performs a calibration sequence any time the operating frequency is reprogrammed. This ensures that the selected band centers the tuning voltage for a VCO's tuning varactor diode in the optimum range to maintain the synthesizer in lock over the required operating temperature range.

The four VCO cores in each ADRF6612 and ADRF6614 ICs are positioned to ensure that their operating ranges provide suitable overlap for changing environmental conditions and device fabrication tolerances. The cores will generally move frequency in the same direction for environmental and process variations, so there is enough overlap built in for the frequency synthesizer to always achieve locked conditions.

Once the calibration solution is determined, frequency should be maintained indefinitely; the tuning voltage range supports the required hold-in range. In time-division-duplex (TDD) systems, where the base station may change frequencies on a time-slot-to-time-slot basis, this operating time may be measured in microseconds. In frequency-division-duplex (FDD) systems, it might be necessary to maintain lock on a single frequency for years.

There is no allowable downtime at any point during the system operation of the ADRF6612 and ADRF6614 ICs. Thus, changes in temperature and component aging effects are covered by the varactor tuning-voltage range and frequency tuning sensitivity (Kv) of the VCO for potentially a 145°C temperature range. Each IC constantly monitors device temperature and adjusts the VCO bias as required.

The ADRF6612 and ADRF6614 ICs use a unique approach to minimize degradation of receiver sensitivity from spurious signal products. Using the synthesizer's integer mode with a tight loop filter results in low reference spurious products of less than −100 dBc. Minimal spurious signals are critical for modulation schemes such as MC-GSM. For LTE and other modulation schemes, or where fine frequency steps are required, the synthesizer can be operated in fractional-N division mode. The reference path incorporates a 13-b divider, and the integer and fractional paths each incorporate 16-b dividers for flexibility.

For applications where co-located, phase-tracked receive channels are required, such as in multiple-input, multiple-output (MIMO) systems, multiple ADRF6612 and ADRF6614 ICs can be cascaded in a daisy-chain manner to permit one unit acting as a master synthesizer to supply additional slave receivers through their external LO output and input ports, respectively. In this way, additional LO distribution amplifiers and their associated increases in phase noise can be minimized.

To support both high- and low-side LO injection, each IC's LO chain provides flexible signal processing *(Fig. 4)*. Using integer division ratios of 1 to 32, low-side injection is possible even for the 700-MHz band with a high IF. The LO stages also provide a square-wave drive to the passive mixer cores over the full LO range from 200 to 2,700 MHz.[1]

Modern wireless base-station receivers must operate in typically hostile signal environments. For example, any other in-band signals close in frequency to low-level input signals to the cellular receiver can act as blocking signals. In such a case, phase noise from the LO amplifier in the vicinity of the blocking signal is mixed into the IF output band directly on top of the desired signal. This increases the noise floor and reduces the signal-to-noise ratio (SNR) of the receiver—sometimes dramatically.

Since the blocking signal may be large (high power), it is important that both the VCO phase noise be extremely low, and the LO chain does not degrade the noise floor at the blocker offset. At these very high blocking levels, the receiver noise figure will eventually become dominated by the blocking signal and degrade according to the power level of the blocker.

In discrete implementations of the receive chain, it would be possible to introduce some filtering into the LO path to minimize the phase noise at the blocker offset coming from the VCO and LO distribution amplifiers. However, in an integrated front end, care must be taken to avoid additive phase noise in the LO chain.

The ADRF6612 and ADRF6614 ICs employ a high-gain LO chain and hard-limiting amplifiers to drive the LO chain into limiting. As each stage enters hard limiting, the small-signal gain of the LO chain that would otherwise increase phase noise is substantially reduced, minimizing noise-figure degradation under blocking conditions.

The noise fold-over from the blocking signal degrades the output noise spectrum of the receiver, and hence the receiver noise figure, by raising the output noise floor. The ADRF6612 and ADRF6614 receiver ICs are designed to withstand significant blocking signals with minimal degradation of receiver noise figure. Even with a +10-dBm input blocking level, the receiver's noise figure is only degraded by 3.2 dB at 10 MHz offset from the carrier, even though the conversion gain is compressed by 1 dB at that extreme blocking level.

The high level of integration in these receiver ICs has enabled significant performance improvements and savings in dc power for modern wireless base-station designers. The ICs feature a technique that simultaneously optimizes the RF and IF stages surrounding the on-chip mixer.[2-4] mw

Editor's Note: This is an abbreviated version of the full article, available with additional performance data, at mwrf.com.

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With the increased level of integration inherent in complete receiver chains comes a much larger development team. While it isn't possible to list all of the people that contributed to this work, the authors take great pleasure in acknowledging the efforts of the following industry experts: Kurt Fletcher and Dominic Mai spent many hours implementing an excellent layout while maintaining symmetry and avoiding unwanted couplings. Vincent Bu worked to develop the necessary packaging with our vendors. Susan Stevens maintained the excellent working relationship with our external foundry partner. Craig Levy and Rachana Kaza developed the production test capability for these parts. Wendy Dutile, Ed Gorzynski, and Chris Norcross all participated in the extensive prototyping of the test circuitry. Mark Hyslip coordinated the business aspects of successfully bringing this project together. The authors would like to dedicate this work in the memory of our colleague, Edward J. Gorzynski.

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Design, Spectrum Challenges Create Different View of Power Sensors

As higher frequencies become more common, power sensors must also provide the necessary measurement capabilities for current and future applications.

ENGINEERS SELECT POWER sensors based on their specific application and how the various sensor designs—thermal or diode—fit their measurement needs. That evaluation process is changing as more designs utilize higher frequencies due to RF spectrum overcrowding, high-bandwidth services, 5G backhaul, IEEE 802.11ad, WirelessHD, and other technologies.

To understand where power sensor trends are going, it is important to realize the pros and cons of each sensor type. A thermocouple sensor has a very good linear relationship between the changes in voltage and power, making it possible to achieve highly accurate power readings. Another benefit is that the thermocouple elements typically have a good resistance to electrostatic discharge (ESD) or other transient burnout. Finally, thermocouple detectors measure root-mean-square (RMS) power and are therefore modulation-independent. They will provide accurate average power readings of almost any signal type.

These accurate readings come with some drawbacks—chief among them, much slower measurement speeds. They also have rise times in the millisecond range, so they are not suitable for measuring peak or pulse power. Thermocouple sensors also have a higher noise floor, which limits the dynamic range to only around –30 or –35 dBm to +20 dBm in typical implementations.

Engineers who need to make true-RMS measurements across a wider dynamic range often select diode sensors (*Fig. 1*). The measurement speed of diode sensors is limited by their ability to process the data. With today's sensors having better processing technologies, diode sensors now feature measurement speeds in the thousands and tens of thousands of readings per second. They typically can measure power down to –40 or –50 dBm.

RADIO RECEIVERS

To measure signals of lower power, many engineers will use radio receivers (mostly in spectrum analyzers), which have much lower noise compared to thermal or diode sensors. These receivers can have noise floors well below –100 dBm, so engineers will be able to find and measure many signals that would never register on a thermal or diode sensor.

The major disadvantage is a high price tag. Most radio receivers are only available in spectrum analyzers, so they are usually restricted to the lab, which adds to the budget, and a wider breadth of measurements is required. Radio receivers also will not have the same amplitude accuracy as traditional power meters, generally achieving around ±2 dB.

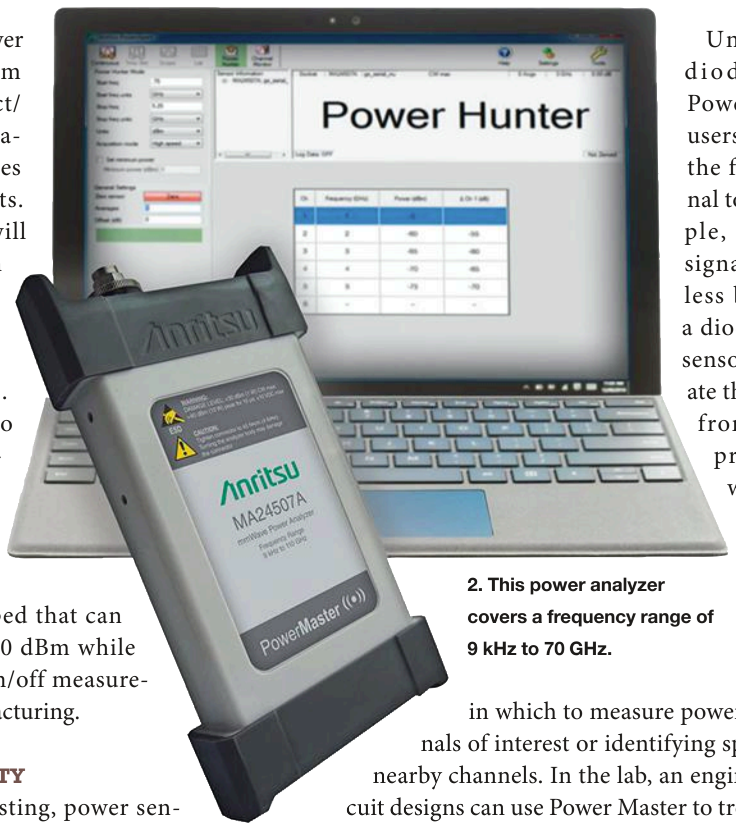
1. Diode sensors are commonly used to perform measurements.

HIGHER-FREQUENCY CHALLENGES

Just as the rollout of LTE and increasing use of modulated signals factored in the power sensor's evolution, so will current designs at higher frequencies. At millimeter-wave bands, power tends to fade due to propagation and transmission losses. For most current power sensors, conducting accurate power measurements at these higher frequencies and lower power levels are problematic.

With Power Master, a field technician can define the frequency channel in which to measure power, focusing on the signals of interest or identifying specific interference in nearby channels.

Being able to measure power down to a level such as –90 dBm will result in greater product/system performance verification of high-frequency devices in production environments. For example, chipmakers will verify designs during research and development using a radio receiver or spectrum analyzer to obtain measurements down to –100 dBm. These instruments are too costly to use during manufacturing, which means power sensors measuring down to –40 dBm maximum are used. New cost-effective solutions are being developed that can measure power down to –90 dBm while conducting the necessary on/off measurements associated with manufacturing.



2. This power analyzer covers a frequency range of 9 kHz to 70 GHz.

FREQUENCY SELECTABILITY

When it comes to field testing, power sensors that are not frequency-dependent and have limited dynamic range are not as effective, owing to the overcrowded RF spectrum where unintended signals such as spurs, harmonics, and interference can impact power readings. Power sensors that let users zero in on their signal of interest enable measurements such as channel power, adjacent channel power (ACP), and spur/harmonic suppression to be conducted with greater efficiency and confidence.

One example of this new wave of instrument is the MA24507A Power Master millimeter-wave power analyzer from Anritsu (*www.anritsu.com*) (*Fig. 2*). Utilizing Anritsu's ShockLine nonlinear-transmission-line (NLTL) technology, this USB-powered, frequency-selectable RF power sensor combines a power measurement range of –100 to +10 dBm with fast measurement speeds in a compact, lightweight housing.

Unlike thermal and diode-based sensors, Power Master also gives users the ability to define the frequency of the signal to measure. For example, when field testing signal strength for wireless backhaul networks, a diode or thermal power sensor will not differentiate the intended RF signal from the other signals present at the input, which could potentially spoil the measurement.

With Power Master, a field technician can define the frequency channel in which to measure power, focusing on the signals of interest or identifying specific interference in nearby channels. In the lab, an engineer verifying RF circuit designs can use Power Master to troubleshoot unexpected signal behavior caused by a dirty local oscillator (LO), bad components, or outside signal interference. With the ability to measure power below –90 dBm, Power Master enables more over-the-air (OTA) testing that would otherwise be difficult to do with a bulky spectrum analyzer or power meter with limited power range.

CONCLUSION

The ability to conduct power measurements will become increasingly important as more designs climb to high frequencies to accommodate bandwidth. To address many of these applications—including millimeter-wave designs, IEEE 802.11ad, WirelessHD, and 5G backhaul—power sensors will need to be able to efficiently conduct the necessary tests at lower power levels. New design architectures will continue to be developed to meet these needs. mw

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RF LDMOS Transistors Power Smaller Base Stations

These high-power transistors boast a 30% savings in board space compared to their LDMOS predecessors.

The A3T18H360W23S Airfast 3 LDMOS RF power transistor delivers peak RF output power of +55.9 dBm, gain of 17.5 dB, and PAE of 52% efficiency.

SMALLER IS OFTEN better, but miniaturizing circuits that handle high power levels poses serious challenges for some engineers, such as designers of RF/microwave power amplifiers (PAs). Wireless service providers want better coverage for their customers by way of smaller (yet more powerful) base stations. Circuit designers are challenged, in turn, to create PAs with increased performance, but smaller footprints, cost, and power consumption than previous models.

Fortunately, advances at the device level, based on silicon LDMOS semiconductor technology, along with enhanced packaging and other improvements, make it possible to create smaller and better PAs for the ever-smaller cells of wireless communications networks.

Reducing operating expenses has always been one of the most important challenges for wireless carriers, and it has become increasingly important as large numbers of small cells complement traditional macrocells, increasing their overall infrastructure overhead. Consequently, carriers today must consider every possible cost-reduction solution, including the efficiency of all elements of the transmission path, and especially RF power transistors and amplifiers.

For example, increasing transistor and amplifier efficiency reduces costs by requiring less current consumption to deliver a specific RF output level. This can potentially reduce the number of transistors—and thus, board space devices—required to achieve it.

The third generation of the Airfast LDMOS device family (*see figure*) from NXP Semiconductors is tailored to meet this challenge by providing high efficiency and gain when employed in asymmetrical Doherty amplifiers. Compared to second-generation Airfast 2 devices, these newest power transistors deliver as much as 4% higher efficiency (53% final-stage efficiency and as much as 50% lineup efficiency). The devices also feature a 20% improvement in thermal performance, up to 90-MHz full-signal bandwidth, and as much as 30% space savings compared to earlier Airfast power transistors.

The first members of the third-generation Airfast LDMOS RF power transistors collectively span 1,805 to 2,690 MHz, making it possible to cover an entire cellular band with a single device. They are also the first Airfast products to be housed in air-cavity plastic packages. These housings combine excellent electrical performance with low thermal resistance for effective dissipation of heat.

The initial third-generation device members include four transistors covering a frequency range of 1,805 to 2,690 MHz in bands with as much as 89 W output power. The lower-frequency devices, models A3T18H450W23S and A3T18H360W23S, are suitable for use from 1,805 to 1,880 MHz, frequencies popular for Fourth-Generation (4G) Long Term Evolution (LTE) cellular base-station deployment. The A3T18H450W23S delivers 89 W average output power with 17.2-dB gain and 51% power-added efficiency (PAE). The A3T18H360W23S has average output power of 56 W with 17.5-dB gain and 53% PAE.

One design goal in developing these new transistors was to reduce the "solution size" resulting from the use of the device, or the number of transistors required (in an amplifier) for specific levels of output power, efficiency, and instantaneous bandwidth. In the past, carriers could use only about 40 MHz of the full frequency range of a device, but the new transistors make it possible to cover their full signal bandwidth without sacrificing efficiency and power.

Earlier cellular base-station amplifier solutions may have required two or three transistors to achieve required performance levels for a wide bandwidth, but this can now be accomplished with these smaller devices. The reduction in size, without sacrificing power or thermal efficiency, was accomplished through advances in packaging, the use of an envelope termination inside the package, changes to device design, and improvements to internal package components. mw

NXP SEMICONDUCTORS, 1300 Alma School Rd., Chandler, AZ 85224; www.nxp.com/RF.

JACK BROWNE | Technical Contributor

Wideband Signal Analyzer Captures16 kHz to 26.5 GHz

For applications requiring long periods of wideband signal capture, this analyzer can grab 800 MHz at a time—from audio frequencies through high microwave signals.

COMMUNICATIONS SIGNAL BANDWIDTHS are growing wider with time, as users find needs for sending more voice, video, and data through wired and wireless systems. On the military side, radar and electronic-warfare (EW) systems also employing wider bandwidths. One of the challenges for system developers in these areas is to perform wideband signal capture, often for long time periods, in search of transient events.

Fortunately, a test solution was recently introduced by Tektronix *(www.tek.com)*: the RSA7100A wideband signal analyzer. It offers a standard real-time capture bandwidth of 320 MHz, which can be optionally extended to as wide as 800 MHz, across a wide frequency range of 16 kHz to 26.5 GHz. The analyzer, with its companion controller and supporting software, is well-suited for wideband communications design, spectrum management, and advanced radar and EW system testing.

For those who don't need the wide frequency range, the RSA7100A also comes in a version covering 16 kHz to 14 GHz, with the same options for real-time analysis bandwidth. Both lower- and higher-frequency versions tune with 0.001-Hz resolution and are available with a front-end preamplifier for increased signal sensitivity from 10 MHz to 3.6 GHz.

The RSA7100A operates both by displaying measured spectrum in real time and by analyzing data from measurements taken over time. It is actually a measurement system (*see figure*), teamed with the CTRL7100A controller specially designed for the signal analyzer. Separating the analyzer from the computing engine allows sophisticated signal record, playback, and graphical visualization of signal data.

The controller enables real-time DPX operation with simultaneous streaming of measured data to RAID (redundant array of independent disks) memory. It runs on a Windows-based OS, including generous RAM and removable hard-disk storage for flexibility.

The broadband real-time analyzer employs a stable 10-MHz reference oscillator to deliver stable performance and high-frequency accuracy. Included with the instrument is a BNC connector for hooking up an external frequency reference source. The single-sideband (SSB) phase noise with the internal reference offers a quite respectable −128 dBc/Hz offset 1 kHz from 1-GHz carrier, −134 dBc/Hz offset 10 kHz from the same carrier, and −142 dBc/Hz offset 1 MHz from a 1-GHz carrier.

The RSA7100A wideband signal analyzer is available in versions covering 16 kHz to either 14.0 or 26.5 GHz, with capture bandwidths as wide as 800 MHz.

For those who don't need the wide frequency range, the RSA7100A also comes in a version covering 16 kHz to 14 GHz, with the same options for real-time analysis bandwidth. Both lower- and higher-frequency versions tune with 0.001-Hz resolution and are available with a front-end preamplifier for increased signal sensitivity from 10 MHz to 3.6 GHz.

The instrument's well-matched input port exhibits VSWR of less than 1.50:1 to 14 GHz and less than 1.70:1 to 26.5 GHz. As much as +30 dBm input power can safely be fed to the input port. Furthermore, several attenuators are built into the analyzer's input signal path for controlling input power levels.

Attenuation of 0 to 100 dB is available in 1-dB steps from 16 kHz to 3.6 GHz, and attenuation from 0 to 75 dB can be set in 5-dB steps from 3.6 to 26.5 GHz. In addition, the analyzer's front end includes a fixed lowpass filter and tunable bandpass preselector filters for image rejection.

Reference levels can be set from −170 to +40 dBm in 0.1-dB steps. For the frequency range of the input preamplifier (10 MHz to 3.6 GHz), the amplitude accuracy (at +25°C) is ±0.13 dB without the preamplifier and ±0.14 dB with the preamplifier.

The typical displayed average noise level (DANL) without the preamplifier is −156 dBm/Hz from 100 MHz to 1.7 GHz, −154 dBm/Hz from 1.7 to 2.8 GHz, −151 dBm/Hz from 2.8 to 3.6 GHz, −156 dBm/Hz from 3.6 to 14 GHz, −152 dBm/Hz from 14 to 24 GHz, and −150 dBm/Hz 24 to 26.5 GHz. With the preamp turned on, the typical DANL is −164 dBm/Hz from 50 MHz to 1.7 GHz and −162 dBm/Hz from just beyond 1.7 to 3.6 GHz.

The RSA7100A offers advanced frequency- and time-domain signal recording and playback capabilities and functions with internal or external triggers. It can capture real-time events as short as 700 ns in the frequency domain and as short as 4 ns in the time domain, with ±4-ns delay uncertainty.

Triggering functions include Power Level within Span, to look for signals at specific power levels, and Frequency Mask triggering, when searching for signals within a certain frequency range. Power-based triggering can be performed for levels from −170 to +30 dBm, with the level set with 0.1-dB resolution.

The RSA7100A is a powerful measurement tool for any users who are concerned about broadband measurements or signal activity within a given environment. Together with its controller, the analyzer is meant to operate with a pair of the company's software packages, DataVu-PC and SignalVu-PC.

DataVu-PC provides the capability to mark events of interest, export waveforms to other formats, and perform pulse analysis and export the data into Pulse Descriptor Word (PDW) file format for further analysis. SignalVu-PC orchestrates real-time spectrum and vector signal analysis, with a host of options for full-featured pulse analysis and analysis of signals with 27 different modulation formats. P&A: $135,000 and up. mw

TEKTRONIX INC., 114150 SW Karl Braun Dr., P.O. Box 500, Beaverton, OR 97077; (800) 833-9200, www.tek.com

JACK BROWNE | Technical Contributor

Robust Switch Matrix Eases Multichannel Testing

This rack-mountable, 20 × 6 nonblocking switch matrix provides the performance and flexibility to speed and simplify connections to multiple test systems.

MODERN COMPONENTS AND subsystems—whether in commercial or military applications—must often be tested for a multitude of different characteristics, often requiring disparate test systems to make the required measurements. This can be done by loading a device under test (DUT) into a test fixture and physically moving it from test system to test system.

However, there is an easier way: Use a switch matrix with the capacity and performance to make the connections between the DUT and the different test systems electronically, such as the model ZT-20X6NB 20 × 6 nonblocking switch matrix from Mini-Circuits *(www.minicircuits.com)*. With a bandwidth of 600 to 6,000 MHz and enough ports to connect a slew of test instruments/systems at one time, it even includes a front-panel touchscreen for easy on-the-spot control.

Better still, the ZT-20X6NB boasts enough digital interfaces for connection to almost any PC. This switch matrix has been built to last, with excellent long-term reliability and minimal degradation in electrical performance.

The rack-mountable ZT-20X6NB 20 × 6 switch matrix, with a frequency range of 600 to 6,000 MHz, covers the bulk of the world's telecommunications bands for programmable signal routing in automated test applications.

For those who may have considered Mini-Circuits "only" a supplier of cost-effective RF/microwave components, the ZT-20X6NB *(see figure)* shows another side of the firm's engineering capabilities. Housed in a solid aluminum 5U-high, 19-in.-wide rack-mount chassis, this subsystem is designed to take on the everyday punishment of high-volume measurements.

Removing the cover reveals a true high-frequency subsystem design and layout, containing many of the company's components. Peering into the heart of the unit shows great attention to detail regarding component placement, coaxial interconnections, and thermal management. The fan-cooled switch matrix can handle input-signal power levels to several watts (+36 dBm) to accommodate a wide range of communications components and systems testing through 6 GHz.

The ZT-20X6NB creates bidirectional signal paths, with an almost unlimited number of port-to-port combinations. These can be set from the front panel or programmed using the ActiveX and .NET APIs provided with the switch.

The front panel is well-organized, with RF/microwave interconnections made by means of Type-N female connectors that are all accessible from the front panel. The connectors are organized into "A" and "B" ports. The six B ports can be connected to any combination of the 20 A ports without compromising the expected switch-matrix performance characteristics, such as isolation and insertion loss.

In fact, all six A ports can be combined to the same B port simultaneously, as might be done for multiple-input, multiple-output (MIMO) system testing. The switch matrix has both USB and Ethernet control interfaces for remote control and programmability via an external PC with internet access.

In terms of performance, the ZT-20X6NB switch matrix is rated for +36 dBm maximum average power into any A port and +26 dBm maximum average power into any B port. The typical return loss is 12 dB across the full frequency range. Typical isolation is 80 dB between any two A ports; 30 dB between any pair of B ports connected to the same A port; and 80 dB for any pair of B ports when connected to different A ports.

The ZT-20X6NB 20 × 6 switch matrix is a well-built signal-routing solution for automated testing of multiple communications channels with a number of test systems. The unit measures 19.00 × 8.73 × 20.18 in. It is designed for 90- to 260-V ac, 47- to 63-Hz supplies. mw

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

Product Feature

JACK BROWNE | Technical Contributor

System Sets Standards for 1/f Noise Measurements

Accurate device noise models and noise-analysis performance start with on-wafer measurements capable of capturing extremely low device noise currents.

NOISE IMPACTS HIGH-FREQUENCY systems in many ways, such as transmission distortion and limiting receiver sensitivity of low-level signals. But to accurately analyze noise via modeling with SPICE and other software simulation programs, it must be measured.

The 9812DX wafer-level 1/f noise characterization system from ProPlus Design Solutions Inc. *(www.proplussolutions.com)* provides new insights into device-level noise with unparalleled 1/f noise measurement speed, resolution, and accuracy. Such wafer-level measurements are critical in various scenarios—for example, semiconductor foundries may seek to enhance the noise performance of a semiconductor process, especially as device geometries shrink to achieve higher-frequency and higher-data-rate operation.

The 9812DX 1/f noise characterization system *(see figure)* is actually an enhanced version of the company's widely used 9812D 1/f noise measurement system. It features increased resolution and measurement speed (as much as 10 times greater speed and resolution compared to the older system) to accommodate the growing complexity and shrinking device geometries of advanced integrated-circuit (IC) designs.

Of course, the new system isn't just for foundries: It can also provide invaluable device data for foundry customers looking to improve a process for lower noise levels. In addition, it can give circuit designers more accurate device noise models for evaluating the performance and quality of a foundry process, and for performing accurate noise analysis of their devices.

The noise-measurement system is suitable for process quality monitoring, statistical noise analysis, and studying the effects of process modifications on device and integrated-circuit (IC) noise performance. It speeds and simplifies the collection of device data at different bias points and various other operating conditions, including across multiple die for fast statistical noise data characterization.

The 9812DX offers a 10-MHz bandwidth, starting at 0.03 Hz for analysis of true wafer-level, low-frequency noise. It can measure the noise of dc current as low as 0.1 nA and as high as 200 mA at bias levels up to 200 V. The improvement in noise performance over the older system results in noise measurement resolution of 1×10^{-27} A^2/Hz.

The enhanced performance results from an improved system architecture, with redesigned critical subsystem blocks and carefully selected system components. The test system is designed with stable, high-performance components, including a low-noise-voltage amplifier (LNA) with a frequency range of 0.03 Hz to 10.0 MHz and 0.65-nV noise at 5 kHz. It also features low-noise-current LNAs ranging from 0.03 Hz to 10 MHz, and with various resolution and bandwidth options.

The 9812DX 1/f noise characterization system provides new levels of speed, accuracy, and resolution for on-wafer active and passive device noise measurements.

The 9812DX 1/f noise characterization system incorporates programmable bias filters, and a large number of input/output load resistors for different measurement setups. It also has built-in electrostatic-discharge (ESD) protection for a device under test (DUT), and a built-in GPIB card for controlling additional programmable test instruments.

Another feature is its built-in dynamic signal analyzer (DSA) with large on-board memory and multithreaded processing for improved performance and reduced cost. This eliminates the need for expensive external signal-processing equipment and reduces upfront investment and risk.

Finally, the company supports the noise analysis with a number of highly effective modeling and simulation tools, including NanoSpice—a generic parallel SPICE simulator for simulations of extremely dense analog circuits with large numbers of active and passive devices. mw

ProPLUS DESIGN SOLUTIONS INC., 2025 Gateway Pl., Ste. 130, San Jose, CA 95110; (408) 459-6129, www.proplus-solutions.com.

CHRIS DeMARTINO | Technical Editor

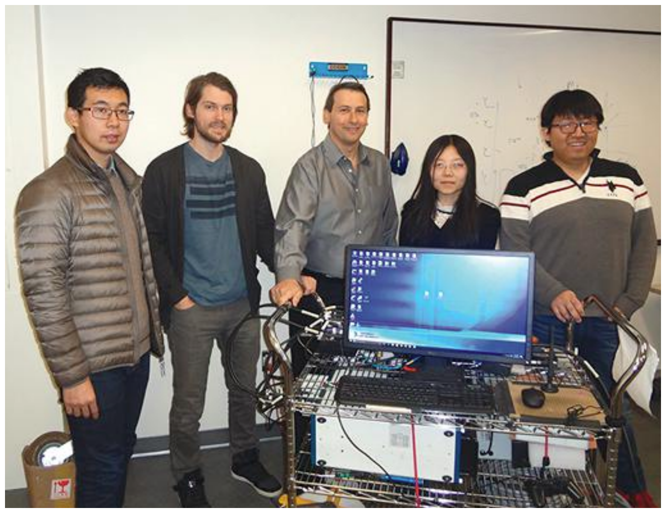
NYU WIRELESS Drives Next-Generation Technology

Students and faculty at NYU WIRELESS are fervently working to create the wireless technology of the future.

THE NEW YORK UNIVERSITY (NYU) WIRELESS (*http://wireless.engineering.nyu.edu*) academic research center in Brooklyn, N.Y., is at the forefront of tomorrow's wireless technology. Led by its founding director, Professor Ted Rappaport, NYU WIRELESS is focused on next-generation 5G wireless networks, with millimeter-wave technology being a major research area. NYU WIRELESS combines NYU's Tandon School of Engineering, School of Medicine, and Courant Institute of Mathematical Sciences. Among its 16 industrial affiliates are Keysight Technologies (*www.keysight.com*) and National Instruments (NI; *www.ni.com*).

Although the center is known for its 5G research, a conversation with Rappaport during a recent visit to the NYU WIRELESS facility revealed that he is actually looking beyond that. He said his goal is to have leaders of "where the market will be." Looking into the future, Rappaport said he believes that we will someday have true three-dimensional (3D) video. He explained how NYU WIRELESS is investigating frequencies above 100 GHz into the sub-terahertz region.

1. This photo shows the transmitter box used for channel-sounding measurements.



2. Here, Professor Rappaport and students are gathered in the channel-sounding lab.

The visit included a tour of two of the facility's labs. The first stop was the channel-sounding lab (*Figs. 1 and 2*). "We have brought our equipment to locations in both Brooklyn and Manhattan to do measurements in the urban environment," said George MacCartney Jr., an engineering Ph.D. candidate. "We elevate the transmitter to a lamppost level, which is expected for millimeter-wave access points in the future.

"Conducting measurements in different environments and scenarios allows us to create an overall physical model," he continued. "Other people can then use our model instead of having to go out into the field and conduct their own measurements. We rotate the antennas along the azimuth and elevation planes at many different angles in order to gain an omnidirectional sense of the environment." Interestingly enough, the antennas can actually be positioned with a PlayStation 3 controller, which is remotely controlled via LabVIEW.

In terms of future goals, MacCartney Jr. added, "We are hoping that future measurement systems utilize phased arrays that can electronically steer the beams. This will allow very fast measurements to be performed." Moreover, new students are examining frequencies above 100 GHz.

According to Rappaport, "Our equipment and our students—past and present—proved that millimeter waves would work. We went out to New York City and proved that you don't need to have line-of-sight (LOS) for millimeter-waves—everyone thought you did. This was driven by our rotational mechanical systems.

"We take the knowledge of the radio channel and put it into software, which can be used by others," he continued. "Over 5,000 people in engineering companies around the world are using the NYUSIM channel simulator, which is freely downloadable (*http://wireless.engineering.nyu.edu/5g-millimeter-wave-channel-modeling-software*)."

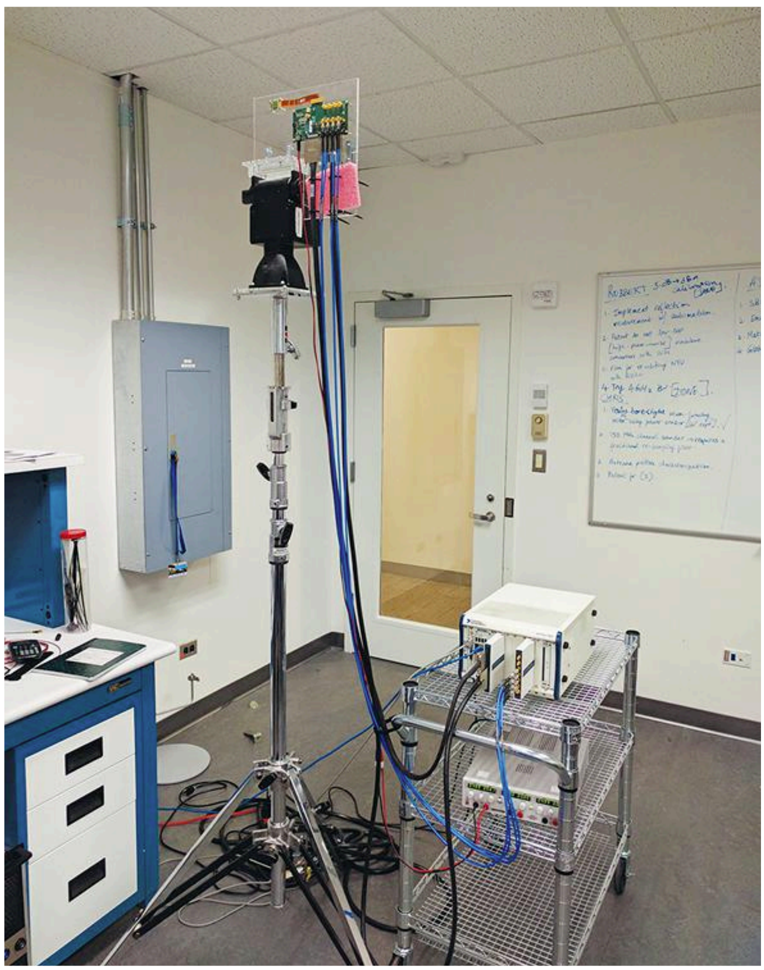
The NYUSIM channel simulator, an open-source 5G channel model simulator, is a result of measurements along with 5G millimeter-wave channel models that have been developed from 2 to 73 GHz. NYUSIM can be used to generate spatial and temporal wideband channel impulse responses.

The next stop of the tour was the lab that is investigating phased arrays (*Fig. 3*). According to Aditya Dhananjay, a post-doctoral research fellow, as well as the co-founder and president of MilliLabs (*www.millilabs.com*), "One of the focal points of our research is tunable millimeter-wave communications. With millimeter-wave systems, highly directional antenna beams are needed to enable communication between a transmitter and a receiver.

"In the lab, steering the beam in different directions can be achieved by rotating mounted antennas," he continued. "But in reality, that's not how you steer beams because they need to be steered on the order of microseconds. Steering beams on the order of microseconds requires phased arrays. We are one of the only schools with access to a phased-array system in our lab. We work with equipment from NI and Keysight.

"We also have millimeter-wave systems for data links," added Dhananjay. "This capability allows us to send real data between a transmitter and a receiver instead of just measuring wireless propagation. We have also developed techniques to do phase-noise correction. At higher frequencies, oscillators tend to behave far worse than oscillators at lower frequencies. The techniques we have developed help to overcome hardware imperfections. We are also building millimeter-wave emulators."

To summarize, NYU WIRELESS is clearly in the driver's seat when it comes to 5G and millimeter-wave research. We can expect to see many more developments in the days ahead. On that note, the next Brooklyn 5G Summit (*http://b5gs.com*) will take place April 19-21, 2017. mw



3. This photo shows the phased-array system being used.

Flexible Cables Test Tight Spots from DC to 18 GHz

Mini-Circuits' ULC-2FT-NMNM+ is an ultra-flexible, 2-ft.-long test cable with stainless-steel male Type N connectors for use from DC to 18 GHz. It features rugged construction with strain relief for long operating lifetime. The RoHS-compliant cable achieves 0.75-in. static bend radius and 2.0-in. dynamic bend radius to accommodate challenging mating configurations. The test cable features excellent shielding effectiveness (SE) through a triple-shielded design, with low insertion loss of typically 0.7 dB from DC to 6 GHz and 1.6 dB to 18 GHz. The return loss is better than 17 dB across the full frequency range and typically better than 25 dB. The test cable handles operating temperatures from -55 to +85°C.

Coaxial Adapter Mates 40-GHz 2.92-mm Connectors

Mini-Circuits' KF-KM50+ 40-GHz coaxial adapter joins 2.92-mm female to 2.92-mm male coaxial connectors with minimal added loss from DC to 40 GHz and minimal impact on amplitude and phase response with frequency. The insertion loss is typically 0.09 dB from DC to 40 GHz. The VSWR is typically 1.03:1 from DC to 18 GHz and typically 1.04:1 from DC to 40 GHz. The RoHS-compliant, 50-Ω adapter features a passivated stainless-steel body and is qualified to 500 mating cycles. It is suitable for operating temperatures from -55 to +100°C. The low-cost adapter is available from stock.

Two-Way 0° Splitter/Combiner Handles 10 to 40 GHz

Mini-Circuits' ZN2PD-K44+ two-way 0° splitter/combiner features outstanding control of amplitude from 10 to 40 GHz, with almost negligible amplitude unbalance of 0.2 dB across the full frequency range. The coaxial splitter/combiner handles as much as 10 W power as a splitter (2 W as a combiner) with only 1.0 dB typical insertion loss (above the nominal 3-dB split point) to 40 GHz. Typical isolation between ports is 20 dB. The broadband splitter/combiner passes as much as 600 mA (300 mA per port). Ideal for satellite and point-to-point microwave radio links as well as in radar and test applications, the component measures 3.5 × 2.0 × 0.5" with female 2.92-mm connectors.

Low-Noise Amplifier Quiets 0.5 to 12.0 GHz

Mini-Circuits' PMA2-123LN+ is a wideband, monolithic low-noise amplifier (LNA) with low noise, high gain, and high linearity from 0.5 to 12.0 GHz. Based on GaAs pHEMT technology, the MMIC amplifier offers noise figure of typically 3.5 dB at 0.5 GHz, 2.2 dB at 2.0 GHz, and 3.1 dB at 12 GHz. It provides gain of typically 18.6 dB at 0.5 GHz, 19.2 dB at 2.0 GHz, and 15.3 dB at 12.0 GHz. The output power at 1-dB compression (P1dB) is typically +15.2 dBm at 0.5 GHz, +15.3 dBm at 2.0 GHz, and +14.0 dBm at 12.0 GHz, while the output third-order intercept point (OIP3) is typically +27.4 dBm at 0.5 GHz, +28.0 dBm at 2.0 GHz, and +26.3 dBm at 12.0 GHz. The LNA typically draws 68 mA current from a +6-Vdc supply and is supplied in a 2 x 2 mm RoHS-compliant surface-mount housing.

SP4T Switch Promises Long Life to 18 GHz

Mini-Circuits' MSP4TA-18-12D+ is a single-pole, four-throw (SP4T) switch rated for 10 million switching cycles (when switching 0.1 W RF power) and high reliability from DC to 18 GHz. The absorptive, 50-Ω fail-safe switch achieves insertion loss of typically 0.15 dB or less from DC to 8 GHz and typically 0.5 dB from DC to 18 GHz. The isolation is typically 100 dB from DC to 8 GHz and typically 80 dB from DC to 18 GHz. VSWR ranges from typically 1.20:1 from DC to 8 GHz and typically 1.30:1 from DC to 18 GHz. The switch, in a break-before-make configuration, is supplied with SMA RF connectors and 9-pin D-sub connectors. It provides reliable "sleep-time" switching, with typical switching time of 20 ms with +12 V control signals.

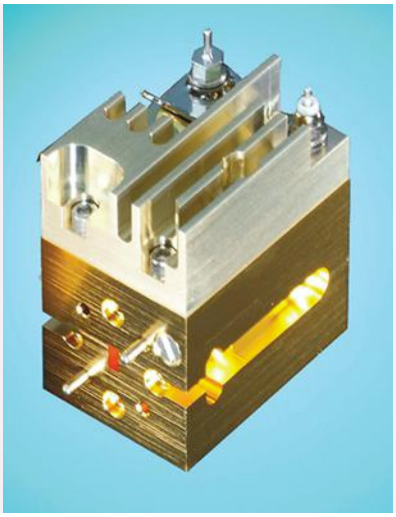
Cavity Filter Passes 11.2 to 11.4 GHz

Mini-Circuits' ZVBP-11G3+ cavity bandpass filter features low insertion loss of typically 2 dB throughout a 200-MHz passband from 11.2 to 11.4 GHz, with low VSWR of typically 1.40:1 through the same passband. It offers 48-dB rejection of unwanted signals throughout a lower stopband of DC to 11.03 GHz and an upper stopband of 11.58 to 20.00 GHz. Suitable for satellite communications (satcom) and radar systems, the cavity filter achieves sharp transitions from passband to stopbands. The RoHS-compliant bandpass filter is rated for 10 W maximum RF input power at operating temperatures from -40 to +85°C. It is supplied in a compact housing with female SMA connectors.

Four-Channel Attenuator Programs 0 to 95 dB to 6 GHz

THE RC4DAT-6G-95 programmable attenuator provides 0- to 95-dB attenuation with 0.25-dB resolution in four independent channels at frequencies from 1 to 6,000 MHz. Suitable for automatic test applications and fading simulators, the attenuator includes USB and Ethernet control ports in a compact shielded metal case measuring just 5.17 × 3.00 × 0.85 in. with female SMA connectors. It achieves 650-ns attenuation transition time with typical attenuation accuracy of ±0.4 dB. The plug-and-play attenuator does not require software drivers and is supplied with easy-to-install and use graphical-user-interface (GUI) software.

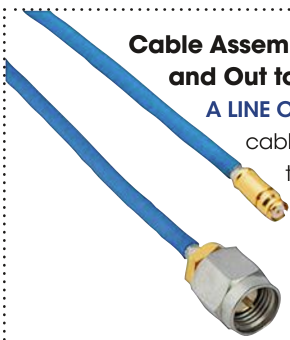
MINI-CIRCUITS, P.O. Box 350166, Brooklyn, NY 11235-003; (718) 934-4500; *www.minicircuits.com*



PAs Boost E- and W-Band Signals

POWER AMPLIFIERS (PAs) based on gallium-nitride (GaN) power transistors provide healthy output-power and efficiency levels at E- and W-band frequencies. These PAs deliver as much as 1 W output power for single-stage designs and as much as 2.5 W saturated output power for two- and four-stage amplifiers. The PAs offer as much as 20% power-added efficiency (PAE) and typical gain ranging from 15 to 40 dB. The amplifiers, which include internal voltage regulation, bias-sequencing circuitry, and reverse-voltage protection, are well-suited for high-frequency radios and test-equipment applications. As an example of an E-band PA, model AMP-12-20010 achieves 15-dB typical gain from 71 to 76 GHz with typical output power of +28.6 dBm at 1-dB compression and typical saturated output power of +31.1 dBm. It is equipped with WR-12 waveguide connectors.

MILLITECH INC., 29 Industrial Dr. E., Northampton, MA 01060; (413) 582-9620; *www.millitech.com*



Cable Assemblies Work Indoors and Out to 6 GHz

A LINE OF TYPE-N-TO-AMC fixed-length cable assemblies is suited for connections to wireless devices in indoor and outdoor applications, such as automated meter readers. The cable assembles are usable from dc to 6 GHz and are constructed with Type-N bulkhead jacks and AMC right-angle plugs terminated to RG-178 cable. The Type-N connectors feature white-bronze-plated bodies with gold-plated contacts. Bulkheads are suitable for panels to 6.5 mm thick and include O-ring protection from moisture. The AMC connectors mate with other industry-standard equivalent connectors. Standard cable assemblies lengths are from 50 to 300 mm, in 50-mm increments; custom lengths are also available.

AMPHENOL RF (HEADQUARTERS), 4 Old Newtown Rd., Danbury, CT 06810; (800) 627-7100, (203) 743-9272; *www.amphenolrf.com*

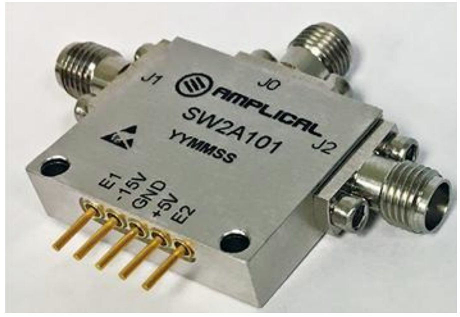
Two-Way Divider Channels 2 to 18 GHz

DESIGNED FOR BROADBAND USE, model R2PD-2-18-Sf-10W-w18 is a two-way power divider with low loss from 2 to 18 GHz. It exhibits 1.5-dB typical insertion loss with 14-dB typical return loss across the full frequency range. The power divider features 16-dB minimum isolation and 20-dB maximum isolation and achieves amplitude balance within 0.2 dB and phase balance within 2 deg. The component is supplied with female SMA input and output coaxial connectors and is usable over operating temperatures from –40 to +85°C.

RADITEK INC., 1702L Meridian Ave. Suite 27, San Jose, CA 95125; (408) 266-7404; *raditek.com*

SPDT Switch Commands Signals from 0.1 to 20.0 GHz

BROADBAND SINGLE-POLE, double-throw (SPDT) absorptive switch model SW2A101 is capable of hot switching 2 W continuous-wave (CW) power from 100 MHz to 20 GHz with low loss and fast switching speed. Supplied in a coaxial package with female SMA connectors, the compact switch exhibits maximum VSWR of 1.80:1 at all ports. The insertion loss is 1.50 dB or less to 500 MHz and 3.8 dB or less to 20 GHz. The minimum isolation is 70 dB from port to port or from input to output. The switch achieves switching speeds of 75 ns from 50% TTL control signal to 90% RF level and 45 ns from 50% TTL control signal to 10% RF signal. It operates on +5 V dc and −120 to −20 V dc supplies, and is designed to maintain rated performance levels at temperatures from −55 to +85°C.



AMPLICAL CORP., 20 Troy Rd., Whippany, NJ 07981; (973) 386-1119; *www.noisewave.com, www.amplical.com*

Broadband Attenuator Handles 4 to 18 GHz

SUITABLE FOR EXTREMELY BROADBAND system and test applications, model 5-9844-15 is a rugged coaxial attenuator with 15-dB attenuation from 4 to 18 GHz. It handles power levels to 5 W continuous wave (CW) and 3 kW peak power with low insertion loss of only 1 dB across the frequency range. It exhibits a VSWR of 1.70:1. The compact component measures just 2.5 × 2.0 × 0.56 in., weighs 3 oz., and can be supplied with SMA or Type-N female connectors. It is available with a number of options, including a panel-mount configuration, turn counter, and digital readout.

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

Cavity Filter Passes 4,395 to 4,955 MHz

CAVITY BANDPASS FILTER (BPF) model AB4675B1348 operates with a 560-MHz passband centered at 4,675 MHz. It handles signal power levels as high as 450 W with low passband insertion loss of 1.5 dB or less. The passband VSWR is 1.50:1 or less. The BPF delivers out-of-band attenuation of better than 40 dB at 4,100 MHz and at 5,250 MHz. The robust filter measures 5.73 × 1.50 × 0.99 in. and is equipped with female SMA connectors. It has an operating temperature range of −30 to +75°C.

ANATECH ELECTRONICS INC., 70 Outwater Ln., Garfield, NJ 07026; (973) 772-4242; *www.anatechelectronics.com*

Low-Jitter Oscillators Lock Networks to 2.1 GHz

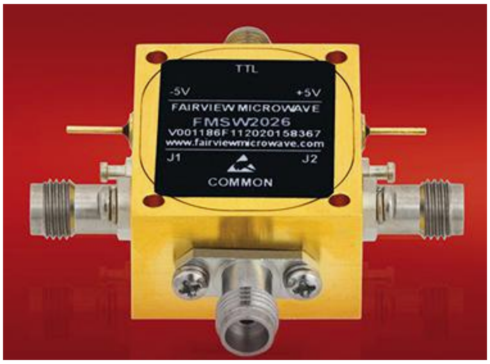
A PAIR of low-jitter oscillators, models NP5032S and NP7050S, provide similar performance levels from 15 MHz to 2.1 GHz, but are supplied in different packages. Suitable for high-speed networking applications, such as SDH and SONET, the NP5032S is housed in an 8-pin ceramic SMD package measuring 5.0 × 3.2 ×1.2 mm. The NP7050S comes in a surface-mount package measuring 7.0 × 5.0 ×1.6 mm. With output types of CMOS, LVPECL, LVDS, CML, and HCSL to choose from, the oscillators achieve typical jitter of 130 fs RMS. The operating temperature range is −40 to +85°C.

NDK AMERICA, 425 N. Martingale Rd., Ste. 1330, Schaumburg, IL 60173; (847) 852-4165; *www.ndk.com*

GaN Power Amplifier Pulses 9.0 to 9.9 GHz

BUILT FOR X-BAND radar systems as well as other high-power applications, model BMPC9X89X8-8000 is a solid-state power amplifier (PA) capable of 8 kW peak output power from 9.0 to 9.9 GHz. The PA, which is based on gallium-nitride (GaN) semiconductor technology, works over instantaneous bandwidths as wide as 500 MHz with 69-dB nominal gain and less than 1-dB pulse droop. The pulse rise/fall time is typically 50 ns. The rugged amplifier handles signals with pulse widths from 0.25 to 100 µs at 10% maximum duty cycle. It includes an Ethernet control port and built-in thermal and load protection.

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



SPDT PIN Diode Switch Commands 0.1 to 67.0 GHz

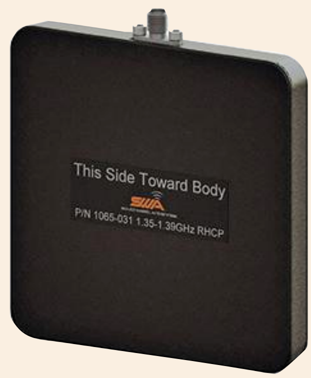
DESIGNED FOR BROADBAND applications, the FMSW2026 single-pole, double-throw (SPDT) PIN diode absorptive switch spans 100 MHz to 67 GHz. It handles input power to 0.5 W continuous wave (CW) with 6-dB typical insertion loss. The switch achieves 65-dB typical isolation and boasts 100-ns switching speed. It has a TTL-compatible driver and features an operating-temperature range of –30 to +60°C. It runs on +5 and –5 V dc, and includes 1.85-mm coaxial connectors.

FAIRVIEW MICROWAVE, 17792 Fitch, Irvine, CA 92614; (978) 682-6936; *www.fairviewmicrowave.com*

Patch Antennas Direct Body-Worn Systems

DIRECTIONAL PATCH ANTENNAS developed by Southwest Antennas for body-worn wireless applications from 1,350 to 1,390 MHz are now available with sales and design support from RFMW, Ltd. Model 1065-031 operates with left-hand circular polarization (LHCP), while model 1065-032 has right-hand circular polarization (RHCP). The antennas are optimized for multiple-input, multiple-output (MIMO) use and mobile ad hoc network (MANET) radio systems. The antennas, which measure 3.75 × 3.75 × 0.51 in., are specified for 4.2-dBic free-space gain. They are supplied with a stainless-steel female SMA connector and ultraviolet (UV)-stable radome, and can withstand two hours' immersion in salt water.

RFMW LTD. (SOUTHWEST ANTENNA STOCKING DISTRIBUTOR), 188 Martinvale Ln., San Jose, CA 95119; (408) 414-1450; *www.rfmw.com*



Schottky Diodes Reach 40 GHz

A SERIES OF SILICON Schottky diodes supports circuits through 40 GHz. They boast low 1/f noise, low resistance, and small junction capacitance for low-, medium-, and high-barrier applications. The diodes, which can be supplied as chips—or else in glass, ceramic, or beam-lead packages—are candidates for RF/microwave mixers, doublers, and detector circuits. The diodes are rated for breakdown voltages from +3 V dc (for low-barrier diodes) to +6 V dc (for high-barrier diodes), capacitances from 0.15 to 0.35 pF, and series resistances from 14 to 20 Ω. Diodes in bridge quad and ring quad configurations provide stable performance across operating temperatures from –55 to +150°C.

SEMIGEN INC., 3920 Candia Rd., Manchester, NH 03109; (603) 624-8311; *www.Semigen.net*

Highpass Filter Cuts Off at 57 GHz

HIGHPASS FILTER MODEL HPF-640 is part of a complete filter series covering bandwidth from 10 to 110 GHz. This unit passes signals within the V-band spectrum as low as 57 GHz with worst-case passband insertion loss of 1.5 dB and typical passband insertion loss of 1.0 dB. It features a rejection cutoff at 57 GHz with 20-dB rejection at 55 GHz and 40-dB rejection at 54 GHz and below. The highpass filter is supplied with WR-15 waveguide connectors.

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

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DC-100	15	±0.3	0682-15F
DC-100	30	±0.5	0682-30F
DC-250	10	±0.5	0682-10F
Uncalibrated models			
DC-60	40	±1.0	0682-40
DC-100	20	±0.6	0682-20
DC-100	30	±0.5	0682-30
DC-200	30	±2.0	0682-30A
DC-250	15	±1.2	0682-15
DC-500	10	±0.25	0682-10

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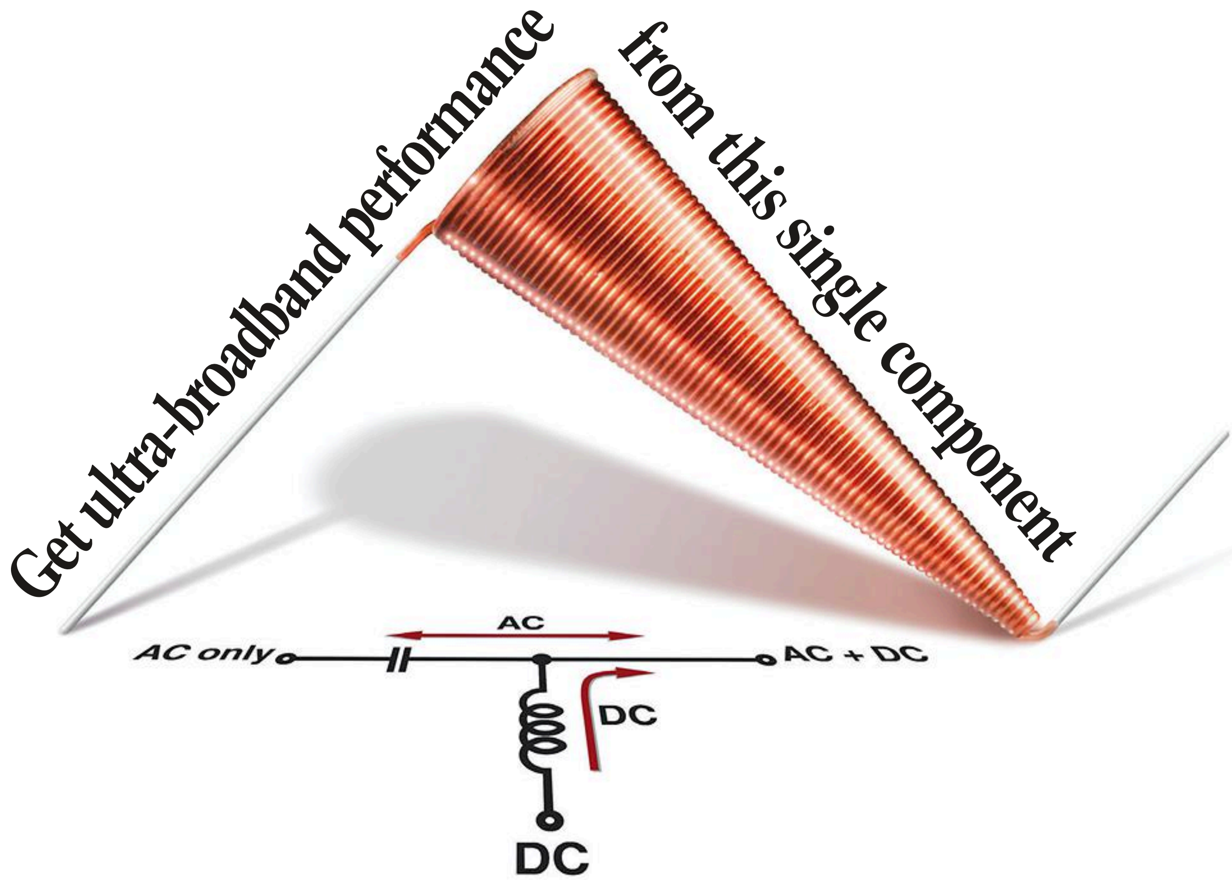

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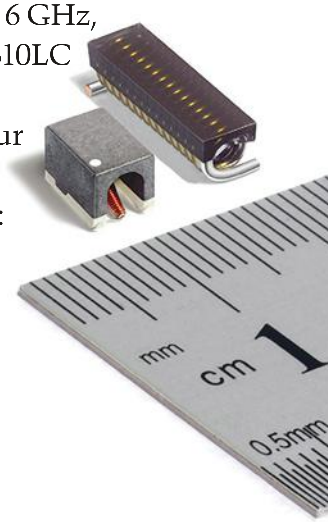

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