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COMMUNICATIONS ISSUE

POWERFUL SIGNAL ANALYSIS *Simplified*

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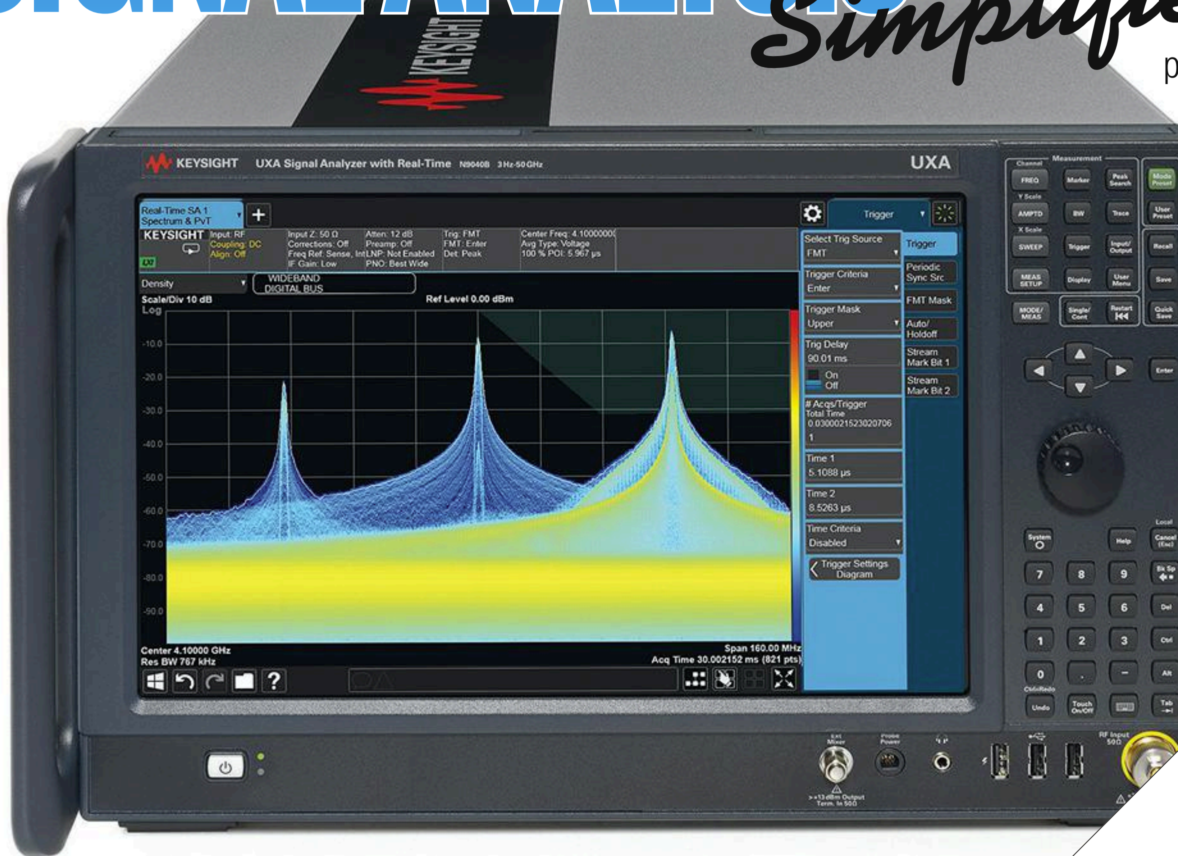

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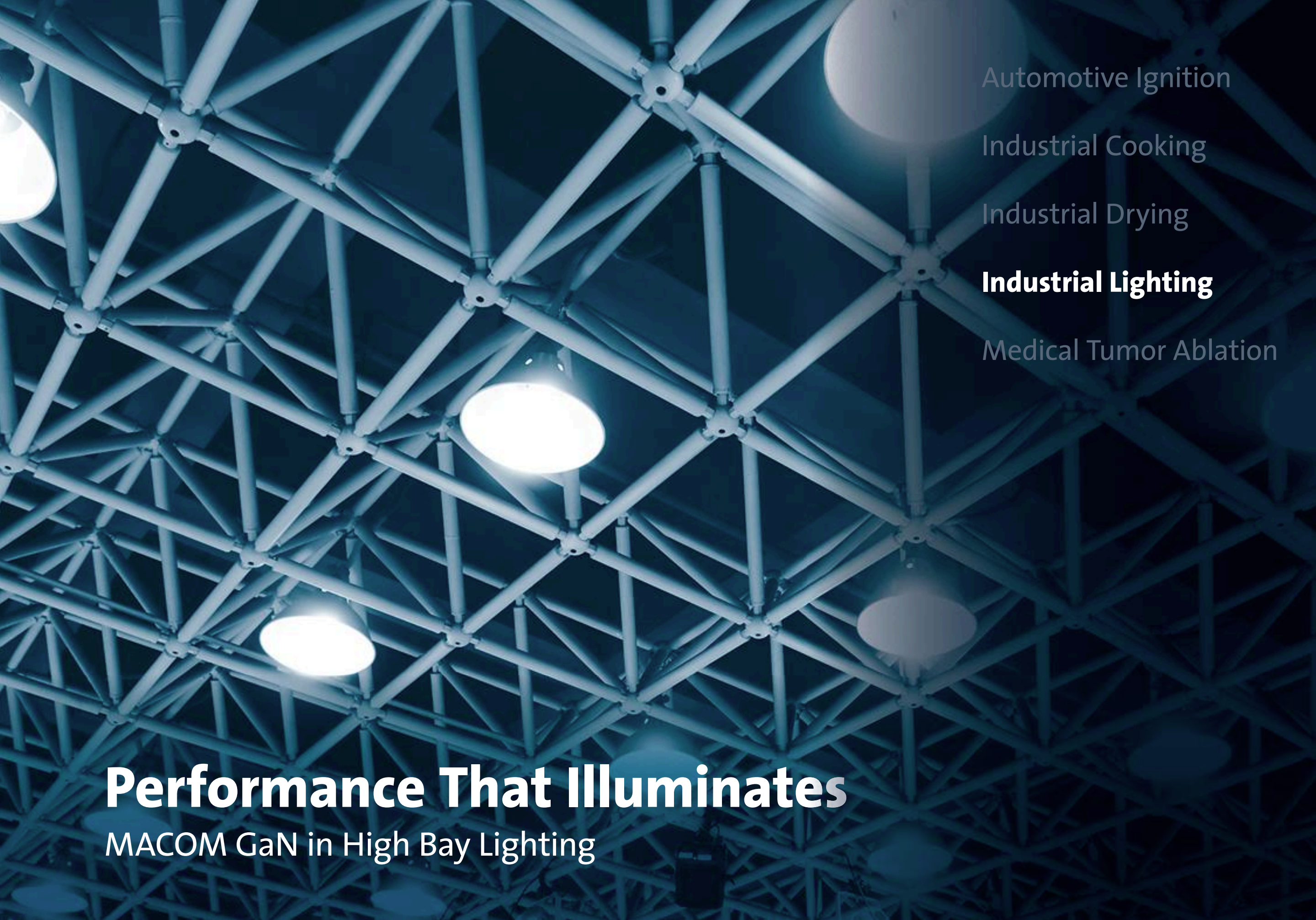

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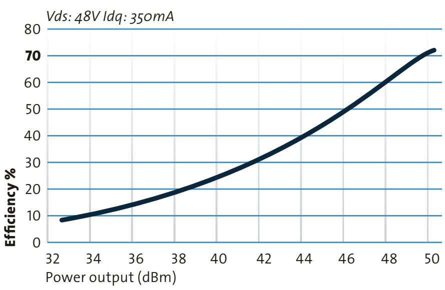

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SPECIFICATIONS

Frequency Range:	100 MHz to 18.0 GHz
Frequency Flatness:	±2.0 dB max. - measured ±1.0 dB
TSS:	-68 dBm min., -70 dBm typ. - measured -68 dBm
Limited Output Power:	8.0 dBm ± 3.0 dBm max., - measured +8 ± 2.5 dBm (Input Power ≥ -65 dBm)
VSWR:	2.0:1 max. - measured 1.97:1
Linear Output Gain:	43 dB ± 3.0 dB max. - measured 43 to 45.7 dB
Linear Output Psat:	3 dBm ± 3.0 dB max. - measured 0.9 to 4.0 dBm
V0 (Video Comparator Signal Amplitude):	3.3 V typ. - measured 2.25 V
Video Comparator Delay:	50 ns typ. - measured 45 ns
Video Comparator Threshold Level:	Adjustable with Analog Voltage, -60 dBm ± 3.0 dB max.
V1 (Log Video Signal Amplitude):	1 Volt max. - measured 0.807 Volt
Log Slope:	10 mV/dB into 50 Ω Load ±1 mV max. - measured 10 mV/dB
Log Range:	-65 to +5 dBm min.
Log Linearity:	±1.75 dB (-40 °C to +85 °C) - measured 0.92 dB
Pulse Range:	100 ns to 250 μs
Rise Time:	35 ns max. - measured 20 ns
Settling Time to ±1 dB:	50 ns typ. - measured 41 ns
Recovery Time:	350 ns max. - measured 220 ns
CW Immunity Range:	TSS to -45 dBm (1 dB degradation) - measured 0.7 dB
Pulse Considered "CW":	1 ms typ. - measured 0.7 ms
Rejection Time:	1 ms typ. - measured 0.5 ms
Droop:	1 dB max. - measured 0 dB
SPST Isolation:	70 dB typ. - measured ≥70 dB
Switching Speed:	20 ns typ. - measured 20 ns

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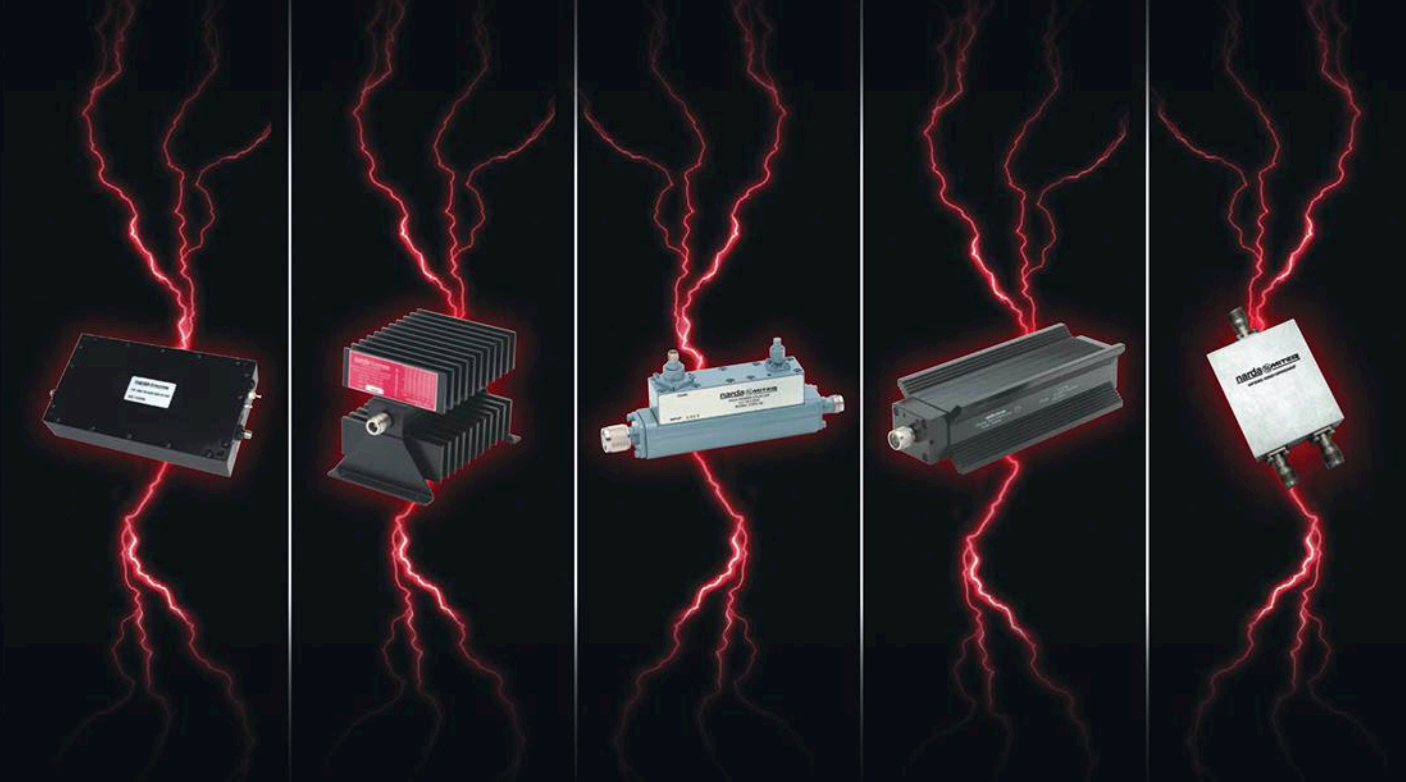

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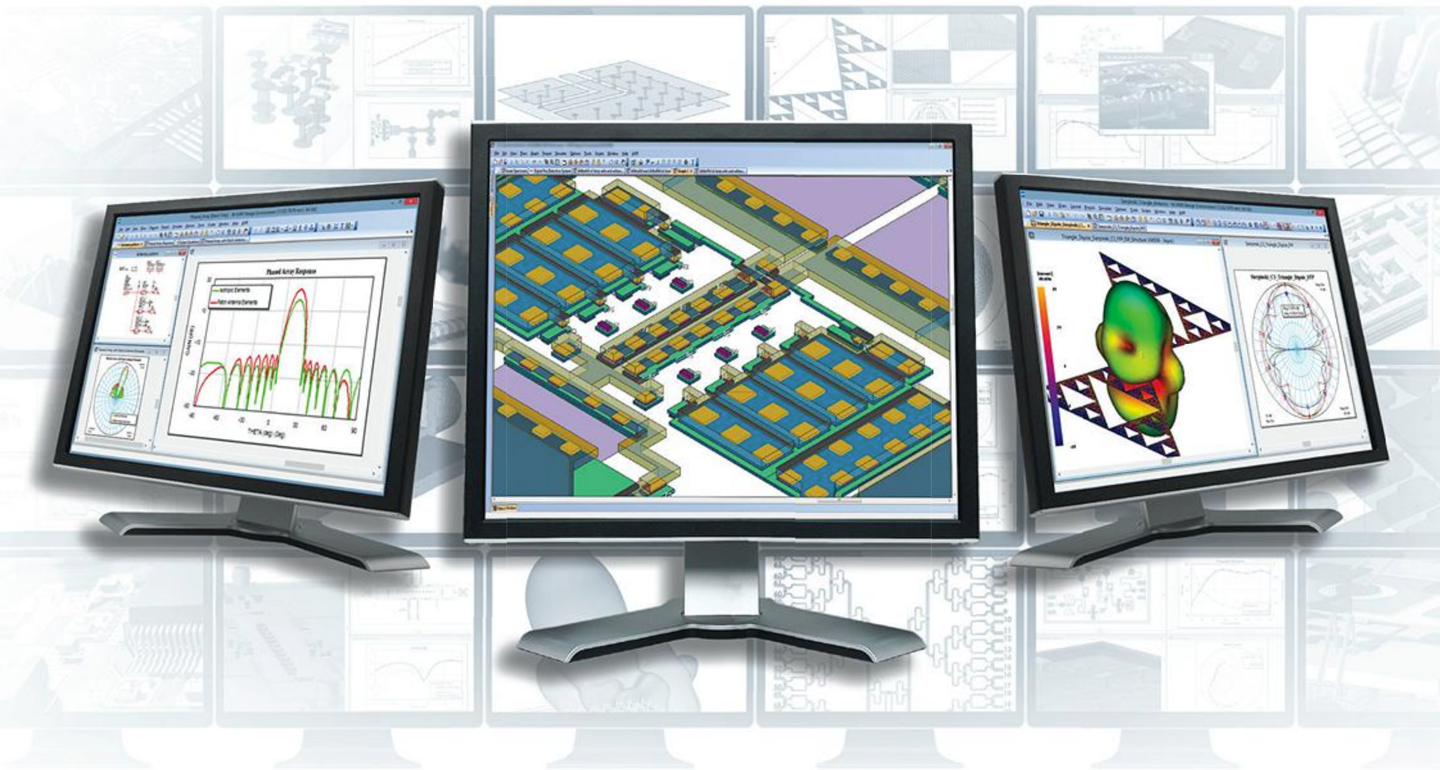

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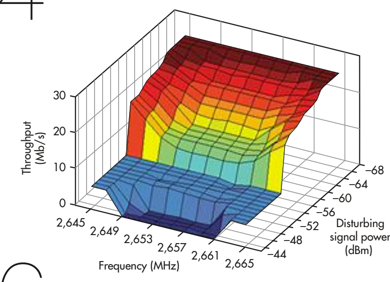

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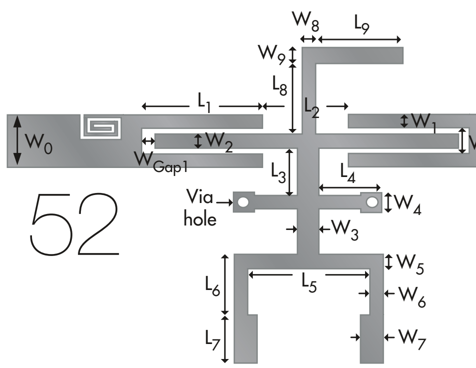

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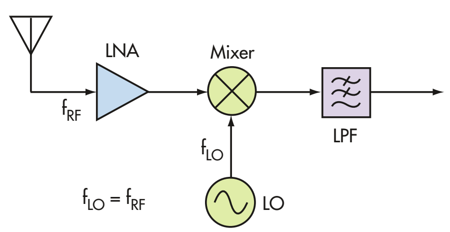

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SIMULATING RF SYSTEM BEHAVIOR

http://mwrf.com/software/software-simulates-rf-system-behavior
System-level software combines many different types of RF/microwave components (and often digital components) to predict the performance of a high-frequency system.

PXI OFFERS COMPLETE TEST SOLUTIONS

http://mwrf.com/test-measurement/pxi-offers-complete-test-solutions
Next-generation devices have prompted suppliers of PXI-based test products to provide complete test solutions to meet the complex testing requirements of these devices. By combining modular PXI-based hardware with measurement software, these test solutions provide comprehensive results with

benefits in test time and cost. In comparison with traditional box instruments, PXI-based test setups can be customized with the instrumentation modules needed to meet each new test requirement.

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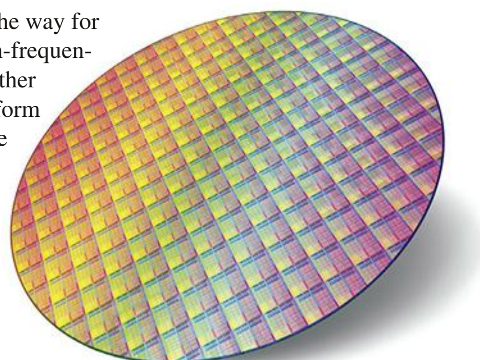
SOFTWARE INNOVATING TEST ENVIRONMENTS

http://mwrf.com/software/software-innovates-rfmicrowave-test-environments
Software is available from a range of vendors in a variety of forms, providing advanced test capabilities that include everything from real-time spectrum analysis to signal creation and more. Automated test engineers, who need to develop innovative systems, can use these tools to develop solutions capable of meeting today's demands.

MATERIALS FORM FOUNDATIONS FOR CIRCUITS

http://mwrf.com/technologies/materials-form-foundations-rf-microwave-circuits
Materials pave the way for high-speed, high-frequency circuits. Whether those materials form the packages, the substrates, the printed-circuit boards (PCB), or even the thermal pathways for dissipating heat, they are essential to electronic circuits ranging from DC to optical wavelengths.



TO TERMINATE OR ATTENUATE?

http://mwrf.com/passive-components/terminate-or-attenuate
Terminations and attenuators can handle high power levels at microwave frequencies, and advanced materials are enabling them to do so in smaller packages.

Editorial

CHRIS DEMARTINO
Technical Editor
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THAAD Seeks to Thwart Enemy Threats

Recent news has centered on talks between the U.S. and South Korea about potentially deploying Lockheed Martin's (www.lockheedmartin.com) Terminal High Altitude Area Defense (THAAD) missile defense system in South Korea. This eye-opening news comes on the heels of a recent North Korean rocket launch. The U.S. says the THAAD defense system would be deployed to enhance South Korea's missile defense capabilities.

For those curious about THAAD, its core purpose is to defend against short- and medium-range ballistic missiles. THAAD can be described as a land-based element of the Ballistic Missile Defense (BMD) system that is intended to be both globally transportable and rapidly deployable. Incoming missiles can be intercepted and destroyed—both inside and outside the atmosphere—during their final, or terminal, phase of flight. Lockheed Martin boasts of a 100% success rate in flight testing, demonstrating superior performance.

The four-step process that THAAD utilizes to intercept a missile goes as follows: First, radar detects an incoming threat. Next, the target is identified and engaged. The launcher then fires an interceptor in the missile's direction. Lastly, the interceptor uses kinetic energy, or "hit-to-kill" technology, to destroy the incoming missile.

The THAAD system consists of interceptors, launchers, radar, a fire control unit, and THAAD-specific support equipment. Launchers are truck-mounted and highly mobile. These launchers each have eight interceptors, which can be fired and rapidly reloaded. THAAD employs Army/Navy Transportable Radar Surveillance (AN/TPY-2), which is the world's largest air-transportable X-band radar. It can search, track, and discriminate objects as well as provide updated tracking data to the interceptor. The fire control unit is considered to be the communication and data-management backbone. It links THAAD components together, as well as linking THAAD to external command and control nodes and to the entire BMDS.

Although a system like THAAD may seem captivating to some, there is another side that is often overlooked. Simply put, none of this technology would be possible without the hard work and dedication of the engineers who were behind it all. There is no question that the state-of-the-art engineering that enables this technology was no small feat. And in today's technology-driven world, it is the engineers who do the work so others can reap the benefits. Perhaps it is time to appreciate engineers for what they do. mw

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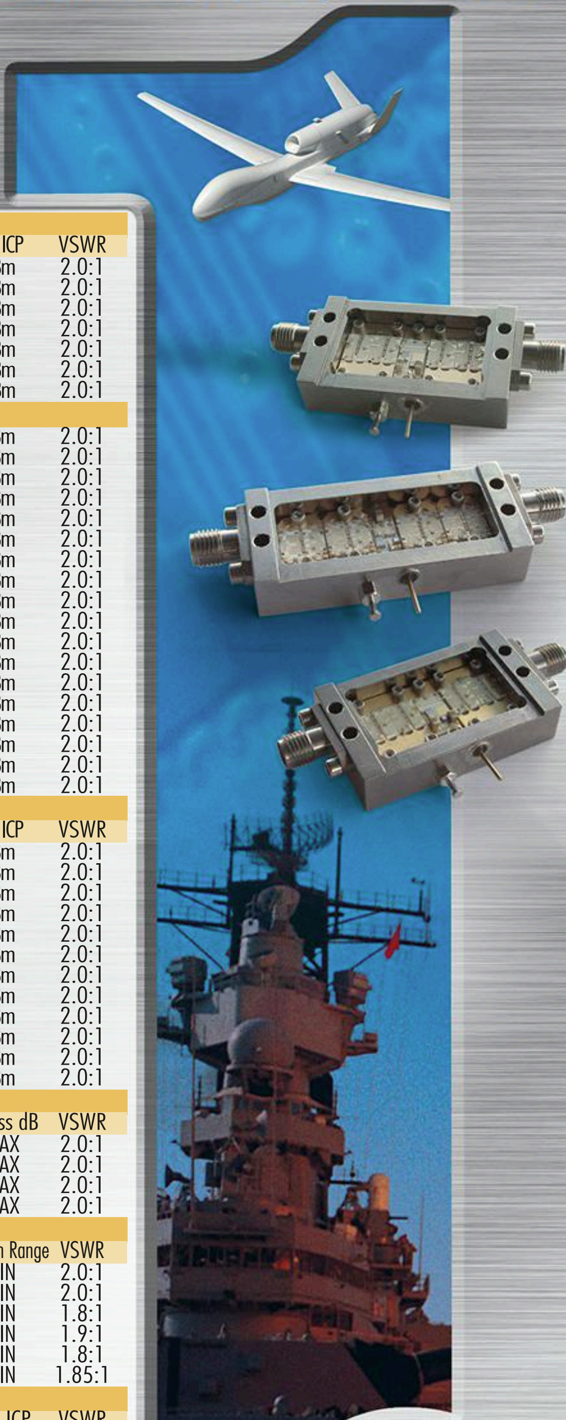

OCTAVE BAND LOW NOISE AMPLIFIERS

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

NARROW BAND LOW NOISE AND MEDIUM POWER AMPLIFIERS

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

ULTRA-BROADBAND & MULTI-OCTAVE BAND AMPLIFIERS

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

LIMITING AMPLIFIERS

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

AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

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

LOW FREQUENCY AMPLIFIERS

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

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A-LESS-THAN-CLEAR PICTURE?

I read your article "Receive a Clear Picture of Antennas" in the January 2016 edition of *Microwaves & RF*, and it seems to me that you may have left an incorrect idea in the minds of young engineers and technicians to whom this article presumably is addressed. You said, "Employing antennas with consistent polarization is important, since as much as one-half the amount of transmitted signal power can be lost at the receiving end by using transmit and receiving antennas with different polarization characteristics."

I'm sure you know better! What you are illustrating is only the unique situation of a path between a linearly polarized antenna and a circularly polarized one. For linear antennas of cross-polarization, or circularly polarized antennas of opposite handedness, the loss could easily be as much as 20 dB, or even greater. It would be an egregious error to allow the young beginners in the microwave field to believe that the worst mis-polarization error would only cost 3 dB.

Doug McGarrett
Retired RF engineer

EDITOR'S NOTE

Thanks for your note. As with many of these tutorial articles, I lack the space to cover all of the bases, so I try to cover a lot of ground with a few examples. My point is valid because of the need for efficiency with limited power; you are bringing up instances that exist, but are not ideal because of the loss of power. When you write tutorial articles, you often have to stress the ideal rather than the actual, which will give too many examples to cover in a short time.

All of that notwithstanding, your feedback is very much appreciated. Reading our readers' insights is always welcome and illuminating (even when we aren't fully in agreement).

Jack Browne
Technical Contributor

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

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News

QUALCOMM TESTS LTE
Over Unlicensed Spectrum in Germany

Confronting a shortage of licensed spectrum, wireless carriers are experimenting with new methods for unloading cellular data into the unlicensed spectrum. Qualcomm and Deutsche Telekom, one of the largest wireless companies in Germany, recently completed the first "over-the-air" tests of one such technology, known as Licensed Assisted Access (LAA).

Also known as LTE-Unlicensed (LTE-U), this technology helps wireless companies supplement their LTE networks by draining congestion into the unlicensed spectrum. LAA is used almost exclusively with small cells, where licensed signals preserve the necessary signaling and scheduling required for a reliable connection. Many early trials have targeted the unlicensed 5-GHz band, which is shared by the latest version of Wi-Fi.

Tests were conducted over a test network installed on Qualcomm's campus in Nuremberg, Germany. Qualcomm designed new test equipment to monitor handoffs between the licensed spectrum, provided by Deutsche Telekom, and the unlicensed 5-GHz spectrum. Unloading data into the Wi-Fi spectrum, the network demonstrated wider coverage and greater capacity than LTE alone, the companies said in a statement. The network also made seamless handoffs between different spectrum bands.

Qualcomm's tests are situated within a larger debate about flooding the unlicensed spectrum with overflow from licensed bands. Many companies are concerned that dipping into 5-GHz spectrum will interfere with Wi-Fi services on the same channels. The debate is playing out between telecommunications and cable companies, Internet and technology companies, and Wi-Fi equipment vendors.

In a statement about the tests, Qualcomm claims repeatedly that LAA shared the unlicensed spectrum with Wi-Fi without any adverse effects. The company says that the network demonstrated "smooth and opportunistic aggregation of unlicensed spectrum." Qualcomm also says there was "fair spectrum usage" throughout the trial.

Deutsche Telekom's headquarters in Bonn, Germany. The wireless carrier, one of the largest in Germany, recently partnered with Qualcomm to test Licensed Assisted Access technology that unloads LTE data into the unlicensed spectrum. *(Image courtesy of Deutsche Telekom).*

Qualcomm adds that its test equipment was designed to ensure that the network meets "listen-before-talk" and clear channel assessment standards. These protocols, which are often cited as the bare minimum for Wi-Fi coexistence, force the network to switch channels if the current one is occupied. According to Qualcomm, the equipment also complies with the next release from the Third-Generation Partnership Project (3GPP), the organization that maintains the LTE standard.

The tests were completed as both sides of the LAA debate have taken steps to standardize tests for Wi-Fi coexistence. Last year, tension flared when the Wi-Fi Alliance proposed a series of guidelines for coexistence tests. Verizon, T-Mobile, Qualcomm, Ericsson, and Alcatel-Lucent sent a letter to the Federal Communications Commission (FCC) complaining that the organization was trying to act as the "gatekeeper" for unlicensed

(continued on page 22)

SEAWATER FOUNTAIN Transmits and Receives Signals Like an Antenna

(Image courtesy of Thinkstock)

RESEARCHERS FROM MITSUBISHI ELECTRIC have developed an antenna system that turns the earth's most abundant resource—seawater—into an antenna for long-range communications.

The system, which can be almost completely submerged underwater, sends a fountain of saltwater into the air through an insulated nozzle. The nozzle itself is connected to a water pump, external power source, and a radio-frequency cable. The water pump shoots the seawater through the specialized nozzle, allowing the stream to transmit and receive RF signals. Mitsubishi says that the height of the saltwater stream can be adjusted to operate over different frequencies.

While an unusual concept, conductive liquids have been investigated as a way to make antennas that can change their frequency and bandwidth. The research has drawn more attention in recent years as electronic devices begin to transmit data over a huge number of spectrum bands, all of which need different antennas. As a result, manufacturers are pumping devices full of filters and specialized antennas to tune into GPS, Wi-Fi, and other signals.

But researchers have not always been satisfied with this brute-force approach. Several companies are developing filters that are capable of tuning into multiple spectrum bands. At the same time, researchers are tapping into synthetic materials, also known as metamaterials, which can be used to control the frequency and polarization of antennas. Liquid antennas, on the other hand, can adjust their frequency by changing the liquid's shape.

Most liquid antennas have been made with liquid metal alloys. Last year, chemical and RF engineers from North Carolina State University built an antenna that could adapt to different frequencies by changing its length inside a tube. The alloy of gallium and indium could change its shape when a small voltage was sent into the material. While it was more suited to larger antennas that operate at lower frequencies, the system could even be used in microfluidic chips to transmit millimeter waves.

Although seawater is around 1,000 times as conductive as drinking water, it is still significantly less conductive than metal alloys. For that reason, the researchers struggled to get the antenna's efficiency high enough to actually transmit data. But using computer simulations, the researchers were able to find the ideal diameter of the seawater plume, resulting in about 70% antenna efficiency.

Mitsubishi says that it tested this antenna, also known as SeaAerial, with digital television broadcasts. The company said that broadcasts sent through the antenna could be watched normally.

Although seawater is an exotic material for an antenna, Mitsubishi is not the first to experiment with it. In 2011, the U.S. Navy's Space and Naval Warfare Systems Center (SPAWAR) patented an antenna that could change its bandwidth and frequency depending on the width and height of a saltwater stream. Shooting seawater through a magnetic coil created an antenna that, like Mitsubishi's, could transmit and receive radio signals.

Daniel Tam, an engineer for the SPAWAR program, said in a video about the technology that a two-foot-high waterspout could function as a millimeter-wave antenna. The antenna could operate at very high frequencies (VHFs) and high frequencies (HFs) when the height of the stream was subsequently adjusted to 6 feet and 80 feet, respectively.

In a short summary of the technology from 2011, the Navy said that the antenna was designed to consolidate some of the antennas used on warships and submarines to communicate over many different frequency bands.

Mitsubishi's antenna could also be used on either land or sea. The researchers say that it could replace large low-frequency antenna towers on land with antenna fountains. Ships could also take it into seas where communications are limited. "It needs just a pump and a nozzle," the company said in a statement. ■

(continued from page 20)

spectrum. Since then, the FCC has become a kind of moderator for the debate. Last month, it gave Qualcomm permission to test LTE-U at two Verizon locations.

Opponents of the technology claim that LTE-U (an earlier version of the standard) was not designed to share spectrum with Wi-Fi. Cable Labs, a research organization supporting cable companies, says that LTE-U employed an on-off switch known as "duty cycling" instead of listen-before-talk. Reviewing the LTE-U specification, the group claimed that wireless carriers could simply turn on LTE-U to invade the unlicensed spectrum and push Wi-Fi out. When LTE-U was turned off, Wi-Fi could access the spectrum again. In recent tests conducted with Qualcomm, Cable Labs claims that LTE-U has still not demonstrated reliable coexistence with Wi-Fi.

However, companies that support LAA contend that this kind of unfair spectrum sharing has been scrapped in newer versions. And even Cable Labs sees "hopeful progress" in the development of LAA.

While Wi-Fi supporters are worried about interference, others are concerned about a fundamental breach in Wi-Fi's unlicensed status, which the FCC has refused to regulate in order to promote innovation in the wireless industry. One commenter on a recent *Microwaves & RF* article said that the more important question is "whether or not we want to allow cell-phone carrier companies to barge into spectrum that's being used for established Wi-Fi."

Although the debate only appears to resurface when new tests are completed, analysts have said that Wi-Fi is too widespread to be anywhere close to expiring. In the meantime, more LAA tests are scheduled to be conducted this year. Cell phones implementing the technology could become available in the coming months. ■

EXPERIMENTAL GaN CMOS TRANSISTORS Make Elusive Integrated Circuits

IN RECENT YEARS, transistors based on gallium-nitride (GaN) semiconductors have been used in the power converters found in computers and smartphones, as well as wireless transmitters operating from millimeter to microwave frequencies. Nevertheless, engineers have struggled to create devices using complementary metal-oxide-semiconductor (CMOS) technology, which forms the transistors implemented in most of today's chips.

Now, researchers have developed a field-effect transistor (FET) based on GaN CMOS, paving the way for integrated circuits (ICs) that could replace silicon chips in wireless amplifiers, power converters, and other products. GaN ICs could be harnessed in power switching components that convert electricity more efficiently on smaller chips and in harsher environments than silicon.

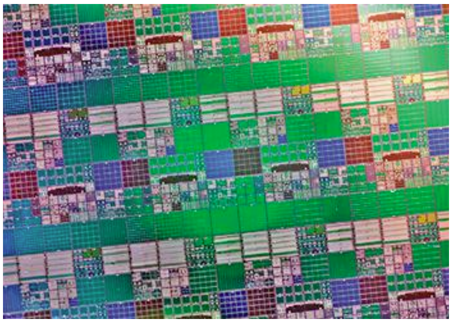
Based out of HRL Laboratories, a research institute funded by General Motors and Boeing, the researchers were able to fabricate a chip with an enhancement-mode n-channel MOSFET and a p-channel MOSFET on the same GaN wafer. The results were published last month in the journal *IEEE Electron Device Letters*.

Rongming Chu, the principal investigator for the project, says that putting "power switches and their driving circuitry on the same chip is the ultimate approach to minimizing the parasitic inductance," which has made it difficult for researchers to produce GaN CMOS.

In earlier attempts to develop the technology, engineers had to intentionally slow down the switching speed of GaN power transistors. This was done in order to control chip-to-chip parasitic inductance, which causes voltage instabilities that ultimately limit performance.

Transistors based on GaN can operate at higher temperatures and voltages than gallium-arsenide (GaAs) transistors, which have long been used in microwave and millimeter-wave power amplifiers and other components. GaN transistors are also gradually finding their way into power converters, as well as cellular base stations and antennas. Lockheed Martin, for instance, recently infused its latest radar technology with GaN transmitters.

In recent years, CMOS technologies have also been plugged into transceivers for antenna and radar systems. Early last year, Panasonic partnered with imec, a microelectronics research center, to develop silicon CMOS for millimeter-wave radars used in automated vehicle-safety systems. One of the major benefits of CMOS, the researchers said, is its intrinsically low manufacturing cost.



A magnified image of a silicon wafer.

(Image courtesy of Jack Spades, Flickr)

Until recently, however, researchers struggled to create GaN CMOS transistors for integrated power conversion. Some considered the task impossible, says Chu. The problem had always been how to go about making the GaN p-channel transistors and integrating them with n-channel transistors. These transistors are the channels that control the flow of electrons through the integrated circuit.

Using a process called selective area epitaxy, the HRL researchers squeezed both of these power transistors onto the same chip. They were then able to fabricate a functional inverter chip from the GaN CMOS technology. According to Chu and other researchers, GaN ICs like these could eventually replace silicon CMOS in a wide range of products and components. ■

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RESEARCHERS USE SOFTWARE-DEFINED Radio for Testing Millimeter-Wave Antennas

THE WIRELESS RESEARCH ARM of New York University recently announced plans to build a programmable testbed for prototyping millimeter-wave, or mm-Wave, antennas. The testbed will eventually become available to universities, government agencies, and companies in the early stages of developing mm-Wave products and standards.

The testbed will combine high-gain phased-array antennas with a software-defined radio (SDR), in which computer programs replace hardware components like filters and amplifiers. This combination will help to direct millimeter waveforms, which are typically concentrated into narrow beams and pointed directly at other antennas. The testbed is built around a baseband processor that will transmit and receive signals with high data rates and low latency.

The phased-array antenna, which directs signals using electrical cues, complements the nature of mm-Waves. The antennas help "to compensate for the enhanced path loss and to exploit the directionality of the millimeter waveforms," says James Kimery, the director of RF Research and SDR at National Instruments, which built the baseband processing system. In addition, with the higher frequencies of mm-Waves, the researchers can fit smaller phased-array antennas onto a substrate chip.

Funded by a research grant from the National Science Foundation, the NYU WIRELESS project is the latest sign that wireless companies are building on early progress in mm-Wave components. "There are few, if any, general-purpose millimeter-wave SDRs available today," says Kimery. The SDR, he says, lends itself to faster prototyping and testing times.

The testbed will be different than current millimeter-wave prototyping systems, which are steered mechanically using horn antennas mounted on rotating gimbals. Though these mechanical systems are sufficient for testing stationary devices, they are generally too slow to keep up with mobile devices, National Instruments said in a statement.

A testbed for testing millimeter-wave antennas will combine high-gain phased-array antennas with a software-defined radio, in which computer programs replace hardware components like filters and amplifiers. *(Image courtesy of National Instruments).*

Millimeter waves are expected to be one of the vertebrae in the backbone of 5G communications, providing up to 200 times the capacity of fourth-generation, or 4G, technologies. Because of their highly directional nature, mm-Waves permit antennas to operate in close proximity without causing interference—an imperative for a wireless future in which everyday things are embedded with both near-field and long-range communications chips. In addition, mm-Waves help to optimize spectrum through frequency reuse.

The testbed will operate in the unlicensed 60 GHz band, the same as the upcoming Wi-Fi standard IEEE 802.11ad. Millimeter waves are ideal for short-range technologies like Wi-Fi—at certain frequencies they can be absorbed by raindrops or oxygen in the atmosphere over long distances. The result is lower signal strength.

Collaborating with the NYU research team and National Instruments is SiBeam, a subsidiary of Lattice Semiconductor that is providing the RF front end and phased array. The prototyping system is based on National Instruments' LabVIEW software and PXI modular testing system. ■

ANADIGICS SALE SPARKS Bidding War

ALTHOUGH IT SEEMED like an insignificant transaction when compared to Freescale's merger with NXP a few months earlier, GaAs Labs' attempt to purchase Anadigics has quietly sparked a bidding war. After signing the merger agreement last year, Anadigics is still fielding bids for the last vestiges of its RF semiconductor business.

The spontaneous auction appeared to have ended earlier this month, when a semiconductor laser company beat out all competing bidders. The company, II-VI, agreed to pay nearly twice the amount that was originally agreed to by GaAs Labs. Anadigics accepted its bid of $0.66 per share, up from the $0.35 per share (or roughly $35 million) that was offered by GaAs Labs.

On Monday, however, Anadigics revealed that a competing bidder, one that appears to have been involved in the auction since late last year, has pledged an even higher price. Anadigics declined to share the bidder's identity in a statement, but it reported that the offer was $0.76 per share.

As part of its original agreement with GaAs Labs, Anadigics was permitted to seek out higher bids for its RF semiconductor foundry and its wide range of reverse-path amplifiers, power amplifiers, line amplifiers, and front-ends. In recent years, the company has focused on the design of gallium-arsenide (GaAs) semiconductors that are intended for the commercial market, while also branching out into indium gallium-phosphide (InGaP) and GaN technologies.

II-VI wanted to purchase Anadigics for its 6-in. GaAs wafer fabrication plant located in New Jersey, said CEO Francis J. Kramer in a statement. It had planned to use this facility to produce vertical cavity surface-emitting lasers (VCSELs), a type of semiconductor laser that can be produced in large numbers on GaAs wafers. VCSELs, the company says, are used for sensors in human-machine interfaces, such as gesture recognition, and high-speed optical cables in data centers. II-VI did not respond to inquiries about the future of Anadigics' RF devices.

The original transaction came as Anadigics reported significant losses last year. In October, Anadigics' stock price fell to $0.21, its lowest point since the company's initial public offering in 1995. Had the original agreement gone through, Anadigics would have joined MA/COM Technology Solutions and Nitronix under GaAs Labs. ■

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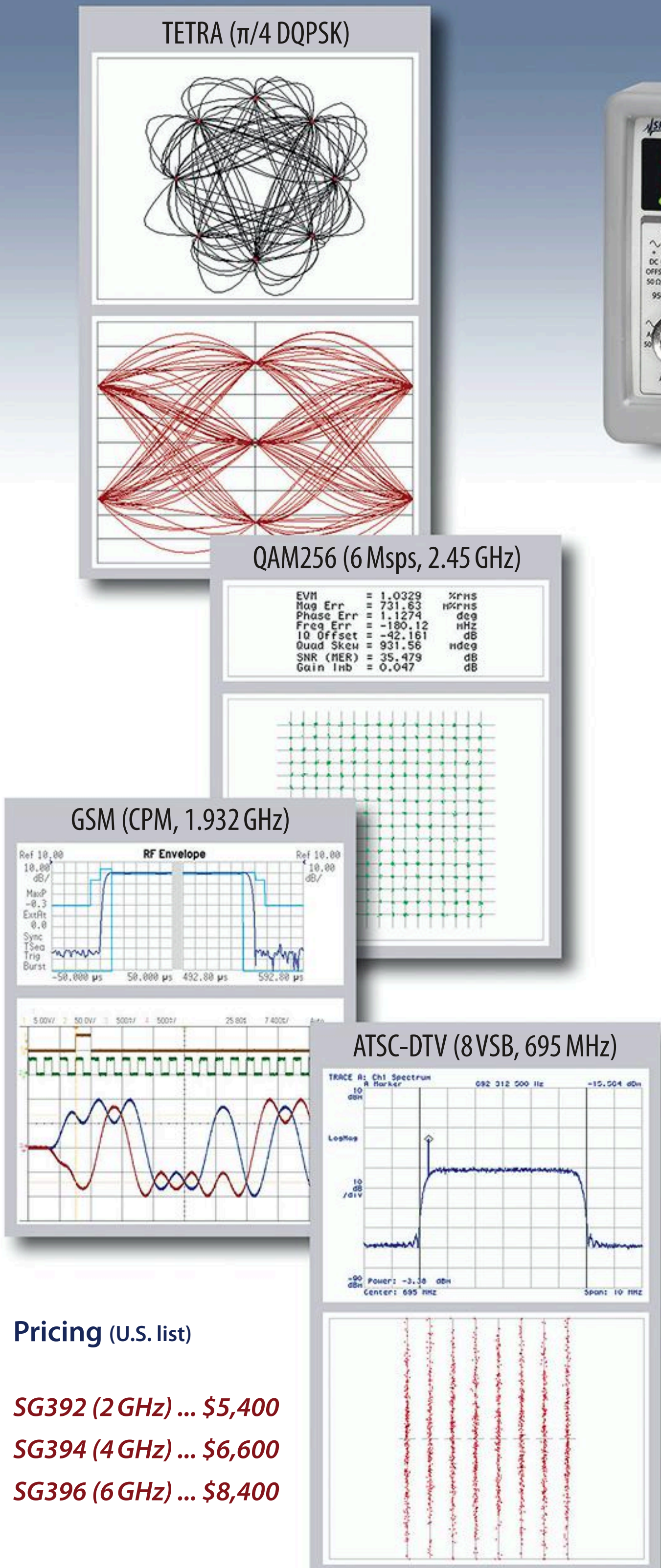

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HARMONIC RADARS SEARCH FOR HIDDEN DEVICES

HARMONIC RADARS HAVE long held the promise of detecting devices at higher frequencies, although designing such systems involves tight control of internally generated harmonic and spurious signals. To aid in the detection of small, hidden electronic devices, researchers at the Sensor and Antenna Systems Group at the Informatics and Information Security Research Center of the Scientific and Technological Research Council of Turkey, Gebze, Turkey (www.tubitak.gov.tr), presented the design and implementation of a portable harmonic radar.

This radar boasts transmit capability from 1.95 to 2.05 GHz and a receive range from 3.90 to 6.15 GHz, with the capability to receive signals as high as third-order harmonics. The portable system features +32-dBm transmit power and −103-dBm receiver sensitivity. The harmonic radar system can discriminate semiconductor targets from corrosive metals, as well as detect a semiconductor target as small as 1.85 × 1.85 cm at a distance of more than 50 cm.

Harmonic radar systems are also referred to as nonlinear junction detectors (NLJDs). They have been designed for the purpose of hidden electronic devices in walls and furniture that might have been implanted for use as surveillance devices, or "bugs." An NLJD-based system is based on employing the nonlinearity of electronic devices because of the p-n junctions of their active devices, such as diodes and transistors. These semiconductor junctions will re-radiate received high-frequency energy at double or triple the frequency, and those harmonic frequencies can be received by a sensitive receiver operating in the proper frequency range.

Unfortunately, harmonic radars are particularly susceptible to false alarms from internal system harmonic leakage, corrosive or junction metals in the scanned area, and harmonic reflectors in the scanned area. The researchers developed their system to operate at multiple transmit frequencies to reduce the occurrence of false alarms. The harmonic radar system includes transmit and receive antennas, transmitter and receiver circuits, a 10-MHz oven-controlled crystal oscillator (OCXO), a digitizer, and a central processing unit (CPU) to run software and a graphical user interface (GUI) for the radar.

The transmit and receive circuit blocks were well isolated to reduce the effects of signal leakage. Transmit and receive filters also contribute a great deal to the excellent performance of the harmonic radar system, with the transmit filter helping to reduce the level of harmonics emitted by the transmitter and the receive filter, reducing the level of transmitted signals to the receiver. See "Getting the Bugs Out," *IEEE Microwave Magazine*, November 2015, p. 40.

DIFFERENTIATING MICROWAVE PHASE DETECTORS

COMPLEX MODULATION SCHEMES, along with many other high-frequency communications applications, require some form of phase detector to determine the phase and frequency of different and differential signals. Phase detectors have been available in many forms for many years, with phase-frequency detectors (PFDs) representing one of the more traditional and trusted components for detecting phase and frequency.

However, researchers at Universiti Kebangsaan Malaysia, Selangor, Malaysia (www.ukm.edu.my) recently presented their work on an effective alternative approach to reading phase and frequency. This takes the form of time-to-digital converters (TDCs), which can be fabricated with silicon digital complementary-metal-oxide-semiconductor (CMOS) integrated-circuit (IC) technology to achieve small component sizes at reasonable cost.

The authors focus on the use of TDCs in all-digital phase-locked loops (ADPLLs) for stable, low-noise signal generation in modern communications systems. The use of this emerging digital phase-detection approach represents an abrupt departure from the analog phase-detection approaches that have long stabilized voltage-controlled oscillators (VCOs) and other frequency sources in PLL circuits. More mature digital phase detectors include logic-gate-based digital phase detectors and dynamic PFDs.

Since PFDs can operate in both linear and nonlinear modes, the choice of a PFD will depend a great deal on the application. Dead zones or blind spots can exist during the normal operation of a digital PFD with a dead zone, for example, representing a region where the phase differences between two signals fed to the input of the PFD cannot be detected due to the low sensitivity of the component. For a particular PLL design, the dead zone and blind-spot characteristics of a digital PFD must be carefully considered to minimize performance degradations for the PLL circuit.

Digital PFDs offer great promise for modern PLL circuits; although, as with any component technology, various tradeoffs must be weighed. These include the input voltage requirements, the maximum operating speed/frequency, the detector phase/frequency sensitivity, and the power dissipation. The article reviews the use of ADPFDs in high-frequency PLLs as well as in more exotic applications, including the measurement of time for less than one clock cycle. See "Investigating Phase Detectors," *IEEE Microwave Magazine*, December 2015, p. 56.


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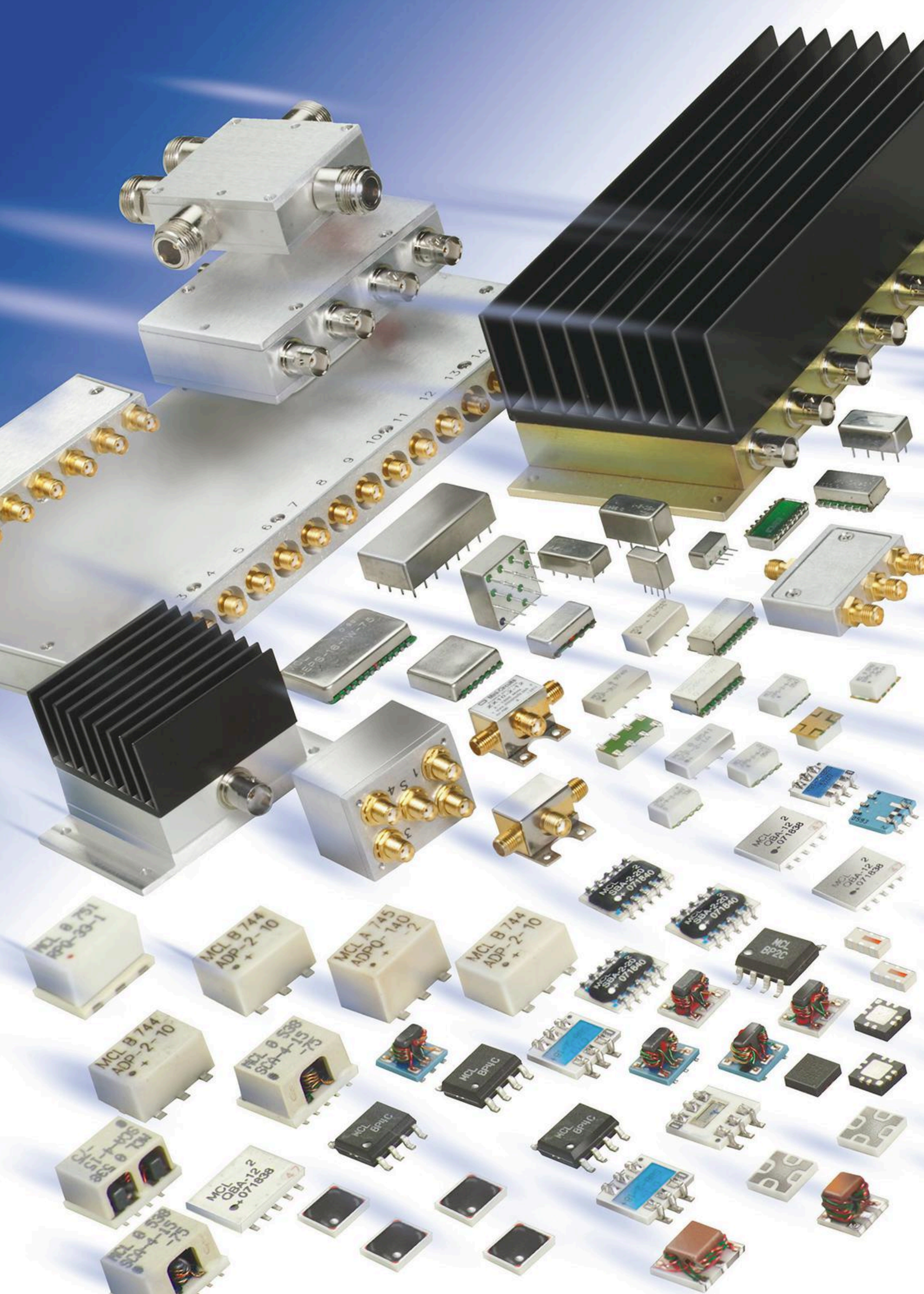
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CHRIS DeMARTINO | Technology Editor

CARRIER AGGREGATION Helps Unclog the Wireless Traffic Jam

To accommodate the increasing demand for wireless data, networks across the globe are implementing carrier aggregation.

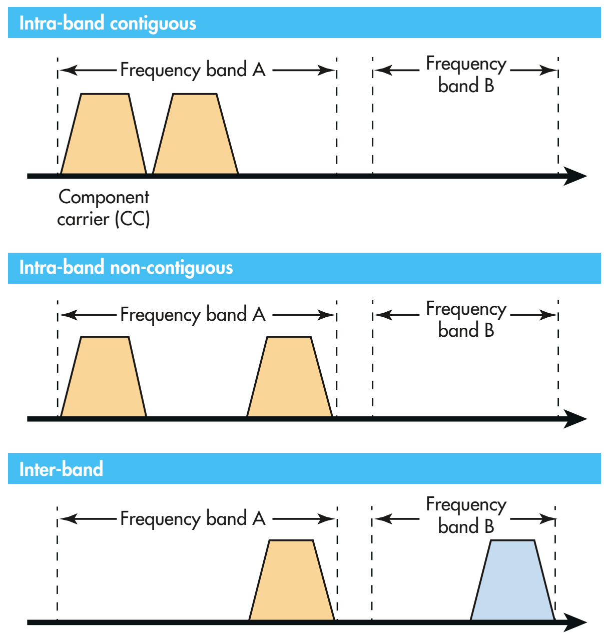
The ever-increasing amount of wireless data traffic in today's technology-driven world is no more evident than in the number of smartphone users worldwide, which has leapt into the billions. And the foreseeable future sees that traffic only becoming more intense. As a consequence, the heat is ratcheting up on mobile network providers to meet the demand.

CARRIER AGGREGATION

To address that challenge, mobile network providers across the globe are adopting and deploying carrier aggregation (CA). CA is a key aspect of LTE-Advanced (LTE-A) because it combines two or more blocks of spectrum, or component carriers (CCs). Adding multiple CCs to create wider channel bandwidths helps achieve the much-needed faster data rates. CA was introduced in 3rd Generation Partnership Program (3GPP) Release 10 in 2011. The first LTE-A network with CA was deployed in South Korea in 2013, and has since been set up in networks across the world.

Each subsequent release since 3GPP Release 10 has changed the parameters for CA for LTE-A. The 3GPP Release 10 allowed the aggregation of as many as five CCs, each with a bandwidth as high as 20 MHz. Thus, combining five 20-MHz CCs would yield a maximum bandwidth of 100 MHz. Release 13 will support as many as 32 CCs.

One company that plays a major role in the CA space is Qorvo (www.qorvo.com). "One of the biggest technical challenges that Qorvo will continue to help smartphone makers overcome in 2016 is carrier aggregation," says Brent Dietz, the firm's director of corporate communications. "Strong global demand for mobile data combined with very limited 4G spectrum has driven the need for CA, which simultaneously combines two or more carrier channels, or bands, for higher data throughput."



1. Network providers can deploy one of three different forms of carrier aggregation.

Dietz further adds, "CA focused on combining two bands for increased downlink (network base station to the smartphone) speeds in 2015. The challenge in 2016 is to combine three carrier bands for even faster downlink as well as uplink (from the smartphone to the base station) speeds, as consumers live stream, upload more content, and move to cloud-based computing."

2. Cobham Wireless's test system supports carrier aggregation with unlicensed frequency bands. *(Courtesy of Cobham Wireless)*

CA VARIETIES

CA can be classified into three types: intra-band contiguous, intra-band non-contiguous, and inter-band *(Fig. 1)*. Intra-band contiguous aggregates multiple adjacent CCs in a single operating band. Intra-band non-contiguous also aggregates multiple CCs in a single operating band. However, the CCs are actually separated rather than adjacent. Inter-band CA aggregates multiple CCs in different operating bands. This is more complex than intra-band CA because the multi-carrier signal cannot be treated like a single signal.

The many challenges associated with CA will likely become more difficult due to the higher-complexity CA deployments expected to arrive over the next few years. Early CC deployments combined only two CCs, while future deployments will combine three, four, five, or even six CCs.

One persistent challenge involves RF filtering, because of the need to prevent interference between CCs. Multiplexers will become crucial components as more CCs are combined. Devices like power amplifiers (PAs) and switches must also be adequately designed to provide the required performance. For example, switches must maintain high isolation to minimize interference from one port to another. And PAs with very high linearity are required for intra-band CA.

"CA poses many RF challenges for smartphone makers," says Dietz. "These challenges include cross-isolation, which means avoiding interference between aggregated bands. Another challenge regards in-band isolation between the transmit and receive frequencies of each band. Minimizing insertion losses to maintain system sensitivity and optimizing power consumption are two additional challenges.

"We plan to help our customers tackle the challenges of CA in 2016 with products like our multiplexers and surface-acoustic-wave (SAW) and bulk-acoustic-wave (BAW) filters," he continues. "Because we see 2016 as a critical year in the rollout of 3-band and uplink CA across the globe, we are focused on delivering products with the performance, size, scale, and speed that customers need to get their newest smartphones to market."

TEST SOLUTIONS

Component suppliers are not alone in the need to deliver CA solutions. CA obviously requires test solutions, which means that test-equipment manufacturers must offer products that can handle the demands of CA.

A number of equipment suppliers offer such solutions. For example, Cobham Wireless's (www.cobhamwireless.com) TM500 network test family *(Fig. 2)* can validate all of LTE-A's main features, include those specified in Release 12 of the 3GPP specification. Furthermore, support was added for CA with unlicensed frequency bands, which represents a major aspect of 3GPP Release 13.

For its part, Rohde & Schwarz (www.rohde-schwarz.com) offers a number of test solutions for LTE-A CA implementations. They include signal generators and signal analyzers for physical-layer testing on base stations, mobile devices, or components. In addition, the company offers base-station emulators for physical-layer and protocol tests for all types of wireless devices and chipsets.

Anritsu (www.anritsu.com) has also entered into the fray, recently making news by announcing that a demonstration featuring the company's MD8430A LTE simulator used 10 simultaneous 100-Mb/s data streams. The company touts this as a breakthrough achievement.

The MD8430A is used to develop LTE-A-compliant chipsets and wireless devices. The scalable LTE network simulator has several models, such as the standard test model (STM) and the enhanced test model (ETM). The MD8430A can verify normal communications procedures. It also supports fault operation tests, which are difficult to perform at connections with live base stations.

To summarize, carrier aggregation is unquestionably a vital technology component that will be counted on to meet the demands of today and tomorrow. With wireless technology being such an integral part of our lives, wireless carriers must look to CA as a means to address the challenges associated with mobile data traffic. Over the next few years, even more sophisticated forms of CA may emerge, which means both components suppliers and test-equipment manufacturers must keep pace by delivering solutions to enable the ever-more complex wireless world. mw

JACK BROWNE | Technical Contributor

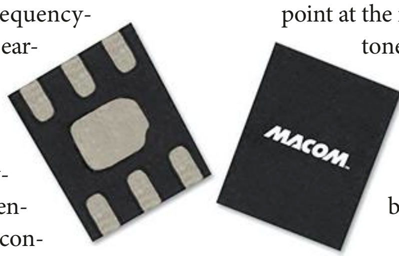
Frequency Conversion Provides Communications Flexibility

Diverse component choices support the translation of signals at different frequencies, as required by transmission and reception in modern communications systems.

FREQUENCY CONVERSION IS an enabling technique for most communications systems and test equipment. By shifting signals with voice, video, and data content to higher frequencies, they can be transmitted and received with quarter-wavelength antennas that are much smaller for those higher frequencies.

At RF and microwave frequencies, systems designers have a number of frequency-conversion options, with each offering its own strengths and weaknesses. Often the choice comes down to size, cost, and frequency range.

Many of the basic requirements for a frequency-conversion component were reviewed in an earlier article *(see "Sort Through Frequency Conversion Choices," September 2015, p. 62)*. As that article notes, frequency mixers are among the most popular of frequency-conversion components, used to shift frequencies higher (upconversion) or lower (downconversion) as needed.



1. The trend of smaller frequency mixers is exhibited by this 35-GHz mixer in a tiny RoHS-compliant plastic package. *(Courtesy of MACOM)*

These three-port components, with radio-frequency (RF), local-oscillator (LO), and intermediate-frequency (IF) signal ports, work by mixing two signals to create a third. For upconversion, the two signals are added in frequency, whereas for downconversion, one of the signals is subtracted from the other.

Decades ago, frequency mixers were considerably larger. They were based on discrete-component circuits and supplied in metal housings with waveguide or coaxial connectors.

Modern demands for smaller, lighter communications equipment and portable radar systems have led to smaller integrated-circuit (IC) mixers in surface-mount-technology (SMT) housings. These may also contain associated circuit functions, such as amplifiers and filters. Low-cost housings can limit the frequency range of an IC mixer, although SMT packaging continues to improve well into the microwave frequency range.

Frequency mixers are available as both active or passive circuits, with a key different between the two types being whether frequency translation occurs with conversion loss (passive mixers) or conversion gain (active mixers). Another difference between an active and passive mixer may be the need to include additional amplification and filtering with the passive mixer compared to the "ready-to-go" nature of an active mixer.

Other specifications for comparing different mixers include the usable frequency ranges of the three ports; the input and output VSWR; the amplitude levels of spurious signal products produced by the nonlinear mixing effects; the 1-dB compression point at the input of the mixer; single-tone and multiple-tone intermodulation distortion (including the input third-order intercept point, or IIP3); the maximum and minimum LO power levels; the noise figure or noise added by the mixer to the output signals; and the isolation between ports.

Mixers can be based on a single semiconductor device—such as a field-effect transistor (FET), a PIN diode, or a Schottky-barrier diode—as well as on two semiconductor devices in a balanced configuration or four semiconductor mixing devices in a double-balanced configuration. Typically, the increasing number of active devices within a mixer can help lower spurious signal content at the output and improve isolation between ports, with a tradeoff of higher conversion loss than a single-device mixer.

An additional mixer configuration, when high image rejection is needed, is the image-reject mixer, formed by connecting a pair of double-balanced mixers. The internal use of 90-deg. hybrids to split RF and LO signals to 0- and 90-deg. phase-offset signals for driving the two internal mixers—and then another 90-deg. hybrid for combining the two phase-offset IF signals into one output IF signal—accounts for higher loss than other mixer types with an image-reject mixer, and the need for more robust LO power and more consumption of power.

In-phase/quadrature (I/Q), or single-sideband (SSB), mixers are also formed by connecting a pair of double-balanced mixers and feeding 0- and 90-deg. signals to LO ports of the two different mixers. Such mixers are commonly used for modulating and demodulating signals with quadrature modulation.

Because the phase-cancellation network formed by the mixers and associated components add phase for one sideband and subtract phase for the other, this mixer can help remove the unwanted sideband during processing. This especially holds true if the sideband is relatively close to the desired signals.

As noted earlier, mixers are increasingly available in SMT housings for higher-frequency applications, and the model MAMX-011021 passive frequency mixer from MACOM (www.macom.com) is an impressive example. Housed in a six-lead, plastic RoHS-compliant package that measures a mere 1.5 × 1.2 mm *(Fig. 1)*, the mixer accepts RF signals from 5 to 35 GHz and LO signals from 3 to 33 GHz, producing IF signals from dc to 4.5 GHz with 8-dB conversion loss.

MULTIPLYING FREQUENCIES

Mixers may be the most oft-used RF/microwave component for frequency conversion, but they are not the only option: Frequency multipliers continue to squeeze into smaller packages while reaching higher frequencies. Frequency multipliers (for frequency upconversion) and their counterparts, frequency dividers or prescalers (for frequency downconversion), are commonly used with integer multiplication or division factors of typically 2, 4, or 8. They are available in active and passive forms with multiplication and division factors of 12 and higher.

When more than one division ratio is required, dual-modulus prescalers are chips or packaged ICs with switchable division ratios, such as 8 and 9, 32 and 33, and 64 and 65.

As with mixers, frequency multipliers and dividers rely on the nonlinear characteristics of semiconductor devices—such as transistors or diodes—to perform the harmonic multiplication or division required to produce higher or lower output frequencies, respectively. Both multipliers and dividers are available in numerous forms, including in coaxial and SMT packages, with power-handling capability typically a function of package size.

As with frequency mixers, frequency multipliers can be active or passive, based on various types of transistors or diodes, respectively. Multipliers can be based on a single diode for simplicity and in cases where the fundamental or carrier frequency signals can be readily suppressed. Balanced diode multipliers may yield higher conversion loss, but will also achieve better suppression of unwanted even-order spurious products and improved fundamental suppression.

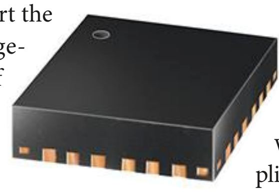
In a frequency mixer, two signals are needed for frequency conversion. When only one signal source is available, and it is (for example) an LO that must be upconverted, a frequency multiplier provides a means of raising the frequency range of the LO with low loss and without introducing a great deal of noise. Frequency dividers are commonly used in phase-locked-loop (PLL) frequency synthesizers to downconvert the frequency of a tunable source, such as a voltage-controlled oscillator (VCO), to bring it into range of a phase detector for comparison with the phase of a reference oscillator.

Frequency multipliers and dividers are specified according to a set of parameters that is closely aligned to those of a frequency mixer. These include multiplication or division ratio; input and output frequency ranges; conversion loss or gain; maximum input power; maximum output power; and fundamental (carrier) and harmonic rejection.

Frequency multipliers operate by multiplying signal phase as part of the process and, in so doing, increase the phase noise of the multiplied signals even under ideal conditions. Still, frequency multipliers offer a cost-effective means of generating high-frequency signals.

The model HMC-XTB1100 is a monolithic frequency tripler from Analog Devices (www.analog.com) based on GaAs Schottky-diode technology. It requires no dc power, but transforms input signals from 24 to 30 GHz to low-noise output signals from 72 to 90 GHz, all as part of a chip measuring 1.1 × 1.4 × 0.1 mm.

For those more comfortable with a packaged part, the model CY2-143+ *(Fig. 2)* from Mini-Circuits (www.minicircuits.com) is a surface-mount frequency doubler that transforms an input frequency range from 2 to 7 GHz to an output frequency range of 4 to 14 GHz, with 12- to 13-dB typical conversion loss. The GaAs heterojunction-bipolar-transistor (HBT) monolithic-microwave-integrated-circuit (MMIC) doubler is supplied in a housing measuring just 4 × 4 × 1 mm.



2. Frequency multipliers such as this frequency doubler are also available in miniature SMT-type housings. This GaAs HBT multiplier measures just 4 × 4 × 1 mm. *(Courtesy of Mini-Circuits)*

Beyond mixers, prescalers, and multipliers, frequency translation is often added to a system in the form of an integrated front-end assembly (IFA) which typically combines a frequency mixer, LO, amplification, and filtering within a drop-in component housing. In the world of satellite communications, these assemblies are also known as block upconverters (BUCs) and block downconverters (BDCs).

The integration simplifies the matching of components, but mandates that performance requirements are well known in advance. Some tuning flexibility is sacrificed as one of the trade-offs for the ready-to-use frequency-conversion assembly. mw

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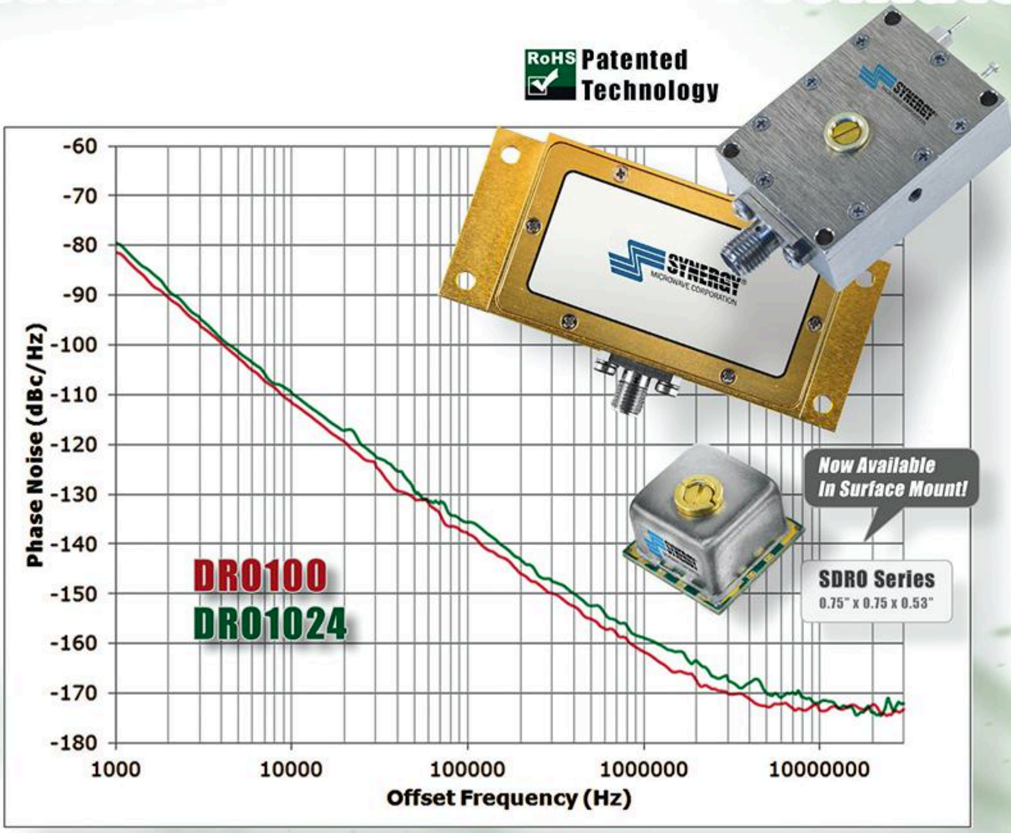

Model	Frequency (GHz)	Tuning Voltage (VDC)	DC Bias (VDC)	Typical Phase Noise @10kHz (dBc/Hz)
Surface Mount Models				
SDRO1000-8	10	1 - 15	+8 @ 25 mA	**-107**
SDRO1024-8	10.24	1 - 15	+8 @ 25 mA	**-111**
Connectorized Models				
DRO100	10	1 - 15	+7 - 10 @ 70 mA	**-111**
DRO1024	10	1 - 15	+7 - 10 @ 70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

Model	Center Frequency (GHz)	Mechanical Tuning (MHz)	Supply Voltage (VDC / Current)	Typical Phase Noise @10kHz (dBc/Hz)
Mechanical Tuning Connectorized Model				
KDRO145-15-411M	14.5	±10 MHz	15 V / 130 mA (Max.)	-88

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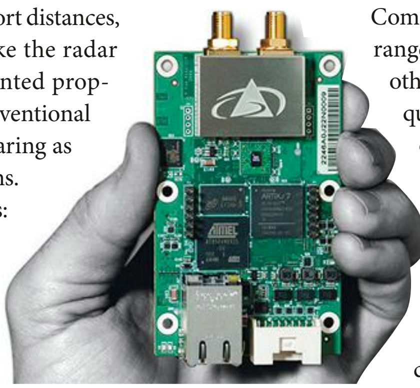
UWB Comms Salvage Crowded Spectrum

As wireless applications continue to fill the RF/microwave spectrum, ultrawideband techniques can transfer high-rate data across short distances at low power levels.

CROWDED FREQUENCY SPECTRUM has led to renewed interest in ultrawideband (UWB) radio technology. With a growing number of wireless electronic devices occupying finite bandwidth, UWB technology, also known as impulse radio, offers the potential to share the available bandwidth with broadband, low-power pulses. Such pulses can communicate not only large amounts of information across short distances, but directional information much like the radar systems that they mimic. If implemented properly, UWB radios can coexist with conventional wireless radio systems, generally appearing as background noise to those other systems.

UWB technology comes in two forms: multicarrier (MC) UWB communications, in which multiple simultaneous carriers are used to transfer information; and as short-duration pulses that are used to transfer information. Multicarrier UWB communications is fairly straightforward. It has been employed with various modulation formats, including orthogonal-frequency-division-multiplex (OFDM) modulation, to achieve high data rates. Impulse UWB radio formats may be the more intriguing of the two UWB types, though, with the ability to transfer data across bandwidths already occupied by other radio formats.

UWB radio technology has never seen widespread use in any market areas. But the scarcity of available frequency spectrum due to the influx of wireless applications and forthcoming data-heavy Internet of Things (IoT) networks may open up realistic opportunities for this technology. It could particularly benefit impulse UWB radars, which can share bandwidth with existing applications. Pulsed UWB radios provide the means to move remote data wirelessly across short distances, and may serve as suitable wireless interconnections between many IoT sensors and gateways to the Internet.



PulsON radio modules are compact subsystems that provide ranging and high-data-rate communications functions based on pulsed UWB technology. *(Courtesy of Time Domain Corp.)*

Impulse UWB radios transmit and receive pulses much like a radar system, with the one difference being that no target is being illuminated by those pulses. If anything, an UWB receiver is the target and is tasked with the time-sensitive reception of short-duration pulses that occupy broad bandwidths of spectrum.

In the United States, the Federal Communications Commission (FCC) in 2002 set aside the frequency range from 3.1 to 10.6 GHz for UWB usage. Since other applications have to function within this frequency range, UWB systems must operate without interfering with those other narrowband and wideband systems. The FCC also set a transmission power limit of –41.3 dBm/MHz or 75 nW. Moreover, UWB systems face the challenge of receiving low-level signals from a signal environment where much higher-level signals already exist (which might be considered jammer signals to a radar system).

TAKING THE PULSE OF UWB

Use of pulsed signals in UWB radios enables successful communications, even in environments with severe multipath conditions as typified by crowded wireless bands. Military users have been intrigued by the potential of UWB communications equipment for many years, since it relies on low-power pulsed signals with a low probability of interception and detection for secure communications.

The data rates possible with UWB signals are a function of the power spectral density (PSD) of a system, with higher data rates potentially a tradeoff with transmit power. The large instantaneous bandwidth of UWB signals enables three-dimensional (3D) distance and time resolution to precisely position the source of received radio signals.

Pulse shaping is typically employed to ensure that UWB transmissions remain within the power- and spectral-density limitations set by the FCC in the U.S. and ETSI (www.etsi.org) in Europe. Pulse shaping also prevents the spread of

electromagnetic (EM) energy into occupied radio bands to enable coexistence with other wireless applications. To satisfy the required spectral mask, digital filtering—including the use of finite-impulse-response (FIR) filters—has proven effective.

A SMATTERING OF PRODUCTS

In spite of its benefits, commercial UWB communications products haven't exactly exploded onto the market. Few manufacturers have taken the plunge into a technology that's admittedly much different than popular, conventional radio systems residing within clearly defined segments of the frequency spectrum, such as LTE and Wi-Fi.

One company that has made progress with practical hardware and software for UWB applications is Time Domain (www.timedomain.com). The firm has developed a number of reliable UWB radio systems, including its P330 and P440 compact PulsON radio modules *(see figure)*.

The P330 offers ranging and high-speed communications capabilities. As a ranging radio, it uses two-way time-of-flight (TW-TOF) ranging to measure the distance between two or more P330 radios. Ranging samples are performed at rates to 200 measurements/s (200 Hz) with accuracy of 10 cm across ranging distances to 100 m.

As a communications device, the P330, which supports multiband operation, reaches data rates up to 6.8 Mb/s in compliance with the IEEE 802.15.4a standard for wireless ranging and communications. The compact module is backed by the firm's suite of ranging and localization software for precise TW-TOF measurements, including in networks optimized for such measurements.

The P330, as with the P440, is designed and constructed for industrial environments, with an operating temperature range of –40 to +85°C and typical power consumption of 1 W. It measures 56 × 103 × 18 mm with antenna connectors and complies with FCC Part 15 regulations in the U.S. and ETSI EN 302 065 standard mask for use in Europe.

The P440 UWB radio module also features TW-TOF ranging at rates to 125 Hz and 2-cm accuracy. As with the P330, it can operate with either the ALOHA or TDMA protocol for ranging purposes. With its pulsed signals, it works as a monostatic, bistatic, or multistatic radar, and is able to achieve high rejection of clutter for target recognition inside buildings and within other challenging operating environments.

At the heart of both UWB radio modules is the model DW1000 silicon CMOS integrated circuit (IC) from fabless Irish semiconductor supplier

DecaWave (www.decawave.com). The DW1000, a single-chip UWB transceiver with 10-cm indoor location precision, can also communicate at data rates to 6.8 Mb/s using pulsed UWB time-synchronized signals. Designed to support high-data-rate IoT devices in wireless sensor networks, the DW1000 UWB transceiver chip uses coherent receiver techniques to achieve a communications range to 290 m. It is highly immune to multipath fading and operates with extremely low power consumption to further extend battery life in portable and remote applications.

For system developers, DecaWave offers DW1000 UWB evaluation kits. It offers flexible operation, supporting six different frequency bands with center frequencies from 3.5 to 6.5 GHz. The DW1000 UWB IC, fabricated with 90-nm CMOS technology, can run on supplies from +2.8 to 3.6 V dc, with only 31-mA current consumption in transmit mode and 64-mA current consumption in receive mode.

Housed in a 6- × 6-mm 48-pin QFN, the DW1000 transmits at power levels of –10 to –14 dBm, achieving transmit power density of –41.3 dBm/MHz. It works with biphase modulation (BPM) and binary-phase-shift-keying (BPSK) modulation to achieve reliable, high-speed data rates in severe industrial environments.

Another supplier of UWB radios is Multispectral Solutions, recently acquired by Zebra Technologies Corp. (www.zebra.com). Multispectral's UWB digital voice/data radio operates with 1-W peak transmit power and 400-MHz instantaneous bandwidth to achieve transmission rates of 128 kb/s for voice and 115.2 kb/s for data. It achieves a range of 1 to 2 km with low-profile omnidirectional antennas.

The antenna, of course, is an important part of any UWB radio system. Numerous multiple-band antennas have been developed to work at two or more "narrowband" wireless frequency bands at the same time, such as Bluetooth and Wi-Fi. But in UWB systems, antennas must receive all frequencies at the same time across a wide bandwidth, preferably with nondispersive characteristics. As a result, their design tends to be more challenging than the others.

Antennas for UWB use are typically categorized as being directional or nondirectional. Directional antennas provide higher gain than nondirectional or omnidirectional antennas, and are typically larger with more limited fields of view. In most cases, the advantages of UWB radio systems are best realized with miniature omnidirectional antennas, although directional antennas serve well when greater range is needed for a given transmit power level. mw

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EVALUATE of LTE and

A test method is available for measuring the effects of S-band radar systems on LTE wireless networks operating within the same frequency range, and how wireless signals affect radars.

Bandwidth is precious and limited—so much so that the evolution of microwave/wireless applications will involve careful planning and accurate measurements to avoid the overlapping of frequencies. For example, potential issues may arise with frequencies occupied by existing S-band radar systems and allocations for Long-Term-Evolution (LTE) cellular/wireless commercial-communications systems.

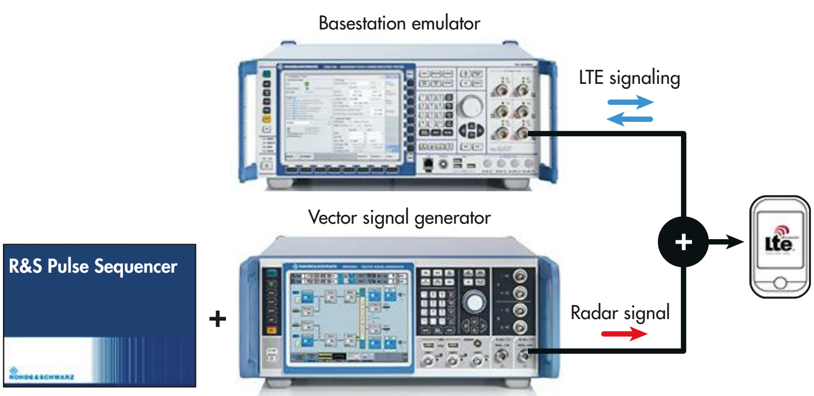
Ideally, the different systems will remain in their proper frequency bands and will not interfere with each other. But performance degradation and system malfunctions can occur, such as excessive spurious levels, that can cause problems. Proper measurement methodologies can help avoid such problems and ensure the coexistence of S-band radar systems and LTE networks.

Multiple applications within the same frequency band can face coexistence problems. As an example, consider the performance of LTE base stations and mobile devices and how they might have coexistence issues with recently allocated frequency bands defined by the Third Generation Partnership Project (3GPP) standard, 3GPP TS 36.101 (Release 13, December 2015). Proper measurements can determine whether interference exists, notably through in-field measurements at critical locations for both applications (such as airports).

The S-band frequency range has been defined by the IEEE as all frequencies between 2 to 4 GHz. Along with aviation and weather-forecasting systems, a number of different maritime radar systems worldwide also operate at S-band frequencies. S-band radar systems include air-traffic-control (ATC) radars (typically between 2,700 and 3,100 MHz) and AN/SPY-1 Naval Air Surveillance Radar (ASR) systems operating between 3,100 and 3,500 MHz.

Coexistence is a concern for different S-band radar systems, especially in the U.S., because of LTE networks operating in Band 42, from 3,400 to 3,600 MHz; Band 43, from 3,600 to 3,800 MHz (with time-division-duplex, or TDD, single-frequency operation for transmit and receive functions); Band 7, from 2,620 to 2,690 MHz in the downlink and 2,500 to 2,570 MHz in the uplink; and Band 22, from 3,510 to 3,590 MHz in the downlink and 3,410 to 3,490 MHz in the uplink. Frequency-division-duplex (FDD) systems falling within this frequency range are also a concern for coexistence with radar systems at S-band frequencies.

While the number of proposed LTE bands has increased from 11 to more than



1. This system setup was used for coexistence testing.

COEXISTENCE

S-Band Radar

50 operational bands in the last four years, 150 MHz of spectrum in Bands 42 and 43 is anticipated for auction in the U.S. This spectrum, from 3,500 to 3,650 MHz, has been proposed for subdivision as 50 MHz for Tier 1 operators, 50 MHz for Public Safety use, and 50 MHz for Citizens Broadband Radio Service (CBRS).

Any use of the spectrum by mobile radio networks must not disrupt primary users within the allocated spectrum. However, no agreement between national and international authorities has been reached on guidelines to assess potential interference issues.

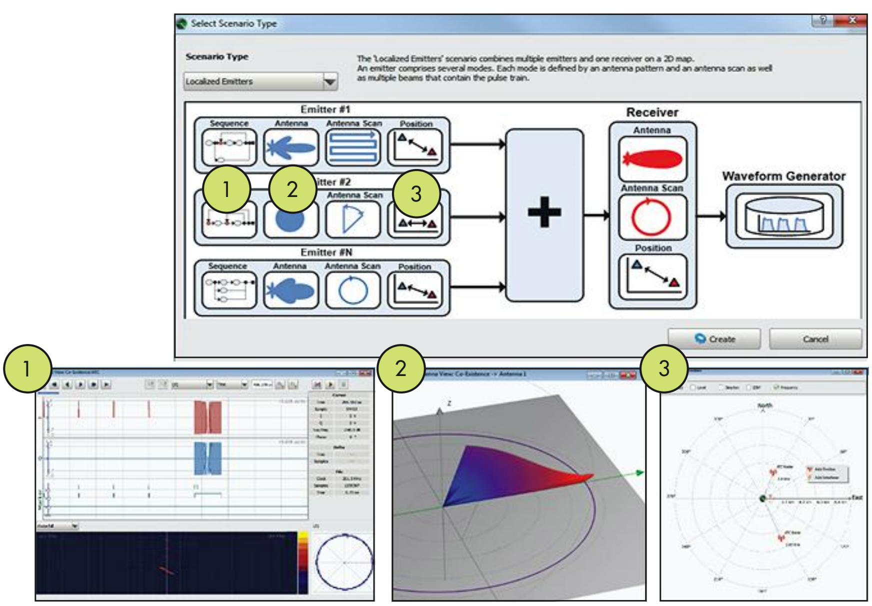
At the recent World Radio Congress 2015 (WRC 2015) in Geneva in November 2015, Recommendation 75 (REV. WRC-15), "Study of the boundary between the out-of-band and spurious domains of primary radars using magnetrons," proposes assessing the improvement of measurement methodologies and performance levels of radars.[5]

Also, recommendation 207 (REV.WRC-15), "Future International Mobile Telecommunications (IMT) Systems," proposes a continuous study of the necessary technical, operational, and spectrum-related issues to meet objectives for developing future mobile telecommunication systems, taking into consideration requirements for other services.[2]

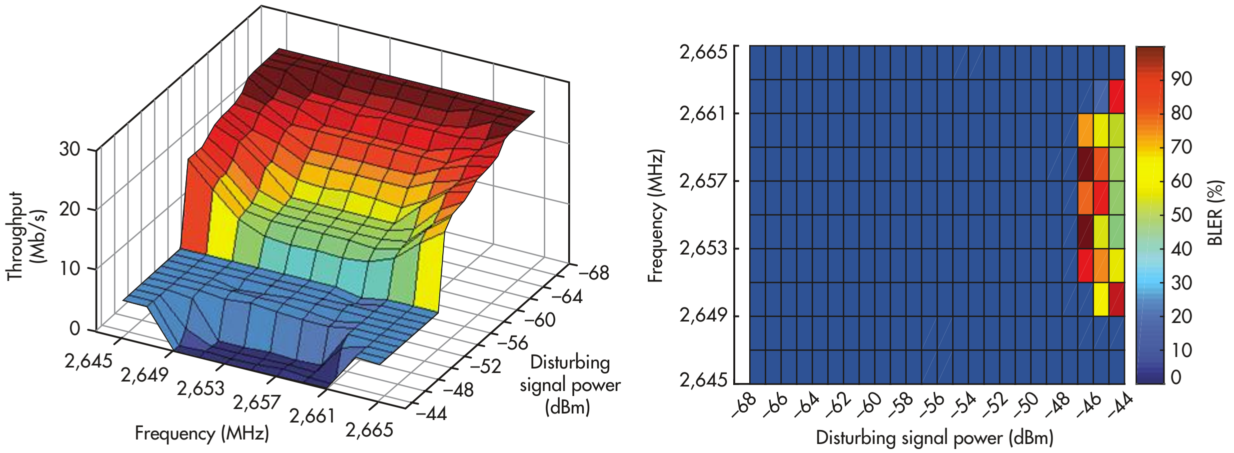
The FCC requires use of cognitive radio technologies and consultation of the national spectrum database, the Spectrum Access System (SAS), with this spectrum. Cognitive radio technologies are certainly not new, and detect and avoid (DAA), transmit power control (TPC), and dynamic frequency selection (DFS) techniques have been employed for many unlicensed radio technologies—including the IEEE 802.11 wireless-local-area-network (WLAN) standards—to avoid interference with weather radar and military applications in the 5-GHz band. However, licensed technologies, such as LTE, have not previously had to assess performance for coexistence with scanning radars.

Most of these types of radars apply pulse and pulse-compression waveforms. After transmitting a pulse, the radar switches to receive mode to obtain radar echo pulses from illuminated targets. The high sensitivity needed to acquire low-level returning pulse echoes also makes radar receivers susceptible to interference signals.

LTE networks using nearby frequencies can cause this interference and may significantly degrade radar performance. Developing capability for an LTE network or mobile device receiver to detect and avoid a scanning radar may also represent a significant challenge.



2. These are the operating conditions for the pulse sequencer test setup.



3. These plots show the throughput and BLER versus interference signal power and frequency (for a 72-μs pulsed signal with 1 ms PRI).

SPECTRUM SHARING

Disturbances to an LTE network can occur due to performance degradation of an S-band radar system, resulting in an increase in the LTE network's block error rate (BLER). This loss of LTE network performance and poor spectral efficiency may not be a major drawback to a mobile communications network operator, but the reduction of power could increase operating costs in order to maintain the performance expected by mobile customers.

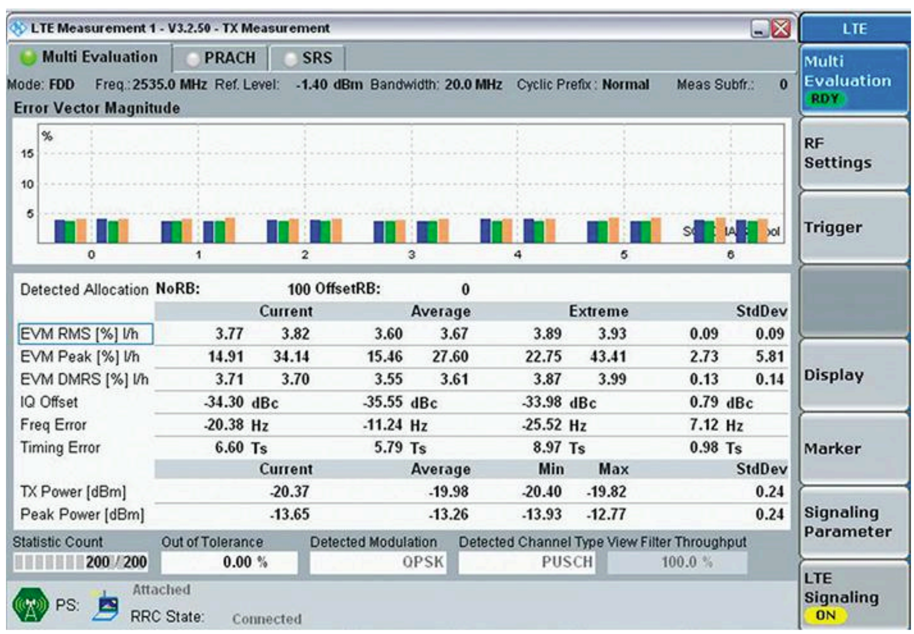
The 3GPP specifications may define solutions for the problem (such as the use of dynamic frequency selection or transmit power control) that do not disturb other signals. Still, the challenge in developing a suitable receiver capable of detecting a scanning S-band radar should not be underestimated.

As an example, a radar scanning at a rate of 12 rpm with 2-deg. antenna beamwidth will illuminate a stationary target with the main beam for about 27 ms. For a typical pulse width of 6 μs and pulse repetition frequency (PRF) of 1 ms, the radar receiver will receive reflected signals from that target for 162 μs during this time, or about 2-ms target illuminations every minute. If the bandwidth and sensitivity of the receiver are considered, the system is also scanning over a frequency range of several megahertz.

For an S-band radar system, the RF emission bandwidth can range from several kilohertz to dozens of megahertz with peak transmission power of typically greater than +90 dBm (i.e., hundreds of megawatts of power). While a disturbance may occur for any on-channel event, an active channel transmission in an adjacent or alternative channel several tens of megahertz away may mitigate the impact to the network.

Mobile network devices employ standard RF channel filtering in line with 3GPP standards to minimize interference. However, measurement results show that LTE infrastructure equipment, such as base stations, can be impacted by radar signals and should be tested for compatible operation.

At the same time, LTE signals can also cause harm to S-band radar systems. A radar receiver may be designed to receive an



4. This is an example of an LTE uplink EVM measurement.

> "Fortunately, test solutions have been developed based on recorded and simulated signals representing the LTE and radar signals. Using realistic test signals, the functionality of both systems can be verified."

echo return as low as –120 dBm. Per the 3GPP TS 36.101 and TS 36.104 standards, LTE base stations are allowed to transmit a maximum of +46 dBm with additional antenna gain of approximately 15 dBi.

Mobile devices are allowed to operate with maximum transmission power of to +23 dBm. An exception enables mobile devices to operate at transmit power of +31 dBm in Band 14 (the Public Safety band in the 700-MHz spectrum in the U.S.).

While power limits for Bands 42 and 43 for the 50-MHz Public Safety allocation have yet to be determined, there is a good chance that these power levels will be substantially higher than +23 dBm. In collocated bands, LTE system levels above –120 dBm can impact the probability of detection and the gain control of an S-band radar receiver. The receiver may be driven into compression, resulting in nonlinear responses or a rise in the constant false alarm rate (CFAR) threshold. Radar targets may be lost or left undetected.

Fortunately, test solutions have been developed based on recorded and simulated signals representing the LTE and radar signals. Using realistic test signals, the functionality of both systems can be verified and mitigation techniques developed to minimize the effects of interference.

The 3GPP has defined multiple test cases for three LTE test areas—protocol/signaling, mobility, and radio resource management (RRM)—as well as for RF conformance. Such testing ensures minimum compliance with the current 3GPP standard.

However, the majority of receiver and performance tests for LTE assume the presence of only additional LTE or 3G signals, such as wideband code-division-multiple-access (WCDMA) signals as part of the Universal Mobile Telecommunications System (UMTS). The 3GPP has not defined tests for the presence of a radar signals in adjacent frequencies to the received signal from an LTE base station.

UPLINK AND DOWNLINK SIGNALING PARAMETERS FOR LTE

Parameter	Value
Downlink	64QAM, Band 7, 2,655 MHz
Uplink	QPSK, Band 7, 2,535 MHz
Full cell bandwidth power	–57.2 dBm
RS EPRE	–85 dBm/15 kHz
RSRP	56 (–85…–84 dBm)
RSRQ	19 (–10.5…–10.0 dB)

To test LTE system operation, it would be beneficial to record an S-band radar signal and play it back on an adjacent frequency while performing a throughput test or receive sensitivity test. A universal network scanner can be used to record ATC radar signals, with in-phase/quadrature (I/Q) data stored in memory and replayed for testing on a vector signal generator (VSG). As shown in refs. 3, 4, and 5, coexistence issues have occurred when an LTE-capable terminal with an active data connection comes close to an S-band radar signal.

One alternative to recording and playing back radar signals for testing LTE coexistence capability is the computer-based synthesis of signals representing a challenging RF environment. This cost-effective approach *(Fig. 1)* allows defining a radar signal, antenna pattern, and radar position in software without on-site testing.[5] Essentially, test signal conditions are generated in software and then replayed on a VSG.

As an example, pulse sequencer software[5] was used to generate a sequence of consecutive pulses without modulation, followed by a pulse with linear frequency modulation (LFM) *(Fig. 2)*. The measurement approach convolves the test signal into a cosecant-square antenna pattern (1 in Fig. 2) and rotational motion (2 in Fig. 2) to form a pulse signal directional position north and east of the receiver under test (3 in Fig. 2).

This test software is not limited to radar signals; it can also define unlimited types of arbitrary signal sequences and antenna patterns. Signals created in software are then calculated as if they would appear at a receiver under test and replayed with a VSG.

In this way, a receiver's baseline performance can be compared to its performance in the presence of a disturbing signal. The reproducible test setup can define an operating environment according to expected performance levels.

The measurement approach was used to create a representative radar signal, a pulsed chirp signal with 20-MHz LFM, 72-μs on time, and 1-ms PRI. A representative, commercially available mobile phone was connected to a model CMW500 base-station emulator in a shielded box with LTE signaling parameters defined in the table and in ref. 4. The base station emulator was set to its "Follow Wideband" signaling mode with a 10-MHz signal bandwidth. In this mode, the LTE mobile phone can track downlink channel quality using embedded reference signals.

The measured signal receive quality is translated to a Channel Quality Indicator (CQI) value that is reported back to the LTE network. The scheduler in an LTE base station can use the CQI information to set the resource allocation, modulation, and coding scheme based on the channel conditions seen by the mobile phone. With any interference present, the mobile phone would measure lower received signal quality, resulting in a lower modulation and coding scheme adopted by the base station.

To evaluate the downlink throughput of the mobile phone, the pulsed radar test signal was varied in frequency and power; the downlink throughput was measured after each change. An average throughput value of a 100,000-subframe measurement was plotted versus frequency and disturbing signal power for analysis *(Fig. 3)*.

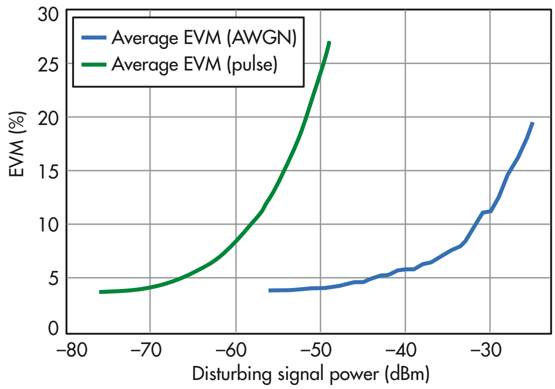
The throughput decreases almost constantly depending on frequency and power. The impact of the disturbing signal is apparent even when it is offset 10 MHz from the downlink center frequency. The BLER is plotted on the right side of Fig. 3, with 100% BLER representing no useful signal and lower BLER showing more useful signals present.

The test setup was changed to evaluate uplink performance for the mobile phone, using the base-station emulation to evaluate error-vector-magnitude (EVM) performance. The LTE measurement mode was FDD with an uplink frequency of 2,535 MHz and bandwidth of 20 MHz. *Figure 4* shows peak and average EVM on the base-station emulator display screen. Under normal conditions, the average EVM is 3.67%. By varying the power level of an interfering pulse signal, the average RMS EVM for the uplink channel can be evaluated.

Figure 5 compares the effects of a pulse signal and 20-MHz-wide average white Gaussian noise (AWGN) on the uplink channel. Any disturbing signal greater than –48 dBm results in the uplink channel being "out of sync." Any disturbing signals lower than this level increase the uplink EVM. The AWGN requires less power than the pulse signal to cause disruption of the uplink performance, since it is a continuous-wave (CW) signal compared to a pulse with 0.5% duty cycle.

This measurement approach provides a practical means for evaluating the coexistence of S-band radar systems with LTE mobile terminals: The test system can evaluate the effects of LTE signals on the radars as well as the pulsed radar signals on LTE network performance.[3]

The test results achieved in the laboratory correlate well with in-field test data, making it possible to use this test methodology to help test and plan networks that can coexist with incumbent radar infrastructure systems. mw



5. This is an uplink EVM comparison of AWGN noise and a pulsed signal.

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Single Stub-Loaded SIR Yields Quad-Band BPF

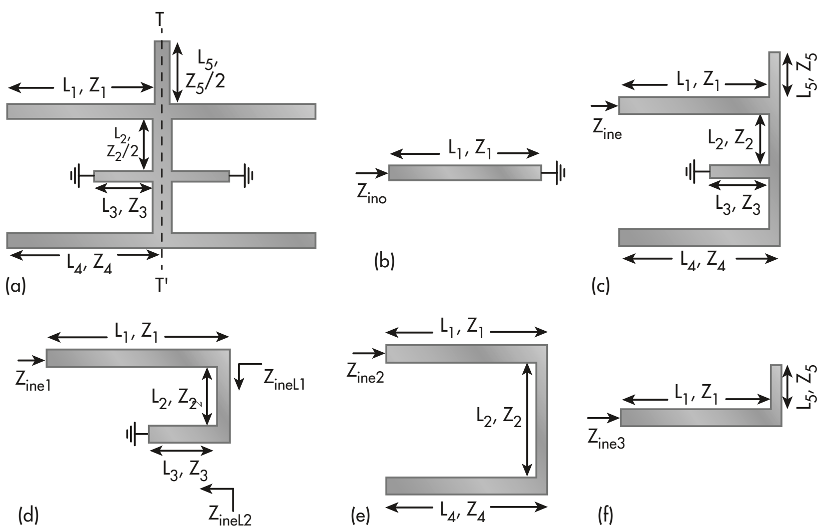
A novel stub-loaded, stepped-impedance resonator is the basis for a compact bandpass filter with four passbands from 1.5 to 5.2 GHz, each with relatively low insertion loss.

Compact filtering can serve the growing number of wireless applications requiring frequency allocations that must be isolated for effective use. Through the design and fabrication of a novel stub-loaded stepped-impedance resonator (SL-SIR), it was possible to develop a compact quad-band bandpass filter (BPF) approximately the size of a conventional, single-passband BPF. To demonstrate the design method, a BPF with passbands centered at 1.5, 2.5, 3.5, and 5.2 GHz was designed and fabricated; good agreement between simulated and measured performance parameters was observed.

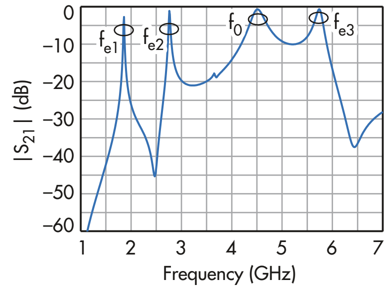
Demand will increase for BPFs with multiple passbands as modern multiband wireless communications systems continue to expand globally. A great deal of research has focused on the development of multiple-band BPFs, although much of this work has covered filters with two or three passbands.[1-10] As an example, ref. 9 details the design of a triband BPF created by combining two quarter-wavelength SIRs.

A triband BPF can also be realized by using a three-section SIR to achieve a higher degree of design freedom.[10] With the continued growth of wireless applications, quad-band BPFs have gained increasing attention as a compact solution for isolating multiple wireless bands. However, the design of a quad-band BPF is challenging due to the limited degrees of freedom in its design parameters.

There's a limited number of methods for realizing quad-band BPFs, with reported design methods classified into three basic approaches. The first introduces transmission zeros inside the passbands of a dual-band BPF to split the two passbands into four.[11] The second approach is to cascade two types of dual-band BPFs or multiple resonators with different resonant frequencies, forming a quad-band filter.[12, 13] The third approach involves the utilization of a single quad-mode resonator.[14] Among these three schools of thought, the third method, with its single resonator, enables the design of a compact quad-band bandpass filter and thus



1. These diagrams show the geometry and equivalent circuits for the SL-SIR: (a) the basic configuration, (b) the odd-mode equivalent circuit, (c) the even-mode equivalent circuit, (d) path I of the even-mode equivalent circuit, (e) path II of the even-mode equivalent circuit, and (f) path III of the even-mode equivalent circuit.



2. These are the resonator characteristics of the proposed SL-SIR with various dimensions.

becomes an appealing approach for creating filters with compact size requirements.

Based on a single stub-loaded SIR (SL-SIR), a compact quad-band BPF was designed and fabricated for study. The four independent passbands can be easily modified by changing the resonator dimensions. The performance of the proposed SL-SIR quad-band filter was analyzed theoretically and with the help of computer-aided-engineering (CAE) simulation software. Measured results show good agreement with the computer-simulated results.

Figure 1a shows the geometry of the SL-SIR. Since the resonator is symmetrical to the T-T′ plane, the odd-even-mode excitation method can be implemented. Based on microwave network knowledge, the input impedance can be expressed as:

$$Z_{in} = Z_0 \frac{Z_L + jZ_0 \tan(\beta L)}{Z_0 + jZ_L \tan(\beta L)} \quad (1)$$

where β is the propagation constant. For odd-mode excitation, the equivalent circuit is a one-quarter-wavelength resonator with one end grounded, as shown in *Fig. 1b*. For $Z_L = 0$, the input impedance of the odd-mode equivalent circuit can be found by Eq. 2:

$$Z_{ino} = jZ_0 \tan(\beta L_1) \quad (2)$$

where

$$\beta L_1 = \frac{2\pi}{\lambda_g} L_1 = \frac{2\pi f \sqrt{\varepsilon_e}}{c} L_1$$

From the resonant condition of $Y_{in0} = 0$, the odd-mode resonant frequency can be deduced by means of Eq. 3:

$$f_{ino} = \frac{c}{4L_1\sqrt{\varepsilon_e}} \quad (3)$$

where:
c = the speed of light in free space and
ε_e = the effective dielectric constant of the printed-circuit substrate material.

For even-mode excitation, the equivalent circuit shown in *Fig. 1c* contains three resonant circuits: a quarter-wavelength resonator with one end grounded and two half-wavelength resonators with one end open, as shown in *Figs. 1d, e, and f.* The input impedance in path I of the even-mode equivalent circuit can be deduced by means of Eq. 4:

$$Z_{ine1} = Z_1 \frac{Z_{ineL1} + jZ_1 \tan\theta_1}{Z_1 + jZ_{ineL1} \tan\theta_1},$$
$$Z_{ineL1} = Z_2 \frac{Z_{ineL2} + jZ_2 \tan\theta_2}{Z_2 + jZ_{ineL2} \tan\theta_2} \quad (4)$$
$$Z_{ineL2} = jZ_3 \tan\theta_3$$

From the resonant condition of $Y_{ine1} = 0$, the resonant frequency in path I of the even-mode equivalent circuit can be deduced as:

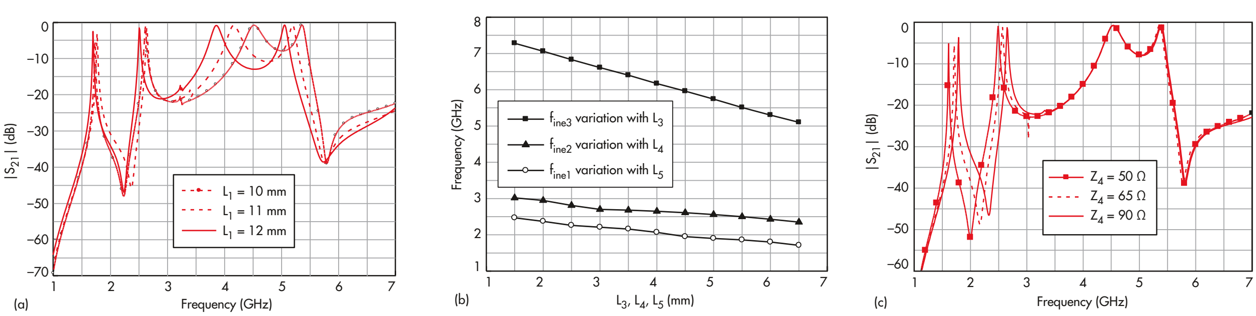
$$f_{ine1} = \frac{c}{(4L_1 + 4L_2 + 4L_3)\sqrt{\varepsilon_e}} \quad (5)$$

where:
$Z_1 = Z_2 = Z_3$ is assumed for simplicity. By employing the exact same method, the resonant frequencies of the other even-mode equivalent circuits can be found by applying both Eqs. 6 and 7:

$$f_{ine2} = \frac{c}{(2L_1 + 2L_2 + 2L_4)\sqrt{\varepsilon_e}} \quad (6)$$

$$f_{ine3} = \frac{c}{(2L_1 + 2L_5)\sqrt{\varepsilon_e}} \quad (7)$$

Electrical length and impedance ratios can determine the resonant frequencies of these circuit structures. Compared with



3. These are the resonator characteristics of the proposed SL-SIR, for (a) L_1, (b) L_3, L_4, and L_5, and (c) Z_4.

a normal stub-loaded resonator, the proposed structure provides four resonant frequencies simultaneously, with a relative high degree of freedom in adjusting the resonant mode locations.

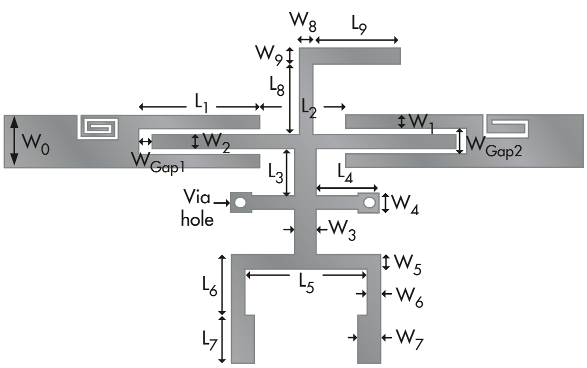
Figure 2 shows the resonator characteristics of the proposed SL-SIR under weakly capacitive coupling, as modeled by the HFSS 11.0 electromagnetic (EM) simulation software from Ansoft Corp. (www.ansoft.com). *Figure 3* shows the even-mode and odd-mode frequency characteristics, respectively, for various resonator dimensions. The bandwidths of the four passbands increase simultaneously as dimension L_1 decreases.

However, the three even-mode resonant frequencies can be controlled independently. Moreover, the resonant frequencies can be controlled by changing the impedance ratios. The simulated and analyzed results for the SL-SIR are in good agreement; they show that, by appropriately adjusting resonator dimensions, four bands can be achieved at four desired frequencies.

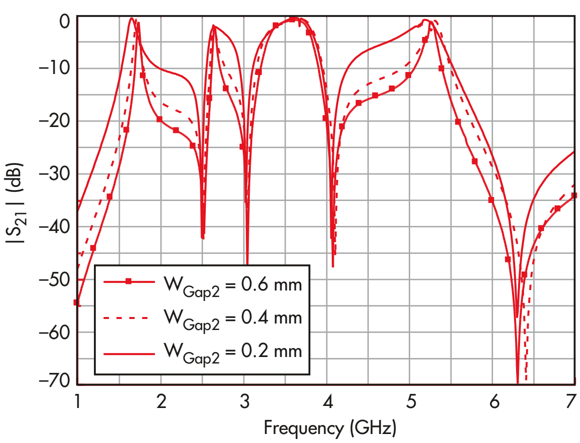
Figure 4 shows the configuration of the proposed quad-band BPF. In the filter realization, for the purpose of improving passband selectivity and isolation, two spiral slots are introduced in the input/output (I/O) port, which can generate two transmission zeros on both sides of the third passband. To reduce filter size, the open-circuited stubs are folded. The SL-SIR quad-band BPF was fabricated on RT/duroid 5880 printed-circuit-board (PCB) from Rogers Corp. (www.rogerscorp.com), with a thickness of 1.0 mm and dielectric constant of 2.2.

The filter/resonator dimensions were selected as follows:
W_0 = 3.0 mm;
W_1 = 0.9 mm;
W_2 = 0.9 mm;
W_3 = 0.2 mm;
W_4 = 0.6 mm;
W_5 = 0.4 mm;
W_6 = 0.4 mm;
W_7 = 1.0 mm;
W_8 = 0.3 mm;
W_9 = 0.5 mm;
L_1 = 10.0 mm;
L_2 = 10.9 mm;
L_3 = 2.35 mm;
L_4 = 6.5 mm;
L_5 = 16.2 mm;
L_6 = 2.4 mm;
L_7 = 3.0 mm;
L_8 = 3.5 mm;
L_9 = 4.7 mm;
W_{gap1} = 0.25 mm; and
W_{gap2} = 1.2 mm.

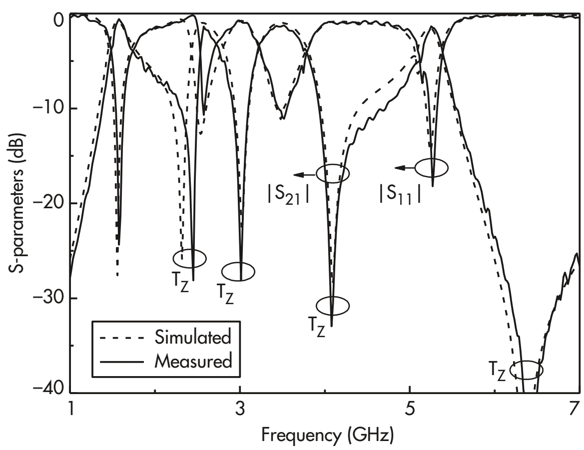
The length and width of the spiral slot on the left side of Fig. 1 is L_{S1} = 19.8 mm and W_{S1} = 0.2 mm. The length and width



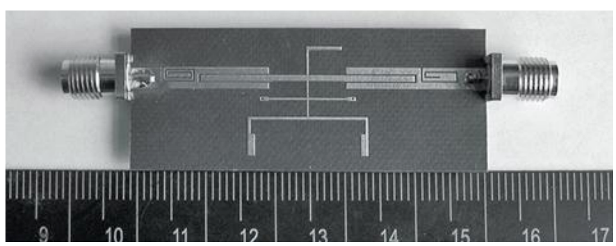
4. This is the configuration of the proposed quad-band BPF.



5. These plots show simulated bandwidths of the proposed BPF for various dimensions.



6. The plots show the simulated and measured S-parameters of the designed quad-band BPF.



7. This photograph shows the fabricated SL-SIR quad-band BPF.

of the spiral slot on the right side of Fig. 1 is L_{S2} = 14.5 mm and W_{S2} = 0.2 mm. The bandwidth is able to be controlled by W_{gap2}. As *Fig. 5* shows, the bandwidth increases as W_{gap2} decreases.

The fabricated bandpass filter was characterized by means of a model N5230A vector network analyzer (VNA) from Agilent Technologies (now Keysight Technologies; www.keysight.com). *Figure 6* offers a comparison between computer simulated and measured results. The fabricated filter features four passbands centered at 1.5, 2.5, 3.5, and 5.2 GHz with 3-dB fractional bandwidths of 13.7, 9.3, 16.8, and 4.6%. The measured minimum insertion losses are 0.58, 1.35, 1.25, and 1.35 dB, respectively, while the return loss of each passband is better than –10 dB.

COMPARING QUAD-BAND BPFs

Parameter	Ref. 12	Ref. 14	Ref. 15	Current work
Substrate height (mm)	1.0	0.508	1.57	1.0
Dielectric constant	27.9	3.55	3.0	2.2
Frequency (GHz)				
First passband	1.57	1.5	0.90	1.5
Second passband	2.45	2.5	1.26	2.5
Third passband	3.50	3.6	1.89	3.5
Fourth passband	5.20	4.6	2.29	5.2
Insertion loss (dB)				
First passband	0.3	1.98	2.2	0.58
Second passband	0.3	1.74	2.1	1.35
Third passband	0.3	3.58	1.4	1.25
Fourth passband	0.8	3.40	0.9	1.35
3-dB fractional bandwidth				
First passband (%)	9.6	5.5	6.7	13.7
Second passband (%)	31.8	12	5.4	9.3
Third passband (%)	11.1	11	12	16.8
Fourth passband (%)	16	4.3	15.3	4.6
Circuit size (mm^2/λ_g^2)	260/0.1	1600/0.09	2500/0.067	950/0.067

The depth of all the transmission zeros among each passband are below –25 dB, which can improve passband selectivity and result in high isolation. The deviations of the measurements from the simulations are expected mainly due to the reflections from the connectors and the finite substrate.

Figure 7 contains a photograph of the fabricated quad-band BPF. The overall size is about $0.45\lambda_g \times 0.15\lambda_g$, where λ_g is the guided wavelength at 1.5 GHz. The *table* offers a comparison of the current quad-band BPF with other reported quad-band BPFs.

In summary, a high performance quad-band BPF based on single SL-SIR has been proposed and designed. This filter is planar in structure, facilitating the design and reducing the fabrication cost. In addition, there is at least one transmission zero on each side of the passband, which improves the skirt selectivity. Due to its simple structure, compact size, and good performance, the filter is attractive for use in future multiband wireless communication systems. mw

ACKNOWLEDGMENT

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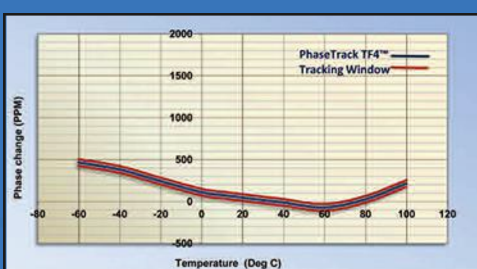

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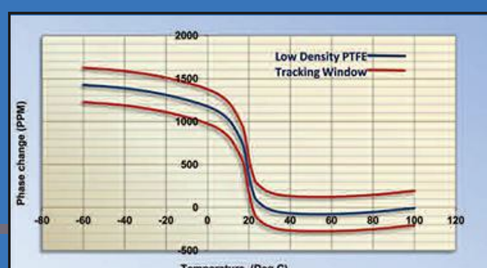

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CHRIS DeMARTINO | Technology Editor

The Differences Between Receiver Types, Part 1

This article, the first in a two-part series, examines various receiver implementations along with the characteristics that describe receiver performance.

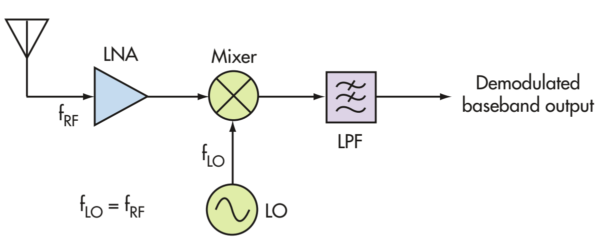
Receivers undoubtedly play a critical role in any communications system. They perform the tasks of receiving an incoming transmitted signal and then recovering the information contained in those signals. Given the massive amount of information that is wirelessly communicated today, it is worthwhile to have a clear understanding of this subject.

This article, Part 1 of the series, provides a general overview of receivers. The direct-conversion receiver and the widely used superheterodyne receiver are both discussed here. Part 2, which will appear in the April issue of *Microwaves & RF*, will discuss the advantages and disadvantages of both implementations. The newer direct RF-sampling technique will also be discussed in the second installment.

THE ROLE OF A RECEIVER

The input signal to a receiver is obtained from a receiving antenna. These received signals, which are typically very weak, can be described as modulated RF carrier signals. The modulation carries the actual information, which can be audio, video, or data. A receiver must perform a number of actions on a received signal so that the modulation information can ultimately be deciphered and processed.

Receivers are required to perform effectively despite the presence of noise and other interfering signals. Therefore, selectivity and sensitivity are important characteristics of one. Selectivity describes the capability of a receiver to identify and select a desired signal despite the presence of other unwanted signals. A receiver with good selectivity will process desired signals while sufficiently rejecting unwanted spurious and interference signals.



1. Direct-conversion receivers translate an RF input signal to a baseband output in one stage.

Sensitivity describes how well a receiver can process very weak input signals. It can be quantified as the weakest signal level that a receiver can detect to meet a given requirement, such as a specified signal-to-noise and distortion (SINAD) ratio or bit error rate (BER).

SENSITIVITY AND NOISE

Thermal noise represents the fundamental limit on achievable signal sensitivity. It is a result of the vibrations of conduction electrons and holes due to their finite temperature. The power delivered by a thermal source into a load is defined as:

$$P = kTB$$

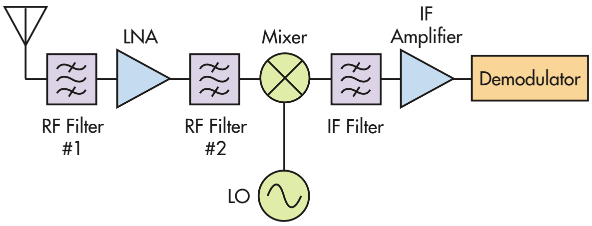
where:
k = Boltzmann's constant (1.38×10^{-23} Joules/K);
T = temperature in degrees Kelvin (K);
B = noise bandwidth.

The standard source noise temperature, or T_o, is 290°K. Thus, the thermal noise generated in a 1-Hz bandwidth is:

$$kTB = (1.38 \times 10^{-23} \text{ Joules/K})(290° \text{ K})(1 \text{ Hz})$$
$$= 4 \times 10^{-21} \text{ W/Hz} = -174 \text{ dBm/Hz}$$

The noise floor sets the limit on the minimum detectable signal level. A noiseless receiver would therefore have a noise floor of −174 dBm/Hz. However, every receiver adds some amount of noise, further limiting its sensitivity. A receiver can be characterized by its noise factor (F), which is a measure of the degradation in the signal-to-noise ratio (SNR) as a signal passes through a network. It can be defined by the following equation:

$$F = \frac{(S_i/N_i)}{(S_o/N_o)}$$



2. The traditional superheterodyne receiver has been used for many years.

where:
S_i = the input signal power;
N_i = the input noise power;
S_o = the output signal power;
N_o = the output noise power.

Noise factor is therefore dependent on the source noise temperature as follows:

$$F = \frac{(S_i/N_i)}{(S_o/N_o)} = \frac{N_o}{GN_i} = \frac{N_o}{GkT_oB} = \frac{(GkT_oB + N_R)}{GkT_oB}$$

where:
T_o = standard noise source temperature (290°K);
N_R = noise added by the receiver;
G = gain of the receiver.

The noise figure (NF) is simply the noise factor expressed in decibels:

$$NF = 10 \text{ x } \log (F)$$

The noise figure of a receiver can be determined by the gain and noise figure of its individual components. It can be calculated by the well-known equation for cascaded noise figure:

$$NF_{Total} = 10\log\left[\left(F_1 + \frac{F_2 - 1}{G_1}\right) + \left(\frac{F_3 - 1}{G_1G_2}\right) ... + \left(\frac{F_n - 1}{G_1G_2 ... G_{n-1}}\right)\right]$$

where:
F_1 = noise factor of stage 1;
F_2 = noise factor of stage 2;
F_n = noise factor of the nth stage;
G_1 = gain of stage 1;
G_2 = gain of stage 2;
G_{n-1} = gain of stage n-1.

DIRECT-CONVERSION RECEIVER

A direct-conversion receiver, also known as a homodyne or zero-IF receiver, is one type of receiver architecture *(Fig. 1)*. Direct-conversion receivers convert an RF signal to a 0-Hz signal in one stage. They are generally considered low-cost solutions, mostly because they require few components. In addition, direct-conversion receivers lend themselves well to integrated-circuit (IC) designs.

Direct-conversion receivers typically filter and amplify a received RF input signal. The signal then enters a mixer along with a local-oscillator (LO) signal that is identical in frequency to the RF input signal. Thus, the input signal is converted to a 0-Hz signal that appears at the output of the mixer. Demodulation occurs during the frequency conversion process, as well. Although the sum of the RF and LO signal frequencies also appears at the mixer's output, this product is removed by means of low-pass filtering that follows the mixer. The demodulated baseband output is, of course, then processed.

Often, direct-conversion receivers are implemented with two mixers to create an in-phase/quadrature (I/Q) demodulator. The same LO drives both mixers. However, the LO signals to each mixer differ in phase by 90 deg. The I/Q signals can then be processed following the demodulation stage.

THE SUPERHETERODYNE RECEIVER

The superheterodyne receiver is a common receiver configuration that has been used for many years *(Fig. 2)*. Superheterodyne receivers basically translate an RF input signal to a lower-frequency intermediate-frequency (IF) signal. The IF signal is then demodulated to allow the modulation data to be processed.

The entire process can be explained by analyzing the basic receiver shown in Fig. 2 (this receiver is only an example; many variations can be implemented). A received signal first enters a bandpass filter. This filter, often called a pre-select filter, rejects out-of-band signals. Next, a low-noise amplifier (LNA) performs the task of boosting the signal amplitude. This LNA is an extremely important component, as the overall noise figure of a superheterodyne receiver is highly dependent on the noise figure of the LNA. Another bandpass filter, known as an image-reject filter, follows the LNA. The purpose of this filter is to reject the unwanted image frequency band.

A mixer then converts the RF signal to a lower-frequency IF signal. Both the RF signal and an LO signal enter the mixer, thereby generating the IF signal that appears at the mixer's output. The frequency of this IF signal is equal to the difference of the RF input signal's frequency and the LO signal's frequency.

Following frequency downconversion, bandpass filtering is implemented in the IF stage to remove any unwanted signals. Next, an IF amplifier provides a significant amount of gain to the IF signal. Multiple amplifiers may be employed as well. The amplified IF signal is then demodulated, allowing the information to be processed.

Superheterodyne receivers are often implemented with two frequency-conversion stages. This configuration is particularly beneficial for higher-frequency applications. Part 2 of this series will further examine dual-conversion superheterodyne receivers. It will also explain the pros and cons of direct-conversion and superheterodyne receivers. mw

MULTIPLEXERS FIT THE BILL
FOR CARRIER-AGGREGATION FILTER CHALLENGES

DEPLOYMENT OF CARRIER aggregation (CA)—combining two or more blocks of spectrum or "component carriers" (CCs)—by mobile network operators worldwide has fueled ever-faster data rates. When CA is implemented, mobile devices are able to communicate on multiple LTE bands simultaneously.

However, to maintain good reception and battery life, interference between the bands must be avoided while minimizing insertion loss. In the white paper, "Addressing Carrier Aggregation Challenges Using Multiplexer Solutions," Qorvo discusses how multiplexers can solve such challenges associated with CA.

Most early CA deployments combined only two CCs. However, network operators will add combinations of three or more bands as a means to further accelerate data rates. But with that benefit comes the challenge of complex RF filtering.

When utilizing CA, each device transmits and/or receives on more than one CC simultaneously. This approach creates the need for cross-isolation, which will prevent interference between CCs. Achieving cross-isolation requires filters to sufficiently attenuate out-of-band signals. Each CC can then avoid loading the other aggregated bands. Every filter must also minimize the insertion loss of the transmitted signal to maintain good reception and minimize power consumption.

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

While cross-isolation is not as difficult to achieve when aggregating widely separated bands, it becomes much more difficult to attain when combining bands that are close together. In these instances, multiplexers become a practical solution to meet system requirements.

Because multiplexers integrate transmit and receive filters for the aggregated CCs into a single component, they provide the required isolation while allowing multiple CCs to connect to the same antenna at the same time. The white paper describes the complex performance requirements for multiplexers by comparing the isolation requirements when communicating without CA versus the requirements when implementing CA. The document also goes into some detail on Qorvo's QM25005 multiplexer.

PEAK POWER METERS
PROVE THEIR METTLE IN PULSED RADAR APPLICATIONS

UNIQUE CHALLENGES ARISE when measuring and characterizing the pulsed RF signals used in radar applications. With pulsed radar signals turned on, the amount of power transmitted by a system can range from kilowatts to megawatts. Such high-power pulsing, however, may stress power amplifiers (PAs). Thus, it's best practice to thoroughly test and evaluate a PA's behavior. In the application note, "GaN or GaAs, TWT or Klystron—Testing High Power Amplifiers for RADAR Signals using Peak Power Meters," Boonton Electronics explains why peak power meters are a necessity when characterizing the behavior of pulsed PAs used in radar systems.

The application note begins with an overview of PAs for radar applications. It then explains that the most critical analysis of the pulsed RF signal occurs in the time domain. Because peak power meters measure, analyze, and display the power envelope of an RF signal in the time domain, they are considered an essential tool for measuring the PAs used in pulsed radar applications. To provide further insight, the app note presents a simplified block diagram of a peak power meter. Each of its stages is then explained in detail.

In addition, the note describes two different setups, each with the ability to make pulsed radar measurements. The first setup is used to test a modulating amplifier. While the amplifier's input is a continuous-wave (CW) signal, the output is pulsed because of a gating signal that modulates the incoming signal. The second setup can be used to test an amplifier that has a pulsed input with no gating signal. It uses three peak power meters and a directional coupler to make scalar-like gain and return loss measurements.

Boonton Electronics, 25 Eastmans Rd., Parsippany, NJ 07054; (973) 386-9696; www.boonton.com

The document describes the calculations required to compute gain and return loss when employing the second setup. Subsequently, three waveforms were measured: the input, reflected, and output waveforms. The application note concludes with a description of some of Boonton's peak power measurement solutions.

JACK BROWNE | Technical Contributor

NEW-LOOK ANALYZERS Scour Bandwidths from 3 Hz to 50 GHz

These next-generation signal analyzers provide different frequency ranges and performance levels, but share an easy-to-use operating interface aided by large, multi-touch display screens.

BANDWIDTH IS A precious commodity, with an increasing amount of applications, from commercial automotive safety systems to military radar systems, occupying RF and microwave bands. Keeping those signals straight can be a chore, but the job just got easier with the latest generation of X-Series signal analyzers from Keysight Technologies.

1. The UXA signal analyzer, available with 1-GHz analysis bandwidth at frequencies to 50 GHz, represents the top of the line of new X-Series signal analyzers.

2. The PXA X-Series signal analyzer offers analysis bandwidths to 510 MHz at frequencies to 50 GHz.

Their improved performance levels compared to the previous-generation analyzers is complemented by a new look—easy-to-use touchscreens help speed the capture and analysis of the most troublesome signals. Five different analyzer configurations provide frequency coverage from 3 Hz to 50 GHz, with frequency extensions available.

Signal analysis is becoming more critical, as new wireless applications continue to compete for bandwidth availability and, perhaps more importantly, pose potential problems for existing applications. Government organizations like the Federal Communications Commission (FCC) may strive to separate different wireless applications according to carefully chosen frequency allocations. However, these organizations cannot control such variables as second and third harmonics and spurious signal content, which can turn any lower-frequency wireless application into interference for higher-frequency applications.

To properly monitor and measure any segment of spectrum, signal analyzers with the desired frequency range and low instrument noise levels, high sensitivity, and wide analysis bandwidths make it possible to capture and display all signals present over a frequency range—even intermittent signals and those close to the noise level. The new X-Series signal analyzers offer that measurement capability with an intuitive user interface and easy-to-read display screens.

HIGH PERFORMANCE WITH A TOUCH

The latest X-Series analyzers include several instruments with similar measurement functions and user interfaces, differentiated by frequency ranges and various performance levels, such as analysis bandwidths and real-time bandwidths. The instruments represent a leap forward in performance and operating ease, with 14.1- or 10.6-in. multi-touch capacitive display screens. Anyone with a touchscreen laptop computer will quickly grasp the ability to move measurement points on a screen with a finger, and compress and shift waveforms by simply gesturing with two fingers along the screen.

With enhancements in phase noise, bandwidth, and real-time streaming capacity that supersede the previous X-Series analyzers, these new instruments offer a common user interface and provide users with as much or as little performance (and corresponding price) as needed for an application. The beauty of the common user interface is that, even when a facility may invest in several different X-Series models (e.g., one for video testing and one for pulse testing), a user learning to operate one model will already know how to operate the other model.

Any choice of instrument model need not mean a commitment to final performance levels, since frequency ranges and performance can be upgraded at any time. The firm even provides liberal trade-in offers for owners of previous-generation X-Series signal analyzers, enabling them to upgrade to the latest generation. In addition, the instruments are backed by a strong library of test software programs that can tailor each instrument for specific measurement applications, from commercial communications to military pulsed radar testing.

COMPARISON OF NEW X-SERIES SIGNAL ANALYZERS

Model	Top frequencies (GHz)	Bandwidth options (MHz)	Real-time bandwidth options (MHz)	Phase noise (dBc/Hz, offset 10 kHz from a 1-GHz carrier)
UXA	8.4, 13.6, 26.5, 44, 50	25, 40, 255, 510, 1000	255, 510	–136
PXA	3.6, 8.4, 13.6, 26.5, 44, 50	25, 40, 85, 160, 255, 510	85, 160, 255, 510	–132
MXA	3.6, 8.4, 13.6, 26.5	25, 40, 85, 125, 160	85, 125, 160	–114
EXA	3.6, 7.0, 13.6, 26.5, 32, 44	25, 40	NA	–109
CXA	3.0, 7.5, 13.6, 26.5	10, 25	NA	–110

NA = not available.

PROMISING PERFORMANCE

Of course, such ease of use is meaningless without performance, and the new X-Series signal analyzers provide a wide selection of frequency ranges and performance levels. The X-Series actually comprises five models, with each model—the UXA, PXA, MXA, EXA, and CXA—featuring a number of different frequency-range options *(see table)*:

UXA: The top-of-the-line UXA X-Series signal analyzer *(Fig. 1)*, covers bandwidths of 3 Hz to 8.4, 13.6, 26.5, 44.0, or 50.0 GHz (and as high as 1.1 THz with external mixing) with a standard analysis bandwidth of 25 MHz. The analysis bandwidth can be extended to 40, 255, 510, and 1,000 MHz as an option. It also provides true fast Fourier transform (FFT) real-time analysis bandwidths as wide a 510 MHz for capture and analysis of the most elusive signals.

Real-time spectrum-analysis capability makes it possible to capture and view signals as short as 3.517 µs with 100% probability of intercept (POI) and spurious-free dynamic range (SFDR) of 78 dBc across a 510-MHz bandwidth. Real-time streaming can be performed across bandwidths as wide as 255 MHz with 16-b resolution at 300 Msamples/s for gap-free recording, ensuring capture of the most elusive, nonrecurring signals.

The UXA analyzers maintain a displayed average noise level (DANL) of –171 dBm at 2 GHz with preamplifier and Noise Floor Extension function turned on. The phase noise is –136 dBc/Hz offset 10 kHz from a 1-GHz carrier and –126 dBc/Hz offset 10 kHz from a 10-GHz carrier. The analyzers achieve amplitude accuracy of ±0.16 dB and third-order intermodulation (TOI) distortion of +23 dBm.

PXA: Down just a notch in performance (and price), the PXA analyzers offer similar frequency coverage as the UXA instruments, with slightly less amplitude accuracy and without the choice of a wide 1-GHz analysis bandwidth. The PXA *(Fig. 2)* covers frequency ranges of 3 Hz to 3.6, 8.4, 13.6, 26.5, 44.0, or 50.0 GHz (and as high as 1.1 THz with external mixing) with a standard analysis bandwidth of 25 MHz. Options exist for analysis bandwidths of 40, 85, 160, 255, and 510 MHz. As with the UXA instruments, DANL is –171 dBm at 2 GHz with preamplifier and Noise Floor Extension function turned on. With real-time bandwidths to 510 MHz, the PXA analyzers can show signals as short as 3.517 µs with 100% POI.

The full amplitude accuracy for the PXA analyzers is slightly less than that of the UXA at ±0.19 dB. They have phase noise of –132 dBc/Hz offset 10 kHz from a 1-GHz carrier and the UXA, PXA, MXA, EXA, and CXA 124 dBc/Hz offset 10 kHz. The TOI distortion is +23 dBm and the SFDR is –75 dBc for a 160-MHz bandwidth. As with the UXA instruments, the PXA analyzers offer gap-free streaming to 255 MHz for real-time analysis.

MXA: In the middle of the "X-Series pack" is the MXA signal analyzer *(Fig. 3)*. It includes a choice of frequency ranges from 10 Hz to 3.6, 8.4, 13.6, or 26.5 GHz (and as high as 1.1 THz with external mixing) with standard analysis bandwidth of 25 MHz and options for analysis bandwidths of 40, 85, 125, and 160 MHz. As with the two higher-performance analyzers, the MXA supports real-time bandwidths to 160 MHz and can capture signals as short as 3.517 µs with 100% POI and SFDR of 72 dBc across a 160-MHz bandwidth.

The MXA achieves a DANL of –171 dBm at 2 GHz with preamplifier and Noise Floor Extension function turned on, and amplitude accuracy of ±0.23 dB. TOI distortion is +19 dBm, while the phase noise is –114 dBc/Hz offset 10 kHz from a 1-GHz carrier and –108 dBc/Hz off-

3. The MXA X-Series signal analyzer features analysis bandwidths to 160 MHz at frequencies to 26.5 GHz

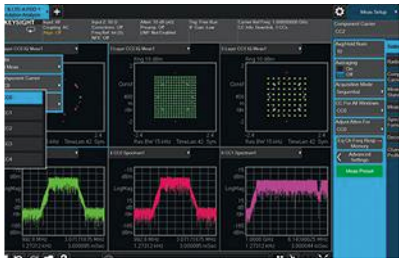
4. The economy CXA signal analyzer includes models operating with an analysis bandwidth of 25 MHz at frequencies to 26.5 GHz.

set 10 kHz from a 10-GHz carrier. These analyzers are well-suited for wireless standards testing, and feature a wideband code-division-multiple-access (WCDMA) adjacent-channel-power (ACP) dynamic range of typically 73 dBc and up to 78 dBc with noise correction.

EXA: For those in search of cost-effective signal analysis through millimeter-wave frequencies, the EXA X-Series signal analyzer, despite lacking the real-time analysis capabilities of the top three models, packs a great deal of measurement power that covers frequencies from 10 Hz to 3.6, 7.0, 13.6, 26.5, 32.0, or 44.0 GHz (and as high as 1.1 THz with external mixing). It features a standard analysis bandwidth of 25 MHz and offers an option for an analysis bandwidth of 40 MHz.

For the value-minded, the EXA still delivers on performance, with amplitude accuracy of ±0.27 dB and phase noise of –109 dBc/Hz offset 10 kHz from a 1-GHz carrier and –102 dBc/Hz offset 10 kHz from a 10-GHz carrier. DANL is –171 dBm at 2 GHz with a preamplifier and noise floor extension function turned on, while TOI distortion is +19 dBm at 2 GHz. Also handy for wireless standards testing, it offers a 68-dBc WCDMA ACP dynamic range (and 73 dBc with noise correction).

CXA: The lowest-cost members the new X-Series, the CXA analyzers *(Fig. 4)*, provide a standard analysis bandwidth of 10 MHz with an option for 25 MHz, along with options covering frequency ranges of 9 kHz to 3.0, 7.5, 13.6, and 26.5 GHz. These analyzers also lack the real-time bandwidth capabilities of the top three models, but still boast impressive performance value, with amplitude accuracy of ±0.50 dB and phase noise of –110 dBc/Hz offset 10 kHz from a 1-GHz carrier. DANL is –163 dBm at 2 GHz with a preamplifier and Noise Floor Extension function turned on, while the TOI distortion is +17 dBm. The standard WCDMA ACP dynamic range is 66 dBc and as good as 73 dBc with noise correction.



5. This screen is an example of the LTE FDD and TDD measurements that can be performed automatically with software developed for the X-Series signal analyzers.

6. This screen shows pulse measurements performed with dedicated software for the X-Series signal analyzers.

DON'T FORGET THE SOFTWARE

To help harness all that power, an extensive library of software measurement programs provide all of the essential measurements for a wide range of in-demand applications, including cellular communications, phase-noise measurements, and pulsed radar system testing. The software covers the latest conformance and standards-based measurements, including WCDMA signals, as well as Long Term Evolution (LTE) and LTE Advanced (LTE-A) frequency-division-duplex (FDD) and time-division-duplex (TDD) signals. There's also support for 256-state quadrature-amplitude-modulation (256QAM) testing. LTE/LTE-A software, for example, dubbed N9080C (for FDD measurements) and N9082C (for TDD measurements), covers all new X-Series signal analyzers *(Fig. 5)*.

Additional software tools, including X-Series measurement applications and 89600 vector-signal-analysis (VSA) software, offer analyzer control for specific wireless standards, such as GSM, cdma2000, Bluetooth, and WiMAX, as well as for general-purpose pulsed, noise-figure, and phase-noise measurements. All feature transportable licensing between different X-Series signal analyzers.

The phase-noise measurement application (model N9068C) supports external mixing for measurements to 110 GHz with Keysight smart harmonic mixers. It also takes advantage of the analyzers' flexible display screens to show phase noise in traditional logarithmic plots, as well as phase-noise values for spot frequencies. Furthermore, it provides useful phase-based parameters, such as root-mean-square (RMS) phase deviations, RMS phase jitter, and residual frequency modulation (FM).

The pulse measurement application (model N9067C), as with the other X-Series measurement applications, supports transportable licensing between different X-Series signal analyzers. The pulse software *(Fig. 6)* can provide parameters on as many as 1,000 continuous pulses, displaying such results as pulse width, average power, peak power, rise/fall time, pulse repetition interval (PRI), and pulse repetition frequency (PRF).

In short, the analyzers provide enormous raw measurement power with operator interfaces that help tap into the measurement power with a short learning curve. With the multi-touch screens, many users will be drawn to developing their own test programs that take advantage of the analyzers' high-performance levels.

But for those who want a ready-made solution, a long list of test software tools has already been developed, for everything from general-purpose measurements to specific tests for cellular communications and wireless-connectivity standards. The measurement power, ease of use, and existing knowledge base make an unbeatable combination for anyone seeking signal-analysis solutions through millimeter-wave frequencies. P&A: $13,284 (3-GHz CXA) to $115,743 (50-GHz UXA). mw

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

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CHRIS DeMARTINO | Technology Editor

Antenna Performance Soars into the Stratosphere

Companies continue to push the technological boundaries of antennas, delivering solutions that conquer today's wireless challenges.

THOUGH THEY MAY be overlooked at times, antennas play a vital role in the performance of any wireless system. Whether it is a critical military application or a home Wi-Fi network, antenna solutions are heavily relied on when it comes to transmitting and receiving information wirelessly. Innovative solutions include antenna arrays, such as active electronically scanned arrays (AESAs), which are finding homes in a range of applications.

Given their already critical nature and the seemingly endless arrival of new applications, antennas are evolving to keep pace performance-wise. In fact, it's fair to say that many recent advances and developments throughout the RF/microwave industry could not move forward without the right antenna.

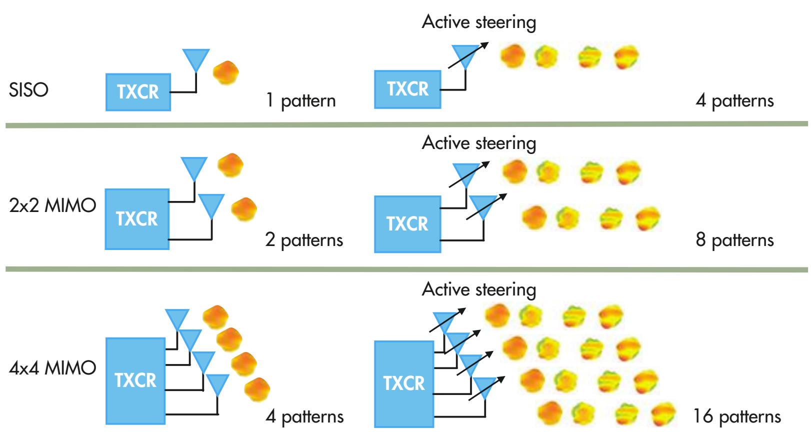
WIRELESS DATA CONGESTION

Wireless carriers are running out of network capacity due to rapidly mounting data traffic. One company, Ethertronics (www.ethertronics.com), believes it can help overcome those challenges with its Active Steering technology. According to the company, Active Steering can achieve performance levels that are unattainable with traditional passive antennas. Ethertronics boasts that its technology offers high data rates and can minimize unwanted interference. In addition, increased spectral efficiency provides carriers with more network capacity.

With Active Steering, multiple radiation patterns can be generated from a single antenna structure *(Fig. 1)*. Therefore, one antenna can basically operate as four different antennas. For instance, when Active Steering is implemented in a standard access point with four antennas, 16 unique radiation patterns and 256 pattern combinations can be generated for the antenna system. An algorithm samples and switches between the different radiation patterns to select the best one to use for the specific environment. As a result, Active Steering can dynamically respond to changing RF conditions fast enough to minimize multipath fading.

Ethertronics recently announced a complete Wi-Fi Active Steering antenna system, which the company says can improve coverage and signal quality by 50%. Up to a 3-dB boost in network performance is possible for a wide range of Wi-Fi devices, too. Such devices include access points, set-top boxes, and smart gateways. The company says that enhanced antenna performance in today's home Wi-Fi networks will help overcome a major bottleneck.

"Array techniques have been applied in the form of smart antennas for IEEE 802.11a/b/g systems since 2004," notes Jeff Shamblin, chief scientist at Ethertronics. "More recently, digital beamforming techniques have been applied to IEEE 802.11n and IEEE 802.11ac systems. The recent introduction of IEEE 802.11ac allows for 8 × 8 multiple-input, multiple-output (MIMO), where as many as eight antennas can be used for MIMO or beamforming applications. Multi-user MIMO (MU-MIMO) is also implemented in IEEE 802.11ac, where



1. When implementing this solution, a single antenna can generate multiple radiation patterns.

one or multiple antennas are used to communicate with one client, while one or multiple antennas in the system are used to communicate with a second client simultaneously."

Shamblin adds, "For example, pairs of antennas can be used to communicate with four clients simultaneously in an 8 × 8 system. These pairs of antennas can be antennas operating in a MIMO mode where each antenna operates individually. These antennas can also be grouped into a two-element array or used in a two-element digital beamforming application.

"It is important to note that antennas in a Wi-Fi system are switched from MIMO to digital beamforming mode and back," continues Shamblin. "For the most optimal MIMO performance, the antennas in a system are typically positioned such that they have different radiation patterns and/or different polarizations—all in an attempt to reduce the envelope correlation coefficient (ECC) between antennas. For better array performance, the opposite scenario is preferred. The radiation patterns and polarizations of the antennas used to populate the array are the same, which results in optimum array performance in terms of peak gain and beamwidth characteristics and control. Our Active Steering technology allows for each antenna in a system to be optimized. The system switches antennas from MIMO to digital beamforming modes by selecting the best radiation pattern per packet/client during operation."

2. The X-band family of integrated circuits is intended for commercial AESAs. *(Courtesy of Anokiwave)*

AESA FOR RADAR

Active electronically scanned array technology powers many of today's radar systems. The technology is a key component of many advanced weapons systems—airborne warfare in particular. AESA typically utilizes a large number of transmit/receive circuits arranged in a pre-determined configuration and connected to an array of radiator elements. These elements collectively transmit and receive a beam of RF pulses to and from a target.

Raytheon's (www.raytheon.com) AN/APG-63(V)3 radar system, which is used to power F-15 aircraft, takes advantage of AESA technology. Benefits of this radar system include multi-role capability, long-term support, and easy future growth options.

The system, used by the U.S. Air Force, Air National Guard, and multiple coalition partners around the world, has certainly spread its wings—Raytheon recently delivered its 200th AN/APG-63(V)3 radar system. The system's reputation is that it's significantly more reliable than older mechanically scanned array radars, which translates into sustained savings and increased availability. Overall, Raytheon has delivered more than 800 AESA radars since introducing the technology in 2000.

In addition to military systems, AESA technology is finding its way into commercial applications. One company thriving in this space is Anokiwave (www.anokiwave.com) with its integrated-circuit (IC) solutions for commercial AESA applications *(Fig. 2)*. The firm recently extended its X-band AESA family, which is intended for commercial radar and 5G communications markets, by releasing two new ICs for single-beam receive (Rx) and transmit (Tx). Anokiwave says that commercial AESAs represent the future in this arena.

Each IC within the family includes an integrated four-channel beamformer, low-noise amplifier (LNA), and power amplifier (PA). Four radiating elements are supported. Customers can opt for devices with either low noise figure or high input linearity. The ICs are further classified as either dual-beam Rx/single-beam Tx or single-beam Rx/single-beam Tx.

Specifically, the AWS-0101 is a low noise figure, dual-beam Rx/single-beam Tx device, while the AWS-0103 is a high input linearity, dual-beam Rx/single-beam Tx device. The AWS-0104 and AWS-0105 are both single-beam Rx/single-beam Tx ICs. The AWS-0104 maintains a low noise figure, while the AWS-0105 provides high input linearity.

All devices include six-bit phase and six-bit gain control. Additional features include gain compensation over temperature, temperature reporting, and forward power telemetry with programmable delay power sampling. In addition, fast beam switching uses on-chip beam weight storage registers that can be accessed via direct address lines.

API Technologies (www.apitech.com) also offers active antenna-array solutions for AESA radar. By taking a line-replaceable-unit (LRU) approach, the company developed a solution that is intended to streamline system integration, simplify repair, and reduce the cost of ownership of AESA radar platforms. Known as the Active Antenna Array Unit (AAAU), this solution consists of common transmit/receive module building blocks called Quad Transmit Receive Modules (QTRMs). The AAAU targets applications such as datalinks, satellite-communications (satcom), and radar.

To summarize, many applications stand to benefit from recent antenna developments. As wireless communications assume a greater role in each of our lives, proficient antenna performance becomes paramount. New technology, such as Active Steering, aims to overcome the challenges of heavy wireless data traffic. And AESA technology will look to drive commercial and military applications. Stay tuned for more antenna advances in the coming weeks and months. mw

JACK BROWNE | Technical Contributor

Short-Haul Solution Covers Two Bands

This dual-band smart radio system brings new levels of flexibility to industrial networks, serving as a reliable interface for both wired and wireless voice, data, video, and sensor connections.

INDUSTRIAL NETWORKS must handle more data than ever before: In addition to channeling voice and data signals, they must contend with growing numbers of sensors and video links from security and surveillance cameras. Reaching the Internet to enable remote access with all of that information can overwhelm a single radio band.

For that reason, the WavePro WP201 platform from FreeWave Technologies incorporates two radio bands, at 2.4 and 5 GHz. By combining the two bands in a single rugged chassis—with multiple channels per frequency band—the WP201 provides secure collection, control, and transfer of voice, video, data, and sensor (VVDS) information using the firm's Sensor-2-Server (S2S) wireless access-layer strategy.

The WP201 *(see figure)* supports short-haul links for a wide range of networks, including for power, water, and sewage utilities; factory automation and industrial control; oil and gas plants; and municipalities. It provides an efficient and effective interface between growing numbers of machine-to-machine (M2M) and industrial Internet of things (IIoT) sensors and the Internet.

The WavePro WP201 standards-based dual-band radio system features IEEE 802.11b/g/n capability at 2.4 GHz with 20- and 40-MHz channels having data rates to 450 Mb/s. Also featured is IEEE 802.11a/n/ac capability on 5 GHz with 20-, 40-, and 80-MHz channels and data rates to 1300 Mb/s. It can actually serve as the basis of a local network "cloud," collecting data signals from wired and wireless connections for short-haul communications and local and remote access. The WavePro WP201 features eight Service Set Identifiers (SSIDs) per radio for ease of network access.

The system is "smart" enough to perform automatic channel switching when data transfer can be optimized by switching frequency bands, such as offloading an overload of data traffic from 2.4 GHz to the typically less-occupied 5-GHz band. Both radio bands support 3 × 3 multiple-input, multiple-output (MIMO) antenna configurations. The 2.4-GHz radio features an omnidirectional antenna with 5-dBi gain, while the 5-GHz radio includes an omnidirectional antenna with 7-dBi gain.

The WavePro WP201 radio system features concurrent wireless operation at 2.4 and 5.0 GHz with data rates as high as 1.3 Gb/s.

The WP201 system can also be used with directional antennas for increased coverage distance.

The WavePro WP201 is built to withstand the rigors of an industrial environment, being housed in a rugged aluminum IP67 enclosure and designed to handle operating temperatures from −40 to +60°C. It is suitable for industrial on-site Voice-over-Internet Protocol (VoIP) use as well as for on-site Wi-Fi use. This is a versatile communications system, with numerous wireline interfaces, including two 802.3ab (Gigabit Ethernet) local-area-network (LAN) ports with Power over Ethernet (PoE) capability to power connected devices. The short-haul radio system can handle IIoT, SCADA, and M2M data and provides seamless wireless connectivity with other S2S radio systems.

The WP201 provides secure dual-band wireless communications in a compact enclosure measuring 200 × 239 × 53 mm (without antennas connected) and weighing 3.2 kg (7 lb). It provides 4-kV Ethernet suppression and 4-kV RF suppression, and consumes less than 20 W of power. The RoHS-compliant system has an operating temperature range of −40 to +60°C and is equipped with male Type-N coaxial connectors for RF connections. mw

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

JACK BROWNE | Technical Contributor

Flexible Antennas Look to the Sky

This pair of lightweight, flexible antennas provides radio links to navigation satellites, as well as in wireless-connectivity bands such as Bluetooth and Wi-Fi, for IoT and M2M applications.

1. The model SRFG017 Bentoni antenna, measuring 40.0 × 14.0 × 0.15 mm, operates from 1,559 to 1,609 MHz for GNSS applications.

NAVIGATION BY SATELLITE is becoming commonplace—so much so that an increasing number of electronic devices are being equipped with receivers for Global Positioning System (GPS) and other satellite navigation constellations. Creating that kind of satellite access requires a compact antenna. And when there's also a demand for a flexible antenna (such as for wearable devices), a pair of miniature, flexible-printed-circuit (FPC), linearly polarized antennas from Antenova might do the trick.

The antennas, which weigh only 0.5 g each, meet the needs of GPS, GLONASS, and GALILEO systems. The Bentoni Global Navigation Satellite System (GNSS) antenna operates from 1,559 to 1,609 MHz, while the Asper2.4G/GNSS antenna can be used at both 1,559 to 1,609 MHz and 2,400 to 2,500 MHz. They're well-suited for satellite navigation and wireless-connectivity applications, including for machine-to-machine (M2M) and Internet of Things (IoT) connections. Compact to start with, the antennas can also be folded within a final product design to further save space.

SINGLE-BAND BENTONI

The single-frequency-band model SRFG017 Bentoni antenna *(Fig. 1)* measures just 40.0 × 14.0 × 0.15 mm and weighs less than 0.5 g. The basic model has three variations—1.13-mm-diameter RF cable lengths of 50, 100, or 150 mm—each terminated with an IPEX MHF connector for ease of installation with a host printed circuit board (PCB).

Targeted at everything from portable and wearable devices to unmanned aerial vehicles (UAVs), the miniature antenna provides better than 75% average efficiency from 1559 to 1609 MHz. It achieves 4-dBi peak gain and –1.2-dBi average gain across its frequency range, with maximum return loss of –14 dB and maximum VSWR of 1.45:1.

2. The model SRFWG018 Asper antenna operates at both 1,509 to 1,669 MHz and 2.4 to 2.5 GHz for GNSS as well as wireless-connectivity applications.

DUAL-BAND ASPER

The dual-frequency-band model SRFWG018 Asper antenna operates at both 1,509 to 1,669 MHz and 2.4 to 2.5 GHz *(Fig. 2)*. It measures a mere 81 × 14 × 0.15 mm and weighs less than 0.5 g, yet achieves average efficiency of better than 75% in the lower frequency band and better than 85% in the upper frequency band. It also comes in three different lengths of 1.13-mm-diameter RF cable (one for each frequency band)—100, 150, or 200 mm—each terminated with an IPEX MHF connector for ease of integration with host circuitry.

The Asper antenna delivers 4.25-dBi peak gain and –1.1-dBi average gain across the lower-frequency band and 5.60-dBi peak gain and –0.6-dBi average gain across the higher-frequency band. Maximum return loss is –18.4 dB across the lower-frequency band and –14.5 dB from 2.4 to 2.5 GHz. Maximum VSWR is 1.30:1 across the lower-frequency band and 1.40:1 across the higher-frequency band.

Both FPC antennas maintain high isolation within the device or package to which they are mounted. Each exhibits characteristic impedance of 50 Ω and can be used over operating temperatures from –40 to +85°C. mw

ANTENOVA LTD., 2nd Floor, Titan Ct., Bishop Square, Hatfield, AL10 9NA United Kingdom; +44 (0) 1233 810600, e-mail: sales@antenova-m2m.com, *www.antenova-m2m.com*

PLL Synthesizer Generates 6,265 MHz

FREQUENCY SYNTHESIZER model SF-S6265A-LF is a fixed-frequency source available for C-band applications. The RoHS-compliant phase-locked-loop (PLL) frequency synthesizer operates at 6,265 MHz with typical phase noise of –89 dBc/Hz offset 1 kHz from the carrier and –90 dBc/Hz offset 10 kHz from the carrier. The synthesizer works with a 100-MHz reference oscillator and provides +3-dBm typical output power. It draws 35-mA typical current from a +5-V dc voltage-controlled-oscillator (VCO) supply and typically 11-mA current from a +3-V dc PLL supply. The synthesizer measures 0.6 × 0.6 × 0.13 in. and is available in tape-and-reel packaging for automated assembly. It has an operating temperature range of –40 to +85°C.

Z-COMMUNICATIONS INC., 14118 Stowe Dr., Ste. B, Poway, CA 92064; (858) 621-2700, *www.zcomm.com*

SMA Limiter Spans 20 MHz to 4 GHz

FEATURING A WIDE LIMITING RANGE of +10 to +37 dBm, model ZFLM-43-5W is a coaxial limiter with a frequency range of 20 MHz to 4 GHz. It handles as much as 5 W of input power with low output power leakage of +12 dBm and low insertion loss of typically 0.36 dB. It has fast recovery time of typically 33 ns. The limiter, which is supplied with an SMA female input connector and SMA male output connector, measures 1.25 × 1.25 × 0.75 in. It is designed for operating temperatures from –40 to +85°C and suitable for military, industrial, and commercial applications, such as protecting amplifiers from overload by high input-level signals.

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

VCO Spans 7.2 to 8.4 GHz

THE MODEL DXO720840-5 voltage-controlled oscillator (VCO), which tunes from 7.2 to 8.4 GHz, is well suited for radar and satellite-communications (satcom) applications. The low-noise oscillator tunes via voltages from 0.5 to 18.0 V dc and draws 25-mA maximum bias current from a +5-V dc supply. The VCO delivers at least 0-dBm output power across the full frequency range. The low-noise source features typical phase noise of –103 dBc/Hz offset 100 kHz from the carrier. The X-band VCO is designed for operating temperatures from –40 to +85°C. It is supplied in a compact housing measuring 0.3 × 0.3 × 0.10 in. and comes in tape-and-reel-format for automated placement and high-volume manufacturing.

SYNERGY MICROWAVE CORP., 201 McLean Blvd., Paterson, NJ 07504; (973) 881-8361, e-mail: sales@synergymwave.com, *www.synergymwave.com*

X-Band GaN Amplifier Module Delivers 1 kW

DESIGNED FOR HIGH-POWER pulsed X-band applications, model BPMC928109-1000 is a coaxial power-amplifier (PA) module based on gallium-nitride (GaN) transistor technology. It delivers 1-kW pulsed output power from 9.2 to 10.0 GHz with 60-dB nominal gain within a ±2-dB gain window. The Class-AB linear amplifier module is designed for use with pulse widths from 0.25 to 100 µs and maximum 10% duty cycle. It exhibits less than 0.5-dB pulse droop with better than –40-dBc second harmonics and –50-dBc third harmonics. The PA module is equipped with load VSWR protection, SMA connectors on input and sample ports, and a TNC connector on the output port. It draws 25.5 A at +28 V dc and includes a RS-485 control interface and RS-422 enable/disable switch with better than 1-µs switching speed. The PA module measures 9.6 × 6.8 × 2.1 in. and weighs 5 lb.

COMTECH PST INC., 105 Baylis Rd., Melville, NY 11747; (631) 777-8900, FAX: (631) 777-8877, e-mail: sales@comtechpst.com, *www.comtechpst.com*

Phase Shifter Spans 4 to 6 GHz

MODEL MSH-4X2XX01-PH is an analog, voltage-controlled phase shifter designed for 4.5 to 5.0 GHz and usable from 4 to 6 GHz. It provides at least 270-deg. phase shift from 4.5 to 5.0 GHz, controlled by a single voltage from 0 to +10 V dc. The phase error is controlled to ±10 deg. The minimum insertion loss is 4 dB and maximum input/output VSWR is 2.0:1. The phase shifter, which is suitable for active electronically scanned array (AESA) and passive electronically scanned array (PESA) applications, measures 1.67 × 0.78 × 0.46 in. (42.42 × 19.81 × 11.73 mm). Custom versions are available upon request.

MICROWAVE SOLUTIONS INC., 3200 Highland Ave., Ste. 300, National City, CA 91950; (619) 474-6906, *www.microwavesolutions.com*

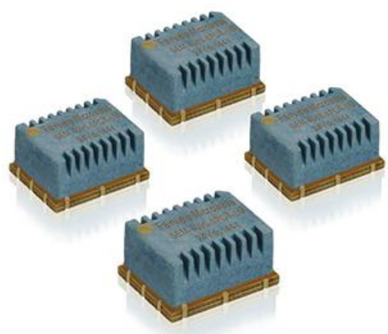
Power Splitter/Combiner Goes 400 to 3,000 MHz

MODEL SYPS-2-33+ is a two-way, 0-deg. power divider/combiner with low insertion loss from 400 to 3,000 MHz. It exhibits 0.6-dB typical insertion loss from 400 to 2,700 MHz and 1.0-dB typical insertion loss from 400 to 3,000 MHz. The isolation between ports is typically 21 dB across the full frequency range. The surface-mount-technology (SMT) power divider/combiner can handle input power levels to 0.5 W (+27 dBm) across operating temperatures from –40 to +85°C. Output signals are closely matched, with low amplitude unbalance of typically 0.1 dB and phase unbalance of typically 1 deg. The compact component measures 0.38 × 0.50 × 0.25 in. for use in densely packed circuit layouts.

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

EM SPDT Switches Control DC to 8 GHz

A LINE OF ELECTROMECHANICAL (EM) single-pole, double-throw (SPDT) switches save space in surface-mount form for frequencies from dc to 8 GHz. Insertion loss is as low as 0.1 dB, while isolation is as high as 50 dB. The high-reliability switches, which are rated for continuous-wave (CW) power levels to 400 W, operate on voltages of +24



V dc. They are designed for operating temperatures from -40 to +85°C. The switches, which come in RoHS-compliant packages, are suitable for applications in aerospace, defense, industrial, telecommunications, instrumentation, and medical applications.

FAIRVIEW MICROWAVE, 1130 Junction Dr., Allen, TX 75013; (800) 715-4396, (949) 261-1920, e-mail: sales@fairview-microwave.com, *www.fairviewmicrowave.com*

Directional Couplers Span 0.5 to 6.0 GHz

A LINE OF HIGH-POWER coaxial directional couplers operates with continuous frequency coverage from 500 MHz to 6 GHz. The couplers feature 20-dB

directivity with ±0.5-dB coupling flatness across the full frequency range. Insertion loss is typically 0.5 dB, while power-handling capability is 100 W. The couplers exhibit mainline VSWR of 1.20:1. The rugged couplers, which measure 5.8 × 2.0 × 0.8 in., can be supplied with Type-N or SMA coaxial connectors.

WERBEL MICROWAVE LLC, 51 Chestnut St., Livingston NJ 07039; (973) 900-2480, *www.werbelmicrowave.com*

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