What Are the Basic Concepts Behind the X-Band Push-Push Oscillator? **p28**

Get to Know the Different Bluetooth Variations to Make the Right Selection for Your App **p34**

This Long-Standing Company Brought Multiple New Solutions to the Table at IMS **p41**

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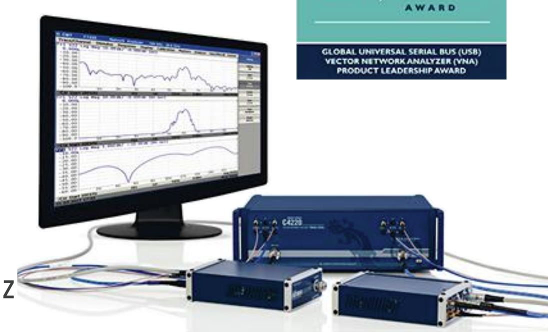

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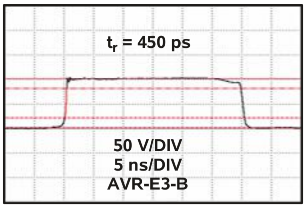

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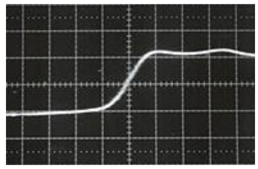

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20 V	200 ps	10 MHz	AVMR-2D-B
15 V	100 ps	25 MHz	AVM-2-C
15 V	150 ps	200 MHz	AVN-3-C
10 V	100 ps	1 MHz	AVP-AV-1-B
10 V	50 ps	1 MHz	AVP-3SA-C
5 V	40 ps	1 MHz	AVP-2SA-C

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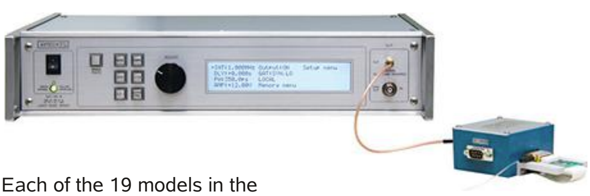

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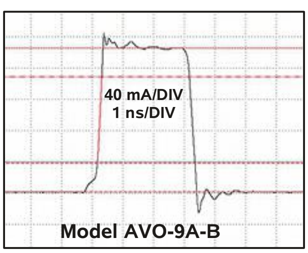

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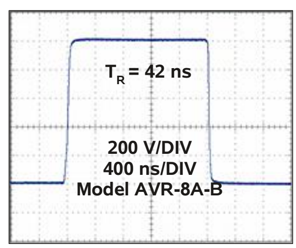

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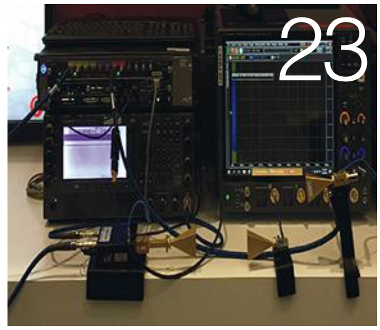

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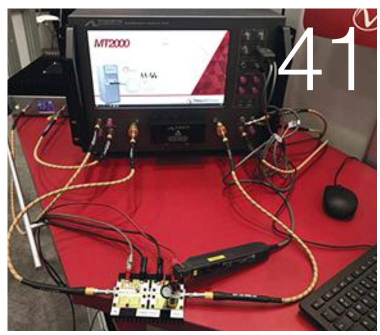

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Editorial
CHRIS DeMARTINO | Editor
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Queensborough Community College Gets an "A" in RF

With a focus on RF education, Queensborough Community College gives students a hands-on experience thanks to its array of industry-standard test equipment and more.

Are enough young people pursuing RF engineering as a career? It's a question that permeates the RF/microwave industry and continues to get louder. With wireless technology more entrenched in our lives than ever before, the industry will need a new wave of engineers focused on high-frequency technology. But as I mentioned in a previous column, is the RF/microwave industry doing enough to attract the next generation of engineers? And are colleges and universities adequately preparing engineering students to enter the RF field?

One college that's doing its part to help foster the next generation of RF engineers is Queensborough Community College *(www.qcc.cuny.edu)*, one of seven community colleges within the City University of New York (CUNY) system. Queensborough Community College is located in Bayside, N.Y., a neighborhood in the New York City borough of Queens.

Now, perhaps you were surprised to hear the name "Queensborough Community College" as a place that's focused on RF education. However, in terms of RF capabilities, I would be willing to say that Queensborough Community College, or QCC, has tools that aren't available in many universities.

Much of the credit for how QCC promotes RF engineering goes to Enrique Haro, who is a senior CUNY lab technician and adjunct lecturer at QCC. Haro attended QCC himself and then started to work at the school in 2014 as a lab technician while pursuing his bachelor's degree. After completing his degree, Haro began to teach at the school.

QCC already had a long history of providing students with hands-on lab experiments *(Fig. 1)*. However, in terms of RF test equipment, the school previously only had rather old, low-frequency equipment. One of Haro's goals was to create a lab with modern RF test instruments to give students a better hands-on experience. That meant bringing in newer and more advanced equipment.

What gave Haro the motivation to upgrade the RF lab at QCC? "I attended the same school and I took the same class," he says. "I wish that I could have

1. This picture taken in 1965 shows QCC's electrical laboratory in the technology building.

had my hands on a spectrum analyzer, but for whatever reason we had only one. The instructor did the demonstration and then asked us if we understood. That was the best we could do for a demo, but I wished that I could get my hands on the equipment."

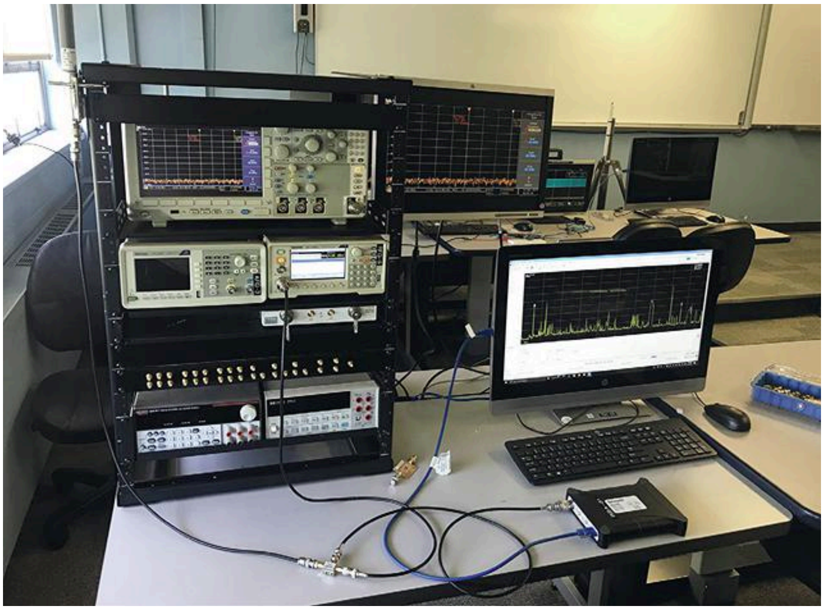
After Haro began teaching at QCC, he focused on bringing new equipment to the school. "I started to attend conferences and talk to field engineers from different companies because I needed to see what was out there," he explains. "I understood that our program needed to be renewed. Our equipment only had capability up to a couple of MHz. You can only do so much with that. How were we not supporting microwave frequencies? So, we needed to bring up our curriculum to make it closer to what's being used in the real world."

Thanks to Haro's efforts, QCC now has industry-standard test equipment with capability at microwave frequencies. *Figure 2* shows some of the equipment that QCC has in its lab. Tektronix's *(www.tek.com)* RSA306B real-time spectrum analyzer and TTR503A vector network analyzer (VNA) are both included in the setup. Also in the mix are a vector signal generator (VSG), arbitrary function generator (AFG), and oscilloscope—all from Tektronix, which is lending a helping hand to QCC.

> "Whenever possible, lab experiments are performed in industrial, scientific, and medical (ISM) bands. This provides students with a realistic scenario in which factors like interference are at play."

"We want to prepare students for a career in RF engineering by focusing on hands-on labs and evaluations," says Haro. "We provide students with RF equipment with capabilities typically found in the industry. In this regard, we built our RF lab with VSGs, VNAs, dual-channel AFGs, and real-time spectrum analyzers."

Now equipped with modern RF test equipment, QCC can provide students with effective hands-on lab experiments. Haro notes, "We develop laboratory experiments that cover RF fundamen-

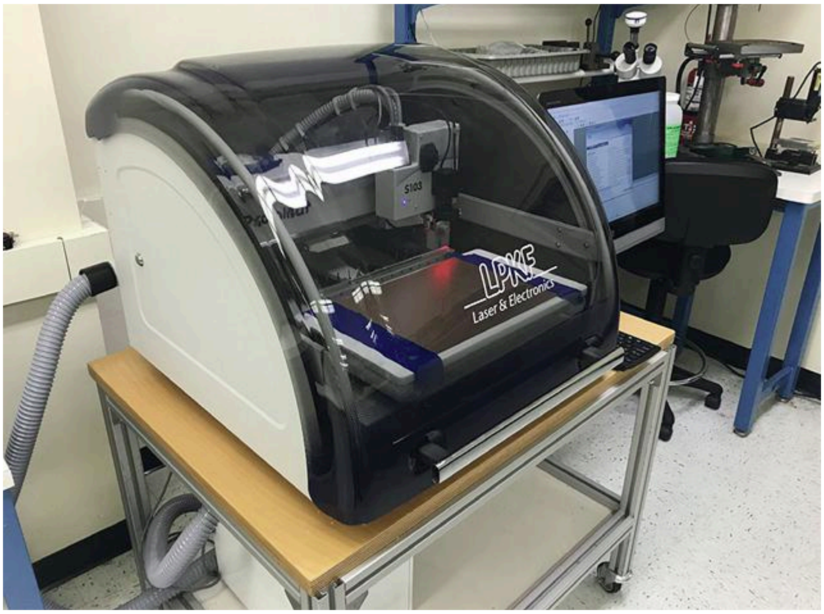


2. Here's some of the equipment in QCC's lab that's currently available to students.

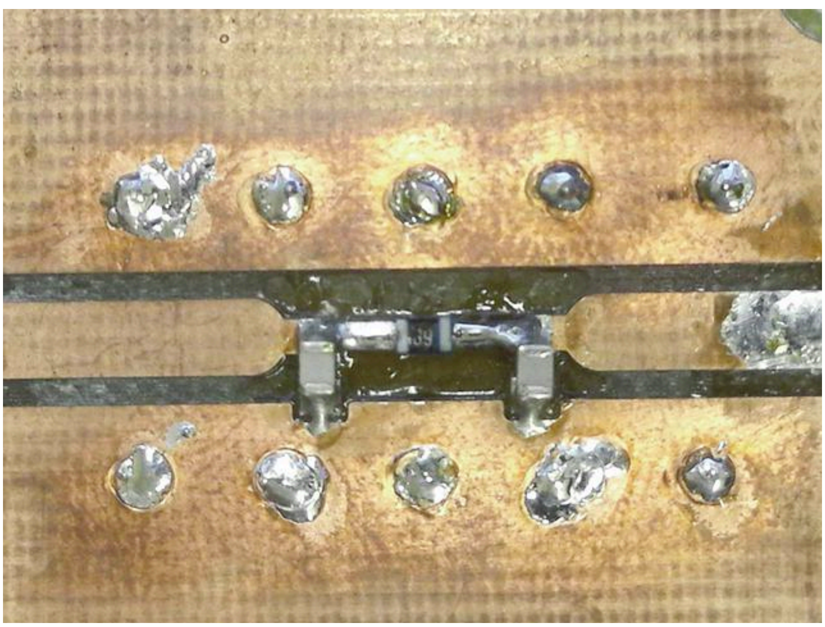
3. QCC is focused on giving students access to commercial-off-the-shelf parts. These products, from Mini-Circuits and JFW Industries, respectively, are some of what the school has in its inventory.

tals applied to technologies currently used that students can relate to, while reinforcing multiple fundamentals at the same time. Whenever possible, lab experiments are performed in industrial, scientific, and medical (ISM) bands. This provides students with a realistic scenario in which factors like interference are at play."

Haro also believes it's important to give students access to commercial-off-the-shelf parts. He says, "We are shifting from some educational modules to using commercial-off-the-shelf compo-

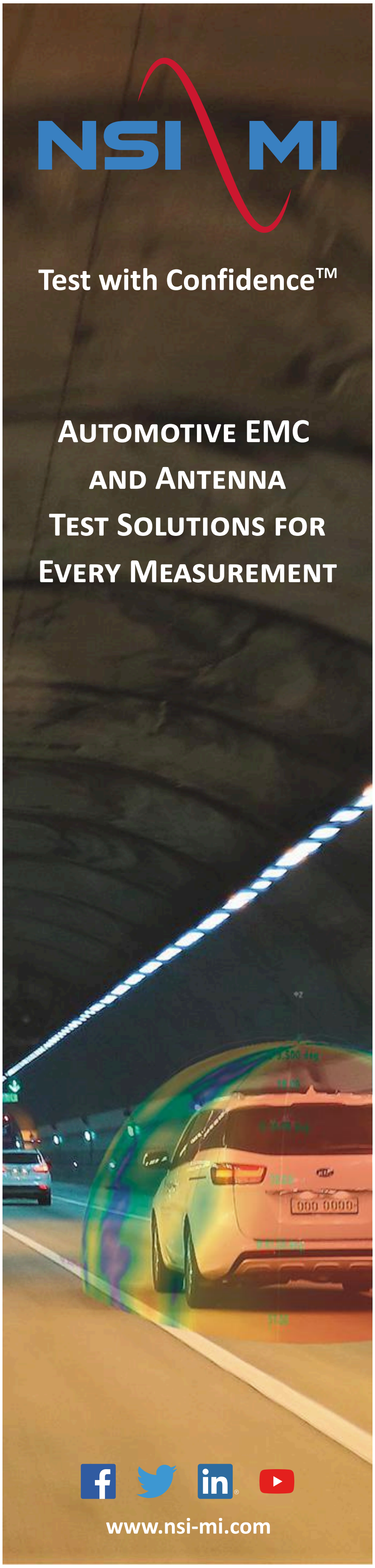


4. Thanks to this equipment, PCBs can be manufactured in-house.



5. It may not always look pretty, but students get the opportunity to solder components themselves.

(Continued on page 53)



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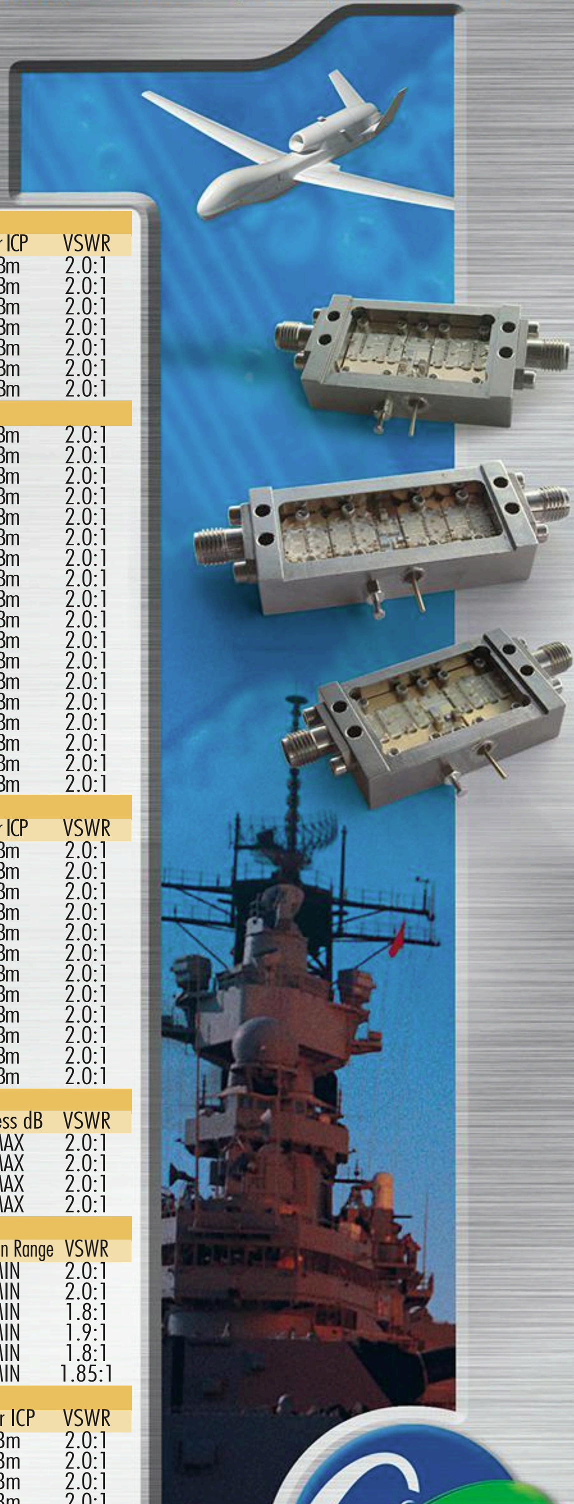

OCTAVE BAND LOW NOISE AMPLIFIERS

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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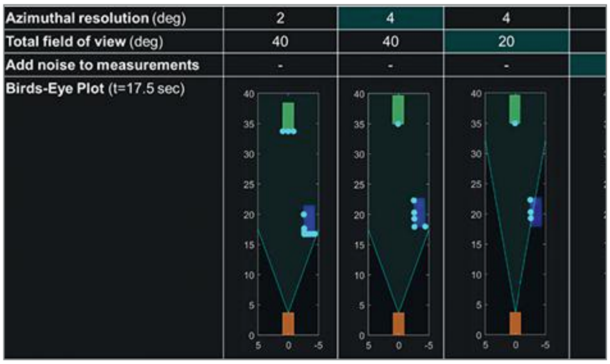

Algorithms to Antenna: Radar Target Modeling

From radar cross sections to multi-scattering centers, this blog explores ways to model radar targets with increasing levels of fidelity.

https://www.mwrf.com/systems/algorithms-antenna-radar-target-modeling

Radar Defends on Land, in the Air, and at Sea

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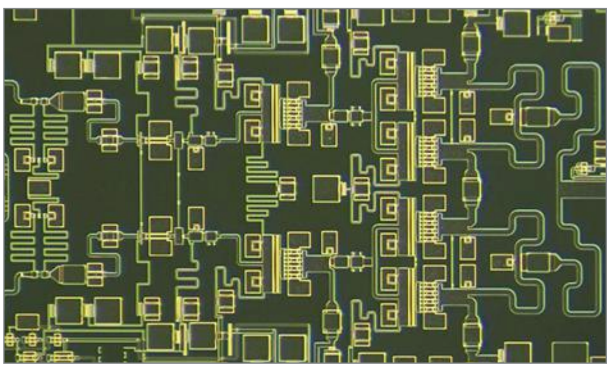

The Design of a Plastic-Packaged PA for 28-GHz 5G

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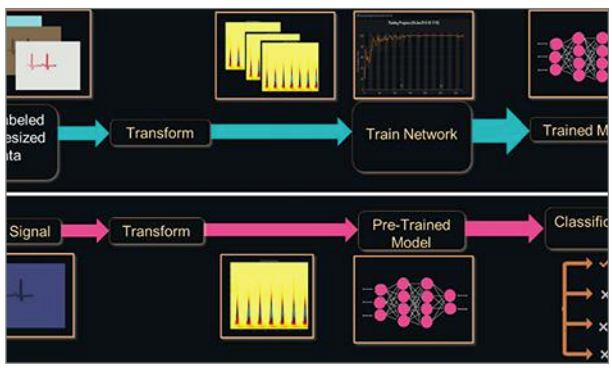

Identify Modulation for Communications and Radar Using Deep Learning

Signals can be extracted automatically using available frameworks and tools, or via alternate messages, which can then be used to perform modulation classification with a deep-learning network.

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News

Establish a Connection to the WAVEGUIDE WORLD

Millimeter-wave (mmWave) frequencies are receiving a great deal of attention these days, with 5G obviously being a major catalyst. One firm right at the forefront of mmWave technology is SAGE Millimeter *(www.sagemillimeter.com)*, which had some new toys to show off at the recent IMS 2019.

At the exhibition, SAGE unveiled its patent-pending Uni-Guide waveguide connectors *(Fig. 1)*. The company asserts that the Uni-Guide waveguide connectors are revolutionary products because they eliminate the need for waveguide-to-coax adapters as well as dedicated packages with built-in waveguide transitions.

Figure 2 shows how a Uni-Guide waveguide connector can directly replace a coaxial connector to form a waveguide interface. With these connectors, a standard waveguide interface is created from the standard coaxial glass bead pin. Hence, the Uni-Guide connectors give customers a standard waveguide interface that doesn't require any mechanical modifications.

The Uni-Guide connectors also offer the flexibility to allow for various orientations. For example, *Figure 2* depicts a vertically aligned connector, but the connectors can be horizontally aligned by simply rotating them 90 degrees *(Fig. 3)*.

In terms of benefits, SAGE Millimeter says that "the Uni-Guide waveguide connector can reduce product development cycle time, eliminate additional design costs, and minimize additional inventory management. Instead of developing various custom waveguide interfaced packages to satisfy different frequency bands and waveguide-orientation requirements, only a few standard housings and waveguide connectors are needed to accommodate many package variations."

Three Uni-Guide connectors are currently offered: the SUF-1912-480-S1, SUF-2212-480-S1, and SUF-2812-480-S1. All three are interchangeable with standard two-hole coaxial connectors with a mounting hole separation of 0.48 inches along with a 12-mil diameter pin.

The SUF-1912-480-S1 is a WR19 waveguide connector that covers a frequency range of 40 to 60 GHz. It achieves a typical insertion loss of 0.7 dB.

The SUF-2212-480-S1 and SUF-2812-480-S1 are WR22 and WR28 waveguide connectors, respectively. The SUF-2212-480-S1 connector spans a frequency range of 33 to 50 GHz and achieves a typical insertion loss of 0.6 dB.

The SUF-2812-480-S1 covers a frequency range of 26.5 to 40.0 GHz. It attains a typical insertion loss of 0.5 dB.

In addition to the Uni-Guide waveguide connectors, SAGE Millimeter unveiled its 1.35-mm (E) connector products. These devices allow for an efficient transition between rectangular waveguide interfaces and 1.35-mm (E) coaxial connector environments. Customers can choose either end-launch or right-angle versions. ■

1. With Uni-Guide waveguide connectors, standard waveguide interfaces can be created from standard coaxial glass bead pins.

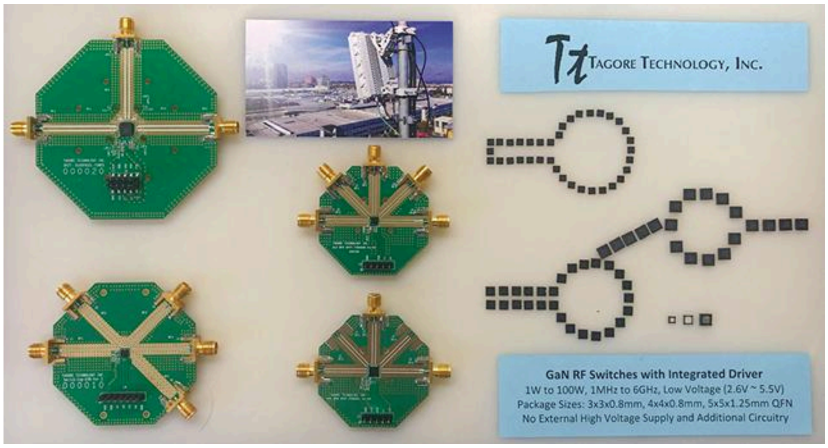
2. The Uni-Guide connectors allow for direct replacement of coaxial connectors.

3. Shown is a horizontally aligned Uni-Guide connector.

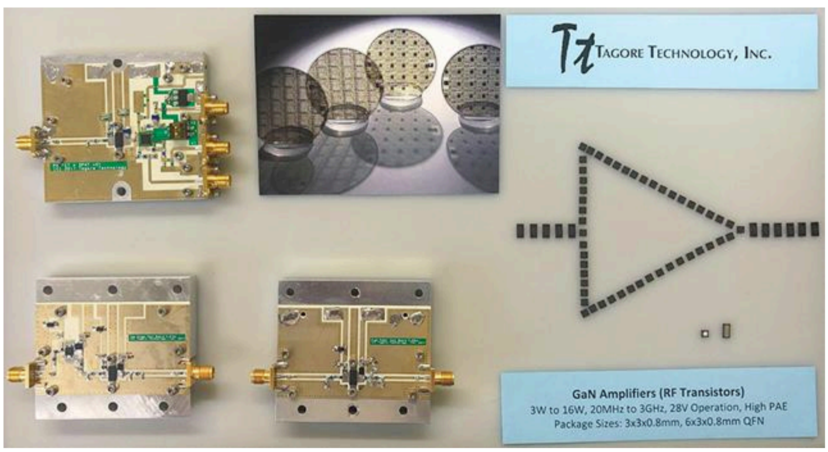
THE RIGHT MIX: RF Switches Adopt the GaN Recipe

UTILIZATION OF GALLIUM NITRIDE (GaN) in the RF/microwave industry has soared in recent years, with the technology now playing a key role in applications across the board. GaN and amplifiers seem to go hand-in-hand, as companies are capitalizing on the benefits of GaN technology to develop the latest and greatest high-power amplifiers.

But one firm, Tagore Technology *(www.tagoretech.com)*, is exploiting GaN for use cases beyond high-power amplifiers. Specifically, Tagore Technology is touting its family of GaN-based RF switches, which the company maintains offers several advantages in comparison to alternative solutions.



1. On display at IMS 2019 was Tagore Technology's family of GaN-based RF switches.



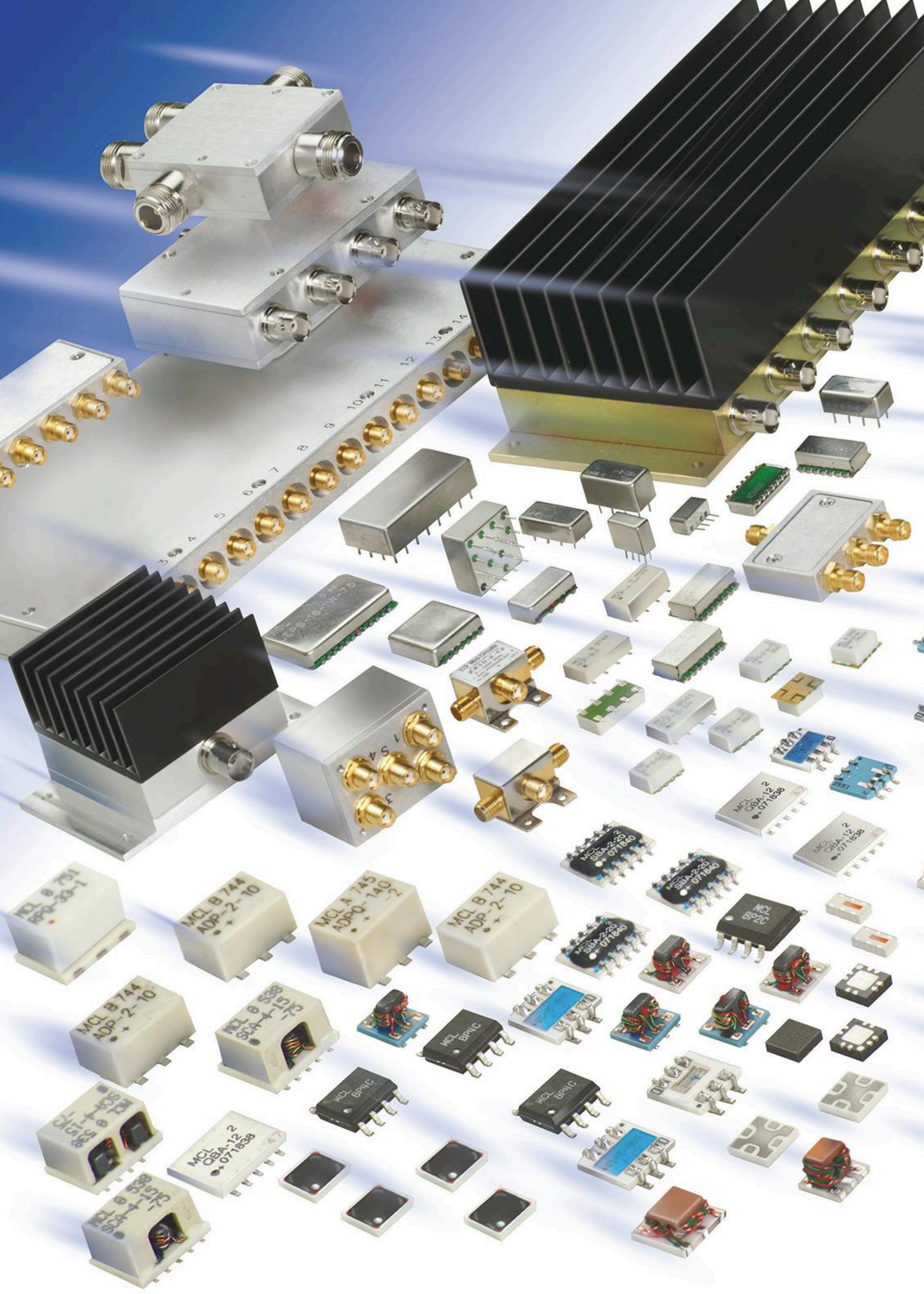
2. Among the products available from Tagore are RF power transistors like the TA8110K and TA8210D.

Tagore Technology, located in Arlington Heights, Ill., is a fabless semiconductor company founded in January of 2011. With more than 50 customers worldwide, the company targets applications that range from cellular infrastructure to land-mobile radios (LMRs). Furthermore, Tagore Technology is not only invested in RF switches, but is using GaN technology to develop RF power transistors as well as power-management solutions.

What's the reasoning behind developing RF switches based on GaN technology? Manish Shah, VP of engineering at Tagore Technology, explains, "There are two key requirements for RF devices used in RF switch circuits. The 'OFF' arm devices need to handle very large voltages under high-RF-power conditions, while the 'ON' arm devices need to handle high currents. For example, 10 W of RF power in a perfectly matched 50-Ω condition will create a peak RF voltage of 32 V and a peak current of 600 mA. A voltage standing wave ratio (VSWR) of 4:1, which is very typical for RF switches close to the antenna, would push that voltage to 51 V and the current to 1 A."

Shah continues, "Existing technologies, such as SOI/SOS/GaAs with a breakdown voltage around 3 V, would require stacking of a prohibitively large number of devices to handle such a large voltage. PIN-diode-based switches achieve this by reverse-biasing the diode with very large voltages to keep them 'OFF' and large currents to achieve low $R_{DS(on)}$ during the 'ON' state."

Shah points out that GaN technology is well-suited for the design of high-power RF switches. "Wide-bandgap GaN HEMT has very high breakdown voltage capability," he says. "The saturation current of GaN is also very high; it's typically in the range of 800 to 900 mA/mm. So high-power switches designed using GaN devices can meet high voltage and high current requirements without stacking devices. Unlike a PIN diode, the GaN HEMT is a voltage-controlled device. Thus, it doesn't require high current during the 'ON' state. This makes GaN an ideal technology for high-power RF switch design."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GETTING TO KNOW THE PRODUCTS

Tagore Technology was on hand at IMS 2019, showcasing its RF switches and other devices *(Fig. 1, page 13)*. The company's complete portfolio of switches covers frequencies that range from 1 MHz to 6 GHz.

One example is the TS7226K symmetrical single-pole, double-throw (SPDT) switch. Covering a frequency range of 500 MHz to 6 GHz, the TS7226K is intended for broadband, high-peak-power switching applications. At 2,600 MHz, the switch has a specified 0.1-dB compression point of +42.5 dBm under continuous-wave (CW) operating conditions. Under pulsed conditions (1% duty cycle and 10-µs frame width), the TS7226K can handle peak power levels as high as +48 dBm. The device comes in a 3- × 3-mm quad-flat no-leads (QFN) package.

Then there's the TS7329K, a 100-W asymmetrical SPDT switch that covers a frequency range of 700 MHz to 5 GHz. Like the TS7226K, the TS7329K comes in a 3- × 3-mm QFN package.

Tagore also offers RF power transistors, which were on display at IMS, too.

As mentioned earlier, Tagore also offers RF power transistors, which were on display at IMS, too *(Fig. 2, page 13)*. One product is the TA8110K 4-W GaN-on-silicon (GaN-on-Si) power transistor that covers a frequency range of 30 MHz to 2.7 GHz. This device is intended to be used as a driver for high-power-amplifier applications. The TA8110K also comes in a 3- × 3-mm QFN package.

Also offered by Tagore is the TA8210D 12.5-W GaN-on-Si power transistor that covers a frequency range of 20 MHz to 3 GHz. The TA8210D will find homes in LMR/PMR/MIL radios.

Speaking of LMR/PMR/MIL radios, Tagore Technology is leveraging its switch technology to enhance the performance of multiband power amplifiers (PAs) for these applications. The company has developed proprietary low-impedance switches, which can be placed at the output of the PA. Each individual output switch path can then be matched, resulting in much higher efficiencies for multiband PA applications. (For more on this, Tagore published an application note titled "Application Board Using TA8210D + SP4T switch.")

Tagore Technology's future plans include products such as low-noise amplifiers (LNAs). ■

TEST CAPABILITIES Offer Reinforcement at Higher Frequencies

NOT SURPRISINGLY, National Instruments (NI) *(www.ni.com)* made its presence felt at the recent IMS 2019, bringing an array of new test solutions. For example, the company expanded the frequency coverage of its vector-signal-transceiver (VST) product family by launching the PXIe-5831 VST, which supports validation and production testing at millimeter-wave (mmWave) frequencies *(Fig. 1).*

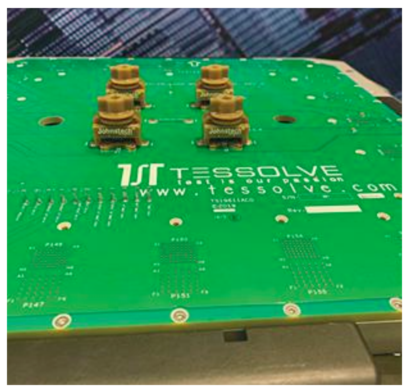
The PXIe-5831 VST incorporates a vector signal generator (VSG), vector signal analyzer (VSA), and high-speed serial interface with FPGA-based real-time signal processing and control. By itself, the VST provides customers with direct signal generation and analysis from 5 to 21 GHz. In addition, the PXIe-5831 can be combined with modular mmWave heads to cover frequencies from 23 to 44 GHz, providing integrated and calibrated switching for as many as 32 channels. Furthermore, the PXIe-5831 offers 1 GHz of instantaneous bandwidth for generation and analysis.

1. The PXIe-5831 VST combined with modular mmWave heads provides coverage for frequencies as high as 44 GHz.

With the PXIe-5831 VST, multichannel beamformers and phased arrays can be measured without the need for additional infrastructure. NI maintains that the new VST helps address time-to-market challenges for X-, Ku-, and Ka-band radar applications, as well as satellite-communications (satcom) components and systems.

"By extending capability to even more radar and satcom frequencies, we are helping address the schedule, cost-of-test, and quality issues inherent in the development of complex transmit/receive systems," says Luke Schreier, VP and general manager, defense and government business, NI. "As a company, we also gain significant technology leverage between these applications and the commercial 5G sectors, which enables us to more efficiently support the product."

The PXIe-5831 wasn't all NI had on hand to showcase at IMS. It also demonstrated a mmWave 5G packaged-part test solution, which was a collaboration between NI and two other companies: Tessolve *(www.tessolve.com)* and Johnstech *(www.johnstech.com) (Fig. 2).*



2. NI, Tessolve, and Johnstech collaborated to create a packaged-part test solution for mmWave 5G applications.

The solution features NI's Semiconductor Test System (STS) for quad-site mmWave 5G testing. It also includes a mmWave-ready interface board designed and manufactured by Tessolve, as well as Johnstech mmWave contactors (rated up to 100 GHz) for final testing of packaged parts. A Johnstech impedance-controlled socket that featured the company's IQtouch Micro contactors helped ensure repeatable test measurements. ■

TAKE A PATH to Accelerated Design Workflows

ONE SIGNIFICANT HEADLINE coming out of IMS 2019 was Keysight Technologies' *(www.keysight.com)* announcement of PathWave Design 2020, a collection of new releases of the company's electronic-design-automation (EDA) software tools. Intended to accelerate design flows across industries, PathWave Design 2020 encompasses RF/microwave circuit design, system-level design, device modeling, high-speed digital design, and power electronics.

PathWave Design 2020 includes PathWave Advanced Design System (ADS) 2020, PathWave System Design (SystemVue) 2020, PathWave RF Synthesis (Genesys) 2020, PathWave RFIC Design (GoldenGate) 2020, and PathWave Device Modeling (IC-CAP) 2020 *(Fig. 1).*

1. PathWave Design 2020 includes PathWave Advanced Design System (ADS) 2020.

Before getting into the specifics of PathWave Design 2020, it's important to have a good grasp of some of today's requirements. According to Keysight, "Gone are the days of simple electronic circuit design. Every year, companies are pushing new limits: longer battery life, smaller components, and higher levels of integration. As a result, design and test engineering requirements are growing exponentially."

"Gone are the days of simple electronic circuit design. Every year, companies are pushing new limits: longer battery life, smaller components, and higher levels of integration. As a result, design and test engineering requirements are growing exponentially."

The company also explains that "as the amount of data collected grows, companies know that they need a new way to share data between design and test teams. Correlating design and simulation data with test results takes months and slows time-to-market. Designers create workarounds and custom scripts to connect multiple design tools, slowing productivity. Companies are looking to speed design and simulation setups and analysis to accelerate overall product time-to-market."

If the goal is to accelerate product development, how can PathWave Design 2020 help make it happen? According to Keysight, "PathWave Design 2020 accelerates product development by reducing the time engineers spend in the design and simulation phase. Its libraries and customized simulators reduce setup time. The software integrates circuit design, electromagnetic (EM) simulation, layout capabilities, and system-level modeling, reducing time spent in importing and exporting designs and fixing errors associated with changing tools. Improvements in data analytics allow for faster analysis and more timely design decisions. Automation improvements reduce manual work."

KEY FEATURES

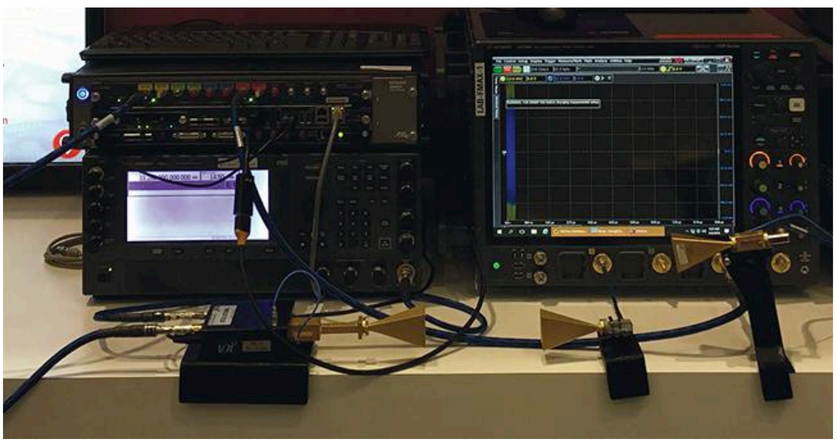
PathWave Design 2020 includes two new EM simulators, RFPro and PEPro, intended for RF/microwave and power electronics design, respectively *(Fig. 2)*. PathWave Design 2020 also features upgraded 5G New Radio (NR), automotive radar, and radar/electronic-warfare design libraries. Other new benefits include improvements to both assembly and packaging layouts.

(Continued on page 50)

GREG JUE | 5G System Engineer, Keysight Technologies
www.keysight.com

Tackling Extreme Bandwidths for Emerging mmWave Applications

Multiple factors should be weighed when designing and testing hardware for 5G and 802.11ay. A mmWave simulation case study, along with the use of a wideband R&D mmWave test bed, shine a light on these considerations.



Large swaths of contiguous millimeter-wave (mmWave) spectrum have opened in the U.S, offering opportunities to use these bands for very-high-data-throughput applications. However, testing mmWave hardware designed for high-data-throughput applications requires careful consideration to gain insight into the actual hardware performance when tested.

Increasing data throughput is possible employing several different methods. One method is to use higher symbol rates and more channel bandwidth. Higher-order modulation, such as 64-QAM, is possible if the radio's performance is sufficient to support the higher-order modulation format.

To measure the radio performance under these conditions, a mmWave test bed system's performance should not be the dominant source of error; otherwise, it can mask the hardware's true performance when testing the hardware. This article will discuss some of the considerations in designing and testing hardware for extreme-bandwidth applications and will highlight these considerations using a simulation case study.

A new research-and-development test bed will be presented, which leverages the latest advances in ultra-high-performance digital-oscilloscope technology. A 110-GHz UXR real-time oscilloscope is used to directly digitize and analyze extreme-bandwidth mmWave signals. The UXR's maximum sampling rate is 256 Gsamples/s per channel (up to four channels) with 10 bits of vertical resolution. This new capability provides flexibility and scalability to address a multitude of mmWave frequency bands, extreme frequency bandwidths, and multiple channels to address demanding emerging mmWave test challenges.

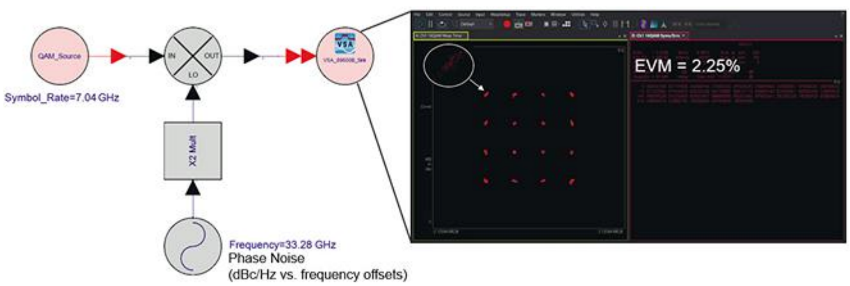
EXTREME BANDWIDTHS FOR AN EMERGING mmWAVE APPLICATION: 802.11ay

802.11ay is the next generation of 802.11ad. Backwards-compatible with 802.11ad, 802.11ay has extended throughput, transmission range, and use cases. The requirement for the 802.11ay standard definition is to enable at least one mode of operation to support a maximum throughput of at least 20 Gb/s while maintaining or improving the power efficiency. It's possible the technology could support speeds beyond 20 Gb/s and reach distances of approximately 1,000 feet. 802.11ay specifies a mandatory two-bonded channel configuration for 2 × 2.16 GHz of bandwidth, or 4.32 GHz, as well as optional channel-bonding configurations for 6.48 and 8.64 GHz of bandwidth.[1]

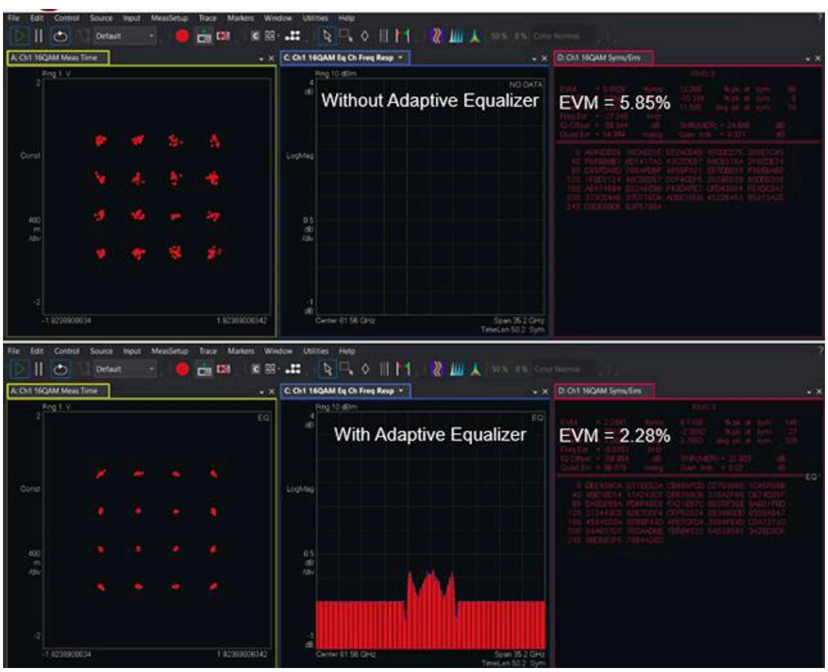
For a discussion of design and test considerations, we'll use a signal centered at 61.56 GHz with a channel bandwidth of 8.64 GHz as an example of an extreme-bandwidth emerging mmWave application.

EXTREME BANDWIDTH: SIMULATION CASE STUDY

Achieving the performance required to support extremely wide bandwidths can be difficult. A simulation case study is used to help understand some of the key system performance considerations. Using simulation is convenient in helping to understand performance considerations and design tradeoffs. That's because design impairments can easily be isolated to evaluate their impact individually as well as their contribution to the overall system performance, which can be difficult in the hardware testing phase. The simulation shown in this case study is a conceptual design to highlight key considerations and is not intended to represent an actual hardware design.



1. Shown on the left is a simple upconverter design that consists of a modulation IF source with a center frequency of 5 GHz. The constellation diagram is on the right.



2. These simulation results with the added bandpass filter are given with and without adaptive equalization enabled.

This simulation case study begins with a simple upconverter design consisting of a modulation IF source with a center frequency of 5 GHz modeled with Keysight's *(www.keysight.com)* SystemVue design software *(Fig. 1)*. The modulation type can be set to QPSK, 16 QAM, or 64 QAM. The symbol rate is set to 7.04 GHz with a root-raised-cosine (RRC) filter alpha of 0.22. These settings are "802.11ay-like" in their values, corresponding to the 802.11ay 8.64-GHz channel bandwidth configuration.

The modulated IF is upconverted to 61.56 GHz using a mixer with a high-side local oscillator (LO). The LO source frequency is 33.28 GHz, followed by a times-two multiplier. Hence, the mixer LO frequency is 66.56 GHz. In turn, 66.56 GHz minus the 5-GHz IF frequency yields an upconverted frequency of 61.56 GHz using a high-side LO. Phase noise is an important consideration for mmWave systems and can be a key contributor to the system's error-vector-magnitude (EVM) performance. LO-source phase noise is modeled in dBc/Hz at various frequency offsets in this simulation.

An 89600 VSA sink element is used at the upconverter output to analyze the simulation results. This same vector-signal-analyzer (VSA) software could be used with Keysight signal analyzers and oscilloscopes to perform hardware measurements. Here, the VSA test-and-measurement software is being used to analyze the simulation results.

The simulation result showing the 16-QAM constellation is shown on the righthand side of *Figure 1*. Zooming into one of the constellation states (circled in white) shows dispersion and constellation rotation resulting from the LO phase noise. The EVM with LO phase noise is 2.25%.

A bandpass filter is added after the mixer. Although a filter has the benefit of filtering out undesired mixing products, it can introduce linear amplitude and phase impairments to the signal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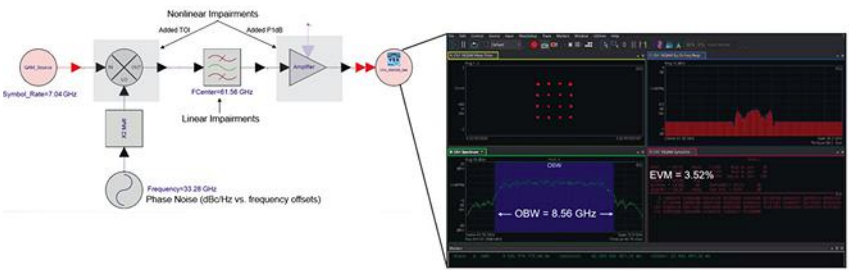

3. A nonlinear power amplifier (PA) was added to the output of the upconverter to achieve these final schematic and simulation results.

path that can impact the waveform quality and EVM.

Figure 2 shows the simulation results with the bandpass filter, with and without adaptive equalization enabled. The simulation result on the top (without adaptive equalization) shows significant constellation dispersion due to the linear amplitude and phase error introduced by the bandpass filter. The increased dispersion raised the EVM to 5.85%. This is useful to understand from a component perspective. However, from a system perspective, a receiver would typically have some baseband equalization because the input signal to a receiver would have channel impairments and other impairments.

The simulation results on the bottom of *Figure 2* show the measurement with the adaptive equalizer enabled. The complex equalizer response that has been fitted to remove the linear amplitude and phase error across the channel bandwidth can be seen. It's effectively the filter's frequency response in this simple simulation example that serves to illustrate a point. However, in an actual hardware design, this could be the cumulative frequency response of cabling, adapters, mixers, filters, amplifiers, etc.

With the equalizer enabled, the constellation looks much like what was simulated with only the phase noise present and no bandpass filter. The adaptive equalizer will only operate on the linear amplitude and phase error. Noise and nonlinear errors will remain and will impact EVM, whether the equalizer is enabled or not. The 2.28% EVM with adaptive equalization is similar to the 2.25% EVM result measured previously, with only the LO phase noise and before adding the bandpass filter.

Maximizing signal-to-noise ratio (SNR) is important for extreme-bandwidth applications. The modulated signal will have some peak-to-average, or crest factor properties, that can be represented by a statistical complementary cumulative distribution function (CCDF). To maximize the SNR, the signal would need to be backed off enough to avoid compressing or clipping the waveform through any nonlinear components in the signal chain while at the same time maximizing the amplitude.

To illustrate this in the simulation example, a nonlinear power amplifier (PA) was added to the output of the upconverter *(Fig. 3)*. The amplifier's output 1-dB compression point (P1dB) is specified, as well as its gain. An output third-order intercept point (OIP3) for the mixer has been specified to model nonlinear characteristics.

The simulation results are shown on the right side of *Figure 3*. The EVM with equalization increased to 3.52% with the adaptive equalizer enabled, relative to the scenario without the PA in which the EVM was previously 2.28%. The higher EVM is a result of the nonlinear impairments from the mixer and the PA. Since the adaptive equalizer cannot correct for nonlinear distortions, it's only removing the linear amplitude and phase errors from the bandpass filter. Nonlinear impairments remain and have increased the EVM result.

This simulation case study highlights some of the key performance considerations in designing and testing hardware for extreme-bandwidth applications. It's important in designing a testbed that can address the demands of emerging mmWave applications, which is discussed in the next section.

The spectrum is shown on the bottom left of the VSA display. An occupied-bandwidth (OBW) measurement is shown in the blue shaded region. The measured OBW is 8.56 GHz. Compression from the PA and mixer are also causing out-of-band spectral regrowth, which can be observed in the spectrum measurement.

This simulation case study highlights some of the key performance considerations in designing and testing hardware for extreme-bandwidth applications. It's important in designing a test bed that can address the demands of emerging mmWave applications, which is discussed in the next section.

EXTREME BANDWIDTH: A NEW WIDEBAND R&D mmWAVE TEST BED

Now, we'll focus in on a new wideband research-and-development mmWave test bed that addresses the

(Continued on page 48)

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X-band Push-Push Oscillator Simulation and Measurement (Part 1)

This first part of a two-part series discusses basic oscillator concepts such as the common-collector oscillator, which leads to the push-push oscillator architecture.

Push-push oscillator configuration via harmonic-balance computer simulation and test measurement is the focus of this article series *(see footnote at end of article)*. Specifically, it lays out basic oscillator theory of generated negative resistance and analyzes the common-collector, single-stage oscillator, which is subsequently utilized as a basic building block of the push-push oscillator configuration (that will be covered in the upcoming part 2).

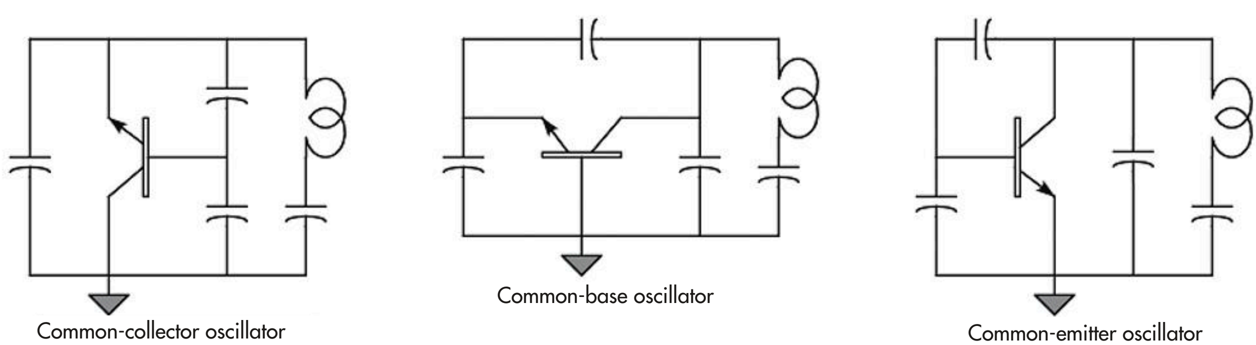
Uncommon aspects of resonator loading and oscillation conditions are explored in this series. Conventional oscillator theory is reinforced via large-signal loading analysis simulation using the single-stage, common-collector oscillator. The unique operation of the push-push oscillator configuration is examined using harmonic-balance simulation of spectral content and time-domain voltage waveforms. Dynamic load lines are investigated and utilized to explore peak signal excursion and degree of nonlinearity. In addition, predictions of power output, phase noise, voltage control, and harmonic content are compared with measured data.

INTRODUCTION

The push-push oscillator configuration has been used to extend the frequency of operation of bipolar transistors well into the microwave and millimeter-wave (mmWave) regions. It has sustained service and attractiveness thanks to performance that's not achievable by other signal-generation methods. Recently, it's been implemented within SiGe and InGaP HBT technologies.

Several authors have attempted to explain the frequency-multiplication and noise-cancellation properties with limited success.[1, 2, 3] A common-collector oscillator is demonstrated to be a fundamental element of the push-push oscillator architecture when implemented with bipolar transistors. The investigation begins with exploration of negative resistance generation, resonator coupling, and loading of the basic oscillator element.

The coupling of oscillator output power is found to profoundly impact power output, load-line, harmonic content, and noise. The push-push oscillator is formed from the back-to-back combination of two common-collector oscillators operating in phase opposition conditions, thereby creating a null at the harmonic output node. Specific aspects of large-signal simulation, device models, and simulation algorithm are discussed with respect to parameter prediction accuracy. Measurement data is



1. Modified Colpitts oscillator configurations include these three electrically equivalent circuit topologies.

presented that correlates satisfactorily with parameters like power output, harmonic content, and phase noise, but less so with respect to operational frequency prediction.

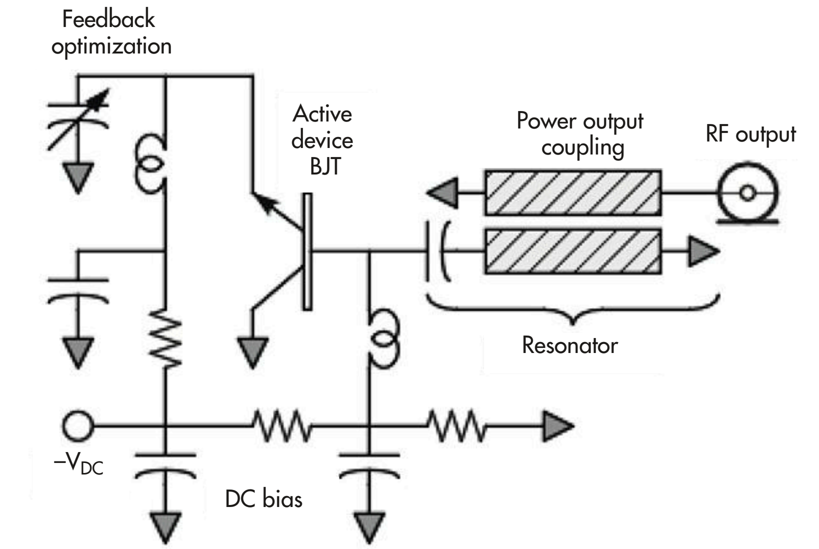
BASIC OSCILLATOR CONCEPTS

Several types of oscillators exist: blocking, relaxation, monostable, and bistable are typical of lower-frequency operation. Higher-frequency oscillators are generally segmented within two classes: negative resistance oscillators and feedback oscillators. Gunn and Impatt diode oscillators represent examples of negative resistance oscillators, while feedback oscillators can be characterized as reflection or reaction types. Feedback oscillators create a negative resistance, i.e., $\Gamma > 1.0$, due to circuit topology. This presentation will focus on feedback-type oscillators.

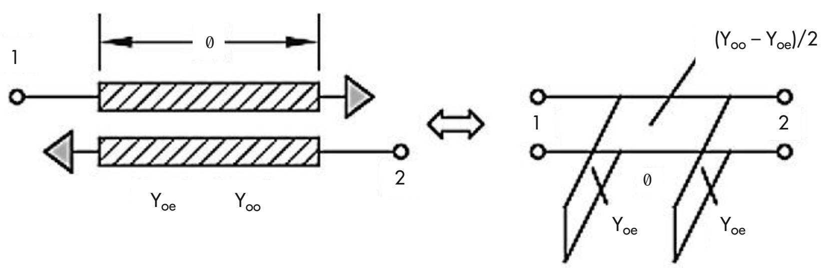
The modified Colpitts oscillator is fundamental to sinusoidal signal generation in RF, microwave, and mmWave frequency bands. *Figure 1* depicts various configurations of the modified Colpitts oscillator in which alternate terminals of the transistor are grounded and the feedback and resonator networks are represented.

In each case, the feedback network is the result of a capacitive voltage divider, while the resonator is formed using the feedback network augmented by an inductor-capacitor resonator. This resonator is selected to increase the slope of the reactance at the resonant frequency, and therefore, also the quality factor (Q).

As will be demonstrated, the inductor-capacitor resonator may also represent a distributed resonator as the operation of the oscillator is extended to higher frequency bands. All of the illustrated configurations are designed to generate negative two-terminal resistance at a desired frequency band from which power may be extracted. An old adage states that *"positive resistance dissipates power while negative resistance generates power."*



2. This is a common-collector, coupled transmission-line resonator oscillator. The common-collector oscillator circuit topology with capacitor-coupled, grounded resonator is fundamental to the push-push oscillator topology.



3. Shown is the equivalent circuit of coupled transmission line. This configuration is selected due to the ease with which to observe the effects of load coupling.

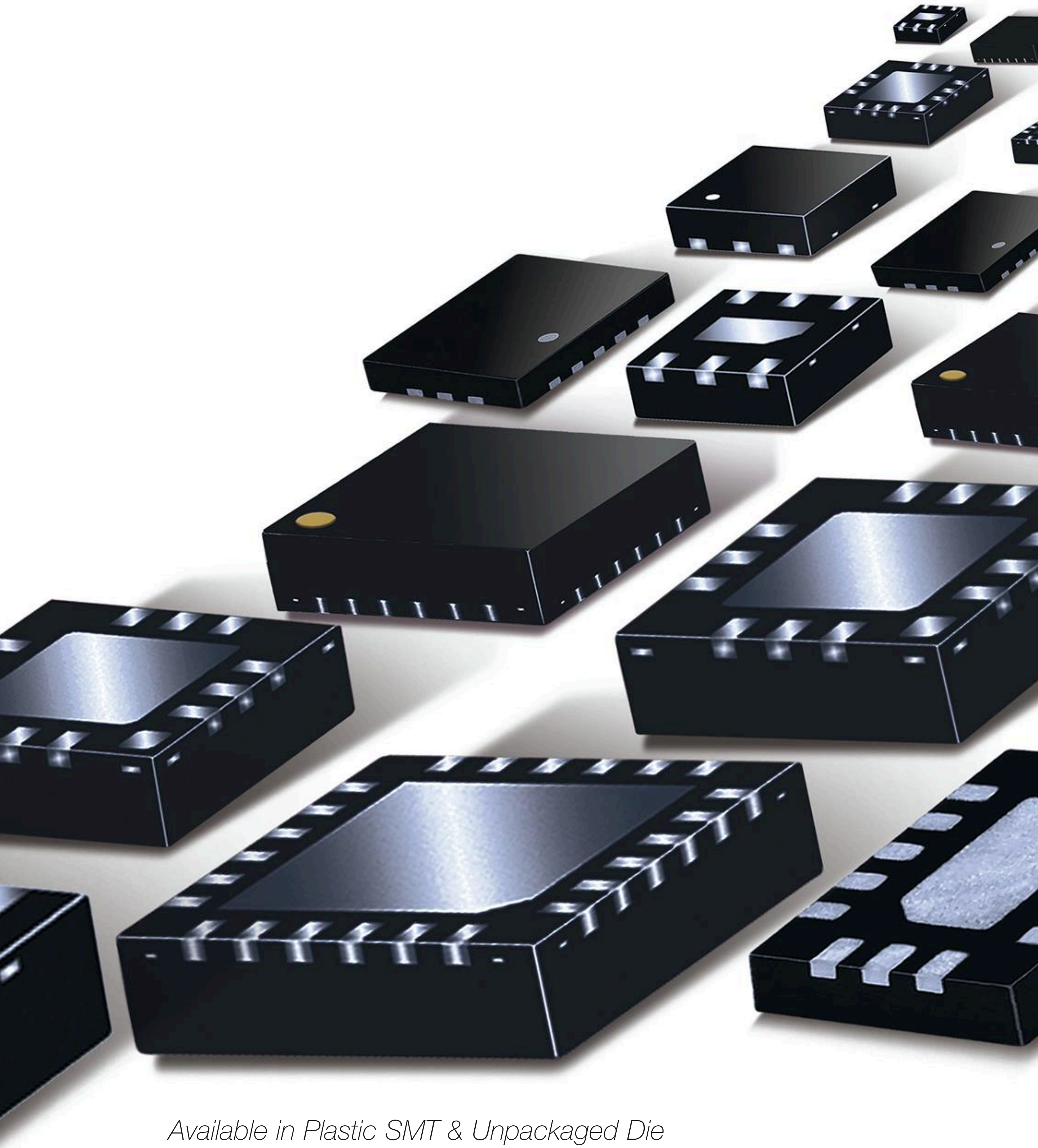
The common-collector oscillator configuration is popular in the microwave frequency band because the collector may be directly attached to ground, which facilitates heat removal. Another driving factor is that the collector is normally the substructure of the bipolar junction transistor.

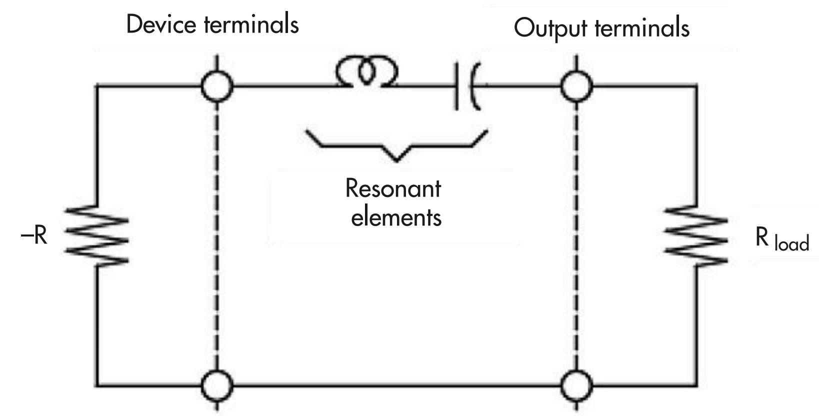
USING A COUPLED TRANSMISSION LINE

A feedback voltage divider is formed using the intrinsic base-emitter capacitance and a discrete capacitor attached from the emitter to ground. In this configuration, a negative resistance is generated at the collector-base junction to which a resonator may be coupled, and from which power at the resonator frequency may be extracted. *Figure 2* illustrates the complete schematic of the grounded-collector oscillator with the discrete inductance replaced with a distributed, coupled transmission line.

The series capacitor serves as an effective coupling mechanism to the coupled transmission-line resonator. In addition, the feedback capacitor is illustrated as an adjustable element to highlight the profound influence on oscillator parameters—specifically, power output, phase noise, and start voltage.

The common-collector oscillator using the coupled transmission-line





4. All oscillators operating in the steady-state, shown here, may be distilled to this circuit embodiment.

resonator is selected for study because the structure forms an element of the push-push oscillator architecture, as will be demonstrated. The coupled transmission-line resonator facilitates examination of the output power coupling via the odd- and even-mode impedance while observing the dynamic load line and determination of the oscillator frequency and power output.

Loading is introduced to the oscillator system by means of the coupled transmission-line resonator and the series capacitor. This is important for all aspects of oscillator design because high-quality signal generation often has been a matter of accepting the output signal quality from a given configuration. Greater spectral signal quality was attainable only when using high-quality resonators. Recently, this adage has been proven false by MMIC oscillator performance that exhibits phase noise comparable to good quality cavity oscillators at X-band (an example is the HMC398QS MMIC VCO, see datasheet). The ability to accurately simulate the loading effects on power output, phase noise, and harmonics suggests the use of lower cost oscillator circuit implementation.

The coupled transmission line facilitates both output loading and control of the total resistance reflected across the collector-base port of the oscillator at the resonant frequency. This effect may be readily understood by observing the equivalent circuit of the coupled transmission line *(Fig. 3)*.

The coupled transmission line implements an impedance transformer in which the impedance transformation ratio is controlled by the odd- and even-mode admittance. This is a powerful analysis tool because the load line and the reflected impedance may now be observed over various coupling values. Under very light loading conditions, the common-collector oscillator behaves in a similar manner to that encountered when connected in the push-push configuration.

STEADY-STATE OPERATION

The “prevailing” wisdom with respect to oscillator operation in the steady-state may be succinctly represented with the graphic in *Figure 4*. Here, a negative resistance—whether created via feedback or transfer electron device, i.e., Gunn or Impatt diode—is connected to a resonant circuit and then to a load.

Typically, both device and load are coupled to the resonator using either distributed or lumped-element circuit components. In the steady-state, the total loop resistance is equal to zero. Otherwise, the oscillator signal would continue to increase until the device saturates and the negative resistance decreases to the value of the positive resistance of the coupled load. It’s for this reason that the large-signal impedance is examined at the negative resistance port of the common-collector oscillator and the coupling value is adjusted to ensure that the conditions for sustained oscillation are achieved.

If the load coupling is adjusted to the point where the net loop resistance becomes positive, the system will cease to oscillate. In fact, this condition was examined and found to validate the intuitive oscillator operation. The fact that this result was validated by the large-signal simulation of the common-collector oscillator and correlation with earlier experimental results of load coupling was quite satisfying. Hence, the simulation algorithm and model proved to be valid. However, specific transistor model parametric values are still in question. mw

FOOTNOTE: The harmonic-balance simulation software for this task is offered by AWR Microwave Office version 5. The harmonic-balance method is a powerful technique for the analysis of high-frequency, nonlinear circuits such as mixers, power amplifiers, and oscillators. Additional information can be found at *www.awrcorp.com*.

AUTHOR’S NOTE: This technical memorandum was originally prepared for a M/A-COM engineering conference in 2005 by Kenneth Puglia and Arjang Pakfar. M/A-COM engineering conferences were initiated by Harlan Howe as a venue to share technical information and advance interaction and communications among the technical staff. The M/A-COM engineering conferences also promoted professionalism and encouragement of the engineering staff to further document and formally present at a company sponsored, off-site annual event. The author recently revisited this article series as part of an assessment of software analysis and simulation tools that provide unique opportunities for education, as well as system and circuit intuitive understanding.

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How to Pick the Best BLUETOOTH PROTOCOL for Your Application

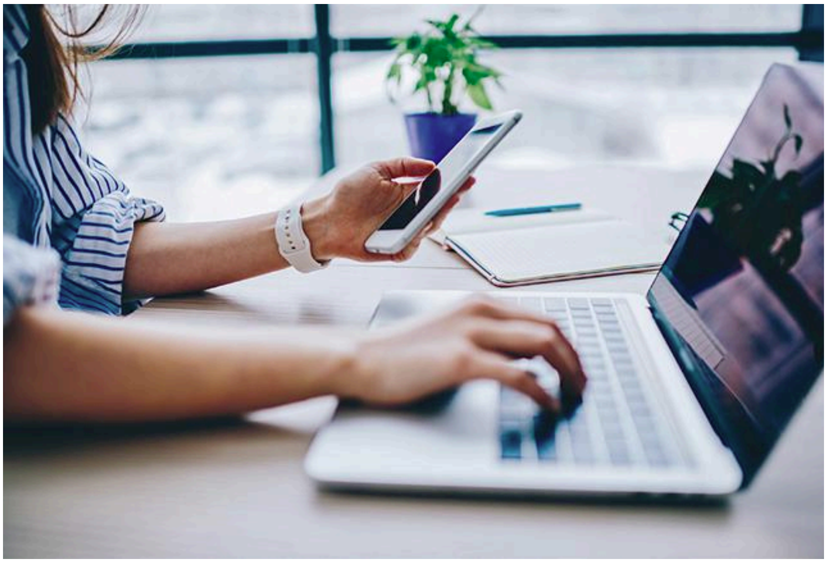
From BLE BR/EDR to BLE to Bluetooth 5, the wireless communications technology has gone through numerous variations to meet disparate needs. What exactly are the differences between them?

Wireless communication is becoming integral to electronics as more and more consumers demand the ability to send and receive data without being tied down with plugs and cables. Among the most popular wireless communication protocols is Bluetooth, which has the versatility to find homes in a range of applications.

Among many other apps, Bluetooth is embedded in cars so that users can play their favorite music from a smartphone on the car stereo. The new field of smart-home security utilizes Bluetooth to allow individuals to perform tasks like locking and unlocking their front door with their phone. Bluetooth can also be used to send files between a tablet and a computer, send updates from a fitness tracker to a computer or phone, and much more. *Figure 1* depicts two common Bluetooth-enabled devices, a smartphone and a laptop.

All of these different applications fall under the blanket term "Bluetooth," but, surprisingly, not all of them use the same wireless protocols. Some employ Bluetooth Low Energy (BLE), while others employ Bluetooth Basic Rate/Enhanced Data Rate (Bluetooth BR/EDR). Newer applications even have the potential to use Bluetooth 5.

Most people don't know the difference between Bluetooth BR/EDR and BLE, nor which of the two is best suited for their specific applications. Things have gotten more confusing with the introduction of Bluetooth 5, which blurs the line between these protocols even more. This article aims to explain where BLE differs from Bluetooth BR/EDR and how Bluetooth 5 promises to enhance both protocols. It will also help you to determine the version that's most appropriate for your application.



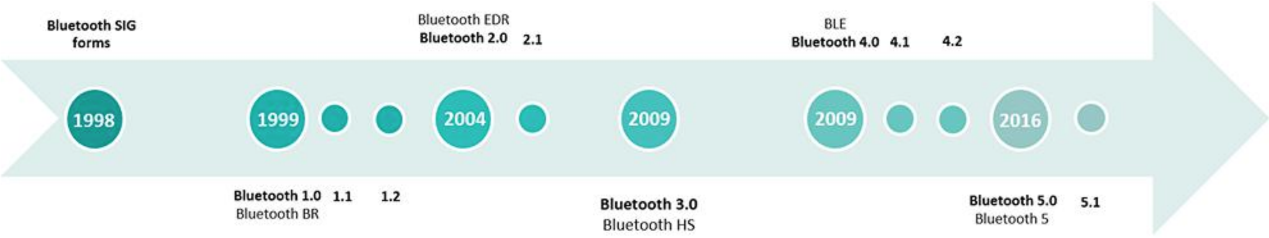
1. Thanks to the Bluetooth protocol, we can send and receive data without the tangle of cords and wires.

HISTORY

To better understand how Bluetooth BR/EDR and BLE differ, it's important to examine the history of these wireless technologies. Each of them was developed by the Bluetooth Special Interest Group (Bluetooth SIG), which manages all Bluetooth protocols. As developments are made, the Bluetooth SIG releases a new specification to introduce improvements. The timeline in *Figure 2* shows the Bluetooth specifications that have been released and where Bluetooth BR, Bluetooth EDR, BLE, and Bluetooth 5 fall within those specifications.

Bluetooth BR/EDR

Bluetooth BR was the first Bluetooth protocol developed. It implemented a unique method of using Gaussian frequency-shift keying (GFSK) to exchange data within the 2.4-GHz ISM band. This band was chosen because, unlike most frequency bands, a license isn't required to operate within it, so communication is free. Bluetooth BR quickly become popular because it provided a low-cost and low-power way



2. The timeline shows each Bluetooth specification release throughout the years.

to send and receive data wirelessly across short ranges at data rates up to 0.7 Mb/s.

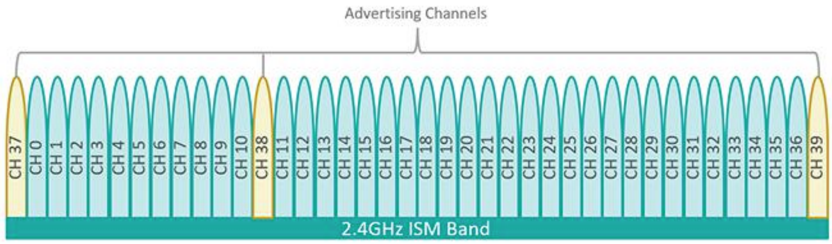
A few years later, a new specification, Bluetooth 2.0, was released that included the option for Bluetooth EDR. Bluetooth EDR allows data to be transferred two to three times faster than Bluetooth BR. That's because it employs differential quadrature phase-shift keying (QDPSK) and differential 8-level phase-shift keying (8DPSK) alongside GFSK. GFSK transmits one bit per symbol, whereas QDPSK transmits two bits per symbol and 8DPSK transmits three bits per symbol.

BLE

When BLE was first developed, it was, in fact, not even Bluetooth at all! It was developed by Nokia as a wireless technology called Wibree. It was designed to consume very little power (as well as be very low cost and easy to configure), making it the perfect solution for devices that run on small batteries.

Wibree included many techniques similar to Bluetooth BR/EDR, including operation in the 2.4-GHz ISM band, GFSK modulation, a channel scheme, and frequency hopping. The parallels between the two caused the Bluetooth SIG to adopt Wibree into its specification. It was released as a new low-energy extension called Bluetooth Low Energy (BLE). BLE made its first appearance in the specification Bluetooth 4.0.

Bluetooth 4.0 did not completely obsolete Bluetooth BR/EDR, but instead offered BLE in addition to Bluetooth BR/EDR. Consumer devices with BLE were often labeled as being Bluetooth Smart, whereas Bluetooth BR/EDR are labeled as Bluetooth Classic; however, these terms are no longer used to differentiate each protocol. Under this specification, radios could be developed to operate as a Bluetooth BD/EDR-only radio, a BLE-only radio, or a dual radio that supports both Bluetooth BR/EDR and BLE.



3. This is the channel scheme for BLE.

Bluetooth 5

Bluetooth SIG does its best to make improvements that match the evolution of technology, and one of the key advances that seems to be driving electronics is the Internet of Things (IoT). BLE has played a big role in growing IoT, but the Bluetooth SIG wanted to further enhance the capabilities of Bluetooth in IoT applications. The new advances to the original BLE technology were released in Bluetooth 5.0, which is being termed Bluetooth 5.

BLUETOOTH BR/EDR vs. BLE

Let's compare the similarities and differences between just Bluetooth BR/EDR and BLE. A good place to start is in the physical layer (PHY) of the protocols. The PHY contains the circuity used to modulate and demodulate analog signals and turn them into digital symbols. The differences in the PHY is one of the factors that makes each protocol geared toward specific applications. Four areas of the PHY where BR/EDR and BLE differ are the channel scheme, power consumption, latency, and throughput.

Channel Scheme

Both Bluetooth BR/EDR and BLE communicate in the 2.4-GHz ISM band, but they differ in the number of channels in which they divide the frequency band. Bluetooth BR/EDR divides the band into 79 channels spaced 1 MHz apart. BLE employs a simpler transmitter and receiver, so it divides the band into only 40 channels spaced 2 MHz apart.

One thing that both Bluetooth BR/EDR and BLE must deal with, regardless of the number of channels used, is interference. The 2.4-GHz ISM band is full of transmitters taking full advantage of the unlicensed band. To minimize interference, both Bluetooth BR/EDR and BLE employ frequency hopping where the radio operates on one channel for a brief period of time before hopping to another channel to continue communication.

BLE also adds another element to its channel scheme. BLE reserves three channels for a BLE radio to advertise that it wants to be discovered. The frequency of these three advertising channels were strategically chosen so that they didn't interfere with the three most frequently used Wi-Fi channels also operating in the 2.4-GHz ISM band. Once a connection is made, the radios will continue their communication on one of the other 37 channels. *Figure 3* depicts the channel scheme for BLE and shows where the three advertising channels are located within the frequency band.

Power

Conservation of energy is a key differentiator between Bluetooth BR/EDR and BLE—made obvious by the fact that BLE has "low energy" in its name! Bluetooth BR/EDR uses a maximum output power of 100 mW to transmit data up to approximately 10 to 100 m. This was fine in the days where most devices could be charged frequently. However, as the demand of products that can run off battery power for months or years without being charged increases, this type of output power will not suffice as it would quickly drain the battery.

RF SWITCHES

DC - 40 GHz

Type	Failsafe	Latching	Normally Open	Terminations	SMA	2.92mm	Type-N	7/16, 4.3-10	SC	High Power (CW)	Low PIM (dBc)	Cycle Life
SPDT	✓	✓	✓	50Ω, 2W	✓	✓	✓	✓	✓	2kW	-170	5M
Transfer	✓	✓			✓	✓	✓	✓	✓	2kW	-170	5M
SPMT*	✓	✓	✓	50Ω, 2W	✓	✓	✓	✓	✓	2kW	-170	5M

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BLE offers the perfect solution. It reduces the energy by only turning on the transmitter and receiver when they're needed to send or receive data, with a maximum power output of only 10 mW to transmit up to the same range. BLE also sends data in short bursts of packets. When packets aren't being sent, the radio sits idle, drawing little to no power. This process helps BLE live up to its name.

Latency

Another way BLE outperforms Bluetooth BR/EDR is in latency. It takes Bluetooth BR/EDR approximately 100 ms to be ready to send data. There's an additional 100-ms latency from when data is received at the transmitter to when it's available at the receiver. This can make for a rather noticeable delay in some cases. It also leads to higher power consumption because the extra time required to send data causes more energy from the battery to be used.

BLE offers much lower latency. It only takes 3 ms for BLE to be ready to send data. Also, the latency from when data is received at the transmitter to when it's available at the receiver is only 6 ms. This allows data to be sent more quickly and saves power.

Throughput

At this point, you might be wondering why anyone would chose Bluetooth BR/EDR over BLE. Well, where BLE lags behind Bluetooth BR/EDR is in throughput. Both Bluetooth BR/EDR and BLE employ GFSK, so theroetically, the maximum limit for the throughput is 1 Mb/s. However, factors such as protocol overhead, radio limitiations, and artifical software restrictions limit the actual throughput.

In practice, Bluetooth BR can reach a throughput up to 0.7 Mb/s, while Bluetooth EDR can achieve a throughput of 2.1 Mb/s. This is enough throughput for applications like streaming audio. Because BLE sends data in short bursts to conserve power, its throughput faces additional restrictions. It can only achieve a maximum throughput of 0.27 Mb/s. While this throughput isn't enough for streaming audio, it's more than enough to send sensor data that don't need to be transmitted constantly.

Through these four sections, it's clear that differences in the PHYs for each of these protocols causes a lot of differences in the operating parameters. *Table 1* summarizes the key parameters between Bluetooth BR/EDR and BLE.

Table 1: Bluetooth BR/EDR vs. Bluetooth BLE

	Bluetooth BR/EDR	BLE
Channel scheme	79 channels	40 channels
Max output power	100 mW	10 mW
Latency	100 ms	6 ms
Time to send data	100 ms	3 ms
Raw data rate	1 Mb/s; 2-3 Mb/s	1 Mb/s
Throughput	0.7 Mb/s; 2.1 Mb/s	0.27 Mb/s
Max range	~100 m	~100 m

TABLE 2: COMPARING BLUETOOTH 5 PHYS

	LE 1M	LE Coded S=2	LE Coded S=8	LE 2M
Symbol rate	1 Msample/s	1 Msample/s	1 Msample/s	2 Msamples/s
Raw data rate	1 Mb/s	0.5 Mb/s	0.125 Mb/s	2 Mb/s
Range multiplier	1X	~2X	~4X	~0.8X
Bluetooth 5 requirement	Mandatory	Optional	Optional	Optional

BLE 5.0

Bluetooth 5 uses the original low-power BLE technology but includes some new enhancements. One of the biggest enhancements is the introduction of three PHYs that can be selected to improve the maximum range or throughput. Bluetooth 5 also adds enhancements that improve advertising.

To better understand how Bluetooth BR/EDR and BLE differ, it's important to examine the history of these wireless technologies. Each of them was developed by the Bluetooth Special Interest Group (Bluetooth SIG), which manages all Bluetooth protocols.

The first PHY that Bluetooth 5 offers is called LE 1M. This is the same PHY used for BLE in the Bluetooth 4.2 specification, so most of its parameters will match those shown in *Table 1*. LE 1M is the only PHY that's mandatory in Bluetooth 5. The other two PHYs are optional.

Bluetooth 5 integrates a coded PHY as one of the optional PHYs, which can extend the range of communication. The coded PHY achieves longer range by introducing redundancy to get some processing gain, instead of increasing the power of the transmitter.

Bluetooth 5 introduces additional redundant bits that are used to determine the correct value of a bit. The coded PHY comes in two variations: S=2 and S=8. S=2 sends two symbols per bit, which decreases the throughput by a factor of two, but theoretically doubles the range. S=8 sends eight symbols per bit. Though this decreases the raw throughput to 125 kb/s, it approximately quadruples the range. In practice, the actual range will be a little lower than the theoretical values, but this method still helps to achieve a much larger range.

Range isn't important to all end applications, so Bluetooth 5 made sure to include something for applications where throughput is more important than range. There's a double-data-rate option called LE 2M, which increases the raw data rate to 2 Mb/s. It allows for data to be sent at a maximum actual throughput of 1.4 Mb/s. This means that data can be transferred even faster than Bluetooth BR with a lower power consumption.

Table 2 compares the three PHYs available in Bluetooth 5 to show how they differ in terms of raw data rate and range.

Bluetooth 5 offers a lot of enhancements to advertising. It still utilizes the same channel scheme as BLE, but includes options for additional advertising on all 40 channels instead of just three. In Bluetooth 5, small advertising packets can be transmitted on the three advertising channels used in BLE. However, they can now point to larger advertising packets (up to 255 octets) that can be sent on the additional 37 channels. This also helps reduce the amount of content on the three primary advertising channels. Bluetooth 5 also includes enhancements for advertising packet chaining, periodic advertising, and a lower minimum advertising interval.

APPLICATIONS

The differences in the PHY are key to determining which protocol best suits each application. We've covered many technical details in the last few sections that can be applied to better understand the ideal use of each protocol.

Let's start with Bluetooth BR/EDR. It compromises packet latency and power for a higher throughput rate, so it is best suited for applications where throughput is a critical specification. This makes it the ideal protocol for applications like streaming or sending large amounts of data. Common applications are wireless headsets *(Fig. 4)* and point-to-point applications.

4. Wireless headsets represent one example of a common application for Bluetooth BR/EDR.

BLE is best suited for applications that only need to send small amounts of data whereby the device can wake up, transmit the data it needs to, and then go back to sleep. BLE's low power consumption makes it a must for devices that are powered from a small battery. An application that's well-suited for BLE is a heart-rate monitor. The heart-rate monitor doesn't need to send data often, but it does need to run for an extended period on a battery. As the field of IoT continues to develop, we will likely see many new applications of BLE.

It's important to note that when you're choosing a Bluetooth-enabled device for your application, you need to be sure you select an IC that supports the protocol you plan to use. You can't buy an IC at random and assume it supports both Bluetooth BR/EDR and BLE.

(Continued on page 52)

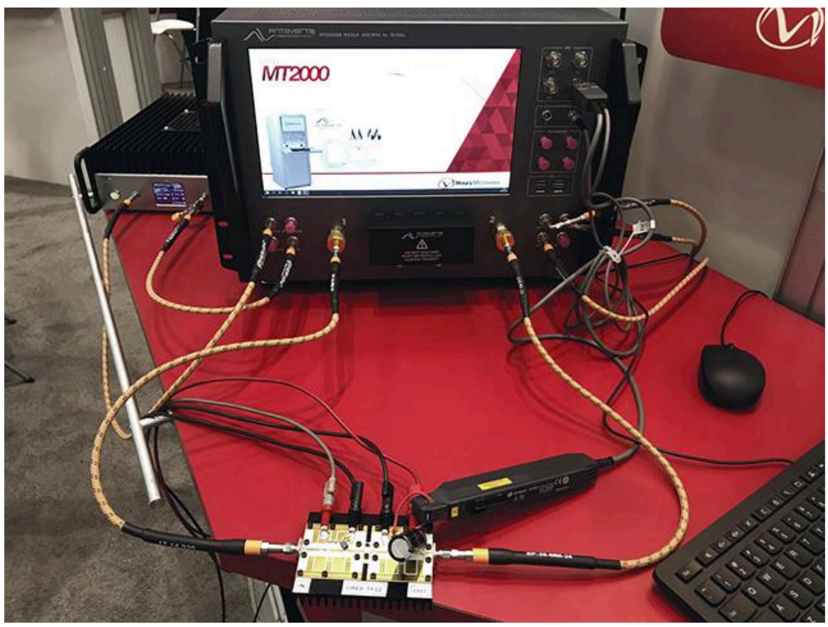
CHRIS DeMARTINO | Editor

Long-Standing Company Reveals Many New Tricks at IMS

Maury Microwave recently unveiled a host of new solutions, such as updated mixed-signal active load-pull systems and characterized device calibration kits.

Anyone involved with RF/microwave device characterization is likely to be familiar with Maury Microwave *(www.maurymw.com)*, one of the venerable companies in the RF/microwave industry. With a history that dates to 1957, the company is a well-known provider of device characterization solutions along with both precision calibration and interconnect products. While Maury Microwave might be considered "old" in terms of age, the company presented some new "tricks" at the recent IMS 2019.

One of the company's focal points at IMS was its MT2000 Series of mixed-signal active load-pull systems, which was recently updated *(Fig. 1)*. The MT2000 systems now deliver 1,000 MHz of wideband impedance control for 5G and Wi-Fi device characterization.



1. On display at IMS 2019 were the MT2000 Series mixed-signal active load-pull systems, which now provide 1,000 MHz of wideband impedance control.

These systems are essentially a turnkey solution—one MT2000 can replace multiple instruments used in counterpart test systems, including a vector network analyzer (VNA), vector signal analyzer (VSA), oscilloscope, modulated signal sources, and automated impedance tuners. Maury Microwave claims that the MT2000 Series is "the only commercial load-pull solution suitable for 5G measurements" and that it "overcomes the well-known limitations of passive load-pull and automated impedance tuners."

The MT2000 solutions can perform load pull at speeds as high as 1,000 impedance/power states per minute under specified conditions. They cover a frequency range from 1 MHz to 40 GHz. The MT2000 systems are intended for research and development, design verification test (DVT), and production test environments.

Maury Microwave also recently launched the AM3100 pulsed source-measure-unit (SMU) system in partnership with AMCAD Engineering *(www.amcad-engineering.com) (Fig. 2)*. The AM3100 is a standalone pulsed IV system for load-pull and general-purpose test applications. It can be used to bias transistors or circuits in pulsed conditions to avoid self-heating and ensure quasi-isothermal conditions during measurements.

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2. The AM3100 system can be used to pulse the bias of power amplifiers.

3. The CK50 Series calibration kits leverage individually characterized calibration standards.

The AM3100 consists of the AM3103 control unit and AM3121 drain pulse SMU. Inside the AM3103 box is the AM3111 gate pulse SMU, which is a four-quadrant dc or pulsed-voltage source. The AM3111 has a voltage range of ±25 V and provides two current ranges: ±5 and ±200 mA. Pulse widths can be as low as 1 µs.

The AM3121 power probe is dedicated to biasing transistor drains. It's optimized for high-power-pulsed measurement applications—specifically, the AM3121 is rated for voltages as high as 120 V and pulsed currents as high as 30 A. The AM3121 can be used either for load-pull applications or as a general-purpose pulsed SMU.

Other key attributes of the AM3100 are internal and external synchronization and triggering. The system can be controlled through direct SCPI commands via USB or Ethernet. In addition, the AM3100 features multiple levels of embedded protection circuitry that includes a fast short-circuit current breaker (electronic fuse). On top of that, the AM3100 is a highly integrated solution—a single AM3100 can replace multiple instruments in corresponding test setups like power supplies, multimeters, and an oscilloscope.

CALIBRATION TOOLS GET THE SPOTLIGHT

Maury Microwave also made some new updates to its portfolio of calibration products. For example, the company unleashed its Insight software platform, which Maury boasts "is the industry's first commercial software suite designed to empower VNA users and help them make better decisions." The firm also maintains that "Insight represents a paradigm shift in the way users approach VNA calibration, validation, measurement, visualization, and analysis."

Maury obviously has some high words for the Insight software platform, but what exactly does it offer? Foremost, Insight is a single software platform that can be used with most commercial VNAs. One feature is that it enables users to define mechanical calibration standards from any vendor, which can then be used with all VNAs.

The company also says that Insight makes it possible to avoid common errors thanks to a simplified calibration process driven by an intuitive graphical user interface (GUI) and wizard. Users can validate VNA calibration using airlines and individually characterized verification kits. In addition, S-parameters can be measured and S2P files can be saved for sharing. Additional features include advanced visualization and analysis tools that allow for a better understanding of the measurement results.

The "tricks" don't stop there, though. Maury Microwave also revealed its CK50 Series characterized device (CD) calibration kits, which consist of individually characterized short, open, and fixed-load standards *(Fig. 3)*. Each kit comes with custom S-parameter files that are used for VNA calibration instead of a generalized polynomial definition. The result, according to Maury, is the accuracy of thru-reflect-line (TRL) calibrations combined with the ease of use of fixed-load short-open-load-thru (SOLT) calibrations.

Lastly, the new CK60 Series verification kits are intended to allow users to validate one- and two-port VNA calibration for well-matched and mismatched devices under test (DUTs). Replete with individually characterized verification standards (short, load, airline, mismatch airline), each kit is used to validate calibrations by comparing the S-parameters of the individual verification standards measured by the user with the S-parameters measured at the factory.

The CK50 Series calibration kits, CK60 Series verification kits, and Insight software can be used in combination. When utilized in tandem, users are able to quantify the uncertainty contribution of the calibration kit with respect to the overall measurement uncertainty and employ overlapping uncertainty boundaries to validate a VNA calibration with increased confidence. mw

CHRIS DeMARTINO | Editor

Multiport VNAs Grapple with Complex Test Scenarios

This new line of multiport vector network analyzers makes it possible to perform a large number of simultaneous measurements.

As one would expect, Rohde & Schwarz *(www.rohde-schwarz.com)* came to IMS 2019 in full force, showcasing various test-and-measurement solutions for all to see. One solution that grabbed the spotlight was its new family of ZNBT multiport vector network analyzers (VNAs), which provides users with as many as 24 test ports *(see figure)*.

The architecture of the ZNBT VNAs allows for various device-under-test (DUT) ports to be stimulated simultaneously, making it possible for users to test multiple DUT paths or multiple DUTs all at once. Furthermore, since the architecture is geared for parallel signal and data acquisition, the instruments can not only measure S-parameters, but also perform phase-synchronous measurements.

Rohde & Schwarz offers four versions of the ZNBT VNAs: the ZNBT8, ZNBT20, ZNBT26, and ZNBT40. The ZNBT8 model has a measurement frequency range of 9 kHz to 8.5 GHz, while the ZNBT20's frequency range covers 100 kHz to 20 GHz. The ZNBT26 has a measurement frequency range extending from 100 kHz to 26.5 GHz. And the ZNBT40 offers the highest frequency performance—it covers a 100-kHz to 40-GHz range.

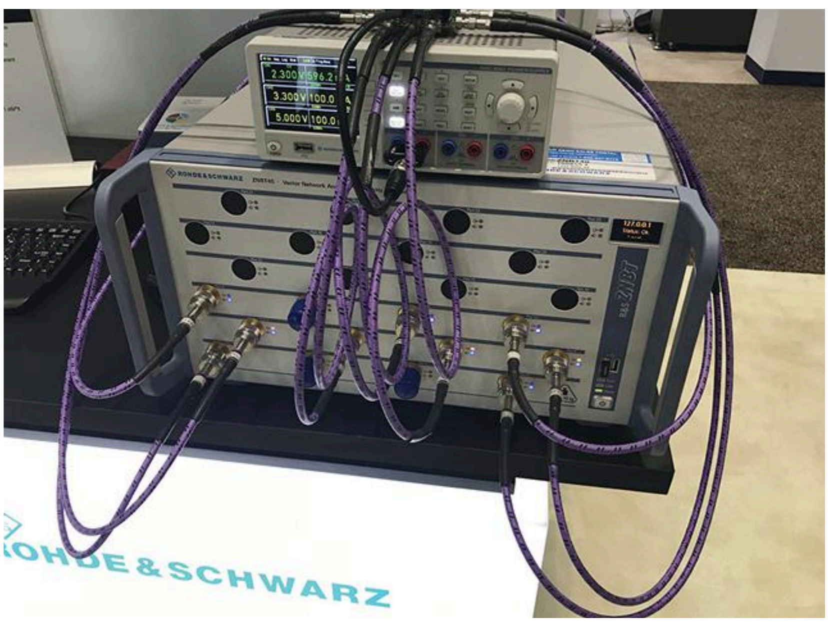
The ZNBT8 base unit comes with 4 ports, but it's possible to upgrade to 8, 12, 16, 20, or 24 ports. The ZNBT20, ZNBT26, and ZNBT40 base units are each built with 8 ports, but customers have the option to upgrade to 12, 16, 20, or 24 ports. The ZNBT8 is built with type-N test port connectors, while 3.5-mm test port connectors are found on the ZNBT20. The ZNBT26 and ZNBT40 both come with 2.92-mm test port connectors.

When set to 201 measurement points with a 900-MHz center frequency and a 200-MHz span, the ZNBT8's sweep time is less than 2.5 ms (1-MHz measurement bandwidth). Under the same conditions, the sweep time of the ZNBT20 is less than 3 ms. Both the ZNBT26 and ZNBT40 achieve sweep speeds of under 3.5 ms with the same settings applied.

Dynamic range is another key aspect of the ZNBT VNAs. Specifically, the ZNBT8 can achieve a typical dynamic range as high as 140 dB with a 10-Hz measurement bandwidth. In addition, Rohde & Schwarz offers an option to extend the dynamic range (145 dB typical) to help support high-blocking-filter measurements.

In terms of the power range of the test port outputs, the ZNBT8 has a specified range of −55 dBm to either +8, +10, or +13 dBm, depending on the frequency band. The company also offers an option to extend its power range down to −85 dBm. The same option exists for the other three models.

Rohde & Schwarz maintains that the ZNBT VNAs are easy to integrate into automated test systems, such as phased-array antenna measurement scenarios. mw



At IMS 2019, Rohde & Schwarz displayed this ZNBT40 multiport VNA, which covers a frequency range of 100 kHz to 40 GHz.

(Continued from page 26)

extreme-bandwidth and performance demands of emerging mmWave applications, such as 802.11ay, while providing flexibility for new applications like 5G NR. *Figure 4* shows the test bed that was displayed at the recent IMS trade show in Boston. In this demonstration, the UXR directly digitizes and demodulates an extreme-bandwidth signal centered at 61.56 GHz with 8.64 GHz of channel bandwidth.

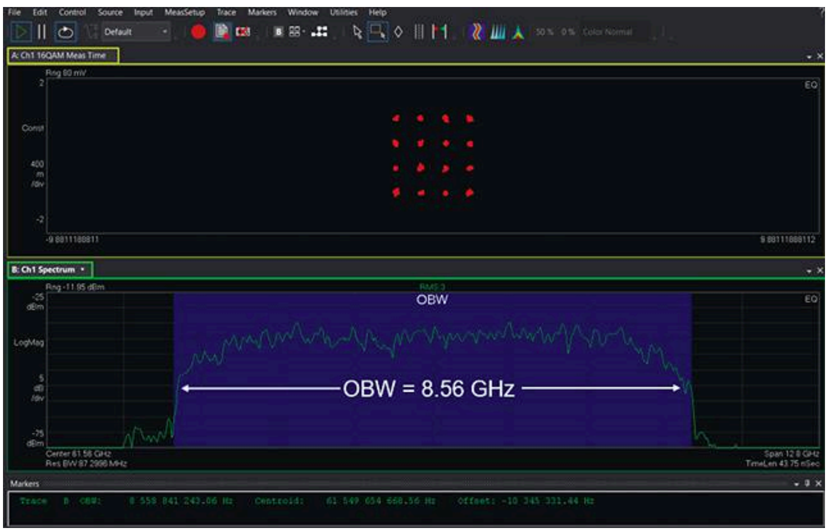
A multichannel, eight-bit Keysight M8195A 65-Gsample/s arbitrary waveform generator (AWG) is used to generate wideband modulated IF signals (upper left of *Figure 4*). Although the M8195A has an analog bandwidth of 25 GHz, an IF frequency anywhere from 4 to 5 GHz is typically used—that's high enough to filter the undesired image product after upconversion to the mmWave frequency band. This also keeps the IF frequency low enough to achieve optimal EVM performance due to the oversampling processing gain with the M8195A's sampling rate.

A compact V-band (50-75 GHz) upconverter from Virginia Diodes (VDI) *(www.vadiodes.com)* is used to upconvert the 5-GHz IF from the M8195A to the 60-GHz frequency band. This upconverter uses an effective ×2 multiplication factor for the LO frequency, providing improved SNR and lower conversion loss for the upconverted signal relative to traditional systems that use a ×6 multiplication factor. Also, the ×2 multiplication factor enables the use of a high-quality, low-phase-noise LO source like the PSG with option UNY (as shown in the lower left of *Figure 4*). VDI E-band (60 to 90 GHz) and W-band (75 to 110 GHz) upconverters could also be utilized to address applications for other frequency bands.

A VDI amplifier, VDI bandpass filter, and a horn antenna combine to transmit the signal over the air. The signal was centered at 61.56 GHz with a 7.04-GHz symbol rate and 8.64-GHz channel bandwidth using an RRC filter alpha of

Figure 4 shows the test bed that was displayed at the recent IMS trade show in Boston. In this demonstration, the UXR directly digitizes and demodulates an extreme-bandwidth signal centered at 61.56 GHz with 8.64 GHz of channel bandwidth.

4. This is a wideband research-and-development mmWave test bed with a four-channel 110-GHz UXR.



5. The UXR measurement revealed an OBW of 8.56 GHz.

0.22, like the simulation case study previously discussed.

Two horns are located on the receive side. The signal is received with the first receive horn antenna and fed into one of the four channels on the new 110-GHz UXR oscilloscope (shown on the right of *Figure 4)* to directly digitize and demodulate the 61.56-GHz signal. A second channel on the UXR was used to simultaneously measure the 5-GHz IF.

VSA software is connected to the UXR oscilloscope to perform the demodulation. *Figure 5* shows the VSA measurement result for the mmWave signal at 61.56 GHz with a symbol rate of 7.04 GHz and channel bandwidth of 8.64 GHz.

The 16-QAM constellation with adaptive equalization enabled can be seen at the top of *Figure 5*. The constellation shows little dispersion, reflecting the performance that's achievable for extreme bandwidths using this test bed with the UXR to directly digitize and analyze the signal. The spectrum is shown on the bottom. The measured OBW in the blue shaded region is 8.56 GHz.

Note: A *Microwaves & RF* video of the actual IMS demo can be viewed at *https://www.linkedin.com/feed/update/urn:li:activity:6554713469789224960/.*

Note: A *Microwaves & RF* video of the actual IMS demo can be viewed at *https://www.linkedin.com/feed/update/urn:li:activity:6554713469789224960/.*

SUMMARY

This article discussed some of the considerations in designing and testing hardware for extreme-bandwidth applications and highlighted these considerations using a simulation case-study. A new research-and-development test bed for emerging mmWave applications was presented. The test bed uses the UXR ultra-performance real-time 110-GHz oscilloscope, which enables extreme-bandwidth mmWave signals (up to 110 GHz) to be directly digitized and analyzed. This new capability provides flexibility and scalability to tackle a multitude of mmWave frequency bands, extreme frequency bandwidths, and multiple channels for emerging mmWave applications.

The UXR was shown to directly digitize and demodulate mmWave signals in the 60-GHz frequency band with 8.64 GHz of channel bandwidth, demonstrating its ability to tackle extreme bandwidths for emerging mmWave applications. In addition, the UXR can be used for wide-bandwidth mmWave applications in the 71-to-76- and 81-to-86-GHz frequency bands. mw

GREG JUE, a 5G system engineer at Keysight Technologies, focuses on emerging mmWave applications. Greg has worked in Keysight's 5G team, aerospace/defense applications team, high-performance scopes team, as well as in EEsof, specializing in 5G, WLAN 802.11ac, LTE, WiMAX, aerospace/defense, and SDR applications. Greg wrote the design simulation section in Agilent Technologies' LTE book, and has authored numerous articles, presentations, application notes, and whitepapers, including Keysight's "Implementing a Flexible Testbed for 5G Waveform Generation and Analysis." He pioneered combining design simulation and test solutions at Agilent Technologies and has authored many application notes on combining simulation and test for emerging technologies. Before joining HP/Agilent in 1995, he worked on system design for the Deep Space Network at the Jet Propulsion Laboratory, Caltech University.

REFERENCE

1. IEEE 802.11ay D3.0 Feb.2019.

(Continued from page 21)

In terms of RF/microwave design, the RFPro EM simulator is one of the new features added to PathWave ADS 2020. It allows for instant EM access during design with a single integration into ADS and Cadence *(www.cadence.com)* Virtuoso. According to Keysight, RFPro is intended for designers who need to routinely perform EM/circuit co-simulation to accurately account for the parasitic effects of physical interconnects on their circuits.

The company maintains that "RFPro's instant and correct setup of EM/circuit co-simulation without layout modification makes running EM analysis as easy as circuit simulation. Fast and correct analysis setup—regardless of the size of the problem—allows for quick, interactive EM and EM/circuit co-simulation on demand."

2. RFPro is Keysight's new EM simulator for RF design.

PathWave ADS 2020 also includes new 5G virtual test benches (VTBs) that are updated with the latest 5G NR tests. In addition, workspace management tools have been enhanced. On top of that, PathWave ADS 2020 contains stackable printed-circuit-board (PCB) vias. They allow designers to create vias that realistically match industry-standard PCB-package-drill technology.

PathWave System Design (SystemVue) 2020 has an improved RF link capability that connects digital and RF domains in system simulations. With PathWave System Design 2020, integration with MATLAB and Simulink workflows is enhanced, too. In addition, it upgrades connections to PathWave circuit simulators, and fosters better real-world modeling of phased arrays. An updated 5G NR library and a new complex modeling environment for automotive radar are other enhancements to PathWave System Design 2020.

In terms of device modeling, PathWave Device Modeling (IC-CAP) 2020 offers extraction flows for three major technologies: GaN HEMT, IGBT, and Si/SiC MOSFET. Other new features include a new extraction suite for discrete devices and a redesigned user interface and data viewer. ■

DISTRIBUTED PA Accepts Frequencies Far and Wide

MICROCHIP TECHNOLOGY, through its Microsemi *(www.microsemi.com)* subsidiary, now offers the MMA052PP45 gallium-arsenide (GaAs) monolithic-microwave-integrated-circuit (MMIC) pseudomorphic high-electron-mobility-transistor (pHEMT) distributed power amplifier (PA) *(see figure).* This self-biased device handles a frequency range of dc to 24 GHz, providing 14 dB of gain with a positive slope.

The MMA052PP45 distributed amplifier operates from dc to 24 GHz.

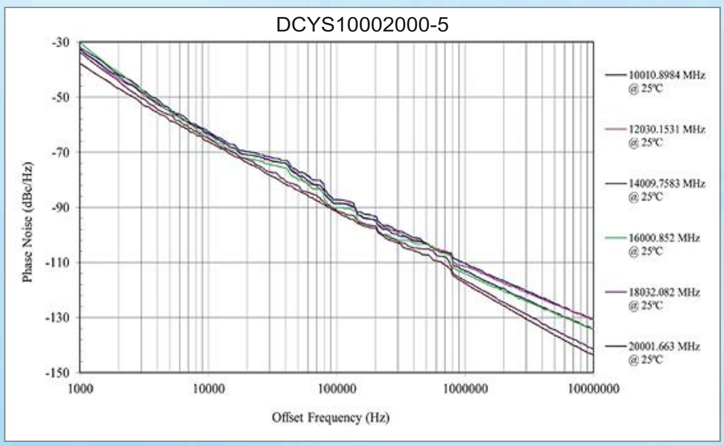
At 10 GHz, the MMA052PP45 achieves a noise figure of 3.5 dB. At the same frequency, its output power at 3-dB compression is +27 dBm with a typical output third-order intercept point (OIP3) of +35 dBm. The amplifier, a self-biased device with 16 selectable drain current states, comes in a 4.5- × 4.5-mm quad-flat no-leads (QFN) package. Input and output ports are both matched to 50 Ω. The MMA052PP45 is well-suited for test-and-measurement, wideband aerospace and defense, and high-linearity microwave radio applications.

Since the MMA052PP45 has a positive gain slope, it can help system designers compensate for high-frequency loss from passive components, as well as other amplifiers with a negative gain slope. The MMA052PP45 was demonstrated at IMS 2019, which gave visitors an opportunity to see it in action. ■

L to K Band Ultra-Wideband

Voltage Controlled Oscillators

Model Number	Frequency	Phase Noise @ 10 kHz offset	Phase Noise @ 100 kHz offset	Tuning Voltage	Output Power
	(GHz)	(dBc/Hz)	(dBc/Hz)	(V)	(dBm)
DCO100200-5	1 - 2	-95	-117	0 - 24	+1
DCYS100200-12	1 - 2	-105	-125	0 - 28	+4
DCO200400-5	2 - 4	-90	-110	0 - 18	-2
DCYS200400P-5	2 - 4	-93	-115	0 - 18	0
DCO300600-5	3 - 6	-75	-104	0 - 16	-3
DCYS300600P-5	3 - 6	-78	-109	0 - 16	+2
DCO400800-5	4 - 8	-75	-98	0 - 15	-4
DCO5001000-5	5 - 10	-80	-106	0 - 18	-2
DCYS6001200-5	6 -12	-70	-94	0 - 15	> +10
DCYS8001600-5	8 - 16	-68	-93	0 - 15	> +10
DCYS10002000-5	10 - 20	-65	-91	0 - 18	> +10



Features:

> *Superior Phase Noise*
> *High Output Power*
> *Small Size Surface Mount Package*
> *Vcc: 5 volts*
> *Future models up to 30 GHz*

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(Continued from page 40)

As mentioned before, Bluetooth BR/EDR and BLE use different PHYs, so you will need to be sure the IC you select supports the PHY for the protocol you plan to use, or it supports both PHYs if you believe both could be beneficial in your application.

Bluetooth 5, which promises extensive improvements, has begun to appear in popular technologies. Many popular smartphones are already offering Bluetooth 5 support. As with most wireless protocols, it has taken a few years for Bluetooth 5 to be integrated into most electronics. However, it's becoming evident that the time for Bluetooth 5 is now.

If you want to be ready for Bluetooth 5, a Bluetooth 5-compatible microcontroller is needed to address the key requirements. One example is Maxim's MAX32666GWPBT, which has dual Arm Cortex-M4 cores and separate hardware dedicated to running the Bluetooth stack *(Fig. 5)*. This leaves the two cores entirely free for your application. Another option is the MAX32665 low-power Arm Cortex-M4 with floating-point unit (FPU) microcontroller with Bluetooth 5. This microcontroller includes power-management features such as a single-inductor multiple-output (SIMO) switched-mode power supply and dynamic voltage scaling to minimize power consumption, and thus is well-suited for battery-operated systems.

CONCLUSION

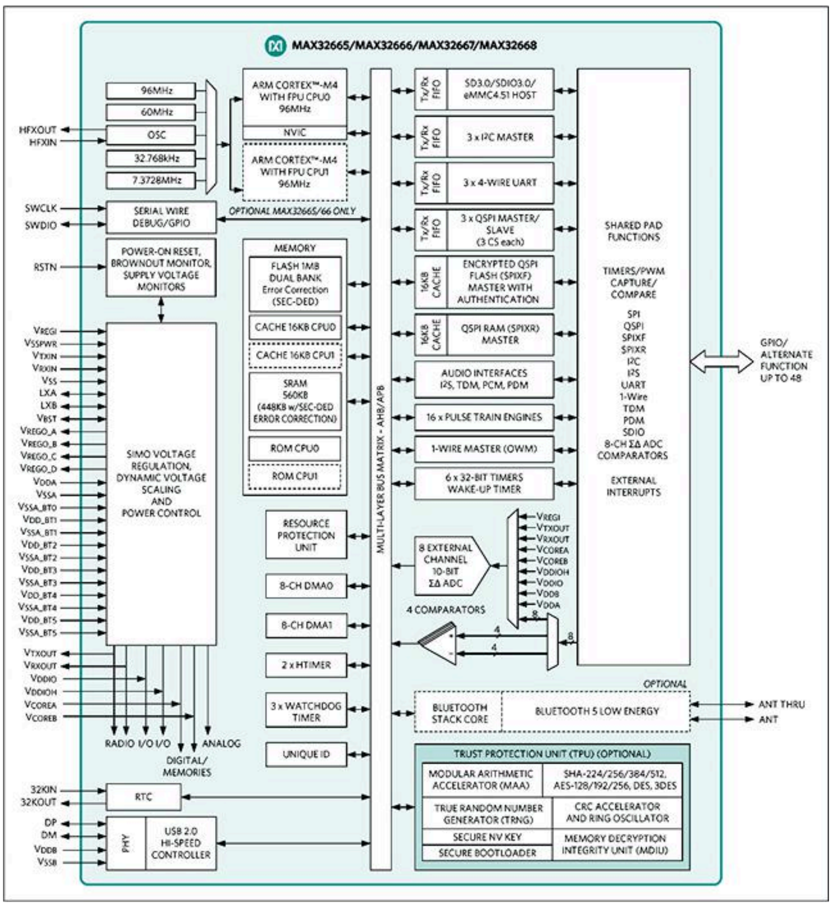
As with any good lesson, the best way to test your knowledge is with a quiz. Challenge yourself to go back to the applications listed in the beginning of this article and see if you can determine which Bluetooth protocol each one uses. If you get stuck, the answers are below…

Bluetooth BR/EDR is good for applications where the maximum throughput is critical. It can consume a significant amount of power, so it's not good for applications that require extended battery life. It also has greater latency and takes longer to set up the connection to send data. Consequently, it's not meant for applications that transmit and receive infrequent, short messages. You can find it used to connect a phone to a car stereo to play music or send files between computers or tablets. Both applications require high throughput and can afford to consume some power.

BLE is used when low power consumption is critical and high throughput isn't required. It can send data very quickly and has a low latency. You will find it used in applications that need to run for a long time on a small battery or those that don't need to send data often. BLE is used in home security systems like smart door locks and in fitness trackers.

Even though these technologies are all called Bluetooth, they truly offer different strengths to the world of wireless electronics. To determine which protocol is best suited for your applications, make sure to look back at the differences in the PHY listed in *Table 1* to see where each protocol excels. Also, be on the lookout for how Bluetooth 5 will change the industry in the next few years with its higher throughput, longer range, and extended advertising capabilities. mw

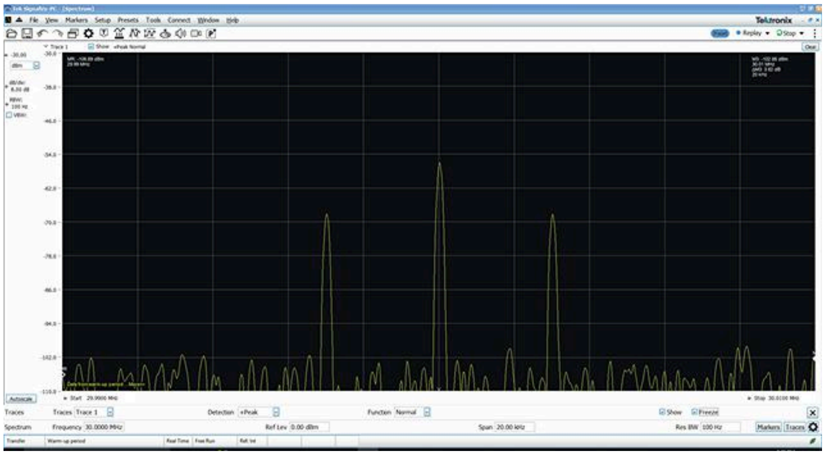
SAMANTHA MOREHEAD joined Maxim Integrated as an Associate Member of Technical Staff after earning her BSEE from Santa Clara University. Samantha provides design assistance in addition to technical training and support for all of Maxim Integrated's broad market products.



5. The MAX32666GWPBT microcontroller targets Bluetooth 5 applications.

(Continued from page 7)

Students who begin their RF journey at QCC have the luxury of getting their hands on modern test equipment that isn't found at every school.



6. In the frequency-conversion experiment, students are able to view the spectrum of the mixer's output using the RSA306B spectrum analyzer and SignalVu-PC software.

nents for lab experiments to familiarize students with components they are likely to work with once they become part of an organization." QCC has built its own inventory that includes components from vendors like Mini-Circuits *(www.minicircuits.com)* and JFW Industries *(www.jfwindustries.com) (Fig. 3).*

Haro continues, "We are moving from an all-written test evaluation during the semester to a two-part evaluation. This involves one written part for problem-solving and calculations and a second part for a hands-on evaluation in which students use off-the-shelf components and utilize the equipment to solve an RF problem."

In one experiment, students receive a hands-on introduction to VNAs. Here, students must first build a simple filter (Pi or T network) by soldering components onto a printed-circuit-board (PCB) themselves. The PCBs are built in-house, since QCC has its own equipment from LPKF *(www.lpkf.com) (Fig. 4).* After measuring their own filter, students must then measure a Mini-Circuits bandpass filter. In the end, students not only get introduced to VNAs and filters, they also get to solder themselves (which is not always a pretty sight) *(Fig. 5).*

A later lab experiment that covers frequency conversion incorporates the filters built in the VNA experiment (at least the good ones). The setup was already shown in *Figure 2*. "Students are presented with an RF signal that's broadcast in one of the ISM bands," explains Haro. "They need to downconvert the signal to drive an analog-to-digital converter (ADC). Students must choose a mixer and a filter that will help them isolate the frequency of interest. They also need to determine a low- or high-side injection for the local oscillator (LO). Students then print the spectrum with markers to denote the RF, LO, sum, and difference frequencies.

"And lastly, the signal of interest, which is AM modulated, has to be characterized in the frequency domain *(Fig. 6).* Students must write the mathematical expression for the modulated signal. In the end, students are evaluated on their answers, performance, and confidence."

Needless to say, QCC is taking RF education very seriously. Students who begin their RF journey there have the luxury of getting their hands on modern test equipment that isn't found at every school. If you're looking for a college that's trying to help cultivate the next generation of RF engineers, QCC is one place doing just that. mw

Low-Noise Amplifier Boosts 24 to 44 GHz

MINI-CIRCUITS' MODEL ZVA-24443G1+ is a coaxial, wideband low-noise amplifier (LNA) with outstanding gain and noise-figure performance from 24 to 44 GHz. It provides 45-dB small-signal gain with ±2.5-dB gain flatness across the full 20-GHz bandwidth, with 1.7-dB typical noise figure and +20-dBm output power at 1-dB compression (P1dB) from 24 to 44 GHz. Ideal for mmWave test and applications in automotive electronics and 5G communications systems, the broadband amplifier operates from a single voltage, from +9 to +15 V dc. The rugged amplifier is fortified by built-in protection from overvoltage, reverse-voltage, and in-rush-current conditions. The RoHS-compliant amplifier comes in a rugged housing measuring just 1.80 × 2.00 × 0.69 in. with 2.92-mm coaxial connectors; an optional heatsink attachment is also available. The model ZVA-24443G1+ is designed for use at operating temperatures from –40 to +85°C.

MINI-CIRCUITS, P.O. Box 350166, Brooklyn, NY 11235-0003; (718) 934-4500
https://www.minicircuits.com/WebStore/dashboard.html?model=ZVA-2443G1%2B

MMIC Gain Block Conquers 22.0 to 43.5 GHz

THE TSS-44+ GAAS MMIC gain block from Mini-Circuits has typical small-signal gain of 15.8 dB or more across a wide bandwidth of 22 to 40 GHz and as much as 10-dB gain to 43.5 GHz. The gain remains flat within ±0.9 dB from 20 to 40 GHz. Well-suited for commercial 5G applications as well as in aerospace and defense radar and electronic-countermeasures (ECM) systems, the broadband gain block offers noise figure of typically 3.7 dB or better from 20 to 40 GHz and typically 4.2 dB at 43.5 GHz. Directivity is typically 28 dB from 22.0 to 43.5 GHz, while input return loss is typically 9 dB or better from 20 to 40 GHz. Output return loss is typically 7 dB or better from 22 to 40 GHz. The durable gain block features efficient, low current consumption of 22 mA from a typical +4-V dc supply, with output power at 1-dB compression that rises with frequency, from +1.2 dBm at 22 GHz to +8.2 dBm at 43.5 GHz. The output third-order intercept (OIP3) also rises with frequency, from +10.1 dBm at 22.0 GHz to +15.9 dBm at 43.5 GHz. The versatile amplifier includes an internal shutdown feature that makes it possible to shut down the amplifier within 10 μs of sending a control signal. Thus, it leads to enhanced safety and power conservation in circuit and system designs, especially for pulsed applications requiring fast shutdown times. The broadband MMIC gain block is supplied in a RoHS-compliant, 12-lead MCLP package measuring just 3 × 3 mm and is designed for operating temperatures from –40 to +85°C.

MINI-CIRCUITS, P.O. Box 350166, Brooklyn, NY 11235-0003; (718) 934-4500, https://www.minicircuits.com/WebStore/dashboard.html?model=TSS-44%2B

Coaxial Highpass Filters are Reflectionless to 11.5 GHz

MINI-CIRCUITS' MODEL VXHF-392+ high-pass filter has a low-loss passband to 11.5 GHz with a high-rejection stopband of dc to 3940 MHz. Thus, it's a good fit for commercial communications applications such as Wi-Fi systems as well as military and aerospace systems. The filter features a novel topology with stopband impedance matched to 50 Ω to absorb rejected signals internally rather than reflect them back to the source. It provides more than 14.5-dB typical stopband rejection through 2.45 GHz with typical VSWR of 1.60:1. The passband insertion loss is typically 1.8 dB with typical VSWR of 2.30:1. Multiple filters can be cascaded for higher rejection. The filter, which is designed for operating temperatures from –55 to +100°C, can handle as much as 2 W passband input power (0.5 W stopband power) and comes in a rugged package measuring 0.41 × 1.43 × 0.312 in. with SMA connectors.

MINI-CIRCUITS, P.O. Box 350166, Brooklyn, NY 11235-0003; (718) 934-4500, https://www.minicircuits.com/WebStore/dashboard.html?model=VXHF-392%2B

Fast-Switching Synthesizer Tunes 0.5 to 18.0 GHz

THE VMESG-18 IS a modular VME frequency synthesizer capable of switching frequencies in 1-Hz steps with 200-µs tuning steps from 0.5 to 18.0 GHz. It exhibits –55 dBc harmonics and –60 dBc spurious levels with a phase-noise floor of –138 dBc/Hz. The single-sideband (SSB) phase noise is –100 dBc/Hz offset 100 kHz from an 18-GHz carrier and –90 dBc/Hz offset 1 kHz from a 10-GHz carrier. The frequency synthesizer provides signals at an output level of +11 dBm, flat within ±1 dB across the frequency range. It's available with a wide range of control interfaces, including RS-232, Ethernet, GPIB, and BCD interfaces.

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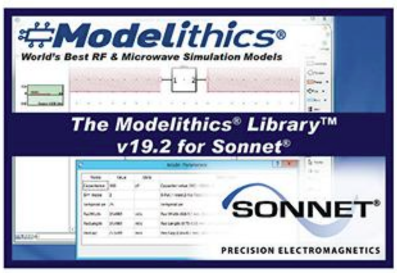
New Models Empower EM Simulation Software

THE LATEST VERSION of the Modelithics Library for Sonnet, version 19.2, is compatible with the new version 17 of the Sonnet full-wave electromagnetic (EM) simulation software. It features more than 75 new models and access to the Modelthics Substrate Library for models of leading circuit substrate materials. Sonnet/Modelithics users can now take advantage of more than 350 models from more than 30 suppliers, including capacitor, inductor, and resistor models. New attenuator models are also available in the SLC (system level component) Library for devices, from leading attenuator suppliers such as Aeroflex, ATC, Barry Industries, and Mini-Circuits.



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75-Ω DC Block Spans 10 to 3000 MHz

MODEL 879-126-BLK IS a 75-Ω dc block with a frequency range of 10 to 3000 MHz that's capable of handling blocking voltage as high as 50 V dc. It exhibits maximum VSWR of 1.40:1 across the full frequency range, with maximum insertion loss of only 0.5 dB. The dc block is well-suited for modulation leakage suppression and for improving system signal-to-noise ratio (SNR). It's equipped with male and female F coaxial connectors. Additional dc blocks for 50-Ω applications are available with BNC, Type N, TNC, and SMA coaxial connectors.

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Power Dividers Reach 67.0 GHz

A LINE OF high-frequency power dividers with 19 new models features components operating to 67.0 GHz in two- and four-port versions. Available with a variety of coaxial connectors, including SMA, 1.85-, 2.4-, and 2.92-mm connectors, the power dividers feature low loss through mmWave frequencies for such applications as 5G and satellite communications (satcom) systems. As an example, model FMDV1056 is a two-way power divider with less than 7.8-dB insertion loss from dc to 50 GHz. It's capable of handling CW input power levels to 0.5 W (+27 dBm) and peak input power levels to 5 W. The resistive, 50-Ω power divider maintains amplitude balance within ±0.2 dB and phase balance within ±3 deg. across the full frequency range.

FAIRVIEW MICROWAVE INC., AN INFINITE ELECTRONICS BRAND, 301 Leora Ln., Ste. 100, Lewisville, TX 75056; (800) 715-4396, (972) 649-6678, FAX: (972) 649-6689, E-mail: sales@fairviewmicrowave.com, www.fairviewmicrowave.com, www.broadwavetechnologies.com

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