Will Wi-Fi 6, BLE, and AI Coalesce to Form 2020's Perfect Storm? **p18**

28-GHz Building Blocks Bolster 5G Network Infrastructure **p24**

Consider the Tradeoffs in Bluetooth Low-Energy Mesh Technology **p30**

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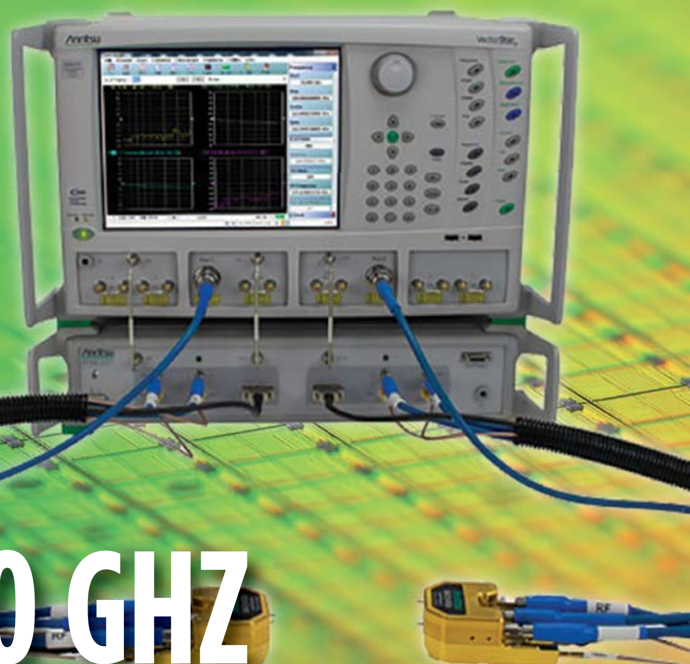

It accurately characterizes mmWave IC devices on-wafer **p40**

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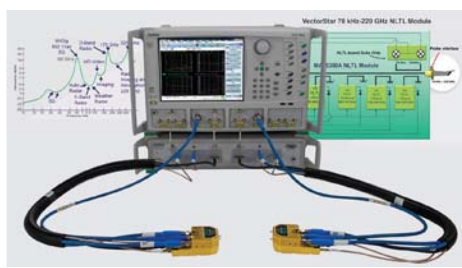

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Editorial

DAVID MALINIAK | Editor
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It Shields from 5G! It's a USB Stick! It's Both!

For those looking to ward off all that harmful 5G electromagnetic radiation—and store a few files—look no further.

While perusing Twitter recently, I came upon a thread by the well-known science-fiction author Cory Doctorow (who, among many other things, posts images of amazing science-fiction/space-age artwork). That thread introduced me to the 5GBioShield, which uses "proprietary quantum holographic nano-layer catalyst technology" to provide "remediation from all harmful radiation, electrosmog, and biohazard pollution." The device performs "balance and harmonization of the harmful effects of imbalanced electric radiation." The maker's website further advises that the "nano-layer operating diameter is either 8 or 40 meters." Yep, that's what it says.

Apparently, the town council of Glastonbury, UK had set up a 5G Advisory Committee to investigate the safety of 5G technology. According to Pen Test Partners, who provides penetration testing and security services, the Committee's final report recommended the 5GBioShield, saying that "we use this device and find it helpful." Unfortunately, the report doesn't detail how it's helpful.

Unable to restrain themselves from examining such an amazing device, Pen Test Partners picked up three 5GBioShield devices and undertook a teardown of what, from external appearances, seems to be nothing more than a USB memory stick.

Well, guess what? The 5GBioShield is a USB memory stick that provides a whopping 128 MB of memory, in addition to its "quantum holographic nano-layer catalyst technology"—all for the bargain price of £283 for one and £795 for three. Now, there was what appeared to be an ordinary circular black sticker on the device's housing. That must be what does all of the shielding and harmonization. I guess.

Meanwhile, I coincidentally stumbled across another link to something called the Vortex BioShield. It turns out that these folks are direct competitors of the 5GBioShield, but with radically different technology involving… quartz crystals. I don't quite know how a teardown could be performed on one of those.

For grins, we posted a few spoof tech articles for April Fool's Day. We had some fun with those, but now I'm thinking we missed a monetization opportunity. Anyone for artificial-stupidity technology? mw

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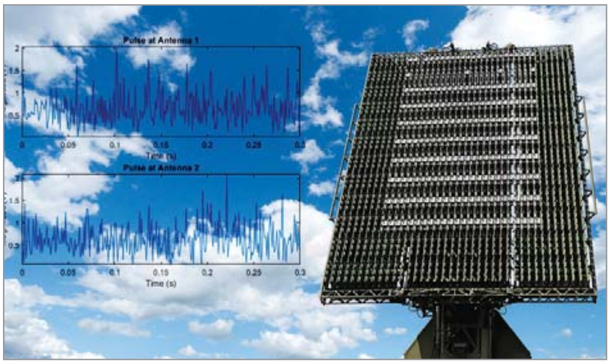
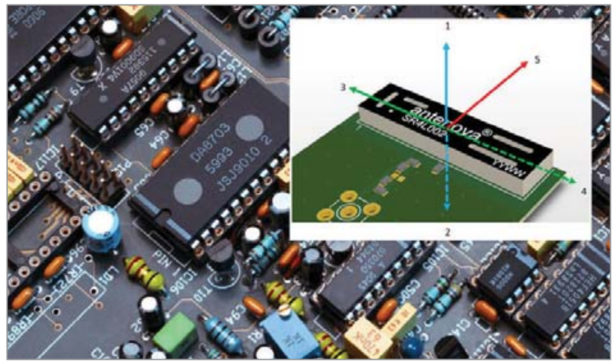


Developing Beamformers for Phased-Array Systems

This "Algorithms to Antenna" blog installment discusses common types of beamforming algorithms as well as a framework to develop and test your own beamformers.

https://www.mwrf.com/technologies/systems/article/21131905/algorithms-to-antenna-developing-beamformers-for-phasedarray-systems



Design Tips for Positioning an Embedded Antenna on a PCB

When integrating an antenna onto a PCB, following the supplier's requirements will get the best performance from the antenna. This article outlines the first steps to designing a PCB that includes an antenna.

https://www.mwrf.com/technologies/systems/article/21128361/design-tips-for-positioning-an-embedded-antenna-on-a-pcb

Start Your 5G Journey Now with 4G LTE

Lost amid the noise around 5G is that well into this decade, 4G LTE will remain the strongest contender for IIoT solutions, even as we prepare for the 5G era.

https://www.mwrf.com/technologies/systems/article/21128692/start-your-5g-journey-now-with-4g-lte

Ceramic Feedthrough Filters: Winning the Finite EMI Fight

In today's world, nearly all electronic devices have wireless-connectivity features built into them, and they rely on transmitting and receiving RF or microwave signals from one device to another.

https://www.mwrf.com/technologies/components/article/21129237/ceramic-feedthrough-filters-winning-the-finite-emi-fight

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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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News

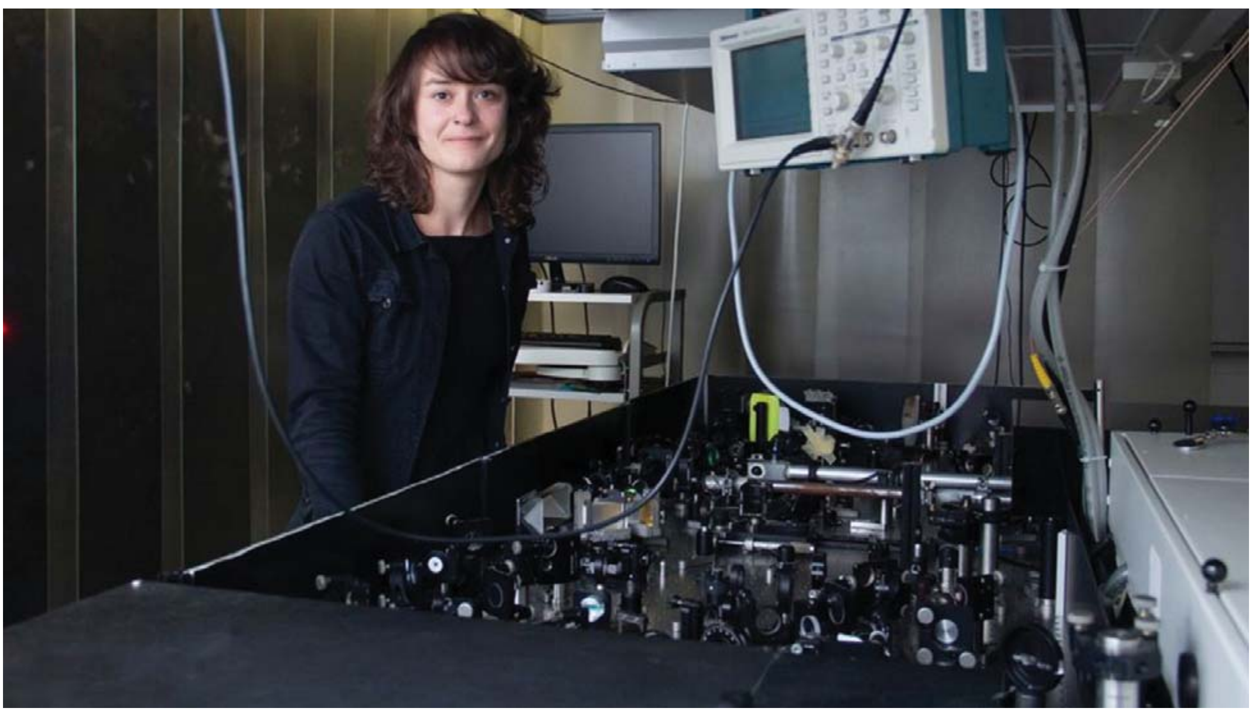
IR LASER MIXING,

Optical "Magic" Yields THz Waves with Relative Efficiency

The terahertz segment of the electromagnetic spectrum exists in a sort of "twilight zone" between about 300 GHz (0.3 THz) to 3 THz (note that the upper boundary value is somewhat arbitrary, and some consider it to be 30 THz). It's bounded below by millimeter-wave RF (30 to 300 GHz) and above by optical wavelengths. Electromagnetic radiation below the terahertz band can be created by many sources and emitted by antennas, while the optical radiation above the terahertz band can be developed by solid-state lasers.

However, the major part of the terahertz span is largely a void. Although it's governed by Maxwell's equations just as the rest of the spectrum, it's relatively difficult to generate these waves as they're too high in frequency for even most leading-edge electronic components and too low for optical sourcing. Due to this and other problems, the terahertz region is far less explored and exploited than the RF or optical areas *(see "References" at end of article).*

Why even investigate the terahertz part of the spectrum? Among the many reasons are because it's there, of course; because it potentially has useful and fascinating characteristics; and it may be needed for 6G, 7G, or 8G wireless links. After all, 20 years ago, if you had told someone that there would be mass-market consumer products operating at ~10 GHz by the first part of the 21st centu-



By mixing and manipulating an infrared laser, a team led by researchers at TU Wein (Vienna University of Technology) has generated a wide band of terahertz waves with relatively high efficiency.

ry, you would have likely been called a wild-eyed dreamer.

POWER PROBLEMS

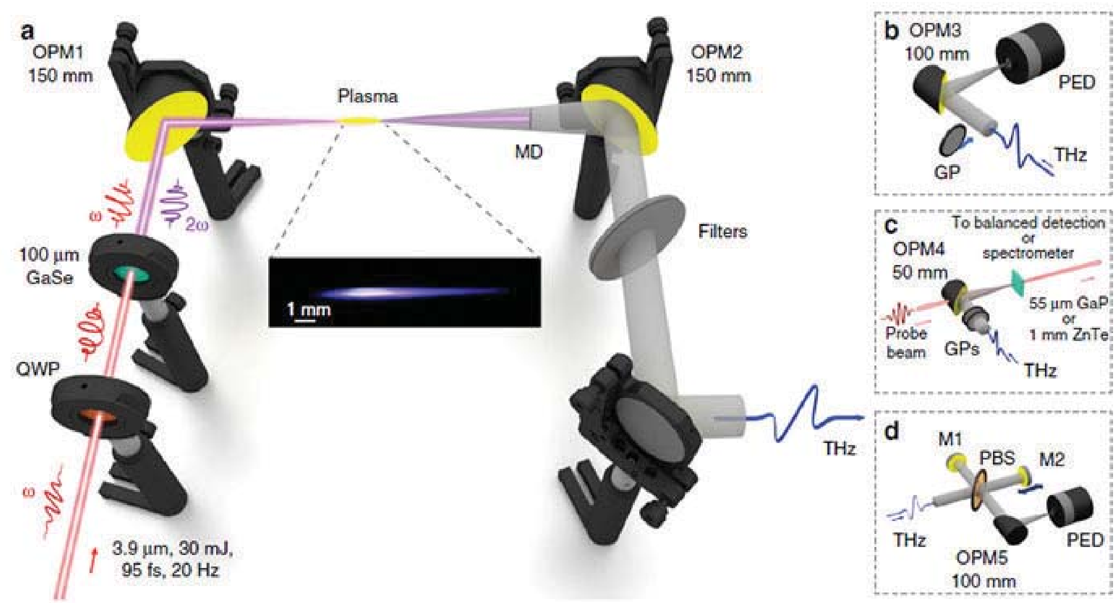
However, the problem remains in terms of efficiently generating useful levels of power in the terahertz band. There are tabletop sources based on either optical rectification in electro-optic crystals or two-color filamentation in gases and liquids. With optical rectification, terahertz pulses with energy up to 0.9 mJ and THz conversion efficiency (ratio of generated THz energy to the input laser pulse energy) up to 3.7% have been generated, but the pulses are long (several picoseconds) with narrow spectra.

Unfortunately, the optical-damage threshold of electro-optic crystals prevents a significant increase in power. Furthermore, while there are no issues with optical damage when using the two-color filamentation approach, it generates only less-energetic near-infrared (NIR) laser pulses, and with a very low conversion efficiency of ~0.01%.

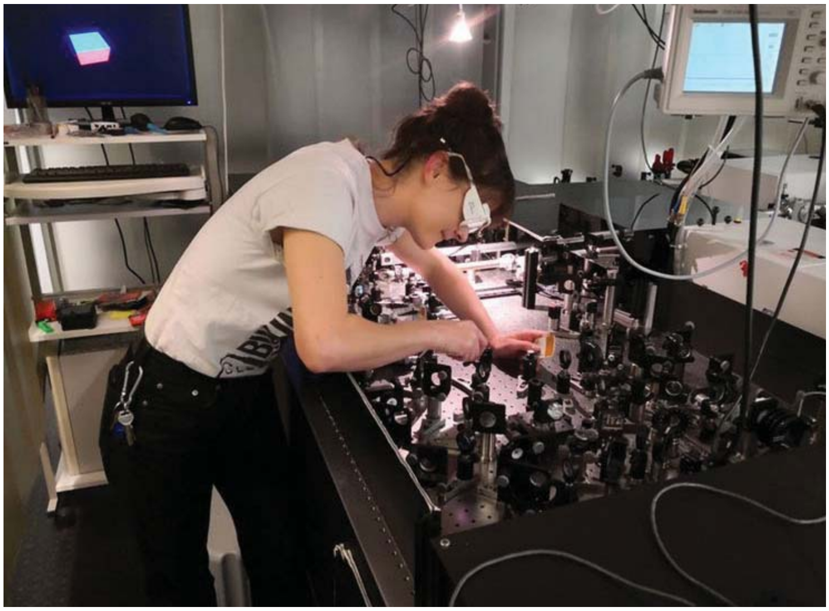
EFFICIENT SOURCE BREAKTHROUGH

Now, a research group based at TU Wein (Vienna University of Technology), in close cooperation with a team from the Institute of Electronic Structure and Laser (IESL) Foundation for Research and Technology-Hellas (FORTH) in Heraklion, Greece, and some help from Texas A&M University at Qatar, has developed a source that's both fairly efficient and can generate waves across the entire terahertz slice of spectrum. The experiment, with results they claim has broken previous records in these areas, was inspired by a theory developed in Texas A&M University, which predicted that long-wavelength laser pulses could be used to achieve extremely efficient terahertz generation in air plasma.

In the setup schematic *(Fig. 1),* the generation of the terahertz waves begins



1. The setup for THz generation by two-color mid-infrared filaments (a). After the quarter wave plate (QWP), the 3.9-µm laser pulse passes through the gallium-selenide (GaSe) crystal and generates the second harmonic pulse. The two-color laser pulse is focused by an off-axis parabolic mirror (OPM1) in ambient air and forms a filament where the THz radiation is generated. A parabolic mirror (OPM2) gathers the emitted THz pulse and guides it into one of the detection setups. The metallic disk (MD) blocks the on-axis mid-infrared radiation and generated supercontinuum, while the conically emitted THz radiation passes around it. A set of lowpass filters filter out the remaining unwanted radiation and prevent the saturation of the pyroelectric detector (PED) by the intense THz pulses. THz detection setups (b-d): The parabolic mirror (OPM3) focuses the THz pulse on the PED to measure its energy (b). The wire grid polarizer (GP), placed before the OPM3, makes it possible to characterize the THz polarization. For the electro-optic measurements, the parabolic mirror (OPM4) focuses the THz pulse into a 55-µm thick gallium phosphide (GaP) crystal (c). A pair of GPs reduces the THz field strength to ensure a linear response. The 680-nm synchronized probe pulse focuses into the GaP crystal through a hole in OPM4 and then is guided to the balanced detection setup. For the cross-phase modulation experiment, the GaP crystal is replaced by the 1-mm-thick zinc-telluride (ZnTe) crystal and the 761-nm probe pulse is guided to the spectrometer. The Michelson interferometer measures the THz field autocorrelation and consists of a pellicle beam splitter (PBS) and two flat mirrors: fixed (M1) and movable (M2) (d). At the exit, a parabolic mirror (OPM5) focuses the radiation on the PED. *(Source: TU Wein)*



2. Researcher Claudia Gollner adjusts the optoelectronic setup in the lab at TU Wein's photonics institute. *(Source: TU Wein)*

by sending infrared laser light through a nonlinear medium, where part of the infrared radiation is transformed into optical radiation at twice the initial frequency. The two radiation waves are then superimposed, creating an electromagnetic wave with an electric field having a very specific asymmetric shape.

But that's only the start of this process. The intense wave "rips" electrons out of the molecules in the air, turning the air into a glowing plasma. The special shape of the wave's electric field accelerates the electrons in such a way that they produce the desired terahertz radiation.

As noted by team member Claudia Gollner *(Fig. 2)*, "Our method is extremely efficient with 2.3% of the supplied energy converted into terahertz radiation. That is orders of magnitude more than can be achieved with other methods. This results in exceptionally high terahertz energies of almost 200 microjoules and terahertz-field amplitudes exceeding 100 MV per cm."

She also added that their approach develops many wavelengths throughout the terahertz range to be emitted simultaneously, and the larger spectrum of

"Our method is extremely efficient with 2.3% of the supplied energy converted into terahertz radiation. That is orders of magnitude more than can be achieved with other methods."

different terahertz wavelengths yields the shorter and more intense pulses.

The details, including a review of existing methods of terahertz generation and their characteristics, are in their paper "Observation of extremely efficient terahertz generation from mid-infrared two-color laser filaments" published in *Nature Communications.* ■

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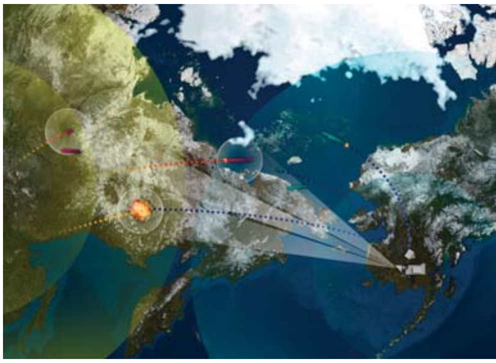
GaN GIVES A BOOST to Long-Range Radar System

AS THE NUMBER OF LOW-EARTH-ORBIT (LEO) satellites grows, the question may arise whether the greater long-distance threat to those satellites comes from a guided missile or falling space debris. In both cases, the Long-Range Discrimination Radar (LRDR) leverages solid-state S-band radar technology to keep track of objects traveling through the atmosphere. The LRDR is taking shape under the guidance of the Missile Defense Agency (MDA) and is being developed by Lockheed Martin.

The LRDR radar system is an example of what can be accomplished by using high-power gallium-nitride (GaN) power transistors for amplification of a radar's target-illuminating transmit signals in place of traditional microwave power sources such as magnetrons. The system is a vital defensive asset, given that the number of ground-based, long-distance detectors is limited but the number of threats (and the decoys that attempt to hide them from radar systems) is growing.

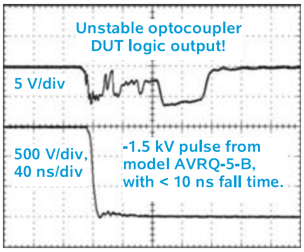
Carl Bannar, vice president of Lockheed Martin's Integrated Warfare and Surveillance Systems business, notes the importance of the signal-processing algorithms: "Our offering meets the MDA's vision for LRDR by pairing an innovative radar discrimination capability with proven ballistic missile defense algorithms."

The LRDR system represents the company's largest solid-state radar program, with extensive testing performed at Lockheed Martin's Solid State Radar Integration Site (SSRIS) in Moorestown, NJ. The radar system will start with two large antenna arrays based on a modular architecture formed with multiple antenna sub-arrays. Arrays will be constructed of multiple antenna panels, each about 27 ft. high. The MDA plans on the long-range radar as part of a layered network of radar systems capable of tracking ballistic data to protect the mainland U.S. against ballistic missile threats. ■



These structures are being erected in Clear, AK to house one part of the GaN-based S-band LRDR system. *(Courtesy of Lockheed Martin, www.lockheedmartin.com)*

Transient Immunity Testers from AVTECH



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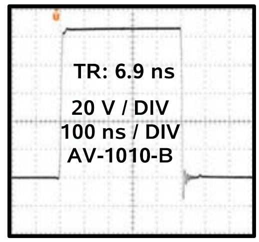

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Model AV-1010-B: 100 Volts, 1 MHz, 25 ns to 10 ms, 10 ns rise time
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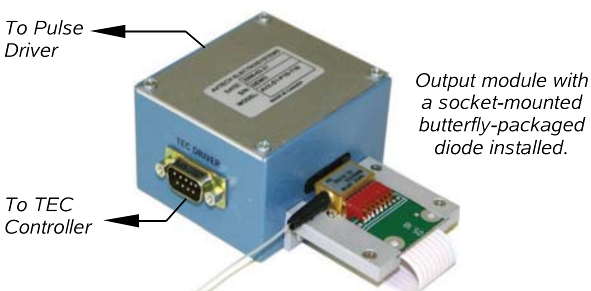

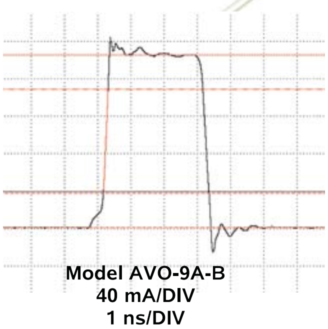

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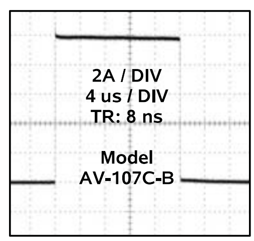

Series	I, V	PW	TR
AV-107	2 - 20 A, 60 V	0.2 - 200 us	10 - 30 ns
AV-106	5 - 100 A, 100 V	0.5 us - 1 ms	50 ns - 1 us
AV-108	12.5 - 200 A, 100V	2 us - 1 ms	5 - 15 us
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RICHARD EDGAR | Senior Director of Product Management, Imagination Technologies

2020's Perfect Storm: Wi-Fi 6, BLE, and AI?

The debut of Wi-Fi 6 and the explosion of AI hardware, networks, and tools will open new markets and spur future technology trends.

The innovations of connectivity and AI are about to shift into full gear as new advances—edge computing, Wi-Fi 6, and Bluetooth Low Energy (BLE) v5.2, to name a few—arrive in full force. These developments are quite significant. Wi-Fi 6 will improve robustness and performance, while Bluetooth audio sharing will make it possible for multiple consumers to personally enjoy the audio of a single device. In addition, edge computing will give a significant boost to the Artificial Intelligence of Things (AIoT).

This is a win-win for those wishing to utilize these technologies, but not everyone will feel like a winner in 2020. The year could bring hardship to AI hardware startups that have risen up after years of long-term and highly intensive R&D. In many ways, this process has led to incredible results, including complex, high-value products. But those products also bring forth a strong patent portfolio, which can act as landmines to competitors. Many firms have failed to keep up, inevitably leading to a decline—and soon, a contraction—within the space.

Let's take a closer look at these and other notable innovations to watch for as 2020 unfolds.

THE POWER OF Wi-Fi

Wi-Fi has changed the world as we know it, but the biggest criticisms are that it often doesn't work or it's too slow. Networks are often strained by the number of users on board, a pain point that's particularly prevalent at airports and other public venues or events. Even the 2012 Olympic Games in London was bogged down by internet access of just 100 kB/s at the opening ceremony.

This was on a network that was supposed to offer several hundred megabits per second! But when overloaded, the network failed to deliver a quality experience.

One of the key challenges is simply the way Wi-Fi works. When a mobile device connects to your router at home, for example, it does something called association. The access point sends out messages every few seconds. In the case of the Olympic Games opening ceremony, the devices were in fact "talking" to the access points, saying, "I'm here and I want to send." However, nothing could actually send, since so many people were on the network simultaneously.

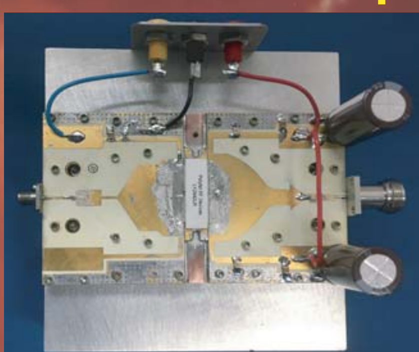
Thus, the most exciting part of Wi-Fi 6 is that it will eliminate this pain point. It will effectively improve robustness and performance with two techniques: colors and orthogonal frequency-division multiple access (OFDMA). The former involves the use of different access points, which are a problem with current Wi-Fi. Now it's possible to have different Basic Service Set (BSS) "colors," or numbers between 0 and 7 that will allow devices to ignore signals from the AP it's not associated with. In other words, if you're in an apartment in New York City, your devices will be able to ignore what your neighbors are doing next door and provide a stronger signal. OFDMA helps speed up our connectivity by breaking the spectrum into smaller chunks, enabling more devices to communicate.

Wi-Fi 6 can also help reduce battery drain for small devices. This may not necessarily apply to mobile phones, but for sensors in the home (such as a thermostat), it will be quite significant. Instead of being required to charge the device or change its batteries on a regular basis, Wi-Fi 6 will make it possible to leave them be for a year or longer.

Finally, Wi-Fi 6 will get an additional boost now that the 6-GHz band (1,200 MHz of spectrum) has been opened to unlicensed uses. The latest version of Wi-Fi, known as Wi-Fi 6E, uses the newly available spectrum to enable devices to connect quicker and for data to transfer faster. It hasn't received approval just yet, but it looks like Wi-Fi 6E could become a reality in 2021, if not sooner.

SHARING IS CARING (AND AURAL BLISS)

The hidden brilliance of Bluetooth Low Energy (BLE) v5.2 can't be denied—it offers one of the most impressive changes since the technology was introduced: audio sharing. While this has been possible with Bluetooth Classic, which is quite power-hungry, this is the first time it can be done with BLE. As a result, you'll receive the same benefits but with much lower power consumption. That means smaller devices with



smaller batteries (such as hearing aids) now can take advantage of this impressive feature.

COMPUTING AT THE EDGE OF INNOVATION

At the same time, artificial intelligence will get a boost as edge computing becomes a major factor and a prominent focus within the market. Powerful accelerators will enable devices to run neural networks at the edge of the network. This could present a host of interesting opportunities, particularly for AIoT. As low-cost edge compute nodes make it possible to do more on a tighter budget, the potential will be limitless.

AI HARDWARE STARTUPS FACE THE MUSIC, BUT AI APPS WILL COME TO THE RESCUE

AI hardware startups have relied on a multi-year and highly intensive process involving near-endless research and development. This has been effective in getting them to where they are today, but it could come at a price. As every company under the sun rushed to take every dollar available from venture capitalists (VCs), they may not have considered how difficult it would be to demonstrate the value of that investment. If they can't show the fruits of their labor in 2020, VCs might not be interested in returning for another investment round.

While AI hardware could be challenged this year, AI apps will have their moment to shine. Two primary kits—Apple's Core ML and Google's ML—have opened the door to thousands of developers, allowing them to incorporate machine-learning models into their software. This will enable AI-centric apps to reach the mainstream, propelling the technology as users come to recognize its incredible value. This will surely get the interest of VCs, who might be intrigued by apps that can offer features that were once limited to very specific hardware.

THE BEST IS YET TO COME

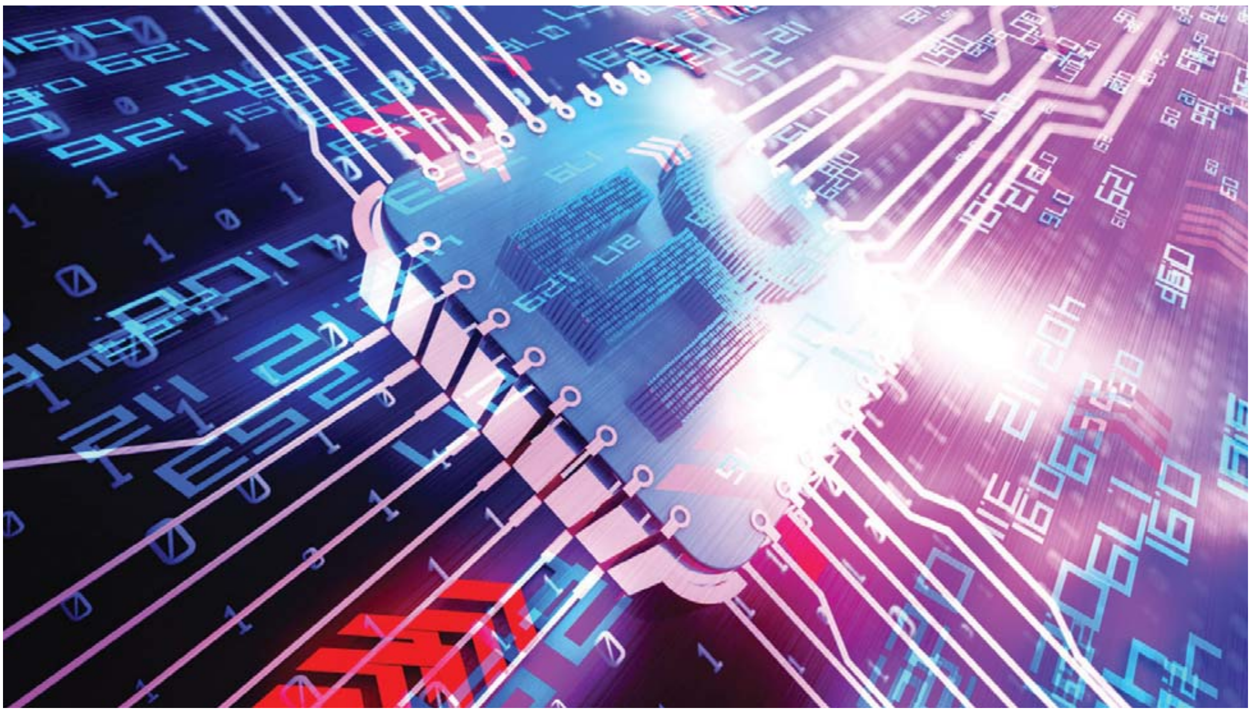
This year will prove to be an outstanding opportunity for some of our most important technologies, such as Bluetooth and Wi-Fi, to shine while giving future innovations like AI software an opportunity to flourish. AI hardware companies could face increasing pressure if they aren't able to show that their VC money was worth the investment, but it's clear others will be waiting to take their place. mw

RICHARD EDGAR is Senior Director of Product Management at Imagination Technologies.

MITCH MAIMAN | President and Cofounder, Intelligent Product Solutions

5G Product Design Considerations for 2020

In the midst of the hype and excitement surrounding 5G, here's a real-world look at the science and facts of the technology as it affects the solutions we're developing in 2020.



Judging from the ads on TV and other media sources, one would think that in 2020 the world will be transformed by the magical leap that 5G technology represents. Because we deal in the world of science and facts—not hype—let's have a gut check on 5G as it affects the solutions we're developing in 2020.

One may be developing products for which incorporating 5G may or may not make sense. Here are a few questions you should be asking:

WHAT BENEFIT ARE YOU GETTING FROM 5G?

Many products deploy particular technologies as a differentiator, even if it provides little benefit—do we *really* need better phone cameras or faster phone processors? In some cases, the market for products is so tight that 5G provides a competitive advantage or merely a means of maintaining technological parity with competitors.

Today, there are many ways to design in wireless communications. As product developers, we're familiar with common technologies such as Wi-Fi, Bluetooth, and yes, 4G cellular, which isn't going away any time soon. The vision of 5G is one of increased communications speed and bandwidth. The question remains: For the specific problem being solved, are both characteristics essential?

WHEN DO YOU NEED THOSE BENEFITS?

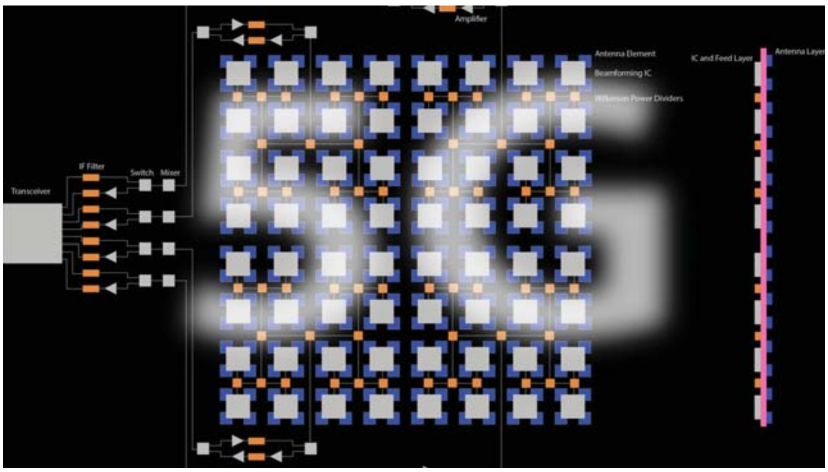
Despite all of the hype, 5G isn't ubiquitous today nor will it become so in the next 12 months. By some estimates, it

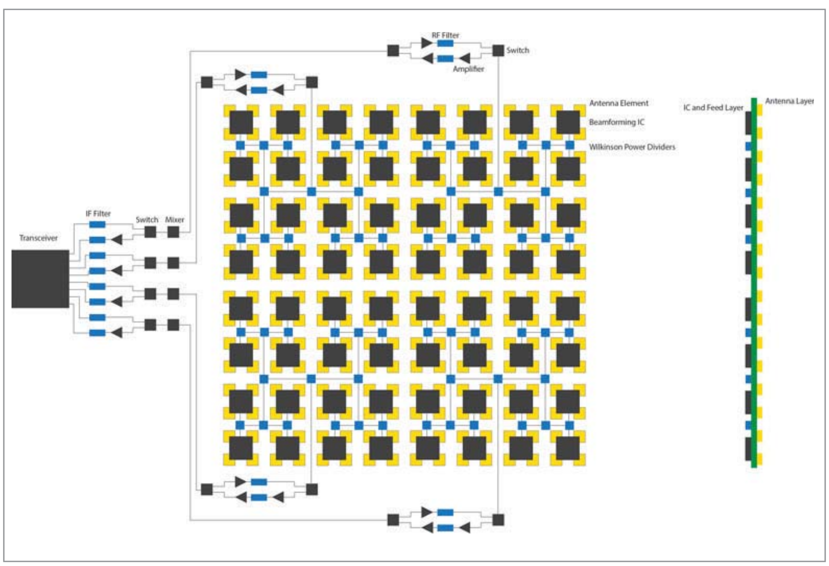
(Continued on page 46)

PETER MATTHEWS | Senior Technical Marketing Manager, Knowles Precision Devices

Building Blocks for 28-GHz Small Cells

One of the more significant 5G innovations is the ability to operate in the millimeter-wave spectrum. Support for high-frequency bands opens underused spectrum to bolster 5G network capacity and provides opportunity to leverage small-cell technology.





1. A 256-element, 28-GHz array might be used in a g Node B (gNb), higher-power 28-GHz radio.

Built to support 5G networks, 28-GHz small cells are compact, lightweight devices mounted on "street furniture" like lampposts or telephone poles. Immediately, this application presents design concerns. These devices need to be small and lightweight to accommodate the installation process. Also, they must withstand temperature extremes, yet they can't always afford the large heat fins often used to manage temperature due to size and weight restrictions. 28-GHz small cells also need to be extremely efficient to be an economically viable approach to building an access network.

A 256-element, 28-GHz array, for example, might be used in a g Node B (gNb), higher-power 28-GHz radio *(Fig. 1)*. Many components are involved in creating a base station; they include antenna assembly, feed network, beamforming ICs, RF filters, RF switches, RF amplifier, mixer, and transceiver. A large macrocell might have the space for all of these components with separate cards for some of the switches, amplifiers, and filters, but as the radio gets smaller, the task is to compress the design without compromising on performance.

In a 28-GHz small cell, reducing the total number of antenna elements helps to reduce cost and complexity to transition from the 256-element

Table 1: Key Considerations When Building Feed Networks	
Size	• No option to move dividers off the board onto a separate card • Feed network implemented in the space between BFICs or in PCB layers
Complexity	• Implementation in-layers could add to mechanical and thermal complexity • Separate passives (resistors) can add to complexity and cost
Performance	• Excess insertion loss impact on EIRP

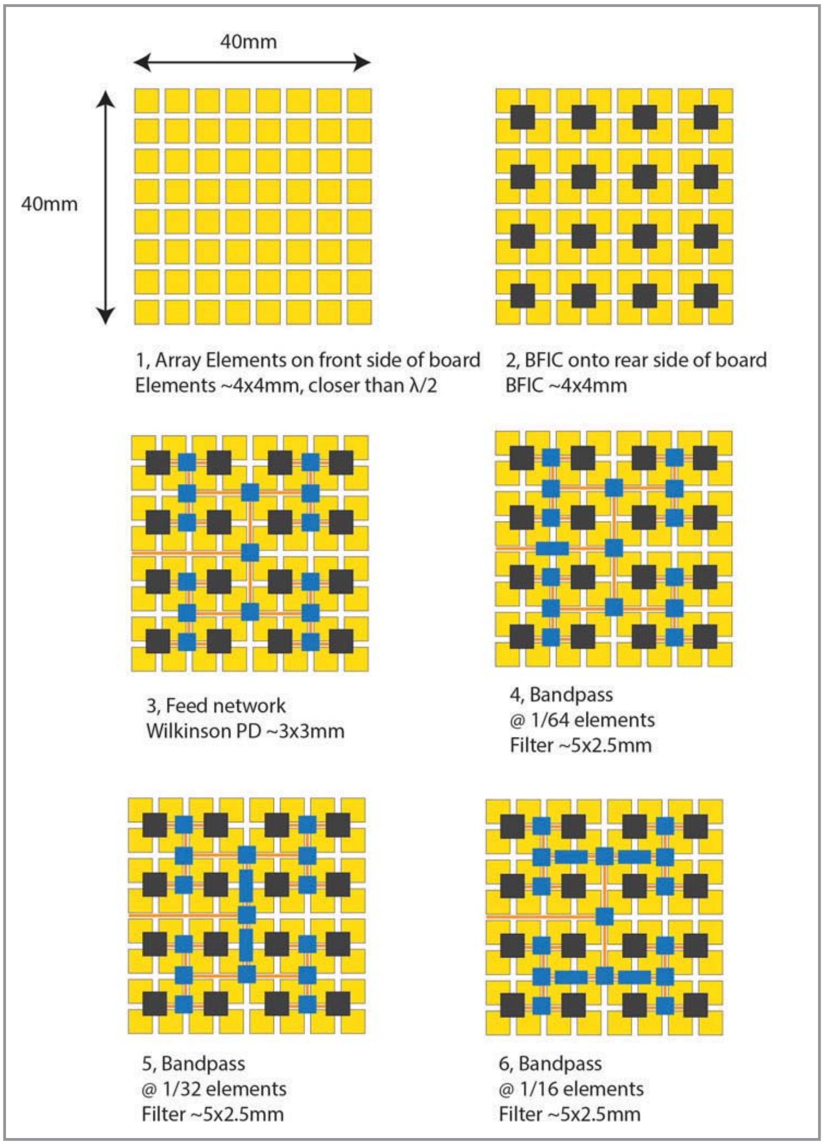
array in the gNb above into something more like a 64-element tile. Ideally, all RF components fit into such a tile or card. RF component dimensions are constrained by the size of the array, and array size is dictated by wavelength. To reduce loss in RF components, shrinking the footprint to fit within a single tile is particularly important. The challenge is to do this while optimizing RF performance.

Figure 2 shows a breakdown of how components might fit on a tile:

- Step 1 moves the element array to the front of the board.
- Step 2 moves the beamforming ICs onto the rear of the board, shown with a single beamforming chip that connects to the four different element arrays.
- Step 3 displays feed networks for a Wilkinson power divider. It's important to shrink these feed networks as much as possible without compromising on performance.
- Steps 4, 5, and 6 show filter placement examples. To identify potential filtering options, consider what level of performance is needed and how much space there is to implement components.

FILTERING IN THE 28-GHZ SMALL CELL

When implementing frequency-control components such as filters, size and performance remain critical fac-

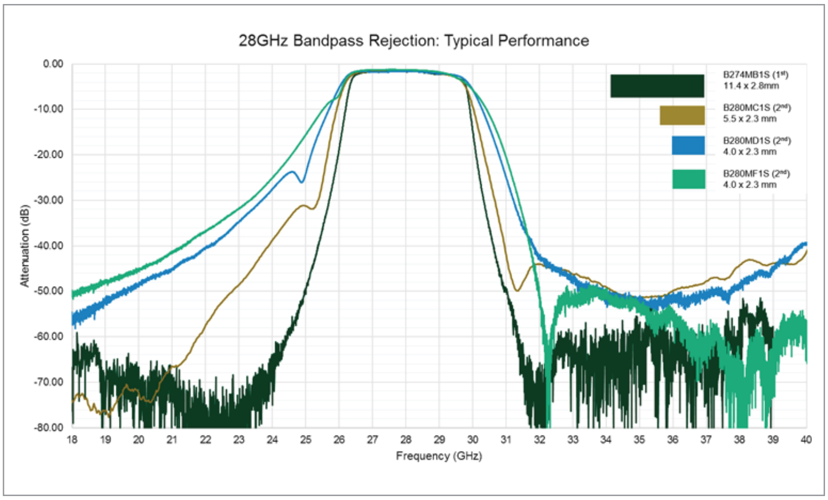


2. RF component dimensions are constrained by the size of the array.

tors. Among the key considerations for implementation are:

- *Size:* In dense tiles, consider the amount of board area available for passive components; otherwise, move components off-board to a separate card, increasing loss.
- *Performance:* Guard banding is influenced by such characteristics of RF components as tolerance and repeatability, as well as temperature stability at higher temperatures

In general, performance affects size—the better the performance, the larger the overall component size. *Figure 3* shows four different Knowles Precision Devices (KPD) filter offerings at the 28-GHz frequency. The dark-green device is the largest component with the highest selectivity. The other three designs employ KPD second-generation components with higher-permittivity dielectric materials. Adjusting filter performance can reduce the overall size and performance of the system at a reduced cost in manufacture.



3. Shown are typical bandpass-rejection curves for four different KPD 28-GHz filter offerings.

Given the small-cell thermal concerns, maintaining temperature stability over a wide range is imperative. Temperature stability impacts guard bands, potentially affecting spectral efficiency.[1] Tolerance is also a key driver. If tolerance isn't considered in manufacture, it can impact the yields of the overall system and further increase the need for guard banding, taking up useful spectrum.[2]

BUILDING FEED NETWORKS

As the RF moves from the transceiver and fans out into the beamforming network ICs, there must be some power dividers on the board to split the signal. Feed networks should be implemented between the beamforming ICs, further complicating the component *(see Table 1 for key considerations)*.

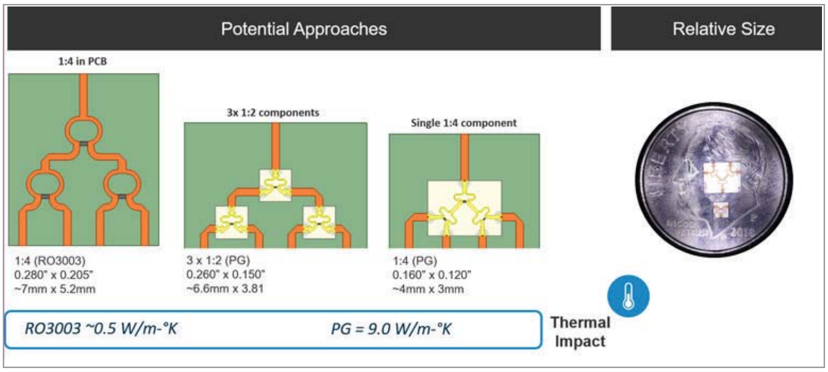
Considering the 1:4 divider/combiner components of the network in our small cell, there are several different approaches for implementation *(Table 2 and Figure 4)*. We can build these Wilkinson power dividers in the PCB; utilize three 1:2 Wilkinsons; or take an all-in-one approach with a single surface-mount 1:4 Wilkinson divider.

Using a fully integrated design featuring thin-film technology and a high-permittivity dielectric gives the designer the opportunity to shrink the overall size and integrate the resistor, reducing variation from resistor tolerances and improving on the overall RF performance.

By managing the thermal properties of ceramic materials (PG below), elements of the feed layer also act as heat-management components. They're temperature-stable by design and capable of operating across a range of temperatures inside the small cell. In addition, the high thermal conductivity of the ceramic material aids in heat distribution in the antenna tile. This second feature has benefits for mechanical complexity (i.e., cost of assembly) and reliability.

PERFORMANCE

Effective isotropic radiated power (EIRP) is an important characteristic



4. A variety of approaches can be taken to implement a 1:4 feed.

5. Effective isotropic radiated power (EIRP) for a beamforming antenna can be derived from the equation shown.

Table 2: RF Performance—Three Approaches to 1:4

Performance @ 28 GHz	4-Way (RO3003)*	Three 2-Way (PG Ceramic)*	4-Way (PG Ceramic)
Excess insertion loss	0.6 dB	0.9 dB	0.6 dB
Amplitude matching (part to part worst case)	±0.3 dB	±0.2 dB	±0.1 dB
Phase matching (part to part worst case)	±13°	±10°	±1.5°

when discussing 5G antenna system performance. In the equation shown in *Figure 5* for EIRP in a beamforming antenna, the engineer can use three factors to optimize EIRP, all of which have an impact on the overall system:

- Element TX Power (P_out) is a function of the RF path loss and component gain; we can balance the cost of adding gain by minimizing loss. P_out affects system dc power dissipation and cost.
- Number of elements (N_elem) is the contribution from the array. N_elem can affect PCB area and cost.
- Individual Element Gain (Elem_gain) is the gain of an individual element; this value is driven by how effectively the antenna radiates. Elem_gain affects element complexity and cost.

In small-cell applications, N_elem and Elem_gain might suffer in the name of cost because of their potential impact on cost and complexity. To influence EIRP, P_out can be optimized. To do this cost-effectively, we look at loss in the passives we have been discussing.

In small-cell applications, N_elem and Elem_gain might suffer in the name of cost because of their potential impact on cost and complexity. To influence EIRP, P_out can be optimized. To do this cost-effectively, we look at loss in the passives we have been discussing.

Innovation in active components drives design improvements in mmWave small-cell design. However, the impact of careful passive-element selection shouldn't be underestimated—thoughtful implementation can reduce both the size and overall cost of the system. The right passive components lay the groundwork for a successful small cell through better efficiency at every level of design. mw

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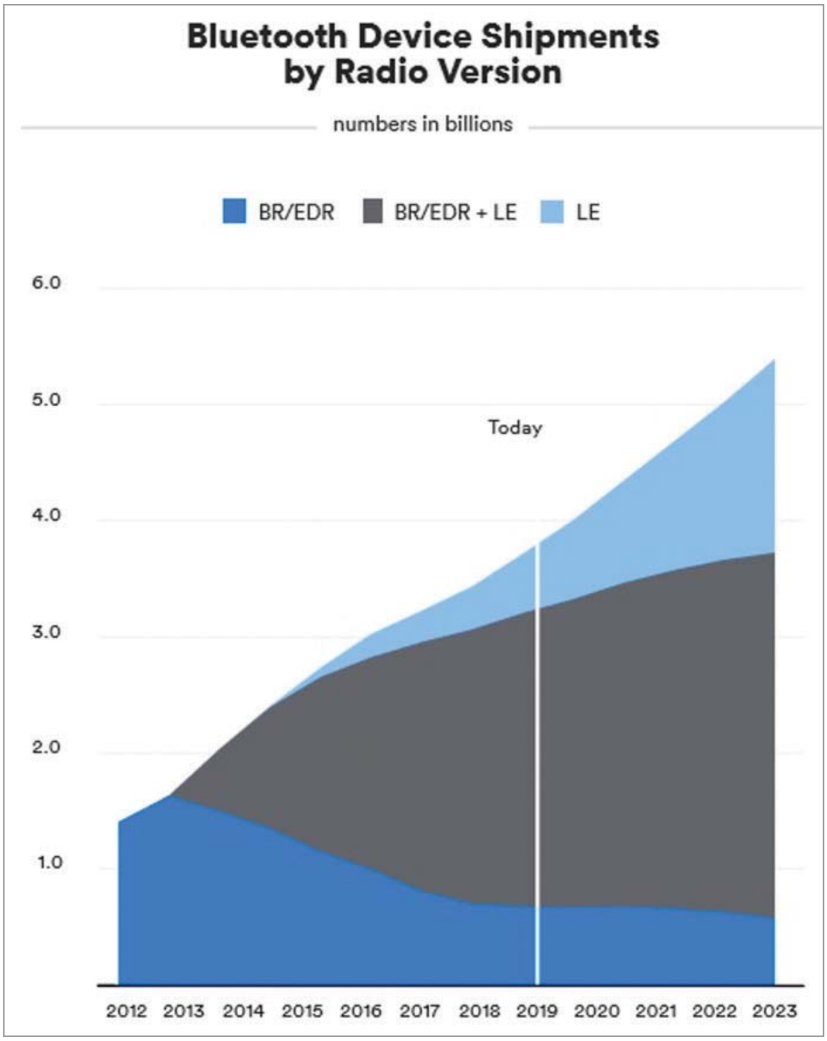
BRIAN BEDROSIAN | Vice President of Marketing, IoT Compute and Wireless Business Unit, Cypress Semiconductor

Design Considerations for Bluetooth Mesh Across Industrial, Home Environments

BLE Mesh technology expands Bluetooth's reach into an array of applications, but it brings to bear numerous design tradeoffs in both hardware and software. Here's an intro to BLE Mesh and an overview of those tradeoffs framed in a smart-lighting context.

Bluetooth is a ubiquitous communications protocol with countless applications in consumer electronics, healthcare, industrial automation, and asset tracking. With Bluetooth Low Energy (BLE) Mesh now added as a network layer, there are even greater opportunities for simultaneous control and monitoring of hundreds—even thousands—of devices. These new capabilities come with added complexity for developers, though.

Bluetooth's many advantages have given rise to its now-ubiquitous presence. The Bluetooth standards are maintained and advanced by the Bluetooth Special Interest Group (SIG), which as of this writing has some 33,000 members in 150 countries. The original standards specified point-to-point (1:1) connections, with multipoint (one-to-many or 1:m) and mesh (many-to-many or m:m) added later. Classic Bluetooth supports 1:1 and 1:m communications with both a Basic Rate (BR) and an Enhanced Data Rate (EDR). Bluetooth Low Energy (BLE) is the only mode that supports m:m mesh networking.



1. The adoption of Bluetooth continues broadly across end markets, with the Low Energy mode taking an increasingly prominent role over time. *(Source: Bluetooth SIG)*

The advent of BLE Mesh networking has further expanded the scale and scope of potential applications for Bluetooth. With support for over 30,000 network nodes, BLE Mesh can handle applications that span large buildings, healthcare enterprises, and campuses.

Bluetooth adoption has grown rapidly and is forecasted to continue apace *(Fig. 1)*. Such widespread use has made Bluetooth networking ubiquitous across virtually all platforms, including smartphones and tablets, smart watches, laptops, and peripherals, ranging from keyboards and mice to speakers and headsets. Such ubiquity across interfaces and widespread interoperability across brands establishes an installed base and developer/user familiarity that makes Bluetooth an obvious choice for many new applications.

BLE MESH OVERVIEW

Every device in a BLE Mesh network must meet fundamental requirements identified in the specifications. This section provides an overview of those requirements using terminology adopted by the Bluetooth SIG.

Mesh-Network Topology

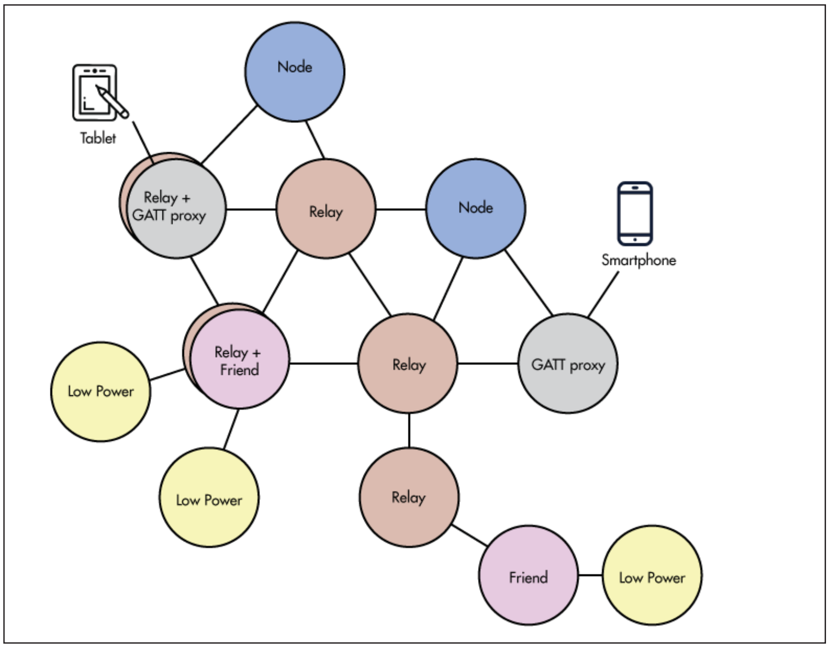
A mesh-network topology enjoys two significant advantages: virtually unlimited scalability and high resiliency, both of which have contributed to the protocol's popularity among product design engineers. These advantages derive from the many-to-many communications that form multiple paths throughout the network from source to destination *(Fig. 2)*.

The m:m connections assure successful communications even when multiple nodes have failed or been taken out of service, whether temporarily or permanently. Putting it another way: BLE Mesh networks can expand far and wide with no single points of failure.

Mesh-Node Types

The scalable topology enables BLE Mesh networks to support a theoretical maximum of 32,767 nodes—a number that places no practical limits on real-world applications. The standards define four types of nodes, and any single node can be configured to support multiple types:

- *Relay Nodes* retransmit or relay received messages to propagate them throughout the mesh network. Messages are only relayed when their time-to-live (TTL) value is greater than zero. Except for Low Power Nodes, all BLE Mesh devices should support this capability.
- *Low Power Nodes (LPNs)* are used primarily for battery-powered, low-duty-cycle sensors. To minimize power consumption, LPNs are normally assigned a companion "Friend Node" to serve as an intermediary for messages.
- *Friend Nodes* receive messages on behalf of their assigned LPN(s), storing them in a queue for later delivery. Each LPN periodically "wakes up" and polls its Friend Node to receive any new messages that might be in its queue.



2. The virtually unlimited scalability and high resiliency of BLE Mesh makes it suitable for a wide variety of new and demanding use cases.

- *Proxy Nodes* relay messages between the connection-oriented General ATTribute (GATT) Bearer and the Advertising Bearer in the BLE Mesh network. This feature enables devices that support BLE (but not the BLE Mesh stack) to communicate with the mesh network without any need for a dedicated gateway or other special provision.

Mesh-Node Element(s)

Every node is required to have a primary identification element that defines its basic functionality. They also may optionally have one or more secondary elements to define additional functionality. For example, a switch (the primary element) might have an occupancy sensor as a secondary element, too. Or, an occupancy sensor (the primary element) might also have a light-level sensor as a secondary element.

Mesh-Network Addresses

There are four types of addresses in a BLE Mesh network, all of which are assigned during the secure provisioning process. Note that addresses are assigned to elements, which means that a node with multiple elements will have multiple addresses:

- *Unicast addresses* uniquely identify each individual element to enable point-to-point communications.
- *Group addresses* represent multiple elements to enable multicast communications. The Bluetooth SIG has defined four Fixed Group addresses: All-proxies, All-friends, All-relays, and All-nodes.
- *Virtual addresses* create virtual groups of elements or nodes to enable additional, dynamic multicast communications capabilities.
- *Unassigned addresses* identify elements that have yet to be provisioned with their Unicast, Group, and/or Virtual addresses.

Mesh-Node Models

BLE Mesh nodes employ one of three different types of models: Client, Server, or Control. These models are determined by a node's basic function or functions, as it's possible to implement more than one model in a single node:

- *Server models* contain and expose the state of an element; for example, a luminaire being on or off or at some intermediate brightness level.
- *Client models* interact with Server models by sending and receiving messages; for example, when a switch is used to turn off or dim a luminaire.
- *Control models* combine Client and Server models in a single node, and typically include control logic (i.e., rules and behaviors). For example, an outdoor luminaire with an ambient light sensor may be configured to turn on at dusk and off at dawn and to turn on and off an indoor entryway luminaire.

BLE Mesh nodes employ one of three different types of models: Client, Server, or Control. These models are determined by a node's basic function or functions, as it's possible to implement more than one model in a single node.

Messages and Messaging

There are two categories of messages in a BLE Mesh network: Access messages for implementing an application and Control messages to manage the operation of the mesh network. Access messages are particularly important to product design engineers, as these are

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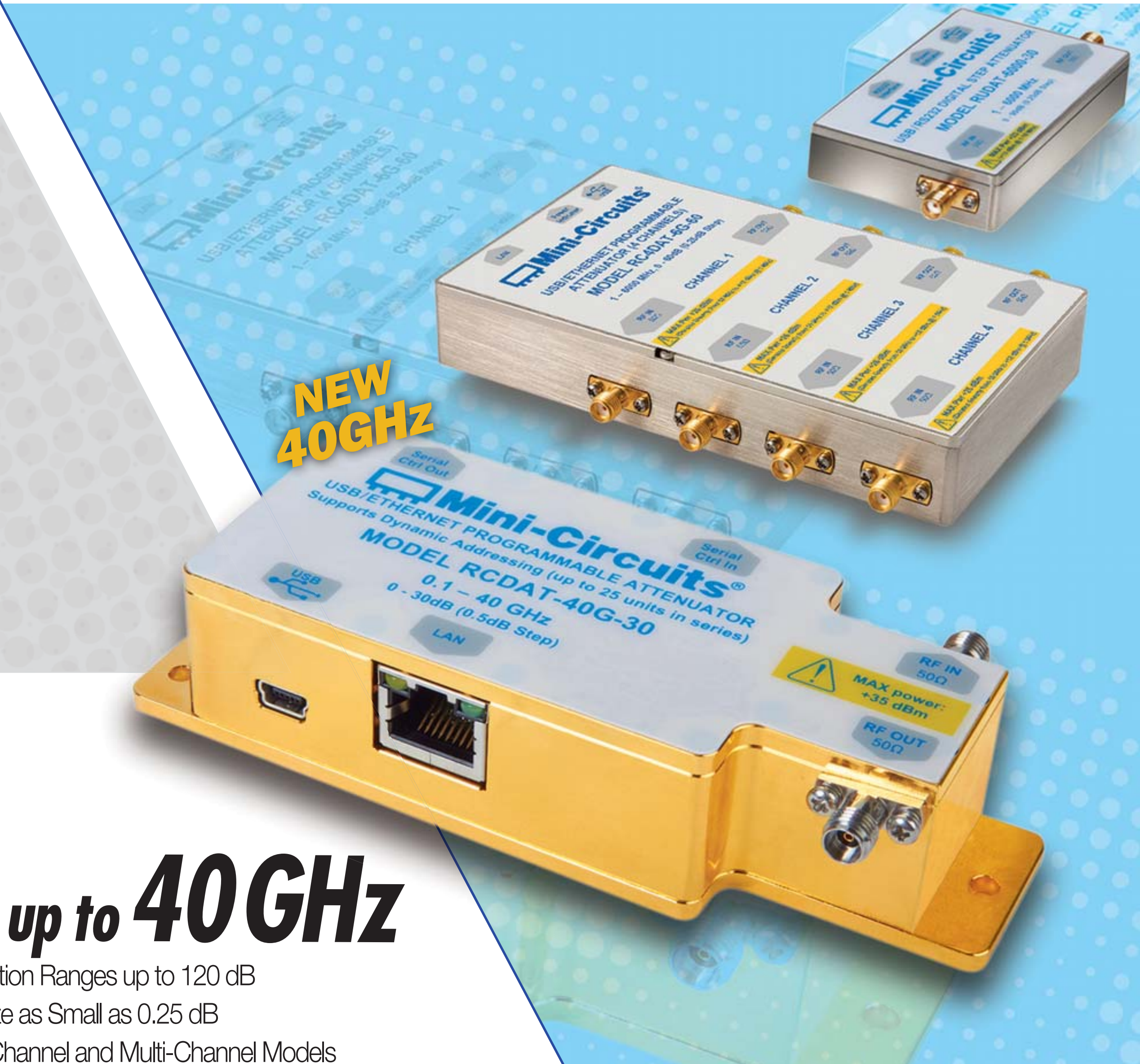

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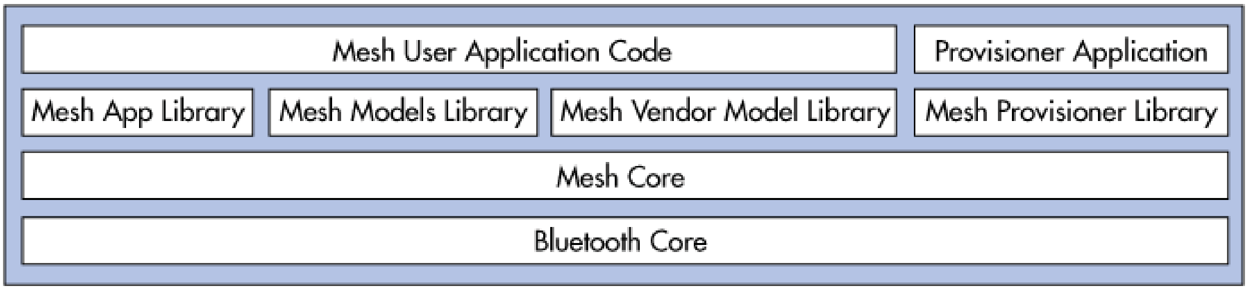


3. The layered architecture enables software engineers to focus their development efforts exclusively on the Mesh User and Provisioner applications and not the BLE Mesh network.

the means for requesting, sending, or changing the state values of elements; for example, turning on or off a luminaire.

The three types of Access messages are GET, SET, and STATUS. GET messages are sent to request state values from elements or groups of elements, which send STATUS messages in response. SET messages are sent to change state values in elements or groups of elements, which normally acknowledge the change by sending a STATUS message. SETs can also be unacknowledged, in which case no STATUS message is sent in response to the change. In addition to GET and SET responses, STATUS messages can be initiated by elements to periodically report their state value(s).

Communications occur within a BLE Mesh network as a managed flood of messages. "Flood" conveys how messages flow throughout the entire mesh topology while being "managed" to ensure efficient and effective use of available bandwidth. Key to a managed flood is the publish/subscribe group messaging used. Any node can publish or send a message, and every node is configured to subscribe to or act on only certain messages it receives, with all others being relayed as needed. The combination of these two aspects help give the BLE Mesh network its industry-leading price/performance, scalability, and dependability.

Device Provisioning

All devices installed must be provisioned before they can join a BLE Mesh network. The provisioning is normally performed by an application running on a smartphone, tablet, or PC. This is a distinct advantage of BLE Mesh because a Provisioner Application and, optionally, Mesh User Application Code *(Fig. 3)* can be run from a mesh participant. Provisioning is a deterministic and secure process that involves the exchange of keys for mutual authentication.

Mesh-Network Security

The BLE Mesh protocols were designed with robust security provisions. Provisioning, authentication, and messaging are subject to strong encryption. Network, application, and device security can all be applied separately using different keys, which provides the means to have multiple entities managing the different elements. These provisions protect against a full spectrum of physical and virtual attacks, including brute force, replay, man-in-the-middle, and trashcan, and provide for user-data privacy.

Software Architecture

Figure 3 depicts the layers of software in BLE Mesh nodes. Note how the Mesh User and Provisioner Applications are located at the top of the architecture, above the libraries and core functions, to make them independent of the underlying BLE Mesh network. Note also how the Mesh Vendor Model Library makes it possible to add advanced, proprietary features while maintaining compatibility with the Bluetooth standards.

DEVELOPING BLE MESH PRODUCTS

This section highlights the BLE Mesh development process, including the tools used, and explores key design considerations. While BLE Mesh networks are suitable for myriad applications and use cases, smart lighting is used here as an example for two reasons. One is that the standards were established with lighting as a basic use case. The other is the popularity of such "smart building" applications that are forecast to experience a compound annual growth rate (CAGR) of 46% in unit shipments through 2023, according to research conducted for the Bluetooth SIG.

The basic development process begins by defining the device's configuration, which must include, at a minimum, its node type, element(s), model, and all hardware- and/or application-specific states and callback functions. The next step involves implementing the callback functions for both the application and the BLE Mesh network.

Various open-source and product-specific tools are normally used during the development process from beginning to end. A specific and more detailed example of the effort involved is available in the "Getting Started with Bluetooth Mesh" application note published by Cypress Semiconductor.

For products supporting BLE Mesh networks, design considerations involve,

To maximize the versatility and, therefore, the benefit of smart lighting, users will want to be able to deploy switches and sensors virtually anywhere. Because some devices might be deployed in locations that aren't easily accessible, the use of energy harvesting with rechargeable batteries might be a desirable feature.This is especially true for sensors that measure illumination or sense the presence/absence of occupants.

at a minimum, device functions (or elements), mesh-network size, antenna range, memory requirements, power consumption, and cost. Separate design consideration must be given to the provisioning, management, and other software that runs on a smartphone, tablet, or PC.

As is common in all product development efforts, tradeoffs are often needed among the various design considerations. The need for such tradeoffs will be addressed here in the context of three products commonly used in smart-lighting applications: switches, sensors, and luminaires. As will be shown, the design consideration at the center of most tradeoffs is power consumption.

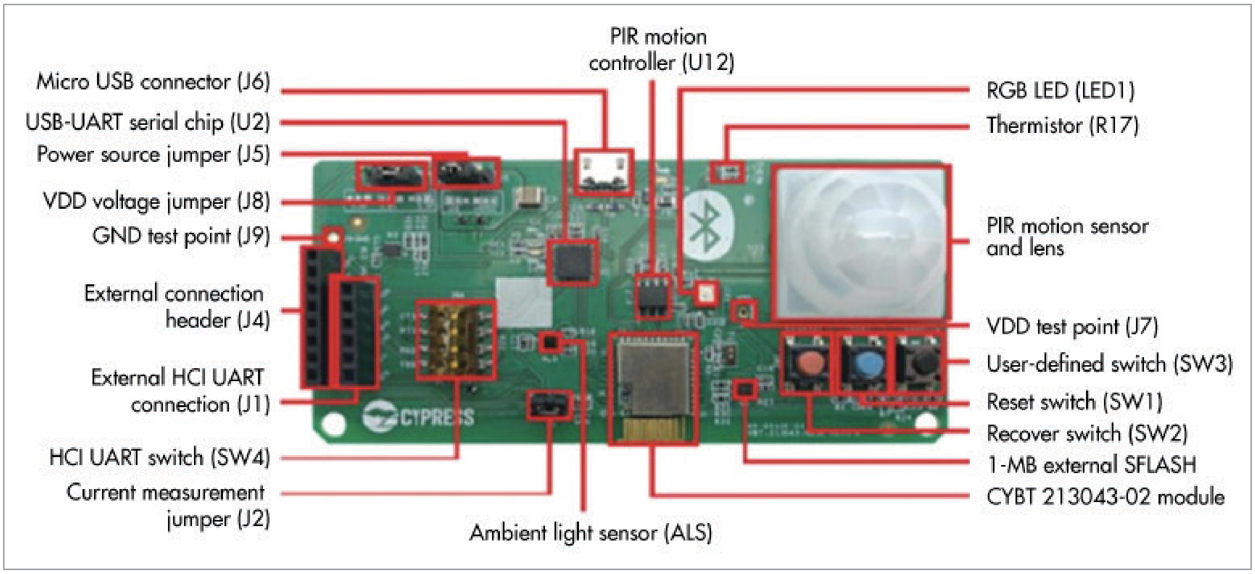
To maximize the versatility and, therefore, the benefit of smart lighting, users will want to be able to deploy switches and sensors virtually anywhere. Because some devices might be deployed in locations that aren't easily accessible, the use of energy harvesting with rechargeable batteries might be a desirable feature. This is especially true for sensors that measure illumination or sense the presence/absence of occupants. Physical switches, by contrast, are by their very nature readily accessible and can, therefore, be designed with replaceable primary batteries when located where ac power isn't available.

For BLE Mesh networks, it's advantageous for battery-powered devices to be designed as Low Power Nodes, which depend on the availability of Friend Node functionality. This requirement can be noted in the product's documentation and/or provided in another product in a family, such as a luminaire, which is assured to have an external power source.

Because a major advantage of BLE Mesh networks is their scalability, they can grow quite large. Though the maximum number of nodes and a high number of hops are rarely limiting factors, products should be designed to work in small-scale deployments that need to span a large area, potentially outdoors, with relatively few nodes. In these use cases, it may be necessary to facilitate increasing a product's antenna range and/or providing Relay Node functionality in a separate (and optionally dedicated) product.

Power consumption is inextricably linked to transmit range, and the BLE Mesh standards give design engineers some powerful (pun intended) capabilities to make the desired tradeoffs that might be needed. One such capability is being able to expand the range without increasing power consumption by decreasing the bandwidth. The converse capability is also possible; that is, boosting the bandwidth by decreasing the range, again while not increasing the power consumption.

Other aspects of a product can elevate the importance of its power consumption. For example, how sensitive does a



4. Shown here is an evaluation board used for prototyping and developing smart-lighting products. Not shown is the battery compartment on the back. *(Source: Cypress Semiconductor)*

sensor need to be, and how frequently does it need to poll for status changes? More frequent communication means more power consumption, heightening the need for a larger primary battery or energy harvesting for a rechargeable battery.

Figure 4 shows an example of an evaluation board that can be used for product prototyping and development. Note the inclusion of three features commonly needed in smart-lighting applications: LEDs for luminaires, switches, and a PIR motion detector for use in an occupancy sensor. The module at the center of the board's bottom edge contains the CPU, memory, and antenna required for the BLE Mesh network, as well as for running the application software.

Given the ubiquity of Bluetooth in smartphones, tablets, and PCs, these systems are normally used for provisioning, configuring, and managing BLE Mesh products, such as the switches, sensors, and luminaires utilized in smart-lighting applications. As noted above, because the Mesh User and Provisioner Applications are layered above the BLE Mesh libraries and core functions, software developers can focus their efforts exclusively on the application and not the network. Here's a sampling of some of the functions Mesh User and Provisioner Applications might need to support:

- Create and delete BLE Mesh networks and groups
- Provision and remove individual nodes
- Configure publications and subscriptions
- Publish GET messages to query the states of elements
- Publish SET messages, which for lighting applications might include On/Off, Level, Lightness and Lightness Hue, Saturation, Lightness Color Temperature, and Delta UV
- Publish SET messages for vendor data and vendor models
- Perform over-the-air (OTA) firmware upgrades

CHOOSING BLE MESH COMPONENTS

One additional design consideration not covered in the previous section is cost, which is always an important factor in the development of any product. Cost always has two dimensions: designing the product and manufacturing it.

With interoperability as the raison d'être for standards, the fundamental requirement when selecting BLE Mesh components is certified compliance with the Bluetooth SIG standards.

Choosing the most cost-effective BLE Mesh components also has two dimensions: the silicon and its software. The silicon is the system-on-chip (SoC) or system-in-package (SiP) modules, and the software is the development tools that accompany them.

With interoperability as the raison d'être for standards, the fundamental requirement when selecting BLE Mesh components is certified compliance with the Bluetooth SIG standards. This applies equally to both the silicon and the software, including the full Bluetooth BR/EDR and BLE Mesh protocol

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As of this writing, certification is available for version 5.0 of the Bluetooth core specifications and for version 1.0 of the BLE Mesh specifications. Version 2.0 of the BLE Mesh specifications are expected to be published in 2020.

When choosing a BLE Mesh platform, designer engineers should seek a solution that meets most or all of the following criteria:

- A family of modules to accommodate different needs—from the basic battery-powered sensor to the most sophisticated devices that might be needed now and in the foreseeable future.
- Fully integrated modules that minimize the need for external components, accelerate time-to-market, and reduce development and manufacturing costs.
- Ultra-low-power designs with the types of antennae and transmit powers needed to accommodate all anticipated node-to-node distances.
- Adequate CPU, memory (flash and RAM), and I/O for all foreseeable applications and upgrades.

For applications in which the BLE Mesh network may need to communicate with a Wi-Fi network, some form of gateway functionality will be required. For example, a home security system could be used to turn on or off certain lights to simulate people being at home or be deactivated with an authorized code. In these situations, an SoC or SiP combo-module that supports both Wi-Fi and BLE networking simplifies the design effort.

Because the software-development environment, tools, and libraries are just as important as the silicon, endeavor to find a solution that meets most or all of the following criteria:

- An easy-to-use integrated development environment (IDE) that abstracts the complexity of the underlying protocols
- Software development kits (SDKs), sample software, prototyping hardware, and a developer community to assist in software development and testing efforts
- Reference software designs for control applications running on the Android, iOS, Linux, and Windows operating systems

Bluetooth is already ubiquitous in "personal area networking" applications, and the advent of BLE Mesh significantly expands both the scale and scope of potential use cases for this popular protocol. The combination of virtually unlimited scalability and high resiliency afforded by BLE Mesh networking now enables Bluetooth applications to span buildings, campuses, and even entire cities. While the smart-lighting application used here serves as a good example, the potential use cases for BLE Mesh are limited only by the imagination.

Its ubiquity also gives Bluetooth another important advantage: the availability of proven techniques, tools, and software needed to develop new products. Hardware and software engineers interested in learning more about these resources are encouraged to review the documents and links listed in the References section below.

The many resources now available make it easy to get started with BLE Mesh. Proof-of-concept designs can be created quickly and affordably using inexpensive evaluation boards, IDEs, and SDKs. A solid head start may also be available in open-source or vendor-supplied sample application software. As a leading supplier of Bluetooth-certified silicon and software, Cypress Semiconductor provides an array of resources at *www.cypress.com/products/ble-bluetooth.*

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By offering enormous upside potential with minimal downside risk and a short time-to-market, BLE Mesh is destined to become the network of choice for a growing number of residential, commercial, and industrial applications. mw

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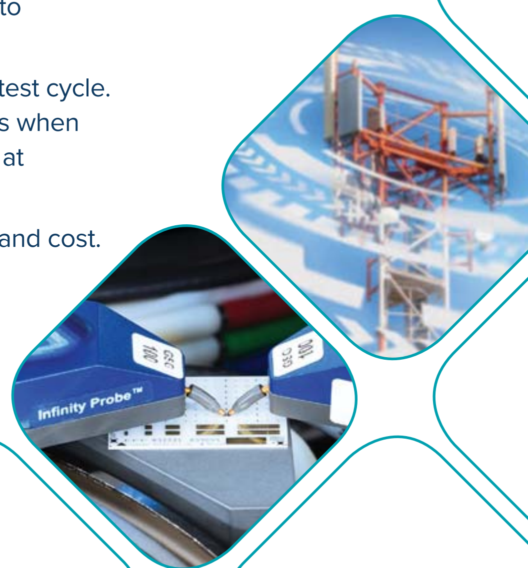
BLE Mesh specifications: https://www.bluetooth.com/specifications/mesh-specifications

Getting Started with Bluetooth Mesh (AppNote AN227069)


5G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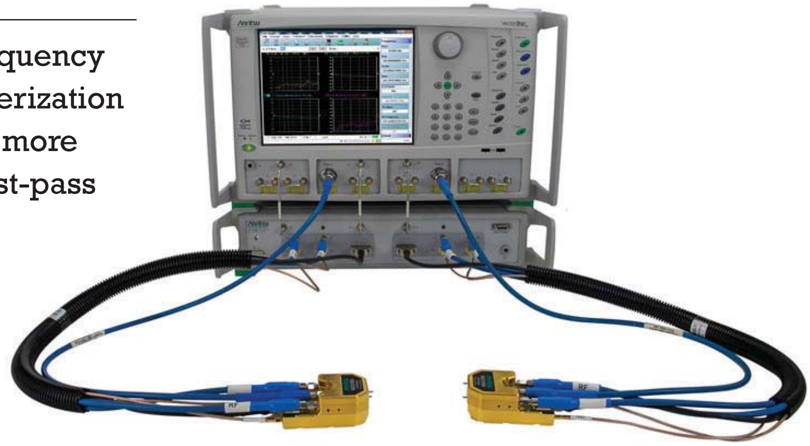
DAVID MALINIAK | Editor

VNA Spans

70 kHz to 220 GHz in a Single Sweep

The instrument's extended frequency coverage translates to characterization of a broader range of devices, more accurate models, and more first-pass design success.



1. Anritsu's VectorStar ME7838G broadband vector network analyzer (VNA) takes a big step toward filling the void in mmWave device characterization.

The design process for complex millimeter-wave (mmWave) ICs is long and often arduous. With such devices finding their way into a widening range of applications from communications to imaging to autonomous vehicles, designers can't afford multiple design iterations caused by iffy modeling and simulation. The way out of the iterative loop is through faster and more accurate on-wafer device characterization, which requires test equipment with very broadband capabilities.

In its VectorStar ME7838G broadband vector network analyzer (VNA), Anritsu has taken a big step toward filling the void in mmWave device characterization *(Fig. 1)*. The ME7838G is the industry's first VNA capable of making measurements from 70 kHz to 220 GHz in a single sweep, enabling engineers to characterize devices more accurately and efficiently over a much broader range of frequencies. This means more accurate S-parameter device models, thus optimizing the chance for accurate simulations and opportunities to reduce design turns.

THE RISING TIDE OF FREQUENCY

Why do engineers need a broadband 220-GHz VNA? As the communications industry migrates more firmly into the mmWave bands, the need for characterization at higher frequencies becomes apparent *(Fig. 2)*. For example, within the 60-GHz range are Wi-Fi, WiGig, and other ISM types of applications. A 70-GHz broadband VNA will allow you to make measurements within that fundamental band. But if you want to sweep your amplifier to the third harmonic, you'll need to reach 180 GHz. The fifth harmonic of 5G takes you to the 190-GHz range.

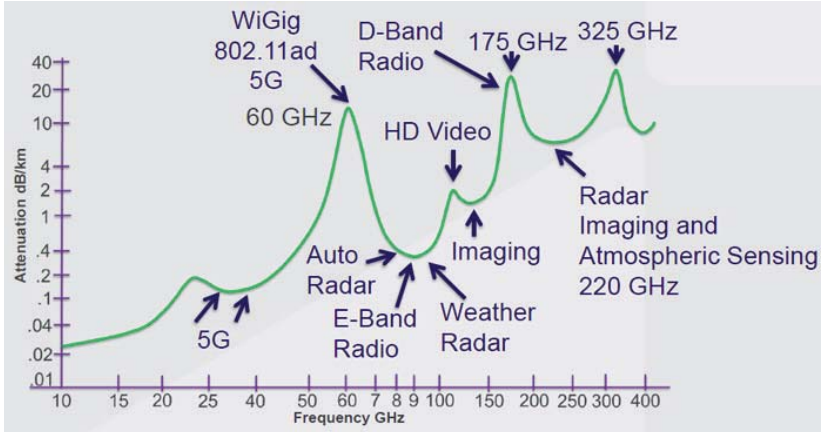
Truly accurate on-wafer characterization of the devices that make up a mmWave IC—amplifiers, mixers, filters, transmission lines, and so on—demands testing of the devices over a frequency range that exceeds their operating-frequency range. VNAs have traditionally been limited in their frequency ranges by the coaxial cables and connectors that access the device under test (DUT). The VNA itself has a broadband frequency range that's combined with waveguide bands to reach higher in frequency.

Consequently, an important element in Anritsu's push toward broader frequency coverage revolves around advances in connector technology. Some years ago, Anritsu started down this path when it pioneered the 40-GHz, 2.92-mm connector. The 1.85-mm connector reached the 70-GHz milestone, and a 1-mm connector allows a VNA to sweep frequencies to about 110 GHz.

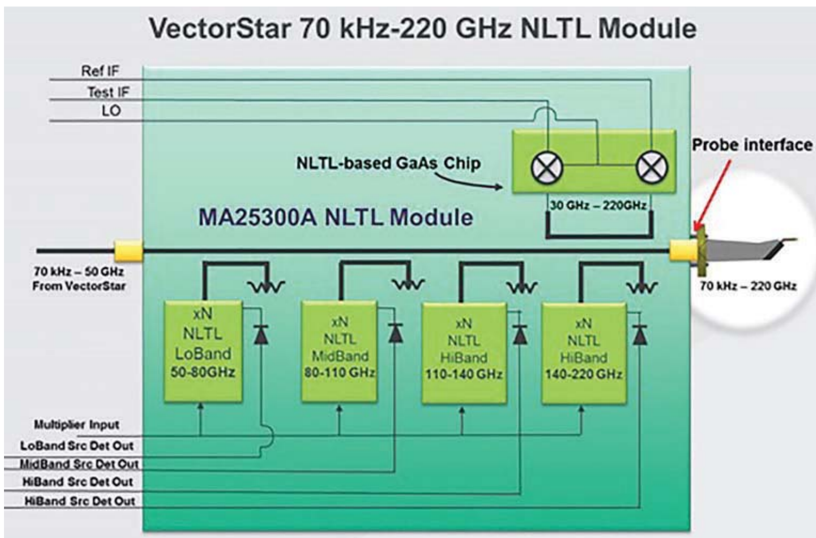
Therefore, to get to as high as 220 GHz, engineers might employ a concatenated waveguide-band approach. A

VNA that operates to 110 GHz with a 1-mm coaxial connector could be paired with a frequency extender with a D-band waveguide to span up to about 170 GHz, followed by more testing with another frequency extender using a WR5 waveguide that covers from 140 to 220 GHz.

While such an approach may work, it brings the headaches of having to calibrate each setup along the way. There's wear to the aluminum on-wafer landing pads, calibration structures, and probes, which reduces repeatability and uncertainty in test results. And, with different calibration standards often in play, successful de-embedding of the test setup becomes more difficult. With a true broadband VNA (dc to maximum frequency), the user realizes more consistent de-embedding, less calibration issues, and fewer wafer touchdowns.



2. Why do engineers need a broadband 220-GHz VNA? With the communications industry moving more solidly into the mmWave bands, the need for characterization at higher frequencies become apparent.



3. Thanks to a direct dc-path transmission line from the VNA, the ME7838G offers optimum raw directivity. The waveguide bands are coupled to that transmission line.

PULLING IT TOGETHER

In the VectorStar ME7838G VNA, several strands of technical achievement are woven together, resulting in an instrument that pushes broadband mmWave testing directly to 220 GHz. First and foremost is Anritsu's nonlinear transmission-line (NLTL) sampling technology—it first appeared in the company's 110-GHz VNA but is used here to even greater effect. NLTL technology, combined with distinctive circuit layout, delivers important benefits.

Its small, tightly integrated packaging enables direct connection to the test probes for stability and performance. In addition, the circuit's layout provides optimum raw directivity. As shown in *Figure 3*, a direct dc-path transmission line goes from the VNA to the test port. The waveguide bands are coupled to that transmission line. Optimum raw directivity lends itself to overall calibration stability that won't be affected by temperature changes or mechanical flexing of cables.

Anritsu's NLTL technology provides very high conversion efficiency and a very low noise floor, translating to excellent system dynamic range at mmWave frequencies. The new module adds a mmWave source band for frequencies from 140 to 226 GHz. Meanwhile, an NLTL-based harmonic sampler converts test and reference signals to IF from 30 to 226 GHz; that sampler is physically located close to the probe interface.

Before all of that, of course, is the interface with the DUT. Anritsu's emphasis on connector technology has brought it to the airline-equivalent 0.6-mm level for this instrument, using a slotted sub-0.4-mm male pin center conductor and a slot-less sub-0.4-mm female center conductor. The UG-387 flange provides alignment for the connection, which eliminates the need for a threaded connector. It's said to be far more repeatable than a coaxial connection that, due to thread wear over time, would see alignment degradation.

Anritsu partnered with MPI to develop the field-replaceable, 220-GHz MPI Titan probes, which are available in pitches of 50, 75, and 100 µm. An important element of the probe's design is good visibility of the tips for accurate, repeatable on-wafer touchdowns. mw

Slogging Toward 5G

Do you really want it? Do you really need it? Here's the latest state-of-the-state for the embattled technology.

What more can we say about 5G that hasn't already been said? If you've followed this hype-loaded saga, you probably already know what's going on. But as a casual observer, you may not be aware of the latest activities. Here's a quickie update.

We've been hearing about 5G New Radio or 5G NR for years now. The Third Generation Partnership Project (3GPP) started working on this standard even before the LTE standard was complete. LTE, or 4G as some want to call it, turned out to be an exceptional wireless technology that most everyone is happy with. However, the industry and the standards people seemed hell-bent to work on 5G. And now that we're nearing the end of the 5G development, we're finally beginning to see real 5G action.

The stated goals of the 3GPP for 5G are:

- Deliver enhanced mobile broadband (eMBB) speed up to 20 Gb/s and increase subscriber capacity about 100X the current levels. You won't get that speed in practice, but you should see download speeds from 100 Mb/s to 1 Gb/s.
- Deliver ultra-reliable low-latency (< 1 ms) communications (URLLC) for critical applications.
- Implement massive machine-type communications (mMTC). Inclusion of LPWAN standards like LTE-M and NB-IoT will boost IoT applications.

Those are tough goals, but most are being achieved. Latency is still an issue with best current levels in the 10- to 30-ms range. Much work must be done as advanced driver-assistance systems (ADAS), self-driving cars, and some factory applications will depend on it.

The electronic and telecom industries are thrilled to have 5G come online, as their bottom lines should be enriched. Yes, some 5G systems are now working at selected cities around the U.S. and Europe. In the U.S., check the websites of AT&T and Verizon for coverage; they are currently the main carriers. Many industry observers and potential customers feel that the rollout is too slow. And it has been. Not only because it's an incredibly complex technology, but also for business and political reasons. Here's a summary of its current status.

THE BATTLE FOR 5G SUPREMACY

Apparently, we're in a knock-down, drag-out war with China as to who will get full 5G service first and who will control the technology, the equipment, and to some extent, the markets. Last year, the FCC and others surmised that the U.S. was leading. This year, most seem to think that China is winning.

China is much bigger than the U.S. population-wise with about 1.4 billion people. And the government funds the 5G effort. As a result, it's believed that they have already deployed more 5G cells than in the U.S. Plus, the Chinese carriers don't have to bid on and pay for spectrum as carriers do in the U.S.

Another big reason why China is ahead is the Chinese company Huawei. Huawei is the world's largest supplier of telecom gear and third in smartphone sales behind Samsung and Apple. The U.S. no longer has a home-based company making cell-site and other equipment. Instead, U.S. carriers rely on Ericsson of Sweden and Nokia of Finland for their cell sites.

THE HUAWEI PROBLEM

The U.S. government claims that Huawei makes its telecom equipment such that they can spy for China. Our government thinks that their equipment has clever features that could be called up remotely to eavesdrop, steal information, and perhaps even to shut down service at any time. I've never seen or heard of any firm evidence of this, but the government is paranoid about it and has basically forbidden U.S. telecom companies from buying Huawei equipment for their 5G systems.

In addition, the government has tried to discourage the telecom companies in Europe and other locations not to buy Huawei gear. That has fallen on deaf ears—a number of European companies have already bought Huawei equipment because its cost is so significantly lower than what Ericsson and Nokia charge.

The latest plan is that the Commerce Department has issued a demand that forbids U.S. semiconductor companies from selling critical chips to Huawei. Because of Huawei's size and market penetration worldwide, they buy a boatload of ICs from U.S. companies who hate to lose those sales. The government may allow sales of some common ICs, but not the real innovative high-tech stuff. For now, most researchers seem to think that as of now, China leads the U.S. in 5G. Are we doing anything about it, or does it really matter?

WHAT'S HOLDING THE U.S. BACK?

There are a couple of reasons for the slow progress toward a nationwide 5G network. First, as most of you know, there are still some spectrum shortages. 5G takes a great deal of bandwidth to fully achieve the peak goals stated for it. Channel widths typically run 20 MHz, but they can be 40, 80, or even 160 MHz when using the advanced orthogonal frequency-division multiplexing (OFDM) modulation modes. That kind of bandwidth just doesn't exist for some carriers.

The FCC is working on the problem by trying to acquire unused or vacant spectrum from current holders of suitable spectrum. Once they get it, the FCC wants to auction it off to the highest bidder. The auctions that implement those sales are time-consuming to set up and conduct. Some take years to complete. And the telecom companies are saddled with enormous costs (billions), which are just passed along to the subscribers. Some advocate eliminating the auctions and creating a new fast-track way to get spectrum assigned more quickly.

If that's not enough, some private investors, government agencies, and large corporations are holding spectrum they're not using—and they refuse to give it up. An example is the fate of the best spectrum block located near the frequencies used by GPS (1.57542 GHz and 1.2276 GHz). The claim is that any nearby cell service will interfere with GPS navigation. While tests have been made to ensure this isn't a bother, the controllers of that spectrum have won the battle.

One other unexpected problem is that there's a shortage of good locations to attach the small cells that will be the heart of the 5G system. Many such cells will be needed when the millimeter-wave (mmWave) bands finally open up. Initially, most U.S. 5G systems will operate below 6 GHz. Some local governments are refusing to permit the carriers to attach small cells to some buildings, light poles, and other city-owned infrastructure that could be used. In other cases, lease costs are high and local government delays have hampered rollouts in some parts of the country.

Of course, there's also the high cost of building a whole new wireless network. The telecom companies will spend billions since all new equipment is needed—and more of it—to provide adequate coverage of an area. And that gear is more complex and expensive than today's cell sites. No doubt some carriers are holding off on that investment.

RECENT FCC ACTIONS

I give the FCC credit for actually doing something about the spectrum issue. Some of those actions should have been taken earlier, but here we are. And the good news is that some new developments are on the spectrum front:

- The FCC is auctioning off 3400 MHz of bandwidth in the mmWave bands of 37, 39, and 47 GHz in 100-MHz blocks. That's a massive amount of spectrum and it will be a while before we see some activity in those bands.
- The FCC will vote soon on freeing up 300 MHz of spectrum in the highly desirable C band (3.5 to 8 GHz) for mobile and fixed wireless service. This is spectrum that will come from satellite companies operating in that range.
- The FCC will vote on improvements to the "white spaces," the unused TV channels that can be used without a license. The Commission will vote on issues like opening more channels, boosting transmit power, and increasing tower heights. One key goal is to provide better options for implementing fast and reliable broadband wireless services in the many underserved rural areas.

THE BIG MERGER

T-Mobile has been wanting to buy Sprint for years. It's been turned down twice before as the Justice Department felt that it would reduce the competition and increase the costs to subscribers. That's never been proven, but the threat is there. Last year, the third and fourth largest cellular companies by number of subscribers tried again. This time a coalition of states once more warned that a monopoly with all of its negative outcomes would occur if such a merger was made.

In February, a judge finally approved the $26.5 billion merger, and finalization of the merger was announced on April 1. The combined company will be in third place behind the leaders Verizon and AT&T. However, it will come closer in size to AT&T and Verizon and should be a formidable competitor. I suspect that if the merger hadn't been approved, Sprint may have eventually gone broke and out of business, leaving a much smaller T-Mobile to compete with the top guns. The new combined company, named T-Mobile, can now go ahead with their plans for 5G systems.

One more thing. These merger deals, especially those that have to go through the courts, usually involve other activities and tradeoffs that aren't too evident. Both T-Mobile and Sprint had to give up some assets (like some spectrum) to clinch the merger. Along with those concessions, "the powers that be" have encouraged (demanded?) Dish Network to launch a cellular/5G business. With their massive unused spectrum holdings, they could become the new fourth largest cellular provider.

JUST A THOUGHT

One hot industry sector right now is the tower business. Companies that rent space on their towers to the wireless carriers are doing well and business is expected to grow significantly due to the space needed for all of the new 5G antennas. 5G antennas for MIMO, agile beamforming antennas, and phased

arrays are bigger and need a specific height. Watch companies like American Tower, Crown Castle, and SBA Communications to see how they perform in the coming years.

SO WHERE ARE WE NOW?

The general consensus is that the rollout will slow down for a while. Some component and equipment makers are actually predicting lower sales for this year as a result. However, progress will be made. The 3GPP standards will work toward a conclusion. We should see Release 16 (MIMO and mmWave enhancements) later this year and Release 17 sometime in 2021 (above 52-GHz mmWave modifications plus M2M enhancements). I bet the 3GPP is already looking forward to starting on 6G. No doubt artificial intelligence and machine learning will be involved.

During the year we should also see more 5G smartphone vendors. To date, there's been a shortage of vendors and 5G phones. But that's changing. Samsung, the smartphone leader, announced its new Galaxy S20 5G phones. There are three models with ever-better AMOLED screens of different sizes and improved cameras. All work on a mixed bag of frequencies, all below 6 GHz. Millimeter-wave phones will come later. S20 phone pricing is $1,000 for the low-end model and $1,400 for the top of the line. Maybe paying that premium price for mainly a better camera is okay for some, but others will expect something better.

Samsung also introduced its new 5G flip phone. Called the Galaxy Z-Flip, it has a split screen that flips open like the popular flip phones of the late 1990s and early 2000s. Remember Motorola's massively popular Razr? The rumor is that they will soon produce a 5G version. People seem to love this format even though it's more likely to fail than a standard no-flip smartphone. Price for the Z-Flip is $1,380.

Huawei also announced a folding phone. Called the Mate-X, it comes in several sizes and has a Leica-brand lens in the camera. The top of the line model will sell for $2704. Like the other smartphone vendors, Huawei is hoping the new models will help boost declining smartphone sales.

I'm still wondering if the extra speed and lower latency offered by 5G are really needed. Most people I talk to don't have any applications on their smartphones that need such speed. Plain-old LTE is good enough for most, including me, for now. But I'm keeping an open mind about 5G. And I'm starting to save up. mw

3U Rackmount Computer Boasts Dual Processors

THE NEWEST BEAST of a computing system from WIN Enterprises is the PL-81990 3U rackmount high-performance networking system. The system features dual Intel Skylake-SP processors, which are based on the Intel Xeon series processors. The processors are combined with Intel's C624 PCH chipset that, together, create a mesh-networking architecture to efficiently handle multiple processing tasks. The targeted applications for the system include cloud data centers, HPC clusters, IT networking, AI computing, and large data storage systems. The device allows for up to 96 Gigabit Ethernet connections as well as support for Gigabit fiber connections.

WIN ENTERPRISES, www.win-ent.com

Anti-Vandal Switch Offers Square Bezel

ANTI-VANDAL SWITCHES are great for applications that are subject to harsh conditions and treatment. A recent design from E-Switch, the PVS7, gives designers the option of a square bezel compared to the many circular and hexagon-shaped bezels available today through the PV series line. The bezel is 25 mm square and requires a 22-mm cutout for mounting. Among the options for the switch are illuminated LED rings including RGB, the possibility to purchase the switch pre-wired, and single-throw or double-throw configurations. All the switches carry an IP65 rating for dust and moisture resistance as well as a guaranteed lifespan of 50,000 cycles. Further specifications include rating of 2 A at 24 Vdc and 50 mΩ of contact resistance.

E-SWITCH, www.e-switch.com

SPI EERAM Safeguards Data at Lower Cost

MICROCHIP TECHNOLOGY has launched a new family of SPI EERAM that's said to offer designers up to a 25% cost savings compared with currently available solutions. Microchip's EERAM is a serial SRAM product that can transfer content to nonvolatile bits upon a power disruption. The EERAM will be available in four different memory densities of 64 kb, 256 kb, 512 kb, and 1 Mb. Furthermore, data can be moved from the SRAM to the nonvolatile cells a guaranteed 100,000 times while the nonvolatile cells can hold their data reliable up to 100 years without power being restored. I^2C serial EERAM products also exist, although they are only available in densities of 4 kb and 16 kb. The products are available now in 8-pin PDIP, SOIC, and TSSOP packages.

MICROCHIP TECHNOLOGY, www.microchip.com

NVIDIA-Based AI Embedded PC Takes Little Space

THE LATEST COMPUTING SOLUTION from AAEON is a small SoC with a quad-core Arm Cortex-A57 MPCore processor and an NVIDIA Jetson Nano AI solution. The BOXER-8220AI's GPU features an NVIDIA Maxwell architecture with 128 NVIDIA CUDA cores capable of processing speeds up to 472 GFLOPS. In addition, for storage, the module houses 4 GB of RAM and 16 GB of eMMC memory. The device also features a lot of options for external interfaces. Five Gigabit Ethernet ports are available as are four USB 3.0 ports. An HDMI, two RS-232, micro-USB, and dc power connection round out the available external connections. The fanless enclosure is resistant to dust and allows the device to operate from -20°C to 60°C without taking a performance hit.

AAEON, www.aaeon.com

(Continued from page 22)

will be several years before it becomes as widespread as the current 4G network.

So, when building real-world applications in 2020 for near-term deployment, or for the next year or two, it's important to acknowledge that most applications being created will not recognize the anticipated benefits from 5G. There simply will be no omnipresent 5G infrastructure available to leverage. If your product lifecycle is long, as is often the case in Industrial Internet of Things (IIoT) applications, then it might make sense to provision the hardware today for this capability tomorrow.

As engineers, we realize that if we include newly available components in a 2020 design project, those components will not have realized the cost advantages that will incur as the market matures.

As engineers, we realize that if we include newly available components in a 2020 design project, those components will not have realized the cost advantages that will incur as the market matures. In addition, if the component doesn't become adopted, it may go end-of-life within two years of release because sales targets weren't met. Likewise, challenges will arise when integrating the latest technology into today's products. We're all too familiar with why new things are often said to be on the "bleeding edge." This begs the question: Is there enough benefit to warrant being on that edge?

WHAT SHOULD I CONSIDER IF IMPLEMENTING 5G TODAY?

If the need, or perceived need, is such that 5G must be in the development plan this year, be prepared to weigh the following considerations:

- The range for a tower or cell site will be significantly shorter for 5G than for lower-frequency 4G. If 5G is a key element of success for your application, think about the 5G network density in the target geographic vicinity. It's one thing for a 5G provider to put a "stick pin" on the map in the vicinity of a 5G site. It's another thing entirely to have a dense network across a wide area.
- 5G coverage, besides being impacted by the physical distance between cell towers/repeaters, depends on the environment. 5G networks aren't particularly good at providing coverage when the signal is interrupted by walls, water towers, and other RF propagation barriers.
- Make sure you're building robust models around power management. Current 5G chipsets draw more power than some other competing technologies. Take measures to assure you have both sufficient battery capacity and well-architected power-management schemas to ensure useful operating life.
- Make sure your project plans allow for the inevitable pitfalls of utilizing any bleeding-edge technology. Early technology adoption inevitably brings implementation challenges such as immature embedded software stacks and the like. Expect to be developing your new product while debugging your supplier's evolving software-development kits (SDKs) and application-programming interfaces (APIs) in real time. Account for these hiccups in your manpower budgeting and scheduling.
- Be prepared to implement a robust test methodology with which to ensure not only that a few systems prove reliable, but that you're also ready to accept issues due to manufacturing process variability. These are all "table stakes" points for those of us who have been among the early adopters of the newest technologies.

IoT applications are doing quite well today without the use of 5G, but 5G could certainly bring significant advantages to other situations. In the coming years, as the infrastructure becomes widely deployed and the technology matures, selection of 5G for implementation will make sense for many more applications. However, in 2020, when considering incorporation of 5G, make sure the use case makes sense and that, as engineers, you're prepared for what could be a bumpy journey along the bleeding edge. mw

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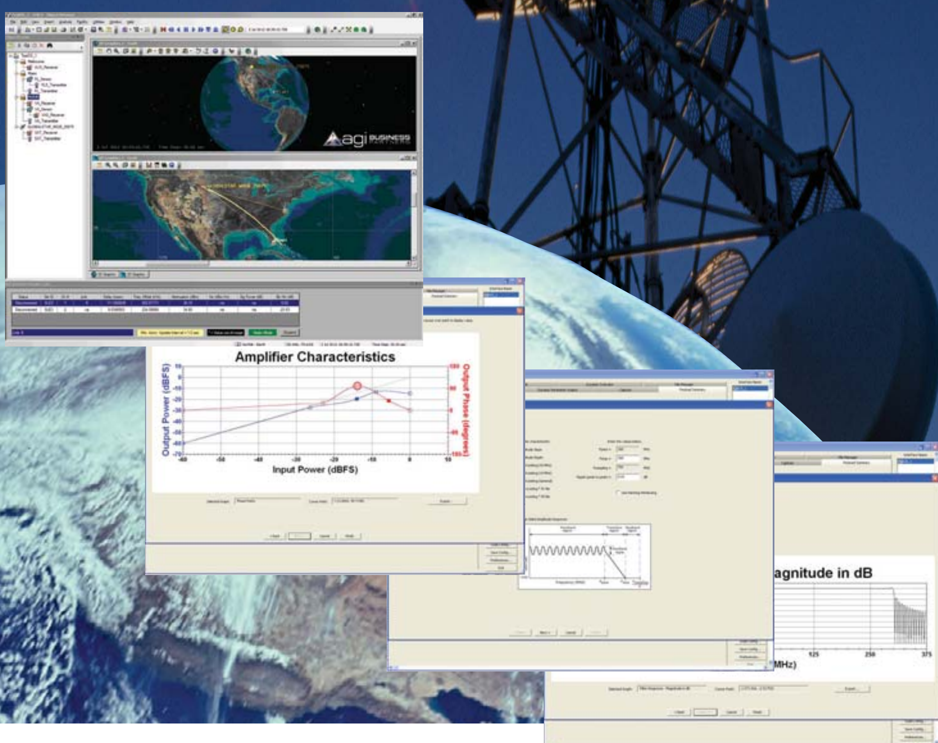

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