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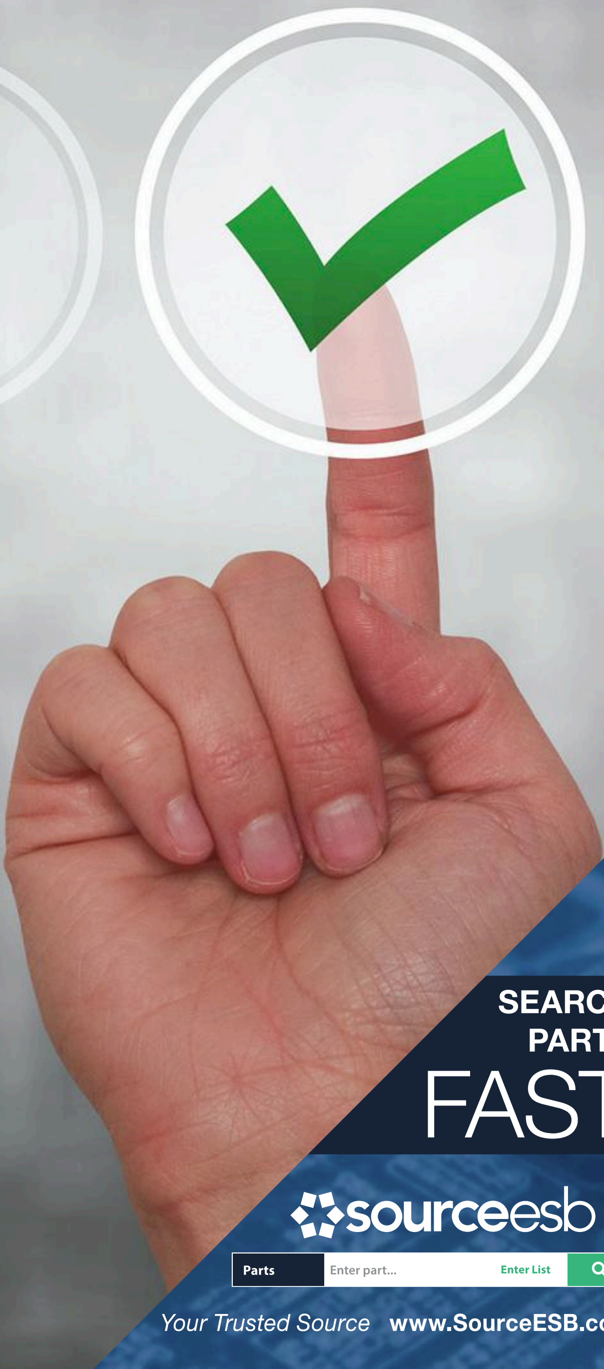

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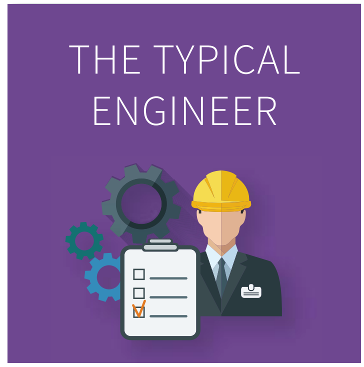

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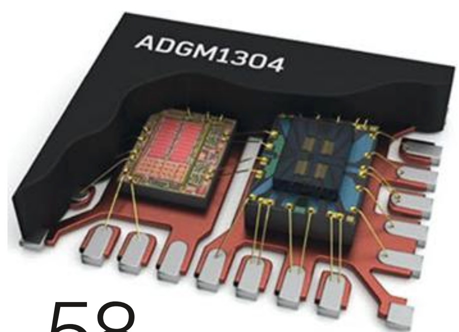

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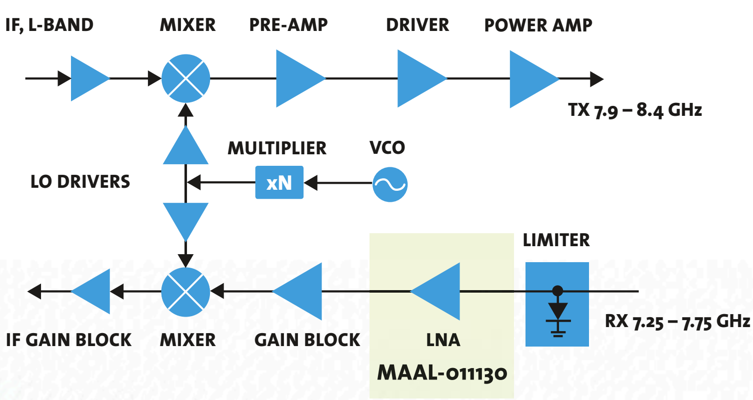

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Metamaterials Provide Novel EM Capabilities

Metamaterials have been under study for several decades due to their novel electrical characteristics and becoming more practical with the growing use of 3D metal printing.

http://www.mwrf.com/materials/metamaterials-provide-novel-em-capabilities

At Qorvo, Big Expectations for GaN

Qorvo systems engineer Bror Peterson discusses several topics in regard to 5G communications, ranging from gallium-nitride technology to module integration, filter requirements, and more.

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Software Centricity Seeks to Make the Impossible Possible

This software-centric platform helps solve today's difficult challenges by allowing for productivity through abstraction, software interoperability, comprehensive data analytics, and the efficient management of distributed systems.

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Cables and Connectors Head for Higher Frequencies

While they can't match the low loss and power handling of waveguide, coaxial cables and connectors are climbing the frequency ladder to cope with anticipated 5G applications.

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Editorial

CHRIS DeMARTINO | Technical Editor
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Will Startups be the Key Ingredient to 5G's Success?

Startup companies are developing innovative technology that could ultimately bring them to the forefront in the 5G arena.

It's no surprise that a large number of established companies are playing major roles in hopes of ultimately enabling next-generation 5G networks. However, that begs the question: "What part will startup companies embrace in this 5G game?" While the big names may seem to get all of the attention when it comes to 5G (and rightfully so), the opportunity is ripe for startup companies to make a big impact as well.

It would be wise to pay attention to what these startup companies have to offer—a number of them are invested in developing technology solutions for 5G. Since 5G still is not defined, startups could assume essential roles in making it a reality.

One startup focused on 5G communications is PHAZR *(www.phazr.net)*, which has developed a solution known as Quadplex. This technology utilizes millimeter-wave frequencies for the downlink while using sub-6-GHz frequencies for the uplink. The company believes its technology can enable "high-performance, cost-effective, and power-efficient 5G systems."

Another startup company fixated on 5G is Movandi *(www.movandi.com; see Q&A on pg. 84)*. The company works extensively with millimeter-wave frequencies—its BeamX front end integrates RF, antenna, beamforming, and control algorithms into a modular, 5G millimeter-wave solution. Movandi's goal is to help accelerate 5G deployments and grow the market faster.

Startup GenXComm *(www.genxcomm.com; see "Imagine Life Without Interference" on mwrf.com)* has also thrown its hat into the 5G ring. With its simultaneous self-interference cancellation (S-SIX) technology, the company is targeting the 5G market, among others. There's also NYC-based MilliLabs *(www.millilabs.com)*, which is focused on channel sounding and channel emulation.

While startup companies may be small in size compared to the established firms, they nonetheless have the chance to significantly impact the 5G landscape. Time will reveal just how much influence they will carry in enabling the next-generation of wireless communications. Perhaps some of the companies that rise to the top in the 5G space will be those you have never even heard of. mw

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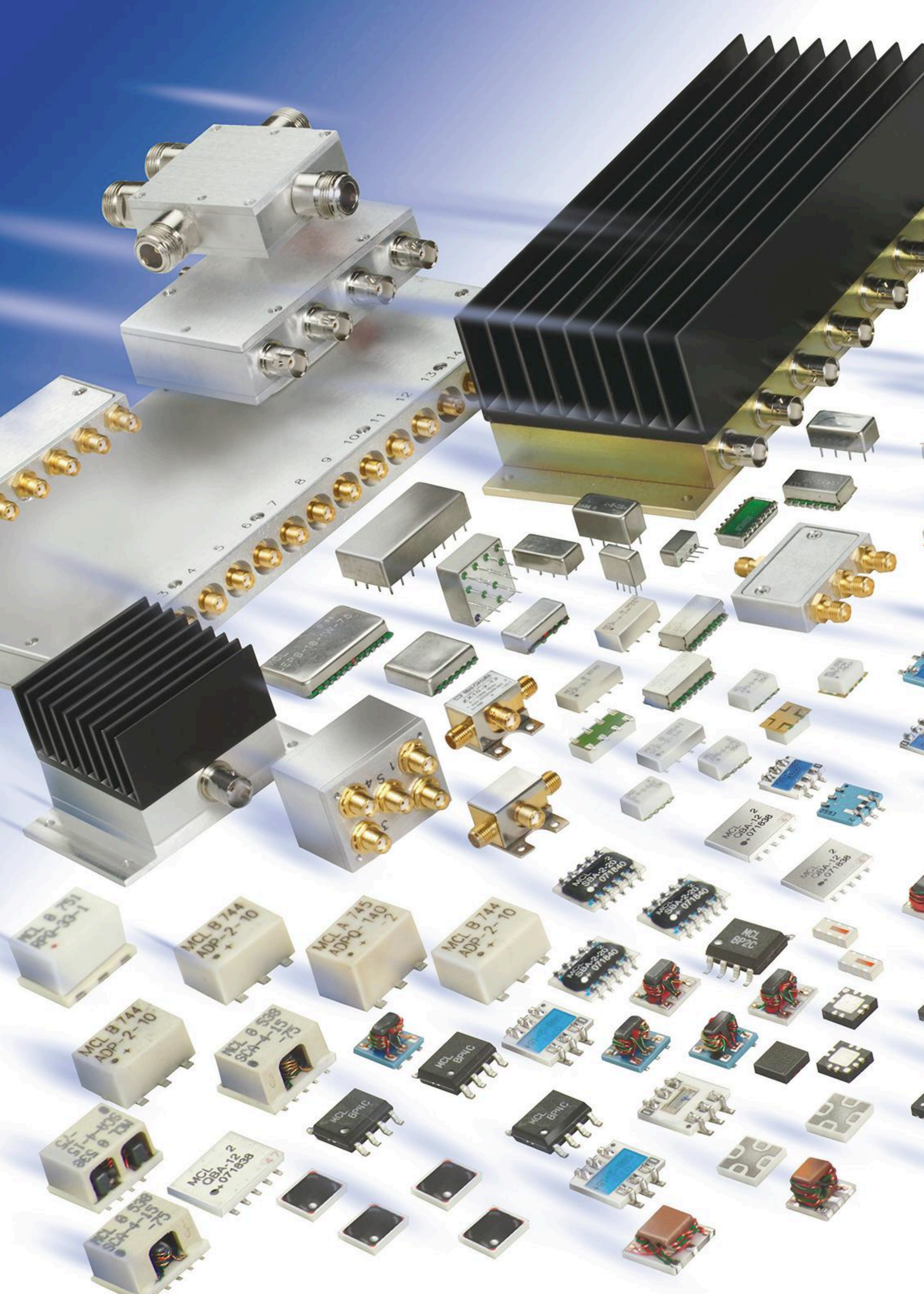

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OCTAVE BAND LOW NOISE AMPLIFIERS

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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JACK BROWNE | Technical Contributor

Master the Basics of MM-Wave Amplifier Design

SO FAR IN 2017, no part of the electromagnetic (EM) spectrum has arguably received more attention in this industry than the millimeter-wave region. The bandwidth is there and available for 5G wireless networks and automotive electronic systems, provided the industry can find the ways to deliver cost-effective components.

One of the more vital of millimeter-wave components is the power amplifier (PA), since it provides the means of boosting signals levels that are often fairly low at those high frequencies (30 to 300 GHz). Fortunately, a newly launched "Basics of Design" white paper sponsored by National Instruments AWR Corp. *(www.awrcorp.com)*, "Raising the Levels of 5G Millimeter-Wave Signals," provides all the essentials of designing millimeter-wave PAs. In an age where time to market can mean the difference between success and failure, this Basics of Design stresses the importance of working with modern computer-aided-engineering (CAE) software simulation tools.

While derivation of fundamental design equations, such as impedance-matching relationships for PAs, is still an excellent way to learn about the critical relationships among transmission lines, passive components, and active semiconductor devices in a PA circuit design, such software tools benefit from proven device and component models. They can provide 10 or more looks at different PA configurations in the time that those fundamental equations are still being solved (if they are being solved).

The National Instruments' Basics of Design on PA design provides a practical starting point on understanding key differences between amplifiers for 30 GHz and above and for amplifiers at lower frequencies. It also provides insights into system-level issues as viewed by service providers such as Verizon, detailing that company's 5G downlink model and how it impacts the design of a millimeter-wave amplifier for 5G.

If 5G has been top of mind, then this is an important piece of literature for your collection. It includes information on EM simulations, load-pull and source-pull analysis, and the use of vector network analyzers (VNAs) for characterizing 5G PAs. "Raising the Levels of 5G Millimeter-Wave Signals" can be downloaded at *http://www.mwrf.com/test-measurement/raising-levels-5g-millimeter-wave-signals.* mw

News

Qualcomm Chip Connects Cars to INTERNET AND EACH OTHER

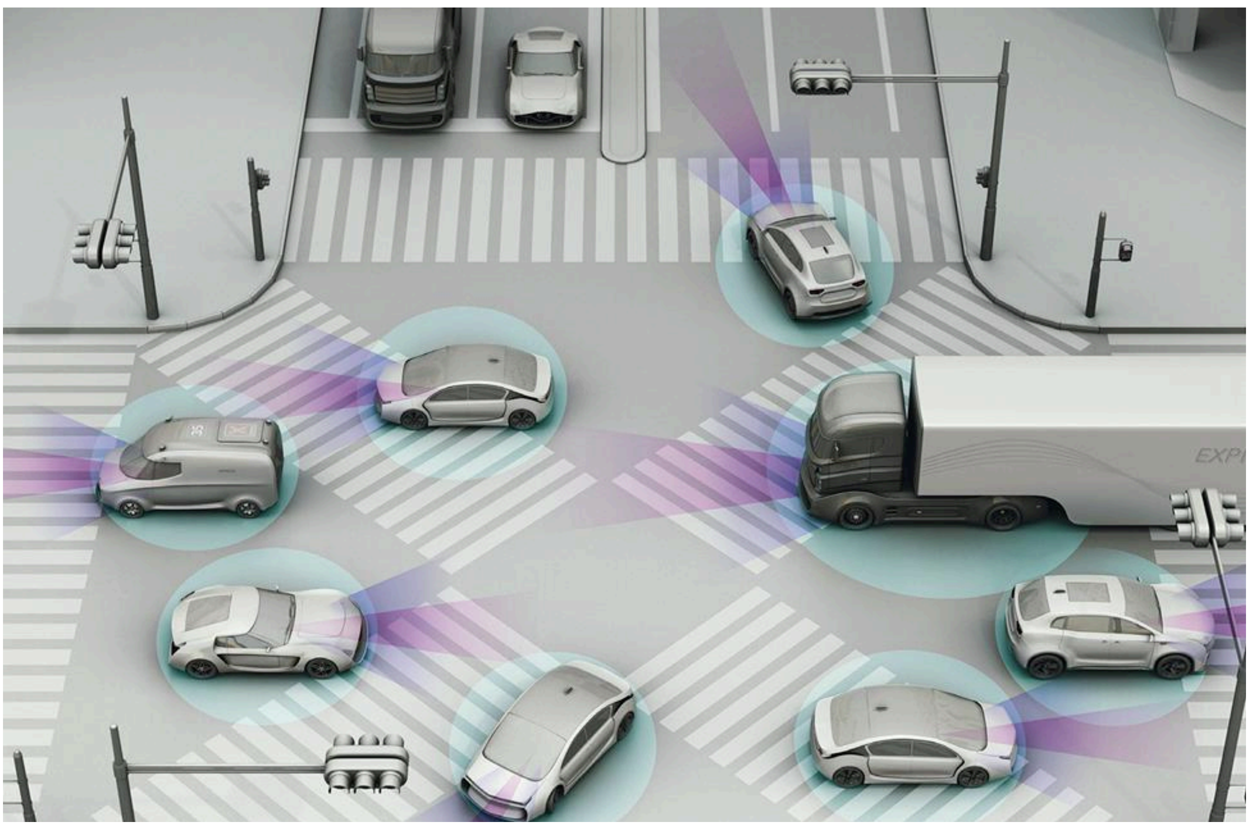
Last year, the Obama administration proposed a rule that would require cars to broadcast their location and speed, enabling safety functions like lane-change warnings and collision avoidance. Officials said that the mandate could reduce crashes and traffic.

Instead of chatting over cellular networks, the rule targets dedicated short-range communications (DSRC), which lets nearby cars know each other's location. But because the fate of the regulation is still unclear, chipmakers are making compromises.

Last month, Qualcomm announced its first modem chip for connected cars, which not only uses cellular connectivity for telematics and other applications that require lots of bandwidth. It also supports D.S.R.C. so that vehicles can talk with traffic lights, smartphones, and other vehicles without having to contend with dead zones.

The C-V2X, which stands for cellular vehicle-to-everything, can be installed into a vehicle's cellular modem. But it can work without using networks operated by Verizon or other wireless carriers. It sends flurries of short DSRC messages to other cars within a 100-foot radius.

The messages ride the 5.9 GHz wireless spectrum, which the Federal Communications Commission has saved for automotive safety applications since 1999. The messages do not contain any information on the owner of the vehicle, make or model, or license plate. Vehicles broadcast these anonymous missives 10 times per second.



Doing so allows cars to quickly spread alerts about nearby accidents, veer around vehicles braking suddenly, or sense other cars speeding around blind corners. Many experts say that DSRC could spot dangers missed by other sensors like lidar, radar, and cameras that act like the eyes of autonomous cars.

To send detailed messages further, Qualcomm's chip also uses 4G networks. That way, companies can remotely cure security glitches without resorting to costly recalls and send camera images into the cloud, where specialized software can stitch them together into digital road maps.

Audi and France's PSA Group signed onto test the C-V2X chips, which also support global satellite navigation. Qualcomm will start sampling the chip to customers in 2018 and expects it to enter production vehicles by 2019.

The mandate, which transportation officials proposed late last year, could be enacted as soon as 2019. It would require all new cars and small trucks to be capable of DSRC communications starting in 2021. Officials said that vehicle-to-vehicle communications (V2V) could eliminate 80% of crashes that do not involve alcohol or drugs.

The rule has faced skepticism and opposition in recent months. The cable industry has lobbied to open the 5.9 GHz spectrum for other applications, while startups have argued that increased regulation hurts the market for self-driving cars. Others say that the rule lacks strong security guidelines and therefore should be loosened.

Qualcomm has also taken issue with the mandate. The company said in public comments that the proposed rule made DSRC the "de facto technology winner." It would pay less attention to 5G technology, which could support automotive applications as soon as next September when the first 5G standard—Release 15—is scheduled to be finished.

It is still unclear if the rule will survive at all. The Trump administration has taken a harsh view of regulation and aggressively rolled back rules enacted in Obama's term. In addition, President Trump has still not nominated anyone to lead the National Highway Transportation and Safety Administration (NHTSA). ■

PROTECTING CONNECTED CARS From Themselves

ANSYS, WHICH SELLS popular tools for simulating and analyzing antennas, announced that it had acquired Computational Engineering International, whose software creates realistic views of simulation data destined to be logged in databases or plotted on graphs.

The company's flagship software, called Ensight, is used for computational fluid dynamics, which can replicate wind curling over car bodies and visualize chemicals swirling through an oil refinery. But ANSYS views that software as a platform that could extend to its entire product portfolio, including tools that predict how electromagnetic fields sprout from antennas.

In an interview, Mark Hindsbo, vice president of ANSYS' design and platform business unit, did not promise specific product changes. But he offered examples of what could be done with Ensight integrated into electromagnetic tools like HFSS, which uses mathematical programs called solvers to flag emissions and coupling issues.

For example, engineers could clearly see how antennas inside drones react to pockets of interference and wireless dead zones. The visualization tools could make it easier to assess how antennas installed on cars cope with interference in cities. Hindsbo said that some partners had already used Ensight and ANSYS electromagnetic solvers together.

"But that is not a product plan, not something we are going to ship tomorrow," Hindsbo said, adding that both companies were meeting this week to discuss what simulation tools—other than those for computational fluid dynamics—could benefit from Ensight's visual prowess.

ANSYS already runs post-processing on its simulation data, but it is not on the same level as CEI's software. Going forward, the two businesses will plan products together closely, Hindsbo said.

Still, microwave and radio frequency engineering seems ripe for the Ensight treatment. As cars and factory equipment start chatting wirelessly, engineers are increasingly using simulation software for antenna prototyping and placement. But these simulations can generate terabytes of data, which CEI's software could make easier to understand.

CEI, which split from supercomputing firm Cray in 1994, has only 28 employees but more than 750 customers in markets like aerospace and automotive. The company, based in Apex, N.C., sells software that turns complex data generated by simulations

(Continued on page 24)

ANSYS SIMULATES ANTENNAS Mounted on Cars and Airplanes

ANSYS UPDATED ITS core software to faithfully simulate how wireless signals react to colliding with trees and buildings as well as hitting patches of electromagnetic interference and rainfall.

The tweaks to the company's software come as engineers face challenges to understanding the nature of millimeter waves. These high-frequency bands are incapable of passing through walls and grapple with other shortcomings. But they are considered vital for 5G communications. Automotive radar systems also harness them to sweep roads for potential dangers.

The updates are not limited to Ansys' electromagnetic software. Mark Hindsbo, vice president of the firm's design and platform business, said in a statement that the software provides "enhanced speed and accuracy—enabling more users, no matter their level of experience, to reduce development time and increase product quality."

Ansys added shooting-and-bouncing-ray algorithms to its electromagnetic tool HFSS, which uses sophisticated solvers to flag emissions and coupling issues. The latest solver visualizes the performance of antennas mounted onto airplanes and cars, which are difficult to simulate without lots of processing power.

Ansys also now includes better visualization and modeling of antennas, which helps engineers find the ideal location for them inside gadgets or large structures like ships. The firm also rolled out an RF link analysis tool that shows how interference hampers radio waves. It can assess the effects of rain, buildings, atmospheric absorption, and statistical signal fading.

The software is another tool with which engineers can chart the behavior of millimeter waves, which are particularly susceptible to signal fading over long distances. Ansys is not alone in trying to make that evaluation process easier: In June, Remcom added diffuse scattering prediction to its radio propagation software.

Other changes also shave down the complexity of meshing, which entails laying triangular cells on models to prep them for simulation. Ansys added what it calls broadband adaptive meshing, which automates the ability of HFSS to refine and optimize the mesh using information taken from a device's frequency spectrum.

Also new are enhanced circuit simulation capabilities. Ansys allows engineers to assemble an electronic system with packaging, sockets, printed circuit boards, and connectors in three dimensions. Then, the entire system can be subjected automatically to electromagnetic and transient circuit analysis. ■

(Continued from page 21)

into animations that run in simulated real-world environments.

"The next generation of products will not be built without simulation up and down the product development cycle, from early concepts to digital twins that run until production," Hindsbo said. CEI's tools will help apply that data more intelligently and present it visually, so that both engineers and executives can grasp it, he added.

ANSYS has already been moving toward simulating antennas in the virtual world. Two years ago, the company acquired Delcross Technologies, whose software lets users not only analyze individual antennas and other parts but also simulate how those parts can affect the ability of a smartphone or car to transmit and receive data.

CEI's software could shed light on a further question: "How do the electromagnetics change if you alter the layout of a fighter jet or car now that you are bouncing between geometry and electromagnetics and the environment?" Hindsbo said. "Those are places where you can speculate on the effects of visualization."

ANSYS—which last year generated $988.5 million from selling software used to design everything from rockets and bridges to wearables and airplanes—did not reveal the terms of the deal.

"Joining ANSYS will give our customers access to the best engineering simulation technology on the planet, and EnSight will help ANSYS users make faster, smarter decisions," said Anders Grimsrud, CEI's president, in a statement. "It's a win-win." ■

BROADCOM STARTS TO SUPPORT New Wi-Fi Standard

BROADCOM ANNOUNCED ITS first series of chips for routers, enterprise access points, and smartphones based on a new Wi-Fi standard, which uses multiple antennas to make space in spectrum for wireless gadgets.

The new standard, more commonly called 802.11ax, will not be agreed upon until around 2019. But chipmakers like Broadcom and Qualcomm have run with early drafts of the standard, which in some ways reflects the fact that Wi-Fi remains the primary window to the internet for billions of people.

"Our reliance on Wi-Fi has increased tremendously as we stream live experiences over social media and upload pictures and files to the cloud while also connecting the many 'things' around our homes," said Greg Fischer, Broadcom's senior vice president of broadband carrier access, in a statement.

The new standard involves coordinating multiple antennas, which send multiple streams of data into devices. An individual stream is split again with orthogonal frequency division multiple access, or OFDMA, the same technology used by cellular networks. In contrast, earlier types of Wi-Fi created multiple streams but assigned only one to each device.

The standard, which is compatible with legacy protocols, creates a wider pipeline for information and eats through less power and spectrum. It aims to provide better coverage and faster loading times in apartment buildings, offices, stadiums, and other locations crowded with smartphones and other gadgets.

Broadcom, which has started sampling the chips to companies like Netgear and Microsoft, was not first out of the gate. It fell behind Quantenna, a scrappy competitor that began sampling a pair of 802.11ax chips in the wake of an initial public offering that raised $107 million late last year.

Broadcom hopes that its three products will inspire customers to create new Wi-Fi routers, gateways, enterprise access points, and smartphones that fit the standard. Competitors could also contribute to the larger market: In February, Qualcomm also announced its first range of 802.11ax chips. ■

RFID SYSTEM HELPS TRACK Sensitive Materials

RADIO-FREQUENCY-IDENTIFICATION (RFID) technology is familiar to most users for its use as the embedded "chip" that serves as a security device for many electronics-based applications. The technology is now also being applied by Argonne National Laboratory to ensure the accountability and security of sensitive materials, including radioactive and hazardous materials.

The ARG-US RFID-based electronic system developed by Argonne is a remote-sensing system for monitoring and tracking nuclear and other sensitive materials. The system uses battery-powered RFID tag sensors to remotely monitor the vital parameters of packages containing sensitive materials. The system was originally developed to support the U.S. Department of Energy (DoE) in modernizing the lifecycle management of nuclear materials, in the process providing enhanced security, safety, and sustainability.

The basic design of the system is a three-chamber module, with the main chamber housing a motherboard and antenna, and additional chambers holding a 10-year battery power supply and a dosimeter printed-circuit board (PCB). The form factor of the system is designed to be compatible with a wide range of packaging formats. It has also undergone radiation endurance testing, ensuring good long-term reliability even when in close proximity to radioactive materials. The suite of sensors within the ARG-US system includes seal integrity, radiation, temperature, humidity, and shock sensors. It features a flexible design that can be expanded to include additional sensors.

The ARG-US RFID system is supported by several specialized software applications, including for on-site monitoring and for active monitoring while transporting sensitive materials. The system has undergone extensive testing at various sites and has shown the capability to monitor thousands of drums of sensitive materials via secure RF/Ethernet communications links. Any unusual actions regarding stored or transported materials will trigger an alarm for immediate action. The information about the material in drums is stored in data tags and archived in servers for convenient access and reference.

See "RFID System for Management of High-Risk Materials," *Tech Briefs,* Vol. 41, No. 8, August 2017, p. 38.

InP HEMT TECHNOLOGY Enables 850-GHz Receiver and Transmitter

BANDWIDTH IS EVERYTHING, even for short-distance communications, and the terahertz frequency range promises a great deal of bandwidth to those who can realize practical communications devices to send and receive information. With that motivation, researchers at Northrop Grumman Corp., with funding from the DARPA THz Electronics Program and U.S. Army Research Laboratory (ARL) under DARPA contract HR0011-09-C-0062, developed receiver and transmitter front ends using a new generation, 25-nm indium phosphide (InP) high electron mobility transistor (HEMT) process capable of direct low-noise and power signal amplification at 850 GHz.

The receiver has two front-end low-noise amplifiers (LNAs) followed by a downconverting subharmonic mixer (SHM). The mixer translates the frequency band from 830 to 865 GHz to an intermediate-frequency (IF) range of 16 to 51 GHz, with the mixer driven by a local oscillator (LO) multiplier chain. The LO channel uses a 45.22-GHz input frequency which is then multiplied by a factor of nine to an output frequency of 407 GHz. The transmitter uses an upconverting SHM to translate frequencies from the IF range to the RF range. Three amplifiers are used to provide signal amplification and power gain, resulting in as much as −2.2 dBm output power from 830 to 865 GHz.

Measurements at these high frequencies were made with a number of test sets and accessories—mainly an 8510XF vector network analyzer (VNA) from Agilent Technologies (now Keysight Technologies) for microwave measurements from 10 to 110 GHz, along with WR1.5 and WR1.0 waveguide frequency extender test sets to make signal measurements at 500 to 700 GHz and 750 to 1000 GHz, respectively. The VNA measurements were calibrated using on-wafer thru-reflect-line (TRL) calibration kits.

To make this terahertz monolithic integrated circuit (TMIC) technology practical, the researchers realized the importance of developing a packaging technology that would enable low-loss transfer of signals from semiconductor chips to package waveguide input and output ports. The packaging approach does away from wirebonds and the losses they impose at such high frequencies. Transitions between the chip conductors and the package ports are formed by using a reactive-ion-etching (RIE) process.

The front-end receiver LNA is an impressive design of itself, using a 10-stage common-source configuration to achieve high gain at 850 GHz. Each stage employs a transistor with 10-μm gate periphery. Because of the short wavelengths at such high frequencies, the line lengths for the interstage matching networks are quite short—typically only 10 to 15 μm or about 19 to 30 deg. electrical length at 850 GHz. Coplanar-waveguide (CPW) transmission lines are used for the matching circuitry, with on-chip EM transitions used to directly interconnect the TMIC with the waveguide ports. The LNA exhibits peak gain of about 14.8 dB at 830 GHz and 13.6 dB at 850 GHz, with about a 12-dB noise figure. It draws 45 mA from a +1.2 V dc supply, for power dissipation of about 55 mW.

The TMIC is an impressive design and points to the possibilities of creating practical device solutions at terahertz frequencies for medical, industrial, and commercial communications applications.

See "850 GHz Receiver and Transmitter Front-Ends Using InP HEMT," *IEEE Transactions on Terahertz Science and Technology,* Vol. 7, No. 4, July 2017, p. 466.

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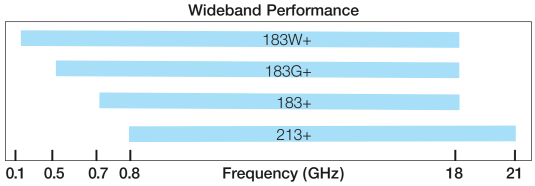
	Model	Frequency (GHz)	Gain (dB)	P1dB (dBm)	IP3 (dBm)	NF (dB)	Price $ * (Qty. 1-9)
	ZVA-183WX+	0.1-18	28±2	27	35	3.0	1479.95
NEW!	ZVA-183GX+	0.5-18	27±2	27	36	3.0	1479.95
	ZVA-183X+	0.7-18	26±1	24	33	3.0	929.95
	ZVA-213X+	0.8-21	26±2	24	33	3.0	1039.95

* Heat sink must be provided to limit base plate temperature. To order with heat sink, remove "X" from model number and add $50 to price.

Wideband Performance



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CHRIS DeMARTINO | Technical Editor

2017 *Microwaves & RF* SALARY & CAREER REPORT:

For Better or Worse, More of the Same in 2017

The 2017 *Microwaves & RF* Salary & Career Report revealed that the RF/microwave industry is relatively stable when comparing the results with those from 2015 and 2016. For example, the average base salary among respondents was $109,533 in 2015. In 2016, that number increased slightly to $110,844. This year, the average base salary was reported to be $112,840.

In addition, 12% of respondents reported some level of job dissatisfaction in 2015, with that number decreasing to 10.3% last year. This year, the percentage of respondents who are dissatisfied with their job is even lower at 9.2%. Furthermore, 9% were actively seeking a new position in 2015. Last year, that number was reported to be 8.5%. This year, only 6.4% said they are actively seeking new employment.

A CALL FOR YOUTH

The striking similarities between the results from this year with the results from the last two years reveal another significant aspect of the industry. Specifically, 55% of respondents were age 55 and older in 2015. Last year, 40.2% of respondents were age 60 and older, while 44.2% of respondents in this year's survey are in the same age bracket. While we are surely thankful for this age demographic in the engineering profession, it also does suggest that the industry is in major need of younger engineers.

Specifically, the percentage of respondents under the age of 35 has hovered around 6% in each of the last three surveys. Does that mean that only 6% of engineers in the RF/microwave industry are under age 35? It's also possible that this low percentage is partially due to younger engineers being less interested in completing our survey. Nonetheless, 6% is still a low number, demonstrating the need for a younger generation of engineers.

Attracting younger engineers should be a focal point of the industry as long as companies are willing to put in the time to help them. The majority of the respondents of this survey believe companies should do exactly that, as 91.5% believe that companies should provide training to entry-level engineers. Furthermore, 56.8% believe there is an engineering shortage. And 89.5% said they would recommend engineering as a career path to a young person looking to choose a profession. One respondent said, "It's been a good profession for me and I believe there will be the need for engineers for years to come."

Lastly, please feel free to contact us and let us know if you find the information useful.

THE TYPICAL ENGINEER

Average Age	
Under 25	1.1%
25-29	2.0%
30-34	2.9%
35-39	3.6%
40-44	3.4%
45-49	7.7%
50-54	16.0%
55-59	19.1%
60 or older	44.2%

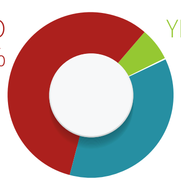
COMPENSATION

- AVG SALARY $112,840
- AVG BONUS $4,294
- AVG STOCK OPTIONS $2,876
- AVG OTHER SOURCES $3,111

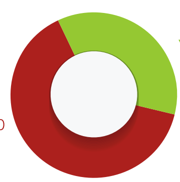
- SALARY INCREASE 53.4%
- SALARY DECREASE 13.6%
- SALARY EQUAL 32.9%

EMPLOYMENT OUTLOOK

Actively seeking a new position



Focused on employee retention



Contacted by recruiter 56.6%

YEARS IN THE PROFESSION

Less than 1 year	1.3%
1-4 years	3.2%
5-9 years	5.1%
10-14 years	4.5%
15-19 years	6.8%
20-24 years	9.6%
25-29 years	11.1%
30-34 years	20.2%
35-39 years	16.1%
40 years or more	22.2%

WORK LOCATION

California	22.7%
Texas	6.7%
Massachusetts	5.6%
Florida	4.3%
Pennsylvania	4.1%
Colorado	3.5%
Illinois	3.5%
New York	3.3%
Ohio	3.3%
Maryland	3.3%

YEARS AT PRESENT COMPANY

Currently unemployed	1.5%
Less than 1 year	8.1%
1-4 years	21.6%
5-9 years	17.6%
10-14 years	13.7%
15-19 years	11.6%
20-24 years	7.7%
25-29 years	5.5%
30-34 years	5.5%
35-39 years	4.5%
40 years or more	2.5%

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Model Family	Capabilities	Freq. (GHz)	Connectors†
KBL	Precision measurement, including phase, through 40 GHz	DC-40	2.92mm
CBL-75+	Precision 75Ω measurement for CATV and DOCSIS® 3.1	DC-18	N, F
CBL	All-purpose workhorse cables for highly-reliable, precision 50Ω measurement through 18 GHz	DC-18	SMA, N
APC	Crush resistant armored cable construction for production floors where heavy machinery is used	DC-18	N
ULC	Ultra-flexible construction, highly popular for lab and production test where tight bends are needed	DC-18	SMA, N
FLC	Flexible construction and wideband coverage for point to point radios, SatCom Systems through K-Band, and more!	DC-26	SMA, N
NEW! SLC	Super-flexible spaghetti cables with 0.047" diameter and 0.25" bend radius, ideal for enviromental test chambers.	DC-18	SMA
VNAC (M to F)	Precision VNA cables for test and measurement equipment through 40 GHz	DC-40	2.92mm

* All models except VNAC-2R1-K+

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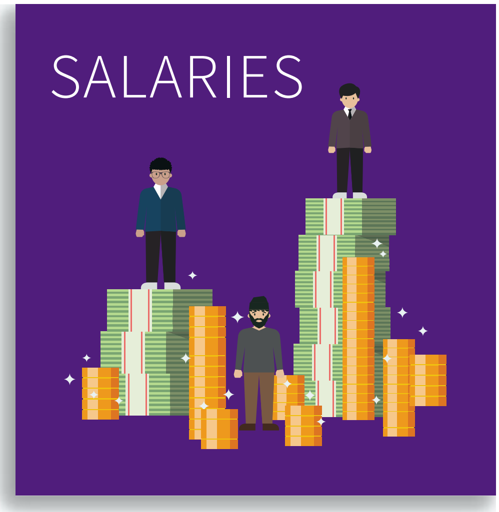
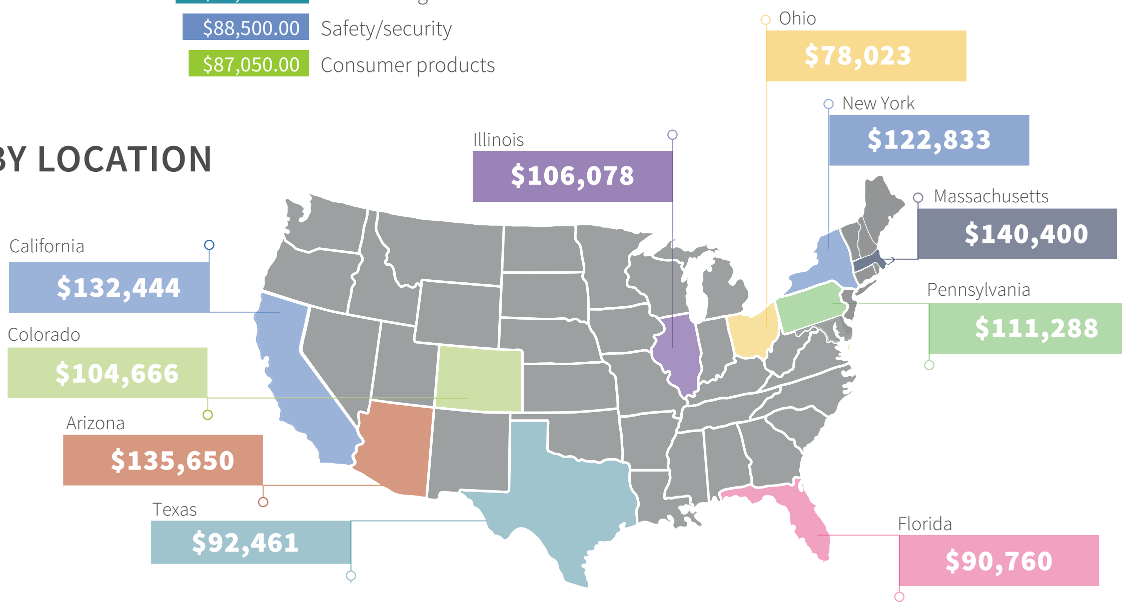


BY INDUSTRY

$145,250.00	ICs and semiconductors
$137,552.63	Military products
$123,153.85	Computer product design
$120,185.90	Research & development
$118,622.58	Communications systems and equipment
$116,260.87	Medical products
$112,926.47	Avionics, marine, or space
$109,500.00	Software design/development/programming
$106,638.89	Components and subassemblies
$104,987.80	Test and measurement equipment
$102,891.89	Industrial controls systems and equipment
$97,547.62	Automotive products
$90,789.47	Power design
$88,500.00	Safety/security
$87,050.00	Consumer products

BY LOCATION

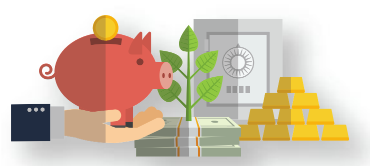


BY EXPERIENCE

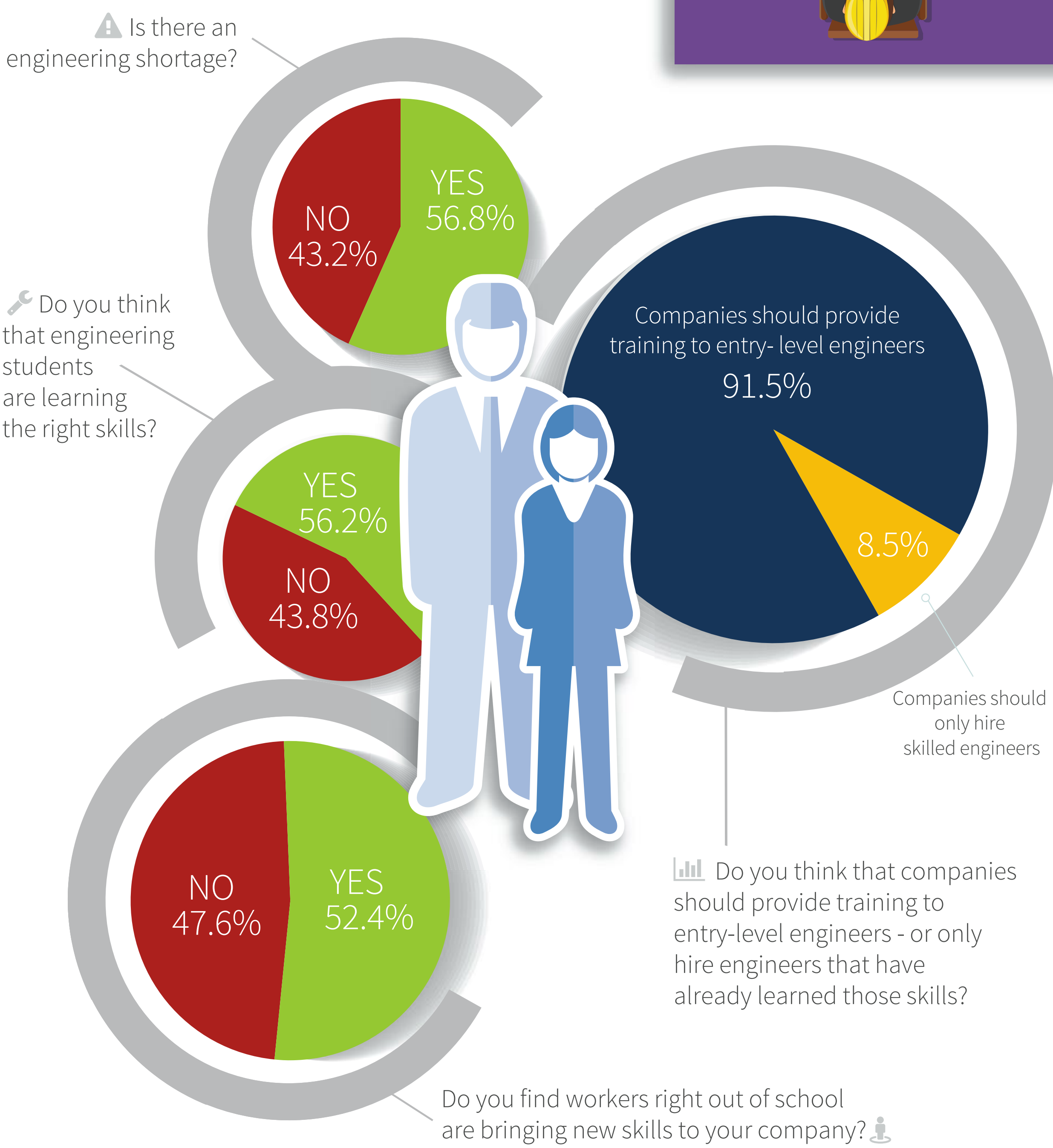
40 years or more	$112,099.26
35-39 years	$120,331.90
30-34 years	$123,259.40
25-29 years	$121,550.72
20-24 years	$118,951.61
15-19 years	$105,467.39
10-14 years	$98,803.57
5-9 years	$85,833.33
1-4 years	$54,475.00
Less than 1 year	$86,500.00

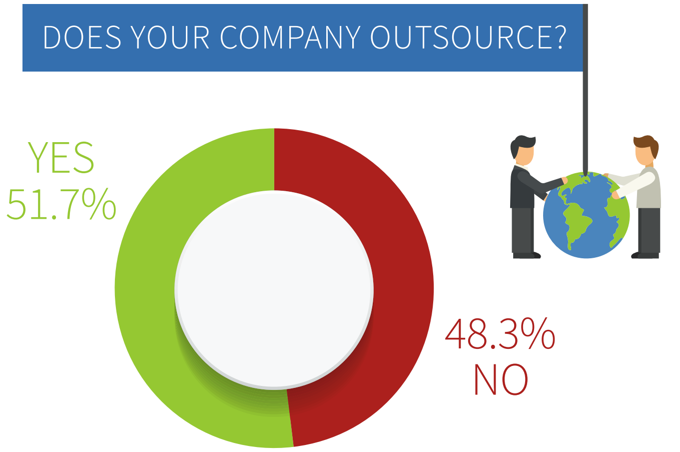
BY JOB

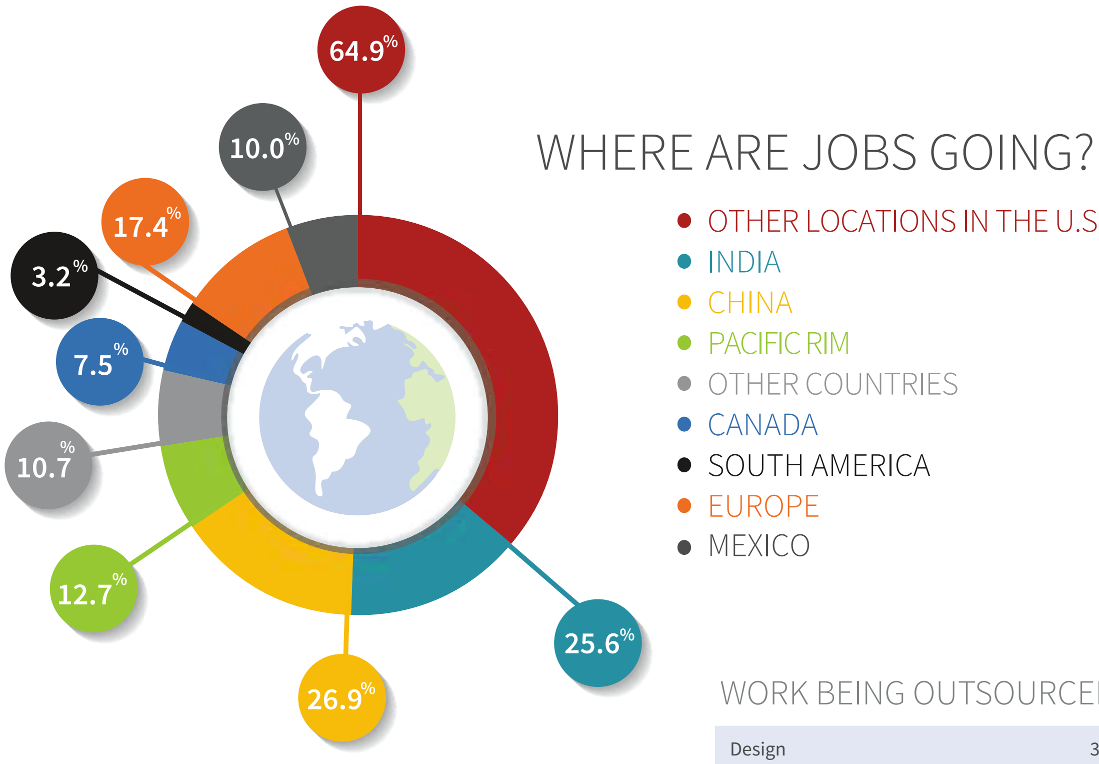
Executive/operating management	$121,286.89
Engineering management	$131,807.14
Design & development engineering	$114,784.26
Other	$91,191.06

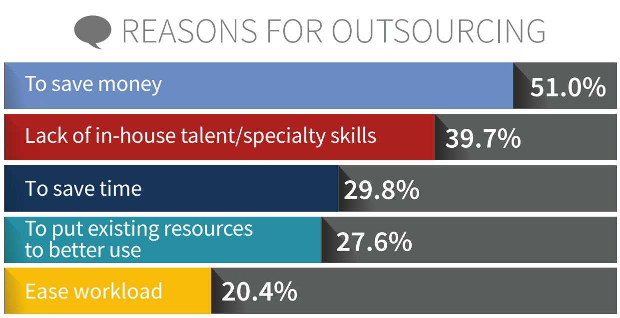


ENGINEERING LABOR FORCE







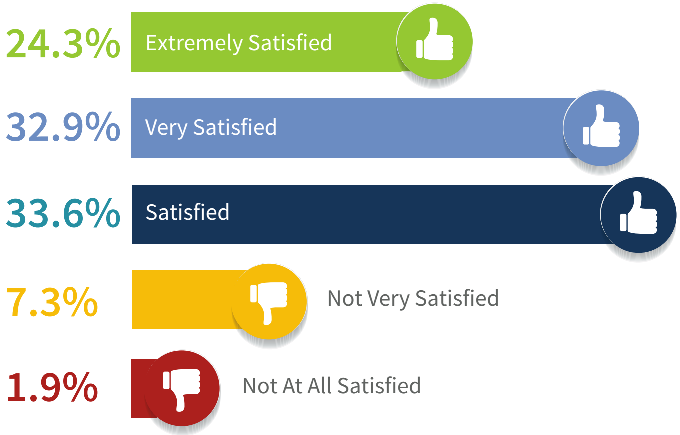


WORK BEING OUTSOURCED

Design	35.3%
Manufacturing/assembly	46.9%
Software engineering/development	47.9%
CAD/CAE	22.6%
Drafting	13.0%
R&D	24.6%
PCB layout	32.8%
Design verification	14.3%
Software verification/test	24.1%
Final test	17.0%
Incoming inspection	3.8%

JOB SATISFACTION

HOW SATISFIED ARE YOU IN YOUR JOB?



MOST IMPORTANT FACTORS IN JOB SATISFACTION

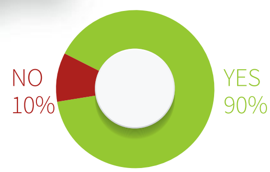
8.1	Challenges that accompany the design of new products
8.18	Researching potential design solutions
7.76	Opportunity to design products that can benefit society
7.68	Compensation you receive for the work you do
6.87	Working in team situations with peers
6.78	The pressures associated with solving design problems
6.99	Working independently of others
6.78	The recognition you get from others for the work you do

[Based on a scale of 1 to 10]

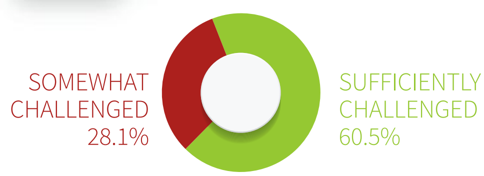
REASONS ENGINEERS WOULD LEAVE THE PROFESSION

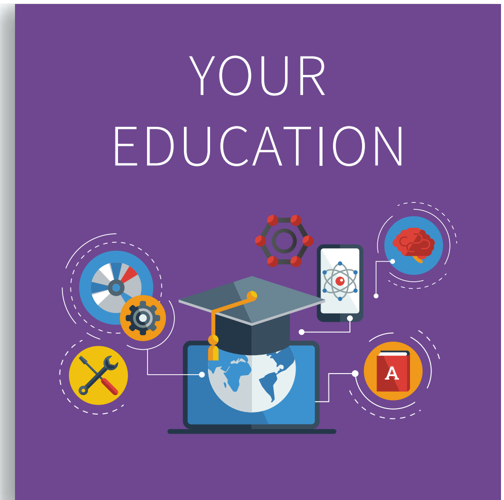
Try something different	35.7%
Pursue other interests or opportunities	32.5%
Do something more fulfilling or satisfying	24.2%
Have more freedom/free time	23.6%
Do something less stressful	26.8%
To make more money	21.0%
Start a business	17.2%
Ready to retire	18.2%
Burnout	22.0%
No further chance for advancement	17.8%
Cut back on long hours	16.9%
The poor job outlook for engineers	16.6%
Switch to teaching	13.7%

Recommend Engineering?

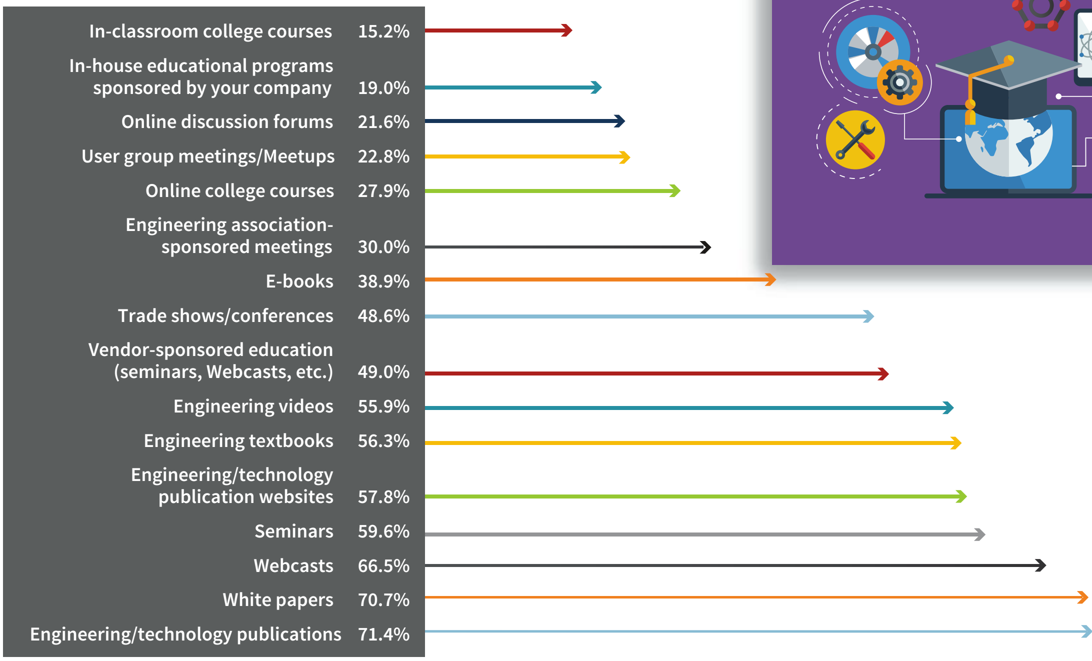


Feeling Challenged?





WHAT ARE SOME OF THE WAYS YOU CONTINUE YOUR ENGINEERING EDUCATION TODAY?



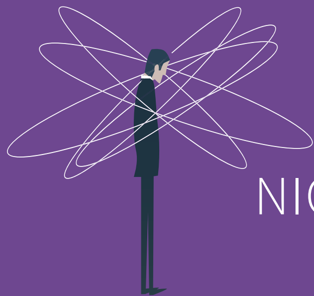
"There is too much for one person to keep up with, so I must pick and choose what to study."

"There is a lot of advancement in areas that I'm not focused on daily, so it is easy to get behind on many things."

FOR WHICH OF THESE FORMS OF EDUCATION DOES YOUR COMPANY REIMBURSE COSTS TO ENGINEERS?

Trade shows/conferences	59.3%
College tuition	46.3%
Seminars	43.9%
Engineering textbooks	33.4%
Engineering association dues	28.5%
Online training	25.2%
Certifications	22.5%
Publication subscriptions	20.5%

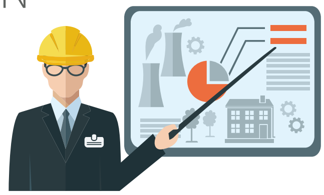
WHAT'S KEEPING ENGINEERS UP AT NIGHT?

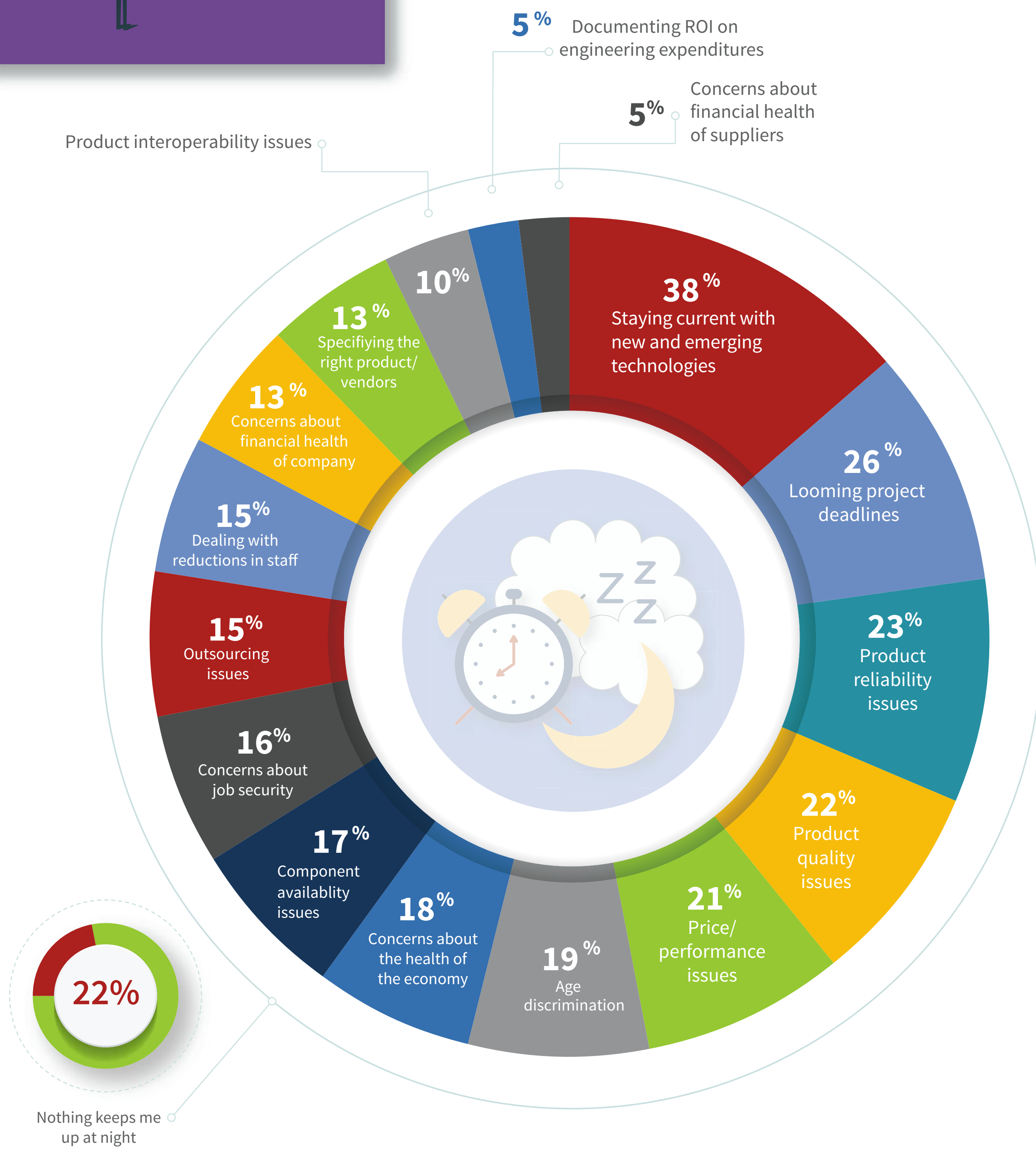


TOP CONCERN

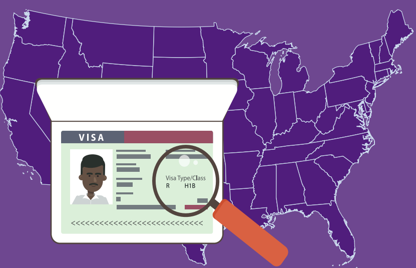
38 %

Staying current with new and emerging technologies





ENGINEERING AND SOCIETY



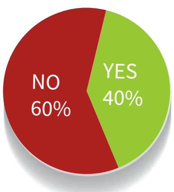
DOES YOUR COMPANY HIRE EMPLOYEES ON H1-B VISAS?

YES 37.2%
NO 62.8%

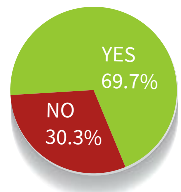
DOES H1-B HURT EMPLOYMENT OPPORTUNITES FOR ELECTRICAL ENGINEERS IN THE UNITED STATES?

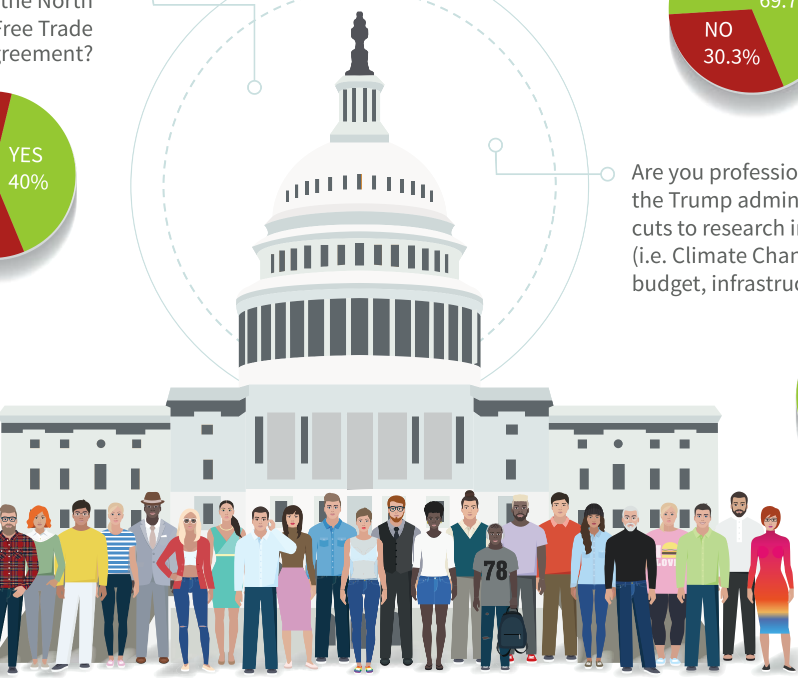
YES 57.9% **NO 42.1%**

Are you worried about President Trump's trade policy, including his decision to withdraw from the Trans-Pacific Partnership and renegotiate the North American Free Trade Agreement?

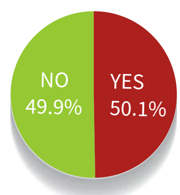


Would you support measures from the Trump administration and Congress to reform how the H1-B system works?





Are you professionally worried about the Trump administration's proposed cuts to research into health and energy (i.e. Climate Change research, NASA budget, infrastructure spending, etc.)



DOES YOUR COMPANY TRACK EMPLOYEE DIVERSITY IN EITHER A PUBLICLY RELEASED OR INTERNAL REPORT?

YES 42.6%
NO 57.4%

68.6% YES
31.4% NO

DO YOU THINK IT IS IMPORTANT TO HAVE A DIVERSE ENGINEERING WORKFORCE, WITH MORE WOMEN AND MINORITY ENGINEERS?

MARK MILLER | L-com Global Connectivity
www.l-com.com

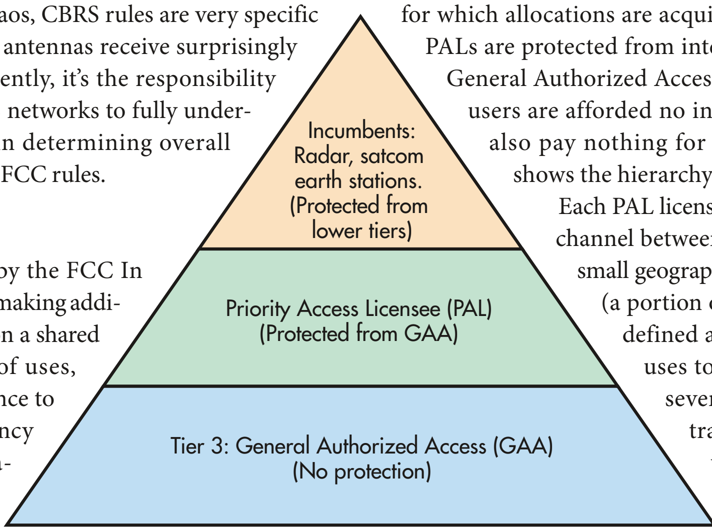
Understand How to Consider Antennas for CBRS Applications

Antenna performance and characteristics will be key factors for CBRS, the FCC's new 150-MHz contiguous spectrum at 3.5 GHz.

THE CITIZENS BROADBAND RADIO SERVICE (CBRS), which makes 150 MHz of shared spectrum available between 3,550 and 3,700 MHz, is arguably the FCC's most interesting offering in years. If it delivers on even half of its promises, the agency will have created a genuinely useful opportunity for innovation. As spectrum sharing is exceedingly difficult to achieve without dissolving into chaos, CBRS rules are very specific in certain areas, although antennas receive surprisingly little treatment. Consequently, it's the responsibility of those developing CBRS networks to fully understand their significance in determining overall performance and meeting FCC rules.

CBRS IN A NUTSHELL

CBRS was formalized by the FCC In April 2015 with the goal of making additional spectrum available on a shared basis for a wide variety of uses, without creating interference to existing services. The agency hopes that the new allocation will enable wireless carriers to increase network performance, provide an alternative for Internet of Things (IoT) connectivity, allow cable companies to get into the wireless business, and perhaps of greatest interest, make it possible for organizations other than wireless carriers to operate private networks using digital (presumably LTE) technology for the first time. These are just a few cases where CBRS will have an impact—there are potentially many others.

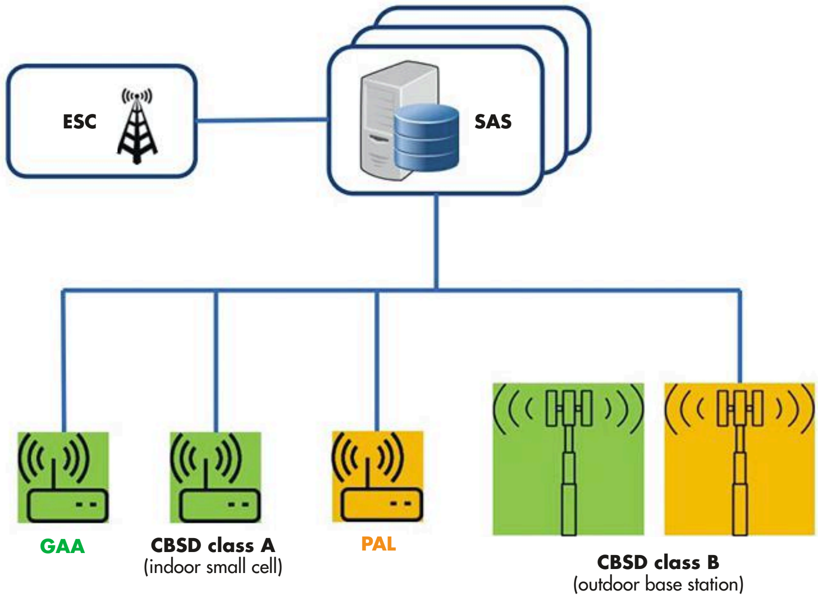


1. CBRS offers two tiers of service, PAL and GAA. PALs are protected from interference from GAA users, who have no interference protection.

CBRS offers two classes of users in addition to those already operating there (the incumbents), which are primarily coastal Navy radars and some fixed satellite services. The incumbents have priority access to the spectrum and protection from interference by devices in the lower classes. Below the incumbents are Priority Access Licensees (PALs), for which allocations are acquired through FCC auctions. PALs are protected from interference by the lowest-tier General Authorized Access (GAA) users. While GAA users are afforded no interference protection, they also pay nothing for spectrum access. *Figure 1* shows the hierarchy of this architecture.

Each PAL license gives the owner a 10-MHz channel between 3,550 and 3,650 MHz in a small geographic area called a census tract (a portion of a county or other clearly-defined area that the Census Bureau uses to divide up the U.S.). Up to seven PALs can operate in each tract, in which a licensee can use only 70 MHz of the full 150-MHz allocation. Although GAA users can operate anywhere within the band not assigned to higher-tier users, only 80 MHz is available when PALs are in operation in a census tract. Digital transmission technologies are mandatory; while LTE will be the choice of most users, other wireless access methods can be used, as well.

As census tracts cover small areas, the auction price for each one should be a fraction of what wireless carriers pay



2. The SAS has the enormous task of managing PAL and GAA devices, as well as sensors providing ESC capability. The ESC device monitors channels to detect the presence of incumbent radar and sends alerts and other information to the SAS, which then commands the offending device to change channels.

for widespread coverage, allowing spectrum to be acquired by smaller organizations. Not surprisingly, wireless carriers seeking spectrum for backhaul, cable companies wishing to become mobile virtual network operators (MVNOs), large corporations wanting to create their own secure networks, the IoT industry, and components manufacturers looking for new sources of revenue all have been anxiously awaiting the arrival of CBRS. The only question that remains is if (or how well) spectrum sharing will work, as it hasn't been terribly successful in the past.

The FCC mandate that incumbent users have ironclad interference, the PALs less, and GAA users none, makes for an "interesting" operating environment. Spectrum sharing is an extremely complicated process, as it requires a mechanism to ensure protection from interference among users and the various classes. Some spectrum sharing schemes use a "listen-before-talk" approach in which a device senses activity on a channel before transmitting.

If it detects the presence of another user, it moves to another channel. This is used by Wi-Fi, Bluetooth, and other standards with reasonable success in most environments. However, another technique called a Spectrum Access System (SAS) used in other spectrum-sharing scenarios such as the "TV white spaces" is also used by CBRS, but is more ambitious than its predecessors.

An SAS (there will be many within CBRS) works by managing and enforcing the shared frequencies using a cloud-based database of all CBRS devices to coordinate channel assignments and prevent interference. Among its many tasks are assigning channels for CBRS devices (called CBSDs); determining their maximum power at every location and ensuring it is not exceeded; registering and authenticating them; and receiving and addressing reports of interference from incumbent users. To protect them, sensors for Environmental Sensing Capability (ESC) will be deployed nearby each location to detect activity from other services. If it occurs, the sensor alerts the SAS, which commands the interfering emitter to change channels *(Fig. 2)*.

There is no guarantee that the CBRS SAS will work this time, as managing hundreds of thousands of devices throughout more than 70,000 census tracts will be an enormously complex task. However, the CBRS SAS is arguably the most advanced such system to date. If successful, it will result in the rapid and successful deployment of many applications.

ANTENNAS: CRITICAL CBRS ELEMENTS

In every RF or microwave system, antennas are a key determinant of overall performance. In CBRS, they take on the major responsibility of helping to ensure that interference is kept in check. The CBRS rules call for two basic classes of CBSDs. Class A devices are suited for indoor use (effectively making them typical small-cell base stations) or low-power outdoor use. The maximum effective isotropic radiated power (EIRP) is 1 W (+30 dBm), although many will likely deliver less. The Class A CBSDs will generally be used with 2-dBi-gain omnidirectional antennas or directional antennas with up to 6-dBi of gain.

A Class B CBSD is targeted for outdoor use with a maximum EIRP of 50 W (+47 dBm). At this power level, an antenna delivering very high gain is well suited for fixed wireless applications, such as Wireless Internet Service Providers (WISPs).

A typical directional antenna that can be used for outdoor Class B systems that require directivity (such as point-to-point and point-to-multipoint) is the L-com *(www.l-com.com)* HG3517DP-090 sector panel antenna *(Fig. 3)*. It combines

The FCC doesn't mandate what type of antenna should be used in a specific application. Therefore, it is up to the user to ensure that CBSDs adhere to the rules designed to mitigate interference.

vertical and horizontal polarization, gain of 17 dBi, a 90-deg. beamwidth, and a 25-dB front-to-back ratio. As the antenna accommodates transmits and receive paths with different polarizations, unwanted signals from adjacent channels or co-located equipment can be attenuated.

The FCC doesn't mandate what type of antenna should be used in a specific application. Therefore, it is up to the user to ensure that CBSDs adhere to the rules designed to mitigate interference. There is a broad array of antennas likely to be used for various CBRS applications, thereby presenting a significant challenge for network designers. A variety of factors must be considered, including the characteristics of the antenna, signal propagation, EIRP, terrain, and other factors, to ensure that signal levels at the mandated coverage boundary are within prescribed values.

All potential PAL and GAA users provide specific information about antennas and their characteristics with their registration, including geographic coordinates within an accuracy of ±50 m horizontal and ±3 m elevation. This and much more information must be reported to the respective SAS when the system is first activated. The managing SAS determines the PAL Protection Area (PPA) boundary by a contour based on maximum allowable radiated power, an RF propagation model, antenna height and gain effects, and radiation patterns.

Each CBSD is assumed to use a single antenna. If it has multiple antennas, such as an array for multiple-input multiple-output (MIMO) operation, the antennas must produce an aggregate signal with radiated power that conforms to all the registration parameters. CBSD transmissions must also be managed so that their received signal strength measured at the boundary with any co-channel PAL cannot exceed an average power level of –80 dBm.

If Category A CBSDs are located outdoors, their antennas must be no higher than 6 m above average terrain. Otherwise, they will be considered Category B CBSDs and subjected to their requirements (including mandatory professional installation). Information provided about CBSD Category-B devices must include antenna gain, beamwidth, azimuth, down-tilt angle, and antenna height. The rules provide a procedure for describing antenna gain to determine aggregate interference in the direction of a receiver. If the antenna beamwidth and the antenna pattern are not available, the SAS will assume the antenna is omnidirectional.

3. This sector panel antenna is a good example of a directional antenna for use with a Class B CBSD. It combines vertical and horizontal polarization, gain of 17 dBi, a 90-deg. beamwidth, and a 25-dB front-to-back ratio.

The FCC also does not dictate what technology an ESC device uses for detecting the presence of signals from an incumbent system. This means that ESC developers can choose any type of sensing technique that will produce the desired result. While this provides significant flexibility, it also requires that ESC designers consider the device's antenna along with the other factors that collectively determine its performance.

CBRS is the first spectrum-sharing effort by the FCC that has made it from concept through various legal and other challenges to the stage where it is likely to be realized in operation, as the first systems should be deployed early in 2018. It will nevertheless take some time before the CBRS SAS approach can be evaluated based on actual performance.

That said, CBRS offers benefits to so many different applications. Unlike other spectrum shared approaches, it has "multi-partisan" support. It also doesn't hurt that CBRS sweetens the deal for those sitting on the fence by offering new revenue-producing opportunities ranging from cellular backhaul to providing LTE coverage in rural areas. This creates private networks for various purposes including IoT connectivity, boosting the resources of WISPs, and allowing cable companies (among others) to create their own LTE networks. mw

KIM LEE | Systems Applications Engineering Manager for the RF and Sensors Product Group, Infineon Technologies

Will Gesture Sensing Drive Home Automation?

Thanks to advances that make it possible to operate in the V-band, radar-based gesture control for home automation could very well become the next big thing.

DEVELOPMENTS IN SMART-HOME electronics and home automation are driving new generations of human-machine interfaces. Handheld universal remotes are extending their capabilities at the same time that remote-control functionality is finding its way into touchscreen devices and even smartphones. Voice-based control using the connected intelligence of smart speakers has gained a high profile, too, though this approach raises privacy concerns.

Gestures, which do not rely on cloud-based intelligence to understand and act on spoken word commands, are an exceptionally promising approach to home-automation control. They are evolving on several fronts.

Wearable (arm-band like) devices and visual/infrared systems have moved from control of entertainment to commanding other in-home systems. However, wearable solutions are limited as a home interface, since a physical device is not greatly superior to current handheld or smartphone-based controls. Vision-based systems also face limitations related to ambient lighting, precision, and the simple requirement that light sources and cameras cannot be hidden within a device. Thus, visual sensors will not be able to control the types of invisible devices envisioned for the in-home Internet of Things (IoT).

This scaled-down single-chip radar operates at V-band frequencies.

ON THE RADAR

Advances in compact low-power radar, based on technology developed by Infineon (*www.infineon.com*) for the Google Soli project, will take gesture control to a new level in addressing IoT applications in and beyond home environments. With this technology, manufacturers have an opportunity to deliver a nearly magical user experience.

Radar has already made inroads in presence detection, with applications that include automated door opening, security, and lighting control based on systems operating in the 24-GHz range. Moving to millimeter-wave frequencies, the unlicensed V-band (57-64 GHz) brings advantages of precise resolution and low likelihood of interference with nearby systems. Infineon collaborated with Google to develop a single-chip radar integrated circuit (IC) that operates in the V-band. The technology was successfully demonstrated in two iterations—first in 2015 and then in 2016 at the Google I/O Conference.

This breakthrough technology is now available to developers of consumer IoT devices. The BGT60TR24B single-chip radar is compact, measuring 9 × 12.5 × 0.8 mm (*see figure*). It incorporates two transmit (Tx) channels, four receive (Rx) channels, and antenna. Moreover, the sensing range is as high as 10 m.

The BGT60TR24B draws just 0.054 W in sensing mode and includes extensive power-management and idle modes. Wake-up and duty cycles can be programmed to further minimize power usage in battery-powered devices as well as limit the active mode for in-wall and tabletop devices likely to be used for home-automation applications.

The ability of radar to distinguish between two closely spaced targets (or range resolution) improves with bandwidth frequency. In the V-band, with 7 GHz of available bandwidth, it is possible to achieve a range resolution of 2 cm. This can be extended to sub-millimeter precision using advanced signal processing to a level that allows recognition of overlapping fingers. Millimeter-wave sensors also have greater sensitivity to detect slow-moving objects and, as noted, large attenuation of the signal due to path loss reduces the likelihood of interference with other sources.

POTENTIAL RADAR-CHIP APPLICATIONS

Early demonstrations of the 60-GHz radar chip include a smart watch and a wireless speaker. In the latter demo, developers working with Google showed control of the on/off and volume functions. Another team has shown a prototype cabinet with locks opened by hand gestures. It's not hard to imagine controlling room temperature, lighting levels, and other in-home systems we use today.

With the high resolution available in V-band radars, controls can range from sweeping hand gestures to finger-sized commands such as pinching and snapping. At this level of precision, radar-based gesture control ultimately may allow designers to develop products with no visible controls at all.

The 60-GHz radar band also can operate through plastic (polycarbonate) surfaces, creating opportunities for gesture-operation of concealed devices in a home. Science-fiction movies showing homes of tomorrow with no visible light sources aren't far away. We have the technology to embed LEDs anywhere and now we have a touchless control mechanism.

Ultimately, operation of devices that exist today is just the beginning of a revolution in human-interface design. As the digital and real worlds converge around systems designed to improve people's lives, seamless human-machine interaction will provide a vital connection to new types of devices and services powered by the IoT. V-band radar offers engineers a path to define next-generation interfaces to an array of automation devices we have just begun to imagine. mw

Design Feature

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Doherty Amplifier Combines High Power and Efficiency

This innovative asymmetric GaN HEMT Doherty amplifier provides both high power and high efficiency for cellular wireless base stations from 1.8 to 2.2 GHz.

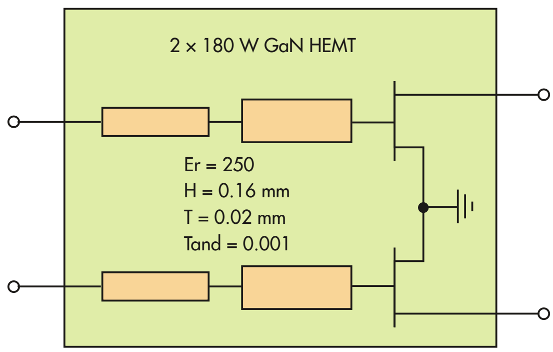
Power amplifiers for modern telecommunication systems often must deliver a wide range of output power levels with high efficiency and high linearity. Generally, when designed for the highest power levels with maximum available efficiency, PAs in cellular base stations tend to operate less efficiently at lower power levels, consuming excessive dc power at lower power levels.

In such wireless systems with wide bandwidths and high data rates, transmitted signals are typically characterized by high peak-to-average power ratio (PAR) due to wide and rapid variations of the instantaneous transmit power. Therefore, it is a real challenge to design a base-station PA with high efficiency not only at maximum output power, but also at lower power levels typically 6 dB or less than the maximum output levels, in a configuration with relatively small size and low cost.

By using GaN HEMT technology and innovative Doherty architectures, however, average efficiencies of 50 to 60% and average output powers to 100 W can be achieved that significantly reduce transmitter power consumption. GaN HEMT technology features many benefits, including high breakdown voltage, high current density, high transition frequency (f_T), low on-state resistance, and low parasitic capacitance. These characteristics result in high output power, wide bandwidth, and high operating efficiency.

The high power density makes it possible to construct physically compact designs at high output power levels, while high dc-supply voltage operation and low parasitic output capacitance result in higher load impedances for ease in obtaining wide operating bandwidths. A drain-to-source breakdown voltage in excess of 150 V dc enables rugged operation at 50 V, regardless of drive level or harmonic load environment.

Sumitomo GaN HEMT technology can provide high-gain operation of a packaged device at output power levels to 300 W for operating frequencies over 8 GHz and beyond for radar applications and can provide excellent, reliable performance for high-power wireless cellular communications transmitters. The progress in power density for the current generation of active devices at 5 W/mm makes it possible to reach 10 W/mm at 50 V dc. The use of silicon-carbide (SiC) substrate material provides excellent thermal management at high power levels.



1. A packaged transistor uses dual-path GaN HEMT configuration with internal input matching to achieve high output power.

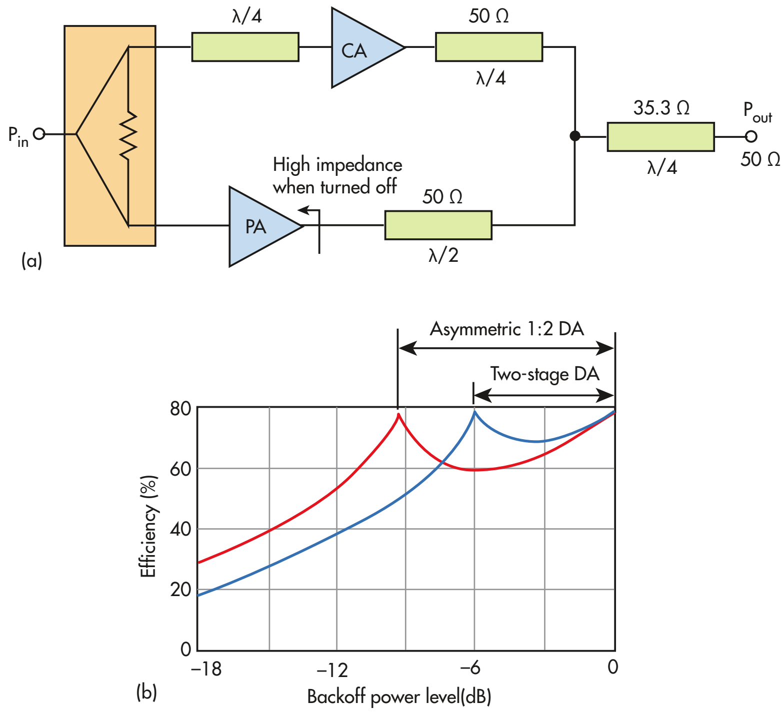
For a conventional Doherty amplifier with a quarter-wave impedance transformer and a quarter-wave output combiner, efficiency of 31% was measured for power levels backed off 6 to 7 dB from a saturated output-power level of about +43 dBm, for a frequency range of 1.5 to 2.14 GHz.[1] To improve the broadband performance of a conventional Doherty amplifier, an output network can be composed of two quarter-wave impedance inverters with reduced impedance transformation ratios.[2] For broadband combining, an output quarter-wave transmission line with fixed characteristic impedance can be replaced by a multiple-section transmission line with different characteristic impedances and different electrical lengths for its multiple sections across a frequency range of 2.2 to 2.96 GHz.[3]

High peak power of 500 W was achieved across the lower frequency band of 760 to 960 MHz using a modified combining scheme with two quarter-wave lines in the peaking path.[4] For an asymmetric Doherty architecture, saturated power of more than 270 W and linear gain of more than 13 dB with drain efficiency of more than 45% at 8-dB back-off were achieved from 2.5 to 2.7 GHz.[5] An average power of 85 W with peak power of 470 to 570 W and relatively flat average efficiency of 45 to 49% was achieved across the frequency band of 1.8 to 2.2 GHz for a single-carrier WCDMA signal with PAR of 10 dB.[6]

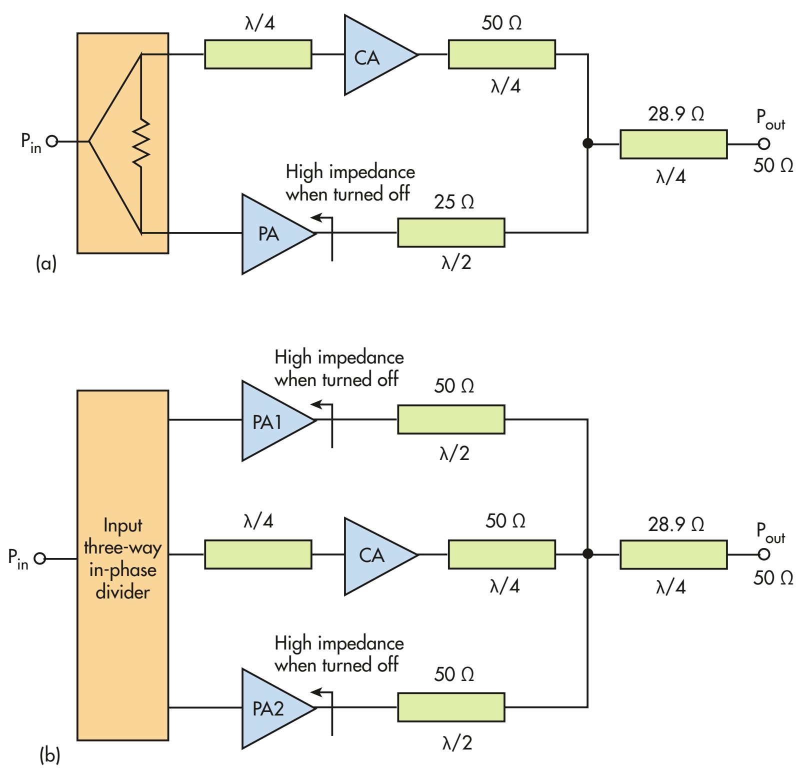
PACKAGED DEVICE

High-power GaN HEMTs can be achieved with large gate periphery resulting in higher power capability for a given package size compared to some other active device structures. The corresponding increase in gate-source capacitance when multiple basic device cells are connected in parallel reduces the optimum input impedance to very low values, close to one or a few tenths of an ohm. Therefore, a low-loss matching network is required inside the package to transform the impedance from the package lead reference plane to the device die reference plane.

For practical use, a packaged GaN HEMT power device should provide reasonably high (not less than 1 Ω) input impedance with a sufficiently low quality (Q) factor to provide flat performance over a required frequency bandwidth. Depending upon the space available within the device package and providing sufficiently wide operating bandwidth to 40%, a two-step microstrip line on a high-permittivity substrate might be considered *(Fig. 1)* for a dual-path package where two 180-W GaN HEMT dice are attached in parallel.



2. The block schematic shows a modified symmetric two-stage Doherty amplifier with the plot providing theoretical efficiency.



3. These block schematic diagrams illustrate a modified 1:2 asymmetric Doherty amplifier.

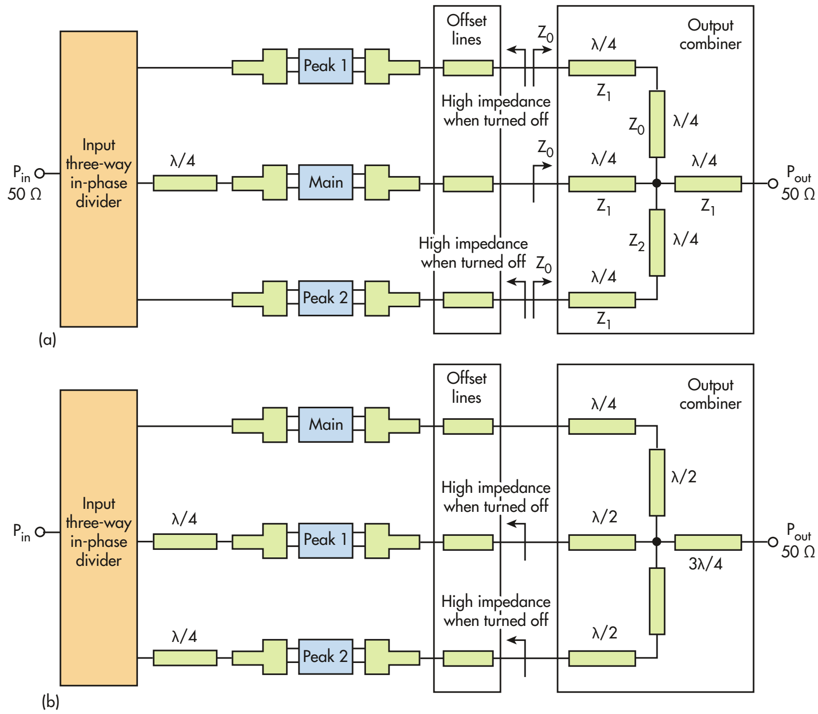
Such a two-stepped microstrip-line transformer for each device can transform the device input impedance of a few tenths of an ohm to an input impedance of several ohms with a flat or a custom required response. The latter will also feature high return loss for each device across the entire frequency bandwidth from 1.8 to 2.2 GHz for this particular application.

MODIFIED DOHERTY AMP

For a high-power amplifier with very low output impedance, the width of the matching microstrip line will be very wide compared to its length. The overall size of the matching circuit, including an offset line to create an open-circuit condition when the peaking amplifier (PA) is turned off, and a quarter-wave transforming line, becomes sufficiently large; it becomes difficult to physically connect the output of the peaking amplifier directly to the main amplifier path. Therefore, for convenience of implementation, a classical Doherty amplifier configuration can be modified by including of an additional half-wave line at the output of the PA.

Figure 2 shows the schematic diagram of a modified two-stage Doherty amplifier configuration where a half-wave line is connected to the output of the PA and a quarter-wave line is included at the input of the main or carrier amplifier (CA) for phase compensation. This configuration is characterized by the same two peak efficiency points, at saturation and –6 dB power back-off, similar to the classical two-stage Doherty amplifier (DA) shown in *Fig. 2b*.

There is a possibility to extend the region of high efficiency over a wider range of output powers if the CA and PAs are designed to operate with different output powers, smaller for the CA and larger for the PA. For instance, for a power-division ratio 1:2, the transition point with maximum drain efficiency corresponds to the back-off power level of –9.5 dB from peak output power, as shown in Fig. 2b. In this case, the characteristic impedance of the half-wave line is 25 Ω, corresponding to the load impedance required for the PA; the characteristic impedance of the combining quarter-wave line is 28.9 Ω, as shown in *Fig. 3a*.



4. These schematic diagrams represent a high-power three-way 1.8-to-2.2-GHz Doherty amplifier.

For packaged devices, where it is difficult to choose the proper power ratio between the devices, it is convenient to use identical power amplifiers which can compose ideally the multi-way Doherty architecture where one carrier power amplifier is in parallel with multiple peaking amplifiers. As a result, a 1:2 asymmetric two-stage Doherty structure can be transformed to a modified three-way asymmetric Doherty configuration with one CA path and two identical PA paths when device sizes for the CA and both PAs (PA1 and PA2) are equal, as shown in *Fig. 3b*.

Here, the half-wave line in each PA path can be split into two quarter-wave lines, each having its own characteristic impedance for the corresponding impedance transformation when the required load impedance for peaking device is sufficiently small.

THREE-WAY DOHERTY AMP

Figure 4a shows the block schematic of a three-way asymmetric Doherty amplifier configuration based on three dual-device packaged transistors. Each has a pair of 180-W GaN HEMT devices with internal input matching microstrip-line networks, where the output combiner includes one quarter-wave microstrip line in a CA path, two quarter-wave microstrip lines in each identical PA path, and one combining quarter-wave microstrip line. Each amplifying path includes the packaged device of the same die size, with input and output matching circuits using microstrip lines.

Offset lines are necessary to provide open-circuit conditions at their ends for PAs when they are turned off. Two quarter-wave microstrip lines with different widths required for the corresponding impedance transformation translate this open-circuit condition in

High backoff efficiency, above 50%, and high-power gain, about 12 dB, can be achieved from 1.8 to 2.2 GHz at an exceptionally high output-power level of about 1 kW corresponding to the 2-dB gain compression point.

each peaking path to an open circuit seen by the carrier path at output power levels lower than –9 dBc at a common node in the output combiner.

For example, for identical amplifiers having optimum load impedance Z_0 = 12 Ω each and $Z_2 = R_L$ = 50 Ω, where R_L is the standard 50-Ω load impedance, $Z_1 = (Z_0Z_2)^{0.5}$ = 24.5 Ω and $Z_3 = (Z_2R_L)^{0.5}/(3)^{0.5}$ = 28.9 Ω. There may be different combinations of the characteristic impedances between quarter-wave microstrip lines in the output combiner. The quarter-wave microstrip line in the input path of the carrier amplifier is used to compensate for the delay of the output combiner.

Another circuit implementation of a high-power asymmetric three-way GaN HEMT Doherty amplifier to operate across the frequency bandwidth of 1.8 to 2.2 GHz, where a half-wave microstrip line is included in the load network of each identical peaking path for better flexibility in practical implementation is shown in *Fig. 4b*, while providing sufficient bandwidth capability at the same time. Here, microstrip line ($\lambda/4 + \lambda/2$) with a total electrical length of 270 deg. provides the corresponding impedance transformation at significant power backoff and the quarterwave microstrip line in each input path of the peaking amplifiers compensate for the delay provided by the output combiner. The broadband output impedance transformation with 50-Ω load is provided by a Klopfenstein taper having an electrical length of 270 deg. at the center bandwidth frequency.

The input three-way in-phase power divider was implemented on a 20-mil-thick RO4350 circuit substrate from Rogers Corp. which was also used to implement the entire Doherty amplifier circuit. It includes a transforming quarter-wave line; an asymmetric 1:2 two-way Wilkinson divider to split power between the two paths, one with the carrier and first peaking amplifiers and the other with the second peaking amplifier; a symmetric two-way Wilkinson divider to equally split power between the carrier and first peaking amplifiers; an additional 50-Ω quarter-wave microstrip line in carrier path; and three equal-length 50-Ω connecting microstrip lines in the carrier and two peaking paths. To provide flatter response over the entire frequency bandwidth, additional input offset lines were connected to the outputs of the input in-phase combiner.

TEST RESULTS

A test board for a three-way Doherty amplifier was fabricated on 20-mil-thick RO4350 circuit material from Rogers Corp. The three-way amplifier is based on three dual-path GaN HEMT devices in metal-ceramic flange packages with a pair of 180-W GaN HEMT die and internal input matching network each, according to the block schematic diagram shown in Fig. 4b. The input three-way divider, input and output matching circuits, offset lines, output combiner, and gate and drain bias circuits (having bypass capacitors on their ends) are fully based on microstrip lines of different electrical lengths and characteristic impedances. Special care was taken for device implementation process in order to minimize the output lead inductances of the packaged GaN HEMT device.

Peak output power of +59.5 dBm was measured at 2-dB gain compression (P_{2dB}) and peak efficiency of 78% was measured with linear flat power gain of about 12 dB, for a supply voltage of 55 V dc and a frequency range of 1.8 to 2.2 GHz. From these test results, it follows that drain efficiency of greater than 50% at 8-dB power back-off can be achieved. This means that, for a 20-MHz LTE signal with 8-dB PAR, average power of 120 W can be obtained with a drain efficiency of equal or greater than 50% over most of the frequency range. This is the best result in industry in terms of power gain flatness, output power, and back-off efficiency achieved over a wide frequency bandwidth of 1.8 to 2.2 GHz.

High backoff efficiency, above 50%, and high-power gain, about 12 dB, can be achieved from 1.8 to 2.2 GHz at an exceptionally high output-power level of about 1 kW corresponding to the 2-dB gain compression point. In addition, the modified asymmetric Doherty amplifier offers the capability to operate with digital predistortion (DPD) in order to meet stringent spectral mask requirements.

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JACK BROWNE | Technical Contributor

Bandying the Benefits of MEMs and MMICs

High-frequency MEMS and MMICs are key components in helping to miniaturize RF/microwave circuit designs, even though they function in completely different ways.

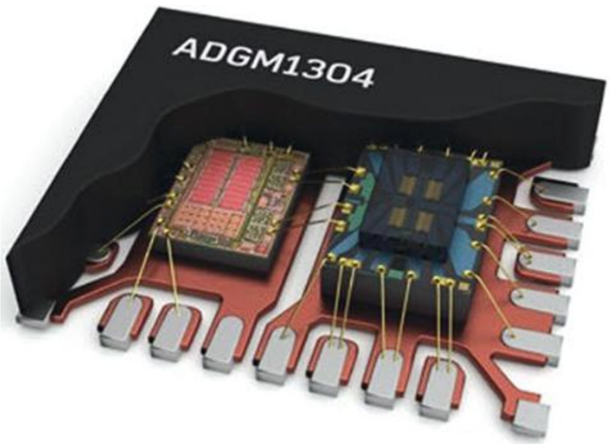
Miniaturization has allowed a growing number of electronic functions to be packed into pocket-sized designs and, in the case of microelectromechanical-systems (MEMS) devices, even mechanical functions can be included in those designs. MEMS devices are perhaps best known as miniature switches, although they are also gaining popularity when used as frequency sources, such as oscillators. They can be packaged in similarly small enclosures as purely electronic devices, but how do MEMS devices differ from similar-sized electronic circuits, such as monolithic-microwave integrated circuits (MMICs)?

The most essential difference between MEMS and MMICs is that MEMS are designed to function with moving parts, as electromechanical devices, while MMICs are meant to operate fully electronically. Because of the mechanical capabilities, MEMS devices are capable of producing high-frequency resonances (serving as resonators and oscillators), as well as the reverse function of detecting vibration (as in audio microphones).

At RF and microwave frequencies, companies such as SiTime *(www.sitime.com)* have built comprehensive portfolios of oscillators and timing products based on MEMS technology which challenge or exceed the performance of traditional quartz crystal temperature-compensated crystal oscillators (TCXOs).

With the capability to fabricate microminiature moving parts, RF MEMS technology is a natural candidate for certain component functions, such as switches. Companies such as Analog Devices (www.analog.com), MEMtronics Corp. *(www.memtronics.coms)*, Radant MEMS *(www.radentmems.com)*, and WiSpry *(wispry.com)* have established strong track records in reliable, high-performance RF/microwave switches based on MEMS technology, with open and closed switching states often determined by the position of a mechanical part, such as a cantilever.

For example, MEMS switches from Analog Devices *(Fig. 1)* are fabricated on silicon (Si) substrates, building on the company's vast experience in designing and constructing silicon integrated circuits. The microminiature switches are based on the use of electrostatically actuated cantilever beam switching elements. When applied, the electrostatic force is sufficient to overcome the spring force of the cantilever beam and form a metal-to-metal contact to close the conductive path of the switching elements.



1. MEMS switches such as this are fabricated on high-resistivity silicon (Si) substrates, using techniques quite similar to those used for creating semiconductor devices. *(Courtesy of Analog Devices)*

MEMS switches have been developed on Si wafers using a variety of different approaches, including Si CMOS semiconductor processes to produce MEMS switches capable of operation at millimeter-wave frequencies for possible use in 5G wireless communications networks. As with transistors and other semiconductor devices, MEMS components have been fabricated on substrate materials other than Si, including gallium arsenide (GaAs) and gallium nitride (GaN) substrates.

MAKING MMICs

In contrast, MMICs are essentially miniaturized RF and microwave circuits, designed and fabricated using many different semiconductor processes and with many different levels of integration. MMICs may have thousands of monolithic active and passive circuit elements and components, with a substrate measuring just a few square millimeters.

Analog circuit functions may be active (such as amplification), or passive (e.g., attenuation), although functional control is performed by means of applied energy. MMIC technology allows highly integrated portions of systems, such as receiver front ends, to be mass produced using proven high-frequency semiconductor processes—for example, those based on silicon germanium (SiGe), Si, GaAs, and GaN substrate materials.

The MMIC circuits can be impedance matched to 50 Ω at input and output ports for ease of cascading in multiple MMIC designs. Although RF/microwave MMICs are available from many suppliers in die form, they are probably more often used in packaged form, added to printed-circuit-board (PCB) designs in the firm of packaged surface-mount-technology (SMT) components.

A single chip or packaged MMIC can replace what was once a receiver front end constructed with a long list of discrete components and matching elements. These include frequency mixers, filters, oscillators, amplifiers, and attenuators and the transmission lines required to interconnect them.

Although the majority of MMIC devices are active in nature (such as amplifiers, receivers, and transceivers), the technology also lends itself to the production of low-cost, highly repeatable passive components (filters and frequency multipliers, to name two). For example, Custom MMIC (www.custommmic.com) has established itself as a reliable supplier of both active and passive MMICs, including a line of passive MMIC frequency doublers. The most recent model, the CMD226N3 frequency doubler *(Fig. 2)*, turns input signals from 7 to 11 GHz to output signals from 14 to 22 GHz.

Because it is passive, signal power is lost from input to output, with typical conversion loss of 9 dB. But because the component is fabricated as a MMIC, it can also be housed in a miniature QFN-type surface-mount package to save circuit-board space, and its input and output ports are matched to 50 Ω, eliminating the need for matching circuit elements or transmission lines on the circuit board.

The passive nature of the doubler also minimizes its contributions to system phase noise, compared to an active frequency doubler in which amplification can also increase the amount of phase noise. For its small size, the MMIC frequency doubler can also handle fairly large input signals, to about 0.5 W (+27 dBm), enabling it to be used in a variety of different applications, including commercial satellite communications (satcom) systems and military radar systems.

MILLIMETER-WAVE MMICs

Both MEMS and MMICs rely on semiconductor processing methods to form small device features on various types of semiconductor wafers. The motivation for both types of components is the same—to save size, weight, and cost for the circuit functions they are implementing—with investments in MMICs tracing back to defense system requirements established by ARPA (now DARPA) for highly integrated circuits capable of operating at low power levels for portable applications, including manpack radios.

Defense and aerospace needs for both MEMS and MMICs are still strong, but a number of emerging commercial applications are creating needs for both types of devices in areas of the spectrum that have been lightly used (compared to lower frequencies) to this point: the millimeter-wave region. The increasing use of millimeter-wave radar devices in automotive collision-avoidance systems and the expected need of mass-produced millimeter-wave radio MMICs and MEMS switches for short-haul links in 5G wireless communications networks has encouraged a number of MEMS and semiconductor companies to pursue higher-frequency devices for the expected large-volume demands for millimeter-wave components.

For example, Plextek RFI *(www.plextek.com)* is a long-time innovator in GaAs MMIC technology currently involved in

A single chip or packaged MMIC can replace what was once a receiver front end constructed with a long list of discrete components and matching elements. These include frequency mixers, filters, oscillators, amplifiers, and attenuators and the transmission lines required to interconnect them.

exploring the possible opportunities for active components in 5G systems. The company notes that no single millimeter-wave frequency band will serve the needs of short-haul links in all 5G systems around the world, due to the different spectrum allocations made by different regulatory groups, such as the FCC in the U.S. The FCC has designated spectrum at 37 GHz (37.0 to 38.6 GHz) and 39 GHz (38.6 to 40.0 GHz) on a flexible trial use basis for 5G systems.

Of course, practical implementation of communications links for these frequency bands assumes the availability of affordable components at these frequencies, which represents an opportunity for a mass-producible device technology such as GaAs MMIC technology. Plextek RFI's design teams have already examined possible design solutions for the two frequency bands, including separate amplifiers or a single broadband amplifier to cover both bands, but created a GaAs MMIC that incorporates two switchable amplifiers to cover the two frequency bands with the best combination of small size, performance, and low cost.

The switchable GaAs MMIC amplifier chip is fabricated on a high-volume 0.15-µm GaAs pHEMT process and housed in an SMT-compatible air-cavity QFN plastic package. The innovative design is just one of the GaAs MMIC devices that the company is developing for 5G applications which, along with automotive electronic safety systems, should drive a growing need for both RF MEMS and RF/microwave MMICs for years to come. mw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SIGNAL GENERATORS STRIVE for Cleanliness

SPECTRAL PURITY IS an important characteristic, as it represents a signal's inherent stability. Furthermore, stability can be defined as either long-term or short-term. Signal generators must be capable of generating spectrally pure signals to allow for effective measurements. This topic is the subject of a new application note from Keysight Technologies titled "Signal Generator Spectral Purity."

The application note first defines both long-term and short-term stability. Long-term stability, or drift, is usually defined over a period of time greater than one second. Current signal generator technology generally allows for good long-term stability, according to the document. Short-term stability is of greater concern. It is a result of fluctuations from non-deterministic signals, such as shot noise and flicker noise. This noise effectively modulates a carrier, affecting both amplitude and phase.

Short-term stability is commonly depicted as a plot of the single-sideband (SSB) phase noise in a 1-Hz bandwidth versus frequency offsets from the carrier. SSB phase noise is expressed as decibels-relative-to-the-carrier (dBc). In addition to SSB phase noise, spurious signals and residual FM are both described.

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The importance of spectral purity for mobile radio is discussed. Essentially, the spacing between radio channels is decreasing due to the scarcity of available spectrum. Thus, designers must ensure that receivers attain greater selectivity. Measuring the selectivity of a receiver requires a signal generator that can generate spectrally pure signals. Furthermore, the application note illustrates an adjacent channel selectivity measurement, which is often performed to determine how well a receiver can reject unwanted signals.

An illustration shows how a signal generator with inadequate phase noise performance can effectively nullify measurements. After mentioning the hum and noise measurement, the application note also explains why it is important for a signal generator to generate spectrally pure signals when it is used it as a local-oscillator (LO) substitution in a test setup. Another point that is mentioned is how current radar systems demand better target resolution. Thus, spectrally pure LOs/signal generators are required.

DISCOVER AN ALTERNATE Approach for Group Delay Measurements

GROUP DELAY IS a critical parameter that helps to characterize the quality of a transmission channel. Group delay measurements are commonly performed with a vector network analyzer (VNA), which essentially steps through a frequency of range of interest and performs a user-specified number of measurements. However, an alternative method, which involves the combination of a spectrum analyzer and signal generator, can also be used to measure group delay. This method is the subject of an application note from Rohde & Schwarz titled "Group Delay measurements with Signal and Spectrum Analyzers."

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www.rohde-schwarz.com

The application note begins with some basic theoretical information concerning group delay. It then explains how VNAs are used to measure the group delay of non-frequency converting components, such as filters and amplifiers. In addition, several techniques can be utilized to enable a VNA to measure group delay when frequency conversion does take place.

Multi-carrier group delay measurements are then discussed, as this technique essentially allows group delay to be measured with a spectrum analyzer together with a signal generator. While the typical VNA-based method is to sweep across a frequency range of interest, the multi-carrier method involves a multi-carrier signal that contains several sine waves. Each sine wave has a specific frequency and phase. By taking advantage of a multi-carrier signal, it is then possible to determine group delay over a given frequency range.

For the sake of comparison, the group delay of a bandpass filter was measured with both a VNA and a spectrum analyzer/signal generator test setup that used the multi-carrier method. The results from both measurements were in good agreement. Moreover, when utilizing the spectrum analyzer/signal generator method, the application note points out the importance of using attenuator pads when measuring a device-under-test (DUT) with high input or output reflections.

While the multi-carrier method offers the benefit of faster measurement times, some challenges are also associated with this approach. One challenge involves signal-to-noise ratio (SNR), which decreases as the number of carriers increase. Another challenge involves intermodulation-distortion (IMD) products.

MEHDI ARDAVAN | Norsat International

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Determining the Safe Distance from a Reflector Antenna

This article explains how to determine the power density of a radiating parabolic reflector antenna in the far- and near-field regions to meet safety requirements.

The electromagnetic (EM) energy radiated from an antenna may exceed the limits of safe human exposure, especially when the safe power levels and field intensities at different frequency bands are specified. Determining whether the safety criteria are satisfied when in a close vicinity of a large parabolic reflector antenna requires the knowledge of the near-field parameters.

In this article, existing methods are used to estimate these parameters, which are then compared with industry standards, such as the Federal Communications Commission's (FCC) OET Bulletin 65 or Health Canada's Safety Code 6, to determine the safe distance.[2, 3] The results provided are for reference only and the user must measure the field parameters to ensure safety.

Norsat International helps to enable satellite communications around the world.

INTRODUCTION

As a provider of different types of antennas for satellite communications (satcom), Norsat International *(www.norsat.com)* and many other companies conduct numerous tests to evaluate product performance. In a recent Norsat project, an X-band terminal underwent a Wideband Global Satcom (WGS) certification process. The antenna had to transmit up to 80 W for multiple 24-hour sessions in order to demonstrate its compliance with the MIL-STD-188 164B standard.[1] To ensure the protection of the staff and public, Norsat used industry safety standards to determine safe human-exposure levels.

The exposure limits, in both FCC Bulletin 65 and Safety Code 6, are provided in terms of the electric field intensity, magnetic field intensity, and power density. To compute these parameters using simple and conventional methods, the observer must be in the far field of the antenna, which is the region beyond the Fraunhofer distance.

As Norsat staff members would approach the antenna regularly, it was essential to establish the safety rules for the near-field region as well. Hence, the field parameters at positions closer than the Fraunhofer distance had to be determined. In this article, we will focus solely on the power density.

Farrar and Chang provide a series of figures and a guideline for estimating the field parameter in the near-field region.[4] However, the shortcoming of this method is that it is only valid on the axis of the boresight of the antenna.

For a given radial distance in the near-field region, Kobayashi provides an estimate of the ratio by which the near-field power and field intensities are reduced versus the offset angle from the boresight axis.[5]

Using both references, the power and field intensities can be estimated at different distances and offset angles from the boresight in the near-field region. Areas with power considered hazardous by industry standards are cordoned off and access is blocked.

The section below reviews the theory for power-density calculation at far field and presents a summary of the method of estimating the power density in the near field. Later on, we will apply this method to a practical problem and determine the safe distances from the antenna.

ELECTROMAGNETIC POWER DENSITY AND SAFETY GUIDELINES

The power density, S, radiated from an antenna with a gain of G_t and at distance of R is given by:

$$S = \frac{P_t G_t}{4\pi R^2} \quad (1)$$

provided the distance, R, is greater than the Fraunhofer distance, which defines the far-field region. The Fraunhofer distance is determined by:

$$R_f = \frac{2D^2}{\lambda} \quad (2)$$

where D is the largest dimension of the antenna and λ is the wavelength.

If located in the far-field region, the power density computed by Eq. 1 can be compared to the exposure limits defined by OET Bulletin 65 or Safety Code 6.

Safety in the Far Field

Safety Code 6 defines the exposure limits differently for controlled and uncontrolled environments. The uncontrolled environments have more conservative limits. For an X-band signal in uncontrolled environments, the maximum RMS value of the electric field intensity (E_m), the maximum RMS value of the magnetic field intensity (H_m), and the maximum power density (S_m) are as follows:

$E_m = 61.4$ (V/m)
$H_m = 0.163$ (A/m)
$S_m = 10$ (W/m^2)

OET Bulletin 65 of FCC provides the same exposure limit of 10 W/m^2 for power density for X-band signals.

In the far field, it is sufficient to satisfy the power-density criterion since the other two parameters are directly related to the power density and the wave impedance.

Knowing the gain of the antenna and the transmitted power, we can compute the distance at which the power density is S_m. This distance is denoted by R_m and determined by:

$$R_m = \sqrt{\frac{P_t G_t}{4\pi S_m}} \quad (3)$$

R_m computed by Eq. 3 is accepted only if it is larger than R_f. The distance R_m is usually computed for the boresight. However, if the observer is away from the boresight by elevation and azimuth angles of θ_o and φ_o, respectively, we then have:

$$R_m = \sqrt{\frac{P_t G_t(\theta_o, \phi_o)}{4\pi S_m}} \quad (4)$$

which will result in a smaller distance as the gain, $G_t(\theta_o, \varphi_o)$, away from the boresight is significantly smaller than the gain at the boresight for any offset angles significantly larger than half-power beamwidth.

Safety in the Near Field

In the near-field region, some approximations are required to estimate the power density. The National Telecommunications and Information Administration (NTIA), located within the Department of Commerce, has a series of documents in which such approximations and procedures are provided.[4, 5]

First, we must determine the far-field power density at the boundary of the far-field and Fresnel regions (S_0). Then the procedure to estimate the power density in closer distances is mainly divided into three sections:

1. Determine the tapering factor of dish illumination, which shows how uniformly the dish is illuminated. A tapering factor of n = 0 means that the feed antenna illuminates the dish uniformly. As n increases, illumination rapidly decreases by moving away from the center of the reflector.
2. Determine the correction factor for power density along the boresight in the Fresnel or near-field regions.[4]
3. Determine the correction factor for the off-boresight angle.[5]

Correction factors depend on the tapering factor of the dish. We apply the correction factors to S_0 and estimate the power density at the desired point.

The above items are described in more detailed steps as follows:

1. Determine the tapering factor, n.
- Determine λ/D, where D is the diameter of the dish and λ is the wavelength at the largest frequency.
- Determine the half-power beamwidth from gain patterns, θ.
- Determine the θ/(λ/D), and compare it to the factor in the second column of Table 1 on Page 3-2 of ref. 5. Based on this comparison, choose a tapering n from the first column.

2. Determine the Fraunhofer distance:

$$R_f = \frac{2D^2}{\lambda}$$

3. Determine field power density at R_f:

$$S_f = \frac{P_t G}{4\pi {R_0}^2}$$

where G is the numerical value of the gain of the antenna.

4. Determine the normalized distance:

$$p = \frac{R}{R_f}$$

5. Use Figure 4-3(b) in ref. 4 to determine the on-axis power density for p and n = 1. If tapering is different, use the applicable plots in Figures 4-3.

6. Determine the off-axis angle according to the desired observation point.

7. Use Figure 3-10e in ref. 5, assuming n = 1, to determine the correction factor. Apply the correction factor.

APPLICATION TO AN 80-W, 1.5-M ANTENNA

An 80-W, X-band antenna with a 1.5-m reflector was used in this project. At the largest frequency, 8.4 GHz, the wavelength is 0.0357 m and the diameter of the parabolic reflector antenna is 1.5 m. Using Eq. 2, we determine the Fraunhofer distance:

$$R_f = \frac{2D^2}{\lambda} = \frac{2\times(1.5)^2}{0.0357} = 126\ \text{m}$$

At this distance, the power density of our terminal is computed by Eq. 1. The computed result is 3.2 W/m^2, less than 10 W/m^2.

Hence, for all off-boresight angles, if the radial distance from the antenna is 126 m or more, the exposure to EM power will be within the safety limits.

Safety at a Specific Position

Given the geometry of our test location, we were interested in knowing the power density at distance of R = 42.2 m. Since $R < R_f$ and we are in the Fresnel region, it is required to go through the steps defined in the previous section.

At 8.15 GHz, our test frequency, the half-power beamwidth, is about 1.74 degrees, which equals $\theta = 0.0304$ radians and $\lambda = 0.0368$ m. Therefore, $\lambda/D = 0.024$.

Hence, $\theta/(\lambda/D) = 1.24$, which is close to the factor 1.27 in column 2 of Table 1 on Page 3-2 in ref. 3. As a result, n = 1. The tapering factor is assumed to be the same at all frequencies of the transmit band.

The smallest distance that can be considered far field at 8.15 GHz for a 1.5-m dish is about 122 meters. At this distance, the power density of our terminal is:

$$\frac{P_t G}{4\pi {R_0}^2} = 3.3\ \text{W/m}^2$$

So the normalized distance is computed by:

$$p = \frac{R}{R_f} = \frac{42.2}{126} = 0.35$$

The correction factor obtained from Figure 4-3 (b) in ref. 2 at p = 0.35 is about 10. Hence, the power density at this distance, on the boresight axis, is about 3.3 × 10 = 33(W/m^2), which is above the safety requirement.

To ensure the safety at this location, we introduce a cone with an apex angle of 20 degrees around the boresight axis. Nobody is allowed to enter the conic section. So at the edge of the cone, the offset angle is 10 degrees. To show that the exposure is within the safety limit at this angle, we use Figure 3-10e in ref. 3. In this figure, the correction factor for angles above 10 degrees is well below –20 dB, which is 1/100 for power density.

Hence, the power density at a radial distance of 42.2 meters and 10 degrees away from the boresight is less than:

$$3.3\times 10\times \frac{1}{100} = 0.33\ \frac{\text{W}}{\text{m}^2}$$

which is far less than 10(W/m^2) as recommend by ref. 1.

In this case, a 20-degree cone, 10 degrees from boresight, provided a good safety level. This can be verified at a worst-case scenario.

Worst-Case Scenario

Figure 4-3(b) of ref. 4 shows that the highest correction factor of 43 occurs at the normalized distance of about 0.1. Therefore, the maximum on-boresight power density is:

$$3.2\times 43 = 137\ \frac{\text{W}}{\text{m}^2}$$

At the edge of the 20-degree cone, the 10-degree offset angle correction factor, as shown by Figure 3-10e, is well below 1/100. Hence, the power density is less than:

$$3.2\times 43\times \frac{1}{100} = 1.37\ \frac{\text{W}}{\text{m}^2}$$

which is less than 10(W/m^2), as recommend by refs. 2 and 3.

The offset angles usually assume that the radiating antenna is a point-source. To ensure safety, it is recommended that the unsafe region is extended such that it encompasses the 20-degree cone plus a margin of D/2 = 75 cm.

The FCC Approach to the Worst-Case Scenario

In the FCC OET Bulletin 65, the maximum on-boresight near-field power density is approximated by:

$$S_{max} = \frac{16eP}{\pi D^2}$$

where e is the aperture efficiency and is usually between 0.5 and 0.75. Considering an aperture efficiency of 0.75, the maximum power density is:

$$S_{max} = \frac{16\times 0.75\times 80}{\pi 1.5^2} = 135.9\ \frac{\text{W}}{\text{m}^2}$$

which is very close to the value computed at the previous section.

However, due to the radome effects, the total efficiency of our antenna is close to 0.5. As a consequence:

$$S_{max} = \frac{16\times 0.5\times 80}{\pi 1.5^2} = 90.6\ \frac{\text{W}}{\text{m}^2}$$

(Continued on page 85)

JACK BROWNE | Technical Contributor

Supporting an Expanding Satellite Constellation

Growing use of satellites for communications, navigation, weather, and other functions is boosting the demand for active and passive components.

1. Satellites are used for a variety of applications, including for communications, navigation, and weather monitoring. *(Courtesy of Princeton Microwave Technology)*

SATELLITES ARE BEING launched with greater frequency as they become more routine parts of communications network infrastructure. In addition to major systems for communications, smaller spacecraft (such as CubeSats) are being launched for research purposes, driven by initiatives from NASA. Global satellite communications (satcom) markets are projected to grow for many years.

Satellites are also used for many other non-communication-related applications *(Fig. 1)*, including for gathering weather and geological data (such as the Landsat system), as well as providing timing and navigational information (such as the GPS systems). Still, it is their capabilities to send and receive signals beyond ground-based physical and electromagnetic (EM) obstructions that make them attractive for communications links.

While an increasing number of smaller satellites are being launched, some big birds still fly. Most recently, ViaSat *(www.viasat.com)* announced the completion of a critical design review (CDR) milestone for its ViaSat-3 class spacecraft, now moving forward with Boeing on building, performing systems integration, and fully testing their first two ViaSat-3 satellites, powered by all-electric propulsion systems.

The ViaSat-3 satellites will be the largest satellites in the industry. Operating at Ka-band frequencies, these first two will provide coverage for the Americas and EMEA (Europe, the Middle East, and Africa), respectively, with a third ViaSat-3 satellite planned for the Asia Pacific region. The Ka-band bandwidth will enable tremendous flexibility and speed in terms of internet access and data transfers. Each satellite is expected to provide more than 1 TB/s network capability.

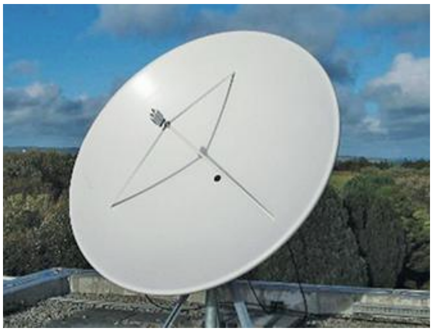
The beauty of communications via satellite is that a system like a ViaSat-3 can reach users wherever they are, requiring simply a ground station in the form of an antenna and transceiver—the satellite is the rest of the infrastructure. There are no copper or optical cables to run along rough terrain and no wireless base stations and antenna towers to build, with limited coverage per base station.

As with any technology, satellites have their tradeoffs, such as signal loss due to rainfall attenuation. But for areas without existing communications infrastructure (e.g., Africa), satcom technology requires an initial investment in the development and launch of an orbiting satellite, and then the network can be expanded over time with a growing number of ground stations.

BUILDING THE PARTS

Satcom systems require a large number of high-frequency components, both in orbit and on the ground, in maritime terminals, and in commercial and military aviation systems that communicate by means of satellites. High-frequency components for use in satellites must be unquestionably reliable with consistent performance over long operating lifetimes, meeting the requirements for "space-qualified" components since they cannot be replaced upon failure.

Crane Aerospace & Electronics *(www.craneae.com)* builds space-qualified passive components, including circulators and isolators, couplers, and power dividers, according to proven designs from acquired companies (such as Signal Technology and Merrimac Industries). The components are rigorously tested and have demonstrated unfailing reliability on a wide range of satellites, including Galileo, GPS, Iridium, MILSTAR, and Inmarsat satellites.



2. Receive antennas are key components in any satcom system, such as this reflector designed for Ka-band reception. *(Courtesy of Elite Antennas)*

3. This feed system was developed for efficient operation with different polarization methods at Ka-band frequencies. *(Courtesy of Elite Antennas)*

Contractors for satellite-based systems rely on space-proven components that will provide high performance levels over a long operating lifetime. In some cases, such as the defense-based satellite systems developed by General Dynamics Mission Systems *(gdmissionsystems.com)*, components are built according to a large library of modeled and constructed components, with physical dimensions and mechanical tolerances of waveguide components carefully controlled for repeatable, predictable performance.

Waveguide is essential for satcom components, due to its durability and low loss at higher frequencies. As satellite systems move towards Ka-band and higher frequencies, waveguide interconnections and components help to preserve the signal power at those frequencies by combining low insertion loss with low return loss (low VSWRs) for reflectionless interconnections.

Because of the rigorous testing required to ensure "space-qualified" performance levels, many suppliers of RF/microwave components for satcom applications are well-established companies with lengthy track records of having supplied various components. ARRA, for example, is a long-time supplier of waveguide bends and other waveguide components for space applications, with the machine shops and expertise to maintain the tight physical tolerances required for matched amplitude and phase performance within different satcom bands.

Several long-time satcom component suppliers are now under the L3 company banner as L3 Narda-MITEQ *(nardamiteq.com)* and L3 Narda-ATM Microwave *(www.atm-microwave.com)*. As with many other areas of high-frequency electronics, satcom equipment is being designed for increased functionality in smaller packages.

A long-time leader in components for satcom applications, L3 Narda-MITEQ, for example, has developed a patented line of space-saving satcom products in one-third-rack configurations, including amplifiers, frequency upconverters and downconverters, frequency translators, frequency synthesizers, and receivers, with the same performance and functionality as the full-rack-size units.

L3 Narda-ATM Microwave, which supplies a variety of coaxial and waveguide components, is well aware of the growing need for satellite components at Ka-band frequencies: 27.5 to 31.0 GHz for the uplink and 18.3 to 20.2 GHz for the downlink. The firm's component lines include power dividers, attenuators, phase shifters, couplers, and terminations, both space-qualified versions and those for ground-station use.

In support of growing needs for antennas for Ka-band satcom links, Elite Antennas *(www.elite-antennas.com)* has developed an extensive line of antenna feeds *(Fig. 2)* and parabolic reflectors *(Fig. 3)* with diameters from 0.9 to 4.5 m diameter for the 17-to-22-GHz receive band. The antennas are available with circular or linear polarization. The company also supplies a wide range of antennas for commercial and military use, including a 600-mm-diameter reflector antenna with SMA connector for broadband coverage from 7.5 to 18.0 GHz, for signal intelligence (SIGINT) applications as well as for test purposes with a spectrum analyzer.

As markets for RF/microwave satcom components become more competitive, pressures force component manufacturers to find ways to provide outstanding performance at lower prices. Even smaller suppliers such as Princeton Microwave Technology (princetonmicrowave.com) must adjust to the pricing pressures and they have responded with competitive amplifier lines, including power amplifiers (PAs) and low-noise amplifiers (LNAs).

For example, a compact X-band LNA developed for 10.9 to 11.7 GHz measures 1.5 × 1.5 × 2.4 in. with WR-75 waveguide input and SMA output connector. It provides 45-dB small-signal gain with +15-dBm output power at 1-dB compression across the frequency range. It features low noise levels, with typical noise figure of 1 dB or less and spurious levels of −80 dBc. In addition to LNAs and power amplifiers for satcom use, the firm also produces lines of passive components, including power dividers, couplers, filters, frequency mixers, bias tees, and DC blocks.

As satcom markets expand, additional component manufacturers are expected to support these markets with active and passive RF/microwave components, both for broadband, multiple-purpose use and targeted for specific satellite frequency bands. This report has provides a brief sampling of suppliers. Interested specifiers are invited to visit Source ESB *(www.sourceesb.com)* for more complete listings of satcom component suppliers. mw

Product Feature

JACK BROWNE | Technical Contributor

RF/Microwave Industry Returns to Boston for EDI CON

The second-ever edition of this event to be held in the continental U.S. drew in a crowd to its show floor and technical sessions.

Given a late-summer chance to gather in Boston, a healthy portion of the RF/microwave industry came together this September for the Electronic Design Innovation Conference & Exhibition (EDI CON; *www.ediconusa.com*), held in the Hynes Convention Center.

The conference and exhibition drew a broad cross section of the industry, from amplifier designers to software and test equipment suppliers, with the common themes of 5G and more millimeter-wave applications running through many of the technical presentations and at the exhibition booths. Visitors to the show were knowledgeable, and many appear to be preparing for the coming of 5G wireless networks—and what that will mean for them and their companies.

Held Sept. 11-13, the 2017 edition of EDI CON attracted thousands of visitors and more than 100 industry company exhibitors, showing everything from tiny active devices to large test systems. The show floor provided a representative sampling of the industry, with opportunities for visitors to pick up free demonstration copies of design and test software and learn more about new developments at some of the leading companies.

MACOM *(www.macom.com)* greeted EDI CON exhibition visitors from a small but highly visible booth near the entrance of the show floor. Although the booth held samples of the company's many diode and optical communications components, perhaps the products of greatest interest were based on MACOM's GaN-on-Si technology, such as high-power transistors and integrated amplifiers.

One of the company's impressive discrete GaN transistors, the MAGe-102425-300, is based on fourth-generation GaN-on-Si technology. It operates on +50 V dc and delivers 300 W saturated output power with 16-dB gain at 2.45 GHz. The transistor, which is supplied in a rugged flange housing *(Fig. 1),* is intended for ISM-band applications at 2.4 to 2.5 GHz. It is a candidate for solid-state heating and cooking applications and even for use in automotive ignition systems.

1. The MAGe-102425-300 discrete power transistor is an example of the output power possible from GaN technology, with 300 W saturated output power with 16-dB gain at 2.45 GHz. *(Courtesy of MACOM)*

Just across the aisle from MACOM, several large booths from Analog Devices *(www.analog.com)* and National Instruments *(www.ni.com)* dominated the show floor and captured the attention of visitors with active demonstrations of their products. For Analog Devices, it was the various versions of its RadioVerse radio integrated circuits (ICs) that brought interested parties to the booth, especially those working on wireless communications systems. This series of agile RF transceivers based on software-defined-radio (SDR) technology provides users with the flexibility to meet performance requirements by means of software tuning, while minimizing power consumption and taking advantage of the network benefits of massive multiple-input, multiple-output (MIMO) antenna techniques.

The EDI CON crowd was energized by the introduction of the latest RadioVerse transceiver, the AD9375 *(Fig. 2)*, at the show. Building on the proven design of the firm's earlier AD9371 radio transceiver, the AD9375 covers a range of 300 to 6,000 MHz with dual differential transmitters and receivers. It includes an observation receiver with two input ports and a sniffer receiver with three input ports.

The highly integrated transceiver includes its own digital-predistortion (DPD) circuitry for a significant reduction in power consumption compared to DPD system approaches based on external field-programmable gate arrays (FPGAs).

2. The AD9375 RadioVerse transceiver was one of the more integrated devices to be found at the 2017 EDI CON, with dual differential transmitters and receivers and several "auxiliary" receivers for use from 300 to 6000 MHz. *(Courtesy of Analog Devices)*

The simplicity and lower cost resulting from the DPD integration helps to speed wireless communications functionality to market in small cells and other smaller wireless application areas. The AD9375 supports 3G and 4G waveforms with instantaneous signal bandwidths as wide as 40 MHz.

Across the floor, National Instruments was showing how modular PXI Express test instruments fit together to create a complete RF/microwave measurement system—in this case, its PXI Vector Signal Transceiver (VST) system. Of the many different test-instrument formats on the EDICON show floor, the VST's three-slot, 3U-high PXI Express format might have been one of the more familiar "plug-and-play" modular measurement systems for many visitors, with its capabilities to perform real-time vector signal measurements through 6 GHz and show results instantly by merit of a high-power SDR architecture. Measurements are greatly simplified through the use of the VST test software, based on the company's popular LabVIEW test software.

SOFTWARE SOLUTIONS

Not to be outdone, the folks on the software side of the house at NI AWR *(www.awrcorp.com)* demonstrated the new features in the latest version of Version 13 of the NI AWR Design Environment (Version 13), including Microwave Office for designing and optimizing the performance of high-frequency circuits. Visitors to the NI AWR booth had a choice of computers with different software programs and could even perform system-level simulations using a copy of the NI AWR Visual System Simulator (VSS).

Visitors to the booth could also learn more about the LabVIEW Communications System Design Suite, which allows users to design and prototype communications systems based on National Instruments' flexible software-defined-radio (SDR) system architecture. The single development platform includes a system designer, compiler, and design simulation tools to explore different architectures before committing to hardware.

Nuhertz Technologies *(www.nuhertz)* offered visitors to its booth (and website) free 30-day trials of its FilterSolutions filter design software, including literature handouts on capabilities for designing RF/microwave filters with defected ground structures (DGS). In a microstrip circuit, a DGS is some form of intentional defect or etching in the ground plane that results in notch resonators, which can be used to reduce, for example, spurious levels or tune spurious frequencies in different kinds of high-frequency filters. The FilterSolutions software includes an export function that allows it to work with DGS models from the NI AWR Design Environment.

Mician GmbH demonstrated how to use its µWave Wizard full-wave three-dimensional (3D) EM simulation software to create high-frequency components, with the help of a large library of predefined shapes and elements. The user-friendly software is written in modular fashion, with blocks devoted to designing different types of filters, such as lowpass filters (LPFs), bandpass filters (BPFs), and antennas. Modules are also devoted to optimization, yield analysis, and even performance tuning, allowing users to perform analyses in the frequency and time domains.

COMSOL *(www.comsol.com)* presented visitors with its versatile COMSOL Multiphysics software and how it can be used for such "unorthodox" modeling challenges as studying the nonlinear thermal effects of heat sources (such as power transistors and amplifiers) embedded in electronic circuits and systems. The software's thermal models are based on computer tomography studies of different materials, and these models provide software users with the opportunity to simulate the impact of, for example, different packaging materials on the thermal management of a design at different power levels.

TESTING THE LIMITS

For engineers in need of an upgrade on the test bench, EDICON offered more than a few examples of the latest RF/microwave test instruments, including pocket-sized one-port VNAs from Copper Mountain Technologies *(www.coppermountaintech.com)*. With units covering bandwidths as wide as 1 MHz to 18 GHz, such as the R180 *(Fig. 3)*, these USB-powered reflectometers make it possible to bring the test equipment to the device under test (DUT), without cables—rather than the other way around—for highly accurate reflectometer (S_{11}) measurements. As with other USB test instruments, data is stored and displayed on the host computer's screen and popular test software programs, such as LabVIEW and MATLAB, can be used to automate measurements.

3. The R180 one-port, USB-powered VNA is a compact reflectometer for measurements as wide as 1 MHz to 18 GHz. *(Courtesy of Copper Mountain Technologies)*

In addition to a fair share of exhibition booths with low-noise signal sources, a number of companies provided the means to measure the phase noise of those sources, including Holtzworth Instrumentation *(www.holtzworth.com)* with its HA7062C real-time phase-noise analyzer. The company leveraged its expertise in frequency synthesizers to create the reconfigurable front-end design of this analyzer, with a base frequency range of 10 MHz to 6 GHz, which can be extended to 26.5 GHz by adding a frequency downconverter. With a measurement noise floor of −195 dBc/Hz, the instrument analyzes source phase noise at offsets from 0.1 Hz to 40 MHz.

Fast switching speed has long been a key characteristic of test signal sources from Berkeley Nucleonics Corp. *(www.berkeley-nucleonics.com)*, and the company's exhibition booth at EDI-CON 2017 didn't disappoint, with a number of models providing microsecond switching speed.

Available with upper-frequency limits of 6.2, 12.5, and 20.0 GHz and from two to eight independent channels, the 855 series signal generators can achieve frequency and power switching as fast as 10 µs for effective use in automatic-test-equipment (ATE) systems. Output-power levels can be adjusted from −90 to +27 dBm and the phase noise is what one would expect from a high-performance test signal generator: −131 dBc/Hz offset 1 kHz from a 500-MHz carrier and −115 dBc/Hz offset 1 kHz from a 4-GHz carrier.

For those who simply required more test signal power in their measurement systems, RF-Lambda *(www.rflambda.com)* showed it line of AC-powered microwave amplifiers, including its model RAMP01G22GA with 8 W output power from 1 to 22 GHz. Suitable for test systems and short-haul communications links, the amplifier provides 50-Ω impedance-matched input and output ports and delivers 42-dB gain with 5-dB noise figure across its wide frequency range. Lower-frequency amplifiers in the line offer higher power levels, while higher-frequency models extend past 100 GHz with less output power.

One of the better-kept secrets among the leading test-and-measurement companies at the 2017 EDI CON was the almost-hidden HA-Z24E external preamplifier used in a spectrum analyzer demonstration at the Rohde & Schwarz booth *(www.rohde-schwarz.com)*. The bandwidth of the amplifier alone, at 1 to 85 GHz, is impressive, but the fact that it delivers about 23 dB small-signal gain from about 65 to 75 GHz—and is as simple to connect as plugging in a couple of 1-mm connectors and a USB connector to the spectrum analyzer—turns a spectrum analyzer with sufficient bandwidth into a millimeter-wave activity receiver.

The low-key approach of Rohde & Schwarz's representatives also belied the outstanding performance of some of the other instruments on display, including the R&S SMA100B signal generators, with reference-quality phase-noise performance. Available in various frequency configurations through 20 GHz, the R&S SMA100B generators *(Fig. 4)* boast phase noise of −152 dBc/Hz offset 20 kHz from a 1-GHz carrier with high carrier power and low harmonic and spurious levels.

Those wishing to learn more about load-pull and source-pull tuners and testing actually had a choice of equipment and software suppliers at the 2017 EDI CON, with representatives from both Focus Microwaves *(focus-microwaves.com)* and Maury Microwave *(www.maurymw.com)* exhibiting their high-performance test systems.

4. The R&S SMA100B signal generators offer reference-quality phase-noise performance to 20 GHz. *(Courtesy of Rohde & Schwarz)*

Growing interest in millimeter-wave frequency bands for automotive and 5G wireless applications fuels the need for developing impedance matching networks for such components as power amplifiers, and a multipurpose impedance tuner such as the MPT 110200 from Focus Microwaves provides a usable frequency range of 20 to 110 GHz for the design and development of millimeter-wave components. Similarly, automated impedance tuners from Maury Microwave were on display at EDI CON for measurements in bands from 33 to 110 GHz, encouraging new product developments in the millimeter-wave frequency ranges.

MATERIAL IMPROVEMENTS

A number of materials-based developments were unveiled on the EDI CON exhibition floor, perhaps most noteworthy the emergence of Menlo Micro *(www.melomicro.com)* and its use of glass substrates to fabricate RF/microwave components. Growing its technology from research begun at General Electric's Global Research Center, Menlo Micro has found a way to fabricate high-power microwave electromechanical switches on glass, using proprietary metal alloys and processing techniques. The company's material-based Digital Micro-Switch (DMS) technology is based on glass substrates from Corning, Inc., a supplier that is also an investor in the new company.

In terms of performance, the electromechanical switches trim insertion loss to less than 0.3 dB through 12 GHz and are usable across bandwidths as wide as DC to 18 GHz. As an example, the MM3100 is a six-channel, single-pole, single-throw (SPST) digital microswitch with bandwidth of greater than DC to 3 GHz. The on-state insertion loss is less than 0.3 dB at 3 GHz with better than 25 dB isolation at 3 GHz.

To support a growing appetite for millimeter-wave applications on the show floor, materials supplier Rogers Corp. *(www.rogerscorp.com)* displayed samples of its ceramic-filled, PTFE-based, woven-glass-reinforced CLTE-MW laminates and 5-mil-thick RO3003 laminates with low loss at millimeter-wave frequencies. The materials have been used in 77-GHz automotive radar and provide a starting point for 60 GHz and other frequencies being considered for 5G wireless networks *(for a full review of CLTE-MW materials, please see p. 76 of this issue)*.

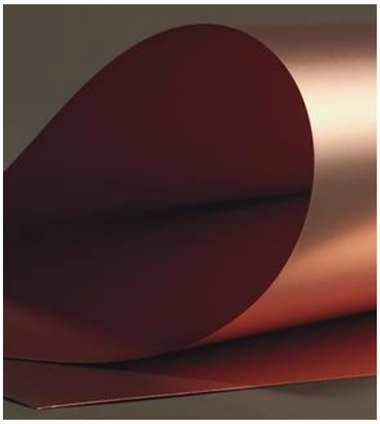
JACK BROWNE | Technical Contributor

Circuit Materials Help Build 5G from the Ground Up

These PTFE-based, ceramic-filled, glass-reinforced circuit materials provide cost-effective stable mechanical and electrical properties needed for mm-wave circuits.

Large amounts of bandwidth will be needed for transferring the huge volumes of data projected to be part of 5G wireless networks, and millimeter-wave frequencies offer the amounts of bandwidth needed. Of course, to make use of that bandwidth at frequencies such as 60 GHz, practical circuits including transceivers, antennas, and amplifiers must be designed and implemented, and the foundation of those circuits is the printed-circuit-board (PCB) material. For effective use at millimeter-wave frequencies, a PCB material must fulfill a set of requirements that can be unique to that frequency range (above about 30 GHz). Fortunately, the latest high-frequency circuit material from Rogers Corp., CLTE-MW laminates, features the characteristics uniquely suited to millimeter-wave applications.

CLTE-MW circuit materials *(see figure)* are based on low-loss polytetrafluoroethylene (PTFE), loaded with ceramic filler and reinforced with spread glass fabric. CLTE-MW materials are well suited for circuits requiring thin laminates, such as millimeter-wave circuits with extremely short signal wavelengths that require tightly controlled dielectric constant and signal-to-ground spacing.



CLTE-MW laminates come in a variety of thicknesses and cladding options for low-loss microwave and millimeter-wave circuits.

MATERIAL REQUIREMENTS

Millimeter-wave frequencies are being looked upon for backhaul and other short-range communication links within 5G systems. In addition to being affordable, the circuit materials for such applications must meet a number of challenges resulting from the short wavelengths and limited energy available at millimeter-wave frequencies. Antennas for 5G networks, for example, are expected to employ large multiple-input, multiple-output (MIMO) arrays of elements which will be fabricated on multilayer circuit boards requiring low loss, low dielectric constant (Dk), and stable electrical and mechanical properties to achieve consistency among the many antenna elements.

CLTE-MW laminates meet these requirements with typical Dk values ranging from 2.94 to 3.05 at 10 GHz (depending upon the thickness of the material), held to a tolerance of ±0.04. For example, 3-mil-thick CLTE-MW laminate exhibits a process Dk of 2.94 at 10 GHz while 10-mil-thick material has a process Dk of 3.00. The design Dk values (used with circuit simulators as part of the design process) are slightly higher than the process Dk values for all thicknesses.

As a function of temperature (thermal coefficient of dielectric constant), the Dk changes only by -35 ppm/°C from 0 to +100°C as measured at 10 GHz. The loss tangent is a low 0.0015 at 10 GHz, to preserve the limited signal energy at millimeter-wave frequencies. When signal power is available, these materials provide the capability to handle higher signal power levels, with a thermal conductivity of 0.42 W/m-K through the thickness (z-axis) of the material.

An important material specification for circuits in which considerable power is generated or transferred, is coefficient of thermal expansion (CTE). CTE indicates the dimensional changes in a circuit material with changes in temperature. For the CLTE-MW laminates, the z-axis CTE is 30 ppm/°C, representing very little change in thickness with temperature—especially important for multilayer circuits and circuits with structures such as plated through-holes which can become mechanically stressed with dimensional changes. The CTE in the x and y axes is typically 8 ppm/°C. These relatively thin circuit materials exhibit high dielectric strength of 630 V/mil for high isolation between conductor layers in multilayer circuit designs. Also, high stability under less-than-ideal operating conditions is evidenced by low moisture absorption of 0.03%. mw

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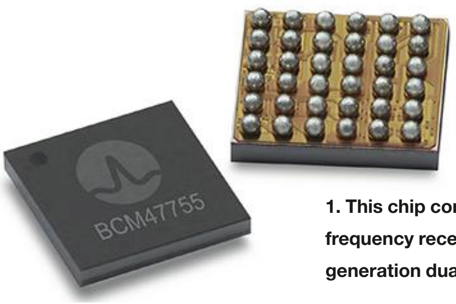
CHRIS DeMARTINO | Technical Editor

Broadcom Boosts Vehicle Navigation with New Dual-Frequency Receiver

This new dual-frequency GNSS receiver chip—which achieves an accuracy of 30 cm—is intended to significantly improve vehicle navigation.

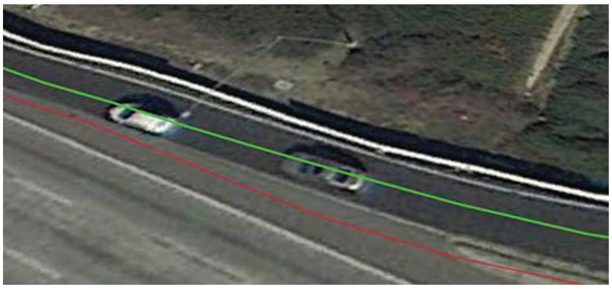
While navigation is obviously something that many drivers depend on, one company decided to create a solution to enhance the navigation experience. That solution is Broadcom Limited's *(www.broadcom.com)* new BCM47755, which is a single-chip, dual-frequency global-navigation satellite-system (GNSS) receiver *(Fig. 1)*. According to Broadcom, the BCM47755 is the first mass-market, dual- frequency GNSS receiver device. It is intended for smartphones, tablets, and wearables. The BCM47755 could also find its way into other Internet of Things (IoT) devices.



1. This chip combines a dual-frequency receiver and a next-generation dual processor.

Traditional GNSS receivers have only used the L1 signal. However, the BCM47755 uses both L1 and L5 signals. As Manuel del Castillo, associate director, GNSS product marketing at Broadcom, explains, "With the BCM47755, both L1 and L5 signals from the same satellite are used. This is needed because L1 is a more basic signal, while L5 is more advanced. With L1, positioning can be computed with fewer resources and in less time. The approach is to start with L1 for basic acquisition and then switch to L5. Once we have L5, we don't need L1. Thus, we believe that the BCM47755 allows for the best of both worlds."

Simultaneously receiving L1 and L5 signals allows for a 30-cm accuracy. Multipath correction, detection of reflected signals, and ionospheric error correction are all benefits that are associated with the BCM47755. Furthermore, the 30-cm accuracy essentially means that "lane-level" accuracy is realized on a highway. *Figure 2* shows an actual driving track when utilizing the BCM47755.



2. This image illustrates the lane-level accuracy of the BCM47755 dual-frequency receiver. The green trace shows the BCM47755 tracking, while the red trace shows the tracking of the previous-generation BCM4774.

Consumers are likely to benefit from lane-level accuracy in several ways. For one, a turn-by-turn navigator could provide much more precise navigation instructions and estimated time of arrival (ETA). Using the BCM47755 could also allow much more accurate information with regard to taxi, car-sharing, and ride-hailing applications. This capability is especially significant with the emergence of services like Uber and Lyft.

Based on 28-nm process technology, the BCM47755 incorporates a dual-frequency, low-power GNSS radio along with a dual-core ARM CM4-CM0 sensor hub. Power consumption is reduced by approximately 50% in comparison with the previous-generation chip. Specifically, current consumption can be less than 5 mA during GNSS tracking.

"In 2017, there are 30 satellites orbiting the earth with dual-band capability," notes del Castillo. "This is the right time to implement L1 and L5 capability in a smartphone." Broadcom has been sampling the BCM47755 since January and expects it to be used in consumer devices in 2018.

JACK BROWNE | Technical Contributor

Mini-Circuits, X-Microwave Partner to Speed Prototyping

A wide diversity of Mini-Circuits components are available for prototyping with the X-Microwave solderless drop-in module approach.

Mini-Circuits, a long trusted supplier of RF/microwave components, is teaming up with X-Microwave to offer the company's components on X-Microwave's X-MWblock drop-in module format. By employing the modular, solderless drop-in system along with companion hardware, software, and simulation tools, designers using Mini-Circuits components can speed and simplify the process of evaluating components working together in subsystems and subassemblies, such as receivers or transmitters. Furthermore, they can quickly redesign and optimize their assemblies as needed thanks to the flexible, modular nature of the X-Microwave approach.

Over 400 X-MWblocks are initially available for Mini-Circuits components, including filters, amplifiers, mixers, multipliers, limiters, couplers, switches, power dividers/combiners, and attenuators, with more planned. Each component for use in the X-MWblock format is supported by a computer simulation model based on measurements, enabling online computer simulations of multiple components working together in a signal chain.

The X-MWsystem drop-in prototyping approach already features components from Analog Devices, Custom MMIC, and others. Using these drop-in X-MWblock components as part of an assembly or subsystem makes it possible to evaluate the interactions among the components, such as reflections or mismatches, in software as well as in hardware.

Users of this design approach gain access to X-Microwave's test probes and prototyping systems to evaluate the performance of an assembly. All assembly accessories are included in the X-MWsystem, along with standard machined housings for connectorized versions of the X-MWblocks.

End-launch connectors for the X-MWblocks provide low-loss, low-reflection performance to 50 GHz. Called X-MWend-launch connectors within the X-MWsystem, they employ a solderless bolt-on design.

FROM BLOCKS TO PROTOTYPING STATIONS

The X-MWsystem essentially adapts components of many different shapes and sizes to a universal package known as an X-MWblock. Adapting different types of components from different suppliers to common launch geometries and mounting arrangements helps simplify integration and speed assembly of multi-function subsystems.

X-MWblocks can be assembled on a prototyping station known as an X-MWprotostation, which consists of a stainless-steel grid plate with a standard hole pattern to simplify component placement. Since the entire design approach is modular, arbitrary enclosures can be formed around the X-MWprotostations using modular wall and lid pieces to emulate cavity effects at the prototype phase.

Assembled X-MWprotostations can be connected for testing using X-MWcables and custom X-MWprobes. The RF probes consist of a 1.85- or 2.92-mm female coaxial connector capable of operating to 67 GHz and 50 GHz, respectively. The probes can connect to any X-MWblock as a ground-signal-ground (GSG) probe.

By using this universal connector and packaging approach, the X-MWsystem makes it possible to eliminate the need for custom evaluation boards while adapting to other components with different connector types. The X-MWblocks and the X-MWprotostation function as the evaluation boards and then, once properly tested, as the production components.

Components available as X-MWblocks are well supported by models based on S-parameter measurements for linear devices and X-parameter measurements for nonlinear devices. For those without ready access to a software simulator, X-Microwave even provides access to an online software simulator, the X-MWsimulator, with models for all components contained in a prototype assembly or subsystem available free of charge. The software simulator is based on the Genesys Spectrasys simulation software from Keysight Technologies.

In support of physical designs, an online Mechanical Layout Tool (MLT) allows users to move two-dimensional (2D) component representations around a layout grid that serves as a form of map to configure actual components on a solderless prototyping plate for testing and design validation. The drop-in components can then be assembled in compatible production housings that support of a full drop-in approach to system design. mw

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Product SPOTLIGHT

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Coax Amp Provides Flat Gain from 5 to 20 GHz

Mini-Circuits' model ZX60-24A+ is a wideband coaxial amplifier that is well suited for applications requiring broadband amplification from a single compact component, such as communications, radar, EW, and test equipment. It offers typical gain of 24 dB flat within ±2.2 dB from 5 to 20 GHz. The unconditionally stable 50-Ω amplifier measures just 0.75 × 0.74 × 0.46 in. but delivers +18.3-dBm typical output power at 1-dB compression. The two-stage amplifier also boasts excellent reverse isolation of typically 67 dB. It is equipped with female SMA connectors and operates from a single +5-V DC supply.

MMIC Balun Transformer Tackles 5500 to 13500 MHz

Mini-Circuits' model MTX2-143+ is a wideband MMIC balun transformer suitable for a wide range of applications from 5500 to 13500 MHz. Operating with a 2:1 impedance ratio, it has low typical insertion loss of 0.8 dB to 11200 MHz and 1.3 dB to 13500 MHz. The wideband balun transformer boasts excellent amplitude and phase unbalance of 1.0 dB and 8 deg., respectively. The compact balun transformer measures just 3 × 3 × 0.89 mm in a QFN package and handles as much as +34 dBm (2.5 W) power. The balun transformer is designed for operating temperatures from -40 to +85°C.

Wide-Dynamic-Range MMIC Amp Boosts 30 MHz to 2.7 GHz

Mini-Circuits' PHA-202+ broadband monolithic amplifier provides a wide dynamic range from 30 MHz to 2.7 GHz without external components. The RoHS-compliant E-pHEMT amplifier combines a low noise figure with +30.4 dBm typical output power at 1-dB compression at 1 GHz and IP3 of typically +46.1 dBm at 1 GHz. The noise figure is typically 3.2 dB at 30 MHz, 3.5 dB at 1 GHz, and 5.4 dB at 2.7 GHz, while the gain ranges from typically 18.3 dB at 30 MHz, 17.0 dB at 1 GHz, and 12.7 dB at 2.7 GHz. The input and output return losses are typically 19.5 dB or better. The amplifier draws 350 mA at +11 V DC and is supplied in an 8-lead package measuring 5 × 6 mm.

18-GHz Electromechanical SP4T Switch Guaranteed for 10 Million Cycles

Mini-Circuits' MSP4TA-18D+ rugged absorptive fail-safe single-pole, four-throw (SP4T) switch provides outstanding reliability and performance from DC to 18 GHz. The RoHS-compliant switch is supplied in a break-before-make configuration well suited for automatic test systems. Guaranteed for 10 million switching cycles, it is powered by +24-V DC and achieves typical switching time of 20 ms. Insertion loss is typically 0.25 dB or less from DC to 12 GHz and 0.5 dB or less from DC to 18 GHz. Isolation is typically 100 dB from DC to 8 GHz and 80 dB or more from DC to 18 GHz. The VSWR at all ports is typically 1.30:1 or better across the full frequency range. The SP4T switch provides reliable sleep-mode switching and handles as much as 20 W cold switching power.

Hand-Formable BNC-Male Cables Connect DC to 3 GHz

Mini-Circuits' 086-BM+ series Hand-Flex™ coaxial cable assemblies are hand-formable cable assemblies that are available in a variety of lengths from 6 to 24 in. long as replacements for custom-bent 0.086-in.-diameter semi-rigid cable in communications, military, aerospace, and test system applications. Usable from DC to 3 GHz with low loss, the cable assemblies feature a minimum bend radius of 6 mm for fitting in the tightest places without bending tools. They are terminated with BNC male connectors that comply with MIL-STD-348 requirements. The cable assemblies include an insulated outer jacket. All assemblies can handle 211 W at 500 MHz, 150 W at 1 GHz, and 80 W at 3 GHz. For a 6-in.-long assembly (model 086-6BM+), insertion loss is 0.21 dB loss at 3 GHz and return loss is 28 dB at 3 GHz. For a 24-in.-long assembly (model 086-24BM+), the insertion loss is 0.8 dB loss at 3 GHz and the return loss is 29 dB at 3 GHz. All of the cable assemblies are rated for operating temperatures from -55 to +105°C.

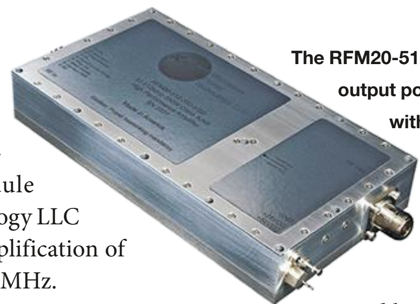
Eight-Way Splitter/Combiner Handles 20 W from 2 to 18 GHz

Mini-Circuits' ZN8PD-02183+ eight-way 0-deg. power splitter/combiner offers excellent electrical performance over a wide frequency range of 2 to 18 GHz. Suitable for electronic-counter-measures (ECM), electronic-warfare (EW), and test applications, the 50-Ω component handles 20 W input power as a splitter and provides 20-dB typical isolation between ports. It has low amplitude and phase unbalances of 0.3 dB and 5 deg., respectively. The typical fullband insertion loss is 1.4 dB above the theoretical 9-dB splitting loss. The typical VSWR is 1.38:1 at the sum port and 1.28:1 at output ports 1 through 8. The RoHS-compliant power splitter/combiner measures 4.46 × 5.75 × 0.38 in. with SMA female connectors. It is designed for operating temperatures from -55 to +100°C.

JACK BROWNE | Technical Contributor

Linear Amplifier Module Powers 20 to 512 MHz

This solidly built Class A/AB power amp incorporates numerous monitoring and protection circuits for safe operation even with 350 W output power at 1-dB compression.



The RFM20-512-350-HSD Class A/AB PA module delivers 350 W output power at 1-dB compression from 20 to 512 MHz with flat gain and high efficiency.

Low-distortion modulated signals are required for communications systems, which is the forte of the RFM20-512-350-HSD power-amplifier (PA) module from RF and Microwave Power Technology LLC *(www.rfmpt.com)*: It provides clean amplification of communications signals from 20 to 512 MHz.

The Class A/AB PA module delivers 350 W output power at 1-dB compression, with high gain and high efficiency. It also includes numerous monitoring and protection circuits to help a user achieve safe operation. The PA module is a good fit for commercial and military communications systems that require high gain to transform low-level input signals at typically –2.3 dBm into high-level output signals for transmit purposes.

The RFM20-512-350-HSD *(see figure)* achieves at least 54.7-dB gain and typically 57.7-dB gain across the full frequency range, with worst-case gain flatness of ±1.2 dB and typical gain flatness of ±0.6 dB. It operates on two power supplies, drawing maximum current of 3.5 A from a voltage supply of +24 to +28 V dc and a maximum of 15 A from a voltage supply of +46 to +50 V dc.

NOT SO HOT

The robust amplifier is built to take whatever excess heat its output stage generates, with a nickel-plated copper base for efficient thermal flow away from the active device. It is also generously equipped with control and monitoring functions for protection, such as output-stage current sensing, an alarm when the package base exceeds +60°C, and an output disable function with a response time of better than 1 µs. When combined, for example, with a user's own VSWR-monitoring circuitry, the amplifier can be quickly shut down in the event of impedance-mismatch conditions.

Also, the amplifier includes an input-stage monolithic microwave integrated circuit (MMIC) with a TTL-compatible enable/disable control pin that allows users to manually enable or disable the MMIC, achieving response times of 50 and 30 µs, respectively. The input-stage MMIC provides additional quieting for applications that may benefit from it, such as over-the-horizon (OTH) radar systems.

In addition to temperature-compensated bias circuitry, the PA makes use of a temperature-monitoring IC that provides an analog output voltage proportional to temperature. At room temperature (+25°C), the IC's nominal level is at +0.75 V dc, and it exhibits a positive voltage slope with temperature of 10 mV/°C for temperature above +25°C. This IC and its associated connection pin are meant to guide a user's choice of PA cooling approach in a system, rather than provide absolute PA temperature measurements.

To control output-power levels, the PA features an integral voltage-variable attenuator (VVA) with attenuation range of better than 30 dB. It operates with control voltages from 0 to +5 V dc, with an attenuation tuning slope of approximately 14 dB/V from +1.4 to +3.6 V dc and maximum attenuation occurring at +4.4 V dc.

The amplifier's second-harmonic performance is typically –46 dBc, with worst-case levels of –34 dBc. Third harmonics are typically –21 dBc, with worst-case levels of –10 dBc. Input return loss is typically –23 dB and maximum of –14 dB. The output-stage efficiency is at least 48% and typically 53%. Measured at 350 W peak envelope power (PEP) and 100-kHz offset, the third-order intermodulation distortion (IMD) is typically –36 dBc.

The multistage PA module runs with quiescent current (I_{DQ}) of 3.3 A at +28 V dc and 0.8 A at +50 V dc. The amplifier comes in a rugged metal housing measuring 4.50 × 8.40 × 1.35 in. (114.30 × 213.36 × 34.29 mm) and weighing 83.2 oz. (2360 g). It includes an SMA input connector and Type N output connector, as well as a DB-9 connector for monitoring and control. mw

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CHRIS DeMARTINO | Technical Editor

Millimeter-Wave Technology for 5G and Beyond

Maryam Rofougaran, Movandi's Co-CEO/COO, talks about the startup company's vision

Can you tell us a little about Movandi *(www.movandi.com)* and why the company was formed?

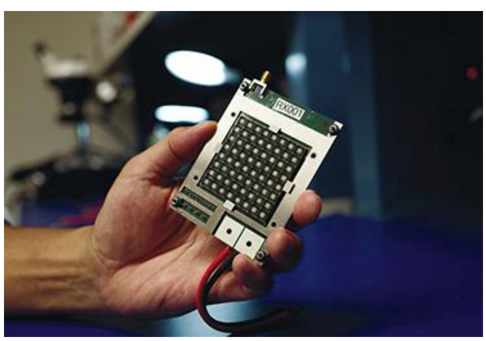
Maryam Rofougaran: Movandi was formed to reinvent multi-gigabit, millimeter-wave networks by bringing together world-class experts in radio, antenna, systems, and beamforming design to develop innovative RF front-end technology for 5G and beyond.

With the demand for wireline performance on wireless networks, the next generation of wireless applications requires orders of magnitude improvements in data rates and latency. Additionally, with 5G deployments on the horizon, the industry is searching for innovative solutions that address the challenges of millimeter-wave networks.

We feel our RF front-end technology provides the foundation for unlocking the potential of high-frequency wireless communications—opening numerous new market opportunities and applications.

A company press release mentioned BeamX technology, which is a scalable RF front-end system solution. What can you tell us about BeamX technology?

Rofougaran: Operating in the millimeter-wave band presents three unique technical challenges versus traditional connectivity and cellular systems. First, traditional approaches to RF design break down, requiring new and innovative architectures to achieve high performance in low-cost bulk CMOS foundries. Second, higher frequencies have greater transmission losses caused by distance, blockage, and non-line-of-sight conditions, depending on the environment and the application. Finally, to achieve longer range and coverage, beamforming antennas are often required, adding to system complexity.



Movandi's BeamX front-end integrates RF, antenna, beamforming, and control algorithms into a modular 5G mm-wave solution targeted for Customer Premises Equipment (CPE), small cell, and base-station applications.

Our BeamX front end integrates RF, antenna, beamforming, and control algorithms into a modular 5G millimeter-wave solution targeted for customer premises equipment (CPE), small cell, and base-station applications. Our technology is configurable to support different baseband/modem SoC solutions and is uniquely positioned to become the complete RF and antenna system, from baseband interface to antenna, for new applications in 5G, indoor gigabit access, the last mile, and satellite networks.

The innovative approach to BeamX can unlock the huge potential offered by much greater bandwidth, spatial reuse, and frequency reuse, which supports much higher-performance systems in the same regions with low cost and optimized power consumption.

With 5G still in development, what does the company hope to achieve in the future?

Rofougaran: Millimeter-wave systems such as 5G are still in their nascent stages, and unlocking their full potential will be a key focus for Movandi as we move forward. The diversity of the applications will only grow as we move from fixed, to portable, to mobile devices.

We hope that our innovations and approach to overcome the known and unknown challenges of millimeter-wave and system-level coverage in an affordable way can accelerate the deployment of 5G both in fixed wireless and mobile and grow its market much quicker than it would otherwise. We hope to repeat what we achieved with growing the connectivity market in the past by innovating solution with combo products now in the 5G market. mw

(Continued from page 68)

Considering the 1/100 factor obtained in the previous section, the power density at an offset angle of 10 degrees will be 1.359 or 0.906(W/m^2), which is less than the exposure limit.

Standing Behind the Reflector

The technical staff may have to approach a transmitting antenna in order to conduct regular maintenance. Here we determine the power density at locations behind the reflector, where there is line-of-sight to the feed antenna. It is not possible to use the method described in the previous section because the correction factor for an off-boresight angle of larger than about 30 degrees is expected to be very small; therefore, it is not provided in ref. 5. The power density computed with this method would be negligible.

Here, to estimate the power density behind the antenna, the spillover effect will be considered. The diffraction that occurs at the edge of the reflector is not accounted for.

Assuming that the largest dimension of the feed of the antenna is 10 cm, the Fraunhofer distance at 8.4 GHz is:

$$R_f = \frac{2D^2}{\lambda} = 0.56\ \text{m}$$

Therefore, a person standing almost behind the reflector at a place from where the feed is visible will be at the far field of the feed antenna. As a result, the transmitted power and the gain of the antenna will be needed to compute the power density leaked to the region behind the reflector where the feed is visible. We cannot use the tapering factor discussed in previous section, as it is does not have the desired accuracy for this purpose.

Given that the gain of the feed of the antenna is about 15 dB and the tapering is 12 dB at the edge of the main reflector, then for a person standing about 1.5 m from the feed, behind the antenna and near the edge of reflector, the power density is:

$$\frac{80\times10^{(15-12)/10}}{4\pi\times1.5^2} = 5.64\ \frac{\text{W}}{\text{m}^2}$$

This value is only about 3 dB below the recommended value by Safety Code 6. Hence, a person standing close behind the reflector may choose not to stay for a long time when the antenna is transmitting with full power.

CONCLUSION

This article provides a step-by-step method for determining the power density of a radiating parabolic reflector antenna in the far- and near-field regions.

We reviewed the safety guidelines in FCC OET Bulletin 65 and Health Canada's Safety Code 6 for human-exposure limits to EM radiation, as well as the power-density calculation in the far field. In the near-field region, the field was estimated in two major steps. After determining the power density at the Fraunhofer distance, a correction factor was applied to approximate the power density on boresight at the closer distance. A second correction factor was applied to estimate the power density at an offset angle. The correction factors were obtained from refs. 4 and 5.

Comparing the results to the guidelines of Safety Code 6 will enable companies conducting outdoor tests to determine the safe region and block access to the unsafe region to ensure the safety of their staff and other public members.

The methods reviewed are limited to reflector antennas. Dipole, Yagi, or other types of antennas must be treated differently and are out of the scope of this article.

The computed distances, angles, and safety margins are only valid for the described antenna. It is the responsibility of the reader to apply the method discussed in this article to his or her problem of interest. mw

DISCLAIMER: The results provided in this article are for reference only; the user must measure the field parameters to ensure proper safety.

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Statement of Ownership, Management, and Circulation **(Requester Publications Only)**

1. Publication Title: Microwaves & RF
2. Publication Number: 797-680
3. Filing Date: 9/6/17
4. Issue of Frequency: Monthly
5. Number of Issues Published Annually: 12
6. Annual Subscription Price: Free to Qualified
7. Complete Mailing Address of Known Office of Publication (Not Printer): Penton, Media, Inc., 9800 Metcalf Ave., Overland Park, Johnson County, KS 66212-2216 — Contact Person: Debbie Brady, Telephone: 216-931-9882
8. Complete Mailing Address of Headquarters or General Business Office of Publisher (Not Printer): Penton Media, Inc. ,1166 Avenue of Americas, New York, NY 10036
9. Full Names and Complete Mailing Addresses of Publisher, Editor, and Managing Editor - Publisher: Paul Miller, Penton Media, Inc., 1166 Avenue of the Americas, New York, NY 10036; Editor: Nancy K Friedrich, Penton Media, Inc., 1166 Avenue of the Americas, New York, NY 10036; Managing Editor: ,
10. Owner - Full name and complete mailing address: Penton Media, Inc., 1166 Avenue of the Americas, New York, NY 10036; Penton Operating Holdings, Inc. (owns 100% of the stock of Penton Media, Inc.), 1166 Avenue of the Americas, New York, NY 10036
11. Known Bondholders, Mortgagees, and Other Security Holders Owning or Holding 1 Percent or More of Total Amount of Bonds, Mortgages or Other Securities: None
12. Tax Status (For completion by nonprofit organizations authorized to mail at nonprofit rates) (Check one) The purpose, function, and nonprofit status of this organization and the exempt status for federal income tax purposes: N/A
13. Publication Title: Microwaves & RF

14. Issue Date for Circulation Data: August 2017 / 15. Extent and Nature of Circulation	Average No. Copies Each Issue During Preceding 12 Months	No. Copies of Single Issue Published Nearest to Filing Date
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b. Total Requested and Paid Print Copies (Line 15c)+ Requested/Paid Electronic Copies (Line 16a)	33,185	33,217
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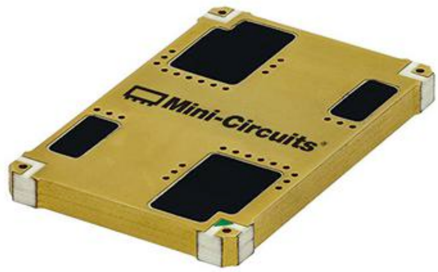

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(ISSN 0745-2993)
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DC-12.4	10	N9510	9510
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3.95- 5.85	750	187-925	2000	187-920
4.90- 7.05	625	159-925	1500	159-920
5.85- 8.20	500	137-925	1000	137-920
7.05-10.0	425	112-925	600	112-920
7.00-11.0	325	102-925	500	102-920
8.20-12.4	225	90-925	500	90-920
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