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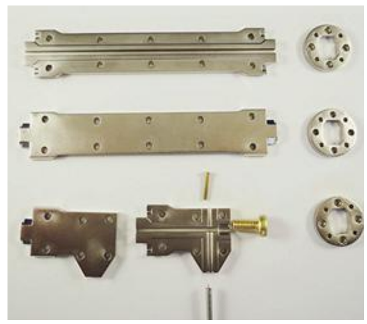

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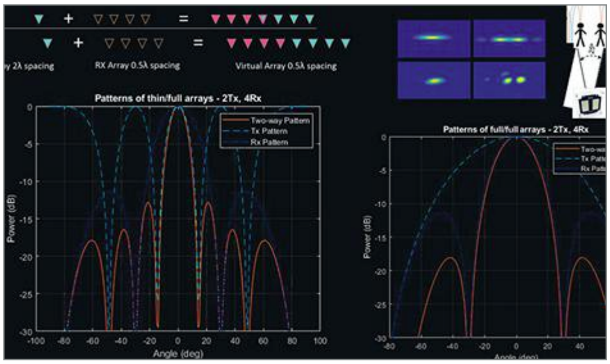

Increasing Angular Resolution Using MIMO Radar

In this Algorithms to Antenna blog post, MathWorks' Rick Gentile explains how forming virtual arrays with multiple-input, multiple-output waveforms makes it possible to generate more focused beam patterns.

https://www.mwrf.com/systems/algorithms-antenna-increasing-angular-resolution-using-mimo-radar

A Brief Insider Look at a Long-Standing Company

Dave George, Chief Technologist and President of Pryme Radio, talks about his company and explains how the IEEE has positively impacted him.

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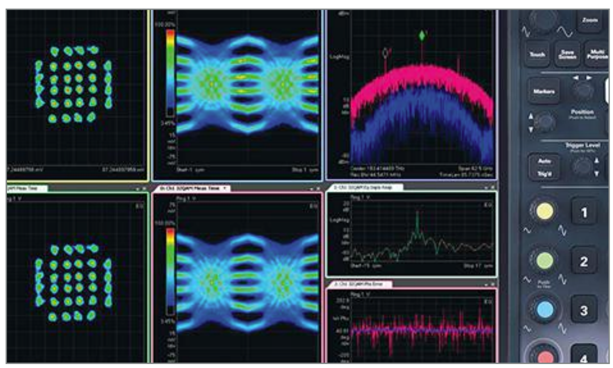

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Editorial

CHRIS DeMARTINO | Technical Editor
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Has GaN Pushed LDMOS into Irrelevance?

Back in July 2015, I wrote a column titled "GaN Taking Control" that discussed the increasing utilization of gallium-nitride (GaN) technology. Today, no one can question the impact that GaN technology has had on the RF/microwave industry. But with GaN receiving so much attention, where does this leave laterally diffused metal-oxide semiconductor—LDMOS—technology? Has LDMOS been completely pushed aside?

LDMOS technology has dominated the wireless infrastructure arena, but is that changing? The answer to that question is yes—at least, according to a recent article titled, "Realizing 5G Sub-6-GHz Massive MIMO Using GaN." The authors, Qorvo's *(www.qorvo.com)* David Schnaufer and Bror Peterson, point out that "high output power, linearity, and power-consumption requirements are pushing base-station and network original equipment manufacturers (OEMs) to switch from using LDMOS technology for power amplifiers (PAs) to gallium nitride (GaN)."

The article also states that "GaN performs well at 3.5-GHz frequencies and above, while LDMOS is challenged at these high frequencies." The additional benefits of GaN are beyond the scope of this column, but I think you get the idea (check out the article for more).

So, does the emphasis on GaN mean that LDMOS is no longer relevant? That doesn't appear to be the case, as LDMOS still figures to find homes in some applications. Of course, choosing the appropriate technology depends on the specific application at hand—and there are scenarios in which LDMOS may still be the way to go.

Take radar applications, for example. Last year, Integra Technologies *(www.integratech.com)* published a tech brief titled, "Zero-in on the Best RF Transistor Technology for Your Radar's High Power Amplifier Designs." The brief explains the advantages and disadvantages of different transistor technologies that one must consider when selecting a technology for high-power applications. The point is that the requirements of an application ultimately determine the appropriate technology to use—and LDMOS is one of those technologies.

If LDMOS is still going strong, it's a good idea to stay up-to-date about any new products that have hit the market. For instance, there's the MRFX Series high-power products from NXP *(www.nxp.com)*. The MRFX Series is based on NXP's 65-V LDMOS technology, which the company says offers a number of advantages.

Is LDMOS dead? The answer appears to be a resounding "no." Though LDMOS may not have quite the same standing it once had, the current prognosis is that it's alive and well. mw

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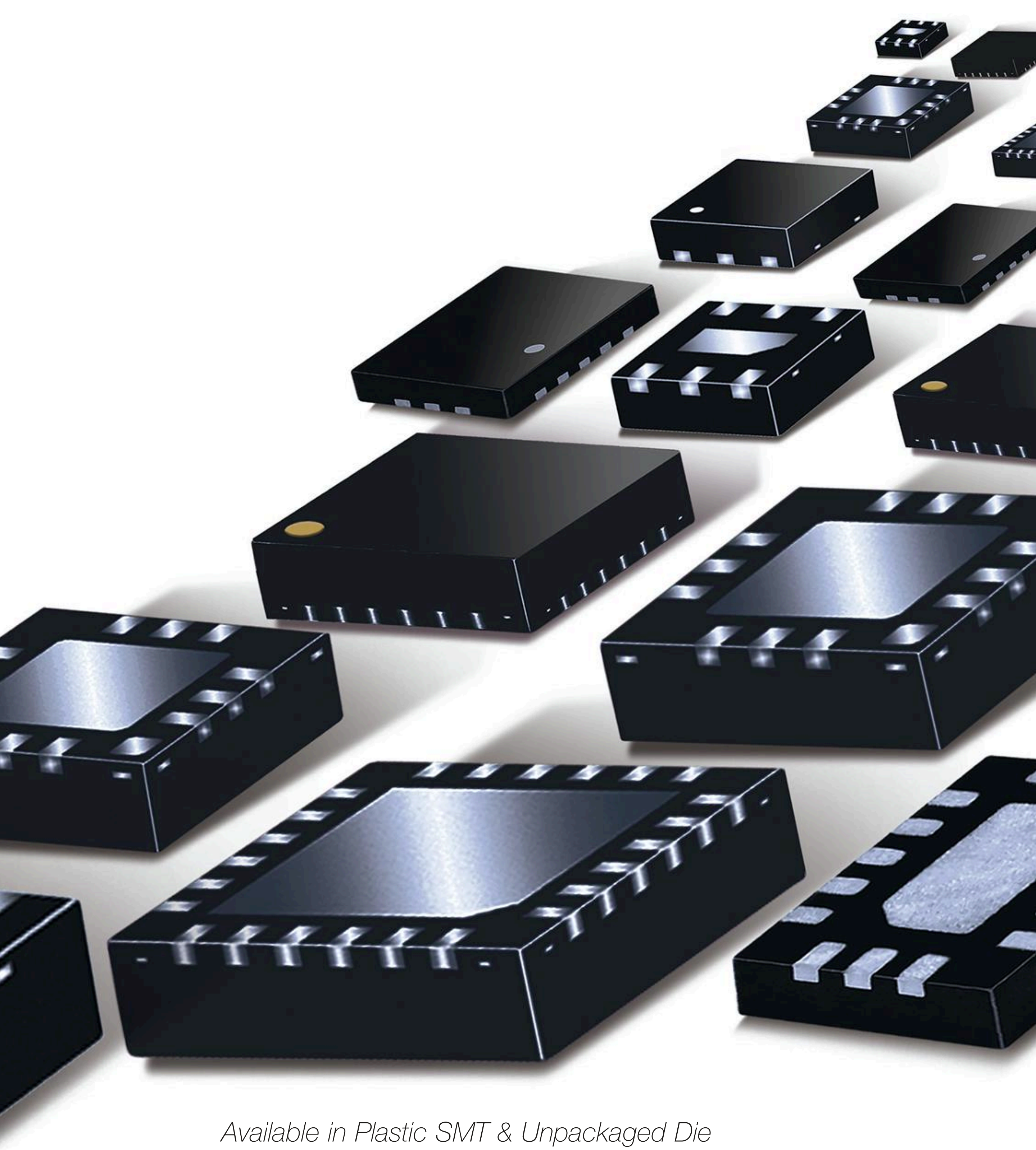

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OCTAVE BAND LOW NOISE AMPLIFIERS

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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News

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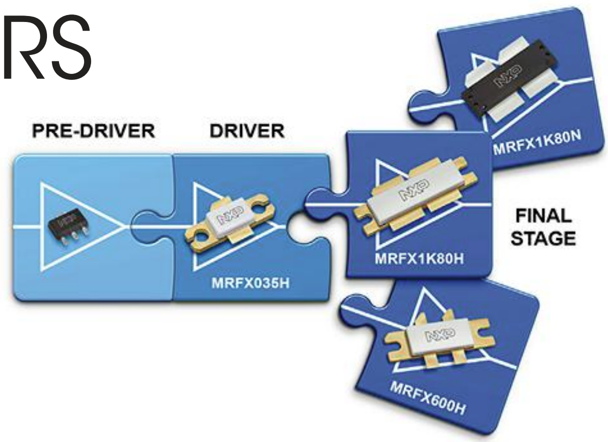
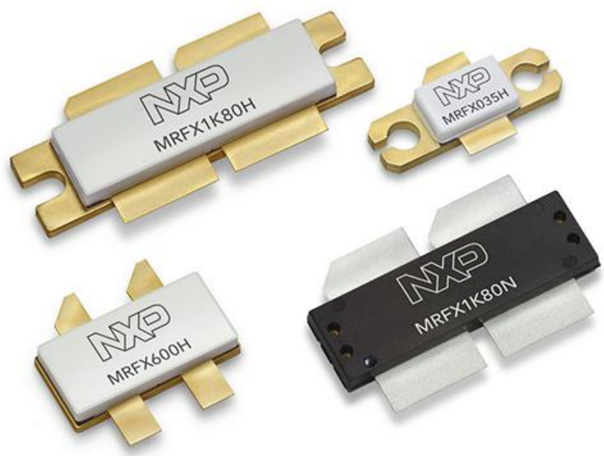




Shown are the MRFX1K80H, MRFX1K80N, MRFX600H, and MRFX035H devices.

For NXP Semiconductors *(www.nxp.com)*, high-power RF is undoubtedly a trademark—the company offers a wide range of RF power products for various applications. NXP has now reached a new milestone with the introduction of the MRFX Series high-power products based on the company's 65-V LDMOS technology. The first product, the MRFX1K80H, was released in 2017. NXP recently expanded the MRFX Series by introducing three new devices: the MRFX1K80N, MRFX600H, and MRFX035H *(see figure)*.

65-V LDMOS technology represents a significant change for high-power applications. "On the consumer and industrial side, 50-V LDMOS technology has been dominant for the last decade," says Franck Nicholls, product line manager at NXP. "In 2017, we introduced a higher-voltage solution, which brings ease of use to our customers."

So, what exactly are the benefits of NXP's 65-V LDMOS technology? The company points out five specific advantages. For one, higher voltage enables higher power density, which helps reduce the number of transistors to combine when building power amplifiers (PAs). Another advantage of the 65-V devices is that the output power can be increased while still retaining a reasonable output impedance. As a result, 50-Ω matching is easier to achieve.

A third benefit is what NXP calls "design reuse," which means that MRFX Series devices can fit onto existing printed circuit boards (PCBs) designed for 50-V devices—with little to no retuning required. Reduced current levels and a wider safety margin due to a higher breakdown voltage are the two remaining benefits.

Looking at the performance of the three new products, the MRFX1K80N is an 1,800-W transistor that covers a frequency range of 1.8 to 400 MHz. It's the plastic-package version of the previously released MRFX1K80H. The MRFX600H is a 600-W transistor that also operates from 1.8 to 400 MHz. Finally, the MRFX035H is a 35-W transistor that covers a frequency range of 1.8 to 512 MHz.

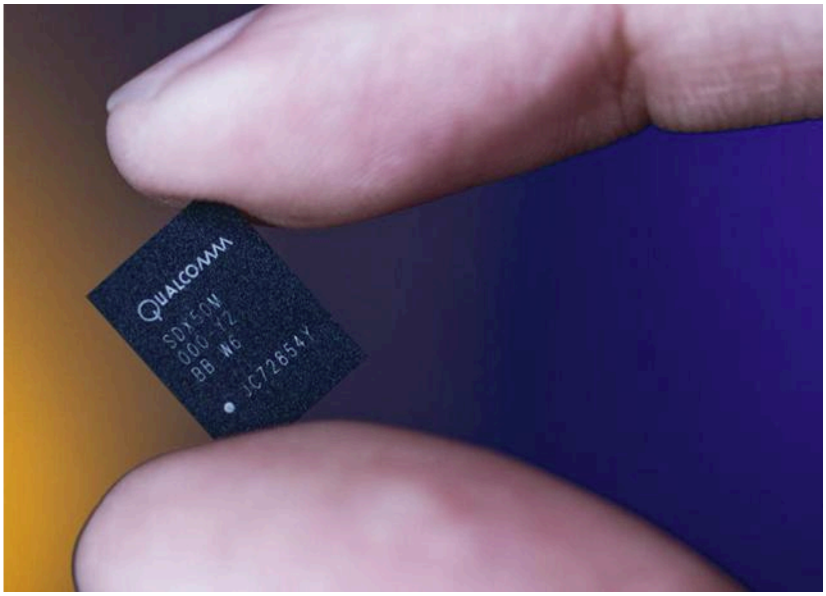
With the MRFX Series, NXP is targeting various markets. Among them are industrial-scientific-medical (ISM) applications, such as laser generation, plasma generation, particle accelerators, and more. Broadcast applications represent another market that NXP is aiming for. Aerospace and defense applications stand to benefit from the MRFX Series as well.

NXP also revealed that it has developed many reference circuits for the MRFX1K80H transistor over the last year, each covering various frequency bands. Lastly, the company also announced a partnership with ABB *(www.abb.com)*, which is developing a power supply unit (PSU) that can power the MRFX Series devices. ■

FOR MORE information, visit www.nxp.com/65V.

QUALCOMM TRYING TO Connect the Cellular Internet of Things

QUALCOMM, THE LARGEST supplier of modem chips used in mobile devices, introduced the X50 modem in 2016 to connect smartphones to 5G networks, which are expected to be 10 to 100 times faster than current LTE technology. But as it attempts to move everything from wearables to factory equipment onto cellular networks, Qualcomm has had to start focusing less on speed and more on power.



The company's latest 9205 LTE modem is designed for Internet of Things devices that send small amounts of information infrequently over long distances without depleting battery power too quickly. The modem supports LTE-M and NB-IoT networks, which are capable of tapping into the same LTE technology used by 4G. It also allows electronic devices to connect to second generation, or 2G, cellular networks.

The company said that the modem is around 50 percent smaller—approximately the size of a dime—and 40% lower cost than its current Internet of Things chip, the MDM9206. The idle power consumption has also been lowered by 70 percent. Qualcomm is targeting tiny battery-powered devices that have to remain functional for years without recharging, according to Vieri Vanghi, Qualcomm Europe's VP of product management.

Since these cellular networks are thousands of times slower than current 4G networks, companies that want to connect Internet of Things devices can do so more economically. More than 50 networks globally had added support for LTE-M and NB-IoT standards, according to Qualcomm. While LTE-M network use is expanding in the United States, the use of NB-IoT networks has grown in other regions, including Europe and Japan.

The company is trying to capitalize at the estimated 250 million devices that could be installed in factories and city infrastructure using such networks by 2023, according to market researcher ON World. The chip is capable of adapting power consumption based on the remaining charge, allowing batteries to last longer without recharging. Qualcomm said that the modem also supports global-positioning capabilities, including GPS and GNSS.

Qualcomm's latest modem increases the competition in the market for chips capable of connecting to LTE-M and NB-IoT networks. In 2017, Altair Semiconductor introduced a miniature module that can support both standards to handle thousands to millions of devices on the same network. Sequans Communications has started shipping chips that give customers access to LTE-M networks, NB-IoT networks or both simultaneously.

Nordic Semiconductor has also jumped into the competition. "Nordic Semiconductor expanded the application-range of Bluetooth by abstracting away from the designer all unnecessary technical complexity," Peder Rand, the company's cellular product manager, said in a statement. He added that the company's new nRF9160 "promises to do the same for cellular IoT by taking a completely different approach to competing solutions."

Qualcomm's move to integrate one of the most critical radio frequency components—more commonly known as the RFFE—into the modem's transceiver could give it a slight advantage over rivals. Nordic Semiconductor and Sequans Communications have had to outsource the development of that component to other companies, including Skyworks Solutions and Qorvo. They end up combining it with the modem in the same module.

Manish Watwani, Telit's executive vice president of global product management, said that the cellular modem will "allow us to reduce power consumption and module footprint giving our customers the ability to design and deploy smaller, battery-powered devices that work worldwide on virtually any cellular Internet of Things network." Qualcomm said that the first products based on the modem will be introduced this year. ■

NAVY EVALUATES Passive RFID/GPS Tracking Solution

THE U.S. NAVY, like other branches of the military, must keep track of critical assets around the world. To that end, it is hoping that a combination of wireless technologies will help to manage inventory. By working through a contract from the National Center for Manufacturing Sciences (NCMS; www.ncms.org), the Navy will receive mobile passive radio-frequency-identification (pRFID) systems for asset tracking at four geographically diverse sites. The MultiTrak mobile pRFID readers from Venture Research (www.ventureresearch.com) integrate GPS capability with a customizable API, enabling the Navy to evaluate the asset-tracking technology on a large scale.

The pRFID/GPS units are built for outdoor use, such as at naval piers, where it is hoped that they will improve asset-tracking efficiency. “We are pleased to be working with NCMS and the U.S. Navy to accurately track military and commercial assets through our unique solution that will improve inventory traceability and reduce wasted labor hours due to lost items,” said John Baker, president of Venture Research. “The American taxpayer will also see cost savings resulting from this implementation due to improved accuracy and reduction of redundant inventory.”

The Venture Research API and the integrated mobile pRFID asset tracking solution will be employed under the strictest military requirements, although the combination also holds promise for consumer and industrial asset tracking applications. Venture Research provides advanced solutions using GPS, pRFID, and Internet of Things (IoT) technologies to aerospace and defense customers, with products and services that have been used in more than 1,000 installations in 28 countries around the world. ■

Rugged MultiTrak mobile passive RFID readers with integrated GPS capabilities and customizable API are being evaluated by the U. S. Navy for worldwide asset tracking. *(Courtesy of Venture Research)*

FIRST GPS III SATELLITE Begins Next Generation

THE FIRST GPS III SATELLITE has been successfully launched to begin the next generation of the precision positioning system. The new satellite, developed by Lockheed Martin *(www.lockheedmartin.com)*, is part of the U.S. Air Force's plan to bring new technology and capabilities to the existing GPS constellation, in orbit at about 12,550 miles above the surface of the Earth. The satellite, known as GPS III Space Vehicle 01 (GPS III SV01), is receiving and responding to signals from Lockheed Martin's Launch and Checkout Center in Denver after a launch from Cape Canaveral, Fla.

The GPS III satellite, nicknamed "Vespucci" by the U.S. Air Force after the Italian explorer Amerigo Vespucci, is claimed to have three times better accuracy than earlier GPS satellites, with longer operating lifetime. The satellite also promises improved connectivity for civilian users, with a new L1C civil signal that makes it the first GPS satellite to transmit signals compatible with other international global navigation satellite systems, such as the Galileo system used throughout Europe. Once it has been tested and found fully operational, it will take its place among the 31-satellite GPS constellation.

"In the coming days, GPS III SV01 will use its liquid apogee engines to climb into its operational orbit about 12,550 miles above the earth," said Johnathon Caldwell, Lockheed Martin's vice president for Navigation Systems. "We will then send it commands to deploy its solar arrays and antennas, and begin on-orbit checkout and tests, including extensive signals testing with our advanced navigation payload provided by Harris Corporation.

"This is the Air Force's first GPS III, so we are excited to begin on-orbit test and demonstrate its capabilities," Caldwell added. "By this time next year, we expect to also have a second GPS III on orbit and users should be receiving signals from this first satellite." ■

The U.S. Air Force's first GPS satellite, the GPS III SV01, has joined the 31-satellite GPS constellation. *(Courtesy of Lockheed Martin)*

ADAS ADDS SAFETY, Raises Auto-Repair Costs

Though advanced driver-assistance system (ADAS) technology is certain to reduce automotive accidents and make for safer roads, there may be a price to pay. According to research released recently by the American Automobile Association (AAA), vehicles equipped with ADAS-based safety features can cost considerably more to repair following a collision than their non-ADAS counterparts. The main reason? Expensive sensors and their calibration requirements for such functions as automatic emergency braking, adaptive cruise control, and lane departure warning systems. The AAA discovered that the repair bill for an ADAS-equipped car involved in a minor front- or rear-end collision could end up as high as $5,300, while the same repairs for a car without the ADAS technology might cost closer to $2,200.

Not every automotive mechanic station is equipped to handle repairs on ADAS-based systems—it's typically the realm of new-car dealers. However, some automobile dealers have not kept pace with the repair and maintenance requirements for the various radar and ultrasonic systems used for increased safety in advanced automotive vehicles.

The AAA's research warns that, although ADAS technology will ultimately mean safer roads and highways, and likely lower insurance costs for ADAS-equipped vehicles, the repair costs for such vehicles will be greater than the overall monetary savings gained from preventing accidents. Much of the ADAS equipment simply does not work effectively at slower speeds and will not prevent low-speed collisions. That could result in higher automotive insurance rates for drivers of both ADAS-equipped and non-ADAS-equipped vehicles, possibly for as long as the next decade of ADAS technology.

See "Auto Safety Features Raise Repair Costs," *IEEE Spectrum*, North America, December 2018, pp. 12-13.

BROKEN-HEART-SHAPED ANTENNA Has High UWB Gain and Efficiency

ULTRAWIDEBAND (UWB) COMMUNICATIONS, whether as integrated services within 5G wireless communications systems or as dedicated systems, holds the promise of rapid connections for voice and data as well as blazingly fast transfers of large amounts of data. Of course, an essential component in any UWB system is the antenna, which must provide the gain and efficiency to recover a wide range of UWB signals from the ambient noise.

A team of professors at the Patuakhali Science and Technology University (Patuakhali, Bangladesh) among other institutions developed a broken-heart-shaped microstrip patch antenna for UWB applications with electrical dimensions of $0.29\lambda \times 0.17\lambda$ and maximum gain of 5.3 dBi across the broad frequency range of 2.90 to 10.70 GHz. It was designed and simulated with the aid of various software approaches, including the finite-element-method (FEM) high-frequency structure simulator (HFSS) from ANSYS (*www.ansys.com*) and the time-domain-based Microwave Studio simulator from Computer Simulation Technology (CST).

The frequency range of the broken-heart-shaped microstrip patch antenna is just a shade beyond the range recognized as UWB by the IEEE, which is 3.1 to 10.6 GHz. Demand has been growing for UWB electronic systems in recent years because of their relative simplicity (and low cost) and their high-data-rate capabilities. One of the challenges facing UWB system designers has been the size of UWB antennas—microstrip patch antennas for UWB applications are typically large.

The UWB antenna consists of a broken-heart-shaped patch with slotted ground plane. The microstrip patch is printed onto one side of the substrate. The substrate has a dielectric constant of 4.6 in the z-direction, with a loss tangent of 0.02.

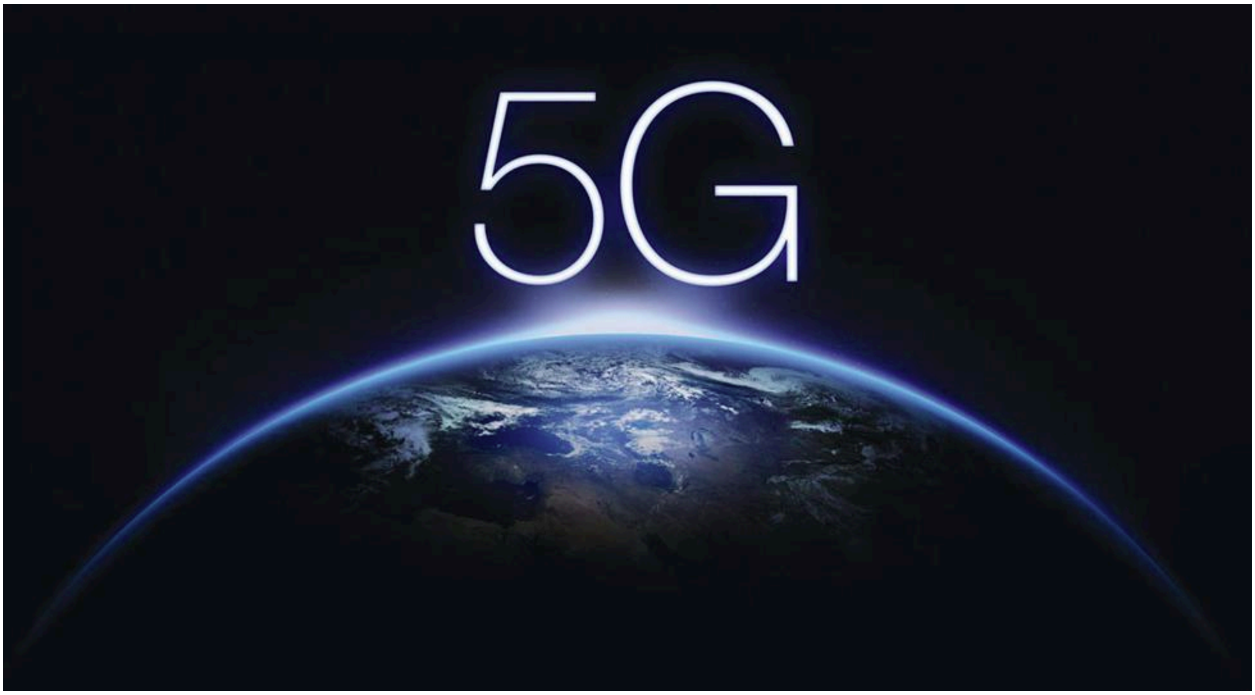
To determine an optimum antenna configuration, four designs with the same outer dimensions were simulated and compared: circle shape, dumb-bell shape, heart shape, and broken-heart shape. The circle-shaped and dumb-bell-shaped antennas fail to cover the full UWB frequency range. The heart-shaped patch antenna covers the range from 2.90 to 10.50 GHz with two resonances at 3.40 and 6.90 GHz, but the broken-heart-shaped patch covers from 3.0 to 10.80 GHz with three resonances at 3.5, 7.0, and 9.5 GHz for the most complete frequency coverage of the different antenna configurations.

The broken-heart-shaped microstrip patch antenna was fabricated on commercial printed-circuit-board (PCB material and characterized with a commercial microwave vector network analyzer (VNA). Measurements closely approached the predictions/simulations by the different software simulation programs.

The antenna has high input impedance below 2.9 GHz, meaning that current flow is interrupted at those frequencies. The real part of the input impedance is close to about 50 Ω throughout the bandwidth from 2.90 to 10.70 GHz. Thus, the design is an excellent candidate for a variety of different UWB applications while maintaining relatively small dimensions for its wide bandwidth with high gain and 86.6% UWB efficiency.

See "The Broken-Heart Printed Antenna for Ultrawideband Applications," *IEEE Antennas & Propagation Magazine*, Vol. 60, No. 6, December 2018, pp. 45-61.

CHRIS DeMARTINO | Technical Editor



A 5G Forecast for 2019

Will 2019 be the year we see extensive 5G deployments? An industry specialist gives his take on what we can expect to see this year.

With the new year now upon us, one topic at the center of attention in the world of wireless technology is obviously 5G. What can we expect to see in 2019 with respect to 5G? Will a substantial amount of 5G smartphones flood the landscape? What frequency bands will be employed?

"In 2019, it's 'showtime' for 5G after several intense years of 3GPP standards definition and predictions about 5G user experience," says Paul Cooper, director of carrier liaison and standards, mobile products at Qorvo *(www.qorvo.com)*. "Let's upfront break the myth that 5G means millimeter-wave (mmWave) frequencies only. For sure, U.S. carriers have launched the first 5G fixed-wireless-access (FWA) systems to wirelessly bring broadband to homes for the cable-cutting folks. This latter-day 'Local Multipoint Distribution Service' (LMDS) has a valid and plausible business case.

"In contrast, mmWave smartphones are certainly coming to the market, but commercially viable solutions are on a longer development cycle than the sub-6-GHz smartphones that will ramp in 2019. The U.S.'s first focus on mmWave technology—specifically in the 28- and 39-GHz bands—is primarily because the FCC has not yet released sub-6-GHz spectrum for 5G at 3.5 GHz that's harmonized with the rest of the world."

SUB-6-GHz WILL DOMINATE

According to Cooper, 5G in 2019 will involve a heavy dosage of sub-6-GHz frequencies. "The big play in 2019, in both the U.S. and the rest of the world, is in the sub-6-GHz spectrum," he says. "In China, 2019 efforts will be centered around the 2.6-, 3.5-, and 4.9-GHz bands. China plans to launch a large-scale trial that will involve multiple cities throughout the country. While a trial may not sound substantial, it shouldn't be overlooked because large-scale trials in China are huge when compared to other regions! China will put thousands of sub-6-GHz 5G smartphones in subscribers' hands in 2019 to analyze performance and will then commercialize their standalone (SA) network in 2020."

What about the U.S. and other countries? Cooper says, "Plans for non-standalone deployment in the 2.6-GHz spectrum in the U.S. are well-advanced, with the first commercial 5G smartphones expected in the first half of 2019. The U.K., Ireland, Spain, Italy, Finland, and South Korea have also issued licenses within the 3.5-GHz band, with first deployments expected in 2019. Japan will allocate 3.5- and 4.6-GHz licenses in March 2019. This is the hotbed of 5G, where early sub-6-GHz products will have the true look and feel of existing 4G smartphones."

5G deployments at sub-6-GHz frequencies are sure to excite many. But what about the mmWave frequencies that we've heard so much about? According to Cooper, "Spectrum in the bands above 24 GHz, grouped under the mmWave name, have not traditionally been used for smartphones. These wide swaths of unused bandwidth at mmWave frequencies are seen by carriers as a lucrative path to urban network densification—as witnessed by the rapidly expanding mmWave spectrum auctions across the globe. Original equipment manufacturers (OEMs) and vendors are currently in the research and development phase for mmWave mobile devices—trying to find a way to squeeze everything effectively into a smartphone format without impacting battery performance and heat dissipation, while making it aesthetically pleasing compared to today's smartphones.

"In 2019, we will see mmWave smartphones enter the market in the U.S. and South Korea. While these devices will give us a glimpse at that technology in action, they will likely lack some of the performance and form-factor advantages of flagship 4G smartphones. The Tokyo Olympics and maturing mmWave base-station FWA infrastructure in the U.S. and South Korea will likely drive mmWave smartphone commercialization in 2020, a year after sub-6-GHz." mw

KENNETH PUGLIA | E × H Consulting Services

A Brief Tutorial on Microstrip Antennas (Part 3)

The third installment of this series focuses in on microstrip antenna arrays, with analysis of both four-element and two-×-two arrays.

Continuing the series on microstrip antennas, this article examines antenna arrays. Parts 1 and 2 focused on the single-element, rectangular microstrip antenna.

MICROSTRIP ANTENNA ARRAY

Although a significant number of applications exist for the single-element microstrip antenna, in many cases, the performance enhancements and features available with multiple microstrip-element arrays add to an expanding list of new opportunities. A microstrip antenna array is formed by the arrangement, or grouping, of multiple, single-element microstrip antennas. The respective geometric positioning of the individual elements, as well as the element amplitude and phase excitation, determines the characteristics of the antenna array.

Microstrip antenna arrays are typically designed to enhance antenna performance beyond that available from a single element. For example, arrays of single-element microstrip antennas offer increased gain and narrower beamwidth at the cost of larger aperture area. In addition, array antennas offer the ability to steer the principal radiation intensity beam via differential phase excitation and reduced sidelobe levels by variable power excitation to the individual elements of the array—properties that compel emphasis in many applications.

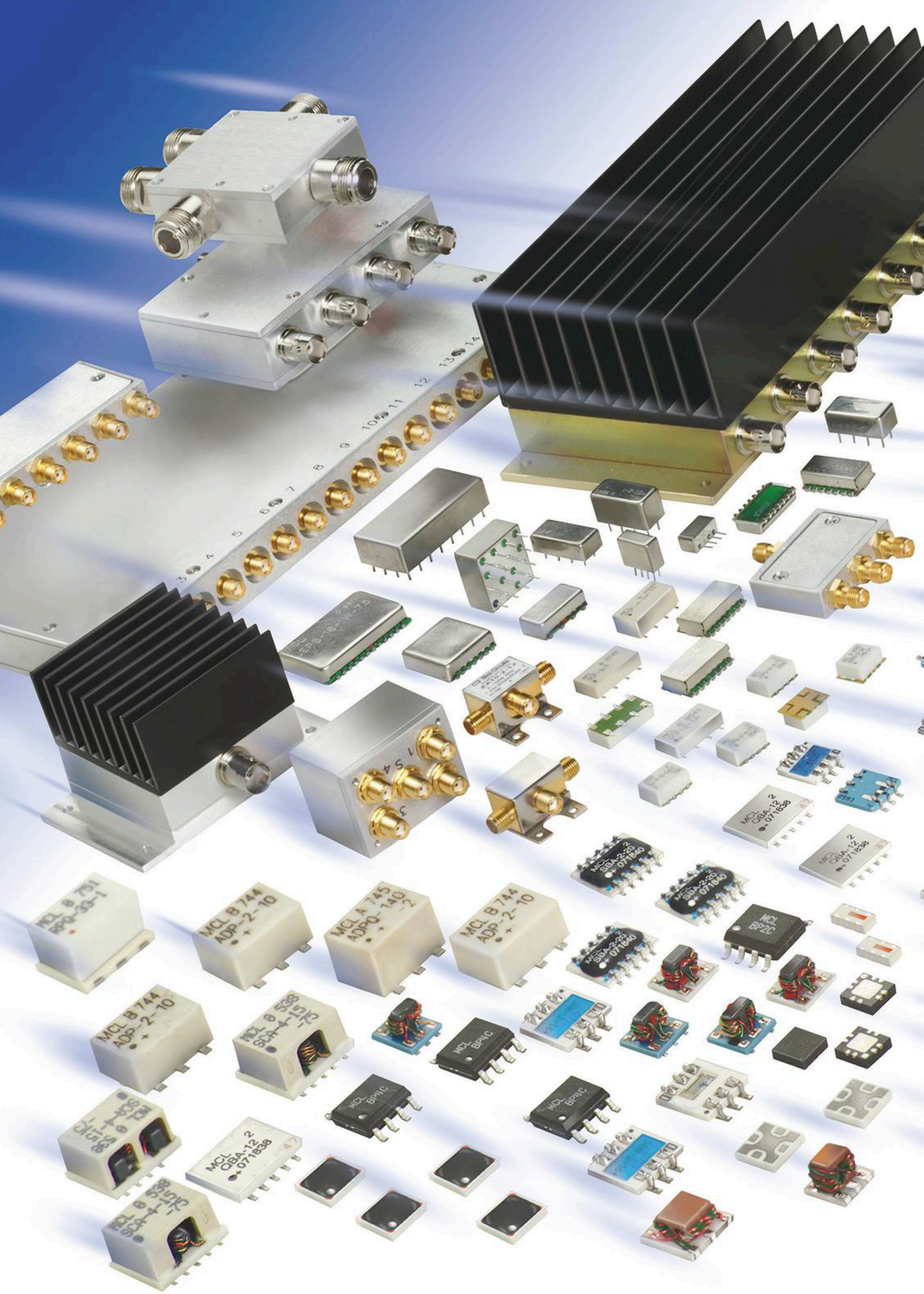
The individual dimensional elements of a microstrip antenna array may vary and may be spatially configured in a linear, planar, or volumetric arrangement. The radiation pattern of an array is determined by the dimensions, spatial distribution, and electrical excitation, i.e., amplitude and phase, of the individual elements. Given the number of variables, a general approach to the synthesis and design of antenna arrays is clearly required. To that end, antenna specialists have been successful in formulating a general methodology using the definitions in *Table 1*.

The product of the array factor and the element factor is referred to as the pattern multiplication theorem. An example will illustrate the convenience and efficiency of the theorem.

Consider the linear distribution of equally spaced, isotropic radiating ele-

TABLE 1: ANTENNA ARRAY DEFINITIONS

ANTENNA ARRAY TERM	ANTENNA ARRAY DEFINITION
Array Factor (AF)	The array factor defines the radiation pattern of spatially distributed isotropic radiating elements in accordance with the amplitude and phase of individual element excitation. The array factor is a function of the number, dimensional spacing, and the amplitude and phase of the excitation signal of the elements.
Element Factor (EF)	The element factor is the radiation pattern of the individual elements of an array.



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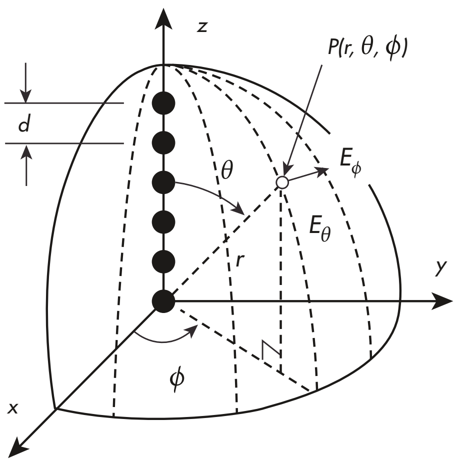
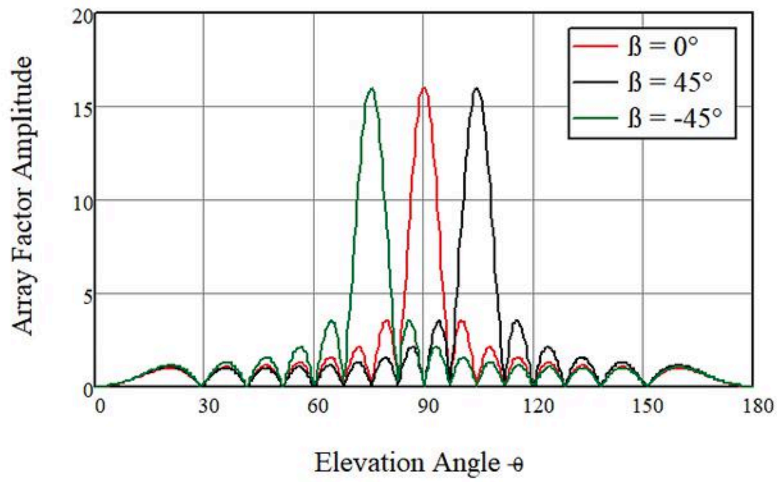


1. The linear array of isotropic radiating elements is depicted.



2. This figure illustrates array factor for a linear array of isotropic elements.

ments along the z-axis *(Fig. 1)*. The E-field radiation pattern of the i^{th} element may be written as:[1]

$$1.\quad E_i(\theta,\phi)=F(\theta,\phi)\cdot I_i\, exp\left[j\left(k_0 z_i \cos\theta+\beta_i\right)\right]$$

The following definitions are applicable to this equation:

F(θ,ϕ) represents the radiation pattern of the element, and $k_0 = 2\pi/\lambda_0$, I_i, and β_i are the amplitude and phase excitation.

For *n* identical elements, the radiation pattern is written as:

$$2.\quad E(\theta,\phi)=F(\theta,\phi)\cdot\sum_{i=0}^{n-1} I_i\, exp\left[j\left(k_0 z_i \cos\theta+\beta_i\right)\right]$$

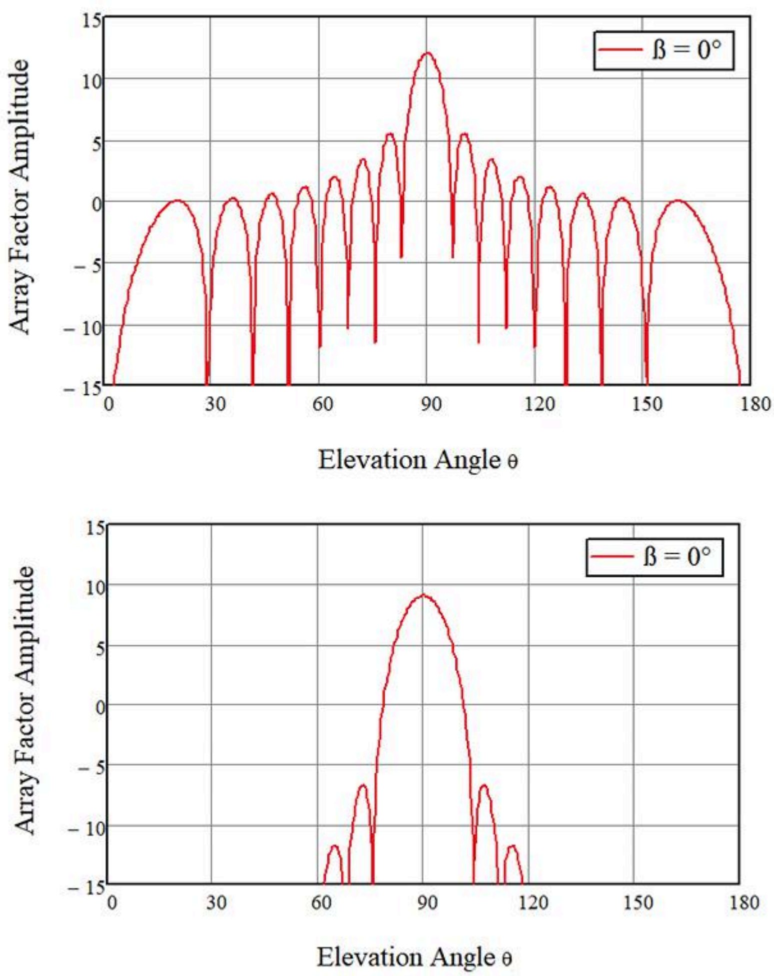
The radiation pattern is the product of the two terms:

F(θ,ϕ) is the element factor (EF), and

$$3.\quad \sum_{i=0}^{n-1} I_i\, exp\left[j\left(k_0 z_i \cos\theta+\beta_i\right)\right]$$

is the array factor (AF).

The perceptive reviewer may recognize the similarity between the array factor and the discrete Fourier transform of the complex linear distribution of amplitude and phase of the radiating



3. This array factor versus element amplitude variation (note logarithmic amplitude scale) comparison reveals constant amplitude excitation (top) and cosine amplitude excitation (bottom).

elements. For the specified equally spaced condition and progressive phase of each element, one may write:

$$4.\quad z_i = 0, d, 2d \ldots (n-1)d$$

and

$$5.\quad \beta_i = 0, \beta_0, 2\beta_0 \ldots (n-1)\beta_0$$

If the indicated substitutions are implemented, the array factor may be written:

$$6.\quad AF(\theta)=\sum_{i=0}^{n-1} I_i\, exp\left[j\left(\frac{2\pi}{\lambda_0} i\cdot d\cos\theta + i\cdot\beta_0\right)\right]$$

Solution of the equation using constant amplitude distribution ($I_i = 1.0$), parametric phase progression ($\beta_0 = 0$, $\beta_0 = -\pi/4$, $\beta_0 = \pi/4$), number of elements ($n = 16$), and element spacing ($d = \lambda_0/2$) is graphically illustrated within *Figure 2*.

The maximum amplitude of the array factor occurs at $\theta = 90$ degrees for 0-degree phase excitation; at 105 degrees for 45-degree phase progression; and at 75 degrees for −45-degree phase progression. Clearly, the phase progression excitation enables the significant property of main beamsteering of antenna arrays. An additional observation is that the array of isotropic radiating elements has provided focus, i.e. gain, over the single element. In this instance, the numeric gain is equal to the number of array elements, *n*.

Another observation from *Figure 2* is the sin(x)/x amplitude function. This behavior might have been anticipated due to the constant amplitude-element excitation and the discrete Fourier transform relationship.

Constant, or uniform, amplitude distribution has been considered to this point of the exercise. However, in addition to phase progression excitation, amplitude variation of the array elements also offers some interesting properties. Consider the graphic of *Figure 3*, where the array factor for constant amplitude element excitation is indicated in the top plot, while raised cosine element amplitude excitation has been implemented in the bottom plot.

The raised cosine amplitude excitation of the array elements significantly reduced the array sidelobes. Unfortunately, the array amplitude also was reduced while the beamwidth increased. These are the significant tradeoffs when considering application of antenna-array implementation.

Microstrip antenna arrays will be further explored within the electromagnetic (EM) simulations in the upcoming sections. In many instances, the element spacing for most applications is approximately half-wavelength ($\lambda_0/2$) in air.

The raised cosine amplitude excitation of the array elements significantly reduced the array sidelobes. Unfortunately, the array amplitude also was reduced while the beamwidth increased. These are the significant tradeoffs when considering application of antenna-array implementation.

Although somewhat higher gain may be attained using element spacing beyond half-wavelength, increased sidelobe levels, particularly near ±90 degrees off-boresight (grating lobes), are a direct result. Therefore, in the simulations that will follow, element spacing in the plane of the antenna will be maintained at approximately half-wavelength.

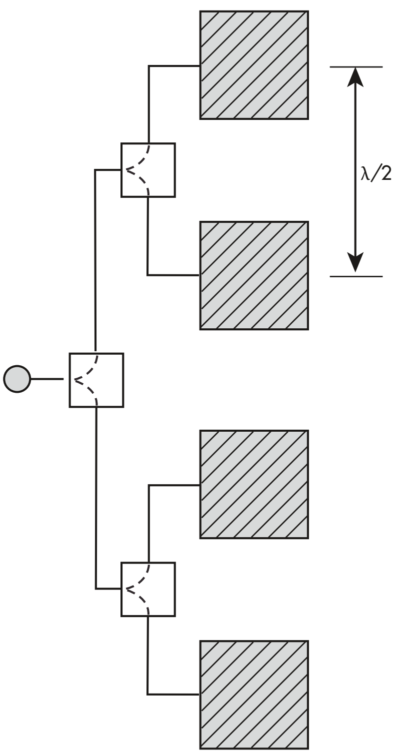
LINEAR MICROSTRIP ARRAY ANTENNAS

Figure 4 illustrates the configuration of a parallel-feed (alternately referred to as corporate feed) linear array composed of four in-line elements. Each element of the linear array is fed from the output of a power divider, which facilitates excitation of either equal or unequal power to each element. The power distribution to the elements of an array, as previously indicated, is commonly referred to as amplitude taper, and is utilized to reduce sidelobe levels. Amplitude taper is accompanied by increased beamwidth and reduced gain with respect to uniform, or equal, power distribution to each element.

The excitation to each element of the array may also be varied in phase. Progressive differential phase excitation is employed to steer the main beam off-boresight and is a unique and attractive feature for large phased-array radar applications as an alternative to inertial (mechanical) platforms.

A four-element linear array has been constructed using the single-element, 5.80-GHz microstrip antenna previously described and analyzed. The data from EM analysis of the four-element array is summarized in *Table 2*.

Table 3 documents the performance of a four-element linear array that has an amplitude taper applied to it. As mentioned previously, the amplitude taper is utilized to reduce sidelobe levels. The amplitude taper is implemented by changes to the impedance of the power divider's lines in a manner that alters the impedance at the principal junction of the power divider. A simple equation governs the power-divider design under the specified conditions.[3]



4. Here's a four-element linear array.

Table 2: Performance of Four-Element Linear Array

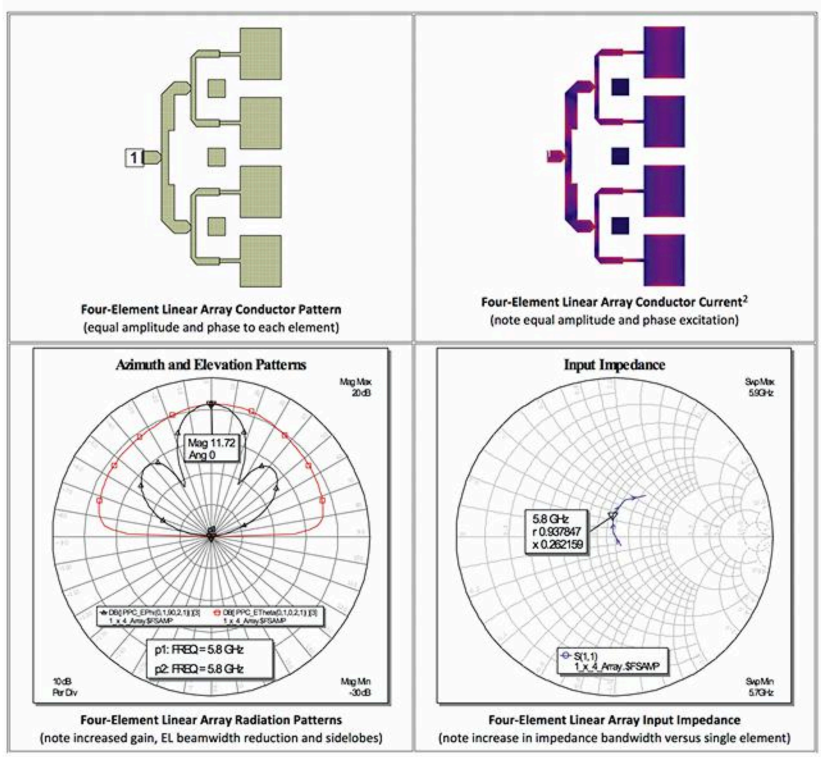


Table 3: Performance of Four-Element Linear Array with Amplitude Taper

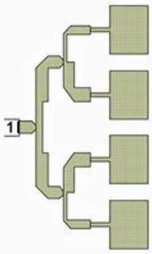
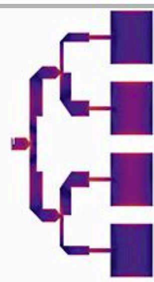
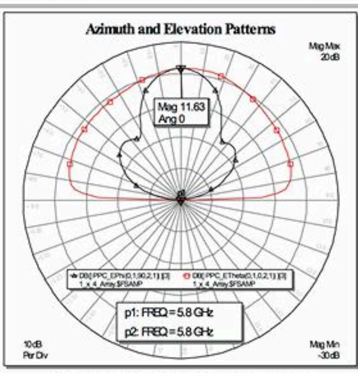
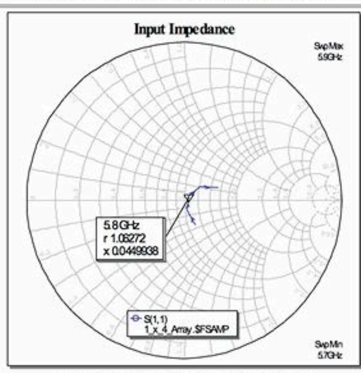
 Four-Element Linear Array Conductor Pattern (note power divider line impedance difference)	 Four-Element Linear Array Conductor Current[2] (note unequal amplitude and equal phase excitation)
 Four-Element Linear Array Radiation Patterns (note reduction to sidelobes versus equal amplitude)	 Four-Element Linear Array Input Impedance (note increase in impedance match bandwidth over single element)

Table 4 illustrates the configuration of a two-×-two array. The two-×-two array excitation is generally uniform; the most prominent feature is that the gain is typically 6 dB above the single-element configuration with the commensurate reduction in *E*-plane and *H*-plane beamwidth. In this case, the gain, 11.45 dB, is limited due to the inclusion of line and impedance-mismatch loss. The conductor current discloses that each element of the array is uniformly excited in amplitude and phase.

The differential feed at the center of the conductor pattern may be implemented from a balun located below the plane of the array. Differential feed is required in this case due to the inverse polarity of the radiating edges. The input impedance is 100 Ω at the center frequency, which is commensurate with typical balun impedance.

The individual excitation parameters of amplitude and phase determine the principal radiation intensity beamwidth, gain, direction, and sidelobe level. Clearly, antenna arrays are significant performance determinants to communication and radar systems. mw

EDITOR'S NOTE: The final equation in part 1 of this tutorial series (see page 62 of the November 2018 issue of *Microwaves & RF*) contains an error. See the online version to view the corrected equation.

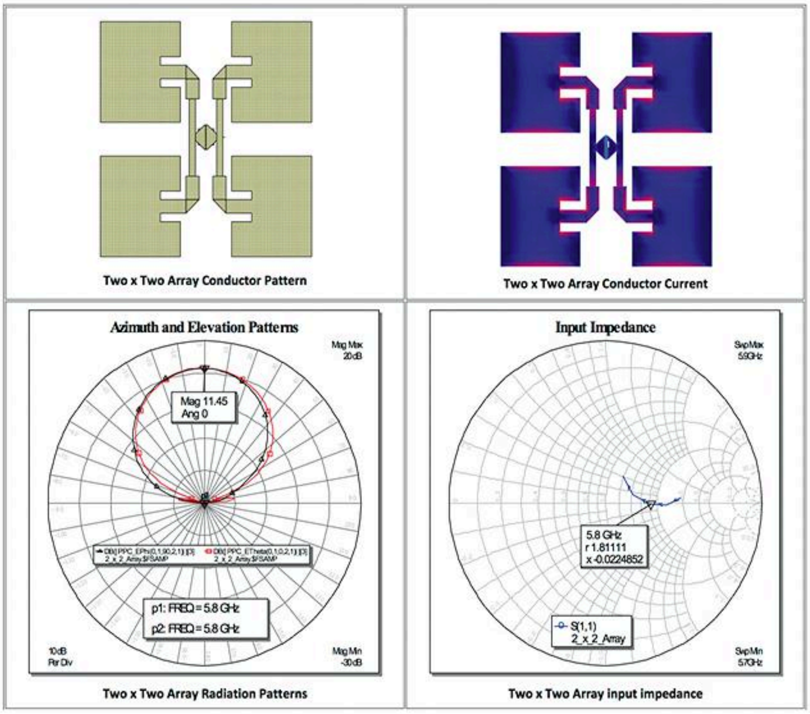
REFERENCES

1. Bahl, I. J. and Bhartia, P., Microstrip Antennas, Chapter 7, Artech House, Dedham, Mass., 1980.

2. The current density annotation feature available within the AXIEM EM analysis software provides significant, physically insightful information. The graphic indicates that the amplitude and phase of the individual element excitation are equal. This feature is uniquely valuable in evaluation of proper amplitude and phase excitation of more complex array structures.

3. The unequal power divider is documented at the website: http://www.microwaves101.com/encyclopedia/calpowerdivider.cfm.

Table 4: Performance of Two-x-Two Microstrip Antenna Array



CHRIS DeMARTINO | Technical Editor

New Resonator Technology Targets Next-Generation Filters

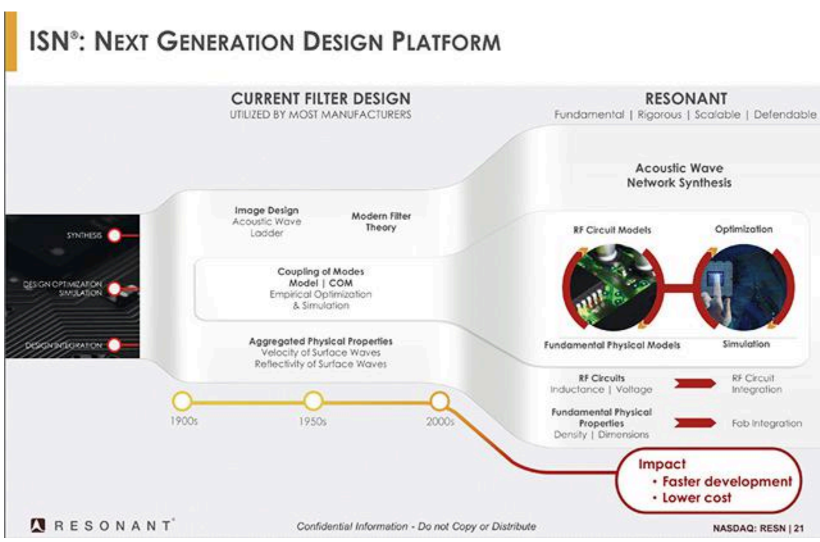
This company's resonator technology could very well become a key factor in enabling filters for 5G applications.

The smartphones that permeate today's world wouldn't be possible without the RF filters found inside of them. And with 5G rapidly approaching, the need for high-frequency filter solutions is only going to intensify. One company that's making a significant impact within the mobile-communications filter space is Resonant *(www.resonant.com)*. The firm recently unveiled its new technology, which it believes holds great promise for future RF filters for 5G mobile devices.

A LOOK AT THE COMPANY AND THE FILTER MARKET

Before getting into the announcement, it's worthwhile to first examine Resonant along with the filter market itself. Founded in May 2012, the firm now has over 60 employees with more than 60 designs under contract from 10 customers. The company's business model is based on licensing rather than manufacturing.

"We're a licensing company," says Mike Eddy, vice president of marketing at Resonant. "We don't make the filters, multiplexers, etc. We create the designs for our customers and then we license those designs on a per-unit royalty basis. Also, we announced the addition of filter IP library products to our offerings. Library products are designed and developed by Resonant against one of its foundry partner's processes, tested against the latest industry and phone board requirements, and then made available to license."



Resonant's ISN technology, based on circuit models and physical models, is used to develop filters for mobile handsets.

The market for RF filters targeted at mobile communications has grown significantly over the last several years. And with 5G coming, that demand is expected to rise. “The highest-growth element in an RF front end (RFFE) is the filter,” explains Eddy. “The reason why is you need a filter for every frequency band the phone is required to operate at. Not only do you need filters for every band, but you need more filters as you add more antennas to get higher data rates. A power amplifier (PA) can operate at multiple frequencies, so you can have one PA for multiple frequency bands. That’s not the case with filters.”

Of course, filters play a critical role in smartphone RFFE architectures—a role that will only be magnified by 5G requirements. Resonant has developed a technology, known as infinite synthesized networks (ISN), that’s made a significant impact in the RF filter realm *(see figure on page 39)*. “We have developed a software platform called ISN, which we use to design complex filters for our customers that go into a mobile handset,” says Eddy. “ISN represents a very different approach compared to the way filters are designed in most cases. What ISN does is bring fundamentals to the design space of a filter.

“The fundamentals we care about are physical dimensions and material properties. Given those fundamentals, we can precisely simulate the performance of our designs using our finite-element analysis. That’s why our customers work with us—what we design is going to be absolutely replicated in the actual measured performance of the filter.”

ISN technology also allows the company to investigate potential new solutions. Eddy adds, “The other part of ISN is that it enables us to start to look at different kinds of structures so that we can come up with structures that are much more applicable to new applications. We’ve been using ISN to look for new structures that will be applicable to 5G filters.

“5G filter requirements involve much higher frequencies because that’s where you have some bandwidth available for use in the mobile market. Higher frequencies mean lower propagation. To get around that, you need higher power. So, you need filters that can handle much higher power.”

Requirements for 5G filters don’t stop there. Eddy continues, “With 5G, the bandwidths will be much larger than the bandwidths currently used by cellular networks at lower frequencies. At lower frequencies, typical bandwidths are approximately 60 to 80 MHz. Now, you’re talking about bandwidths in the 500 to 800 MHz range—and even up to 1 GHz. That means the coupling coefficient of resonating structures must be significantly larger than what's currently available. Also, you want much higher quality factors (Qs). Q generally drops as a function of frequency, so you want to increase the Q at high frequencies in order to make useful filters that have low loss. Finally, you want to make sure that any kind of spurious modes are eliminated."

XBAR TECHNOLOGY

Everything discussed so far leads to Resonant's recent announcement of its new resonator technology, known as XBAR. "We've spent time looking at different kinds of structures using ISN that would meet all the new requirements," explains Eddy. "We've developed a structure called XBAR, which satisfies the requirements for 5G at these high frequencies. XBAR-based designs will first be offered through our library products program."

Resonant speaks very highly of XBAR, boasting that it's a "revolutionary acoustic resonator." So, what's special about it? Eddy says, "With XBAR, we now have a resonating structure that has the strongest acoustic-wave coupling of any resonating structure on the market right now. It offers three to four times more bandwidth than the 4G resonators used in the mobile space right now. This technology gives us the ability to design filters for very wide radio channels—the bandwidths we're talking about are in the hundreds of megahertz. We're also looking at going up to 1 GHz.

"XBAR also offers performance at very high frequencies—much higher than other acoustic-wave filter technologies. It goes beyond 3 to 4 GHz into the millimeter-wave (mmWave) range, i.e., 30 to 300 GHz. The other aspect of this resonating structure is that it can handle very high power. Our ISN toolset can not only model performance with regard to loss and rejection, but it can also model power—which is essential for these very high frequencies."

Eddy sums it up with these words: "Mobile filters are critical for smartphones now and they'll be even more critical for 5G. Our ISN design platform has allowed us to invent new structures that can be applied to the new requirements for 5G. Our XBAR simulations currently show that we can achieve high Q along with resonances at very high frequencies with high coupling coefficients to enable large bandwidths. In addition, the simulations show that XBAR can handle high power. We currently have test structures going through fabs that show that our simulations match the measured performance of these resonators. The agreement has been excellent so far."

Stay tuned for more on Resonant's XBAR technology. mw

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Smart Antennas Steer Mission-Critical IoT Applications

By using smart antennas, IoT devices can gain the most benefits from operating on a cellular communications network, such as 4G LTE or 5G, especially for demanding situations.

Use of Internet of Things (IoT) technology is ramping up, with many of the use cases falling into vertical markets such as agriculture, finance, and asset tracking. For most of these applications, a small-form-factor radio modem with passive antenna will suffice for good connectivity.

However, for some mission-critical IoT applications, such as public safety or asset tracking in high multipath environments encountered in factories and oil refineries, or ATMs and vending machines located in basements of buildings where signals are weak, a better antenna system can be key to successful communication link performance. A smart, or software-defined, antenna (SDA) can provide the extra performance needed to close the link in more challenging IoT environments. The performance enhancements that SDAs can bring to a radio system will typically be range and reliability.

IoT devices that use cellular modems and networks for communications will not be alone on the network, whether it's 4G LTE or 5G, since IoT devices on any cellular network will compete with others for network resources. Smartphone-enabled consumers continue to drive up congestion on the cellular networks that IoT devices require for connectivity. In congested cellular environments, an SDA approach will provide several decibels of system-level improvement compared to client devices that incorporate only passive antennas.

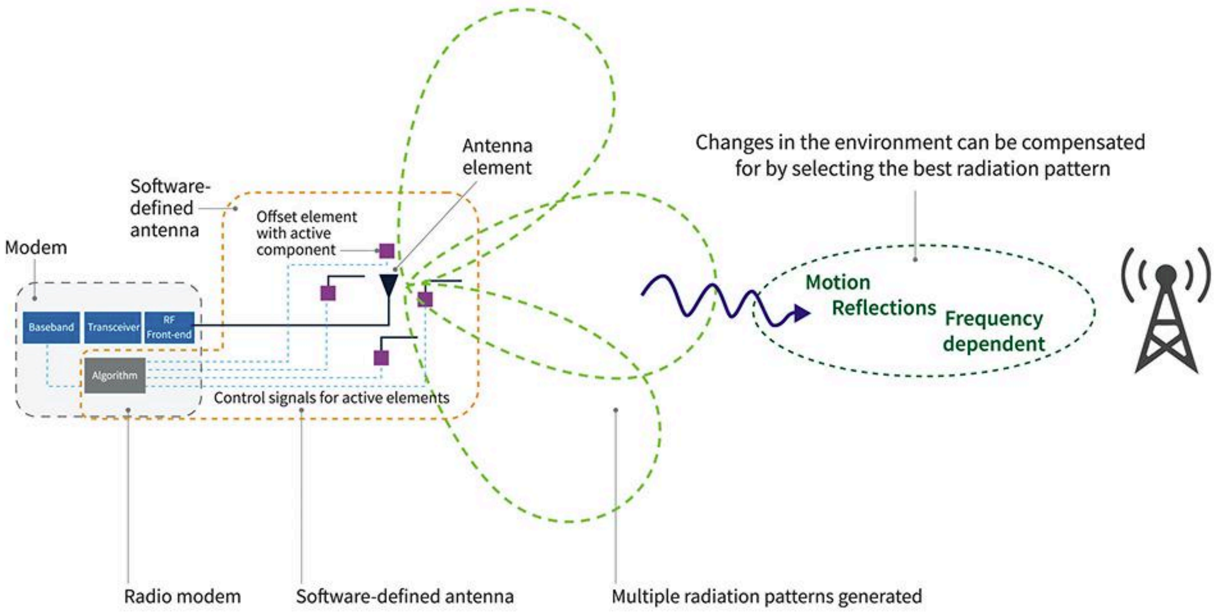
BASICS OF SMART ANTENNAS

A smart, or software-defined, antenna can be dynamically reconfigured so that it's optimized for changes in the radio protocol, propagation channel, or other variations in the operating environment. This reconfigurability can take the form of a beamsteered antenna that's able to dynamically direct the peak gain in the intended direction of propagation to improve the communication link quality. When the antenna radiation pattern can be modified to direct the peak gain in a specific direction, two benefits emerge:

- The gain increase realized by better pointing of the antenna beam results in signal-to-interference-and-noise-ratio (SINR) improvements that translates into a stronger transmitted or received signal.
- The directive antenna pattern tends to reduce the antenna gain in other directions, resulting in better interference mitigation of undesired signals.

Compared to commonly used passive antennas, an SDA provides a beamsteering function that can direct signal gain at the optimal direction or area of the communication link. This improved gain at the intended node of a cellular network along with interference suppression makes it possible to optimize both signal and interference, which substantially improves SINR. This improved SINR will increase the range and reliability of the communication link.

An SDA system can bring multiple additional decibels of gain and system-level benefits compared to a conventional passive antenna. This is particularly true when dynamic optimization of the radiating element is incorporated along with signaling from the baseband modem chipset and an algorithm to command the antenna optimization.



1. This diagram shows how a mobile software-defined antenna and radio modem receive signals from a base-station transmitter.

Besides more gain in the intended direction, an SDA that provides a directive steered beam will reduce the level of interfering signals arriving from directions other than the direction of the intended base station. The underlying principle at play is the relationship between gain and beamwidth of an antenna. As a higher peak gain in the radiation pattern is generated, other angular regions will be under-illuminated, i.e., lower gain in directions outside of the main lobe of the radiation pattern.

If an SINR metric is available from the baseband modem chipset for use by an algorithm to optimize the SDA, then the interference aspects of the propagational channel will be considered as the radiation pattern characteristics are surveyed and optimized. This attribute is becoming more important in today's cellular networks as a more-dense layout of base stations or nodes are being deployed to keep up with capacity demands. As more base stations are deployed, interference becomes a more limiting factor in terms of link reliability and throughput compared to signal strength.

Figure 1, depicting a radio modem and an SDA, highlights the capability of an SDA to generate multiple radiation patterns that can be selected from to optimize for the propagation channel. Another possible reconfigurability path with an SDA-based product is an antenna that can change frequency response as frequency bands are switched to optimize the communication link One more possibility is an antenna that can be dynamically impedance-matched to accommodate changes to the near-field of the IoT modem/antenna module.

SDAs have become more feasible in the last several years due to innovations on two fronts: RF modem chipset design and RF tuning components. These two component types or subsystems will be linked together and communicate with each other to provide the dynamic control needed to optimize a software-defined antenna to a changing environment.

In terms of chipsets for 4G and Wi-Fi modems, the metrics available for "real-time" dynamic optimization are available at moderate to low latency, with these metrics typically including SINR, received signal strength indicator (RSSI), and channel quality indicator (CQI). Metrics like these can be used to make decisions as to optimal antenna system tuning state.

On the RF tuning component side, a wide variety of components and manufacturing techniques to support these components has matured over the last 10 years. The component list includes RF switches, RF tunable capacitors, microelectromechanical-systems (MEMS) switches and tunable capacitors, and PIN diodes. The important attribute of the tuning component is the ability to connect or disconnect portions of an antenna or change reactance at a junction of an antenna, and to do this quickly to allow for "real-time" antenna reconfigurability.

COMBINING ANTENNAS WITH SOFTWARE

As well as the antenna design itself, the software in the form of an algorithm to drive the SDA is key to optimizing the radio modem/antenna combination to the propagation channel or environment. The algorithm will access a handful of metrics from the radio baseband processor and use them while sampling radiation patterns from the antenna to decide which radiation pattern provides the most benefit for a specific scenario or point in time.

It's important to mention "point in time," because things can and do change in the local environment that require a surveying of the SDA's radiation patterns to ensure optimal communication link performance. A well-configured software-defined antenna will have an algorithm coupled to it that can quickly access these baseband metrics to allow for real-time optimization.

An SDA that provides a beamsteering function can provide 3 to 6 dB (or more) of additional antenna system gain. This added gain directly translates to 3 to 6 dB of system-level gain, which can result in higher data rates, a more reliable connection, and increased communication range.

With many IoT applications developed to handle low data rates, the main benefits that an SDA can bring to the mix are range improvements and link reliability. Thanks to the improved antenna system gain provided by an SDA, IoT devices can be placed further from an established cellular base station and still maintain connectivity. For ISM-based systems, the improved antenna gain will mean less infrastructure spend and management, since more range and performance can be achieved from existing equipment.

A more reliable connection will come into play when an IoT device is used on a cellular- or ISM-based network and devices are in weaker signal areas, such as basements, or congested areas like urban environments. The beamsteering function of an SDA effectively provides "antenna diversity" from a single antenna, with the single antenna looking like many antennas as radiation patterns are changed and sampled.

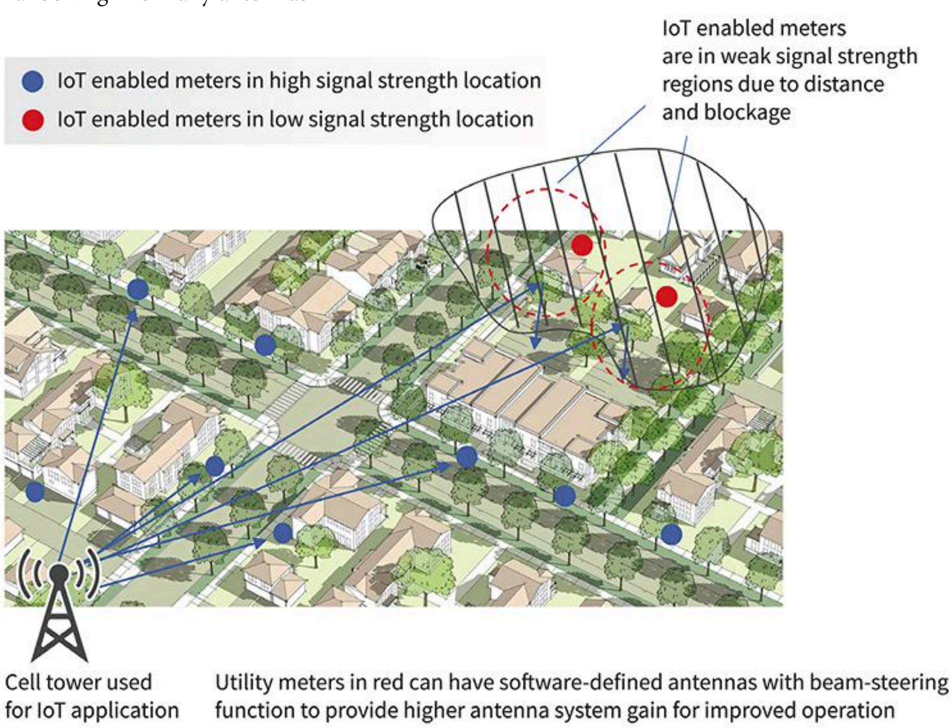
EXPLORING AN EXAMPLE

Figure 2 offers an example of an application that would benefit from a beamsteering function designed into a software-defined antenna. The application is a cellular-based utility metering system implemented in neighborhoods. The existing cellular towers provide adequate signal strength across most regions of the neighborhood, but several homes are located at an extended distance from the cell tower and/or suffer from blockage of the cellular signal from adjacent houses.

The utility meters shown in red are prime examples of IoT-enabled devices that could benefit from an additional 3 to 6 dB of antenna system gain to overcome distance and blockage issues. Implementing an improved antenna system on the IoT devices at these disadvantaged locations proves to be a cost-effective choice compared to putting in additional cellular infrastructure.

For IoT devices operating by means of a cellular network, an SDA can be the difference between being connected or not. It will provide the added system performance needed for demanding IoT applications where maintaining a reliable connection is important. The 3 to 6 dB of antenna system gain achievable from a beamsteering function in the antenna system can be used to extend the signal range as well as improve the reliability of the overall system by maintaining a better communication link.

Today's cellular and LoRaWAN modems have the capabilities for real-time optimization from an algorithm-based SDA, and a wide variety of switching and tuning components can be used in the antenna system design for dynamic optimization of one or more antenna characteristics. Instead of relying on further improvements to the node or cellular tower side of the link, an SDA can bring the benefits of beamsteering antennas to the anticipated large number of client devices as new and more IoT applications are brought to market. mw



2. As shown in this example configuration of a cell tower and IoT devices, many factors can lead to weak signal regions.

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How Can 3D-Printed Plastic Waveguides Enable V-Band Applications?

To demonstrate the performance of 3D-printed plastic waveguide components at V-band frequencies, two prototypes manufactured using 3D-printing technology were examined.

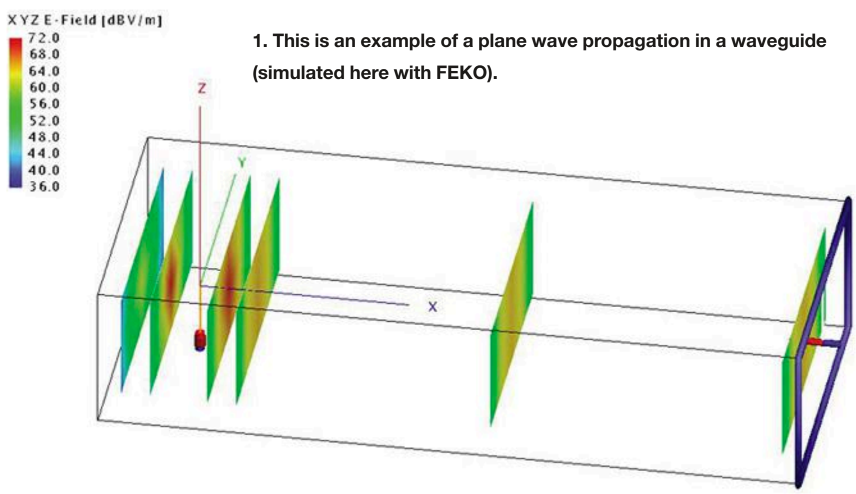
Waveguides structures have been well known for ages. Proposed by J.J. Thomson in 1893 and formally calculated by Lord Rayleigh a couple years later, they have been used heavily since World War II in a wide range of microwave and millimeter-wave (mmWave) applications. Such applications include radar, military and civil transmissions, aerospace and satellites, industrial ovens, etc.

The benefits of waveguides over coaxial transmission lines are numerous, but two standouts are very low loss and high power-handling capabilities. The guided wave propagation theory is also well-known, with the ubiquitous transverse-electric (TE) and transverse-magnetic (TM) propagation modes and associated cutoff frequencies, depending on waveguide dimensions *(Fig. 1)*.

Nevertheless, waveguides are still scarcely used in low-end commercial products. This is mainly due to their cost and size, but also to the relatively low frequency range used in such products. However, the situation is evolving quickly, as mmWave bands find their way into more and more mass-market products, i.e., automotive radar (77 and 24 GHz), Wi-Fi in its 802.11ad version (60 GHz), as well as new 5G cellular bands (24 to 29 GHz and 37 to 40 GHz).

LOW-COST WAVEGUIDES?

As a consulting and design house company focused on RF, microwaves, and



1. This is an example of a plane wave propagation in a waveguide (simulated here with FEKO).

signal processing, ALCIOM has worked on several projects in which small waveguide sections would make sense. These projects include microstrip-to-antenna transitions, antenna structures, cavity filters, and even as a lower-cost alternative to high-frequency connectors and coaxial cables.

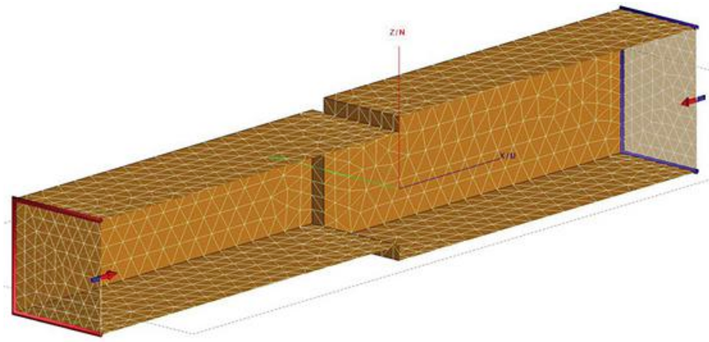
For commercial products, slightly degraded performance can often be tolerated if there's a significant cost improvement. But what are the options for waveguides structures when standard high-end machined metallic solutions are not adequate? Moreover, which solutions could also provide a fast time-to-market and easy prototyping?

Having these targets in mind, we decided to evaluate the cheapest possible solution: plastic. Of course, this material can be molded for mass production, but it's also compatible with 3D-printer technologies. Acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA) can be used on ultra-low-cost filament printers, and plenty of other materials are compatible with easily accessible stereolithography printers (STL).

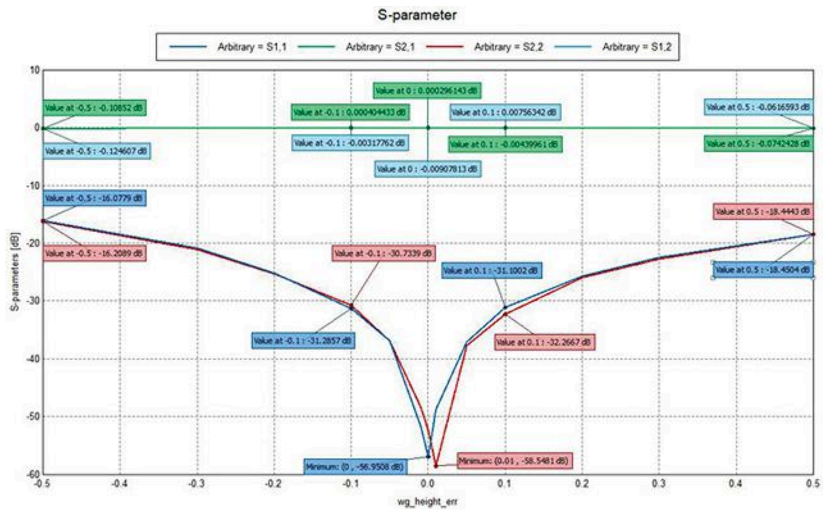
Based on previous tests, we put aside 3D-metal printer solutions too expensive for our goals, as well as "conductive" plastics that provide dc and low-frequency conduction but huge losses at microwave frequencies. Therefore, we decided to test standard plastic materials with a conductive plating on their surface. This article shares our theoretical and experimental results, targeting V-band applications (50 to 75 GHz), and more specifically, the 60-GHz band.

DIMENSIONAL TOLERANCES

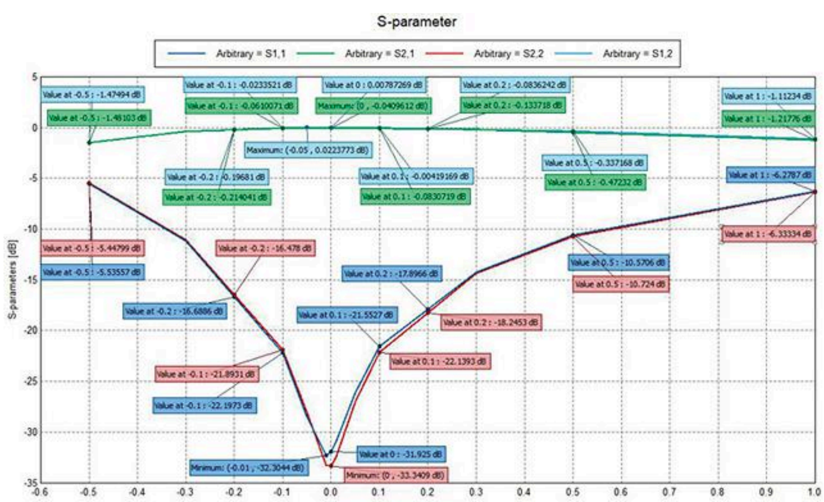
Dimensional tolerances represent the first potential difficulty associated with low-cost manufacturing techniques like plastic injection or 3D printing. For relatively narrowband applications, the inner dimensions of the waveguide itself are not really critical—at least as long as the application stays in the center of the waveguide usable bandwidth.



2. To evaluate the impact of dimensional errors, a waveguide-to-waveguide transition was modeled with errors in both axis.



3. This is the simulated impact of a waveguide height mismatch between two sections. The horizontal axis represents the value of the error (–0.5 to +0.5 mm), whereas the vertical axis reveals the impact on reflection and transmission S-parameters.

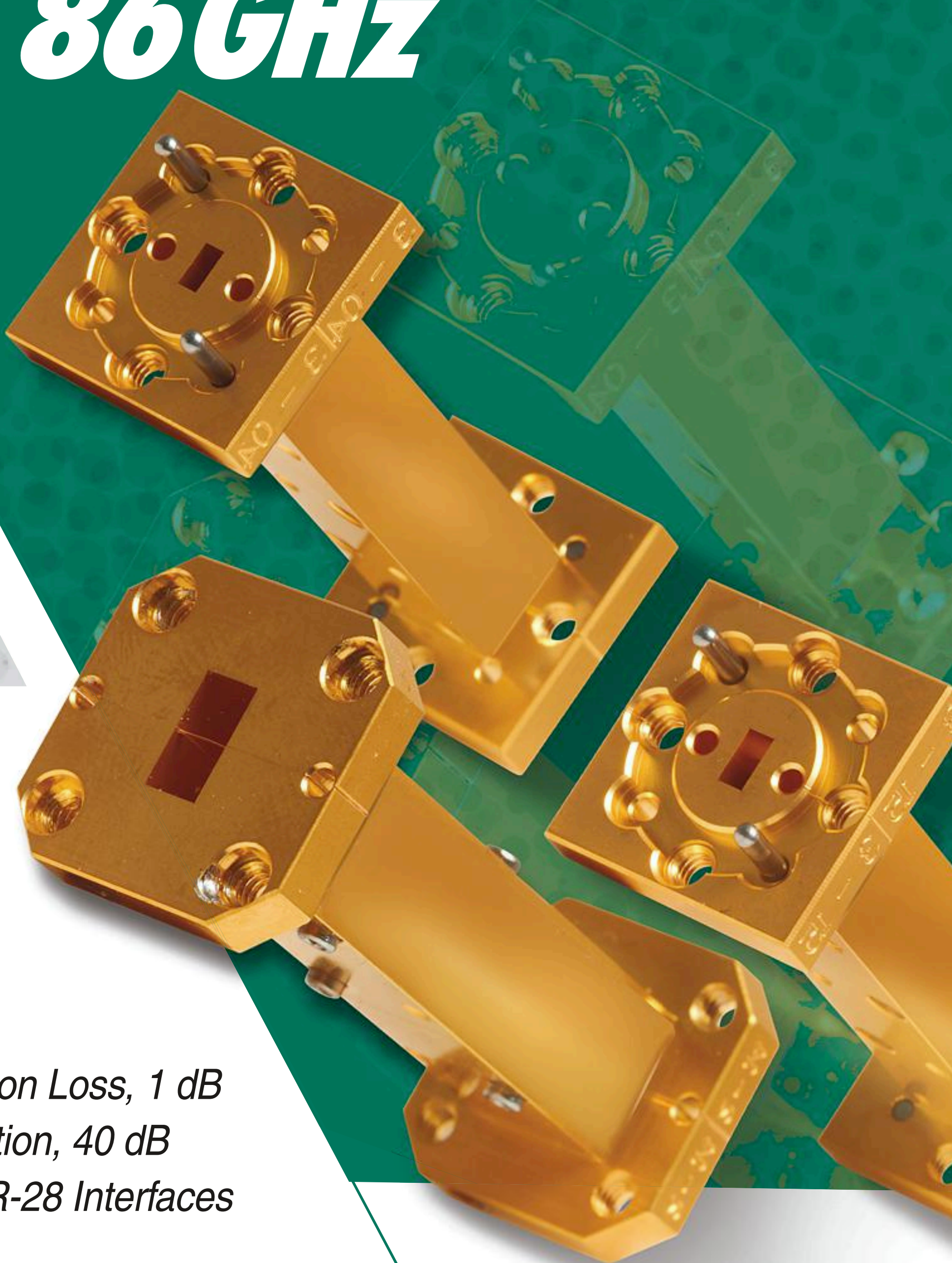


4. Illustrated is the simulation of a dimensional error on a coax-to-waveguide transition (on the back-short distance).

INSTRUMENT GRADE

WAVEGUIDE FILTERS

to 86GHz



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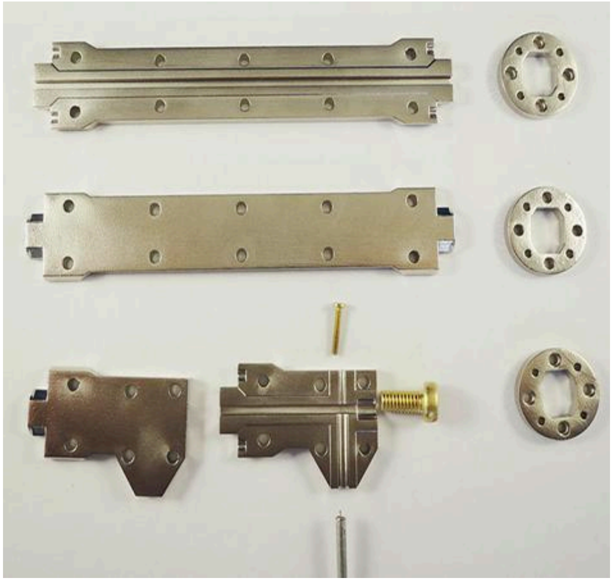
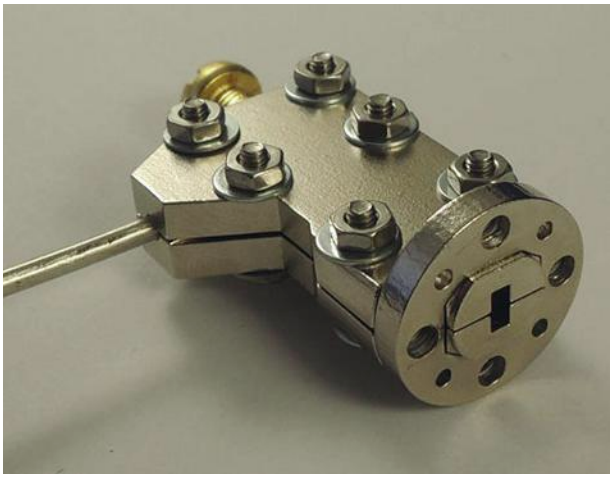


5. The prototypes were built using STL 3D-printed plastic and Ni-Ci electrochemical plating.

6. This is the assembled waveguide section prototype.



7. The coax-to-waveguide transition prototype was built using a semi-rigid coax and 3D-printed parts.

For example, for 60 GHz, the standard waveguide size is WR15, with inner dimensions of 3.76 × 1.88 mm. Such a WR15 waveguide provides a usable bandwidth from 50 to 75 GHz. While a 10% size error will shift these frequencies by 10%, the waveguide will still be usable at 60 GHz.

However, the junction between two waveguides manufactured using low-cost processes will inevitably show some misalignments and size variations. What is the impact of such variations regarding insertion loss and return loss? To evaluate this impact, we developed a numerical model of such a junction *(Fig. 2)*. Two waveguide sections were interconnected, but with dimensional errors. We then ran several parametric simulations using the FEKO 3D electromagnetic (EM) solver from Altair *(www.altair.com)* with varying dimensional errors (size, offset, angle, etc.) and evaluated the impact on the S-parameters (S_{11}, S_{22}, and S_{21}).

Figure 3 shows a typical result. Here, only one parameter is swept: the height mismatch between the two waveguides. The horizontal axis ranges from −0.5 to +0.5 mm of error. Of course, any dimensional error affects performance, but this simulation reveals that S_{11} is better than 20 dB as long as the dimensional error is within ±0.3 mm. Assuming that 20 dB of matching is acceptable for the application, such an accuracy is compatible with standard plastic manufacturing processes.

However, our simulations also pinpointed that other dimensional parameters are more stringent than such a waveguide height error. For example, we performed a simulation of a coaxial-to-waveguide transition. *Figure 4* shows the result of this simulation while sweeping the dimension error between the back-short of the waveguide and the position of the coax entry. Here, the same 20-dB mismatch corresponds to a position error of only 0.15 mm (intuitively half of 0.3 mm, as the waves propagates back and forth in this area). Therefore, such a transition will most likely require a tuning screw to achieve acceptable performance.

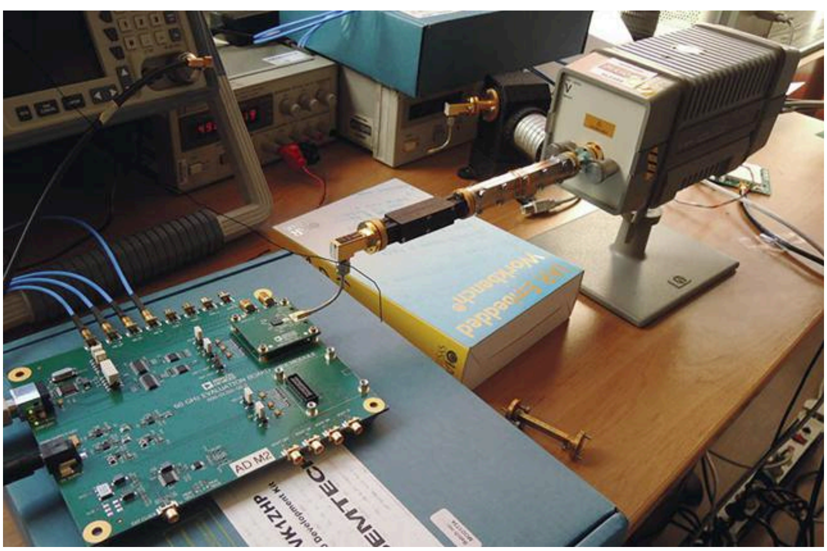
Dimensional tolerances represent the first potential difficulty associated with low-cost manufacturing techniques like plastic injection or 3D printing. For relatively narrowband applications, the inner dimensions of the waveguide itself are not really critical—at least as long as the application stays in the center of the waveguide usable bandwidth.

BUILDING PROTOTYPES

Based on these promising EM simulations, we decided to build some prototypes and evaluate their actual performance. We developed a simple mechanical model for a WR15 section with a length of 20 cm *(Fig. 5, top)*. This model includes two identical half-sections, cut at the middle of the H-plane to limit conductive losses, and two separate flanges. Screws and nuts were used to assemble the prototypes. Of course, other solutions would be applicable for mass production.

We also developed a prototype for a coax-to-waveguide transition *(Fig. 5, bottom)*. It's based on the same concept with two half-waveguide sections and a separate flange. A semi-rigid coax with a 1.85-mm connector creates the antenna. Two tuning screws allow for compensating the antenna length and back-short position.

These prototypes were manufactured using a standard STL 3D-printing process with a 50-µm layer height. The material used was perFORM (from Somos), which provides good detail resolution as well as reasonable heat tolerance. After 3D printing, the pieces were processed for deposition of a conductive plating on all their surfaces. To check their performance with ultra-low-cost techniques, a standard EMC plating was used (20-µm copper and 10-µm nickel). *Figures 6 and 7* show the assembled first prototypes.



8. Shown is the test bench used to evaluate the S_{21} performance of the waveguide section.

Our experimental work was a simple attempt to use ultra-low-cost techniques (standard STL 3D printers and EMC-type Ni-Cu plating) to build V-band waveguide parts. The simulations presented in this article, confirmed by prototypes and lab tests, show that such a technique allows for performance degradations that are reasonable in comparison to high-end, machined, full-metal waveguides. Additional losses ranging from 0.1 to 1 dB were achieved on the first prototypes, with room for improvement.

TEST RESULTS

To evaluate the performance of these prototypes, we performed comparative measurements in our labs between these plastic-based waveguide prototypes and high-end waveguide components with similar size and function—both for a 20-cm long section and for a coax-to-waveguide transition. *Figure 8* shows the actual test setup. As a generator, we used an evaluation board of the HMC6300 60-GHz mmWave transmitter from Analog Devices *(www.analog.com)*. An old but trusted Keysight HP71210C spectrum analyzer with companion HP11974V V-band preselected mixer was used as a measurement receiver.

For the 20-cm waveguide section, the measured S_{21} performance was nearly identical between the plated plastic 3D-printed prototype and a full metallic WR15 waveguide section. We measured about a 0.1-dB difference, which is far below the measurement uncertainty at 60 GHz. The behavior of this plastic waveguide was therefore very close to its high-end counterpart.

For the coax-to-waveguide transition, and after a quick attempt to optimize the tuning of the two adjustment screws, we measured 1 dB of extra loss. Nonetheless, this difference seems more than acceptable due to the very crude prototyping assembly used for these experiments. The discrepancy probably results more from the very simple mechanical model rather than the 3D-printed material itself.

WRAPPING UP

Several papers study the performance of 3D-printed structures for waveguides or microwave/mmWave antennas *(see bibliography)*, using mainly metal 3D printing.

Our experimental work was a simple attempt to use ultra-low-cost techniques (standard STL 3D printers and EMC-type Ni-Cu plating) to build V-band waveguide parts. The simulations presented in this article, confirmed by prototypes and lab tests, show that such a technique allows for performance degradations that are reasonable in comparison to high-end, machined, full-metal waveguides. Additional losses ranging from 0.1 to 1 dB were achieved on the first prototypes, with room for improvement.

Based on these promising results, new solutions could be proposed even for low-volume and low-cost commercial devices, particularly in the 60-GHz band now available for Wi-Fi. mw

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JACK BROWNE | Technical Contributor

Grappling with Those Unwanted Signals

As more wireless applications crowd into the available frequency bands, signal congestion is forcing RF/microwave system designers to find ways to cope with unwanted signals.

Radio signals are part of many wireless applications, from consumer and commercial through industrial and military systems. Whether in licensed or unlicensed applications, especially at RF and lower-microwave frequency bands, any operating environment can become tangled with too many signals. Some of them are signals intended for a receiver, others are intended but too much for a receiver to handle at one time, and some are simply unwanted signals or interference.

Those unwanted signals can start from many sources, whether they're as familiar as an AM radio or television broadcast transmitter and or in the form of harmonics of intended signals or even excessive energy leaking from electronic devices as electromagnetic interference (EMI). Typically, unwanted signal interference starts with some form of transmitter or as electronic equipment lacking adequate shielding to maintain electromagnetic compatibility (EMC) for a given operating environment. By knowing a little more about these unwanted signals, they can be sidestepped by the desired signals or filtered out when they occur at some point outside of the frequency bands of intended signals.

Organizations such as the Federal Communications Commission (FCC) and the International Telecommunication Union (ITU), and even the Amateur Radio Relay League, work hard to organize frequency-spectrum use into carefully organized and managed bands of frequencies for each application. This includes, for example, the 2.4- to 2.5-GHz band for Wi-Fi wireless local-area networks (WLANs) and their essential access to the internet for many different electronic devices. Starting within the kilohertz range for AM radios through VHF/UHF broadcast television channels (*Fig. 1*), spectrum use is carefully monitored to prevent unwanted overlapping of signals that can interfere with the reception of designed signals.

The 2.4-GHz span is part of the unlicensed industrial, scientific, and medical (ISM) band of frequencies intended for widespread and easy-to-use wireless applications. One of those applications, though, is the microwave oven at 2.45 GHz, where such relatively long wavelengths are effective for heating water and any foods or materials with water content. As effective as microwave ovens are for home and industrial heating, they are also a potential source of EMI and unwanted signals if improperly shielded and sealed during the heating process.

1. Radio broadcast antennas can be a starting point for radio waves that become unwanted interference signals. *(Courtesy of TE Connectivity)*

Although microwave ovens are designed to operate with relatively low levels of RF radiation, small amounts of leaking RF energy are enough to jam or interfere with the operation of nearby Wi-Fi equipment and prevent wireless access. Interference within the 2.4-GHz band may not be enough to prevent a Wi-Fi system from operating altogether, but may surface as slow internet access speeds and slow computer file transfers using the Wi-Fi system. For a Bluetooth device at 2.4 GHz, interference may result in simply not being able to wirelessly connect a Bluetooth device, such as a printer or computer mouse, to a computer controller.

Interference can also occur within Wi-Fi bands (at both 2.4 and 5 GHz) simply because of signal congestion. Interference results between fixed in-home wireless networks when a neighbor has set a wireless router to the same channel at the same frequency as the Wi-Fi system next door. Since Wi-Fi operates over a designated frequency bandwidth with multiple channels each set to its own frequency, changing the channel number will usually avoid interference in a Wi-Fi system from a too-near Wi-Fi wireless router (*Fig. 2*).

Interference occurs when attempts are made to use multiple signals within the same frequency channel at the same time without some form of synchronization. Such instances may involve frequency-division multiplexing (FDM) to slightly

2. Standard Wi-Fi routers operating at ISM frequencies can be the sources—and victims—of unwanted interference signals. *(Courtesy of Linksys, www.linksys.com)*

offset the frequencies of the different signals or time-division multiplexing (TDM) when signals are transmitted in pulses or packets that are slightly offset in time to prevent the signals from blocking each other.

Of course, even the most dedicated attempts at signal synchronization cannot avoid interference in all cases. For example, in the case of a Wi-Fi system that may be initiating operation from a cable-television (CATV) service provider, coaxial cables running into a house and to a junction box can also be the source of interference. Frayed or cut insulation on those cables, even coaxial connectors with poor EMC interfaces, can leak enough EM energy to jam the intended RF signals from the wireless router to a nearby wireless device and degrade the overall performance of the Wi-Fi network.

In some wireless transmit systems, it's also possible that out-of-band signals generated by second or third harmonics from internal power amplifiers for the transmitter may be emitted by the system at sufficient power levels to become interference for higher-frequency bands. Harmonics can occur for any transmitted frequency band that must be amplified, simply as the result of all amplifiers being guilty of some amounts of harmonic distortion. Systems with known harmonic levels will usually integrate bandpass filters (BPFs) that have enough bandwidth and low-enough passband loss to allow desired signals to pass through the system and adequate out-of-band signal rejection to prevent the transmission of those unwanted, higher-frequency signals.

In contrast to unlicensed ISM band frequencies, frequency bands licensed by the FCC, such as the cellular radio bands at 824 to 849 MHz and 869 to 894 MHz, are organized into what became 25-MHz channel blocks for different cellular carriers. The intention was to maintain effectively spaced signals that would provide multiple users within the same channel block and same locale with minimal or no interference from unwanted signals, such as radiating harmonics from lower-frequency emitters that might occur within a cellular channel at the same time as an intended transmission. Similarly, the FCC licensed higher-frequency spectrum at 1850 to 1990 for cellular communications use, in what became known as the personal communications service (PCS) band. The frequency range was divided into blocks between 10 to 30 MHz for wireless communications in different geographic areas of the U.S., as a means of preventing signal overlap and interference.

Receivers designed for a single frequency at a time can only process one signal at a time from a single transmitter. Such wireless circuits are often used in remote-control apps or as keyless-entry systems in automobiles. When more than one signal is transmitted at the same frequency, at the same time, the signals will jam and interfere with each other, and the receiver will fail to receive either signal due to the interference.

When an application requires that multiple signals be transmitted and received within the same frequency, some form of TDM arrangement is often applied to prevent the short bursts of signals at the same frequency from transmitting at the same time. By offsetting multiple signals even by short durations, interference from unwanted signals can be avoided and the multiple signals are able to share the same frequency or even a narrow-bandwidth frequency channel.

How does one locate unwanted signals within an operating environment? One of the best tools is a portable spectrum analyzer, available from several high-frequency instrument suppliers (*see, for example, p. 56*) and covering many different frequency ranges, through millimeter-wave (mmWave) frequencies. An analyzer with sufficient measurement bandwidth, when used with an antenna that covers the frequency range of interest and is as low in frequency as possible (to look for fundamental-frequency sources of harmonic signals that may be falling into the desired frequency band), can be used to measure the power levels of RF/microwave signals present in that operating environment. It also will likely display those signals along with a desired signal to compare the frequency congestion and power levels of the different signals.

In addition, the portability of the analyzer and antenna may make it possible to move the measurement rig in different directions to identify when the signal levels of the interference increase. This helps locate the source of the unwanted, interfering signals, especially if within a home or an office.

As frequency spectrum use moves higher in frequency, into the millimeter-wave (mmWave) bands from 30 to 300 GHz, the intention by the FCC and other frequency-management organizations is to prevent interference as much as possible. Although the mmWave frequency range is currently uncongested, the same was once true at many RF and microwave frequency bands, such as 2.4 to 2.5 GHz.

These higher-frequency mmWave signals, whether for emerging applications like 5G or automated driver-assistance systems (ADAS) for future autonomous vehicles, are subject to many of the same traits as lower-frequency signals. Such mmWave signals can result in interference and generation of unwanted signals if improperly managed. mw

JACK BROWNE | Technical Contributor

HARVEST ENERGY from RF Sources

Growing reliance on electronic devices in industrial and commercial applications is fueling the use of RF energy harvesting as a source of power.

Electronic devices are insinuating themselves further into everyday lives, and, of course, they all require power in some form to continue working. Fortunately, energy is all around us in many forms. Power can be converted from wind, light, objects in motion, even by tapping the leftover energy from high-frequency radio transmissions. As the world becomes more electronic in nature, it makes more sense to reuse energy when available, such as in RF/microwave signals, to establish more-efficient overall energy use.

Energy harvesting is probably best known for applications that start with the sun as the source of the energy. Especially for devices that require only small amounts of power for operation, light from the sun can be converted to enough dc voltage using relatively small solar panels.

In sparsely populated areas, it's common to see the roofs of single-residence homes covered with enough solar panels to provide a significant source of energy as a backup or replacement for a local energy utility company. Similarly, in areas where open plains provide exposure to relatively high winds, such as the Midwest United States, it's not unusual to see wind turbines that can convert the wind into "almost free" sources of electrical energy.

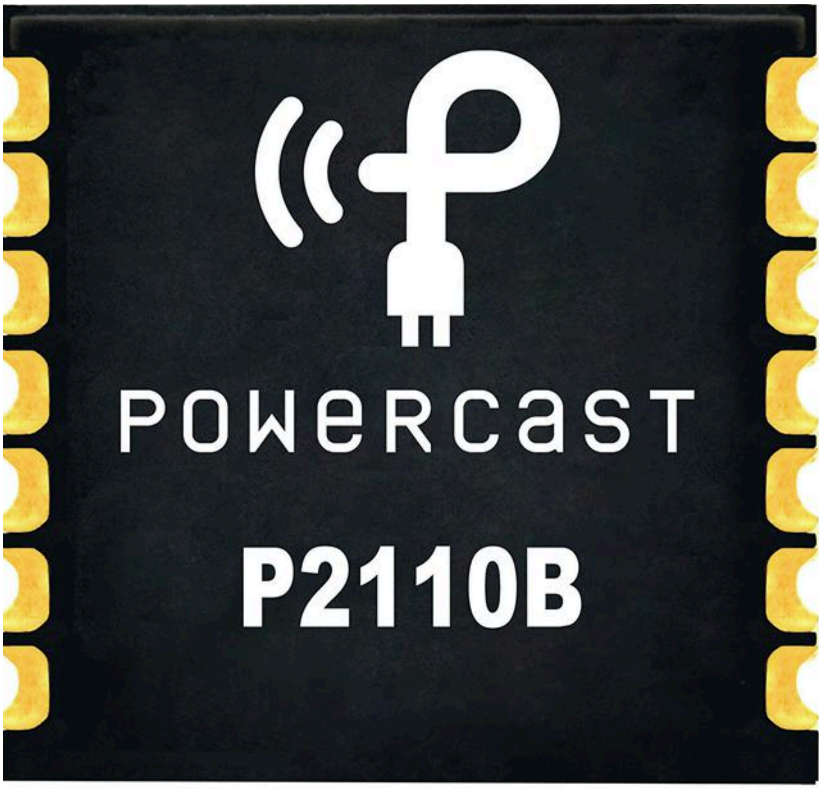
Today, sunlight is probably the most popular source of power that can be converted into dc voltage, with companies such as Analog Devices *(www.analog.com)*, Silicon Laboratories *(www.silabs.com)*, and Texas Instruments *(www.ti.com)* offering extensive lines of solar-powered wireless transceivers, oscillators, and other high-frequency components. In addition, EnOcean *(www.enocean.com)* has developed a series of self-powered switches that draw their power from solar sources, as well as many ICs that use wireless communications at ISM frequencies to perform solar-powered electronic functions. The most recent arrival is a solar-powered occupancy sensor for Bluetooth lighting-control systems, using Bluetooth Low Energy (BLE) to simplify in-building automation.

Not as widespread, but quickly growing in popularity, is the process of harvesting energy from RF/microwave signals, such as from radio/television broadcast stations and wireless equipment. Harvesting energy in this manner makes it possible to replace batteries in low-power applications, such as Internet of Things (IoT) sensors and radio-frequency-identification (RFID) tags. Reusing the energy can cut operating costs and improve the efficiency of existing electronic systems and devices.

Harvesting energy from RF/microwave signals is a clear-cut process. It can be performed with integrated circuits (ICs) containing basic components like radio receivers and boost converters that convert RF signal energy from an antenna to ac or dc voltage and then transfer the energy to a storage device, such as a rechargeable battery or capacitor. Straightforward Vivaldi antenna designs *(see "Design an X-Band Vivaldi Antenna" on mwrf.com)* have shown excellent capability in providing ultrawideband (UWB) frequency coverage (e.g., 100 MHz to 6 GHz) in support of many RF energy-harvesting ICs.

CONVERTING RF ENERGY

Commercial RF energy-harvesting receivers like the P2110B Powerharvester from Powercast Corp. (www.powercastco.com) provide the capability to convert RF signals to dc voltage *(see figure)*. It's a receiver designed for use



This surface-mount package holds the P2110B Powerharvester, an RF energy-harvesting IC that converts ISM signals from 902 to 928 MHz to dc voltage. *(Courtesy of Powercast Corp.)*

in the lower portion of the industrial, scientific, and medical (ISM) band (902 to 928 MHz).

With the aid of an antenna, the P2110B can process RF input levels from −12 to +10 dBm, convert them to a dc voltage, and store the energy in a capacitor for use as needed. This low-level sensitivity allows for effective energy harvesting even at considerable distances from an RF source. The compact device is an example of currently available RF energy-harvesting technology that enables power management of small electronic products without a battery.

The P2110B uses its internal capacitor as part of its own controlled energy-conversion process. Regulated voltage levels from the energy harvester can be set from +2.0 to +5.5 V dc at maximum current of 50 mA. The output voltage flows once a high charge threshold is met on the capacitor. When the energy stored within the capacitor drops to a low-voltage threshold, the output voltage from the P2110B is turned off. As the manufacturer suggests, a microprocessor can be used with the energy harvester to optimize power usage and improve the performance of connected electronic devices, such as sensors.

Given the expected rapid growth of wireless IoT sensors and the need for remote wireless sensors in 5G cellular networks, energy harvesting will no doubt take many forms, including from photovoltaic and thermoelectric sources. One such example is an IC for harvesting energy from photovoltaic sources. The AEM10940 from e-peas semiconductors *(www.e-peas.com)*, developed for use with solar panels, can supply two independent regulated voltages to extend battery lifetimes or even eliminate the need for a battery in an electronic system.

More recently, the same firm developed a pair of semiconductor devices, models AEM30940 and AEM40940, for extracting energy from RF sources. Both feature integrated boost converters that supply charge to batteries and capacitors, and are designed to extract energy from low-power ISM-band signals. The AEM30940 can work with RF input levels as low as −18.2 dBm from 863 to 868 MHz and 915 to 921 MHz, −14 dBm from 2110 to 2170 MHz, and −9.5 dBm from 2.4 to 2.5 GHz. The surface-mount device features configuration pins to simplify implementation of different operating modes, and has low- and high-voltage package pins to supply a full range of voltages from 50 mV to 5 V.

The AEM40940 extracts ac power from RF signal sources, producing two independently regulated output voltages. It integrates a low-power rectifier and a boost converter in a plastic quad flatpack housing measuring just 5 × 5 mm. It's usable at ISM frequencies of 868 MHz, 915 MHz, and 2.45 GHz, and input power levels of −20 to +10 dBm. The RF energy harvester features relatively high overall efficiency (measured from input port to output of the boost converter)—typically better than 20% for input power levels of −20 to 0 dBm at 868 and 915 MHz and typically better than 10% for input power levels of −10 to +5 dBm at 2.45 GHz.

Energy-harvesting devices are currently available for many different sources of power, including sunlight, wind, motion, temperature, even for capturing micropower from a user's body heat. The capabilities vary for each harvesting approach, with solar power still the most popular and efficient form of harvesting energy already in the environment. But with the worldwide spread of wireless communications devices and the increase of RF/microwave signal energy in most populated areas, opportunities are growing for RF energy-harvesting technology as a means of running low-power electronic devices, such as the billions of IoT sensors expected to blanket the planet in the years to come.

JACK BROWNE | Technical Contributor

Instruments Bring the Value to Precision Measurements

These test instruments deliver cost-effective multiple-function measurement capabilities from a source known for its highly accurate though typically more expensive equipment.

Test-and-measurement instruments are essential, but often expensive, tools that aid in the design and development of electronic products. For most electronic device, component, and system manufacturers, acquisition of building-block instruments such as oscilloscopes, spectrum analyzers, and power supplies can represent major investments—and thus put sizable dents—in a company's operating expenses.

Addressing those concerns, Rohde & Schwarz, a leading supplier of high-end electronic test instruments, introduced a line of "value" instruments, including three digital oscilloscopes, an RF/microwave spectrum analyzer, and a precision power supply, that provide top performance levels without charging top dollar. They are designed and built with cost-effective quality in mind, yet manufactured in the same European facilities as the firm's top-of-the-line electronic instruments, bringing even more electronic measurement power for the dollar than ever before.

The oscilloscope models are more like three different series of instruments, with many different options and upgrades. It's possible to start with a basic set of measurement functions and capabilities, and then via license keys, unlock much more extended performance later.

For example, the "entry-level" oscilloscope, the R&SRTB2000 is available with two or four channels and 3-dB measurement bandwidths of 70, 100, 200, and 300 MHz *(Fig. 1).* Real-time sampling extends to 1.25 Gsamples/s in normal measurement mode and to 2.5 Gsamples/s when channels are interleaved. The memory per channel is 10 Msamples in normal mode and 20 Msamples for interleaved measurements. As much as 160-Msample segmented memory enables more than 13,000 recordings when long-term measurements are required.

1. The R&SRTB2000 oscilloscopes come with two or four channels and 3-dB bandwidths of 70, 100, 200, and 300 MHz.

These "budget" digital oscilloscopes leverage a high-resolution, 10-b analog-to-digital converter (ADC) at the 2.5-Gsample/s sampling rate (with as much as 16-b vertical resolution in high-resolution decimation mode). Test results are shown on a bright, 10.1-in. capacitive touchscreen display with 12 horizontal divisions and 180- × 800-pixel resolution. The display screen also provides straightforward access to the operating menus.

The R&SRTB2000 oscilloscopes provide 1-mV/div vertical resolution at full bandwidth to go with an input sensitivity range of 1 mV/div to 5 V/div and 10%/90% rise times of 5 ns or better. The instruments feature a history mode for analysis of saved, earlier measurements, among many other handy, automatic measurement functions.

In addition to being digital oscilloscopes, the R&SRTB2000 value instruments include several measurement functions that can be activated via license keys, including a 4-bit pattern gen-

2. The R&SRTM3000 oscilloscopes (left) include models with two and four channels and bandwidths of 100, 200, 350, 500, and 1000 MHz. The R&SRTA4000 instruments (right) are digital oscilloscopes with bandwidths to 1000 MHz that also incorporate a logic analyzer, spectrum analyzer, protocol analyzer, arbitrary waveform generator, pattern generator, counter, and digital voltmeter.

3. The R&SFPC1500 spectrum analyzers are available from 5 kHz to 1, 2, or 3 GHz, with vector network analyzer and test signal sources included.

erator and a signal waveform generator with 14-bit resolution and 250-Msample/s sample rate.

The waveform generator is capable of an amplitude range of 20 mV to 5 V into high-impedance loads and 10 mV to 2.5 V into 50-Ω loads. It can create sine waves from 0.1 Hz to 25 MHz and pulses from 0.1 Hz to 10 MHz. The oscilloscopes are supported by a wide range of available probes and accessories, including lower- and high-voltage single-ended passive probes, ac/dc current probes, and active differential probes.

When more bandwidth and measurement power is needed, the R&SRTM3000 digital oscilloscopes are also available with two and four channels, but with 3-dB bandwidths of 100, 200, 350, 500, and 1000 MHz *(Fig. 2)*. They provide 40-Msample memory depth on each channel with maximum sampling rate to 5 Gsamples/s, also showing results on a 10.1-in. capacitive touchscreen with 1280- × 800-pixel display resolution and 12 horizontal divisions.

The R&SRTM3000 is even closer to being a complete measurement system than the R&SRTB2000, with available additions of a logic analyzer, protocol analyzer, waveform and pattern generators, and digital voltmeter. In addition, there are dedicated operating modes for frequency analysis, mask tests, and long data acquisitions for serial protocol signal analysis.

Finally, for the value oscilloscopes, the R&SRTA4000 instruments are also built around a 10.1-in. capacitive touchscreen display with 12 horizontal divisions and 180- × 800-pixel resolution, but provide the highest sensitivity at 500 µV/div. Models/upgrades are available with bandwidths of 200, 350, 500, and 1000 MHz and standard sampling rates of 2.5 Gsamples/s per channel and 5.0 Gsamples/s interleaved with up to 1,000 Msamples of memory. It offers low noise performance, even at 1 mV/div and full bandwidth.

In terms of packing measurement power into one package, these are eight instruments in one, with oscilloscope, logic analyzer, spectrum analyzer, protocol analyzer, arbitrary waveform generator, pattern generator, counter, and digital voltmeter. The built-in protocol analyzer, for example, can be used to analyze and debug serial buses with long-duration signals.

SPECTRUM ANALYSIS

For measurements in the frequency domain, the R&SFPC1500 spectrum analyzer *(Fig. 3)* has a starting frequency range of 5 kHz to 1 GHz with license key upgrades that activate measurement capabilities extending to 2 and 3 GHz as needed. These analyzers handle input signal levels as high as 1 W (+30 dBm) and feature a noise floor of −165 dBm when using a preamplifier.

With resolution bandwidth as fine as 1 Hz, the analyzer can resolve the smallest signal details, which are shown on a high-resolution 10.1-in. WXGA display screen. As with the other value instruments, the R&SFPC1500 spectrum analyzer is not “simply” a spectrum analyzer, but rather include two additional high-frequency instruments—a vector network analyzer and tracking generator—both of which are available for frequency coverage from 5 kHz to 1, 2, or 3 GHz.

When laboratory power is needed, the R&SHMP power supplies provide two, three, or four electrically equivalent channels of low-ripple voltage to 32 V in a single instrument. Models come with two or three channels and as much as 188 W total output power or three or four channels and as much as 384 W total output power. The supplies use remote sensing to eliminate voltage drops on load leads, and incorporate galvanically isolated, floating output ports with overload and short-circuit protection. When teamed with any of the other value instruments, they provide part of a cost-effective measurement solution that’s as useful in the laboratory as the production line. P&A: $1,370 (USD) and up (R&SRTB2000).

CHRIS DeMARTINO | Technical Editor

How is This Company's Technology Enabling New Markets?

In this Q&A, Abhishek Kapoor talks about his new position with Anokiwave, the company's goal of commercializing active antennas for 5G and other applications, and more.

Can you tell us about your position with Anokiwave?

I am the Vice President of Sales at Anokiwave. My role is to build a sales team and sales channels to globally reach and support companies developing active-antenna/phased-array architectures for 5G, satellite communications (satcom), and radar applications. We provide enabling integrated-circuit (IC) technology that makes commercialization of active antennas possible—something that was not possible before. My key focus is to build, enable, and manage a sales team that closely works with all customers—big or small—and helps them complete their active-antenna designs.

Abhishek Kapoor

The adoption of active-antenna architectures for 5G, satcom, and radar applications is happening very fast. To support this growth, we continue to expand fast. My goal is to reach every customer across the globe who's trying to do a millimeter-wave (mmWave) active-antenna design and help them at an IC level, as well as system level, to build their solution. We are already on a path to doing that.

We started with a small team five years ago and today have a growing direct sales team, worldwide distributor, and more than 10 regional sales representatives covering all key regions across the globe. We recently opened our Taiwan office to provide close sales and application support to our Asia Pacific customers, and we continue to add more people in sales and application engineering roles.

What made you want to join the company?

One of the key reasons to join Anokiwave was to be part of a team that's thinking big, different, and truly enabling new markets. While a lot of traditional players now talk about how active antennas will become prevalent in mmWave 5G, satcom, and radar markets, Anokiwave is the one that started the action. The company saw a growing need for commercialization of active antennas years before the rest of the market and took the risk of standing out and developing ICs to enable this market.

Most of the microwave community looked at Anokiwave skeptically and questioned our approach. But with a clear focus and a committed team, Anokiwave continued to make a difference—and that's the kind of culture I wanted to be part of.

Anokiwave has a clear market focus of commercializing active antennas, proven technological leadership with the broadest portfolio of Silicon Core ICs available today, and a truly inspiring management team and culture. The culture at Anokiwave is unique and a great fit for me. Everyone here is motivated, works as a team, and goes above and beyond to make a difference. It's a small company and so it's agile—there's no bureaucracy and very action-oriented. I believe most of the industry still underestimates us, which we like. We have a very diverse mix of young, as well as experienced, people working together equally to innovate in new ways that I have never seen before. It's an honor to be part of this very experienced and motivated group of people. Every day I learn something new and we challenge each other in new ways.

The company is founded on our core principles of respect, collaboration, accountability, and innovation, and you can see these values being reflected by every Anokiwaver, each day. Personally, to me, these values matched exactly with mine, and so it was almost a no-brainer to join the team.

What applications are you focused on?

As I mentioned before, our over-arching company goal is to commercialize active antennas to enable a new world of mmWave 5G, satcom, and radar. From an application perspective, we are addressing each use case within these markets, ranging from, but not limited to, active-antenna-based mmWave 5G infrastructure, CPE, satcom ground equipment, satcom-on-the-move, airborne connectivity, military radars, and many others.

We continue to see customers utilize our Silicon Core ICs for multiple new applications, such as sensing and over-the-air testing, which continues to surprise us. But it's clearly evidence of the fact that active antennas are truly becoming mainstream in microwave and mmWave design, and we are glad to be on the leading edge of providing the enabling ICs and supporting these developments.

What do you expect to see in the near future in regard to 5G?

Well, I would like to begin by first noting that October 2018 marked a foretelling milestone in the microwave industry when mmWave commercial 5G truly became a reality. Since October, it's no longer a question of if or when 5G will be used, but rather how fast?

On Oct 1, 2018, Verizon started offering mmWave 5G as a commercial service. You can go to Verizon's website and sign up for it. This is fantastic because despite all of the skepticism concerning mmWave frequencies and whether they can propagate properly, the only commercially deployed service today is mmWave 5G in the U.S.—not the sub-6-GHz that everyone expected. This is a watershed moment for the industry, as it answers the key question about the technical and business viability of mmWave 5G.

Going forward, we see an explosive growth in 5G use cases. We expect to see all major operators accelerating their mmWave 5G deployments in all three bands: 24/26, 28, and 39 GHz. All tier 1 and 2 original equipment manufacturers (OEMs), including the ones who were initially not convinced about the

> "Anokiwave has a clear market focus of commercializing active antennas, proven technological leadership with the broadest portfolio of Silicon Core ICs available today, and a truly inspiring management team and culture... Everyone here is motivated, works as a team, and goes above and beyond to make a difference. It's a small company and so it's agile—there's no bureaucracy and very action-oriented."

mmWave 5G earlier, are now ramping up their developments.

We expect to see a rapid growth of active-antenna-based mmWave infrastructure products, CPE, and even portable consumer devices. Within each of these categories, there will be subcategories of products based on form factor, portability, and power requirements. And each application will require a variant of underlying ICs to meet the power, size, and heat requirements. We are already hearing from the market that mmWave smartphones will be available starting in 2019.

Can you tell us about what Anokiwave is doing in terms of 5G Communications?

We are enabling the commercialization of phased arrays/active antennas in all forms and use cases of 5G communications. We started with a focus on 24/26-, 28-, and 39-GHz Silicon Core ICs for infrastructure products and provided learning platforms, or ready-to-use arrays, to help the market get started.

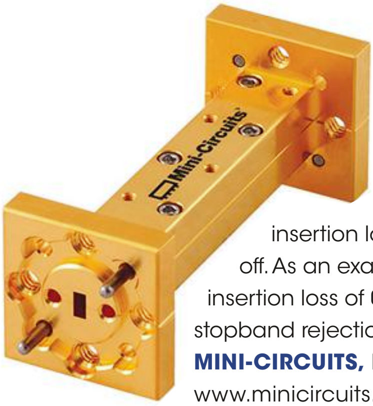
Now that the market has momentum by itself, and as we have gone through the technology learning and implementation curve, we are hyper-focused on continuing to improve performance, to offer multiple variants to meet the unique requirements of each use case within 5G, and most importantly, to drive the cost down to what we call "ultra-low-cost" ICs.

With silicon-based ICs, we continue to innovate and lead the market in performance, digital functionality, cost reduction, and thermal management. With innovation on these fronts, we expect mmWave active-antenna technology to become ubiquitous and that by 2020, every network operator, every OEM, and likely every UE manufacturer will be using active antennas in high volume. This market is moving faster than anyone predicted, and we are prepared to address every use case within the 5G applications.

Lastly, Anokiwave recently opened an office in Taiwan. Can you talk about the reasons behind that?

Absolutely. We opened a new sales office in Taiwan to provide close sales, application engineering, and operations support to all customers in the Asia Pacific region. One of the key philosophies of Anokiwave has been to support our customers at a system level. For us, we feel it's our responsibility to work closely with our customers from the time they identify a need, through their design process, and then during and after production.

A local presence allows us to work even closer and support our customers by minimizing delays due to time differences, eliminating bureaucracy, minimizing language and cultural barriers, and most importantly, providing direct face-to-face support. We expect to continue to build our team in Taiwan and other locations in Asia in the coming year, as we are seeing very strong pull from the market.

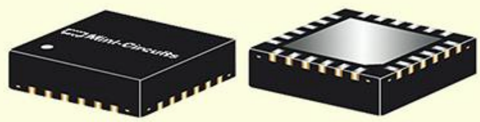


Waveguide Bandpass Filter Passes 81 to 86 GHz

MINI-CIRCUITS AND VIRGINIA DIODES have teamed up to offer a new series of high-performance, high-fidelity waveguide bandpass filters for millimeter-wave applications. WVBP-series filters come in various passbands spanning 27 to 86 GHz and are offered with standard WR rectangular waveguide interfaces. Built with precise machine tolerances and high-quality plating, WVBP-series filters feature low insertion loss in the passband, outstanding return loss, and high stopband rejection with fast roll off. As an example, model WVBP-833-WR12+ has a passband of 81 to 86 GHz with typical passband insertion loss of 0.5 dB, typical return loss of 26 dB, lower stopband rejection of 90 dB, and upper stopband rejection of 49 dB. It maintains a WR12 waveguide interface and is 2.0 in. long.

MINI-CIRCUITS, P.O. Box 350166, Brooklyn, NY 11235-0003; (718) 934-4500, www.minicircuits.com/WebStore/dashboard.html?model=WVBP-833-WR12%2B

Wideband MMIC Directional Coupler Covers 6.0 to 26.5 GHz



MINI-CIRCUITS' MODEL EDC10-273+ is a surface-mount, GaAs MMIC directional coupler with a frequency range from 6.0 to 26.5 GHz. The 10-dB coupler offers typical coupling flatness of ±1.5 dB across the full frequency range. It has low mainline loss of typically 1.4 dB and maintains typical directivity of 15 dB through 18 GHz and 11 dB to 26.5 GHz. The typical input return loss is 24 dB to 10 GHz, 17 dB to 18 GHz, and 15 dB to 26.5 GHz. Typical output return loss is 22 dB to 10 GHz and 16 dB or better through 26.5 GHz. Typical coupled-port return loss is 24 dB to 10 GHz and 14 dB or better through 26.5 GHz. The miniature directional coupler is supplied in a 24-lead QFN package measuring just 4 × 4 mm.

MINI-CIRCUITS, P.O. Box 350166, Brooklyn, NY 11235-0003; (718) 934-4500, www.minicircuits.com/WebStore/dashboard.html?model=EDC10-273%2B

Coaxial Directional Coupler Extends from 2 to 40 GHz

MINI-CIRCUITS' MODEL ZCDC13-K0244+ is an extremely wideband, dc-passing directional coupler with an operating frequency range of 2 to 40 GHz. This model provides 13-dB coupling with flatness of ±0.6 dB across the frequency range, and typical directivity of 16 dB through 40 GHz. It can handle signal power levels to 20 W with low mainline loss of typically 0.8 dB through 18 GHz and 1.5 dB through 40 GHz. The input, output, and coupled-port return losses are typically 14.0 dB through 18 GHz and 11.7 dB through 40 GHz. The broadband, RoHS-compliant directional coupler is well-suited for many applications in 5G, fixed-satellite, mobile-communications systems, and more. It measures 2.25 × 0.7 × 0.50 in. (57.15 × 17.78 × 12.70 mm) with 2.92-mm female coaxial connectors and can handle operating temperatures from –55 to +100°C.

MINI-CIRCUITS, P.O. Box 350166, Brooklyn, NY 11235-0003; (718) 934-4500, www.minicircuits.com/WebStore/dashboard.html?model=ZCDC13-K0244%2B

Amp Module Delivers 100 W from 6 to 18 GHz

MODEL BME69189-100 is a compact Class AB power-amplifier module capable of 100 W saturated output power from 6 to 18 GHz with 46-dB typical gain. Based on solid-state GaN technology, it's a lightweight replacement for traveling-wave-tube (TWT) amplifiers. Standard units operate on +28 V dc, with an option for use at +270 V dc. Typical gain flatness is ±2 dB for a +5-dBm input signal level. The amplifier module maintains low noise levels, with second harmonics of –12 dBc or less, third harmonics of –22 dBc or less, and spurious levels of –60 dBc or less. Typical noise power output is –90 dBc/Hz. The amplifier module measures 8.0 × 6.0 × 2.5 in., weighs 5.5 lbs., and has an operating temperature range of –40 to +75°C (and is designed for use with an external heatsink). It's equipped with field-replaceable SMA female input RF connectors and field-replaceable TNC female output RF connectors.

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

USB Spectrum Analyzer Spans 1 Hz to 4.4 GHz

THE MODEL USB-SA44B is a USB-powered economy spectrum analyzer with frequency range of 1 Hz to 4.4 GHz. It offers resolution bandwidth of 0.1 Hz to 250 kHz and 5 MHz, with real-time measurement modes for spans of 250 kHz or less. The compact instrument is well-suited for general laboratory and field use, with a measuring receiver capable of ±1% typical AM accuracy and ±1% typical FM accuracy from 150 kHz to 4.4 GHz. The instrument's Spike software running on a PC with USB cable provides the measurements. The displayed average noise level (DANL) ranges from –124 dBm at 10 Hz with no preamplifier to –161 dBm from 10 to 100 MHz with preamplifier on. Standard operating temperature range is 0 to +70°C, although an operating range of –40 to +85°C is available as an option. The USB spectrum analyzer comes with several accessories (manufactured by Mini-Circuits), including a dc block and 20-dB fixed attenuator.
BRL TEST, (authorized distributor), La Center, WA 98629; (360) 263-5006, FAX: (360) 263-5007, www.signalhound.com

Flexible, Twistable Waveguide Extend from 5.85 to 50 GHz

A TOTAL OF 78 flexible and twistable waveguide sections have been developed in 10 frequency bands from WR-137 through WR-22 for frequency coverage from 5.85 to 50.00 GHz. Of the 78 models, 39 are seamless, flexible sections and the other 39 are twistable. Seamless, flexible units are constructed of solid brass and feature insertion loss as low as 0.06 dB, VSWR as low as 1.07:1, and power-handling capability as high as 5 kW, depending on frequency. Twistable models are made of twist-flex material formed of interlocking brass that allows it to slide on itself in different directions. These twistable sections offer insertion loss as low as 0.15 dB, VSWR as low as 1.05:1, and power-handling capability as high as 1.5 kW.
FAIRVIEW MICROWAVE, 17792 Fitch, Irvine, CA 92614; (978) 682-6936, www.fairviewmicrowave.com

Micro-D Connectors Handle High Shock and Vibration

A LINE OF QPL Micro-D subminiature connectors meet or exceed the requirements of MIL-DTL-83513 for high shock and vibration applications in military and commercial systems. The connectors feature a beryllium-copper spring-pin-to-socket system with nickel and gold plating to ensure reliable connections with low contact resistance even after multiple connect/disconnect cycles. Pins and sockets are set at 0.050-in. center-to-center spacing. Standard and commercial-off-the-shelf (COTS) connectors are available with pin counts from 9 through 51 and come in solder cup and wired as well as board-mount configurations.
OMNETICS CONNECTOR CORP., 7260 Commerce Circle East, Minneapolis, MN 55432; (763) 572-0656, FAX: (763) 572-3925, e-mail: sales@omnetics.com, www.omnetics.com

Compact Recorders Capture RF/IF Signals

MODEL RTX 2590 small-form-factor signal recorders are packed into compact ½ ATR housings for capturing RF and intermediate-frequency (IF) signals with eight high-speed digitizing channels. It measures just 7.688 × 4.880 × 14.125 in. Powered by eight phase-coherent 16-b analog-to-digital converters (ADCs) operating at 250 Msamples/s, the subsystem can sustain real-time recording rates to 4 GB/s. It's designed to work with dc power supplies from +12 to +28 V dc and can be equipped with an optional GPS receiver for precise time and position stamping of captured signals. Built to MIL-STD-810 requirements for harsh mechanical and thermal environments, the RF/IF signal recorder weighs just 22 lbs. (10 kg) and is a good fit for military vehicles and UAVs.
PENTEK INC., One Park Way, Upper Saddle River, NJ 07458; (201) 818-5000, FAX: (201) 818-5904, e-mail: info@pentek.com, www.pentek.com

Low-Profile Antenna Provides 6-GHz DAS Coverage

MODEL CFSA35606P is a low-profile antenna designed for public-safety and FirstNet distributed-antenna-system (DAS) applications. It exhibits low passive-intermodulation (PIM) performance with coverage from 350 to 520 MHz and 0.6 to 6.0 GHz. The ceiling-mounted indoor antenna achieves gain ranging from 4.4 dBi or higher at the lowest frequencies to 7.3 dBi from 4.9 to 5.9 GHz. The PIM is better than –150 dBc at all frequencies. The 50-Ω, omnidirectional, horizontally polarized antenna has a height of 0.3 in. (7.6 mm) and diameter of 10.6 in (270 mm) with a 30-cm cable. It can handle power levels to 50 W at room temperature and is usable at temperatures from –40 to +85°C.
LAIRD CONNECTIVITY, Akron, OH; (847) 839-6925, www.connectivity.lairdtech.com/rf-antennas

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