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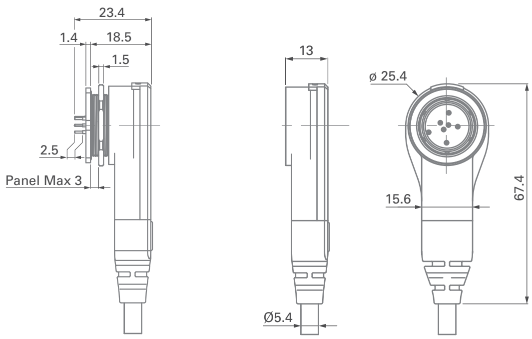

LP360™ RECEPTACLE - PANEL MOUNTED OR SEWN-IN

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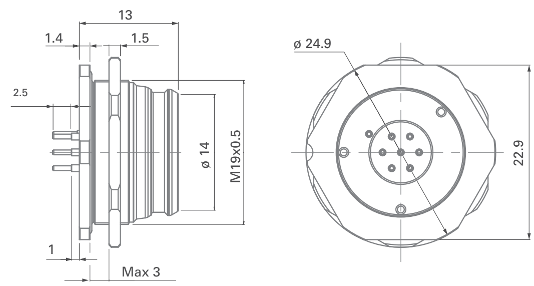

ELECTRICAL DATA

Number of contacts	7
Rated voltage (rms)	≤ 250 V
Typical operating voltage	9-48 V
Max. current rating	3x 5A + 4x 1A
Max. wire size	AWG 24
Data protocols	USB 2.0 and Ethernet

ENVIRONMENTAL DATA

Characteristic	Performance	Standard
Corrosion resistance	1,000h salt mist	MIL-STD-883 Method 1009.8
Sealing	IP67 unmated	MIL-STD-810 Method 512.6
	IP68 mated -20m/24h	
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EMI/EMC	360°	Protection by design

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3D-Print Your High-Frequency RF/Microwave Antennas p44

How Does GaN Figure Prominently in 5G Sub-6-GHz Massive MIMO? p52

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P20T-4G8G-80-T-515-SFF
P20T-7G18G-80-T-515-SFF-SP

P32T-0R5G18G-60-T-SFF

P16T-100M20G-60-T-512-SFF
P16T-100M20G-60-T-512-SFF-DEC
P16T-18G40G-90-T-512-SFF-DEC

P16T-100M40G-100-T-I-292
P16T-100M50G-100-T-I

PMI Model No.	FREQ Range (GHz)	Insertion Loss (dB)	Isolation (dB)	Switching Speed	Configuration	DC Voltage Supply / Current Drtaw	Size (Inches) / Connectors
P20T-4G8G-80-T-515-SFF https://www.pmi-rf.com/products-details/p20t-4g8g-80-t-515-sff	4 - 8	4 dB Max	80 dB Min	100 ns Typ	SP20T Absorptive	+5 VDC (±5%) @ 300 mA Max, +15 VDC (±2%) @ 200 mA Max	4.0" SQ X 0.63" SMA Female
P20T-7G18G-80-T-515-SFF-SP https://www.pmi-rf.com/products-details/p20t-7g18g-80-t-515-sff-sp 20 Output Ports are Amplitude Balanced to +/-0.25 dB Peak to Peak Max.	7 - 18	7.5 dB Max	65 dB Min	240 ns Typ	SP20T Absorptive	+5 VDC (±5%) @ 500 mA Max, -12 to -15 VDC (±2%) @ 200 mA Max	4.0" SQ X 0.63" SMA Female
P32T-0R5G18G-60-T-SFF https://www.pmi-rf.com/products-details/p32t-0r5g18g-60-t-sff	0.5 - 18	9.5 dB Max	70 dB Min	100 ns Max	SP32T Absorptive	+5 VDC @ 1600 mA, -5 VDC @ 20 mA	8.0" x 3.0" x 0.65" SMA Female
P16T-100M20G-60-T-512-SFF https://www.pmi-rf.com/products-details/p16t-100m20g-60-t-512-sff	0.1 - 20	8.5 dB Max	60 dB Min	150 ns Max	SP16T Absorptive	+5 VDC @ 750 mA Max, -12 VDC @ 200 mA Max	8.0" x 3.0" x 0.65" SMA Female
P16T-100M20G-60-T-512-SFF-DEC https://www.pmi-rf.com/products-details/p16t-100m20g-60-t-512-sff-dec	0.1 - 20	8.5 dB Max	60 dB Min	150 ns Max	SP16T Absorptive	+5 VDC @ 750 mA Max, -12 VDC @ 200 mA Max	8.0" x 3.0" x 0.65" SMA Female
P16T-18G40G-90-T-512-SFF-DEC https://www.pmi-rf.com/products-details/p16t-18g40g-90-t-512-sff-dec	18 - 40	12 dB Max	50 dB Min	150 ns Max	SP16T Absorptive	+5 VDC @ 750 mA Max, -12 VDC @ 200 mA Max	8.0" x 3.0" x 0.65" 2.92mm Female
P16T-100M40G-100-T-I-292 https://www.pmi-rf.com/products-details/p16t-100m40g-100-t-i-292	0.1 - 40	10 dB Typ	100 dB Typ	50 ns Typ	SP16T Absorptive	+5 VDC @ 800 mA Max, -5 VDC @ 700 mA Max	12.0" x 5.5" x 0.65" 2.92mm Female
P16T-100M50G-100-T-I https://www.pmi-rf.com/products-details/p16t-100m50g-100-t-i	0.1 - 50	16 dB Typ	70 dB Typ	100 ns Max	SP16T Absorptive	+5 VDC @ 800 mA Max, -5 VDC @ 700 mA Max	12.0" x 5.5" x 0.65" 2.4mm Female

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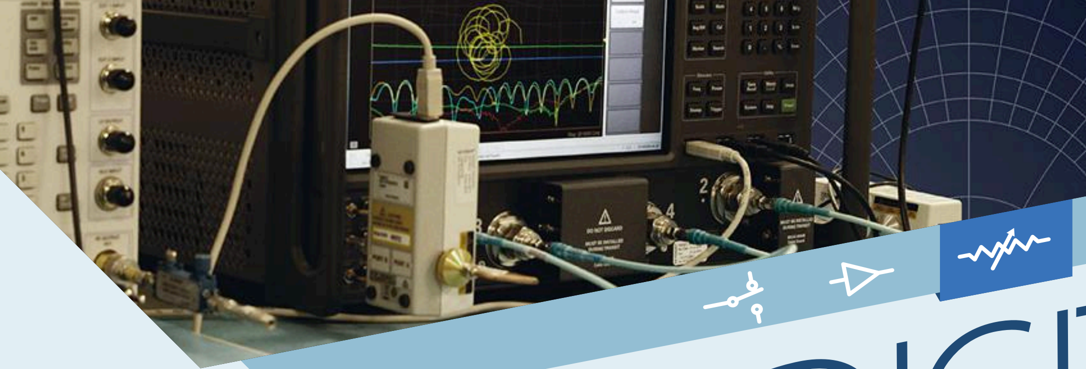

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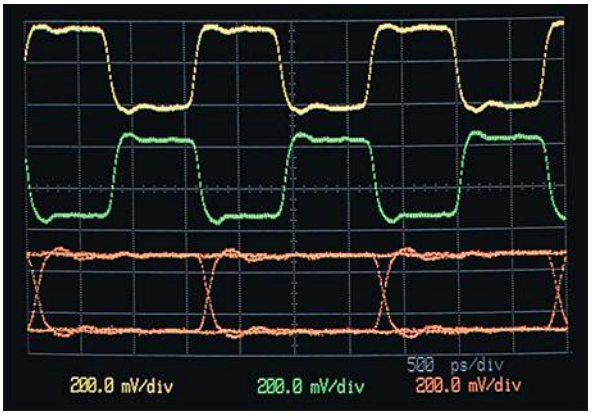

Plot shows complementary clocks and PRBS (opt. 01) outputs at 622.08 Mb/s with LVDS levels. Traces have transition times of 80 ps and jitter less than 1 ps (rms).

The CG635 generates clock signals—flawlessly. The clock signals are fast, clean and accurate, and can be set to standard logic levels.

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PRODUCTS & TECHNOLOGY

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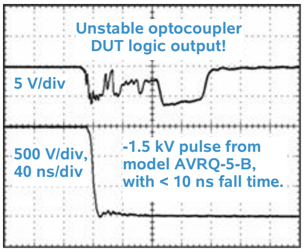
Transient Immunity Testers from AVTECH

The Avtech AVRQ series of high-voltage, high-speed pulse generators is ideal for testing the common-mode transient immunity (CMTI) of next-generation optocouplers, isolated gate drivers, and other semiconductors.



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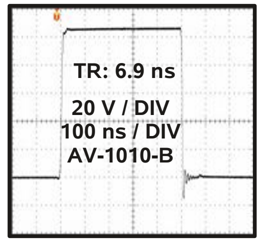

Model AV-1015-B:	**50 Volts, 10 MHz**
Model AV-1010-B:	**100 Volts, 1 MHz, 25 ns to 10 ms, 10 ns rise time**
Model AV-1011B1-B:	**100 Volts, 2 ns rise time**
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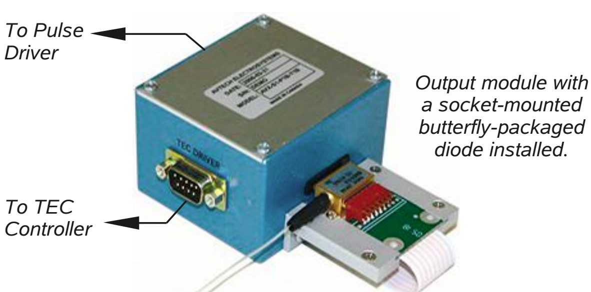
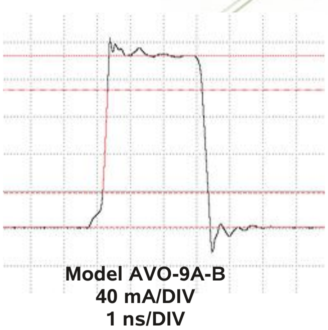
Nanosecond Laser Diode Drivers With Butterfly Diode Sockets





Each of the 19 models in the Avtech AVO-9 series of pulsed laser diode drivers includes a replaceable output module with an ultra-high-speed socket suitable for use with sub-nanosecond rise time pulses. Models with maximum currents of 0.1A to 10A are available with pulse widths from 400 ps to 1 us. GPIB, RS-232, and Ethernet control available.

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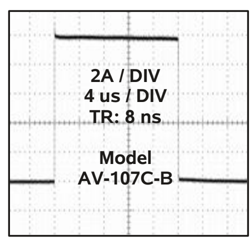

Series	I, V	PW	TR
AV-107	2 - 20 A, 60 V	0.2 - 200 us	10 - 30 ns
AV-106	5 - 100 A, 100 V	0.5 us - 1 ms	50 ns - 1 us
AV-108	12.5 - 200 A, 100V	2 us - 1 ms	5 - 15 us
AV-109	10 - 100 A, 5 V	10 us - 1 s	10 us
AV-156	2 - 30 A, 30 V	1 us -100 ms	0.2 - 50 us

Avtech has a long history of producing one-of-a-kind custom units.

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MACOM’s cross reference search will assist you in finding MMIC, Transistor and Diode alternatives to recently announced end-of-life products.

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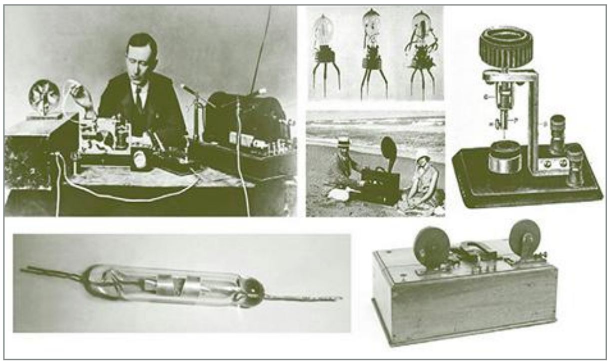

A Selected History of Receiver Innovations Over the Last 100 Years (Part 1)

From Marconi's early inventions, to the Fleming valve, to the Coherer device, among a number of other milestone developments, this article explores the beginnings of the wireless world, focusing on receivers.

https://www.mwrf.com/systems/selected-history-receiver-innovations-over-last-100-years-part-1

Synthesizing an Antenna Array with Optimization Techniques

In this "Algorithms to Antenna" installment, MathWorks' Rick Gentile discusses how array-synthesis optimization techniques can prove beneficial in the development of phased-array antennas.

https://www.mwrf.com/systems/algorithms-antenna-synthesizing-antenna-array-optimization-techniques

Power Dividers: Basic Tools Designers Can't Live Without

Power dividers, which are used extensively in a range of scenarios that require power to be split, seem to be simple devices on the surface—but that's not the case at all.

https://www.mwrf.com/components/power-dividers-basic-tools-designers-can-t-live-without

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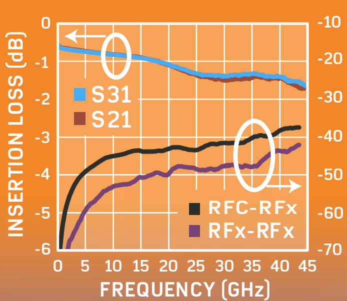

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Editorial

CHRIS DeMARTINO | Technical Editor
chris.demartino@informa.com

Does Your Company's Website Do It Justice?

RF/microwave companies are pushing out new websites to meet modern business needs. How do they stack up against your firm's site?

The RF/microwave industry has recently seen the launch of several new websites from companies such as Integra Technologies *(www.integratech.com)*, Copper Mountain Technologies *(www.coppermountaintech.com)*, and Rohde & Schwarz *(www.rohde-schwarz.com)*, just to name a few. It's good to see companies unveiling fresh new sites—it's obviously no secret that a good website is vital for businesses today.

The recipe for a good website in 2018 is, of course, quite a bit different than it was back in 2008. With smartphones now being an essential part of our lives, a large percentage of web traffic originates from mobile devices. Needless to say, then, that a website should be developed with mobile-device usability in mind.

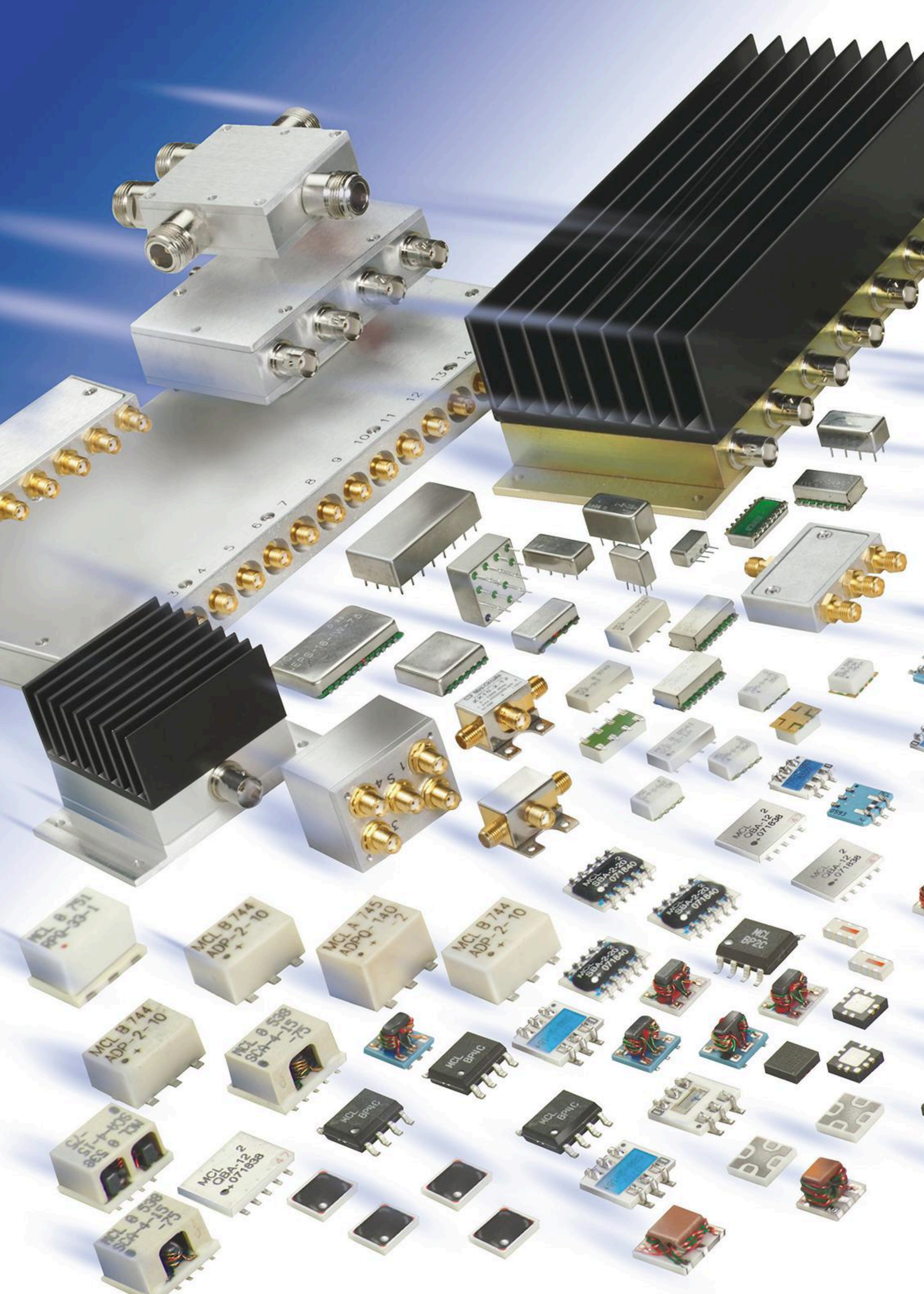
Websites for RF/microwave companies shouldn't be an exception to mobile usability. For instance, let's say you're waiting for your flight with your phone in hand. You suddenly realize that you need to go online to check on some sort of product information from a company trying to sell you that product. If that company's website wasn't developed for mobile usability, you could have a hard time getting the information you need.

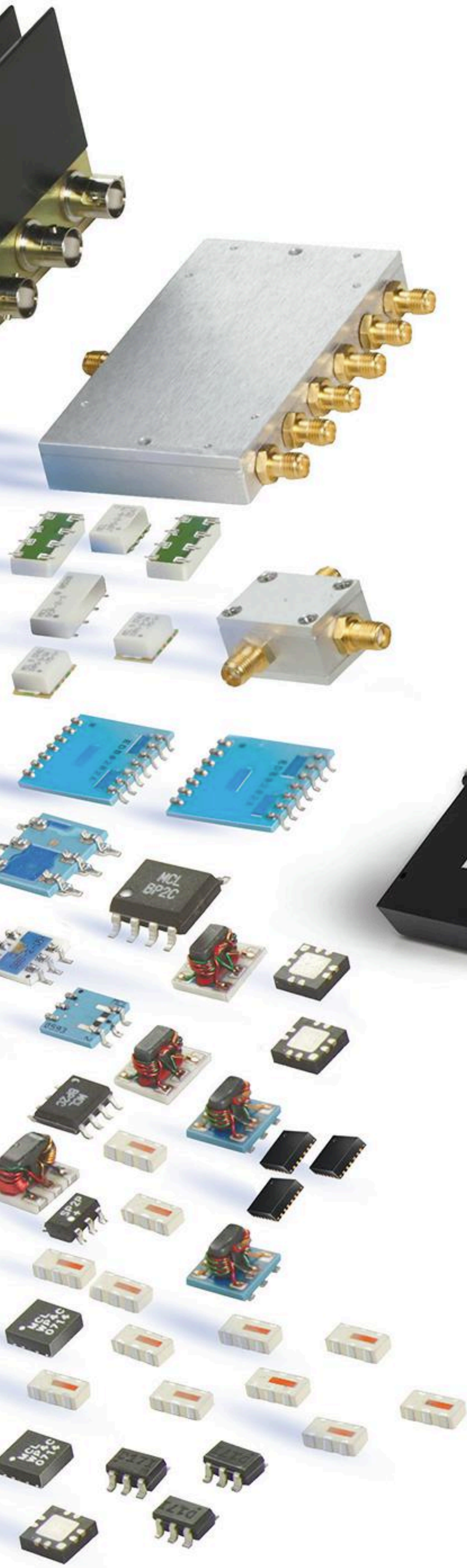
Another important factor when it comes to websites is the content management system (CMS). WordPress, which now powers about 30% of websites, is used by many smaller RF/microwave companies as their CMS.

Then there's Strand Marketing *(www.strandmarketing.com)*, which developed its own CMS, known as Intent ICMS (integrated content management system). The agency has built websites for several companies in the RF/microwave industry, including the aforementioned Integra Technologies. Additional clients include Custom MMIC *(www.custommmic.com)* and SemiGen *(www.semigen.net)*, among others.

So, what makes a good website? Answers to that question tend to vary somewhat. Personally, I like a site that makes it easy to find the information you are searching out. For example, let's say you need to access a white paper or application note from a company's site. I would venture to say that some of you have had the experience of not being able to easily find that sort of information. I think that experience should be considered when developing a site. That's just one of several factors, all of which I may address at some point in the future.

This discussion could go on in greater detail, getting into topics such as analytics, blogging, social media, etc. In the end, companies in the RF/microwave industry will hopefully continue to realize the importance of a good website because it can only help them in today's instant-access age. mw


MCL B 744
ADP-2-10
MCL QBA-12
071838
MCL SBA-2-20
071840
MCL BP2C
MCL BP4C
MCL B 538
SCA-4-15
-75



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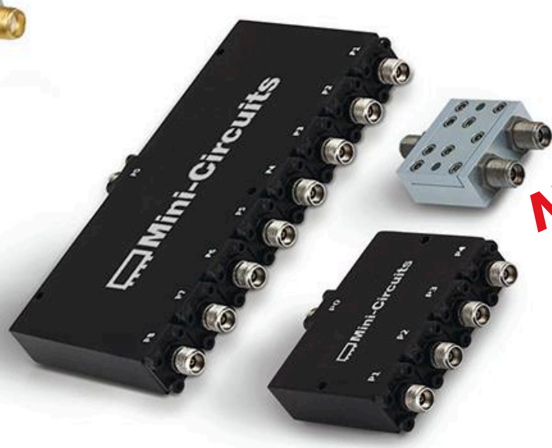

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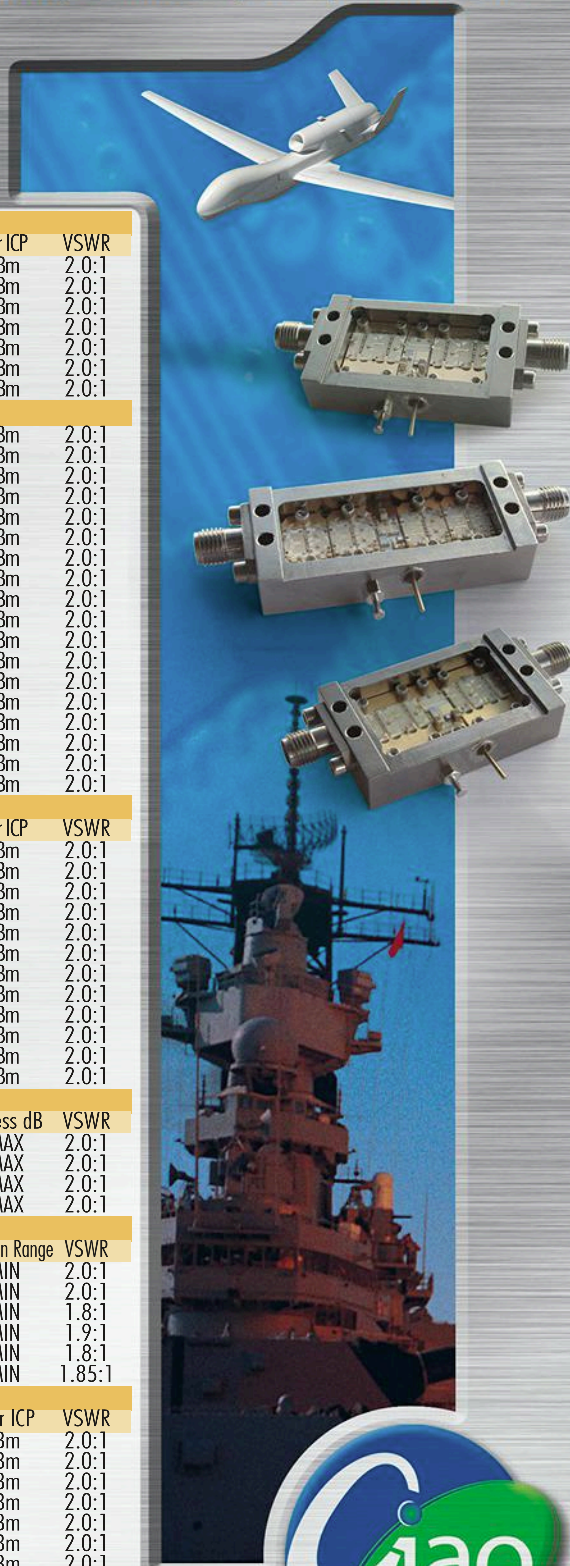

OCTAVE BAND LOW NOISE AMPLIFIERS

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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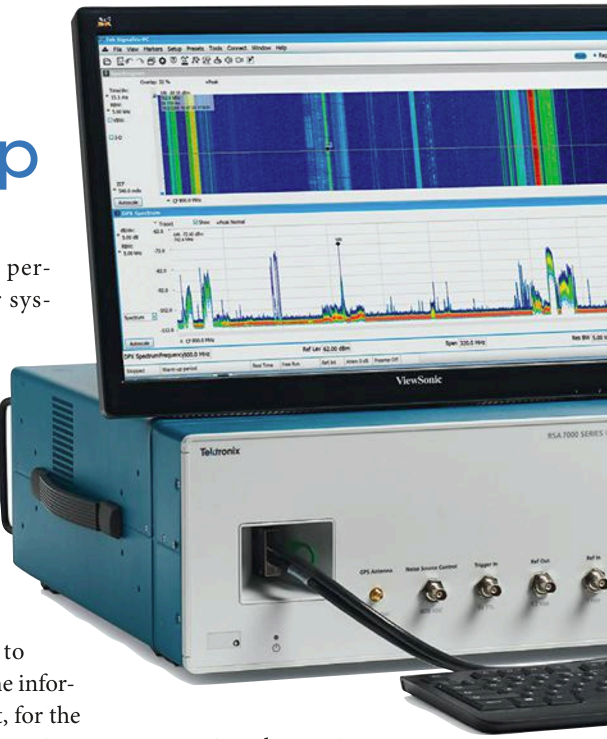
News

GETTING LOOPED into Hardware-In-The-Loop



In a recent announcement, Tektronix *(www.tek.com)* revealed that its RSA7100A wideband signal-analysis solution is now equipped with IQFlow functionality *(see figure)*. This enhancement makes it possible to perform real-time digital signal processing (DSP) and support hardware-in-the-loop (HIL) testing for radar and electronic-warfare (EW) systems.

"Defense contractors in the U.S. are increasingly under pressure to get a more reliable, accurate assessment of how well the radar systems will deploy in a threat/response military environment," explains Chris Loberg, senior marketing manager for the wideband solutions group at Tektronix. "They want that assessment to the extent that they can simulate the threat/response without actually physically running wartime exercises. HIL attempts to emulate that environment and provide a radar system designer with a more accurate assessment of what's happening."

Closely emulating a real-time environment is of paramount importance when it comes to HIL, according to Loberg. "The key is to get as close as possible to a real-time environment," he says. "That enables a radar system that's looking for a threat to confirm, with the highest possible degree of confidence, that the threat is there. The radar system should then be able to initiate a response in a manner that provides something that extinguishes that threat—in other words, a missile being activated or triggered in response to a threat being perceived as real from the radar system. That threat/response scenario is what we're trying to help defense contractors deploy today."

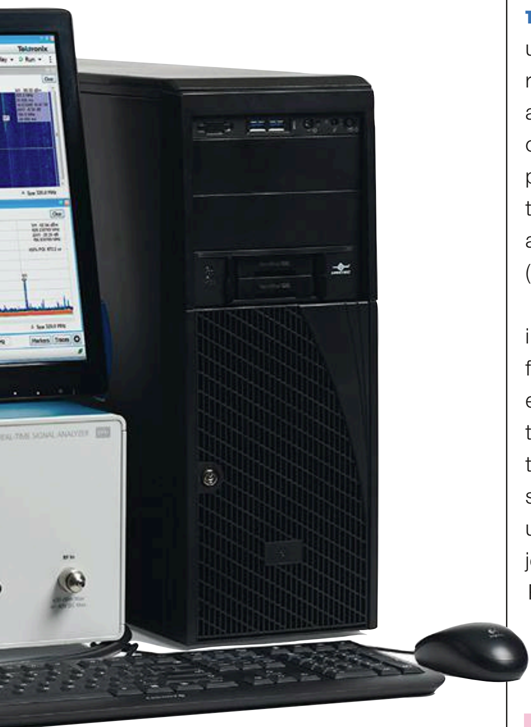
What were some of the roadblocks associated with this technology? Loberg notes, "The real-time nature has been out of reach. That's primarily because the FPGAs lacked the processing speeds to accurately detect and provide the information to the system under test, for the system to then send out a response in a quick enough timeframe. The response must have all the directional and signal intelligence guidance necessary to go after the threat in a way that will extinguish it."

"In the past," continues Loberg, "with the lack of a real-time response, we contracted with and worked closely with large RAID (redundant array of independent disks) vendors to save all the detection sequences from the environmental warfare system in a recorded fashion. All the detected I/Q data was stored away on a RAID drive.

"The designers would later assess timing of threats. They would also have to determine if they could play back the data and reconstruct, so that response systems are triggered off the timing of the threat. But that would only happen in a non-real-time fashion. One would have to go offline and sort through hours and hours of data to find specific threats and then look at those trigger events as just that—triggers for the response stimuli."

Tektronix asserts that IQFlow brings a new dimension to the table. Loberg adds, "With the announcement of IQFlow, we've now moved closer to modified real-time EW from an HIL perspective. With the enhancements made to the RSA7100A, we can provide access to the streamed I/Q data in real-time. Contractors can use the latest and greatest FPGA technology to get the system as close as possible to a real-time state. That effort is taking place right now on the east coast with one defense contractor. As these firms are armed with very fast FPGA capability, Tektronix with IQFlow is opening up the I/Q data for direct querying and assessment of threats."

Loberg also mentions what Tektronix is planning to introduce in the future. "The next step for us is to provide the arbitrary waveform generators (AWGs) with the same capability.



With IQFlow, the RSA7100A real-time spectrum analyzer can perform real-time digital-signal-processing algorithms and record/analyze long event sequences.

The AWG forms the response stimuli. In a modified system, it will send out a response to a threat like initiating into the spectral environment a pulse that would represent some deterrent device. We're enhancing the ability of the AWG to receive and respond more quickly by opening up an Ethernet port on the instrument that will enable the FPGA controller to say it's time to send out a response and identify the waveform type to send. The AWG would respond and play the role of the response emitter."

Loberg sums it up with this: "The key takeaways are the closer to real-time the system can be, the more effective the EW simulation, and the lower the risks associated with live wartime simulation." ■

MINIATURIZING SMART WEARABLES for Fitness and Activity Tracking

TRADITIONALLY, SMALL CHIP ANTENNAS used in Bluetooth-enabled devices have required a designated ground "keep out" area to minimize interference from other components and ensure the ideal radiation pattern for wireless signals. In some cases, this reserved space can eat up as much as 15 × 20 mm of the printed circuit board (PCB).

However, with the drive to further miniaturize connected "smart" wearables for fitness and activity tracking, new tiny embedded chip antennas are now available that mount directly above metal surfaces to save as much as 10% to 20% of board space. This has major implications for manufacturers of smart rings, bracelets, shoes, jeans, shirts, and other apparel since the PCB, along with its coin-cell batteries, typically dictate the minimum size of the electronics involved.

SMART WEARABLES

A wave of "smart" wearable devices has already entered the market to monitor everything from fitness and health to the physical environment. Often equipped with gyroscope, accelerometer, temperature and pressure sensors, along with GPS and even microphones, these tiny devices can track vital signs, sleep, emotions, stress, breathing, movement, and send/receive messages and alerts through text, audible sounds, and even colors. As with any "connected" device, this information is then shared via wireless signals such as Bluetooth to a smartphone.

Among the products already incorporating this type of technology are smart bracelets that monitor movement, body position, and vital signs to detect if an elderly person has had a debilitating fall; a necklace that records voice memos before translating them into text; and even 8k gold-plated rings with choice of gemstone that serve as activity trackers.

Connected clothing and other apparel, such as jeans, yoga pants, and other attire, also now contain sensors designed to keep track of workouts and monitor body temperature, posture, and movement. Not to be outdone, the $130.3 billion retail sports footwear market offers intelligent running shoes that connect to popular distance/speed tracking apps while also measuring acceleration, cadence, ground contact time, and other factors to improve performance.

EMBEDDED CHIP ANTENNAS

To make this all work, each device must contain small RF chip antennas embedded on the PCB or behind the scenes underneath the encasement of the product. These chip antennas radiate and receive electromagnetic (EM) waves much like other types of antennas, but the most notable difference is their small size. In fact, today's mobile phones incorporate a minimum of four antennas and up to 13 in some models. Smaller wearable devices may only contain one or two antennas.

To work properly, chip antennas usually depend on a ground plane, meaning they require an appropriately sized and positioned ground plane to form a complete resonant circuit. While the PCB can serve as the ground plane, the antenna itself must typically be placed on the edge of the board in an isolated section free from ground and metal components that would otherwise distort its radiation. Without the isolation distance, the performance of the antenna is significantly affected.

"The 'keep-out area' is fundamental to ensure the chip antenna can electromagnetically radiate to antenna applications, because everything affects the radiation pattern, including the package size, where the antenna is mounted, and its proximity to the human body," says Manuel Carmona of Johanson Technology, a leader in high-frequency ceramic components, including chip antennas, high-Q capacitors, and EMI chip filters.

According to Carmona, Johanson Technology has been able to eliminate the requirement for a designated ground keep-out area by optimizing materials (ceramics and inks), manufacturing processes, and RF circuit design.

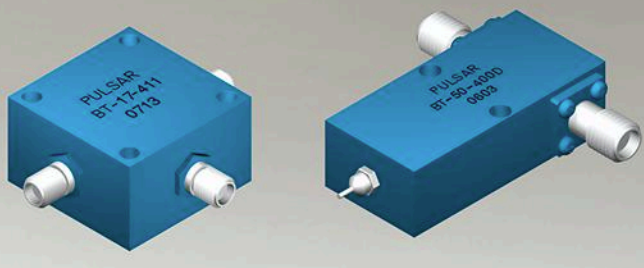
The company has developed a 2.4-GHz antenna that can be mounted directly onto the metal ground plane. Measuring 2 × 5 mm, it's designed for small coin-cell-battery-operated wearable applications where metal or a battery/display covers the entire length or side of the PCB.

"With PCB real estate at a prime, the size and placement of the chip antenna is critical because as everything gets smaller, it becomes increasingly difficult to place more components on the board," explains Carmona. "Therefore, design engineers are looking to component manufacturers to deliver miniaturized solutions that occupy next to no real board space."

The design of the antenna itself is also critical to its range and performance. With smart wearables, radio interference or some other glitch could result in interrupted connectivity.

There can be legal ramifications as well. As with any wireless device, products that utilize RF technology, including Bluetooth, to collect or transmit information are subject to regulation by the Federal Communications Commission (FCC). Therefore, it's essential that the device perform at the designated frequency, and the design and placement of the antenna is critical to proper tuning.

Despite the critical nature of the antenna, Carmona says it's often overlooked until late in the design process, at which point optimal antenna performance may not be achievable within the space provided. To assist with chip antenna design and selection, Johanson Technology offers a program in which design engineers can send in a miniaturized device and the company will tune the antenna for optimum functionality.



"A chip antenna that can be mounted over a ground plane opens up many applications for products that want to incorporate wireless," says Carmona. "To date, we have received everything from smart shirt buttons to jewelry and other wearables in various shapes and sizes."

For more information, contact Johanson Technology at (805) 389-1166, e-mail antenna@johansontechnology.com, or visit www.johansontechnology.com/ant. The company is located at 4001 Calle Tecate, Camarillo, CA 93012 ■

JEFF ELLIOTT is a Torrance, Calif.-based technical writer. He has researched and written about industrial technologies and issues for the past 20 years.

ARMY EYES GENERAL DYNAMICS for Common Hardware Systems

GENERAL DYNAMICS MISSIONS SYSTEMS was awarded a contract for the fifth generation of the Common Hardware Systems (CHS-5) program from the Army Contracting Command at Aberdeen Proving Ground, Maryland. The indefinite delivery, indefinite quantity (IDIQ) contract consists of a three-year base contract with two one-year options, with a potential maximum value of $3.9 billion.

"The CHS program is a great example of how the Army and industry can partner to ensure military services can rapidly acquire C4ISR solutions and other products that are not only cost-competitive with the commercial market, but logistically managed and supported for an extended period," said Chris Marzilli, president of General Dynamics Mission Systems. "More importantly, the ability of the CHS program to quickly adapt to the evolving challenges of today's battlefield plays a critical role in supporting the Army's tactical network modernization efforts."

The various phases of CHS programs were developed to provide speedy tactical information technology (IT) solutions for the various branches of the military *(see photo)*. The different military branches and Department of Defense (DoD) program offices participating in the CHS programs can complete IT hardware orders in 90 days or less using commercial-off-the-shelf (COTS) IT hardware and services. As many as 100,000 pieces of hardware will be acquired through the contract from General Dynamics Missions Systems and its partners. ■

A Common Hardware Systems contract with General Dynamics Missions Systems and partners provides the Army with rapid delivery of tactical IT equipment and services. *(Photo courtesy of General Dynamics)*

DON'T HOLD THAT CELL PHONE Quite So Close!

Many people rely on their portable cellular telephones; some even spend a better part of each day with the electronic device close to either ear. But they may want to reconsider, according to recent research revealed by the National Institute of Environmental Health Sciences' (NIEHS) National Toxicology Program (NTP), a part of the U.S. National Institute of Health. The NIEHS reviewed the NTP's draft reports on its carcinogenesis studies of cellular-telephone RF radiation in mice and rats during a three-day March 26-28, 2018 meeting in Research Triangle Park, N.C.

The extensive review on the effects of electromagnetic (EM) energy on living tissues has been the largest of the NTP's animal cancer studies. Results were checked by an invited 14-member peer-review panel, including electrical-engineering professors and toxicologists, were part of the review, but no members of the cell-phone industry.

The study was initiated by the U.S. Food and Drug Administration (FDA) in 1999 as a five-year project that was then sole-sourced in 2004 to an industrial research firm. The project, which suffered enormous budget overruns, had an eventual estimated price tag of $25 million. Part of the study involved lifelong exposure of rats (lifelong being two years in their cases) to 900- and 1900-MHz RF radiation with code-division-multiple-access (CDMA) and Global System for Mobile Communications (GSM) cell-phone modulation formats.

During the third day of the scientific/medical meeting (March 28), the researchers revealed that both GSM- and CDMA-modulated RF radiation led to development of malignant schwannoma (cancer) in the hearts of male rats. They also pointed out that the same risk for malignant schwannoma existed for female rats exposed to the same conditions. Those conditions included exposure in large reverberation chambers, using 10-minute-on and 10-minute-off cycling for 19 hr/day during the two-year research period.

Different specific absorption rates (SARs) were used on the subjects, never raising the body temperatures of the exposed animals by more than 1°C. To achieve realistic exposure levels, the reported SARs in the brains and the hearts of the rats were only 1.05 and 2.27 times, respectively, the whole-body average SARs of the test subjects.

The NTP cell-phone RF study is the largest study of its kind. While it may not provide significant enough evidence (statistical significance) for most cell-phone users to put down their portable telephones, it does reveal evidence that prolonged exposure to RF radiation at or a little above currently accepted RF exposure regulation levels could lead to the development of tumors in cell-phone users.

See "Clear Evidence of Cell-Phone RF Radiation Cancer Risk," *IEEE Microwave Magazine*, Vol. 19, No. 6, September/October 2018, p. 16.

MAKE SURFACES INVISIBLE to Microwave Beams

AUTOMOTIVE ELECTRONIC SAFETY systems are increasingly using radar technology to warn of obstacles and other vehicles in a driver's path. It's just one electronic technology that has made a transition from warfare to peacetime applications. Could it be just a matter of time when electronic cloaking systems also find their way over to peacetime applications?

Cloaking systems for warfare usually have a way of applying some layer of negative permittivity to a conducting or dielectric object to ensure that it does not appear on an adversary's radar screen. A conceivable peacetime cloaking system could provide police officers with a means of avoiding detection by motorists ignoring posted speed limits and on the lookout for law enforcers.

Researchers at the CommSensLab of the Universitat Politecnica de Catalunya-BarcelonaTech (Barcelona, Spain) essentially took a "ground-floor" look at microwave cloaking and investigated a means for achieving simple but effective microwave cloaking using a frequency-selective surface (FSS). Their approach involves the use of an inhomogeneous layer to bend electromagnetic (EM) waves around the region occupied by the cloaked object without interacting with it. This "mantle coat" for EM scattering cancellation made it possible to build a microwave cloak for electrically thin cylinders using a thin, patterned, conducting surface that's light in weight, broad in bandwidth, and with a low profile.

The researchers detailed the design approach for their microwave cloaking method, along with software simulation procedures for modeling the effects of the method and the prototypes used to demonstrate its effectiveness. Objects to be cloaked consisted of thin sheets of copper wrapped around a polyvinylchloride (PVC) cylinder. Bistatic scattering measurements were performed in a well-equipped test laboratory/anechoic chamber, with transmit and receive antennas and wideband commercial vector network analyzer (VNA).

Design equations are presented for achieving a surface reactance at a frequency of interest, such as 192.5 Ω at 3.77 GHz using a mesh grid of FSS cells on a target surface. Full-wave, three-dimensional (3D) computer simulations of the FSS microwave cloaking surface were performed to show the computed attenuation of a microwave cloak.

See "A Microwave Invisibility Cloak," *IEEE Antennas & Propagation Magazine*, Vol. 60, No. 4, August 2018, p. 49.

Microwaves&RF

2018 SALARY & CAREER REPORT

CHRIS DeMARTINO | Technology Editor

The Results Are In

What's the outlook of the RF/microwave industry in 2018? Our Annual Salary & Career Report aims to provide some insight into the state of the industry.

Once again, we present the *Microwaves & RF* Annual Salary & Career Report. It's intended to provide an inside look at the RF/microwave industry from those who know it best: our readers. This article reveals the results from three sections, focusing in on salary, job satisfaction, and education. The 2018 Salary & Career Report in its entirety will be available, in a new multi-part series format, on the *Microwaves & RF* website *(www.mwrf.com).*

A LOOK AT SALARIES

What do salaries in the industry currently look like? One positive bit of information is that the average salary among respondents has increased every year since 2015. This year, the average base salary was reported to be $120,544.37—an increase from last year's number of $112,840. In 2016, the average base salary came in at $110,844.

In terms of how salaries relate to location, looking at average salaries by state, California and Massachusetts ranked the highest. That shouldn't come as a huge surprise, though, given the large amount of top-notch engineering companies in those two states.

EMPLOYMENT OUTLOOK

How did respondents feel about their current job situation? The results revealed relatively good news: Only 7.5% said their company plans to scale back engineering staff in the coming year. Of course, that percentage could be even lower, but 7.5% is a promising number nonetheless.

In terms of hiring, 61.7% of respondents said their company is having difficulty finding qualified candidates for open engineering positions. Does that mean that there's a current shortage of engineers? Some respondents believe so. One respondent's comment on why it's difficult to find qualified candidates was rather telling, "There's a shortage of engineers with sufficient experience who are looking for a change in employment. The solution seems obvious: higher compensation. But budget constraints won't allow that."

Another respondent quipped, "Microwave engineering is a niche field that no one knows about. Even if one knows about it, why would someone take up microwave engineering over software engineering? That pays twice as much."

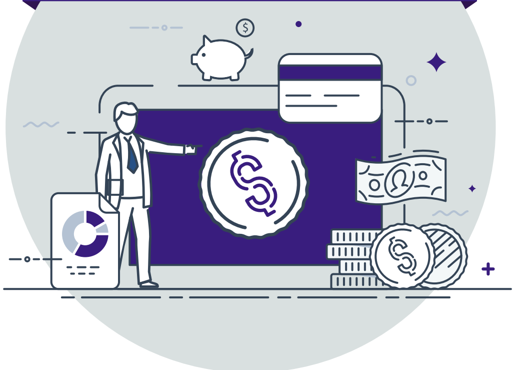
UNIVERSITIES

One theme of the report centers on university involvement within the industry. This year, 39.9% of respondents are age 60 and older (last year's percentage was 44.2%). In contrast, only 9.1% of respondents are under age 35 (a slight tick up from last year's 6%). This begs the question: Does the industry need more youth?

Furthermore, should companies work more closely with universities? While 91.1% of respondents said they should, only 43.6% said their company maintains close ties with universities. Among the companies with such relationships, internship programs continue to be a heavy focus. One respondent said, "We hire interns every summer. We have a program in our company to hire a large quantity of new grads and help them find a career path within our company." Another respondent stated, "We make frequent visits to campus, we work with professors on projects, and we work with students as interns. We are involved with sponsoring of graduate or senior projects."

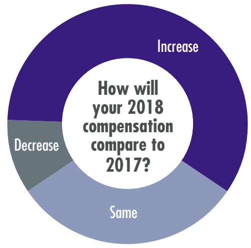
If you'd like to add to the discussion, feel free to contact us with any comments. mw

SALARIES

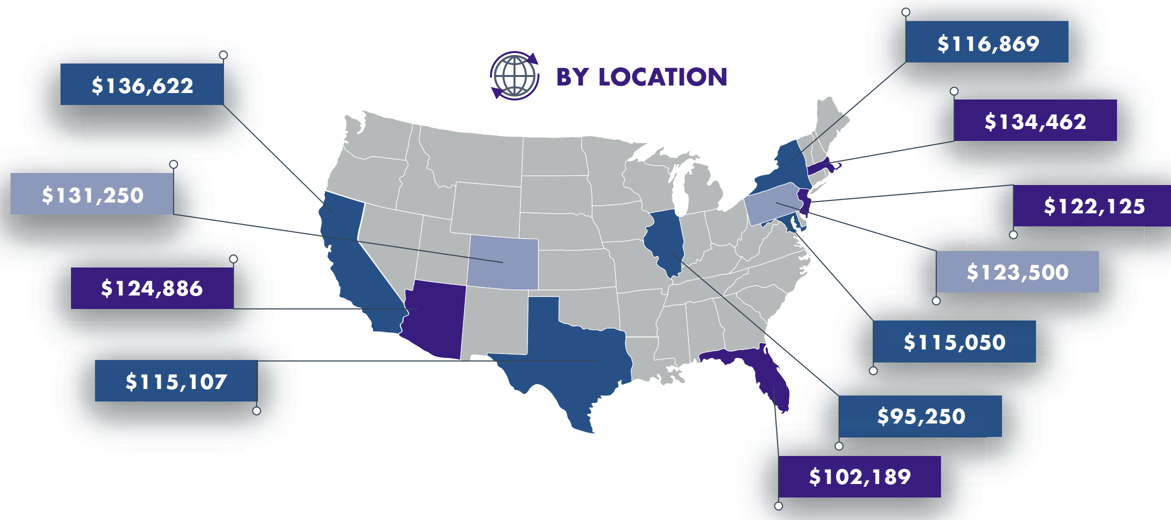


AVERAGE SALARIES

Average Base Salary	**$120,544**
Average Bonus	**$4,593**
Average stock and/or stock options	**$2,994**
Average other sources	**$3,168**



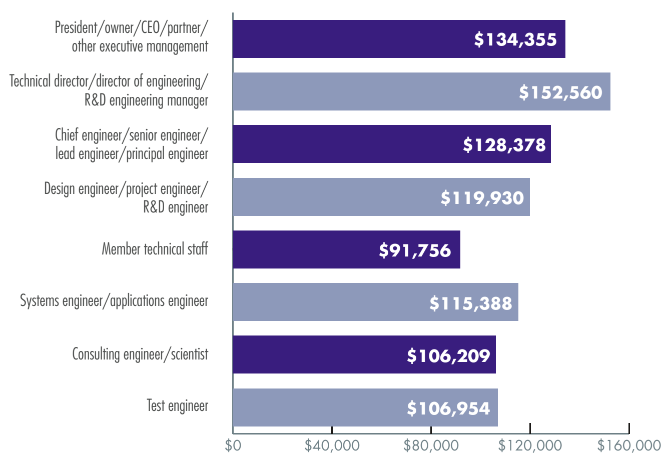
BY LOCATION



BY EXPERIENCE

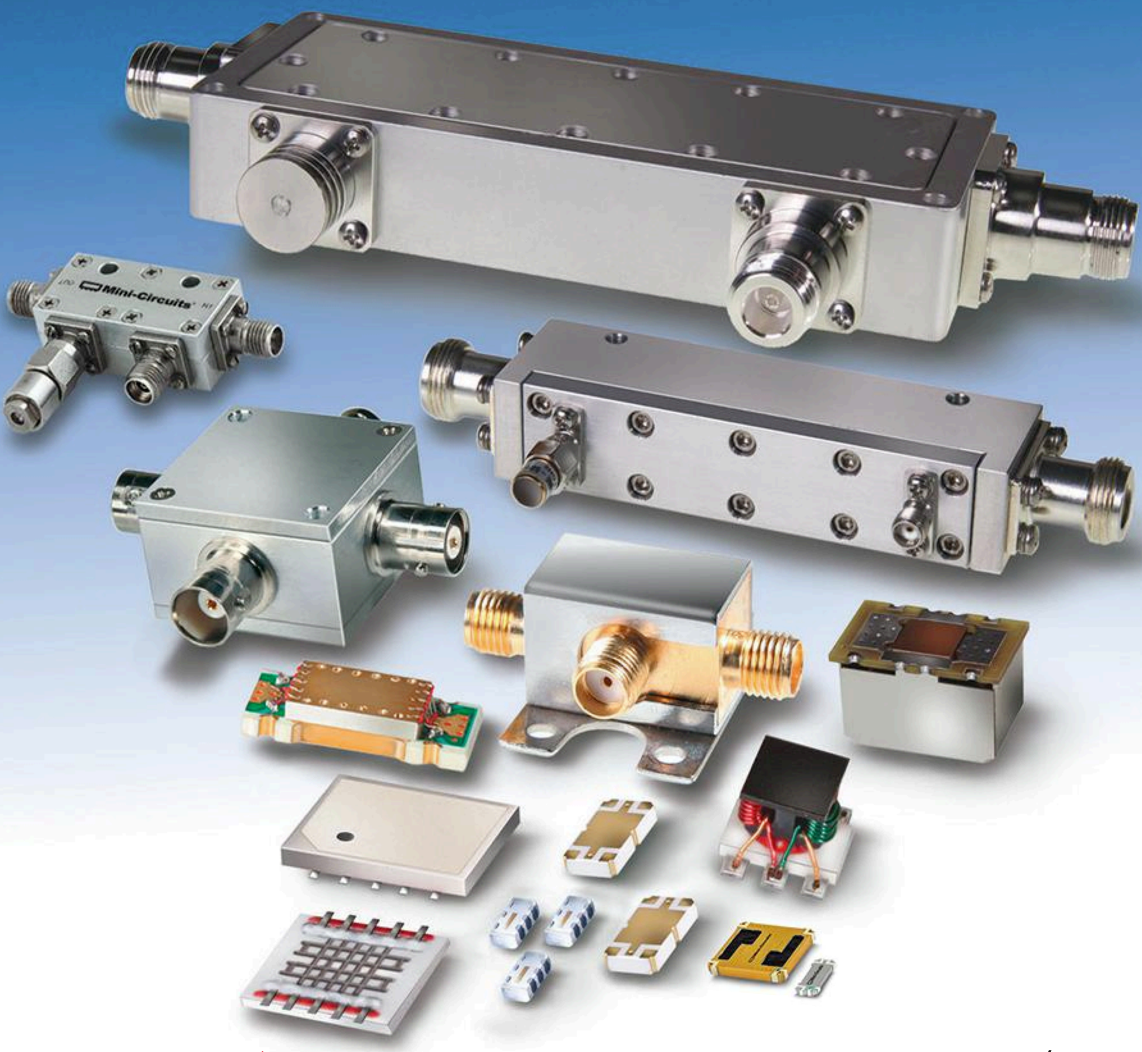
40 years or more	**$118,040**
35–39 years	**$142,546**
30–34 years	**$139,801**
25–29 years	**$128,940**
20–24 years	**$112,992**
15–19 years	**$117,486**
10–14 years	**$100,682**
5–9 years	**$96,088**
1–4 years	**$82,040**
Less than 1 year	**$49,727**

BY CAREER



Directional / Bi-Directional

COUPLERS



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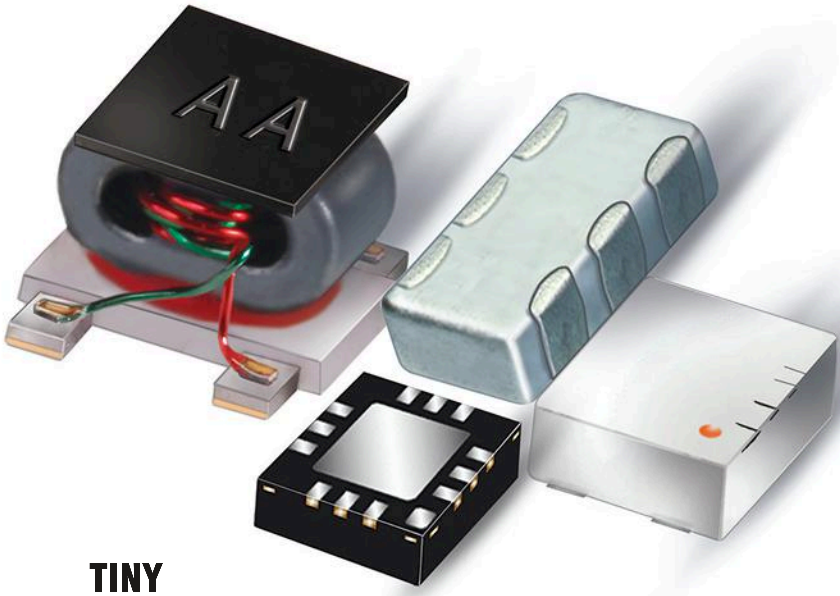

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To support an even wider range of applications, Mini-Circuits' tiny surface-mount transformers and baluns now cover frequencies from 4 kHz up to 18 GHz! Our latest designs achieve consistent performance across very wide frequency bands, and our baluns have demonstrated great utility for use with your chipsets. With over 250 models in stock including a wide range of MMIC, LTCC, and core-and-wire designs, chances are, we have a solution for your needs!

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TC	NC	NCR2	MTX
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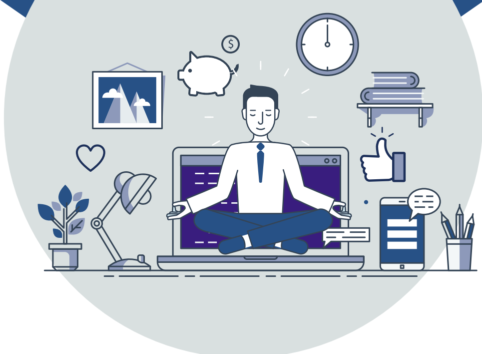
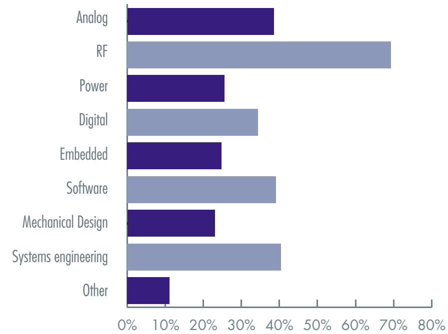
JOB SATISFACTION



IS YOUR COMPANY HAVING DIFFICULTY HIRING? IF YES WHICH SPECIALTIES?

YES 62%
NO 38%



WOULD YOU RECOMMEND ENGINEERING?

YES 89%
NO 11%

WHAT IS THE EMPLOYMENT OUTLOOK AT YOUR COMPANY

INCREASE JOBS 44%
MAINTAIN JOBS 48%
REDUCE STAFF 8%

HAVE YOU BEEN CONTACTED BY A HEADHUNTER

YES 63%
NO 37%

IS YOUR ORGANIZATION MORE FOCUSED ON EMPLOYEE RETENTION THIS YEAR?

YES 37%
NO 63%

ARE YOU FEELING CHALLENGED?

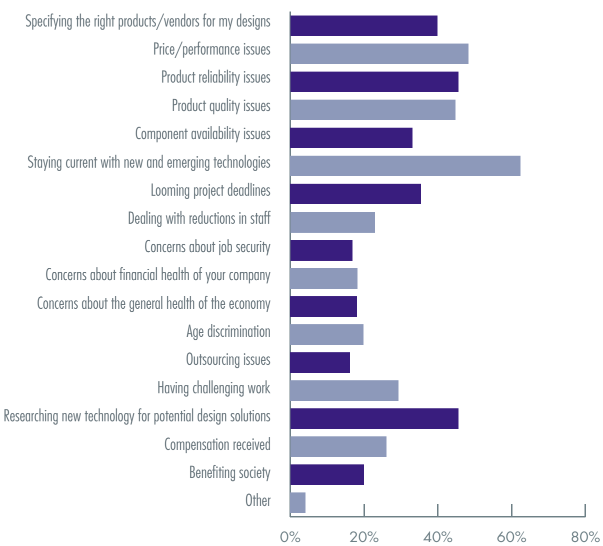
YES 56%
SOMEWHAT 32%
NO 12%

MOST IMPORTANT FACTORS IN JOB SATISFACTION

8.09	Researching potential design solutions
8.09	Challenges that accompany the design of new products
7.86	Compensation you receive for the work you do
7.56	Opportunity to design products that can benefit society
7.11	Working in team situations with peers
7.01	Working independently of others
6.91	The pressures associated with solving design problems
6.87	The recognition you get from others for the work you do

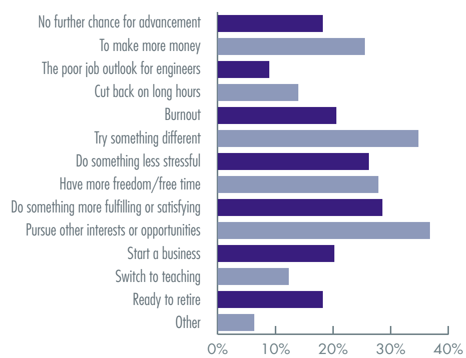
[Based on a scale of 1 to 10]

WHAT ARE THE MAJOR INFLUENCES ON YOUR JOB?



WOULD YOU LEAVE THE PROFESSION AND WHY?

YES 40%
NO 60%



HOW SATISFIED ARE YOU IN YOUR JOB?

EXTREMELY SATISFIED
23%

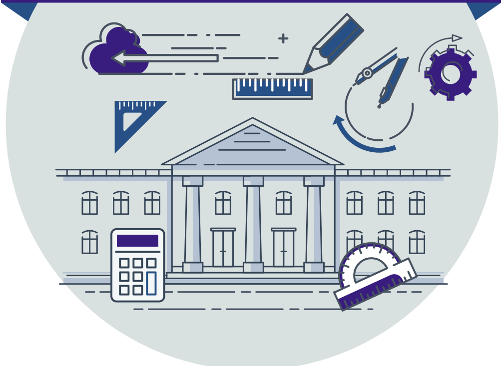
VERY SATISFIED
32%

SATISFIED
37%

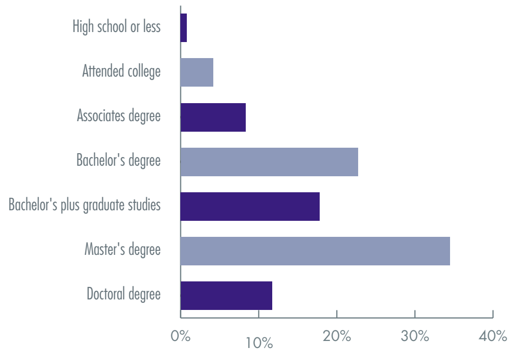
NOT VERY SATISFIED
8%

NOT AT ALL SATISFIED
1%

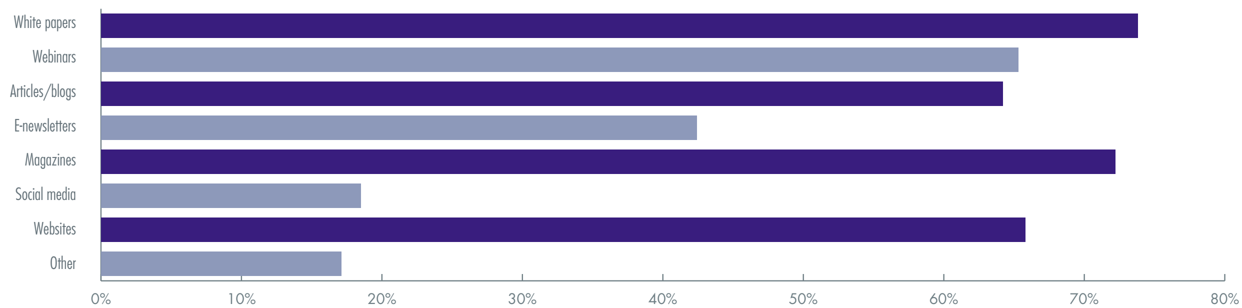
EDUCATION



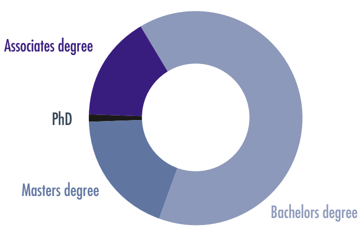
WHICH ONE OF THE FOLLOWING BEST DESCRIBES YOUR HIGHEST LEVEL OF EDUCATION?



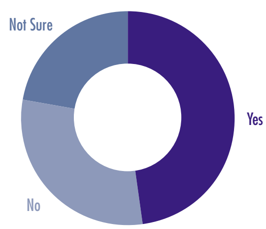
HOW DO YOU MAINTAIN YOUR EDUCATION?



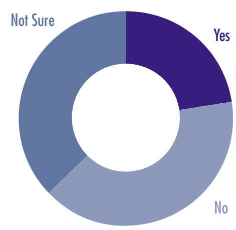
WHAT IS THE MINIMUM EDUCATION AN ENGINEER SHOULD HAVE?



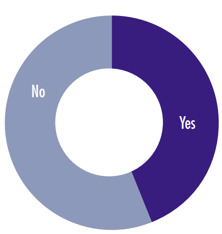
HAS TODAY'S SOFTWARE ALLOWED AVOIDING LEARNING BASIC MATH?



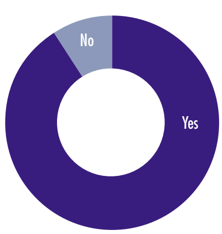
ARE UNIVERSITIES ADEQUATELY PREPARING STUDENTS?



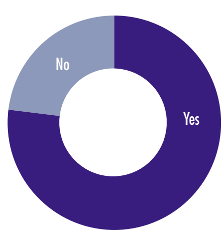
DOES YOUR COMPANY MAINTAIN CLOSE TIES WITH UNIVERSITIES?



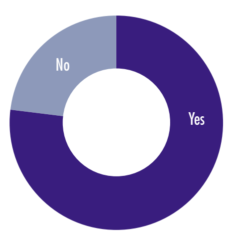
SHOULD COMPANIESV WORK MORE CLOSELY WITH UNIVERSITIES?



HAS YOUR JOB REQUIRED YOU TO LEARN NEW SKILLS?



NEED TO WIDEN YOUR SKILL SET IN THE FUTURE?



RF SWITCHES

DC - 40 GHz

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

*SP3T to SP12T designs

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JONATHAN KAYE | Senior Director, Product Management, Laird Connectivity

From Farm *to* Fork: A Wireless-Sensor Approach to Food Safety

How can restaurants take advantage of wireless sensors based on LoRa technology to monitor food temperature?

The restaurant industry has very strict guidelines controlling food safety, as outlined by Hazard Analysis and Critical Control Points (HACCP) management system. According to the Food and Drug Administration (FDA), HACCP provides a systematic preventative approach to food safety by identifying, evaluating, and controlling factors that present hazards throughout the entire process (farm to fork). This includes everything from the raw materials to shipping to the finished product.

One aspect of food safety that requires special attention is controlling and monitoring food temperature, which is necessary to prevent problems that can cause foodborne illnesses. It's important to note that both raw ingredients and cooked products must be kept at certain temperatures to prevent growth and/or provide a "kill" step during cooking. Temperature monitoring can be done manually by having someone check a thermometer and write the temperature on a sheet of paper, or automatically by utilizing wireless-sensor technology that electronically measures and records temperatures.

1. ComplianceMate temperature-monitoring technology collects temperature data inside coolers and other kitchen equipment at all hours.

2. Laird's Sentrius RS1xx LoRa-enabled sensor is a battery-powered, long-range integrated sensor platform that leverages the benefits of LoRaWAN and Bluetooth Low Energy (BLE) connectivity.

APPLICATION

The U.S. Centers for Disease Control and Prevention (CDC) estimates 48 million Americans (or about one in six people) get sick from a foodborne illness each year, of which 128,000 are hospitalized and 3,000 die.[1] Obviously, not all of these cases are associated with the restaurant industry, but this statistic highlights the need for improved food safety and for enforcing food-safety guidelines to reduce the number of cases in which people become ill after eating contaminated food.

One aspect of food safety is maintaining food temperatures at certain critical levels. Foods that need to be refrigerated or frozen must be kept at specified temperature levels to maintain adequate food safety, as well as prevent premature spoilage due to improper storage. Cooked foods must be heated to specific internal temperatures and then maintained at minimum temperatures. The temperature limits for coolers, freezers, and cooked foods are necessary to prevent the development of bacteria, viruses, and parasites leading to foodborne illnesses.

There are different ways to monitor and control food temperature. The manual method of checking a thermometer and recording the temperature has many drawbacks. Someone must actually do it, which cuts into his or her time when the focus could be on other tasks. The person must also be able to correctly use and read a thermometer and accurately record the temperature. He or she then must know what to do, as a corrective action, if the temperature is either too warm or cold.

Many cases of foodborne illness can be prevented if staff addressed the problem sooner rather than later. The aspect of human error exists, too, potentially leading to situations in which food temperature is improperly maintained.

Implementing an automatic method that uses sensors to electronically measure and record temperatures can substantially improve food safety. This method allows for a continuous data stream of temperatures—24 hours a day, 7 days a week, every day of the year. Temperatures are recorded consistently, on time, and leave little room for interpretation—just the facts and nothing but the facts.

The data can be stored in the cloud and accessed via any type of internet-connected device (be it smartphone, tablet, or computer). This means that the person responsible can retrieve the temperature readings from anywhere in the world at any time. Notifications can be established that will send real-time alerts if the temperature strays outside preset limits, allowing for immediate action to remedy the situation. Wireless sensors improve food safety by providing instant access to the food-temperature data.

WIRELESS ADVANTAGES

Wireless sensors, with their reliable record-keeping capability, make it easier for restaurants to comply with various regulatory agencies. While the FDA endorses participation in an HACCP management system, taking part is purely voluntary. HACCP has developed guidelines for establishing the necessary record-keeping and documentation procedures,[2] which lets restaurants have the required data on hand.

State and local regulatory agencies responsible for enforcing food safety in restaurants are able to adopt the model presented by the FDA's Food Code;[3] these agencies may have their own specifications as well. Some mandatory aspects of the Food Code, such as the food temperature requirements, have been incorporated in HACCP.

Wireless sensors collect the data needed to prepare for health inspections as well. Rather than having to search for the appropriate handwritten records, electronic temperature data is always available and complete, and the display format can be customized as needed.

The FDA has developed rules for the sanitary transportation of foods, as part of the Food Safety Modernization Act (FSMA),[4] to keep foods safe from contamination during transportation by motor or rail vehicles. One of the goals is to require that foods are properly refrigerated during transport. This is done by specifying that the equipment is able to control and maintain the temperatures necessary for safe transport, as well as specify that records must be made and kept. The use of wireless sensors would help meet these requirements and provide precise temperature data, while significantly improving the safety of food products in transit.

CHALLENGES

The restaurant industry is an especially difficult environment for using wireless temperature sensors. The work area usually consists of stainless-steel surfaces, concrete walls, and a variety of other obstacles that frankly do not play well with radio signals. That's combined with potentially harsh temperature and moisture environments associated with putting sensors inside heavily insulated and sealed coolers and walk-in freezers. The distance between the food storage and preparation areas can be long, and their physical locations may be around corners, behind steel and concrete walls, and even on different floors. These factors provide a particularly unfavorable environment for transmitting wireless signals.

Wired sensors could eliminate many of the challenges faced by wireless sensors, but they bring their own issues relative to the wires themselves. For example, installing a wired sensor inside a walk-in freezer means that a hole must be drilled somewhere to accommodate the wire.

Also, the constant activity in a busy kitchen area means that sensors are prone to being damaged. A detached or mangled wired sensor would be detected fairly quickly when no data is transmitted from it, but it would take time to be repaired or replaced and valuable data could be lost. What happens if a cooler goes out during this repair period?

These issues create a situation in which a restaurant kitchen environment can be even harsher than those in some industrial and healthcare settings.

SOLUTION

Current temperature sensor technologies using Bluetooth or Wi-Fi were appropriate years ago as the technology first started. Today, sensor technology has improved and will work better in the challenging restaurant environment. Specifically, LoRaWAN can provide the solution to this problem.

LoRa wireless technology is a long-range, low-power platform used extensively in Internet of Things (IoT) applications. LoRa technology provides low-power wide-area-network (LPWAN) connectivity between wireless sensors and the cloud. It's much more effective and reliable than either

Bluetooth or Wi-Fi in the restaurant kitchen environments.

USE CASE

ComplianceMate *(www.compliancemate.com)*, a leader in food-safety-monitoring technology, temperature monitoring, and HACCP compliance systems, and Laird *(www.lairdtech.com)*, a leader in state-of-the-art wireless technology, have partnered in developing LoRa wireless sensors intended to monitor and control food temperatures, with the ultimate goal of enhancing food safety in restaurant kitchens *(Fig. 1)*.

Laird's Sentrius RM1xx module hardware, which provides LoRaWAN options at 868/915 MHz, is based on the Semtech SX1272 and Nordic nRF51 silicon. The battery-powered, LoRa-enabled Sentrius RS1xx sensor is rugged with a small form factor *(Fig. 2)*. It offers high RF performance in a precise temperature and humidity sensor. The RS1xx series sensors work with the Sentrius RG1xx series of LoRa/multi-wireless gateways to deliver cloud connectivity.

The Sentrius wireless temperature sensor and gateway has been incorporated into the newest ComplianceMate System to provide the food-service industry with a wireless sensor network that can readily operate in the harsh RF environment of restaurant kitchens. This product, the first of its kind in the restaurant industry, provides temperature monitoring and control with enhanced security. In addition, the LoRa technology promises exceptional battery life—sensors can last for years without a battery change.

ComplianceMate has successfully implemented this technology for several clients, and Laird's LoRa sensor/gateway network is providing the temperature data needed for improved food safety. The network connectivity gives smartphones and tablets immediate access to both real-time and historical data, as well as receive alerts if the temperatures are outside the preset limits.

CONCLUSION

Wireless sensors are finally making their way into one of the world's biggest industries. LoRa technology allows wireless temperature sensors to perform in the demanding environment of commercial restaurant kitchens. By continuously monitoring the temperature in coolers, walk-in freezers, and cooking stations, food temperatures can be maintained, alerts can be issued upon variations beyond the limits, and customers are kept safe. mw

REFERENCES:

1. https://www.cdc.gov/foodsafety/foodborne-germs.html
2. https://www.fda.gov/food/guidanceregulation/haccp/ucm2006801.htm
3. https://www.fda.gov/food/guidanceregulation/retailfoodprotection/foodcode/ucm595139.htm
4. https://www.fda.gov/food/guidanceregulation/fsma/ucm383763.htm

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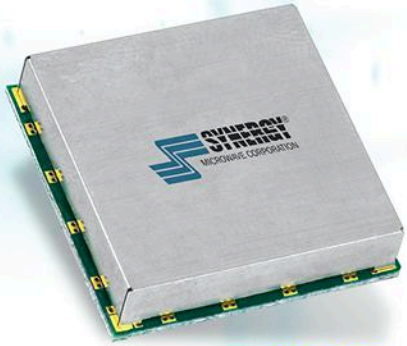

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HFSO640-5	640	0.5 - 12	+5 VDC @ 35 mA	-151
HFSO745R84-5	745.84	0.5 - 12	+5 VDC @ 35 mA	-147
HFSO776R82-5	776.82	0.5 - 12	+5 VDC @ 35 mA	-146
HFSO800-5	800	0.5 - 12	+5 VDC @ 20 mA	-146
HFSO800-5H	800	0.5 - 12	+5 VDC @ 20 mA	-150
HFSO800-5L	800	0.5 - 12	+5 VDC @ 20 mA	-142
HFSO914R8-5	914.8	0.5 - 12	+5 VDC @ 35 mA	-139
HFSO1000-5	1000	0.5 - 12	+5 VDC @ 35 mA	-141
HFSO1000-5L	1000	0.5 - 12	+5 VDC @ 35 mA	-137
MSO1000-3	1000	0.5 - 14	+3 VDC @ 35 mA	-138
HFSO1200-5	1200	0.5 - 12	+5 VDC @ 100 mA	-140
HFSO1600-5	1600	0.5 - 12	+5 VDC @ 100 mA	-137
HFSO1600-5L	1600	0.5 - 12	+5 VDC @ 100 mA	-133
HFSO2000-5	2000	0.5 - 12	+5 VDC @ 100 mA	-137
HFSO2000-5L	2000	0.5 - 12	+5 VDC @ 100 mA	-133

** Package dimension varies by model. (0.3" x 0.3" to 0.75" x 0.75")*

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Assemble Antennas with 3D Printing

Three-dimensional printers working with plastic materials can create the foundations that are then spray-painted with metallic coatings to form high-frequency RF/microwave antennas.

Why assemble an RF component when it can be printed? Three-dimensional (3D) printing holds great promise for the design and manufacturing of many RF/microwave components. The use of 3D printers offers tremendous opportunities for achieving reduced size, weight, and lead times for complex designs. Antennas are one such component, where smaller sizes and weights can benefit portable communications systems, satellite communications (satcom) systems, and airborne systems such as those on unmanned aerial vehicles (UAVs).

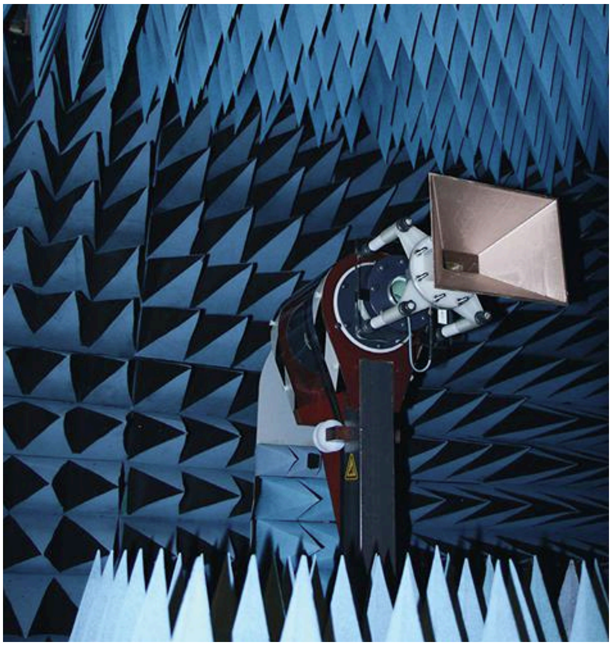
A new high-volume 3D-printing process is especially useful for producing miniature, high-performance antennas for mobile communications applications, particularly in terms of lowering manufacturing costs. The process works with standard injection-molded plastic materials and does not require special coatings or additives to achieve high performance.

Based on aerosol jet technology, the process prints conformal antennas using conductive nanoparticle silver inks. It accurately controls the location, geometry, and thickness of a material deposit and produces a smooth, mirror-like surface finish for optimum antenna performance. In addition, the antenna manufacturing process does not require any plating or environmentally harmful materials.

Aerosol jet printing has been used for some time to produce compact antennas for mobile communications devices, targeting applications such as Bluetooth, GPS, Wi-Fi, WLAN, and cellular 4G Long Term Evolution (LTE) telephones. Antennas produced by aerosol jet printing have been independently tested by a leading cellular-telephone component supplier with good results. The measured performance levels of these antennas are comparable to antennas produced by other manufacturing methods. Aerosol jet printing is scalable—antennas can be printed on as many as four cases simultaneously on a single printer. The machine throughput for a typical antenna pattern measuring about 300 mm^2 averages 30,000 units per week.

DEFINING THE PROCESS

Antennas are RF/microwave components that lend themselves to 3D printing, especially with the large volumes, miniaturization, and repeatability required for antennas in many mobile applications. Certainly, design engineers have considered the possibility of printing different types of miniature RF/microwave antennas. However, they may have wondered about how the performance of these printed antennas might compare to traditionally manufactured antennas.



1. This anechoic chamber was used to isolate and test the 3D-printed antennas to 40 GHz.

To help RF/microwave engineers better understand the capabilities of antennas produced by 3D printing, Antenna Test Lab Company modeled printed, metallized, and tested a family of 15-dBi standard-gain horns for use from 2 to 40 GHz. The company is a professional antenna test laboratory with anechoic chamber *(Fig. 1)* to isolate antennas under test from outside RF/microwave energy sources and signals.

Some trial-and-error is involved in the process of producing and characterizing these antennas, especially over such a wide frequency range, but the benefits of 3D printing can be dramatic. For example, commercially available standard gain horns are typically quite expensive, with price tags ranging from $500 to $1500 depending on frequency range. Once the expense of learning how to print RF/microwave antennas has passed, compare those prices to the cost of producing a 3D standard gain horn at microwave frequencies for about $1.

The 2- to 40-GHz frequency range was chosen for antenna testing to encompass the practical limits of current 3D-printing technology. At S-band frequencies (2 to 4 GHz), a 15-dBi standard gain horn is about the size of a salad bowl and requires the use of a large-format printer to produce. It can also be printed in sections; the sections are combined to form a larger antenna. Since this S-band frequency range includes Wi-Fi, it should have a great deal of appeal for experimenters despite the antenna's large size.

At Ka-band frequencies (26 to 40 GHz), the smaller wavelengths will result in a much smaller antenna—the same 15-dBi standard gain horn will fit into the palm of the hand *(Fig. 2)*. The smaller dimensions of the antenna will also challenge the tolerance capabilities of typical 3D printers. Since test equipment, such as signal generators and vector network analyzers (VNAs), can be quite expensive for use above 40 GHz, these 3D antenna experiments were limited to a top frequency of 40 GHz.

For metallization, shielding spray paints from MG Chemicals *(www.mgchemicals.com)* were selected for their ease of use and ready availability (even online from Amazon). The first test antenna was an X-band horn (8 to 12 GHz) with an easy-to-print 4-in. aperture. Two copies of the antenna were printed to evaluate two common shielding spray paints: "841 Super Shield Nickel" and "843AR Super Shield Silver Coated Copper." Each copy of the antenna was given two coats of the shielding spray paint, with suitable drying time between coats.

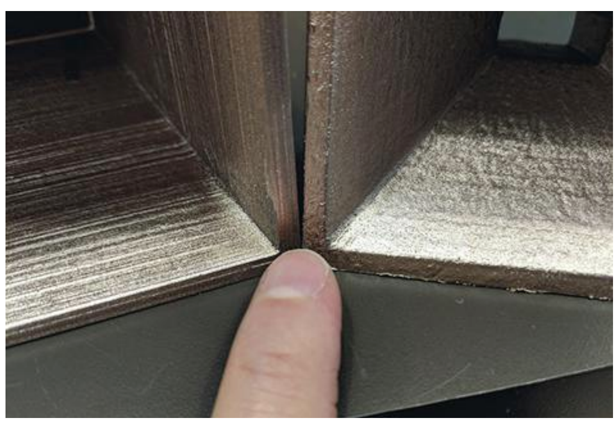
Datasheets for both shielding spray paints indicated impressive values for surface conductivities, and the resulting metallized horns provided attractive surface appearances *(left side of Fig. 3)*. Unfortunately, appearances can be deceiving, as was revealed by the resulting measurements from within the anechoic chamber. The forward gain for these X-band horns was only about 5 dBi, or about 10 dB less than the expected level of 15 dBi.

Still, measurements showed that both antennas provided respectable directivity of about 15 dB with the expected beam widths of 30 deg. The return loss was considered good, at better than 20 dB. This combination of some good performance parameters with poor gain was considered a result of poor surface conductivity for the metallization treatment, causing the horns to suffer about 10 dB of loss from the expected gain.

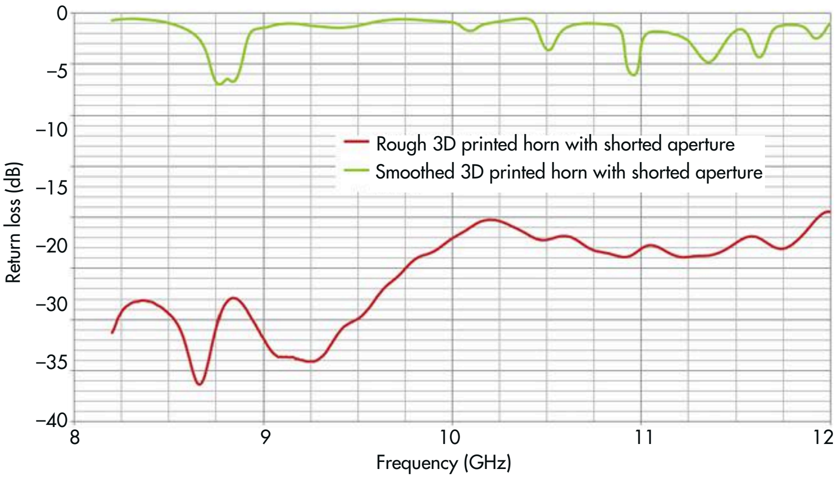
A simple bench test was devised to prove this theory and to "pretest" antennas for this kind of loss. The method does not require an antenna test laboratory or even an anechoic chamber and can be quite useful for anyone working with antennas. The evaluation method involves measuring the return loss (VSWR) of an antenna as a quick pretest characterization.

As a rule of thumb, an antenna with high return loss, or more than 10 dB, is considered a good antenna. This evaluation is based on the thinking that, for a return loss of 10 dB, 90% or more of the transmitted energy sent to the antenna will radiate from the antenna since it's not reflected to the energy source.

2. A variety of different antenna types and sizes can be formed by 3D-printing plastic foundations that are subsequently coated with conductive paints.



3. The antenna surface roughness resulting from 3D printing must be smoothed by sanding or via solvents to achieve low-loss performance at high frequencies.



4. These plots of return loss through 12 GHz show the difference for 3D-printed surfaces that have been unaltered versus antenna surfaces that have been smoothed.

Such a test of return loss or VSWR is normally useful, when an antenna can be assumed to have low losses. However, even lossy antennas or dummy loads are capable of excellent return loss.

A short circuit will yield low return loss. When a coaxial cable or the aperture of a low-loss metal horn antenna is short-circuited, low return loss (large reflections) can be expected. Such low return-loss behavior was verified for "shorted" laboratory-grade commercial horn antennas by covering their apertures with aluminum foil used for baking and cooking. The same shorted aperture test on the 3D-printed horn antennas showed large (greater than 20 dB) return loss, indicating that they were functioning better as attenuators than as antennas.

Figure 4 shows how an antenna with a "smoothed" surface exhibits low return loss. While there's some ripple due to the unevenness of the cooking foil short circuit on the horn, the important behavior is the low return loss (about 1 dB) at some frequencies. This could not happen if the inside surfaces of the antenna were lossy.

Despite the shiny appearance of the metallized paint, and the near-zero measured ohmmeter resistance readings of the applied metallized surface, the suspected loss mechanism was the surface resistance of the metallized finish. The tiny surface ripple artifacts of the 3D-printing layers are small compared to the relatively large operating wavelength (1 in. at X-band frequencies). However, surface smoothing did eventually prove to be the key to removing this loss and achieving the target 15-dBi gain across the full 2- to 40-GHz target frequency range for the printed antennas. But even applying multiple "liberal" coats of conductive paint did not sufficiently lower this loss without prior smoothing.

SMOOTH OPERATOR

Smoothing the plastic surfaces of a 3D-printed antenna is a necessary step in achieving the target gain performance from those surfaces once they are metallized. Sanding is one way to smooth the 3D layer surface roughness, but it's time-consuming. The funnel shape of the horn also results in triangular facets that are enclosed and tapered, forming a surface that's not practical for power sanding tools to work on.

After experimentation, it was found that "solvent smoothing" required the least time and effort with satisfactory results. Acetone is a useful and well-known solvent for ABS plastic prints, and it worked well with prints from a smaller ABS filament printer. The large-format printer uses only PLA filament, for which there does not seem to be a readily available solvent. Some research did reveal that dichloromethane (methylene chloride) was a candidate solvent for PLA plastic, and was found to be highly effective at softening and smoothing the plastic's surface roughness.

Both acetone and dichloromethane solvents are hazardous, but dichloromethane is especially poisonous. Though historically the key ingredient in common paint-stripper products, it's being phased out due to its toxicity when used for do-it-yourself (DIY) home projects. After some trial-and-error, the following process was found to work quite well. The smoothed surface of the 3D-printed antenna that resulted from this process is shown on the right-hand side of *Fig. 3*.

For those inclined to work on their own 3D-printed antennas, the smoothing process should be performed outdoors, since it's typically not possible to achieve adequate ventilation to be safe indoors. A respirator mask will still be needed when working outdoors *(Fig. 4, again)*. The mask should be rated for organic solvents (commonly available for use with oil-based paints). It's important to use full-length chemical gloves that are specifically rated for the type of solvent used. Such delicate chemical gloves should be protected by also wearing work gloves on top of them. Eye protection should also be worn during this chemical smoothing process, since it can be difficult to control where solvent lands in the workplace.

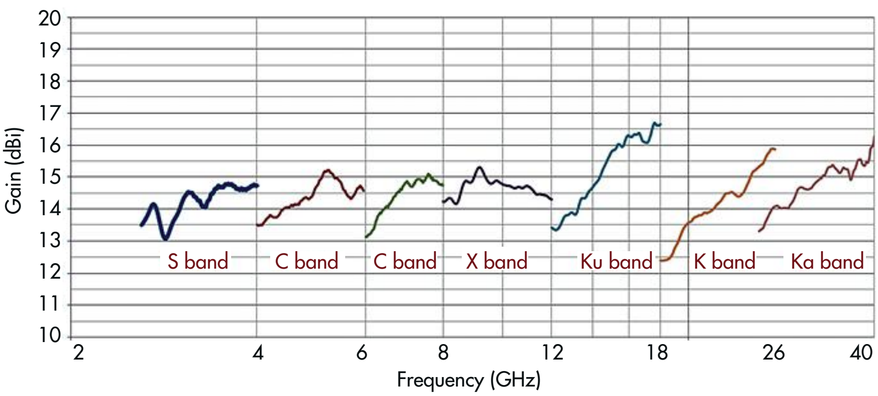
For convenience, solvent was poured into a standard metal paint-roller tray from which it could be applied to the 3D-printed antennas *(Fig. 5)*. Common kitchen utensils such as disposable bristle brushes and metal pot-scrubbing pads were used in the application of solvent. Dichloromethane should not be handled with plastic brushes of any kind, since it will soften the material. It takes only a minute to smooth the inside of even the largest horn with the pot scrubber (or

5. These are the tools for smoothing a 3D-printed antenna surface outdoors.

steel wool) if it's kept wet with solvent. A round bottle brush worked well in scrubbing the waveguide portion of the horn. The outside of the horn was not smoothed or metallized; just the inside surfaces and mating flange.

For those attempting to assemble a larger antenna from smaller component parts, the process involving application of the solvent is also a good time to perform a "solvent weld," since the plastic parts will already be softened by the solvent. The plastic welds can be achieved by pressing and holding together the parts to be joined for about 1 min. while the solvent evaporates.

Applying the conductive spray paint to the surface of the 3D-printed antennas is straightforward, as is done with any form of spray painting. For safety, it's best done outdoors, with care to completely coat all inside surfaces and the flange. When working outdoors, excess paint is easily shaken off. Two coats of conductive paint were always applied and found to work well.



6. The plots show the gain for 3D-printed standard gain horn antennas across a wide range of frequencies.

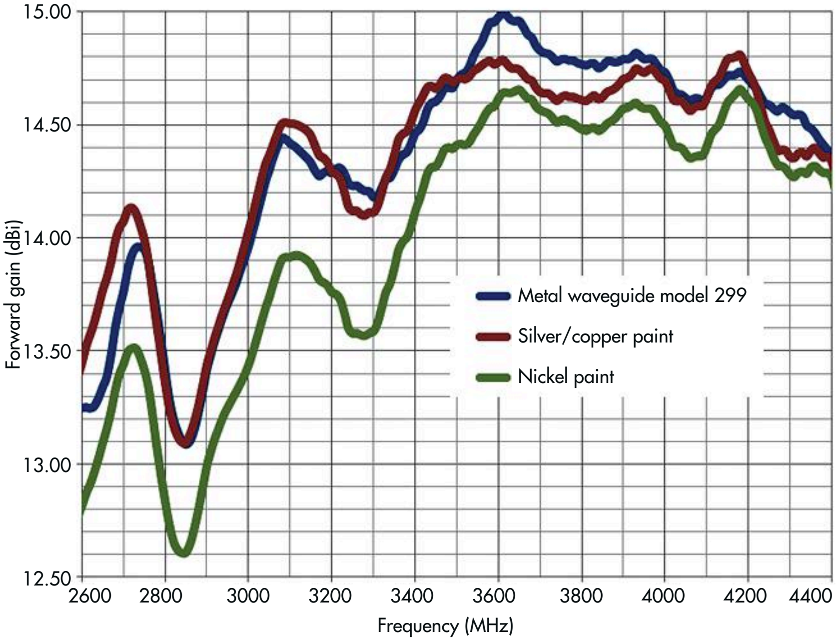
The nickel-based version of the conductive paint apparently exhibited several decibels loss at all frequencies, even following smoothing of the plastic horn surfaces. The silver/copper-based point, on the other hand, worked well to 26 GHz. From 26 to 40 GHz, the small horn exhibited about 3 dB loss (12 dBi gain) even when the plastic surfaces were smoothed by application of the solvents.

The 3-dB loss could be overcome by sanding the horn completely smooth with a small file, brushing with solvent, and recoating the surface with conductive paint. Since this Ka-band horn is only 1 in. in size, its soft plastic walls can easily be filed smooth in a manner of minutes. This extra smoothing step allowed it to achieve very low shorted aperture return loss while also reaching the expected 15-dBi gain when tested in the anechoic chamber *(Fig. 6)*.

As was shown for such a wide frequency range, it's possible to 3D-print a plastic microwave antenna and achieve good performance by applying several coats of conductive paint. One of the keys is in smoothing the active surfaces of the antenna with solvent or mechanical sanding before applying the conductive paint, to achieve the smoothest surface possible. By checking the VSWR of an antenna produced in this manner, it can be verified to have good low-loss performance through microwave frequencies, with performance comparable to that of a solid metal antenna.

Complex antenna shapes can be accommodated by splitting prints into sections that allow for sanding/smoothing access before assembly by gluing or solvent welding. Conductive spray paint easily flows over and covers surface sanding scratches and seams.

Figure 7 compares the gain of a laboratory-grade standard gain horn antenna with 15-dBi gain at S-band frequencies (a model 299 from Waveline) and two copies of a replica produced by means of 3D printing and metallization with two different kinds of conductive paint. The plastic antennas were printed in PLA, solvent-smoothed, and spray-painted with conductive metal paint.



7. These plots compare the gain of two identical 3D-printed standard gain horn antennas using different conductive coatings and a commercial standard gain horn antenna operating across the same frequency range.

All three antennas were tested using the same model 201NF coaxial adapter from Waveline. The gain of the copper/silver-painted 3D-printed antenna was only ±0.2 dB different than that of the commercial horn antenna, well within measurement repeatability. The third curve in Fig. 7 shows the response of the other printed antenna, formed with two coats of nickel-based conductive coating. This conductive coating yields about 0.5 dB less gain than the copper/silver conductive for the identical antenna configuration, degrading by as much as 5 dB to 10 GHz.

For those wishing to experiment with 3D-printed RF/microwave antennas, the STL printable files are available for download. All 3D designs were completed with Sketchup, a free-of-charge n-dimension computer-aided-design (CAD) software tool. The Sketchup files for these horns are also downloadable for those who would like to edit the geometries. mw

SQUEEZE MORE Dynamic Range Out of Your Network Analyzer

Achieving the highest possible network-analyzer dynamic range is extremely important in many instances. To attain that goal, it's important to understand its essence along with the methods that can be employed to increase dynamic range. In the application note, "Understanding and Improving Network Analyzer Dynamic Range," Keysight Technologies discusses methods that can be utilized to maximize such an analyzer's dynamic range.

The application note begins by defining dynamic range, with an explanation of the difference between system and receiver dynamic range. System dynamic range can be achieved without amplification, which applies when measuring passive components like attenuators and filters. Receiver dynamic range is the system's true dynamic range if it's considered to be a receiver.

After discussing noise floor, the document explains that it's sometimes desirable to increase the network analyzer's dynamic range beyond the level obtained with the default settings. The noise floor determines the minimum power level that can be measured by the instrument, thus limiting the dynamic range.

Keysight Technologies, 1400 Fountaingrove Parkway, Santa Rosa, CA 95403-1738; (800) 829-4444; www.keysight.com

Using averaging techniques or reducing the system IF bandwidth (IF BW) can improve noise floor. Averaging is first discussed in greater detail. When applying the averaging function available in most vector network analyzers (VNAs), signal-to-noise ratio (SNR) is improved by 3 dB for every factor-of-two increase in averages. The downside of averaging is that it also reduces measurement speed, since the measurement time doubles when two traces must be averaged.

Following that discussion, the application note delves into IF BW. The IF BW value affects the digital filtering that's performed on the data collected in the analyzer's receivers. Decreasing the IF BW will reduce the noise floor by filtering out noise that's outside the bandwidth of the digital filter. But like the averaging method, decreasing IF BW also slows the measurement speed. The document also mentions the segmented sweep feature, which is useful for applications that must optimize both speed and dynamic range. Test setup reconfiguration is also mentioned.

IS CONTRACT MANUFACTURING a Good Fit for Your Firm?

FOR RF/MICROWAVE companies, shortening the design, development, and manufacturing cycle can be especially challenging for several reasons. One way to tackle this process involves working with a contract manufacturer. In the tech brief, "How RF and Microwave Companies Can be Empowered by US-based Contract Manufacturing," SemiGen explains that contract manufacturers can help companies by providing them with cost-effective delivery of products while allowing their staff members to focus on other significant tasks.

The tech brief starts out by noting that the design and development process is optimized when an original equipment manufacturer (OEM) can allow its employees to concentrate on their respective specialties. However, oftentimes, design engineers must also perform tasks associated with test engineers and assembly technicians, hindering them from focusing on other responsibilities.

According to the tech brief, establishing a relationship with a qualified RF/microwave contract manufacturer can provide a management team with the opportunity to step back and evaluate internal production lines. The document states that outsourcing some assembly work when needed can help OEMs avoid "idle hands and machines." A good outsourcing plan also reduces equipment and training costs, as well as slashes the time that OEM engineering talent must spend on tasks outside of research and development.

SemiGen, 54 Grenier Field Rd., Londonderry, NH 03053; (603) 624-8311; www.semigen.net

The RF module assembly process can involve many aspects, such as hand soldering, eutectic attachment, ribbon bonding, and more. Manufacturing high-frequency circuits and assemblies often requires full-time allocated staff with precision assembly expertise along with a large amount of related equipment. Working with a contract manufacturer can help the situation—OEMs are then able to offload the various hand-assembly tasks.

The tech brief also touches on the "repair or replace" decision. While OEMs will often replace RF products and components, repairs can be more cost-effective. The document points out that entrusting a partner with repair functionality can result in considerable benefits when breakdowns and failures occur. The tech brief concludes with a discussion on approved vendor lists (AVLs), noting that keeping and maintaining an AVL is a necessary procedure for OEMs.

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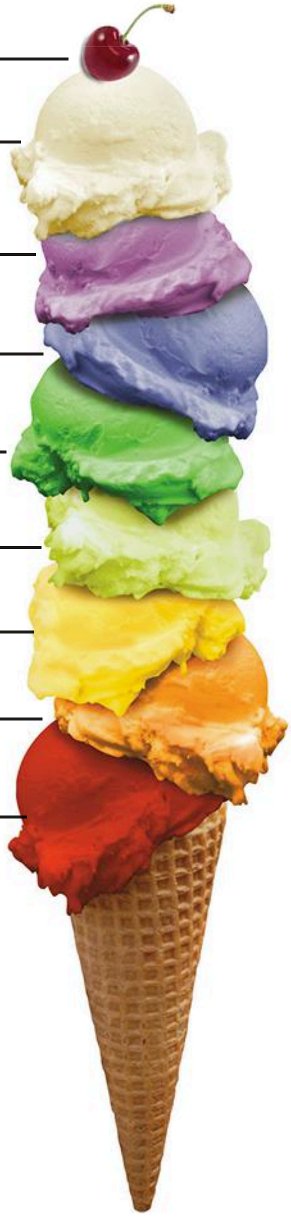

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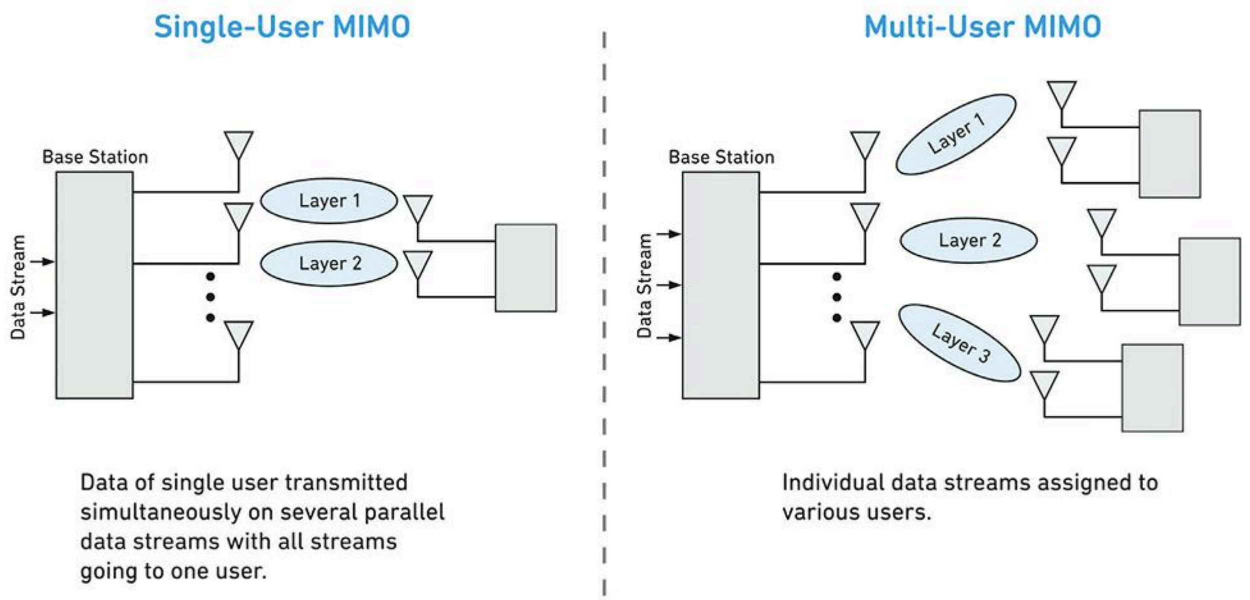
REALIZING 5G
Sub-6-GHz Massive MIMO Using GaN

Gallium-nitride technology figures to play a significant role in sub-6-GHz 5G applications to help achieve goals like higher data rates.



1. Single-user MIMO systems were used for 3G, while 4G adopted multi-user MIMO system technology.

By 2021, it's estimated that more people will have mobile phones (5.5 billion) than running water (5.3 billion). Bandwidth-hungry video will further increase the demands on mobile networks, accounting for 78% of mobile traffic.[1] 5G networks using massive multiple-input, multiple-output (MIMO) technology will be key to supporting this growth. It's expected that 5G mobile connections will grow from just 5 million in 2019 to nearly 600 million by 2023, according to Strategy Analytics.[2]

MIMO: THE BASICS

Each generation of wireless technology has used advances in antenna technology to help improve network speeds. 3G employed single-user MIMO, which leverages multiple simultaneous data streams to transmit data from the base station to a single user. Multi-user MIMO is a dominant technology in 4G systems—it assigns different data streams to different users, providing significant capacity and performance advantages over 3G *(Fig. 1)*. 5G will introduce massive MIMO, further increasing capacity and delivering data rates up to 20 Gb/s *(Fig. 2)*.

5G MASSIVE MIMO EXPLAINED

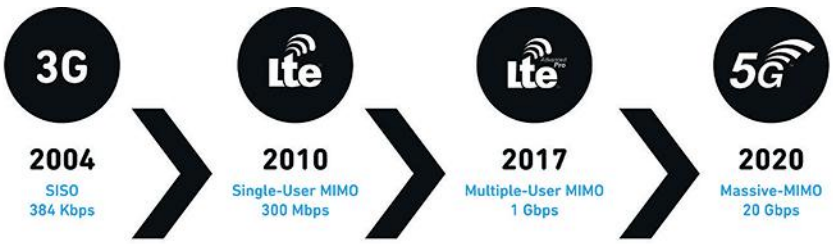
The 5G mantra is to increase network capacity and data rates while minimizing operator expenses. Users also increasingly expect wireless data services to deliver wireline quality.

5G massive MIMO will help operators achieve these goals. It will deliver high data rates to many users, helping to increase capacity. It will support real-time multimedia services without requiring much additional spectrum. In addition, massive MIMO will reduce energy consumption by targeting signals to individual users utilizing beamforming, a technique that focuses the signal from multiple antennas into a single strong beam.

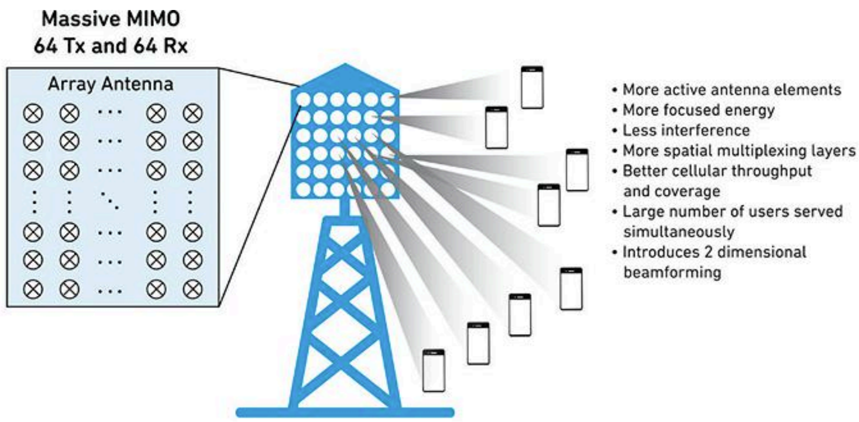
SPATIAL MULTIPLEXING AND MASSIVE-MIMO BENEFITS

Massive-MIMO technology uses large antenna arrays (typically comprising 64 dual-polarized, but at a minimum 16, array elements) to exploit spatial multiplexing *(Fig. 3)*. Spatial multiplexing delivers multiple parallel streams of data within the same resource block. By expanding the total number of virtual channels, it increases capacity and data rates without additional towers and spectrum.

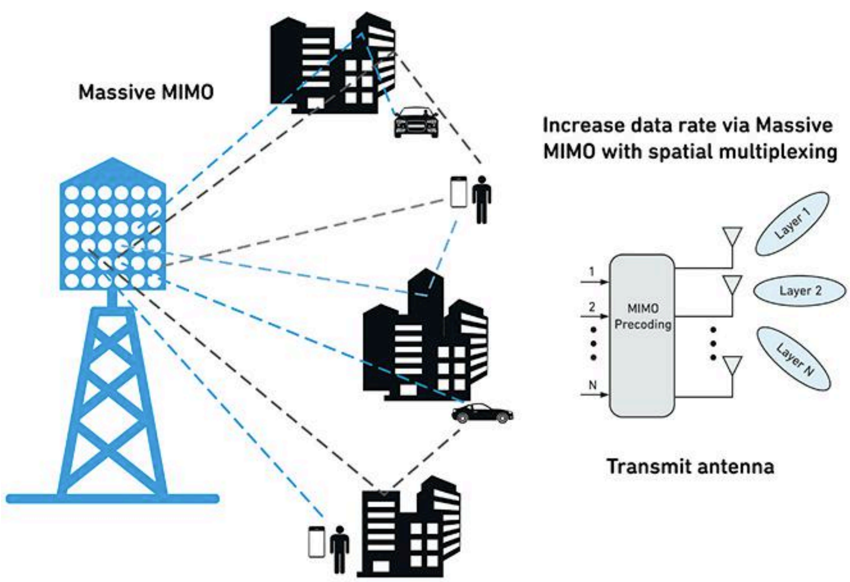
In spatial multiplexing, each spatial channel carries independent information *(Fig. 4)*. If the environmental scattering is rich enough, many independent sub-channels are created in the same allocated bandwidth, thus achieving multiplexing gains with no additional cost in bandwidth or power. The multiplexing gain is also referred to as degrees of freedom in reference to the signal space constellation; in a massive-MIMO configuration, the degrees of freedom govern the overall capacity of the system.[3]



2. The evolution of MIMO in wireless technology generations will ultimately lead to the use of massive MIMO for 5G.



3. Various benefits are associated with massive MIMO, such as spatial multiplexing.



4. Each channel involved in spatial multiplexing with massive MIMO carries independent information.

With massive MIMO, multiple antennas focus the transmit and receive signals into smaller regions of space, bringing huge improvements in throughput and energy efficiency. The more data streams, the greater the data rate and more efficient use of radiated power. This approach also improves link reliability. The increase in antennas means more degrees of freedom that can be spent on spatial diversity. It improves selectivity in the transmit and receive data streams and enhances interference cancellation.

Massive MIMO will provide benefits, including:

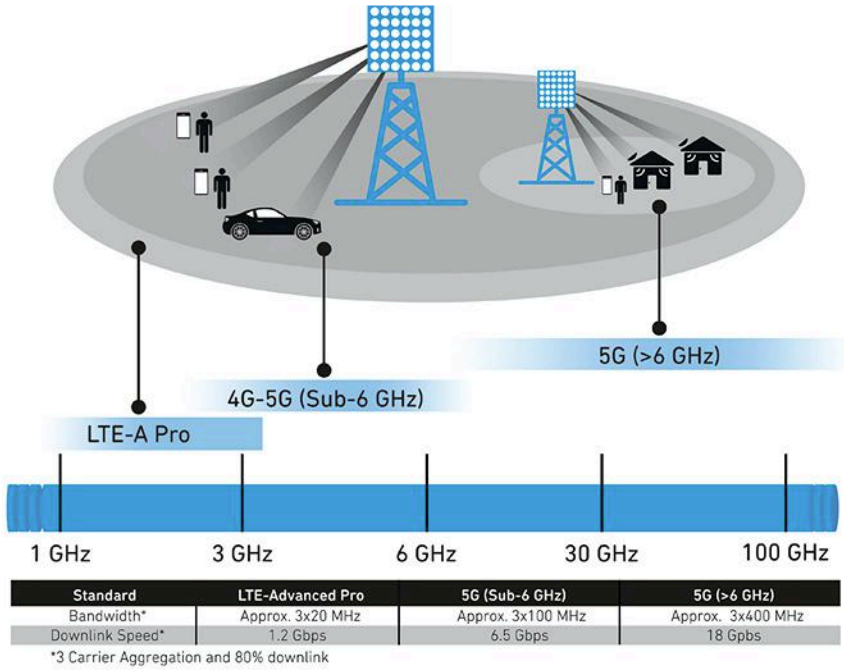
- Preventing transmission in undesired directions, alleviating interference
- Decreasing latency, allowing for faster speeds and higher reliability
- Reducing fading and drops, boosting signal-to-noise-ratio (SNR)
- Increasing spectral efficiency and high reliability
- Greater energy efficiency

5G MASSIVE MIMO AND SUB-6-GHz DEPLOYMENT

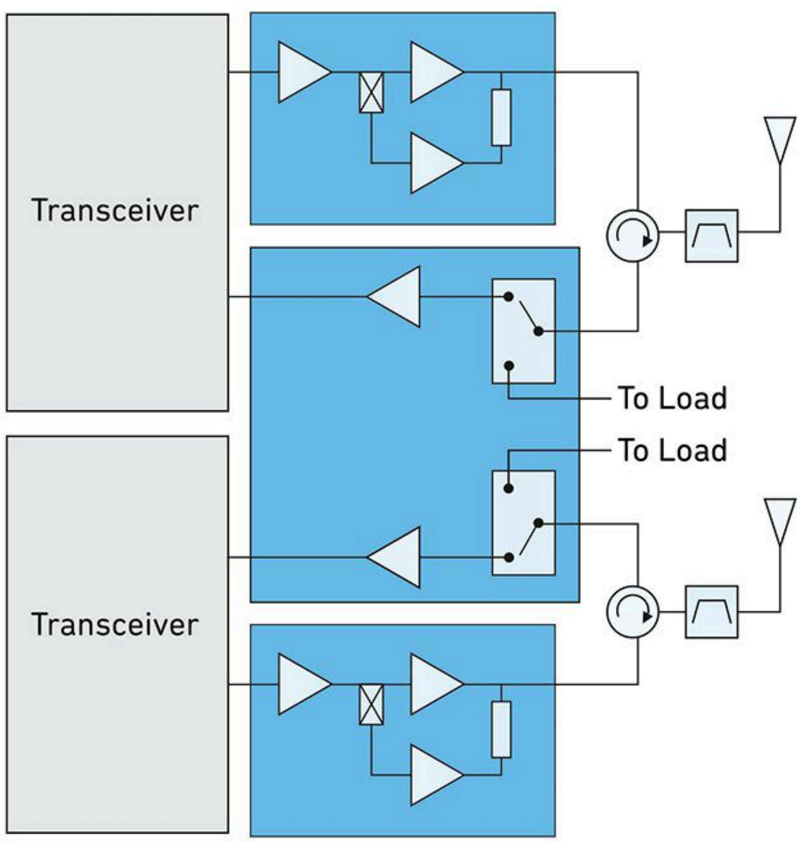
It's clear that to achieve the 5G target of 20-Gb/s data rates, it will be necessary to use millimeter-wave (mmWave) spectrum. However, several key challenges must be addressed before mmWave can truly be used for mobile communications.

While operators and original equipment manufacturers (OEMs) continue working to finalize mmWave technology, sub-6-GHz will be the go-to 5G network technology in the near term. Sub-6-GHz frequencies are suited for both rural and urban areas since the technology can deliver high data rates over long distances *(Fig. 5)*. Operators are initially expected to deploy 5G in 3,300- to 4,200-MHz and 4,400- to 5,000-MHz frequency ranges, which will allow up to 100-MHz channel bandwidths.

Sub-6-GHz massive MIMO will solve interference problems by using a large



5. Differences in coverage and capacity are distinct between 5G mmWave and sub-6-GHz.



6. This sub-6-GHz massive MIMO RFFE includes a Doherty PA.

Coax Amplifier Negates Noise from 2 to 20 GHz

Mini-Circuits' model ZVA-203GX+ is a coaxial amplifier with low noise figure and flat gain from 2 to 20 GHz. Well suited for EW, radar, and laboratory test, the 50-Ω amplifier has typical noise figure of 4.8 dB at 2 GHz, 2.0 dB at 8 GHz, and 4.0 dB at 20 GHz, with typical gain of 29.5 dB at 2 and 8 GHz and 30.0 dB at 20 GHz. It maintains flat gain across the full bandwidth, at ±0.1 dB from 2 to 20 GHz. The output power at 1-dB compression is typically +14.5 dBm at 2 GHz and +12.0 dBm at 20 GHz while the output third-order intercept (IP3) is typically +23 dBm at 2 GHz, +24 dBm at 8 GHz, and +21 dBm at 20 GHz. The RoHS-compliant amplifier is supplied in a metal case with 2.92-mm connectors that measures 1.50 × 1.82 × 0.53 in. (38.10 × 46.23 ×13.46 mm).

Couplers Command Flat Directivity from 2 to 18 GHz

Mini-Circuits' ZUDC10-02183-S+ series of 50-Ω coaxial directional couplers features 10-, 15-, 20-, and 30-dB directional couplers with high directivity and excellent coupling flatness from 2 to 18 GHz, all with the capability to pass DC current from input to output ports. As an example, model ZUDC10-02-183+ is a 10-dB directional coupler with 20-W power-handling capability from 2 to 18 GHz. It has typical coupling flatness of ±0.4 dB across the frequency range with typical full band directivity of 17 dB and typical full band return loss of 15 dB. The RoHS-compliant directional coupler is well suited for wideband commercial and military systems. It measures 2.25 × 0.73 × 0.50 in. (57.18 × 18.54 × 12.70 mm) with female SMA connectors and has an operating temperature range of -55 to +100°C.

SSS Filter Passes DC to 14 GHz

Mini-Circuits' model ZLSS-14G-S+ is an example of the company's advanced suspended substrate stripline (SSS) circuit technology, a broadband lowpass filter well suited for broadband transmitter, receiver, and test applications. The technology can realize high-Q filter and multiplexer circuits with passbands to 26.0 GHz and stopbands to 26.5 GHz and extending as high as 40.0 GHz. The model ZLSS-14G-S+ is a RoHS-compliant lowpass filter with low-loss passband of DC to 14 GHz and high-rejection stopband of 16.5 to 26.5 GHz. The compact 50-Ω filter has typical passband insertion loss of 2 dB. The typical stopband rejection is 30 dB from 16.5 to 18.0 GHz, 50 dB from 18.0 to 19.7 GHz, and 80 dB from 19.7 to 26.5 GHz. It is supplied in a rugged metal housing measuring 0.90 x 0.70 x 0.60 in. (22.86 x 17.78 x 16.24 mm) with female SMA connectors.

Coaxial Bandpass Filter Cleans 63 to 85 MHz

Mini-Circuits' model ZABP-73-S+ is a compact coaxial bandpass filter with low-loss passband from 63 to 85 MHz designed for use in transmitters, receivers, and test equipment. The RoHS-compliant 50-Ω filter features passband insertion loss of typically 1.20 dB with typical passband VSWR of 1.30:1. The stopband rejection is typically 50 dB from DC to 40 MHz, 30 dB from 40 to 45 MHz, 27 dB from 105 to 110 MHz, and 45 dB or better from 110 to 500 MHz. The bandpass filter, which handles input power levels to 0.5 W, is supplied in a rugged metal housing measuring 2.300 × 2.250 × 0.75 in. (58.42 × 57.15 × 19.05 mm) with male SMA input connector and female SMA output connector. The filter is rated for operating temperatures from -40 to +85°C.

Monolithic InGaP Amp Drives DC to 7 GHz

Mini-Circuits' model LHY-84+ is a monolithic surface-mount amplifier based on InGaP HBT technology for applications from DC to 7 GHz, such as CATV and portable wireless devices. It delivers typical gain of 24.4 dB at 10 MHz, 20 dB at 2 GHz, 15.7 dB at 4 GHz, and 9.8 dB at 7 GHz. The typical output power at 1-dB compression is +20.8 dBm at 10 MHz, +21.1 dBm at 2 GHz, +19.6 dBm at 4 GHz, and +15.5 dBm at 7 GHz. The broadband amplifier also achieves respectable noise figure across its wide frequency range, with typical noise figure of 5.1 dB at 10 MHz, 5.2 dB at 1 GHz, 5.4 dB at 2 GHz, 5.6 dB at 4 GHz, and 6.5 dB at 7 GHz. The amplifier runs on +5 V dc and is supplied in a six-lead MCLP surface-mount package measuring just 2 × 2 mm.

Coax Cable Assemblies Flex DC to 40 GHz

Mini-Circuits' 086-KM Series of Hand Flex coaxial cables provide the final touch to many designs with low-loss interconnections in tight places. Covering DC to 40 GHz, the cable assemblies are available in 9-in. (model 086-9KM+) and 15-in. (model 086-15KM+) lengths with 2.92-mm male connectors. With 6-mm bend radius, the cables can make critical, close connections with excellent electrical performance. Insertion loss for 9-in. cables is typically only 0.3 dB to 6 GHz, 1.0 dB to 26.5 GHz, and 1.6 dB to 40 GHz. Return loss for 0-in. cables is typically 25 dB at 18 GHz and 30 dB at 40 GHz. The 50-Ω, RoHS-compliant cables handle high power levels, to 61 W at 1 GHz, 12 W at 18 GHz, and 7 W at 40 GHz, and meet MIL-STD-348 interface requirements at operating temperatures from -55 to +85°C. In addition, a built-in anti-torque nut takes the stress out of installation.

While operators and original equipment manufacturers (OEMs) continue working to finalize mmWave technology, sub-6-GHz will be the go-to 5G network technology in the near term.

number of antennas at the base station and will enable base stations to serve large numbers of users in urban areas. Massive MIMO also boosts peak, average, and cell-edge throughput, maximizing cost efficiency by providing the optimal balance between user coverage and capacity.

These technology advances do not come without system design challenges. Sub-6-GHz massive-MIMO beamforming technology will drive demand for small, highly efficient, cost-effective power amplifiers (PAs) that can be used in massive-MIMO arrays. Also, because the 5G modulation schemes are becoming more complex (i.e., 256 QAM), wireless infrastructure PAs will need to be very efficient under the deep output-power back-off conditions (up to 8 dB or more) that will be required to achieve the necessary linearity.

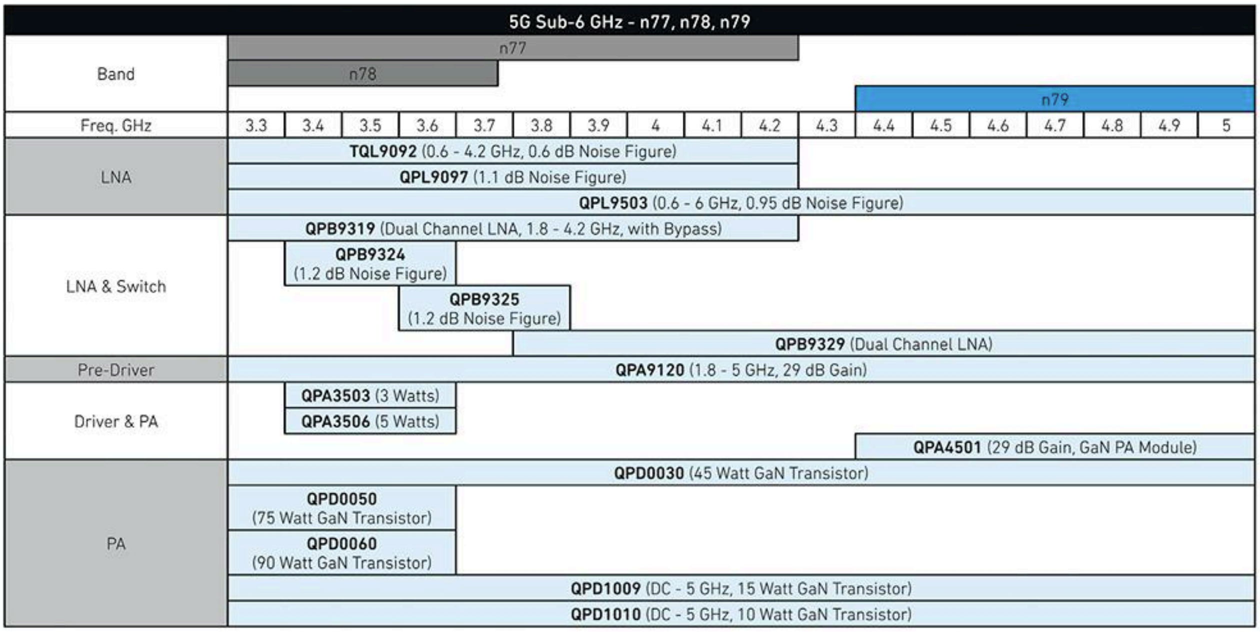
MAKING 5G MASSIVE-MIMO SUB-6-GHz A REALITY USING GaN

High output power, linearity, and power-consumption requirements are pushing base-station and network OEMs to switch from using LDMOS technology for PAs to gallium nitride (GaN). GaN offers numerous advantages for 5G sub-6-GHz massive-MIMO base-station applications:

- GaN performs well at 3.5-GHz frequencies and above, while LDMOS is challenged at these high frequencies.
- GaN has high breakdown voltage, high current density, high transition frequency, low on-state resistance, and low parasitic capacitance. These properties translate into high output power, wide bandwidth, and high efficiency.
- GaN in a Doherty PA configuration attains average efficiencies of 50% to 60% with 100-W output power, significantly reducing transmit power consumption.
- The high-power density of GaN PAs enables small form factors that require less printed-circuit-board (PCB) space.
- Using GaN in a Doherty PA configuration allows for the use of quad-flat no-leads (QFN) plastic packages rather than the expensive ceramic packages.
- GaN's efficiency at high frequency and over wide bandwidths means that massive-MIMO systems can be more compact. GaN reliably runs at higher operating temperatures, meaning it can use a smaller heat sink. This enables a more compact form factor.

MEETING SUB-6-GHz RFFE DESIGN GOALS

Building the RF front end (RFFE) to support these new sub-6-GHz 5G applications will be a challenge. The RFFE is critical to the system's power output, selectivity, and power consumption. The complexity and higher frequency range are driving the need for RFFE integration, size reductions, lower power consumption, high output power, wider bandwidth, improved linearity, and



7. Qorvo offers an array of sub-6-GHz products.

increased receiver sensitivity. In addition, there are tighter coupling requirements between the transceiver, RFFE, and antenna.

Some of the goals of the 5G sub-6-GHz RFFE, and how GaN PAs can help achieve them, include:

- **Higher frequencies and increased bandwidth:** 5G uses higher frequencies than 4G and requires much wider component carrier bandwidths (up to 100 MHz). GaN-on-silicon-carbide (GaN-on-SiC) Doherty PAs achieve wider bandwidths and higher power-added efficiencies (PAEs) than LDMOS at these frequencies. The higher efficiency, higher output impedance, and lower parasitic capacitance of GaN devices allow for easier wideband matching and scaling to very high output power.
- **High power efficiency at higher data rates:** GaN has soft compression characteristics, making it easier to pre-distort and linearize. Thus, it's easier to use in digital pre-distortion (DPD) high-efficiency applications. GaN is able to operate across multiple cellular bands, helping network operators deploy carrier aggregation to increase spectrum and create larger data pipes for increasing network capacity.
- **Minimizing system power consumption:** How do we meet the high data requirements of 5G? We will need more infrastructure, such as data centers, servers, and small cells. This means an overall increase in network power consumption, thus driving the need for system efficiency and overall power savings. Ultimately, the carriers demand more for less, which might seem difficult. But again, GaN can help provide the solution by offering high output power coupled with increased efficiency in base stations.

Figure 6 shows a high-level block diagram of an example sub-6-GHz RFFE, which uses a Qorvo Doherty PA design to attain high efficiency.

GaN is becoming one of the go-to technologies for 5G. Qorvo has been manufacturing GaN for many years, and is able to quickly bring discrete and integrated modules to market. As shown in *Figure 7*, the company provides an array of products for greater design flexibility.

SUMMARY

5G massive-MIMO sub-6-GHz infrastructure designs are already being rolled out. This means the technology and system designs needed to address higher frequencies, higher power output, and lower power consumption must be available now to support global carrier build-out. Technologies such as GaN help carriers and base-station OEMs achieve their goals for 5G sub-6-GHz and mmWave massive MIMO. mw

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JACK BROWNE | Technical Contributor

Wearable Wireless is Becoming Fashionable

1. This third-generation iWatch wireless watch features a vivid graphics display within an electronics-packed housing. *(Courtesy of Apple Inc.)*

Wireless technology extends well beyond cell phones to a host of often interconnected wearable wireless devices in support of personal healthcare and location tracking.

Wireless telephone users may feel naked walking out of the house without their cell phones. But the day is drawing near where the cell phone may be joined by other wireless devices on a person, as dependence on wireless technology grows for communication, location, and even healthcare. Wearable wireless devices are increasingly combining function with fashion—a trend that's expected to continue with the emergence of support from 5G wireless networks.

The earliest wearable wireless devices have typically been some form of radio-frequency identification (RFID) tag that have been used to keep track of small children and pets, or elderly users in need of special monitoring or medical requirements. Another form of short-range wireless technology, such as Bluetooth, is often combined on the same monitoring device for additional communications capabilities. Products such as audio hearing aids and headphones have been available for some time with some form of short-range wireless technology, to free users from the entanglement of wired connections.

MARKET DRIVERS

The strong current market growth in wearable wireless devices centers around "smart watches" and the increasing use of wireless technology for electronic devices that keep users informed in some way, such as medical-monitoring and healthcare-tracking functions. As with cell phones, the earliest smart watches have been bulky, attempting to cram as much wireless transceiver electronics as possible into the small volume of a wristwatch to enable some form of wireless near-field communication (NFC), such as Bluetooth or Wi-Fi.

Much credit, of course, is due to Apple Inc. and the clever marketing of its Apple Watch "smart watches" (now available in Series 4 products). They pack NFC capabilities and supporting displays into a compact, watch-sized device that's as wearable as a conventional time-keeping watch. The Apple Watches build on the popularity of the company's iPhone cell phones and their multifunctional capabilities. Apple Watches *(Fig. 1)*, like other wearable wireless devices, make use of available wireless bands typically reserved for short-range wireless communications, such as the 2.4- and 5.0-GHz Wi-Fi frequency bands and Bluetooth Low Energy (BLE) bands.

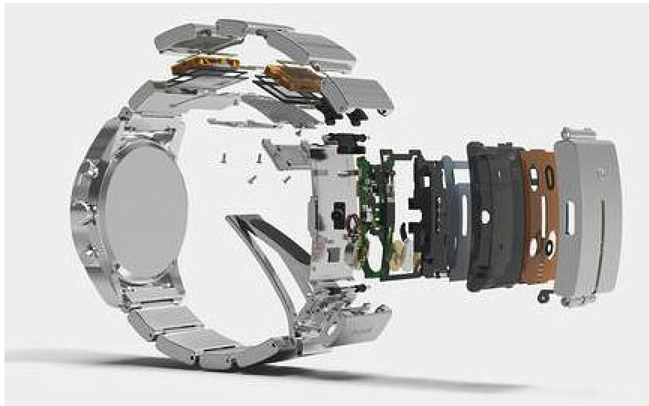
As mentioned, like early cellular communications products, early wireless watches were accused of being oversized (at least compared to conventional watches) in attempts to squeeze as much RF and signal-processing electronics as possible into small packages that were also light enough to be worn without noticing. The antenna is a key component that's not easy to miniaturize, especially at lower frequencies with their

2. Healthcare monitoring and reporting are of growing importance for wearables such as this compact communications badge operating within the Wi-Fi band. *(Courtesy of Vocera)*

longer wavelengths. This has prompted designers of wearable wireless devices such as smart watches to explore the use of antennas built into the fabric of watch wristbands or even the use of higher, millimeter-wave frequencies and their shorter wavelengths to enable the use of smaller antennas.

The success of early developers such as Apple with its smart watches has spurred a virtual explosion in the development of wearable wireless devices for applications such as medical alerts, general healthcare and fitness, and even pet-location monitoring. Implantable healthcare sensors are being used as part of body-area networks (BANs) to provide doctors and other healthcare providers with almost instant access via a wireless mobile device to a critical parameter of a patient's health, such as blood pressure, heart rate, or pulse rate.

NFC between patients and healthcare providers can be supported by wearable wireless devices in various forms, including pendants and badges typically operating within wireless-local-area-network (WLAN) frequency bands at 2.4 and 5.0 GHz. Wireless devices designed for medical BAN communication systems



3. The Wena wireless watch is constructed with the electronic components within the wristband rather than the watch housing. *(Courtesy of Sony Corp.)*

and medical telemetry also make use of the Wireless Medical Telemetry Service (WMTS) bands within 608 to 614 MHz, 1395 to 1400 MHz, and 1427 to 1432 MHz, as well as the Medical Implant Communication Services (MICS) band from 402 to 405 MHz set aside by the FCC for such purposes.

As with other wireless electronic products, wearables are being designed to fit smaller, lighter packages with as much capability as possible. As an example, the B3000n Communications Badge *(Fig. 2)* from Vocera *(www.vocera.com)* is designed for medical monitoring within the Wi-Fi frequency bands from 2400 to 2484 MHz and 5180 to 5805 MHz, supporting data rates from 1 to 54 Mb/s within those bands. It's constructed for simple operation by multiple users—it can be passed along by factory or medical workers from shift to shift for ease of short-distance communications regarding manufacturing processes or patient conditions, respectively. The wireless badge, including its lithium-ion-polymer rechargeable battery, weighs less than 2 oz. It employs direct sequence spread spectrum (DSSS) and orthogonal frequency division multiplexing (OFDM) within the Wi-Fi bands to avoid interference with existing Wi-Fi communications.

SHOWING STYLE

One major electronics manufacturer taking a different look at wearable wireless devices, Sony Corp., developed a "not so smart" wireless watch that it calls Wena. It takes a departure from the traditional electronics-packed housing and passive wristband by using a traditional analog face and cramming the radio and signal-processing electronics into the wristband *(Fig. 3)*.

The Wena was developed as part of an internal product development program in which employees were encouraged to design and develop a smart watch that would have much greater appeal than the company's earlier wireless watches. The watch name is an acronym for "Wear Electronics Naturally," since the smart watch was designed to appeal to those who felt that smart watches with graphics-loaded displays may be too much of a compromise fashion-wise when attending meetings requiring a more serious tone.

Coupled with the growing use of wearables will be the increasing importance of some way to easily provide power to those rechargeable devices. Solutions will likely come in the form of wireless charging or energy-harvesting technology. Wireless charging, by which an RF/microwave receiver transforms high-frequency signals from a local transmitter base station to energy for a nearby rechargeable battery, will be especially critical for implanted wireless medical devices. But it's also being viewed by many commercial businesses, such as drive-through restaurants, as a means of attracting customers with rechargeable cell phones and wearable wireless devices who might be at "low energy levels" in more ways than one! mw

DAVID VYE | Technical Marketing Director, NI AWR Group
JACK BROWNE | Technical Contributor

Platform Propels RF Designs from Concepts to Products

The latest version of a popular multifunction RF/microwave design and simulation software suite provides the means to turn ideas into ready-to-test and manufacture products.

Accelerating wireless communications and other electronic products driven by coming 5G networks, Internet of Things (IoT) applications, and ADAS vehicles are pressuring engineers to develop unique solutions more quickly and efficiently. As a result, RF/microwave designers must develop smaller, more capable antenna and other RF front-end components in less time than before.

In many cases, engineers must adapt novel designs based on evolving techniques and materials, advanced device integration, and greater exploration of the design space with unique topologies and architectures. Fortunately, computer-aided-design (CAD) software can help, especially when it's the latest version—V14—of the NI AWR Design Environment from National Instruments AWR.

As demands increase for new RF front-end components with higher levels of performance, such as improved linearity and lower noise figure, designers must learn to juggle an often-conflicting set of design parameters. Circuit, system, and electromagnetic (EM) simulation must work seamlessly together along with design automation that helps engineers define and manage complex RF electronics, including chip, package, and board structures.

Simulation must accurately predict the response to standards-based signals, and the environment must help engineers create and organize simulation results to gain insight into component behavior. And these capabilities must integrate well with other design tools. These qualities are built into NI AWR Design Environment software, inclusive of Microwave Office, Analog Office, Visual System Simulator (VSS), AXIEM, and Analyst software, providing a robust and complete platform for RF/microwave engineers to develop these next-generation communication electronics.

The V14 release of NI AWR Design Environment software focuses on all of these stages of RF/microwave design. It emphasizes accelerating design starts through powerful network synthesis, enhanced design flow automation for printed-circuit-board (PCB) and module design, phased-array antenna system generation, and standards-compliant test benches. In addition, solver improvements provide fast and reliable simulation, as well as tuning and optimization, to help engineers convert their initial design starts into physically realizable RF components and systems. Powerful data visualization through dynamic data reporting and linked measurements provides a better understanding of how design choices impact performance. On top of that, enhanced automation within NI AWR software further supports back-end design operations.

AIDING DESIGN FLOW

Design-flow automation connects simulation models, third-party tools, and layout geometries to printed circuit board (PCB), monolithic microwave integrated circuit (MMIC), RFIC, and multichip module manufacturing processes. This expedites EM verification of passive structures and board/package designs and enables the extracted models to be incorporated into circuit- or system-level analysis. The V14 release of the NI AWR Design Environment features new functionality that assists users with design starts, design entry, analysis/optimization, and report generation. Such capabilities allow users to manage measurement data sources and parameters from a single location and create sets of linked reports in a single dashboard display.

When pursuing a complex set of component performance specifications, designers often must simultaneously track multiple simulation results. In support of this, V14 of the NI AWR Design Environment enables users to manage measurement data sources and parameters from a single location. Thus, they can create sets of linked reports in a single dashboard display. Variables can be used to define and control groups of measurement parameters together.

Users are able to combine measurement variables, document sets that create a symbolic link of one or more simulation documents that can be used by measurements, and embedded plots within a new window-in-windows feature coupled with an output equation document. This document helps create a dynamic data display that automatically updates graphs and embedded windows with the single click of a computer mouse. For power-amplifier (PA) designers, these new capabilities make it possible to directly plot measurements versus output power (or voltage or current) and/or define the output power measurement on the schematic more easily.

PHASED ARRAYS

The newly enhanced phased-array generator wizard lets users interactively design phased-array antenna systems and then generate schematics or system diagrams representing designs in formats most suitable for further analysis. This latest version of the software suite makes it possible to easily define a phased-array geometry (configuration), feed structures, gain tapers, and the characteristics of individual array elements and their respective RF links.

When performing a simulation, the array response is immediately displayed and reflects any changes due to the operating signal power level, beamsteering, or element failures. Once the design is complete, the phased-array generator wizard produces a system diagram implementation that can be further analyzed in VSS software or be incorporated as part of a larger, complete VSS communication system.

Another role of the phased-array generator wizard is to create schematics/layouts for full EM analysis with the software suite's AXIEM planar EM simulator or Analyst finite-element-method (FEM) three-dimensional (3D) simulator. It also creates schematics/layouts by performing analysis with third-party EM tools such as the ANSYS High-Frequency Structure Simulator (HFSS) software.

PREPARING FOR 5G

Multiple-in, multiple-out (MIMO) and beamsteering phased-array antennas are enabling technologies for achieving the over-the-air spatial efficiency called for by 5G and emerging radar applications such as self-driving cars. In addition to the enhanced phased-array generator wizard, new standards-compliant WINNER II and 5G spatial channel models are available as an add on-module. This module provides high-accuracy modeling of channel-specific propagation effects that support more realistic link-budget analysis for rapid validation of end-to-end system performance and specification of individual component requirements.

The updated VSS model library offers data encoding/decoding and signal generation/analysis for the latest 5G New Radio (NR) specifications. With new VSS projects that support LTE, 5G transmit (TX) and receive (RX), and narrowband IoT (NB-IoT) standards-compliant signals and test benches, engineers can simulate systems or perform measurements on components based on the corresponding specifications.

VSS V14 supports an NB-IoT uplink coexistence RX test bench, an NB-IoT uplink enriched narrowband (eNB) RX test bench in the guard band of an LTE signal, and an in-band uplink eNB RX test bench. Component designers and system architects can use the default configurations to perform what-if analyses or modify them as needed. It also adds new data encoding and decoding capabilities for LTE, NR, and DVB-S2, including support for various low-density parity check (LDPC) codes.

NETWORK SYNTHESIS WIZARD

The new network synthesis wizard is an add-on utility for creating optimized two-port impedance-matching networks of discrete and distributed components. To create an impedance-matching network, a user specifies the maximum number of sections and the types of components to include in the search space. Using the evolutionary algorithms employed within AntSyn antenna design and synthesis software, the network synthesis wizard searches for the best circuit typologies and optimizes the component parameter values.

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CAD Software Suite

The user interface for the network synthesis wizard lets designers interactively develop an unlimited number of networks optimized for noise, power, or impedance matching between amplifier stages or different components, such as an amplifier and an antenna. The optimum reflection coefficients are found for specified frequencies and can be provided in the form of load-pull data, network-parameter data files, or circuit schematic diagrams. On the synthesis definition tab, users can specify a default impedance or the impedance of the desired source/load network, as well as the desired match frequencies.

The NI AWR Design Environment V14 release offers significant new functionality to help guide designers developing circuit-level components—from generating circuit topologies that achieve specified performance goals to interactively optimizing element parameter values to improve overall circuit behavior. The new tuner interface utilizes space-efficient horizontal sliders to support parametric tuning of complex designs with many variable design properties, while the updated property dialog provides greater control and organization of element parameters.

FASTER EM

The AXIEM and Analyst EM simulators apply Maxwell's equations to compute the electrical behavior of a structure from its physical geometry. The AXIEM simulator provides responses for 3D planar structures such as transmission lines, spiral inductors, and metal-insulator-metal (MIM) capacitors, whereas the Analyst simulator addresses arbitrarily shaped 3D objects such as wire bonds, ball grids, finite substrates, and 3D horn antennas.

Multiple V14 software improvements target EM analysis and supporting design flows, delivering enhanced layout editing, new EM-port types and faster, more powerful solver technology. Additionally, the new planar body wrapping feature supports modeling and EM

(Continued on page 69)

CHRIS DeMARTINO | Technical Engineering Editor

Oscilloscopes Set Out to Boost Measurement Confidence

A new series of mixed-signal oscilloscopes offers bandwidths as high as 8 GHz, plus other advanced features like visual triggering.

Last year, Tektronix *(www.tek.com)* made headlines by introducing the 5 Series MSO product line. These mixed-signal oscilloscopes (MSOs) offer bandwidths as high as 2 GHz along with a 12-b vertical resolution and real-time sampling rates as high as 6.25 Gsamples/s. Not stopping there, Tektronix raised the MSO bar higher with the recent introduction of its 6 Series MSO oscilloscopes *(see figure)*.

While the 5 Series MSO oscilloscopes offer bandwidths as high as 2 GHz, the 6 Series MSO instruments take it further by reaching bandwidths topping out at 8 GHz. Customers have five different bandwidth options to choose from when selecting a 6 Series model: 1, 2.5, 4, 6, and 8 GHz. Furthermore, the 6 Series MSO oscilloscopes achieve 25-Gsample/s sample rates on all channels simultaneously.

Like the 5 Series, the 6 Series MSO instruments feature a 12-bit analog-to-digital converter (ADC). High-res mode extends the number of bits to 16. A digital-signal-processing (DSP) filter is the driving force behind high-res mode—it limits bandwidth, and thus noise, to provide a more accurate view of a signal.

A significant trait of the 6 Series MSO oscilloscopes is the new TEK061 front-end application-specific integrated circuit (ASIC). According to Tektronix, it enables "breakthrough" noise performance at the highest sensitivity settings. In fact, the company states that the 6 Series oscilloscopes provide greater than 75% reduction in noise at 1 mV/div in comparison to a typical oscilloscope. With a 1-GHz bandwidth, RMS noise is 54.8 µV at 1 mV/div.

Another point to take note of is visual triggering, which is a new feature that uses graphical areas to define triggers to enable users to save time hunting for the signal of interest. With visual triggering, the oscilloscope scans through all waveform acquisitions and compares them to geometric shapes, such as triangles, rectangles, hexagons, or trapezoids. Users can also build their own custom shapes.

The 6 Series MSO oscilloscopes offer bandwidths as high as 8 GHz along with 25-Gsample/s sample rates.

The 6 Series MSO oscilloscopes also feature FlexChannel technology, which enables each of the four inputs on an instrument to be used as a single analog channel or as eight digital channels. Accessing the eight digital channels requires using a TLP058 probe. Users can connect as many TLP058 probes to an instrument as needed, allowing for as many as 32 digital channels.

Speaking of probes, Tektronix also launched some new versions that tie into the 6 Series MSO oscilloscopes. The TDP7700 TriMode probes are available with bandwidths of 4, 6, or 8 GHz. With TriMode functionality, one probe setup can accurately make differential, single-ended, and common-mode measurements. Tektronix also launched the TDP4000 and TAP4000 4-GHz bandwidth probes. The TDP4000 probes are differential, while the TAP4000 probes are single-ended versions.

Like the 5 Series MSO instruments, the 6 Series MSO oscilloscopes display results on a 15.6-in capacitive touchscreen. The scopes weigh about 28 pounds. mw

CHRIS DeMARTINO | Technical Engineering Editor

RF ENERGY Development in a Box

Whether going with the complete lab box or starting with a module, pallet, or transistor, this series offers engineers new ways to prototype and develop RF energy systems.

A great deal of interest surrounds RF energy applications, with various companies leading the charge in that arena. One such firm is NXP Semiconductors *(www.nxp.com)*, which recently unveiled its RFE Series of system solutions for RF energy applications. This RF energy platform offers performance at 2.45 GHz and can deliver 250 W of RF power.

NXP maintains that "the enhanced control features and reliability that solid-state technology brings to systems using RF energy have long been understood. However, RF power transistors lacked development tools to help engineers leverage them." This is where the RFE Series steps in—the platform delivers new ways to prototype and develop high-performance systems.

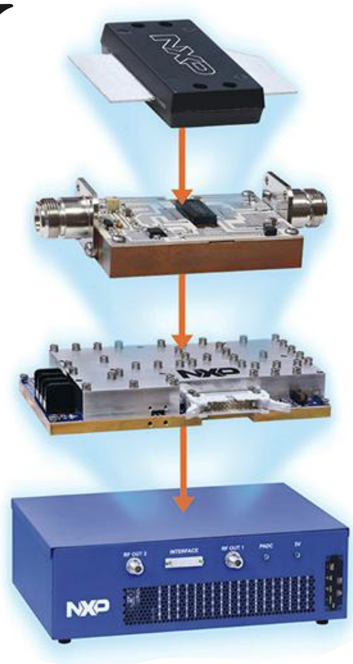
The RFE Series consists of the RF energy lab box (RFEL24-500), RF energy module (RFEM24-250), RF energy pallet (RFEP24-300), and the MRF24300N RF power transistor. *Figure 1* shows all four of these elements in a top-to-bottom representation, starting with the power transistor. This multi-level portfolio is intended to address all levels of expertise, according to NXP.

BREAKING DOWN THE RFE SERIES

The RFEL24-500 lab box covers a frequency range of 2,400 to 2,500 MHz *(Fig. 2)*. It has two channels that can each deliver 250 W of continuous-wave (CW) power. The box includes two RFEM24-250 modules along with fans, a power supply unit, and a heatsink. It also features a USB interface. The 13- × 17- × 5-in. lab box is designed for evaluation and initial prototyping—no RF expertise or RF equipment is required.

A PC-based graphical user interface (GUI) is a significant aspect of the RFEL24-500 lab box *(Fig. 3)*. The software lets users control power, frequency, and phase. Power and phase can be controlled for each module separately; frequency is controlled for both modules simultaneously (i.e., dual-module frequency control). Furthermore, four measurements per module are displayed: forward power, reverse power, temperature, and current.

Another dimension of the software is its *Extended Features* section, which allows for frequency and phase sweeps. Once complete, the software can automatically select the frequency/phase combinations that enable the highest transfer of energy (forward power – reflected power).



1. Shown from top to bottom: the MRF24300N RF power transistor, the RFEP24-300 pallet, the RFEM24-250 module, and the RFEL24-500 lab box.

The RFEM24-250 module delivers 250 W from 2,400 to 2,500 MHz. It requires a supply voltage ranging from 24 to 32 V, as well as 5-V control voltage. *Figure 4* shows a block diagram of the RFEM24-250, revealing three amplifier stages, an integrated RF source, an I^2C communications interface, and more. The MRF24300N power transistor is used for the final amplifier stage.

In addition, the RFEM24-250, which measures 3 × 4 × 1 in., includes sensing for forward power, reflected power, current, voltage, and temperature. As many as four modules can be combined and synchronized.

The RFEP24-300 pallet provides 290 W of CW power from 2,400 to 2,500 MHz. It's a three-stage reference design that's intended to "jump-start power-amplifier (PA) development," according to NXP. The MMG20271H9 monolithic microwave integrated-circuit (MMIC)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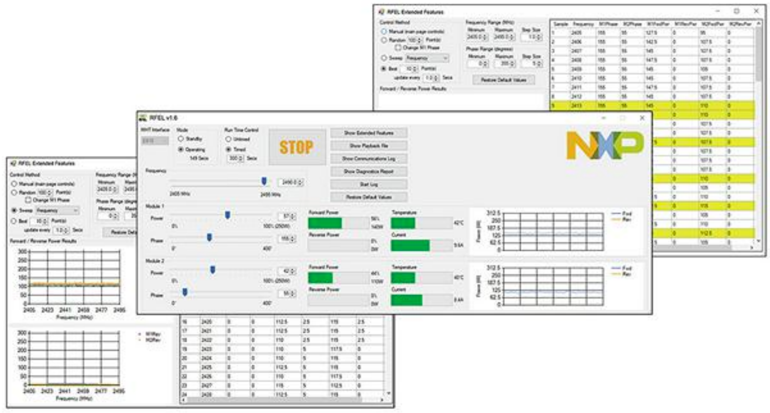
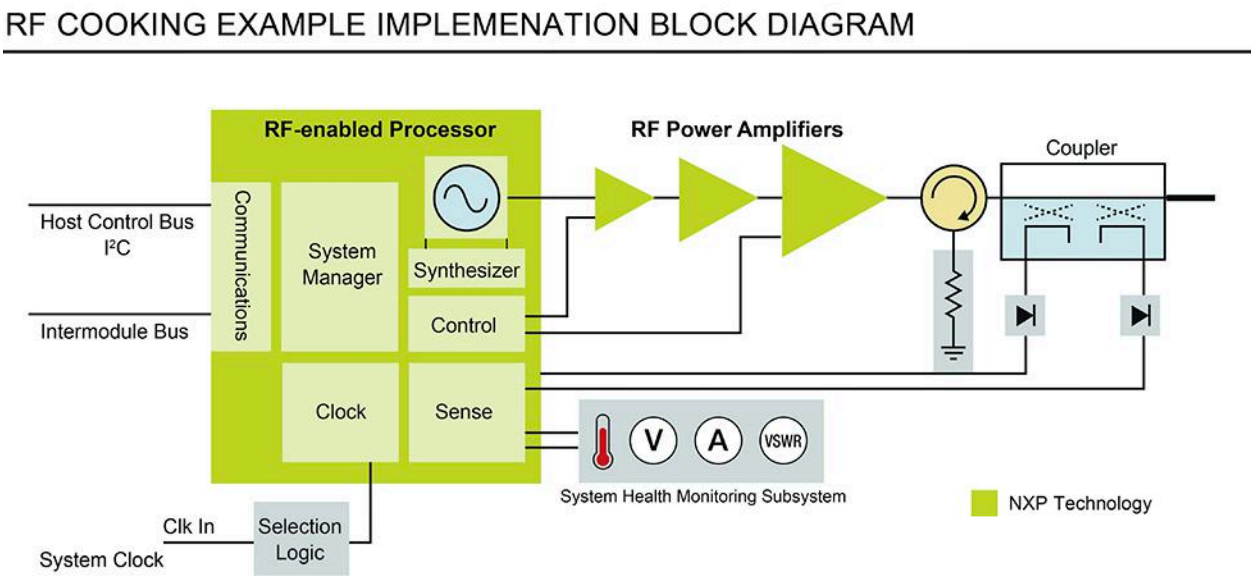
(ULC-Series)
Flexible (FLC-Series)
Precision 75Ω
(CBL-Series)
Precision VNA Cables
(VNAX / VNAC Series)
Armored
(APC-Series)

2. The RFEL24-500 lab box contains two RFEM24-250 modules plus other integral series devices.



3. The lab box software lets users control power, frequency, and phase, as well as view various measurements.



4. Key to the RFEM24-250 module is its three amplifier stages.

amplifier serves as the pre-driver, while the MHT1008N RF power transistor is utilized for the driver stage. The MRF24300N transistor is used for the final amplifier stage. Overall, the complete lineup provides over 41 dB of gain. The pallet measures 2 × 3 in.

The MRF24300N transistor itself delivers 300 W of CW power from 2,400 to 2,500 MHz. It provides 13 dB of gain and achieves a drain efficiency of 60%. The device is known for its ruggedness—it can withstand a voltage standing wave ratio (VSWR) as high as 5:1.

BRINGING EVERYTHING TOGETHER

So, how can customers take advantage of these multiple solutions? The first option is to use the RFEL24-500 lab box for evaluation of solid-state RF energy and initial prototyping. NXP recommends to start with the lab box, which is essentially a turnkey solution.

Another option involves the RFEM24-250 module to create a proof of concept (PoC). Customers would combine the module with their own power supplies, cooling system, control logic, and software. An NXP-recommend third-party would then tailor the module to meet the customer's specific needs to create a cost-effective, high-volume manufacturable solution.

Customers could also start with the RFEP24-300 pallet and then work with NXP-recommended third-party RF PA and/or electromagnetic antenna/cavity design houses to build a solution. Alternatively, they could invest in moderate RF lab equipment and expertise and then copy the reference design. Lastly, a customer could choose to start with the MRF24300N transistor and work with a contract manufacturer. mw

(Continued from page 64)

analysis of conformal structures such as embedded antennas found in consumer electronics and mobile and IoT devices.

Novel port technology helps design engineers characterize substrates more effectively. 3D EM internal wave ports support characterization of complex MMIC and RFIC structures with excitation ports that are not located on a defined simulation boundary. For PCB modeling, new features support port points that allow exact placement of surface-mount components, frequency-dependent materials, and the ability to solve inside metal structures, providing users with greater accuracy.

New functionality added to the PCB import wizard accelerates EM verification of designs created in board-layout tools from leading CAD vendors such as Cadence, Zuken, and Mentor Graphics with powerful geometry selection and editing capabilities. RF design engineers can easily isolate areas of interest with powerful net and area selection for faster, more reliable EM analysis and optimization. It's possible to extract broadband S-parameters for critical traces and densely populated circuit boards, where unintended coupling and parasitic elements can be detected and addressed before they cause design failures.

The powerful new editing capabilities within the NI AWR Design Environment V14 release enable RF designers to easily set up complex imported PCB designs for analysis in the AXIEM or Analyst simulators. A new smart editing tool lets users interactively isolate circuit-board sections and multilayer traces and viaholes, automatically define unlimited EM ports from the imported data, generate an EM structure with schematic view for surface-mount component insertion, and perform related simulation setup tasks. Finally, the enhanced iNet intelligent net functionality with improved trace routing addresses the need for rapid EM modeling and analysis of advanced modules, MMICs, and PCBs utilizing heterogeneous structures and dense networks of high-frequency interconnects.

The release of the V14 NI AWR Design Environment platform offers new and enhanced innovative solutions in design automation and simulation technology for the advancement of high-frequency electronic products serving communications and aerospace/defense industries. As component requirements for these applications drive advances in semiconductor, PCB, and multichip module integration, this latest NI AWR software addresses evolving product-development challenges with powerful enhancements in design flow automation and greater speed and accuracy for its system, circuit, and EM simulation technologies. mw

NATIONAL INSTRUMENTS, AWR Corp., 1960 E. Grand Ave., Ste. 430, El Segundo, CA 90245; (310) 726-3000, FAX: (310) 726-3005, www.awrcorp.com.

Transistor Drives 300 W to 2.5 GHz

MODEL MAGE-102425-300S00 is a high-power transistor capable of operating from 2.40 to 2.50 GHz with 16-dB gain. Capable of operating under pulsed and CW signal conditions, it achieves as much as 300 W saturated output power at 2.45 GHz. The transistor runs on +50-V dc bias and is well-suited for RF heating applications, including for solid-state cooking, RF plasma generation, material drying, industrial heating, automotive ignition, lighting, and medical systems. It comes in an air-cavity package.

MACOM, 100 Chelmsford St., Lowell, MA 01851; (978) 656-2500, (800) 366-2266, FAX: (978) 656-2804, www.macom.com

GaN-on-Si Transistor Powers CW C-Band Radars

MODEL IGT5259CW25 is a GaN-on-Si high-electron-mobility-transistor (HEMT) device designed to deliver 25 W continuous-wave (CW) output power at C-band frequencies from 5.2 to 5.9 GHz. Well-suited for C-band CW radar systems, the power transistor is assembled with chip-and-wire technology. It's internally prematched to 50 Ω and supplied in a metal-based package with a ceramic-epoxy sealed lid. The transistor features 12-dB gain across the frequency range when operating on 36-V drain bias and –6-V gate-source voltage. It achieves 48% typical drain efficiency when operating under CW signal conditions.

INTEGRA TECHNOLOGIES INC., 321 Coral Circle, El Segundo, CA 90245-4620; (310) 606-0855, FAX: (310) 606-0865, www.integratech.com

DAS Samples Eight Simultaneous Channels

MODEL AD7606-EP1 is a 16-b analog-to-digital-converter (ADC) data-acquisition system (DAS) with the capability to simultaneously sample all eight of its input channels. This is a true miniature system, containing analog input clamp protection, a second-order antialiasing filter, track-and-hold amplifier, 16-b charge redistribution successive approximation ADC, flexible digital filter, a 2.5-V reference and reference buffer, and high-speed serial and parallel interfaces. It operates at throughput rates to 150 ksamples/s for all channels and runs on a single +5-V dc supply. It can accommodate ±10- and ±5-V true bipolar input signals. The antialiasing filter has a 3-dB cutoff frequency of 23 kHz. The DAS is well-suited for defense and aerospace applications, with an operating temperature range of –55 to +125°C. It's supplied in a 64-lead low-profile quad flatpack.

ANALOG DEVICES INC., Corporate Headquarters, One Technology Way, Norwood, MA 02062; (781) 329-4700, www.analog.com

Evaluation Kit Handles 2.4-GHz S-Band Radar

THOSE INTERESTED IN expanding S-band Doppler radar applications for measuring target distance and velocity at 2.45 GHz can use the SDR-KIT 240B evaluation kit with versatile software-defined-radio (SDR) module and a copy of graphical-user-interface (GUI) software for the radar module. The kit also includes an ac/dc power adapter, a pair of RF cables, a pair of transmit and receive antennas, and a processing module. An SDR-PM 404 processing module is compatible with all of the company's dual-channel receiving SDR-RF modules, while an SDR-PM-402 processing module is compatible with the company's single-channel SDR-RF modules, allowing experimenters to customize their 2.45-GHz radar designs.

ANCORTEK INC., 11092 B Lee Highway, Ste. 104, Fairfax, VA 22030; (703) 531-8997, E-mail: info@ancortek.com, www.ancortek.com

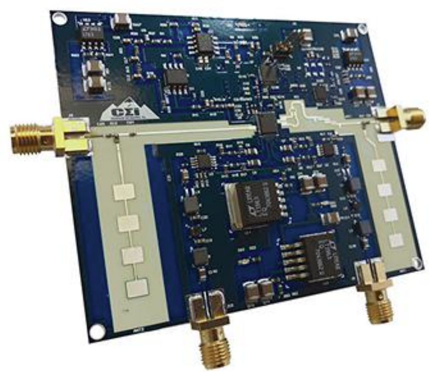
Splitter/Combiner Goes Two Ways from 10 to 50 GHz

MODEL ZN2PD-V54+ is a two-way, 0-deg. power splitter/combiner with a broadband microwave/millimeter-wave frequency range of 10 to 50 GHz. Well suited for 5G and satellite communications (satcom) applications, the 50-Ω, dc-pass component handles as much as 10 W input power as a splitter with maximum internal power dissipation of 1 W. The insertion loss (above the 3-dB splitting loss) is typically 1.0 dB from 10 to 40 GHz and 1.8 dB from 40 to 50 GHz. The isolation between ports is typically 23 dB from 10 to 40 GHz and 22 dB from 40 to 50 GHz. The power splitter/combiner has low amplitude unbalance of typically 0.10 dB from 10 to 40 GHz and 0.13 dB from 40 to 50 GHz, with typical phase unbalance of 1.40 deg. from 10 to 40 GHz and 2.7 deg. from 40 to 50 GHz. When used as a power splitter, the VSWR at the input port is typically 1.20:1 from 10 to 40 GHz and 1.27:1 from 40 to 50 GHz, while the VSWR at the two output ports is typically 1.23:1 from 10 to 40 GHz and 1.24:1 from 40 to 50 GHz. The RoHS-compliant power splitter/combiner comes in a rugged aluminum-alloy case measuring just 1.84 × 1.00 × 0.37 in. It includes 1.85-mm coaxial connectors and rated for operating temperatures from –55 to +100°C.
MINI-CIRCUITS, P.O. Box 350166, Brooklyn, NY 11235-0003; (718) 934-4500, www.mini-circuits.com

Bandpass Filter Screens 48 to 72 GHz

MODEL FC2-625-9 a WR-15 waveguide bandpass filter, is a member of a series of filters in bandwidths of 30 to 100% from 18 to 110 GHz. It features a passband of 48 to 72 GHz with lower and upper 20-dB rejection points at 45 and 74 GHz, respectively. The filter has better than 30-dB rejection to 110 GHz. The typical passband insertion loss is 1 dB and no more than 2 dB.
SPACEK LABS INC., 212 East Gutierrez St., Santa Barbara, CA 93101; (805) 564-4404, FAX: (805) 966-3249, E-mail: sales@spaceklabs.com, www.spaceklabs.com

Radar Module Targets 24 GHz



THE iSCAN©24F fixed-beam radar module is designed to speed and simplify the design of many different radar systems at 24 GHz, including target tracking, collision avoidance, radar-cross-section (RCS) measurements, and occupancy sensing. Built for land, sea, and air environments where size and weight must be minimized, the radar module incorporates steerable beams and digital beamforming, and is available with options for 24-, 60-, and 77-GHz radar operation. The radar module features a 32-b processor core and 16-MB onboard dynamic random-access memory (DRAM). A built-in patch antenna includes three switchable transmit and receive beams, with a total field of view (FOV) of ±36.5 deg. azimuth and ±8 deg. elevation.
COLORADO ENGINEERING INC., 1915 Jamboree Dr., Ste. 165, Colorado Springs, CO 80920; (719) 388-8582, E-mail: sales@coloradoengineering.com, www.ColoradoEngineering.com

Filter Covers Two Passbands to 4.5 GHz

MODEL AM3134 is a dual MMIC analog voltage-tunable bandpass filter with passbands of 2.0 to 3.2 GHz and 2.5 to 4.5 GHz. It provides independent voltage-tunable control of center frequency and passband via a +1- to +10-V tuning voltage range. Typical passband insertion loss is 9 dB. The typical input third-order intercept point (IP3) for a wide bandwidth is +40 dBm, while the typical input IP3 for a narrower bandwidth is +39 dBm. The filter, which comes in a QFN package measuring 5 × 5 × 1.2 mm, has an operating temperature range of –40 to +85°C. It achieves 1-dB input compression (P1dB) at +25 dBm.
ATLANTA MICRO INC., 3720 DaVinci Ct., Ste. 125, Norcross, GA 30041; (470) 253-7640, www.atlantamicro.com

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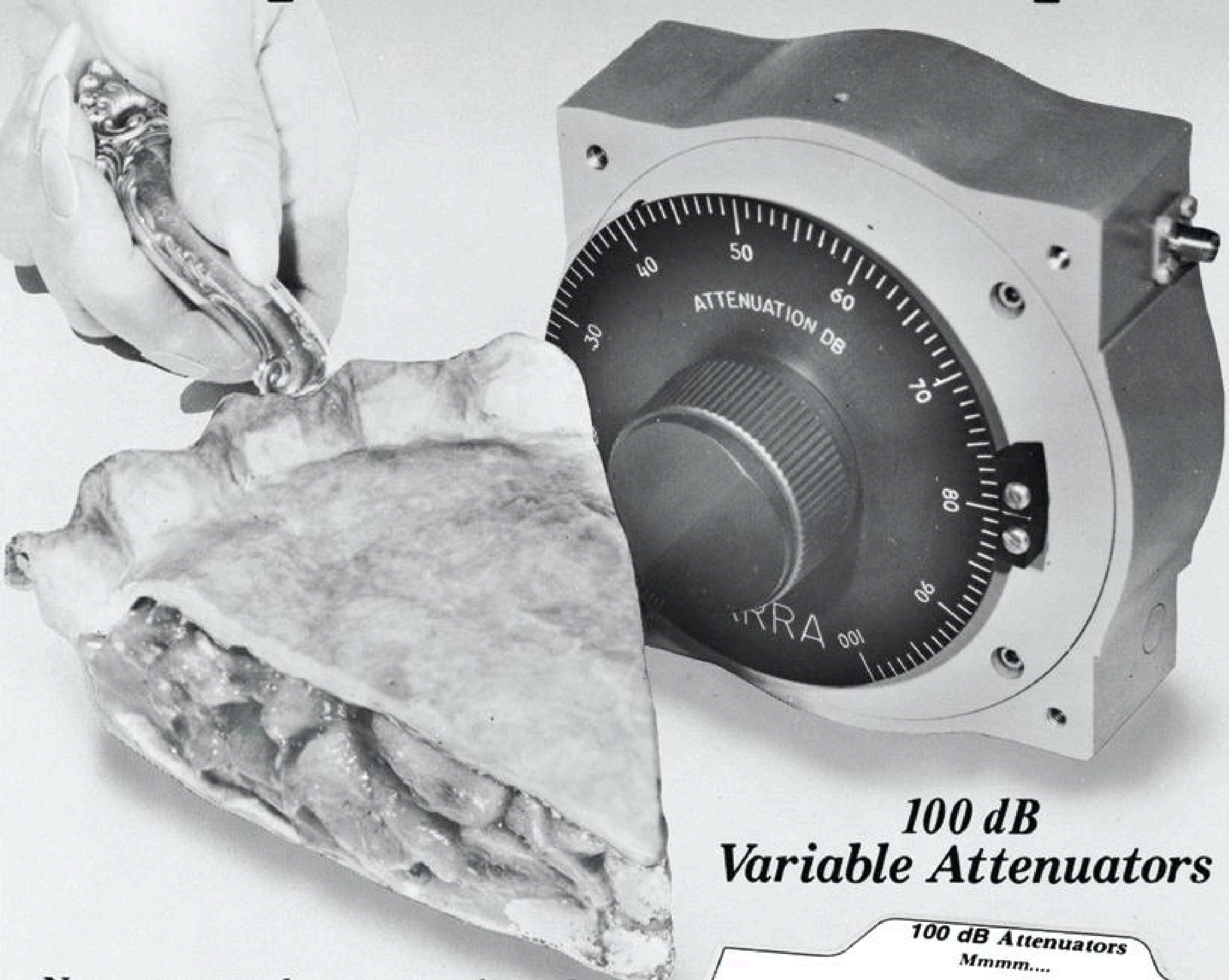

100 dB Variable Attenuators

100 dB Attenuators
Mmmm....

Freq Range	Atten vs Freq dB	Model #
500 - 1000 MHz	1.5	2952 - 100
900 - 1300 MHz	0.75	2-3952 - 100
1000 - 2000 MHz	1.5	3952 - 100X
2000 - 4000 MHz	1.5	4952 - 100 X
4000 - 8000 MHz	1.5	5952 - 100X

Insertion loss - 6 dB
VSWR - 1.5
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Temperature -30 to +120 C

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