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Designing a Signal Chain for Satcom Systems at Ka-Band Frequencies p128

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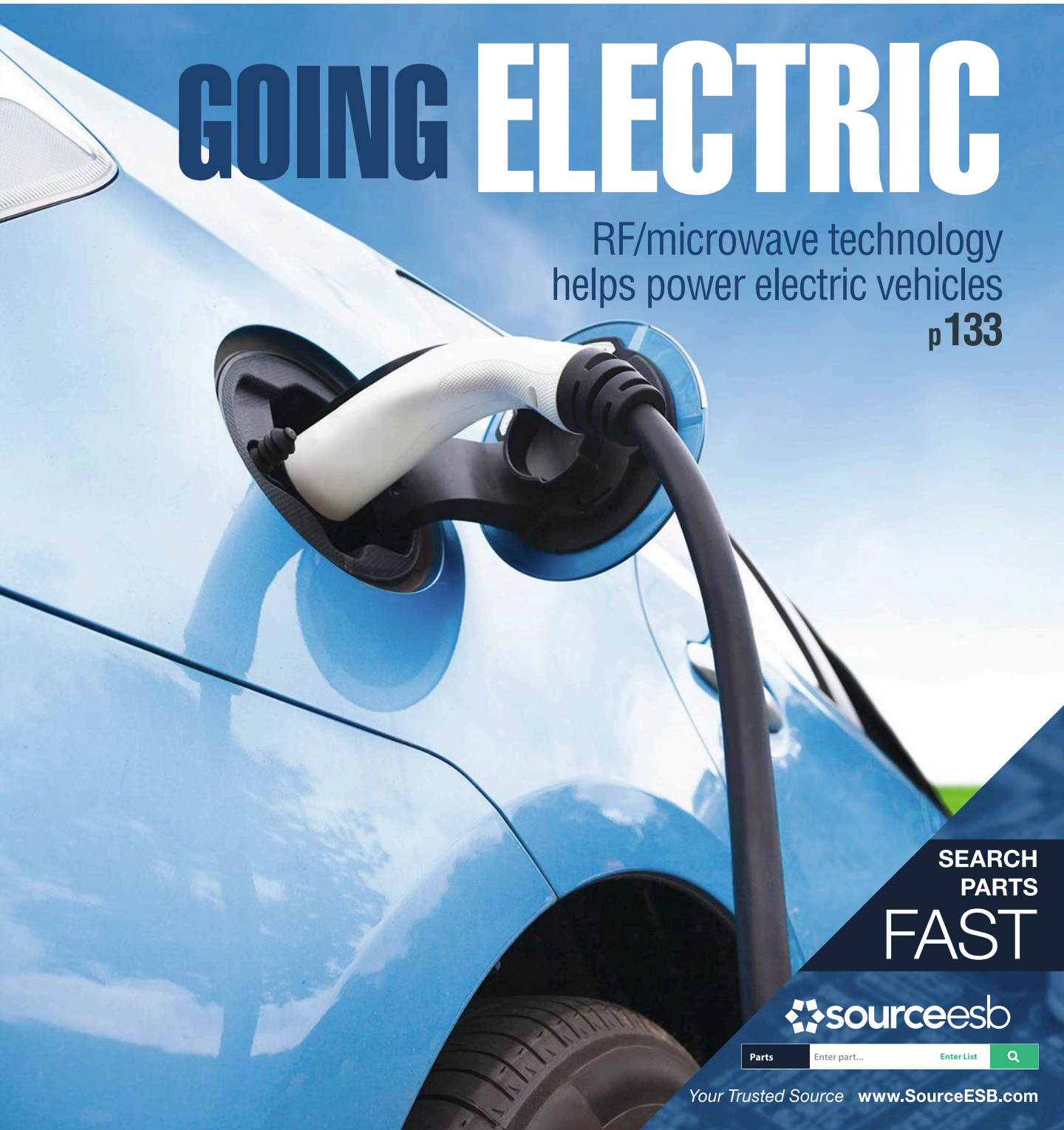
RF/microwave technology helps power electric vehicles p133



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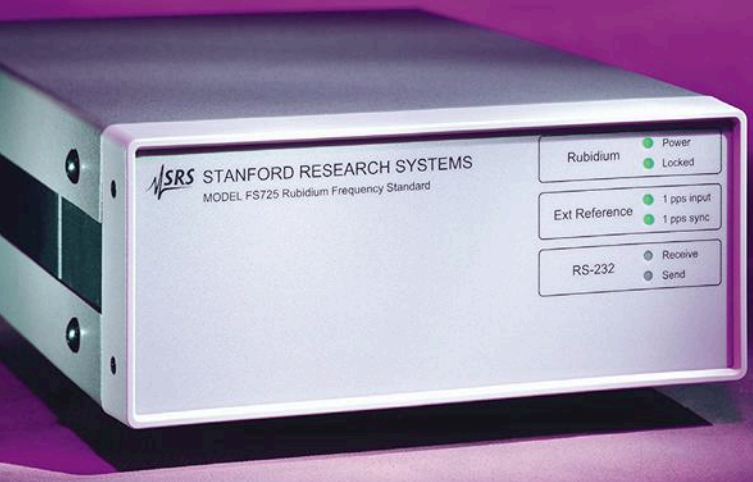

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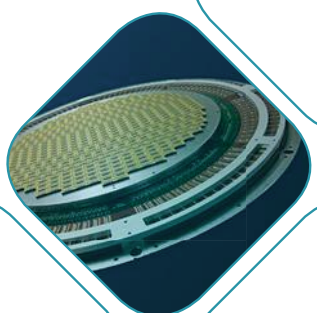

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Fixed	10	1000	-110	LNFT-10-1000-15

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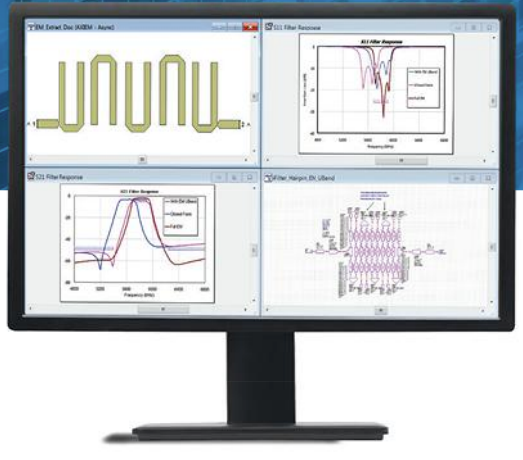

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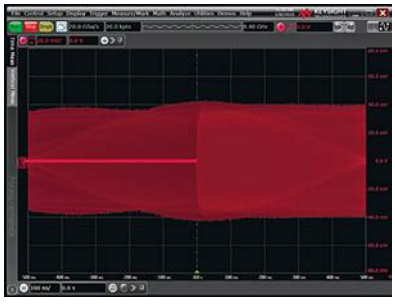

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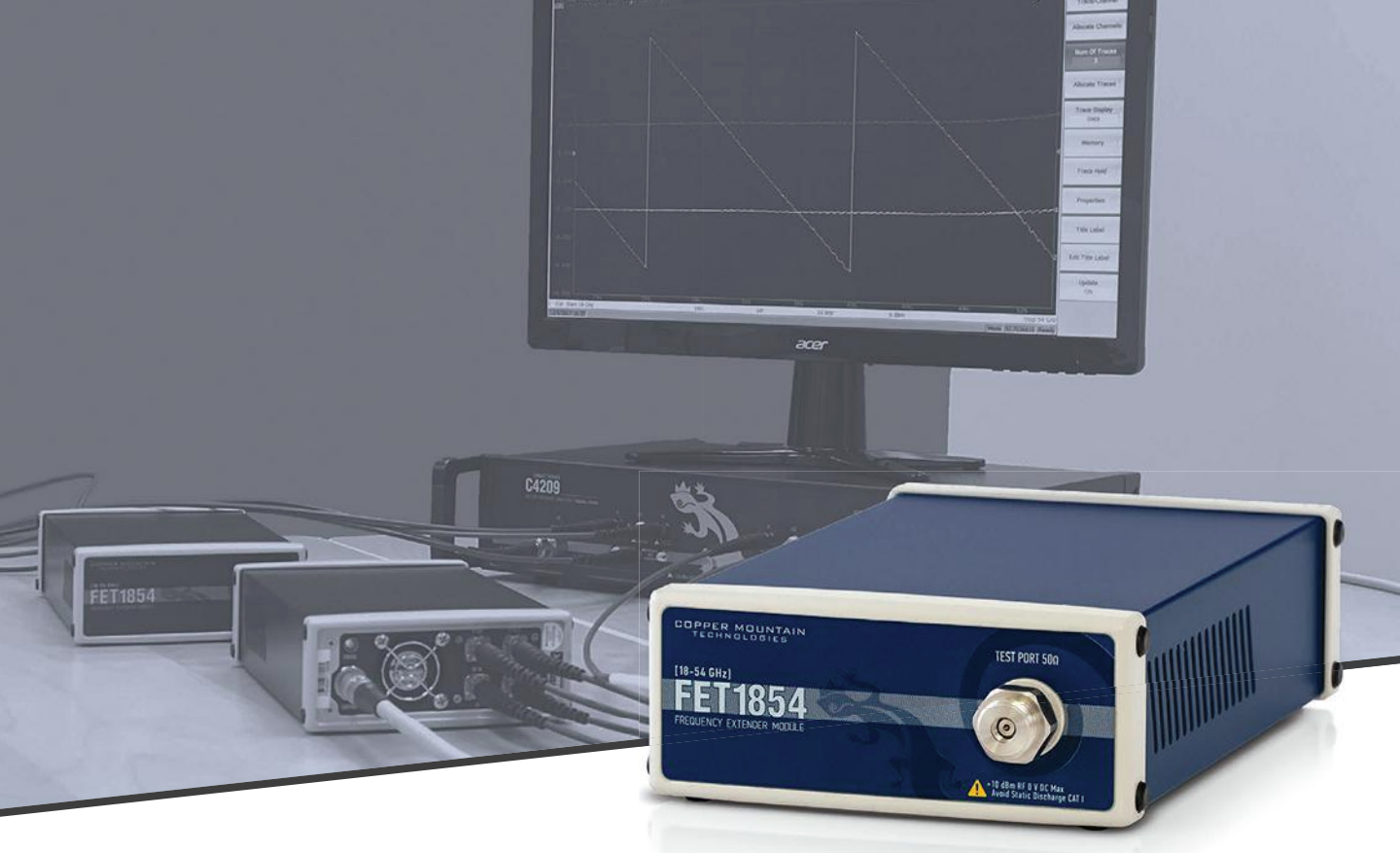

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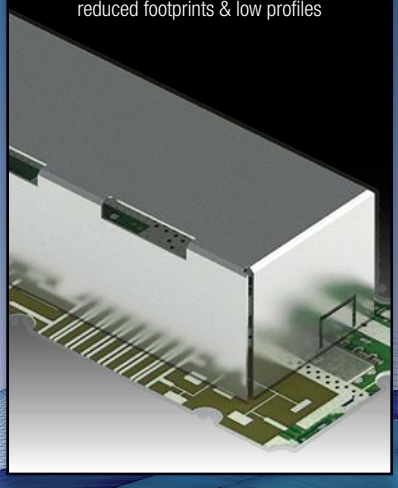
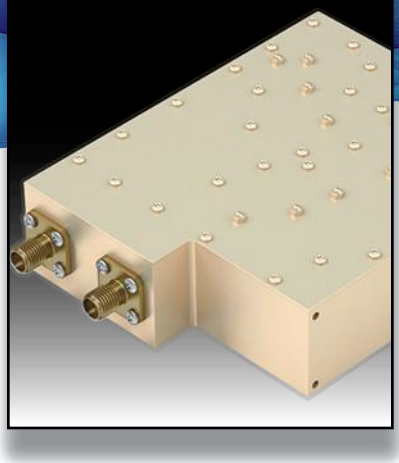


Cavity Filters
multiplexers and multi-functions assemblies



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Frequency range (MHz)	1.5 to 30
RF output, CW (kW)	1.8, 2 typical
THD, 5 to 90% modulation (%)	<5
Gain (dB)	54
AC-to-RF efficiency at rated power (%)	57
Noise floor in transmit-disable mode (dBm/Hz)	-173
Harmonic suppression (dBc)	-10 second order -28 third order -60 with filter
Spurious rejection (dBc)	<-70
Third-order IMD (dBm)	+75
Input/output return loss (dB)	-22/-16
Phase flatness (±2 MHz BW) (deg)	<1
Maximum duty cycle (%)	100
Maximum VSWR	2:1, 30:1 with foldback
TX/RX isolation (option)(dB)	60
RX/TX switching time (option)(μs)	5, 2 typical
Prime power (VAC)	85 to 265
Control/Monitoring	RS-232 or RS-485, Ethernet
Altitude (ft.)	30,000
Dimensions (in. HWD)	7x19x20. Amplifier 5.25 H , power supply 1.25 H
Weight (lb.)	Amplifier (29), total (57)
Protection	Thermal overload, over/under voltage, temperature, fan
Monitoring	Forward/reflected power, gain, temperature, hours of operation, fan status, filter selection, BIT status, others

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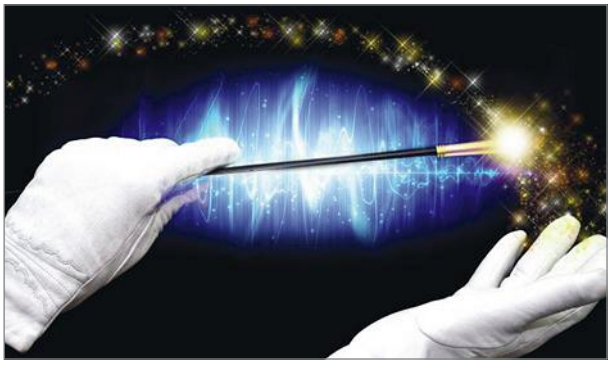
2018 Wireless Trends to Watch

2017 was a great year for engineering and tech. SpaceX, OneWeb, and Tesla provided some great technological advancements in 2017 (just to name a few). However, we're already excited to see what 2018 holds for RF, engineering, and other technology innovations.

http://www.mwrf.com/community/2018-wireless-trends-watch



The Magic Component that Makes Wireless Work

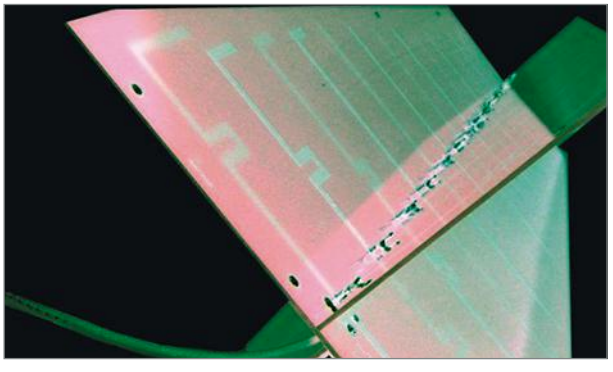
Two antenna technologies–MIMO and phased arrays–have emerged as the solution to many of the problems faced in implementing new wireless technologies like 5G cellular, Wi-Fi, and other high-speed digital standards.

http://www.mwrf.com/components/magic-component-makes-wireless-work

UAVs Keep an Eye on Enemy Movements

Surveillance has long been one of several ways of keeping track of an adversary. Once referred to simply as "spying" on an enemy, surveillance has grown in sophistication, enabled very much by advances in analog, digital, and mixed-signal electronics.

http://www.mwrf.com/systems/uavs-keep-eye-enemy-movements



Choosing Circuit Materials for Low-PIM PCB Antennas

Circuit materials with the right blend of characteristics can provide foundations for PCB antennas with the low distortion needed for modern wireless communications systems.

http://www.mwrf.com/components/choosing-circuit-materials-low-pim-pcb-antennas

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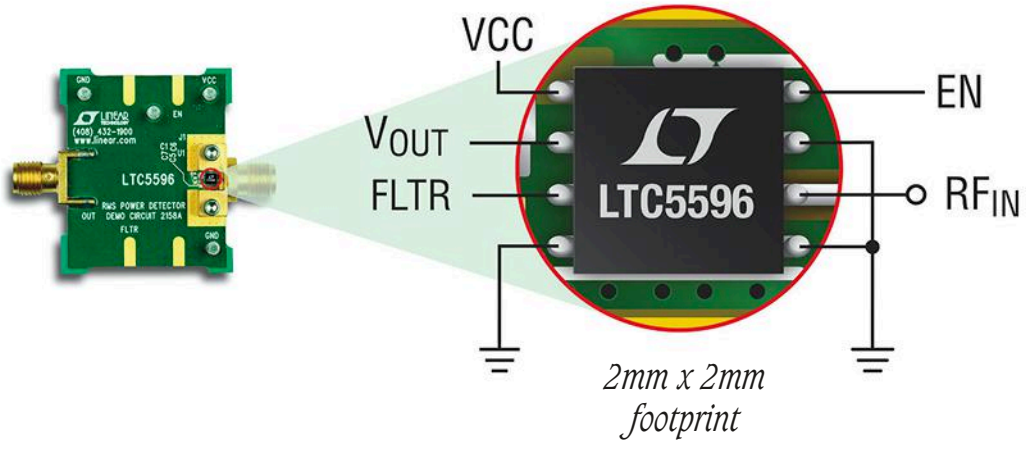

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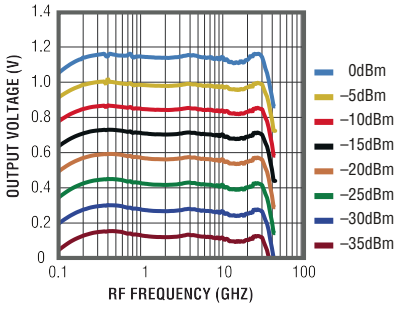
Output at Different RF Inputs



Info & Online Store

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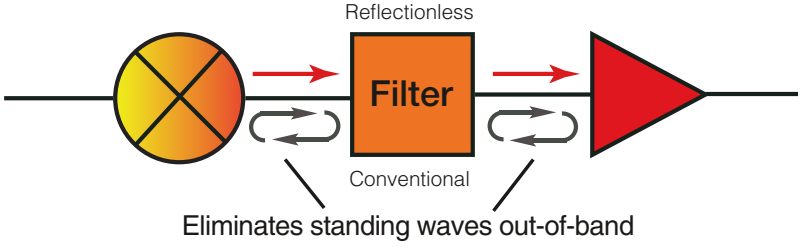

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[2] See application note AN-75-007 on our website
[3] See application note AN-75-008 on our website
[4] Defined to 3 dB cutoff point

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Editorial

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

Will 2018 Be the Year of 5G?

Could we possibly see mobile 5G service before the end of 2018?

AT&T recently made headlines by announcing its plans to introduce mobile 5G service in a dozen markets by the end of 2018. AT&T is hoping to beat its competitors to the punch and become the first U.S. carrier to deliver 5G mobile service to customers. Meanwhile, Verizon also has plans of delivering 5G service before the year is over, while Sprint and T-Mobile are also expected to be players in the 5G game.

The news from AT&T is significant, as we have been hearing about 5G for quite some time now. If you've been reading this magazine, you have surely seen plenty when it comes to this subject matter. With this announcement, AT&T clearly believes it can lead the way in terms of 5G actually becoming a reality.

No doubt, AT&T has high expectations for 5G. According to Melissa Arnoldi, president, AT&T technology and operations, "5G will change the way we live, work, and enjoy entertainment. We're moving quickly to begin deploying mobile 5G this year and start unlocking the future of connectivity for consumers and businesses. With faster speeds and ultra-low latency, 5G will ultimately deliver and enhance experiences like virtual reality, future driverless cars, immersive 4K video, and more."

With all of the talk surrounding 5G, it begs the question: Are we in desperate need of 5G right now? Lou Frenzel, my colleague at *Microwaves & RF* and *Electronic Design*, doesn't necessarily think so, as he recently wrote, "Our current 4G cellular standard Long Term Evolution (LTE) is adequately serving most of us right now." Nonetheless, 5G does offer tremendous potential for many people. In any case, 5G is certainly on its way regardless of how you feel.

Part of what makes 5G so intriguing is that it prompts folks to think beyond smartphones. Virtual reality and driverless cars are two examples, according to Arnoldi. Will we see 5G-enabled virtual reality and driverless cars in the near future? AT&T believes that we will.

With all of that being said, 2018 should be an eventful year with regard to 5G. With all the activity currently taking place, it is possible that we could see 5G-equipped iPhones sooner than you may think. Stay tuned, as we will try to bring you the latest 5G developments throughout the year. mw

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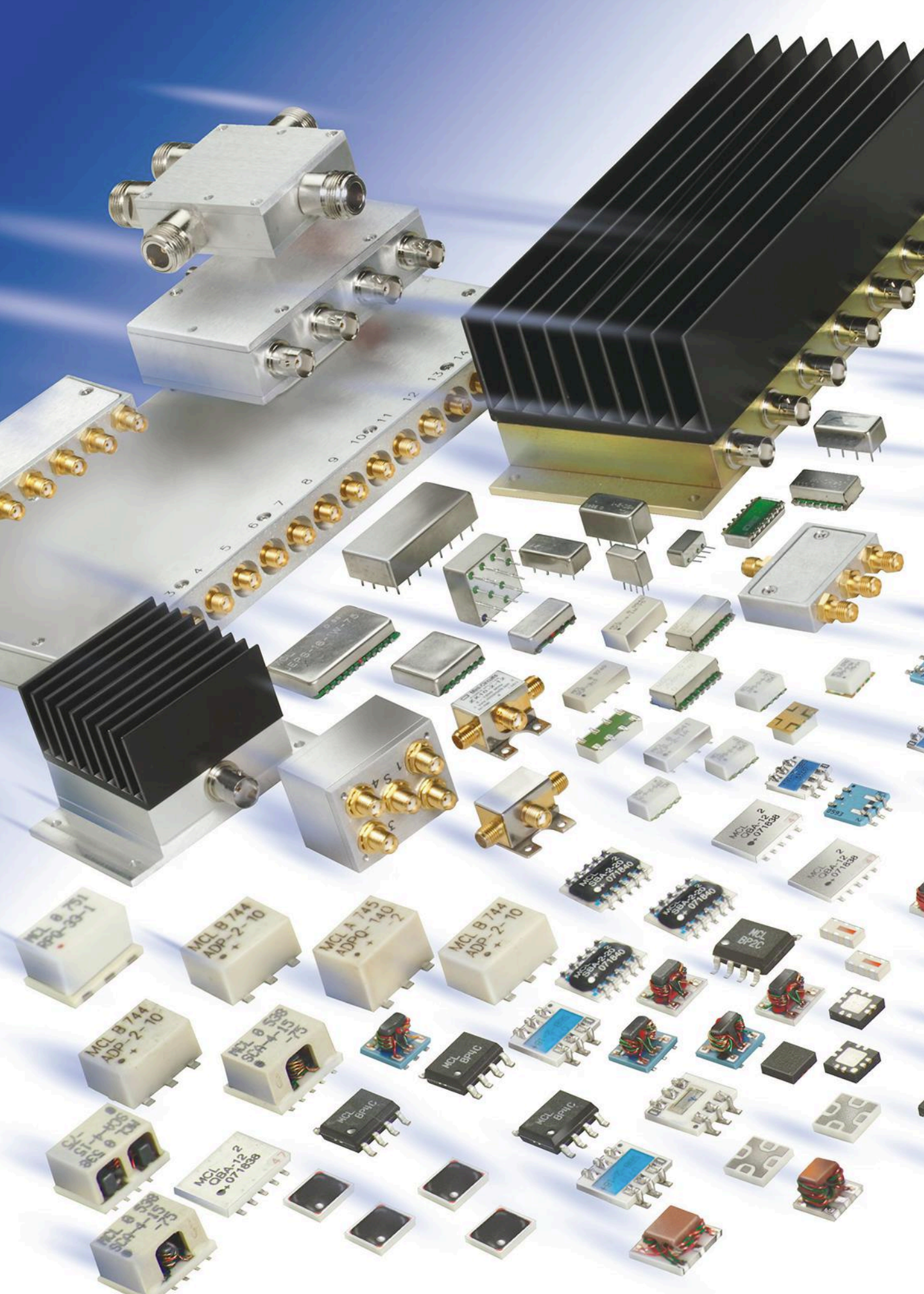

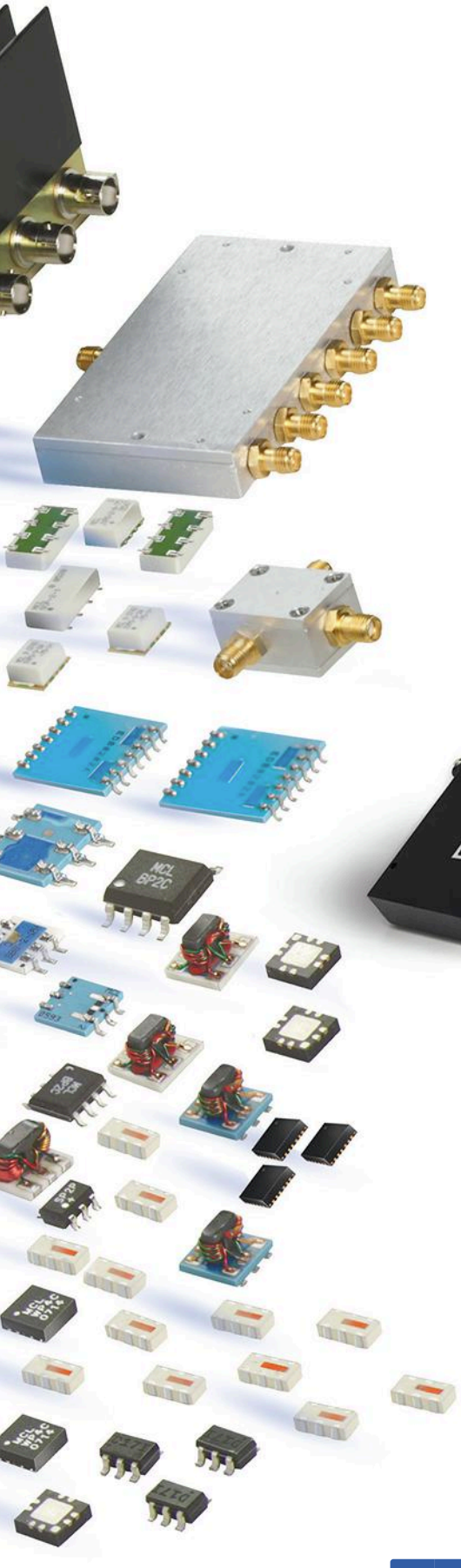

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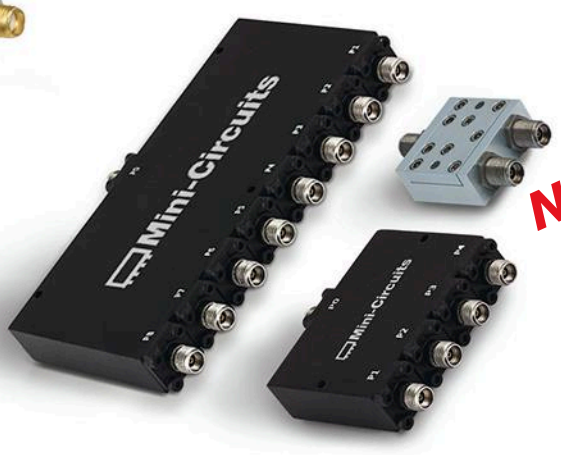

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EDITORIAL

CONTENT DIRECTOR: **NANCY K. FRIEDRICH** nancy.friedrich@informa.com
TECHNICAL CONTRIBUTOR: **JACK BROWNE** jack.browne@informa.com
TECHNICAL ENGINEERING EDITOR: **CHRIS DeMARTINO** chris.demartino@informa.com
CONTENT PRODUCTION DIRECTOR: **MICHAEL BROWNE** michael.browne@informa.com
PRODUCTION EDITOR: **JEREMY COHEN** jeremy.cohen@informa.com
CONTENT PRODUCTION SPECIALIST: **ROGER ENGELKE** roger.engelke@informa.com
CONTENT OPTIMIZATION SPECIALIST: **WES SHOCKLEY** wes.shockley@informa.com
ASSOCIATE CONTENT PRODUCER: **LEAH SCULLY** leah.scully@informa.com
ASSOCIATE CONTENT PRODUCER: **JAMES MORRA** james.morra@informa.com

ART DEPARTMENT

GROUP DESIGN DIRECTOR: **ANTHONY VITOLO** tony.vitolo@informa.com
SENIOR ARTIST: **JIM MILLER** jim.miller@informa.com
CONTENT DESIGN SPECIALIST: **JOCELYN HARTZOG** jocelyn.hartzog@informa.com
CONTENT & DESIGN PRODUCTION MANAGER: **JULIE JANTZER-WARD** julie.jantzer-ward@informa.com

PRODUCTION

GROUP PRODUCTION MANAGER: **GREG ARAUJO** greg.araujo@informa.com
PRODUCTION MANAGER: **VICKI McCARTY** vicki.mccarty@informa.com

AUDIENCE MARKETING

USER MARKETING DIRECTOR: **BRENDA ROODE** brenda.roode@informa.com
USER MARKETING MANAGER: **DEBBIE BRADY** debbie.brady@informa.com
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ITALY: **DIEGO CASIRAGHI** diego@casiraghi-adv.com
PAN-ASIA: **HELEN LAI** **T** | 886 2-2727 7799 helen@twoway-com.com
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ONLINE

PRODUCT DEVELOPMENT DIRECTOR **RYAN MALEC** ryan.malec@informa.com

DESIGN ENGINEERING & SOURCING GROUP

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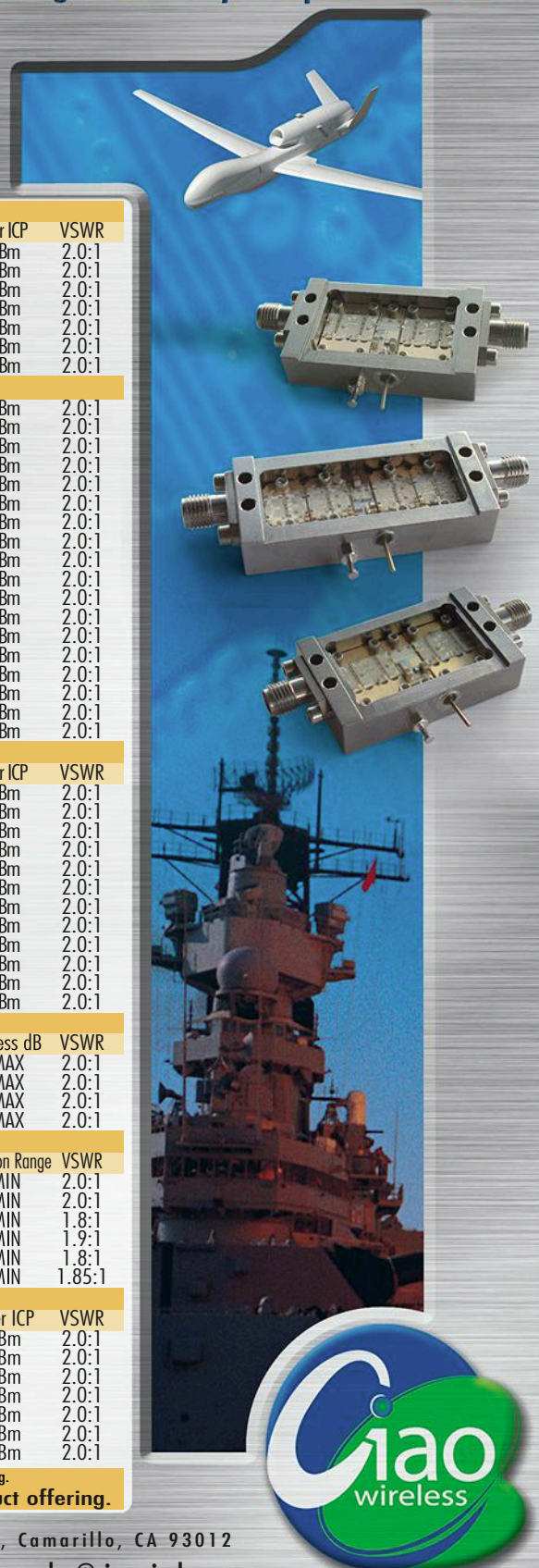

OCTAVE BAND LOW NOISE AMPLIFIERS

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

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

HERE, WHICH MAKES DIGITAL

Road Maps, Moves Into Over-the-Air Updates

Here, which drafts digital road maps for the automotive industry, said that it had acquired Germany's Advanced Telematic Systems, whose software stack allows infotainment and advanced driver assisted systems in cars to be updated wirelessly, closing security gaps and making upgrades.

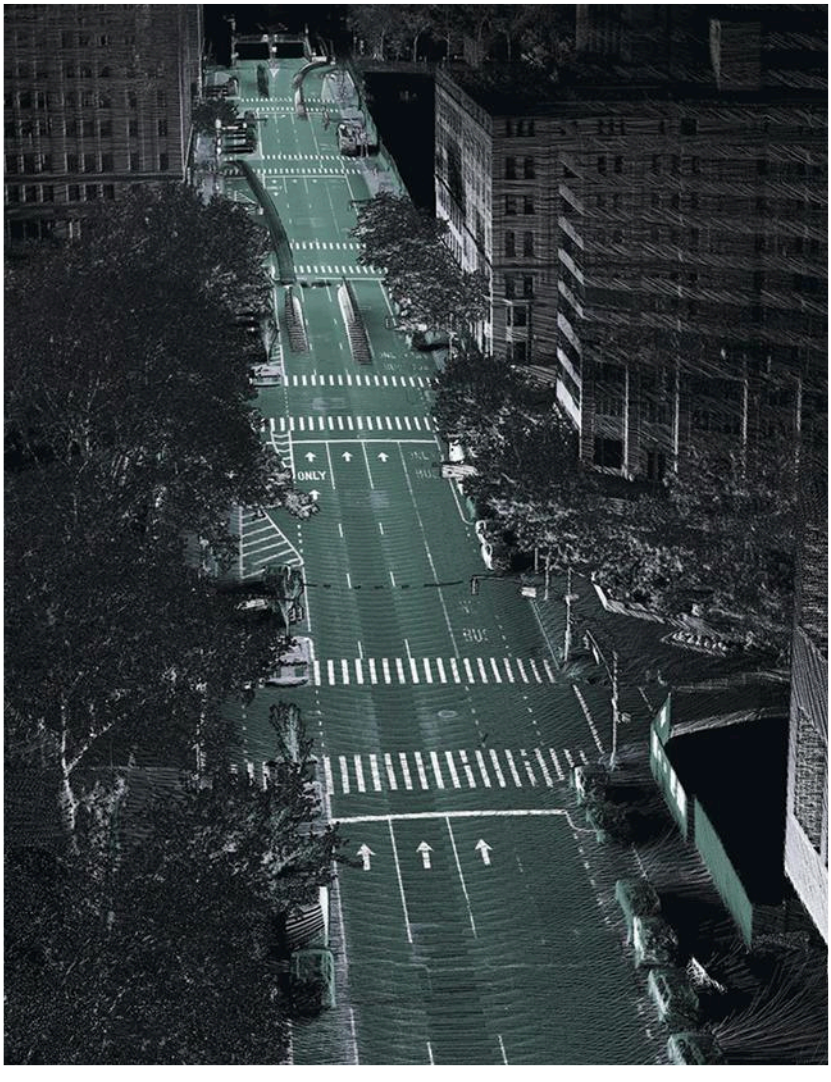
Like other automotive suppliers, Here is targeting ways to update the electronic control units in vehicles, particularly the self-driving cars that could be released in a few years. With the software stack from ATS, the company could simultaneously and securely update all the control units in an entire vehicle and across an entire fleet of vehicles.

Many companies including General Motors plan to start using over-the-air technology for remote updates as cars grow increasingly connected and vulnerable to hackers. With it, Here could also continuously update the digital maps it provides to more than 100 million cars worldwide to give them an almost real-time picture of the road.

"Data and software delivery is a defining factor for future success within the automotive industry," said Ralf Herrtwich, senior vice president of Here's automotive business, in a statement. "The acquisition of ATS is a hugely important strategic investment for us to complement our portfolio as a premium automotive cloud provider."

Going forward, Here will compete with other suppliers like Wind River and Delphi's Movimiento unit. To stand out, the firm could extol the security virtues of its products. ATS supports its software with Uptane, a framework being developed by the U.S. Department of Homeland Security to address security concerns with connected cars.

The terms of the acquisition were not disclosed, and the deal should close in the first quarter next year. Here—acquired by Audi, BMW, and Daimler in 2015—said that it would continue to develop the software for the automotive industry and weigh the possibility of using it to support secure software updates in other devices including drones. ■



The wireless headphone market is currently dominated by Apple, which started selling AirPods after it eliminated the headphone jack in its smartphones.

QUALCOMM CUTS POWER OF CHIPS Used in Wireless Headphones

KEYSIGHT TECHNOLOGIES HAS reopened its corporate headquarters in Santa Rosa after wildfires in northern California in October chased away employees.

The test equipment supplier said in a statement that it is still cleaning soot from inside several buildings, repairing minor fire damage, and clearing out debris. Keysight also said that it had rented out office space for employees unable to return to the corporate headquarters.

The company reiterated that its four main buildings only suffered minor damage in wildfires that forced thousands of

(Continued on page 22)

NXP SHAREHOLDERS CLAMOR for Qualcomm to Sweeten Deal

STOCK PRICES can be misleading. That is the message that Elliott Management, the largest shareholder of NXP Semiconductors, was trying to convey when it argued in early January that the company should be sold for significantly more than Qualcomm's $38 billion cash offer last year.

The hedge fund, famous for its activist investor streak, disclosed that it had bought 6% of the Dutch company in August and that it would push for Qualcomm to pay more in the deal. On Jan. 5, it said that NXP's stock should actually be valued around $135, up from its current price of around $115 and the $110 per share offered by Qualcomm.

"We also believe that this offer has been acting as a ceiling on NXP's stock price, keeping it depressed while the rest of the semiconductor sector experienced a strong performance since rumors of Qualcomm's interest in NXP arose," the New York-based hedge fund wrote in a letter to other NXP shareholders, which have hesitated to pledge support for the deal.

It is not clear what Elliott wants from Qualcomm, whose offer of $110 per share represents a 34% premium over NXP's stock price before reports of the deal leaked. If the same premium was attached to Elliott's $135 valuation, Qualcomm would pay around $181 per share for NXP, which would glob another $23 billion onto the deal. But that seems unlikely.

"We believe NXP's prospects are bright. Approximately half of NXP's revenue is exposed to exciting growth engines of the semiconductor market—automotive and industrial," said the New York-based hedge fund, adding that it had hired UBS to conduct a financial analysis on NXP's business, which it would share with other shareholders.

Only around 2.4% of NXP's outstanding shares have been tendered to Qualcomm. The San Diego-based company needs around 80% to close the deal, which would turn it into the world's largest maker of automotive chips. To make matter worse, Qualcomm fell into a proxy battle after last month it rejected Broadcom's $105 billion takeover bid as being too low.

Qualcomm said in a statement that its offer is "full and fair." The company added: "Elliott's value assertion for NXP is unsupportable and is clearly nothing more than an attempt to advance its own self-serving agenda."

Elliott's challenge comes two months after Richard Clemmer, NXP's chief executive, warned that it is possible that the deal will not close until early next year. The companies needed more time to sway shareholders and resolve regulatory finger-wagging. The companies previously said that the deal would close before the end of 2017.

This has been a tough year for Qualcomm, which is brawling with Apple over allegations that it overcharges for its cellular communications chips. The company is also fighting a series of regulatory slaps over its patent licensing business on three continents. It has toiled to convince antitrust regulators in Europe that the NXP acquisition is harmless.

Elliott Management argued on Monday that the $38 billion deal significantly undervalues NXP. Qualcomm should pay more, NXP's largest shareholder said.

U.S. regulators quickly gave the green light to the deal, which combines two companies with different product portfolios. On the other hand, the European Commission halted the review in October after Qualcomm failed to present important financial documents to regulators, and the investigation's deadline still has not been reset.

The regulators worry that Qualcomm will package NXP's standard essential patents with its own intellectual property, raising rates for 3G and 4G technology and preventing rivals from licensing NXP's technology. They also worry that the acquisition would put Qualcomm's rivals at a significant disadvantage in the wireless chip market.

It would be a significant relief to strike a compromise with regulators. Qualcomm is grappling with a dizzying amount of blowback from customers and regulators, and without the NXP deal, it would lose out secure microcontrollers and communication chips that can be used in everything traffic lights and connected cars to thermostats and sensors. ■

AVX BUYS ETHERTRONICS IN MOVE from Passive Components to Active Antennas

AVX CORP., one of the largest makers of passive components and interconnects, has agreed to acquire Ethertronics, whose advanced antenna systems are installed in everything from connected cars to medical equipment.

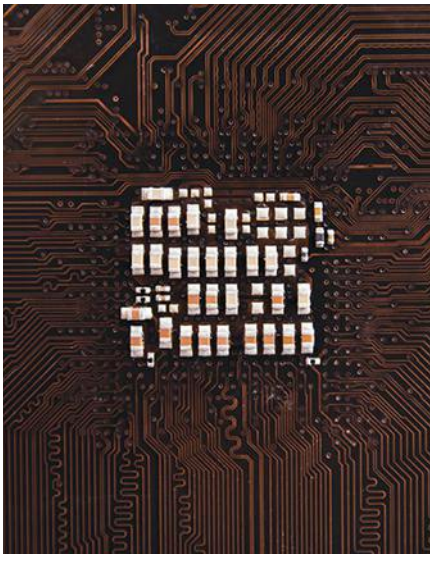
As part of the deal, the company is paying $142 million in cash as well as assuming $8 million of debt.

Ethertronics supplies both passive and active antenna systems, precisely engineered to suppress local interference or changes in ground planes. The company's chips plot out radiation patterns every millisecond and then its algorithms sample and switch between them to optimize for reliability, range and efficiency based on the surrounding environment.

Ethertronics retails isolated magnetic dipole antennas for many different applications like personal computers and phones. It has expanded into the market for connected cars, which share their location and other information with each other and the cloud. The company also built an advanced test chamber specifically for the automotive applications of its chips.

For AVX, the acquisition expands its product portfolio, which is dominated by passive components like tantalum and ceramic capacitors. Ethertronics, which is privately owned, generated around $90 million of revenue over the last year and employs around 700 people. The company was founded in 2000 and is based in San Diego, California.

"The addition of Ethertronics is an exciting opportunity for AVX as we expand our extensive electronic product offering into a new arena," said John Sarvis, chief executive officer of AVX Corporation, in a statement. "The combination of AVX and Ethertronics offers exciting growth potential for the years ahead." ■



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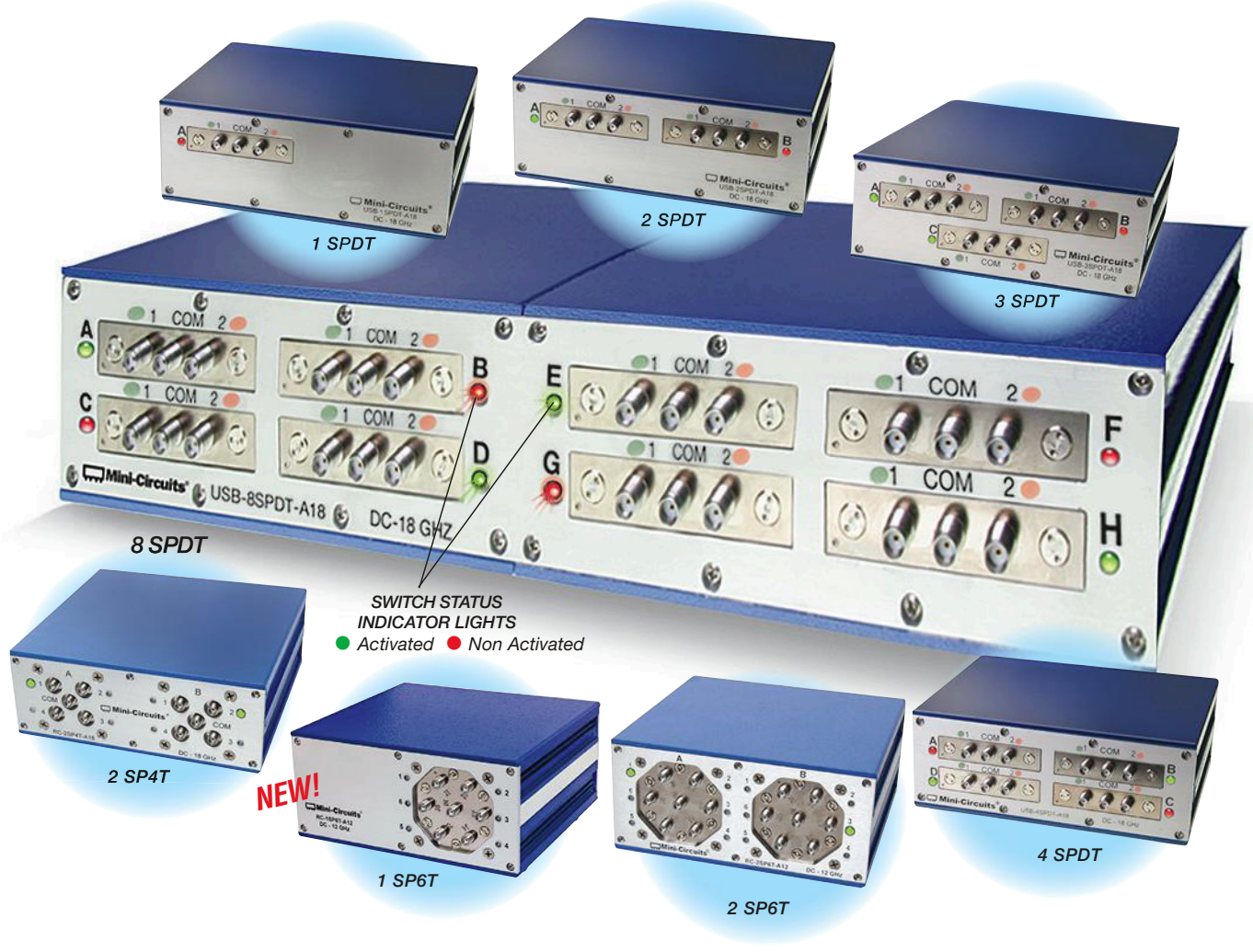

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(Continued from page 19)

evacuations in northern California and billions of dollars in property damage. Contrary to local reports last month, Keysight said the fires inflicted the worst damage on two smaller buildings and several cars in its parking lot.

However, other lost property might not be easily replaced. Keysight, the former test division of Hewlett Packard spinoff Agilent Technologies, confirmed in a statement to trade publication *EETimes* that the flames had consumed a cache of historical documents from founders Bill Hewlett and Dave Packard stored at the headquarters.

The loss angered and confounded Silicon Valley historians. Keysight said that early products, manuals, and other Hewlett Packard artifacts had not been lost because they were stored in buildings that only sustained minor damage. Other documents had already been backed up digitally.

Keysight, which operates out of 145 locations worldwide, released a statement to tamp down concerns that it could not fulfill orders as it recovers. "As the company restores the Santa Rosa site, it continues to take orders, ship products and otherwise meet the needs of its customers," the company said. ■

DARPA DESIGNATES DRAPER to Boost DoD Security

ELECTRONIC SECURITY IS a critical and difficult-to-establish segment of any defense electronic system, and a function for which DARPA now looks to Draper for assistance. That help will come in the form of Draper's System Security Through Hardware and Firmware (SSTH) program and a contract worth as much as $9.8 million. The contract provides the resources to develop hardware design tools with built-in cybersecurity and computing capabilities to counter software vulnerabilities in both military and commercial electronic systems. Draper's cybersecurity technology has proven itself an effective information protection solution. It leverages the commercial processing ecosystem to provide information protection even under warfare applications.

Draper has developed a cyber-resilient embedded processor chip known as the Inherently Secure Processor (ISP), which makes it possible to focus on hardware security at the microarchitecture level. Although the device was nominally developed for commercial use, Draper hopes to show through the contract that it can be used to develop architectures and design tools that provide cybersecurity both for Department of Defense (DoD) and commercial applications.

"Draper's cybersecurity capabilities and Inherently Secure Processor enable us to provide silicon chip developers and manufacturers with a design that embeds security directly into hardware at the processor level," said Paul Rosenstrach, the company's principal director of special programs. "ISP hardware enforces customizable software-defined security rules, enabling system designers to develop individual policies that fit their application."

The ISP can be implemented with any reduced-instruction-set-computer (RISC) processor (*see photo*), and is currently optimized for the RISC-V architecture to operate as a co-processor with a system's main processor or processors. The ISP approach features adaptable and updatable technology that arms customers with a flexible, long-term security solution. ■

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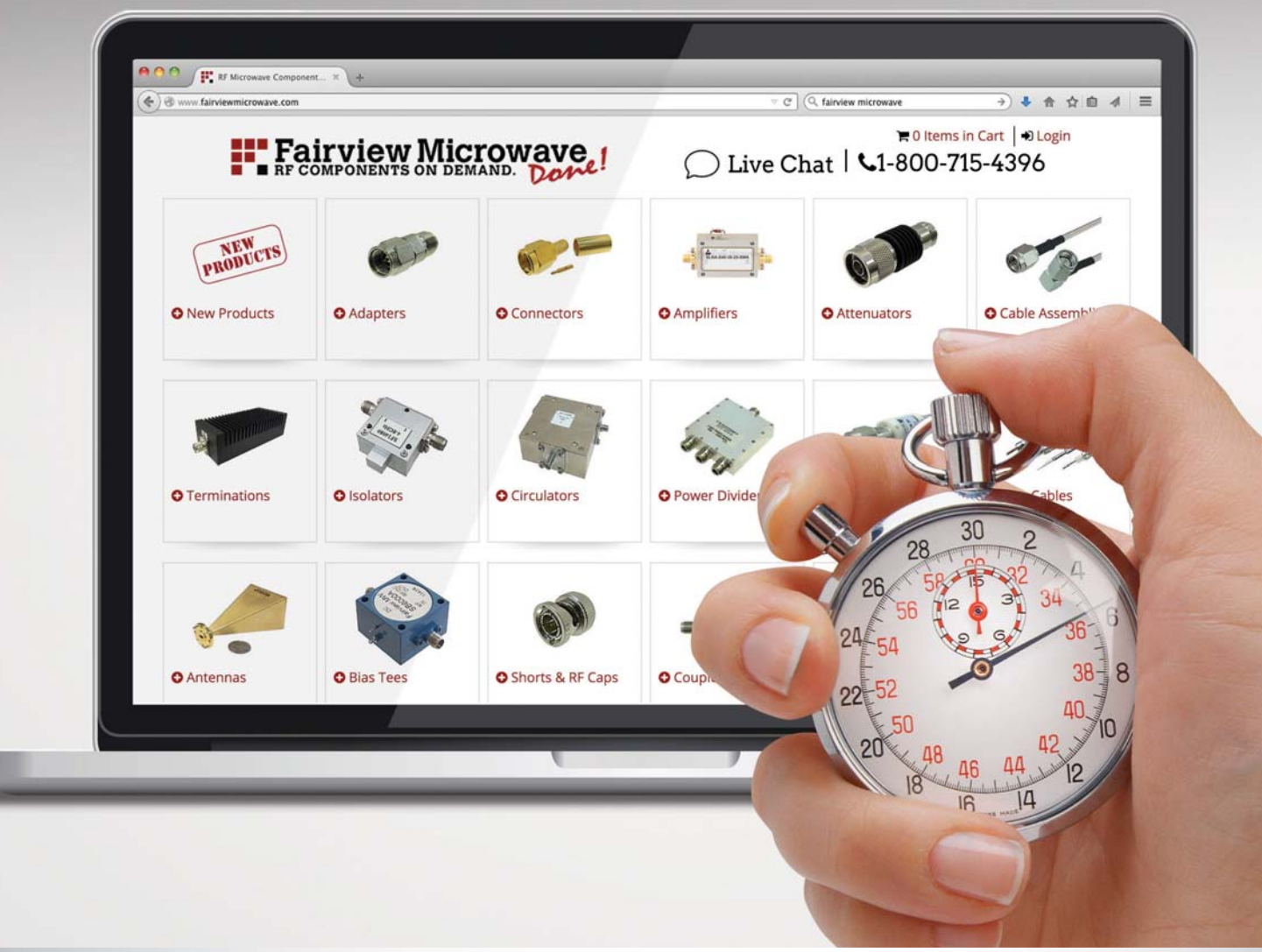

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ROBOTS USE EM WAVES to See Through Walls

Robots are by now well-established parts of the military electronics landscape, whether on the ground, in the air, or at sea. By combining ground robots with detection systems based on electromagnetic (EM) energy, they can also play quite effective roles in search and rescue, as well as surveillance and security applications. These see-through imaging systems, which are also known as "through-wall imaging," can work with EM energy as popular as 2.4-GHz Wi-Fi signals and a pair of robots to perform the through-wall detection. Using Wi-Fi received signal strength indicator (RSSI) signals, one of the robots measures the received signal power of the signals transmitted by the other robot to perform imaging of objects through a wall.

A trio of researchers developed both narrowband and ultrawideband (UWB) imaging approaches using commercial transceivers and antennas. The researchers, Saandeep Depatla, Chitra R. Karanam, and Yasamin Mostofi, are all with the University of California at Santa Barbara. Their research was funded by a National Science Foundation Communications, Circuits, and Sensing Systems award. A number of different scenarios were modeled, one in which two unmanned vehicles with RF sensors were used for imaging of a completely unknown area, and another scenario in which the only signal power available for imaging was Wi-Fi signals at 2.4 GHz.

The researchers developed an effective UWB imaging approach based on the use of a commercially available UWB transceiver chipset from DecaWave (model EVK1000 transceiver), coupled with an omnidirectional antenna. Along with comparisons of Wi-Fi and UWB imaging approaches, the researchers show how the use of antenna directionality can improve imaging quality. Having a large number of robot localization positions also helps to minimize the localization errors when determining the positions of the in-wall images.

Experimental scenarios are presented based on the use of two ground robots for in-wall imaging, in one case performing imaging only with Wi-Fi RSSI signals and in another case using only two robots with UWB signals. The researchers note that the availability of small UWB transceiver chipsets makes it possible to add such UWB imaging capabilities to small robotic platforms. By programming the trajectories of the two robots so that their transmit and receive antennas follow a precise path, detailed imaging can be achieved. In addition, the transmit and receive robots can also be used to travel nonspecific patterns and simply perform wireless measurements as they move about an unknown area, in what is referred to as a random motion pattern.

The researchers present results for a number of different unknown areas, showing scanned 2D images for areas of different complexity and size and comparing the effectiveness of the Wi-Fi and UWB imaging approaches. Robotic path planning is a key ingredient in achieving detailed in-wall scans, with semi-parallel routes at various angles providing effective results even when tackling complex unknown areas. The robotic in-wall scanning technique clearly has great promise for government and possibly even military search-and-rescue operations.

See "Robotic Through-Wall Imaging," *IEEE Antennas & Propagation Magazine*, Vol. 59, No. 5, October 2017, p. 47.

AGILE FRONT ENDS Assist Mobile Satcom Terminals

SATELLITE COMMUNICATIONS (SATCOM) was once associated with fixed ground stations. But as wireless communications in its various forms truly becomes mobile, more advanced RF/microwave front-ends are being developed that are capable of tracking a satellite's signals even as a ground terminal is mobile. A great deal of innovative design on these mobile satcom front-ends and antennas has been performed by IMST GmbH *(www.imst.com)* from L-band to Ka-band frequencies, using advanced beamforming techniques on compact MMIC devices.

Many of these mobile satcom applications are targeting automotive mobile stations, designed as radio front-ends with transmitters, receivers, and antennas that can be fabricated as miniature, low-cost circuit assemblies for mass production and low cost. At higher frequencies, MMICs based on GaAs substrates, for example, provide the core front-end functions for receive-only and transmit/receive systems.

The GaAs ICs for many of these mobile satcom circuit designs were fabricated in the OMMIC GaAs foundry located in Paris. Modular design approaches were practiced which allowed for the buildup of large antennas consisting of thousands of antenna elements. Satcom radio and antenna front-ends were realized on reliable, low-cost low-temperature-cofired-ceramic (LTCC) circuit materials, which provided final results with high reliability using commercial-off-the-shelf (COTS) devices and components.

This innovative combination of commercial and military architectures, such as the phased-array antennas common to military system systems and the COTS building-block components of commercial products, hints at the possibilities to come for mobile satcom systems in commercial vehicles. Examples of satcom front-end designs developed by IMST and various partners are presented for L-band through Ka-band frequencies, with many different sizes, depending upon wavelengths and operating frequencies. It is clear that satellite communications can be made "vehicle-friendly" and made to fit the needs of different mobile automotive applications.

See "Innovative Antenna Front Ends from L-Band to Ka-Band," *IEEE Antennas & Propagation Magazine*, Vol. 59, No. 5, October 2017, p. 116.

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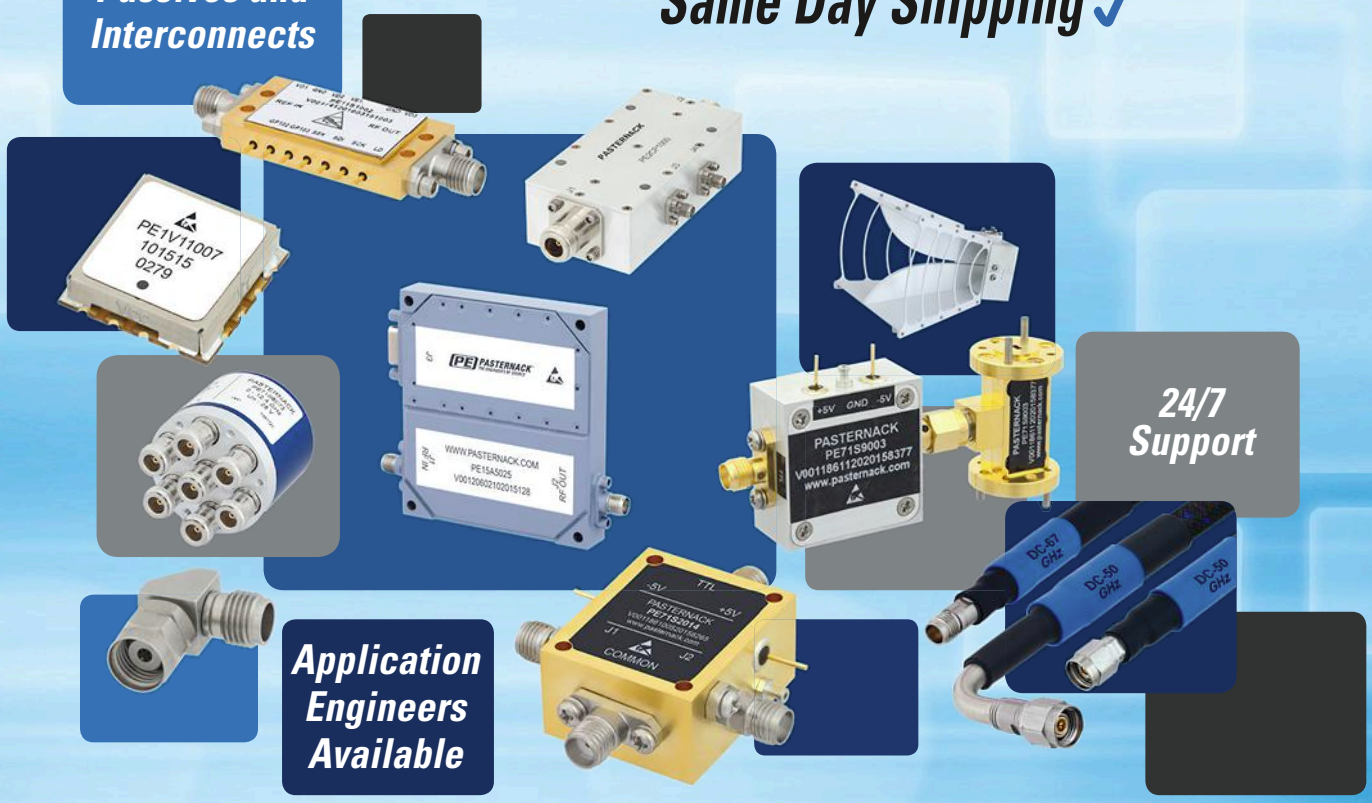

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Count on Design Software for Millimeter-Wave Automotive Radar and Antenna System Development, Part 1

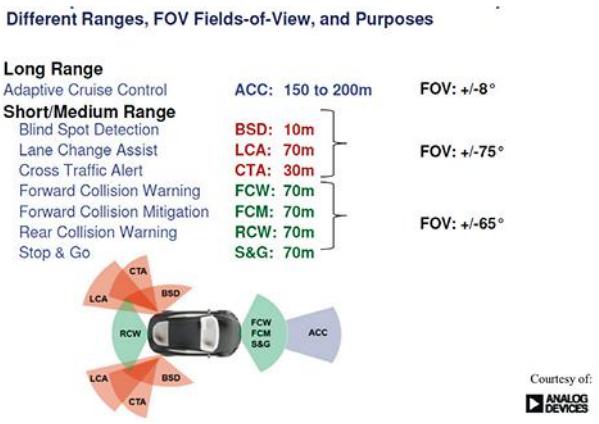
Those involved with designing the radar systems needed in today's vehicles can turn to design software that can accurately predict system performance.

Ongoing developments in advanced driver assistance systems (ADAS) are expanding the capabilities and affordability of vehicles that can alert and assist drivers using radar technology mostly focused over the 76-to-81 GHz spectrum. These systems must perform over a range of applications, operating conditions, and object-detection challenges in order to provide reliable coverage over the range (distance) and field of view (angle) as dictated by the particular driver assistance function.

This article examines some of the challenges behind developing millimeter-wave radar systems and the antenna-array technologies that will be responsible for the next generation of smart cars and trucks. Part 1 provides an overview of ADAS systems and discusses various radar systems and architectures. Part 2 discusses multi-beam and multi-range design and examines antenna design for multiple-input, multiple-output (MIMO) and beam-steering technologies for 5G that will be useful for automotive safety in the future.

OVERVIEW OF ADAS

To obtain high safety ratings, automobile manufacturers are equipping their new models with driver assistance systems made possible through a network of sensors that perform specific safety functions. Manufacturers are currently implementing these systems based on vision sensor technology and radar systems operating at either 24 and/or 77 GHz. Vision systems detect lane markings and process other visual road information. However, they are susceptible to inadequate performance due to precipitation—particularly snow and fog—as well as distance.



1. Shown here are different ranges, field-of-views (FOVs), and functions for ADAS systems (Image courtesy of Analog Devices).

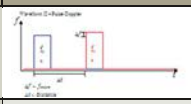
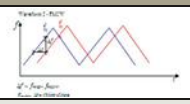
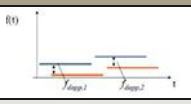
Long-range radar (LRR) supports multiple functions, comfortably handling distances between 30 and 200 meters, while short-range radar (SRR) can detect objects within distances of 30 meters. While the 24-GHz frequency band, which addresses SRR detection, is expected to be phased out of new vehicles by 2022, today it is commonly found in hybrid architectures. Meanwhile, the 77-GHz band (76 to 81 GHz) supporting LRR is expected to provide both short- and long-range detection for all future automotive radars. *Figure 1* provides details on short/medium- and long-range radar.

Technical advantages of the 77-GHz band include smaller antennas (a third of the size of the current 24-GHz ones), higher permitted transmit power, and, most importantly, wider available bandwidth, which enables higher object resolution. As a result, advances in radar modulation techniques,

antenna beam steering, system architecture, and semiconductor technology are driving the rapid adoption of millimeter-wave radar in future ADAS-enabled cars and trucks.

To manage the adoption of these technologies, radar developers require RF-aware system-design software that supports radar simulations with detailed analysis of RF front-end components, including nonlinear RF chains, advanced antenna design, and channel modeling. Co-simulation with circuit and electromagnetic (EM) analysis provides an accurate representation of true system performance prior to building and testing costly radar prototypes.

TABLE 1. DIFFERENT RADAR ARCHITECTURES AND THEIR TECHNICAL ADVANTAGES/DISADVANTAGES IN TARGET DETECTION, RANGE, ROBUSTNESS, AND RESOLUTION.

	Pulse Doppler	FMCW	FSK	UWB
				
Description	Single carrier frequency is transmitted in a short burst.	Frequency Modulated Continuous Wave. Typically a saw tooth waveform with BW 100-150 MHz .	Frequency shift keying with 1 MHz steps. CPI for each frequency is 5ms. Range info is derived from phase difference	Dirac Pulse Measure time of flight-auto correlation
Advantages	Simple algorithm for distance	- Good range accuracy - Easy to calculate relative speed and range	- Simple VCO modulation - Short measurement cycle	-Simple principle - Can measure at close range due to large BW
Disadvantages	- Difficult to determine range rate - Can not transmit and receive simultaneously	- Computation to eliminate ghost targets - Long measurement time for multiple chirps	- Coherent signal required for accuracy - Poor range direction information	- Medium to low range - No direct measure of range rate - Sensitive to disturbance

NI AWR software provides these capabilities, all within a platform that manages automotive radar product development—from initial architecture and modulation studies through the physical design of the antenna array and front-end electronics based on either III-V or silicon integrated-circuit (IC) technologies.

The NI AWR Design Environment platform integrates these critical radar simulation technologies while providing the necessary automation to assist the engineering team with the very complex task of managing the physical and electrical design data associated with ADAS electronics. ADAS support includes:

- Design of waveforms, baseband signal processing, and parameter estimation for radar systems, with specific analyses for radar measurements along with comprehensive behavioral models for RF components and signal processing.
- Design of transceiver RF/microwave front-end with circuit-level analyses and modeling (distributed transmission lines and active and passive devices) to address printed circuit board (PCB) and monolithic-microwave-integrated-circuit (MMIC)/RF integrated-circuit (RFIC) design.
- Planar/3D EM analysis for characterizing the electrical behavior of passive structures, complex interconnects, and housings, as well as antennas and antenna arrays.
- The connection between simulation software and test and measurement instruments.

RADAR ARCHITECTURES AND MODULATION

For adaptive cruise control (ACC), simultaneous target range and velocity measurements require both high resolution and accuracy to manage multi-target scenarios such as highway traffic. Future developments targeting safety applications like collision avoidance (CA) or autonomous driving (AD) call for even greater reliability (extreme low false-alarm rates) and significantly faster reaction times compared to current ACC systems, which utilize relatively well-known waveforms with long measurement times (50-100 ms).

Important requirements for automotive radar systems include the maximum range of approximately 200 m for ACC, a range resolution of about 1 m, and a velocity resolution of 2.5 km/h. To meet all these system requirements, various waveform modulation techniques and architectures have been implemented, including a continuous wave (CW) transmit signal or a classical pulsed waveform with ultra-short pulse length.

The main advantages of CW radar systems in comparison with pulsed waveforms are the relatively low measurement time and computation complexity for a fixed high-range resolution system requirement. The two classes of CW waveforms widely reported in literature include linear-frequency modulation (LFMCW) and frequency-shift-keying (FSK), which use at least two different discrete transmit frequencies. The *table* compares the different radar architectures and their advantages and disadvantages.

For ACC applications, simultaneous range and relative velocity are of the utmost importance. While LFMCW and FSK fulfill these requirements, LFMCW needs multiple mea-

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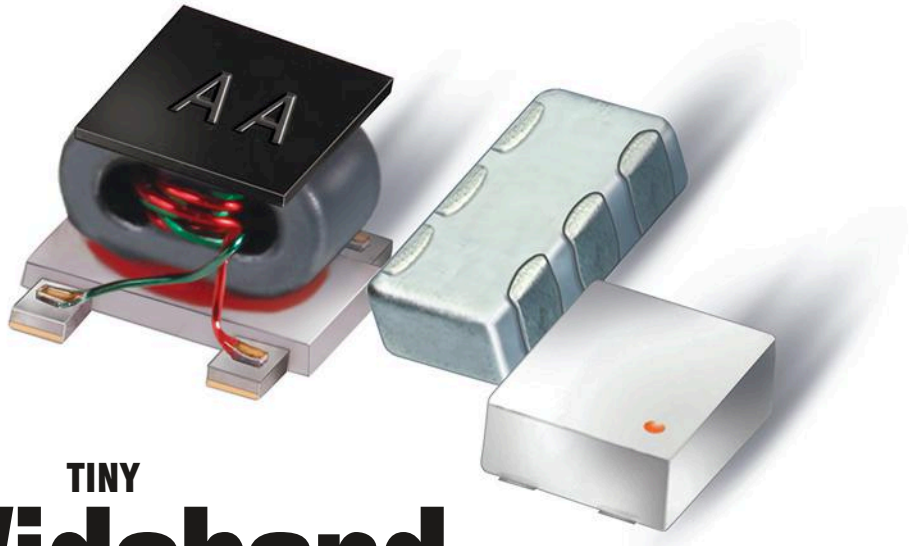

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ZFBT-6GW-FT+	0.1-6000	0.6	N/A	500	89.95
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ZFBT-352-FT+	30-3500	0.4	23	4000	49.95
ZNBT-60-1W+	2.5-6000	0.6	45	500	82.95
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ZX85: U.S. Patent 6,790,049.

Note: Isolation dB applies to DC to (RF) and DC to (RF+DC) ports.
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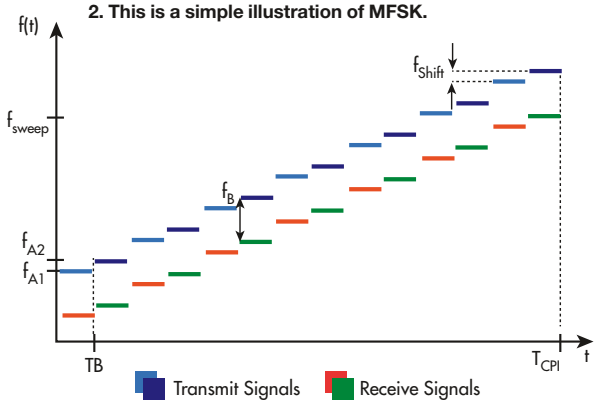
surement cycles and mathematical solution algorithms to solve ambiguities, while FSK lacks in terms of range resolution. As a result, a technique combining LFMCW and FSK into a single waveform called multiple-frequency-shift-keying (MFSK) is of considerable interest. MFSK was specifically developed to serve radar development for automotive applications and consists of two or more transmit frequencies with an intertwined frequency shift and with a certain bandwidth and duration *(Fig. 2)*.[1]

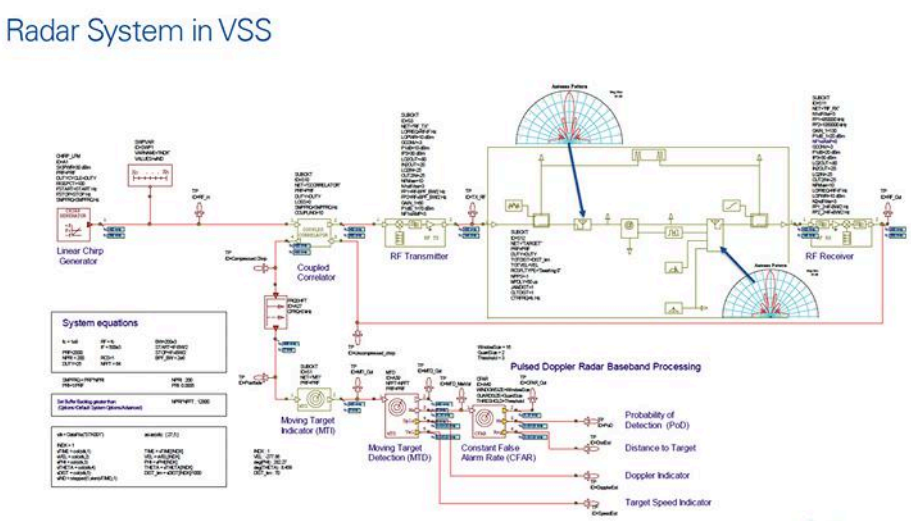
2. This is a simple illustration of MFSK.



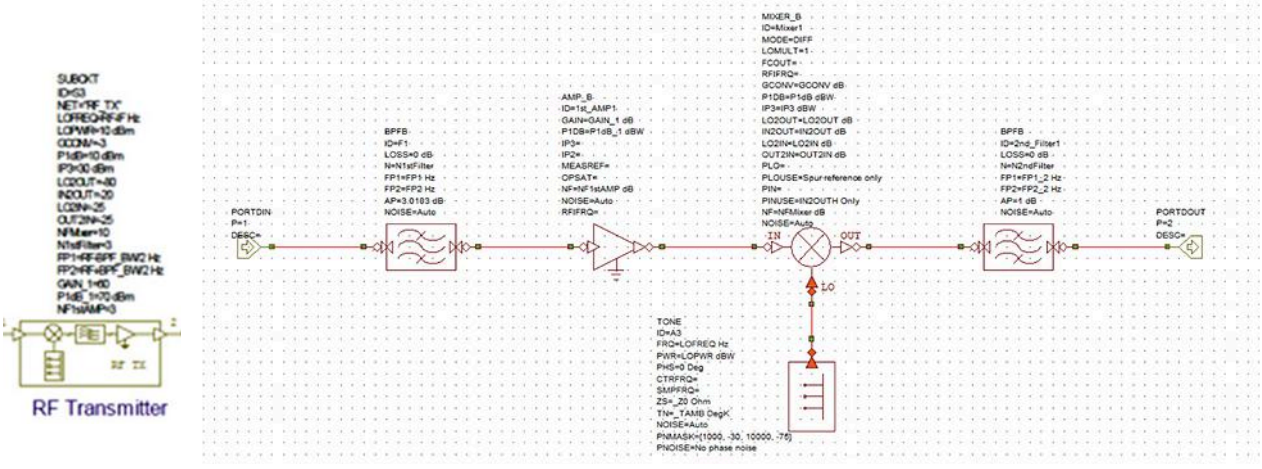
As previously mentioned, pulsed radars are also widely used in automotive radar systems. Relative velocity can be determined from consecutive pulses using a coherent transmitter and receiver to measure pulse-to-pulse phase variations containing the Doppler frequency that conveys relative velocity. For a pulsed-Doppler (PD) radar, range is still measured by signal propagation time. To measure both range and relative velocity, the pulse-repetition frequency (PRF) is an important parameter.

There are many tradeoffs to be considered when deciding which architecture and waveform modulation technology delivers the necessary performance while maintaining development and production cost goals. These requirements can be met with NI AWR Design Environment, specifically Visual System Simulator (VSS) system design software that is dedicated to RF system design and implementation. It offers a toolbox of commonly called-for simulation technologies and radio block/signal processing models, along with support for user-developed coding.

VSS is an RF and wireless communications and radar systems design solution that provides the simulation and detailed modeling of RF and digital signal processing (DSP) components necessary to accurately represent the signal generation, transmission, antenna,



3. Shown is a pulsed-Doppler radar system design created with VSS software.



4. This RF transmitter block is based on a sub-circuit that contains filtering, amplification, and frequency conversion.

T/R switching, clutter, noise, jamming, receiving, signal processing, and channel-model design challenges and analysis requirements for today's advanced radar systems.

Figure 3 shows a VSS workspace example that demonstrates a possible ACC radar architecture, modulation scheme, channel modeling, and measurement configuration. This workspace includes a pulse-Doppler (PD) radar system design with signal generator, RF transmitter, antenna, clutters, RF receiver, moving target detection (MTD), constant false alarm rate (CFAR) processor, and signal detector for simulation purposes.

The chirp signal level is set to 0 dBm, with a PRF of 2 kHz and duty cycle of 25%. The target model is defined by the Doppler frequency offset and target distance. Angles of arrival (THETA/PHI) are specified in a data file and vary over time. The Doppler frequency and channel delay were generated to describe the target return signal with different velocities and distance, while the radar clutter model can be included and the power spectrum can be shaped. In this example, the clutter magnitude distribution was set to Rayleigh and the clutter power spectrum was formed by a Weibull probability distribution.

Figure 4 shows an RF transmitter that includes oscillators, mixers, amplifiers, and filters. Gain, bandwidth, and carrier frequency were specified based on the requirements of the system or actual hardware performance as provided by the RF design team. Likewise, the RF receiver includes oscillators, mixers, amplifiers, and filters. Gain, bandwidth, and carrier frequency were specified according to the system requirements.

Co-simulation with the circuit simulator Microwave Office is possible as the transceiver front-end design details become available. As will be discussed later, the interaction between the transceiver electronics and a beamforming antenna array can be analyzed via circuit, system, and EM co-simulation.

MTD is used to detect the moving object more effectively. The MTD is based on a high-performance signal-processing algorithm for PD radar. A bank of Doppler filters or FFT operators cover all possible expected target Doppler shifts and the output of the MTD is used for the CFAR processing. In this particular example, measurements for detection rate and CFAR are provided.

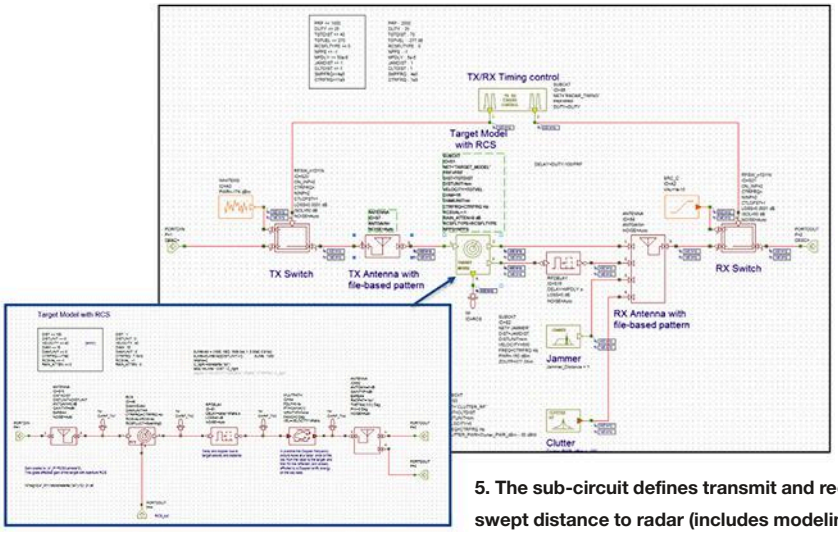
The radar-signal waveform must be measured in the time domain at the receiver input. Since the target return signal is often blocked by clutter, jamming, and noise, detection in the

time domain is not possible and an MTD is used to perform the Doppler and range detection in the frequency domain. In the MTD model, the data is grouped for corresponding target range and Doppler frequency. Afterwards, a CFAR processor is used to set the decision threshold based on the required probabilities of detection and false alarm *(Fig. 5)*.

This relatively simple design can be used as a template for different PD applications. The radar signal is a function of PRF, power, and pulse width (duty cycle). These parameters can be modified for different cases. In the simulation, the radar signal also can be replaced by any defined signal through the data file reader in which the recorded or other custom data can be easily used. VSS provides the simulation and modeling capabilities to refine the radar architecture, implement increasingly accurate channel models (including multi-path fading and ground clutter), and develop performance specifications for the transceiver link budget and detailed antenna radiation pattern requirements.

The plots in *Fig. 6* show several simulation results, including the transmitted and received chirp waveform, the antenna radiation pattern, and several system measurements, including the relative

(Continued on page 137)



5. The sub-circuit defines transmit and receive antennas, channel, and target with swept distance to radar (includes modeling of ground clutter).

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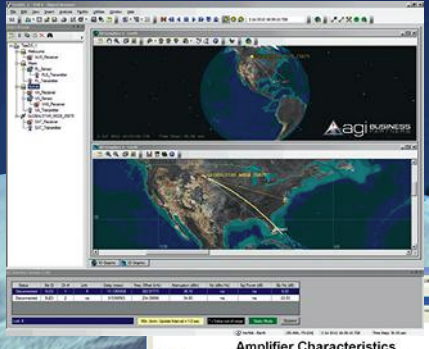

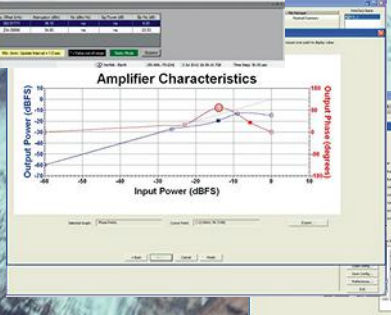

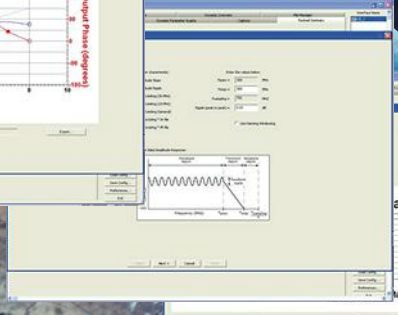

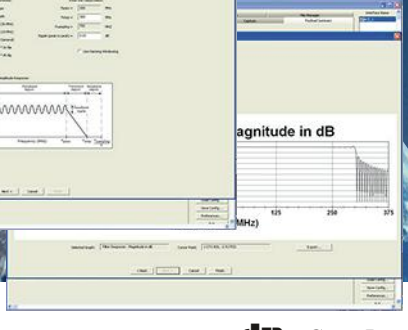

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Taking Steps to Boost Power Amp Efficiency

High efficiency in a power amplifier depends on the types of input waveforms to be boosted and typically comes at the cost of other amplifier performance parameters, such as linearity or output power.

Efficiency is often the difference between a power amplifier (PA) being selected or rejected for a particular application. Because higher-power PAs can require large amounts of bias energy to achieve a target output-power level, a difference in efficiency of just a few percent can mean a difference in the size and cost of a power supply for a particular PA. A basic overview of PA efficiency can also help to better understand how that efficiency can impact the overall performance of a system, as well as the performance of other PA parameters (notably linearity).

An amplifier with high efficiency uses power-supply energy more effectively than an amplifier with lower efficiency. At lower efficiency levels, wasted power-supply energy is typically converted into heat at the amplifier's active devices, which are increasingly gallium-nitride (GaN) transistors for RF/microwave PAs. GaN high-electron-mobility-transistor (HEMT) devices are noteworthy for a number of features that enable high-efficiency PAs at microwave frequencies, including high breakdown voltages, high current densities, high transition frequencies, low on-state resistances, and low parasitic capacitances. To protect the active devices and the surrounding electronic circuits, the heat must be removed. This results in the need for additional hardware, such as fans and heatsinks, which can add to the size, weight, and cost of a power amplifier.

Model PE15A5019 is an SMA modular PA with 15 W saturated output power from 7.2 to 7.5 GHz. It combines high linearity with relatively high PAE of 35% to minimize heat dispersion. *(Courtesy of Pasternack Enterprises)*

A PA's efficiency is often denoted by the symbol η. It can be defined by the relationship

η = (signal power delivered to the load)/(DC power supplied to the output circuit) (1)

It can also be expressed as the power-added efficiency (PAE), as

$$PAE = (P_{out} - P_{in})/PDC \quad (2)$$

where

P_{DC} = the bias energy applied to the amplifier;

P_{in} = the input signal waveform power fed to the amplifier; and

P_{out} = the output power level of the signal waveform produced by the amplifier.

Theoretically, the highest efficiency of 100% would result in an amplifier in which all of the applied DC bias energy is converted into the increase in signal waveform power. For a truly linear amplifier, the output signal waveforms would exactly resemble the input signal waveforms, with the increase in power level. Unfortunately, starting with the transistors, some applied power-supply energy is lost as heat, conducted due to device materials; imperfect impedance matching at the inputs and outputs of the power transistors; and other factors. Increased dissipation of heat is a sign of decreased efficiency.

In addition, amplifier linearity usually suffers as a result of increased efficiency, so PA transistor biasing points require a tradeoff among key amplifier parameters, including efficiency, linearity, and output power for a given frequency range.

An amplifier with the highest efficiency will not necessarily provide the highest linearity—for example, since the conditions for optimizing each parameter are not the same. High efficiency requires turning as much of the supply voltage and current into a boost of the amplifier's input signal wave-

forms, while linearity requires that higher-level output signal waveforms exactly resemble the form of applied input signal waveforms, preserving any modulation, such as amplitude modulation (AM) or frequency modulation (FM).

But for sinewave input waveforms, only 180 deg. of the waveform is positive while the other 180 deg. is negative. Ideally, a power supply would follow the waveform format, turning on and off or positive and negative at the same frequency as the input waveform. Because such a condition is difficult (if not impossible) to achieve, the efficiency is not 100% and some of the energy will be lost.

Over time, many different circuit formats have been developed with one or more active devices in attempts to achieve PAs with high efficiency and linearity, while also delivering as much output power and amplifier signal gain as possible. The circuit formats are known as Class A, B, C, D, E, and F configurations, with different biasing arrangements which provide different combinations of optimized key amplifier parameters.

For example, in a Class A amplifier, the output current flows constantly and the power transistors are conducting for the full 360 deg. of the input signal waveform; the active devices are powered on all the time. The DC input power supplied to the active devices must be constant. This is the most linear of the amplifier classes, and is a good match for AM signals. An ideal Class A amplifier has 50% efficiency when delivering peak envelope power (PEP). As an example, with 50% theoretical efficiency, a transmitter PA that consumes 100 W power would deliver a maximum of 50 W power to the transmitter antenna. Of course, this is a theoretical number and, typically, the efficiency of real-world Class A PAs is somewhat less than 50%.

In a Class B amplifier, the power transistors are conducing at 180 deg. of the input signal waveform, so that the active devices are essentially powered on for one-half of the time. As a result, this amplifier format uses applied power more efficiently than a Class A amplifier, with as much as 78.5% efficiency at PEP. But it is less linear than a Class A amplifier, and is subject to much higher harmonic distortion than a Class A amplifier. A push-pull amplifier is a common circuit construction for a Class B amplifier, typically based on two transistors. One transistor conducts during the positive half-cycles of the input signal waveform, while the other transistor conducts during the negative half-cycle of the input signal waveform.

A Class AB amplifier combines the two approaches, using a conduction angle that is between 180 and 360 deg. for the two transistors, so that the active devices are essentially on for three-quarters of the time. As a result, it yields efficiency that is between 50% and 78.5% at PEP. The savings in power results in a sacrifice in linearity, so that Class AB amplifiers will cause a great deal of distortion with AM input signals.

In a Class C amplifier, the transistors are biased at less than a 180-deg. conduction angle. The transistors will conduct for a relatively small portion of the positive input signal waveform, with no current draw or conduction through the entire negative portion of the input signal waveform. This biasing scheme results in efficiency that can approach 85%—considerably higher than Class A, B, or AB amplifiers. But with no conduction during the negative portion of signal waveforms, the linearity suffers. This amplifier class is effective for signals that turn on and off, such as pulsed waveforms, but can provide challenging operating conditions for transistors that must be switching on and off at such high frequencies.

Class D and E amplifiers use multiple or single transistors, respectively, as switches to produce square-wave output-signal waveforms with high efficiency but poor linearity. Class F amplifiers aim for higher efficiency and output power by adding harmonic resonators to an amplifier's output network, using harmonics to form an output waveform that is something of a cross between a half sinewave and a square wave. Class F amplifiers have complex input and output impedance requirements and call for complex output filtering to achieve theoretical efficiency approaching 100%.

In these different amplifier circuit configurations, various techniques have been developed to provide improved performance for specific amplifier parameters, such as efficiency. In a Class A amplifier, which is always "on" and at 50% maximum efficiency, power-supply back off is often used to increase the efficiency. In amplifiers with higher efficiency and lower linearity, linearization methods such as predistortion are used to try to make up for the lack of linearity with a higher-efficiency amplifier. In these techniques, input signal waveforms are essentially altered in ways that compensate for the changes that are expected to occur as a result of the PA's lack of linearity.

Unfortunately, many PA manufacturers don't list efficiency performance either on their websites or their product data sheets, making it difficult to compare RF/microwave PAs in terms of efficiency. In general, however, most suppliers do provide the amplifier class, typically, with Class A designs meant for high linearity and Class AB, C, or higher meant to provide higher efficiency. Practical performance levels are far from theoretical, with the PAE for many commercial Class AB amplifiers considered good when reaching or exceeding 25%.

One supplier that did list PAE specifications for the PAs on its website, Pasternack Enterprises (*www.pasternack.com*), employs Class AB configurations to achieve high gain, high linearity, and high efficiency in their line of modular coaxial amplifiers. Their GaN-based model PE15A5019, for example (*see photo*), delivers 15 W saturated output power with 58-dB gain from 7.2 to 7.5 GHz. It has the linearity needed for boosting modulated signals with minimal distortion, but is also relatively efficient, with a typical PAE of 35%. Higher efficiency levels are available, although typically in Class E and F amplifiers meant for boosting square waves or pulsed waveforms, such as in radar systems. MW

COLIN F. MATTSON | Keysight Technologies
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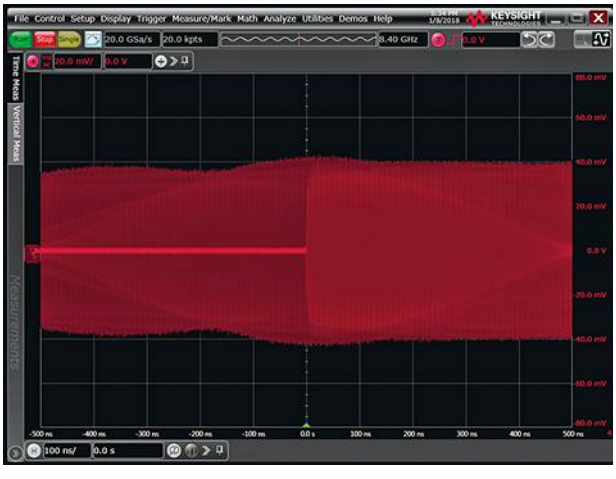
Oscilloscope Trigger Techniques for the RF Engineer

This article discusses several triggering techniques that can be utilized to effectively analyze RF signals with an oscilloscope.

Modern real-time oscilloscopes are so powerful and feature-rich that for many engineers, the *AutoScale* button is all they ever need to learn. However, this is not usually the case for RF engineers. Bursty RF signals can be difficult to work with in the time domain, due in no small part to the difficulty many engineers have dialing in a stable trigger. In this article, we'll walk through several different strategies for oscilloscope triggering on RF signals and, by the end, you'll wonder why you haven't been using a scope more often!

WHAT IS TRIGGERING?

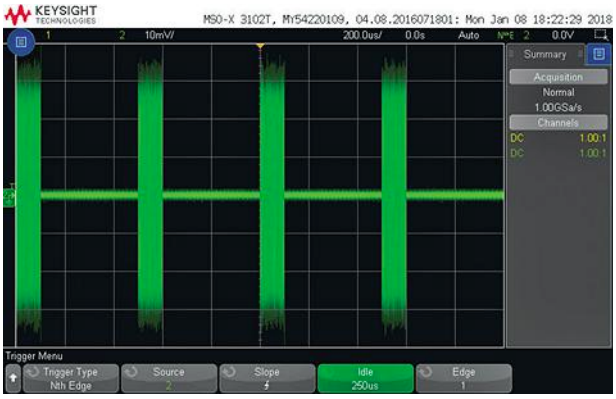
It's common for modern real-time scopes to have model numbers that start with "DSO," short for "digital storage oscilloscope." The term "storage" is important; modern scopes operate kind of like an old tape recorder. Just like an audio tape recorder that picks up sound waves with a microphone, stores them on a magnetic tape, and then plays them back from that tape, a modern real-time scope picks up analog electrical signals, digitizes them, stores them to memory and then "plays them back" (aka, displays them onscreen for you to view and measure).



1. Here we see a modulated RF signal displayed on a Keysight Infiniium S-Series oscilloscope with a default configuration. Unless you're only concerned with the vertical parameters of your signal, this isn't going to be very helpful.

2. Unsatisfied with the default setup from Fig. 1, we tried the *AutoScale* button, and this is what we got. Still not very useful.

The oscilloscope's trigger system causes the acquire/store/playback process to start. In the tape player analogy, the trigger system is what pushes the "record" button. When viewing a stable, "live" (continuously updating) waveform on a real-time scope, what you're seeing is many repeated record/playback cycles, one after the other. Each of these cycles begins with a trigger event. If the signal activity around the trigger event is consistent from acquisition to acquisition, the repeated playback cycles fall on top of each other and form a clear picture on the scope screen; this is often referred to as a "stable" trigger.



3. Shown is the same signal from Figs. 1 and 2 displayed on a Keysight InfiniiVision MSO-X 3000 Series oscilloscope using *Nth Edge Burst* trigger mode, which allows you to specify an idle time and edge count. Every signal transition resets the idle time counter, and if the counter finishes, the scope will trigger on the nth edge event afterwards.

4. Here we see the same signal again on a Keysight Infiniium S-Series scope. This time, we're using Edge-Then-Edge trigger mode. Like the Burst mode described in Fig. 3, Edge-Then-Edge allows you to specify an idle time (called "Delay Time" here) and a trigger edge.

On the other hand, if the activity near the trigger event is different from trigger to trigger, the consecutive playback images of your signal, layered on top of each other, tend to look like garbage. This is the fundamental problem we aim to solve when dealing with bursty RF signals; we need to qualify the trigger event such that it only occurs when the signal activity near the trigger (the scope screen) is relatively consistent.

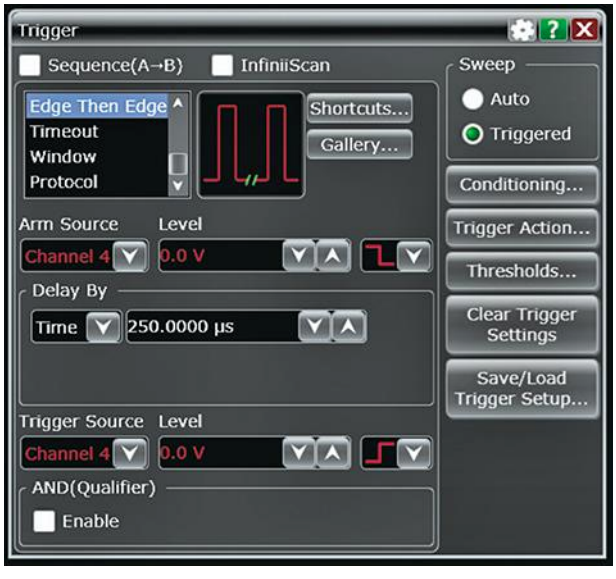
So, what is a trigger event? It's whatever you tell the scope you want it to be! Although *Edge* trigger mode is most commonly used, most modern scopes have an arsenal of different trigger modes based on signal transitions, timing, counting, polarity shifts, and more. We can use these to our advantage when trying to configure a stable trigger for an RF signal. Let's look at a few different strategies.

RF/BURST SPECIALTY TRIGGER MODES

Some modern oscilloscopes offer trigger modes specifically designed for RF applications. Often referred to as "Burst" mode, or something similar, these modes will use a combination of edge-counting and timing to qualify trigger events. Typically, they will allow you to specify an arm event, an idle period or another time parameter, and then a trigger event. For the trigger to fire and the scope to acquire data, each of the configured events must be fulfilled in the order specified. Specialty modes like this are almost always the best way to go when trying to define a stable trigger event for bursty data.

GENERIC TIME-QUALIFIED TRIGGER MODES

Unfortunately, RF-specific trigger modes are somewhat uncommon, especially on older and less-fully-featured (cheaper) scopes. Fear not! Most scopes still have a slew of



5. Here we see the Trigger setup dialog for *Edge-Then-Edge* mode on a Keysight Infiniium S-Series scope.

generic timed trigger modes that we can use to our advantage. They'll have names like *Timeout* and *Pulse Width*, but when used carefully, they can work well with RF signals.

DIFFERENTIATING BURSTS WITH AMPLITUDE

So far the techniques we've discussed have all focused on generating stable trigger events using idle time (*Burst, Edge-Then-Edge*) or carrier period (*Timeout*). But what if your signal includes bursts of different amplitudes and you're interested in having a stable trigger on one of them? By adjusting the oscilloscope channel trigger threshold appropriately, you can effectively single out bursts that have either higher amplitude or greater dc offset than others; simply adjust the threshold outside of the vertical range of the other bursts and use the time-based techniques described above in conjunction.

TRIGGER HOLDOFF

While almost all scopes available today have advanced trigger modes, if your scope is older, you may be stuck with plain old *Edge* mode only. Don't worry—we're not out of tricks yet. All real-time scope trigger systems (or at least, those the author has ever seen or heard of) allow the user to adjust the holdoff time. Holdoff is the amount of time the trigger system waits after a trigger event before arming the system again (i.e., it represents the minimum possible time between triggers).

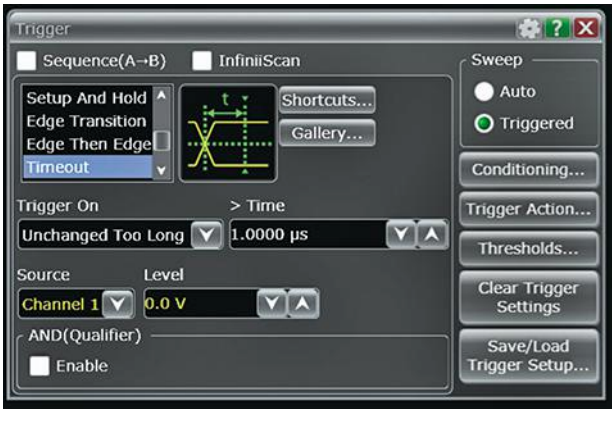
By configuring a sufficiently large holdoff time, you can sync the trigger up with the repetition of bursts in your signal (in a rough sense). Using holdoff time to stabilize the trigger won't yield results such as those that can be achieved with advanced trigger modes, and it will likely take more tweaking to get right. But if the only scope you've got is older than you are—and you can't convince your boss to buy you a new one—it may be your only choice.

Trigger holdoff time adjustment isn't just for old boxes. It can also come in handy on even the newest and fanciest scopes. Regardless of how a scope implements the trigger, either with analog circuitry as with most scopes, or with digitized acquisition data as with a few recent models, the trigger system is a totally separate apparatus from the acquisition system in the scope. It has different performance characteristics, including frequency response and bandwidth.

It is typical with high-performance scopes for the trigger system to have significantly lower bandwidth than the acquisition system. Even if your scope has sufficient bandwidth to acquire the signal you're working with, it may not be able to trigger on it very well. In this case, carefully adjusting threshold and holdoff time may be able to coax the scope into giving you a stable trigger when advanced modes won't work.

That wraps up our discussion on oscilloscope trigger techniques for RF engineers. May you never rely on the *AutoScale* button again! mw

6. Once again we see a modulated RF signal on a Keysight Infiniium S-Series scope. This time we're using Timeout trigger mode set to "Unchanged Too Long." This means the scope starts a timer and resets it every time there's any signal transition through the trigger threshold (trigger level). When the timer finally completes, the scope triggers.



7. Shown is the trigger setup dialog for Timeout mode on a Keysight Infiniium S-Series scope.

8. This Hewlett Packard 54615B oscilloscope is more than 20 years old, and even it allows the user to adjust trigger holdoff time via the "Holdoff" knob on the far-right side of the instrument.

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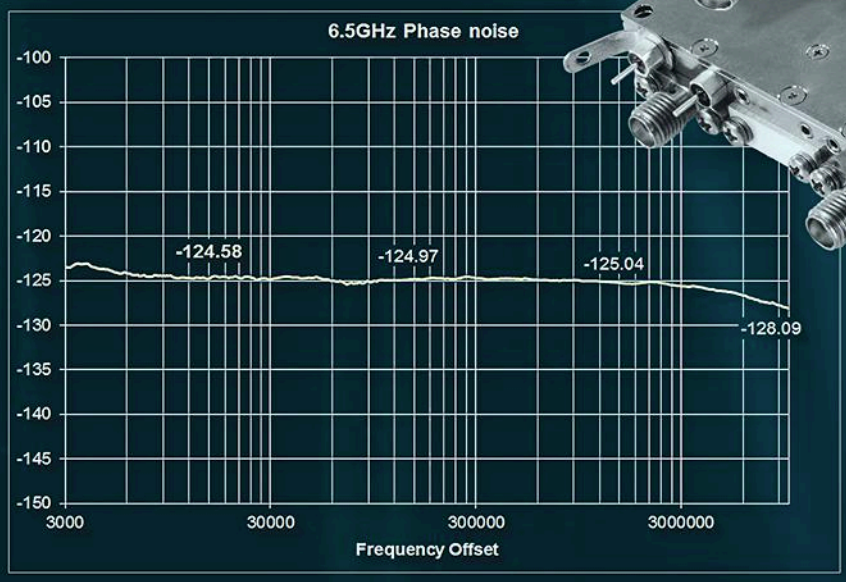

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Design Feature

AHMED BOUTEJDAR | Associate Professor and Researcher, German Research Foundation, Department of Electrical Engineering, Bonn-Braunschweig, Germany; e-mail: boutejdar69@gmail.com

MOHAMMAD A. SALAMIN | Engineer - Researcher, Department of Electrical Engineering, University of Palestine, Palestine; e-mail: m.sal_1994@outlook.sa

SOUMIA EL HANI | Professor and Researcher, ENSET BP 6207, Mohammed V University, Rabat, Morocco; e-mail: s.elhani@um5s.net.ma

LARBI BELLARBI | Professor and Researcher, CR-STIS Laboratory ENSET/ENSIAS, Mohammed V University, Rabat, Morocco; e-mail: l.bellarbi@um5s.net.ma

AMAL AFYFLARBI BELLARBI | Ph. D. - Researcher, CR-STIS Laboratory ENSET/ENSIAS, Mohammed V University, Rabat, Morocco; e-mail: afyf.amal@gmail.com

Tiny Microstrip Antenna Covers WLAN, LTE, and WiMAX

This design combines three wireless operating frequencies into one easy-to-integrate microstrip antenna that can be made extremely small in size.

Growing use of radio/wireless technology creates greater demand for small, efficient, and low-cost antennas in a range of telecommunications and wireless local area network (WLAN) applications, as well as worldwide interoperability for microwave access (WiMAX), satellite communications (satcom), and spacecraft.[1] Desirable properties for such an antenna include mechanical durability, conformability, low cross-polarized radiation patterns, and economical fabrication.

Microstrip patch antennas became well received in wireless communications systems due to their low cost of fabrication and effectiveness in those systems.[2] With the increasing number of wireless applications, an antenna for wireless communications must also operate across multiple frequencies, so that it can be used for a number of different applications at the same time.[3] Several different antenna designs have been proposed and published for wireless communications systems, including WLAN, LTE, and WiMAX applications.[4-20]

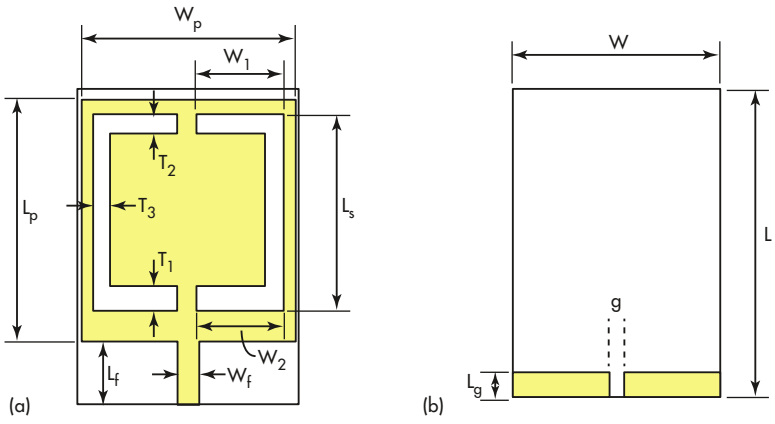
The main drawback of microstrip antennas is their narrow bandwidth. Classical microstrip antennas yield a maximum bandwidth of about 8%. A number of approaches have been developed to overcome this limit,[21-27] with a great deal of research on microstrip being performed by the current authors.

In ref. 28, for example, a broadband stacked U-slot microstrip patch antenna was presented. The single U-shaped slot is added based on a circuit theory concept to provide dual-band broadband characteristics. In this case, adding the U-shaped slot in the patch enhances bandwidth by 33.52%. In ref. 29, a broadband high-gain microstrip patch antenna with a slot was proposed. A dual-band characteristic was obtained by using a double U-slot in the patch. The antenna has a 37% impedance bandwidth.

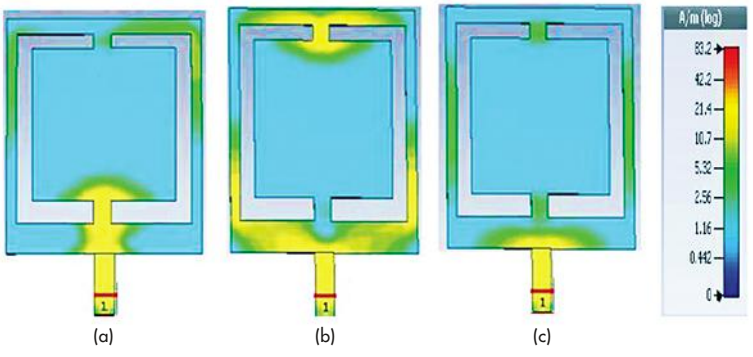
In ref. 30, the design of a broadband printed microstrip antenna for WLAN and WiMAX application was presented, in which two parasitic elements are printed in the ground plane to enhance antenna performance. In ref. 31, a novel dual-band antenna with two U-shaped slots was presented. By using two slots, the dual-band characteristics are obtained. Using two L-shaped slot in the ground plane enhanced the antenna's bandwidth. This antenna is suitable for WLAN and WiMAX applications.

DOING A TRIPLE TAKE

Through the insertion of two symmetrical U-shaped slots, a triple-band microscript antenna was designed and fabricated. It can provide three operating frequency bands for use in 2.45-GHz WLAN networks; at 2.60 GHz for LTE operation; and at 3.69 GHz for WiMAX use. The proposed antenna has low VSWR and achieves good radiation pattern characteristics. Simulations were performed by means of commercial computer-simulation-technology (CST) software.



1. This is the structure of the proposed multiple-band wireless communications antenna: (a) front view and (b) rear view.



2. The current distributions of the proposed multiple-band antenna are shown for (a) 2.45 GHz, (b) 2.60 GHz, and (c) 3.69 GHz.

TABLE 1: PARAMETERS FOR PROPOSED ANTENNA (in mm)

L	W	L_g	G	L_p	L_s	W_p
40	30	3.4	2	31	25	29
W_1	W_2	W_f	L_f	T_1	T_2	T_3
12	12	2.9	8	3	2	2.3

The proposed antenna is designed using FR4 as the substrate, which has a relative permittivity of 4.3. Dimensions of the antenna are $30 \times 40 \times 0.8$ mm^3. The patch is easily fed using a 50-Ω microstrip feed line. A rectangular radiation patch with a U-shaped slot is used on the top face of the substrate. To enhance the bandwidth and create extra notch (more than in ref. 18), the position, thickness, and lengths of the double U-shaped slot are fixed. *Figure 1* shows the dimensions of the proposed antenna, while *Table 1* presents the values of the dimensions.

To understand the behavior of the band-notched characteristics, the simulated current distributions of the proposed antenna at each resonant frequency are shown in *Figure 2*. The current distribution at 2.45 GHz is shown in Fig. 2a, at 2.6 GHz in Fig. 2b, and at 3.69 GHz in Fig. 2c.

In Fig. 2a, the current is mainly concentrated at the gap between the two U-shaped slots above the feed line. At 2.60 GHz, Fig. 2b shows that the current is mainly concentrated at the gap between the two U-shaped slots at the upper side, and around the lower U-shaped slot. At 3.69 GHz, Fig. 2c shows that the current is concentrated at the upper and lower gaps between the two U-shaped slots.

Figure 3 illustrates the simulated return loss of the proposed antenna for different widths of g, which represents the width of the gap. The width of the gap introduced in the ground plane affects each resonant frequency—at 2.45, 2.60, and 3.69 GHz—and can increase or decrease the S11 magnitude in dB. It may also cause a shift in the resonant frequency at 3.69 GHz, as shown in Fig. 3.

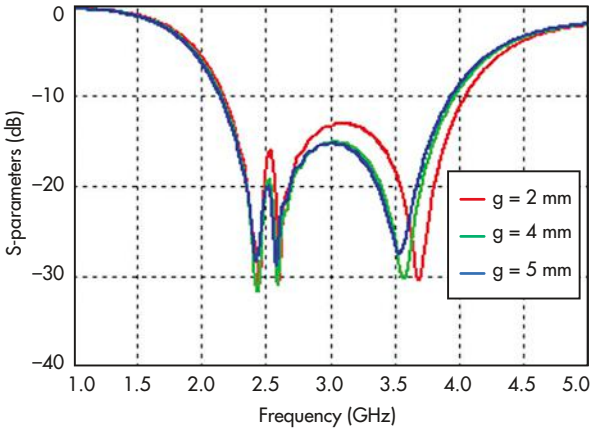
Figure 4 presents the simulated return loss of the proposed antenna for various values of W_1. As shown, the length of W_1 affects the resonant frequency at 2.60 GHz, while there is little effect on the resonant frequency at 2.4 GHz, which is in agreement with the current distribution shown by Fig. 2b.

Figure 5 offers the simulated return loss of the proposed antenna for various values of W_2. It is apparent that the length of W_2 affects the resonant frequency at 2.45 GHz, while there is little effect on the resonant frequency at 2.60 GHz, in agreement with the current distribution at Fig. 2a.

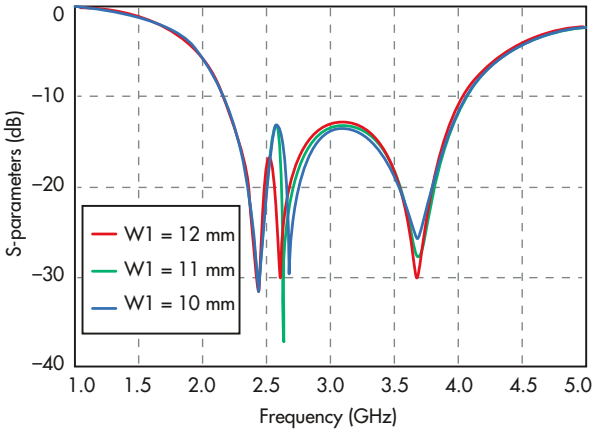
THE GAP EFFECT

In an attempt to enhance the antenna's performance, a gap was introduced into the ground plane, as shown in Fig. 1a. The effect of this gap on the return loss of the proposed antenna is shown in *Figure 6*. Performance of the proposed antenna before and after the gap is created is provided in *Table 2*. As can be seen from the results, the gap has a positive effect on return-loss performance at the operating frequencies.

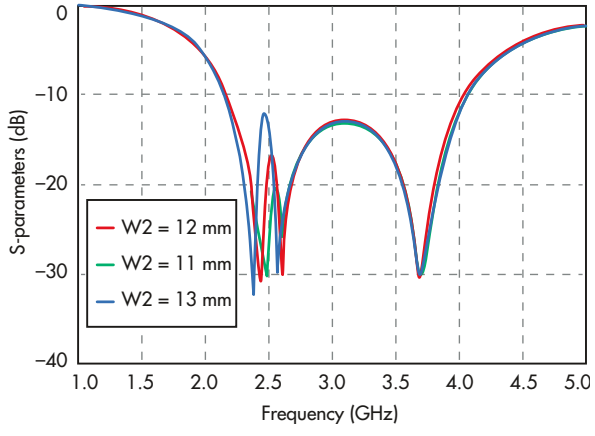
Figure 7 plots the simulated S_{11} performance of the proposed antenna as a function of frequency, using CST software for the simulation. This antenna has three different operating frequencies, with center frequencies of 2.45, 2.60, and 3.69 GHz. Its return-loss performance determines the impedance-matching properties of the antenna, showing how efficiently the antenna is transmitting/receiving electromagnetic (EM) energy over a particular band of frequencies.



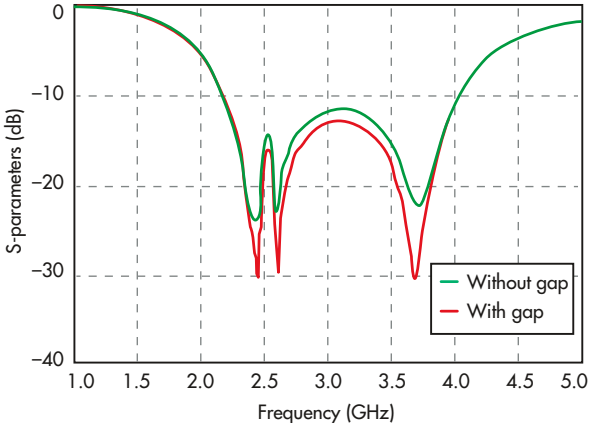
3. The return loss of the proposed antenna is simulated here for various values of gap width, g.



4. The return loss of the proposed antenna is simulated here for various values of W_1.



5. The return loss of the proposed antenna is simulated for various values of W_2.



6. The simulated return loss of the proposed antenna is shown with and without the gap in the ground plane; the former helps enhance performance.

Figure 8 plots the projected bandwidth of the proposed antenna. The fractional bandwidth (FBW) is the ratio of the difference of the upper and lower frequencies of acceptable operation to the center frequency of the band multiplied by 100.19

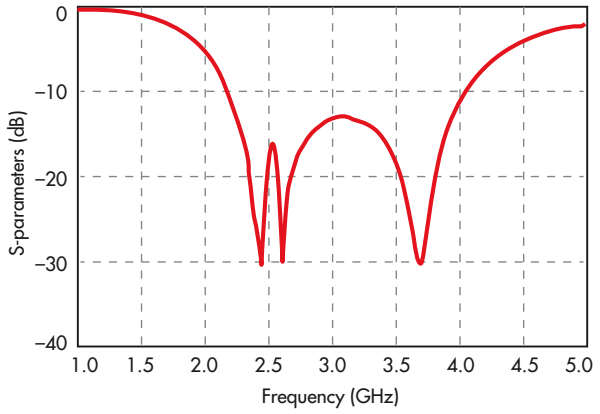
The bandwidth (BW) of the antenna can be found from 4.0531 – 2.1711 GHz = 1.882 GHz. The fractional bandwidth at 2.45 GHz is found from BW/2.45 = (1.882/2.45)100% = 76.81%. The fractional bandwidth at 2.60 GHz is found by BW/2.60 = (1.882/2.60)100% = 72.38%. The fractional bandwidth at 3.69 GHz is found by BW/3.69 = (1.882/3.69)100% = 51.00%.

Figure 9 shows the VSWR of the proposed antenna. Its VSWR is a measure of how well impedance-matched an antenna is to the impedance of the cable connecting the antenna to the system. A perfectly matched antenna would have a VSWR of 1:10. As can be seen in Fig. 4, the VSWR of the proposed antenna is equal to 1 at each operating center frequency. This indicates that the proposed antenna has good impedance matching.

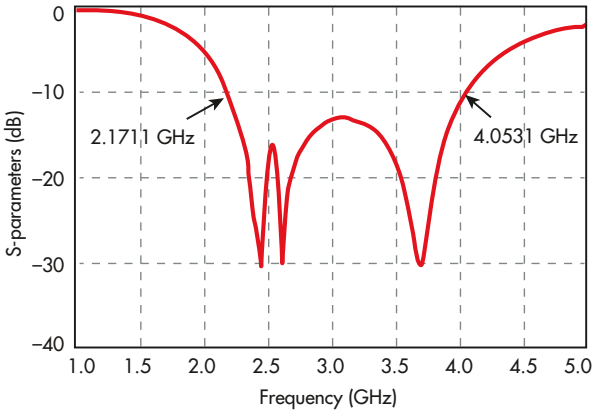
The radiation pattern of the proposed antenna was simulated using CST software. *Figure 10* shows the simulated

TABLE 2: EFFECT OF THE GAP ON THE RETURN LOSS OF THE PROPOSED ANTENNA

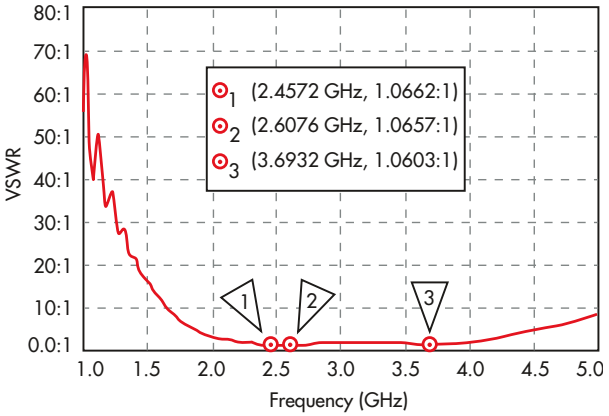
Resonant frequency (GHz)	S_{11} (without gap) (dB)	S_{11} (with gap) (dB)
2.450	-24.245	-30.388
2.60	-23.577	-30.010
3.690	-22.774	-30.735



7. The simulated S_{11} performance of the proposed antenna is plotted here as a function of frequency.



8. This plot projects the bandwidth of the proposed triple-center-frequency antenna.

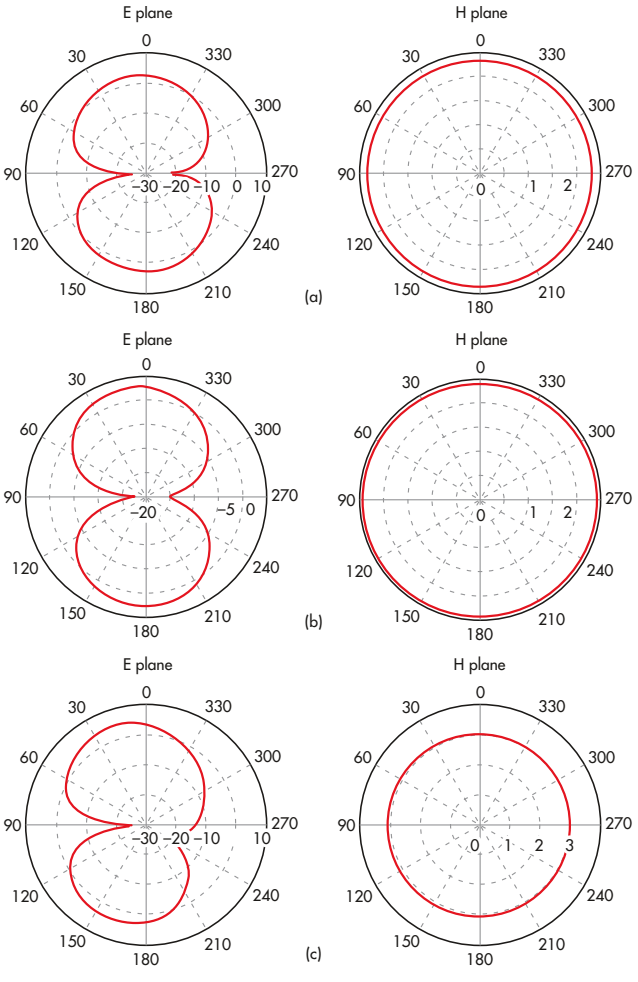


9. The simulated VSWR of the proposed antenna design shows good impedance match at its three operating frequencies.

radiation patterns of the proposed antenna in the E-plane and H-plane at 2.45, 2.60, and 3.69 GHz. As illustrated in Fig. 5, the antenna has a bidirectional radiation pattern at its E- and H-planes. The measured directivities of the proposed antenna at 2.45, 2.60, and 3.69 GHz are 2.45, 2.55, and 4.24 dBi, respectively.

The proposed antenna can provide sufficient gain and stable radiation patterns at those three center frequencies, making it suitable and preferred for various wireless communication systems. *Table 3* offers a comparison between the proposed antenna and other related components in term of size, relative permittivity, bandwidth, and operating frequency.

A wideband microstrip patch antenna using a dual U-slot with low profile has been proposed, and was simulated by means of CST software. The U-slot technique can be used to design and fabricate multiple-band rectangular patch antennas. Through the precise positioning of the slot in the patch, triple-band resonant modes are achievable. The antenna's



10. These are the simulated radiation patterns in the E- and H-planes for the proposed antenna design at (a) 2.45 GHz, (b) 2.60 GHz, and (c) 3.69 GHz.

TABLE 3: COMPARING DESIGNS

Source of work	Dimensions (mm^2)	Substrate	Relative permittivity	Feed method	Operating frequencies (GHz)		
					First band	Second band	Third band
Ref. 17	40 × 50 × 1.6	FR-4	4.3	Microstrip	2.40 (73.67%)	3.5 (50.51%)	---
Ref. 18	34.5 × 40 × 0.8	FR-4	2.95	CPW	2.45 (65.4%)	3.44 (45.6%)	---
Ref. 20	41.36 × 51.88 × 1.6	FR-4	4.2	Microstrip	1.56 115%)	2.364 (76.14%)	3.0 (60%)
Ref. 21	80 × 60 × 0.2	RO4003	3.38	CPW	2.40 74.58%)	3.0 (59.66%)	3.8 (47.10%)
This work	30 × 40 × 0.8	FR-4	4.3	Microstrip	2.45 (76.81%)	2.60 (72.38%)	3.69 (51.00%)

Note: RO4003® is a registered trademark of Rogers Corp. (www.rogerscorp.com).

performance is enhanced by adding a gap in the ground plane. The VSWR of the proposed antenna at each operating frequency is equal to 1, indicating that the antenna exhibits good impedance matching at those frequencies. The simulated results showed that the antenna would be effective in WLAN, LTE cellular, and WiMAX applications. mw

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MATT MAXWELL | Product Manager for Spectrum Analyzers, Tektronix
www.tek.com

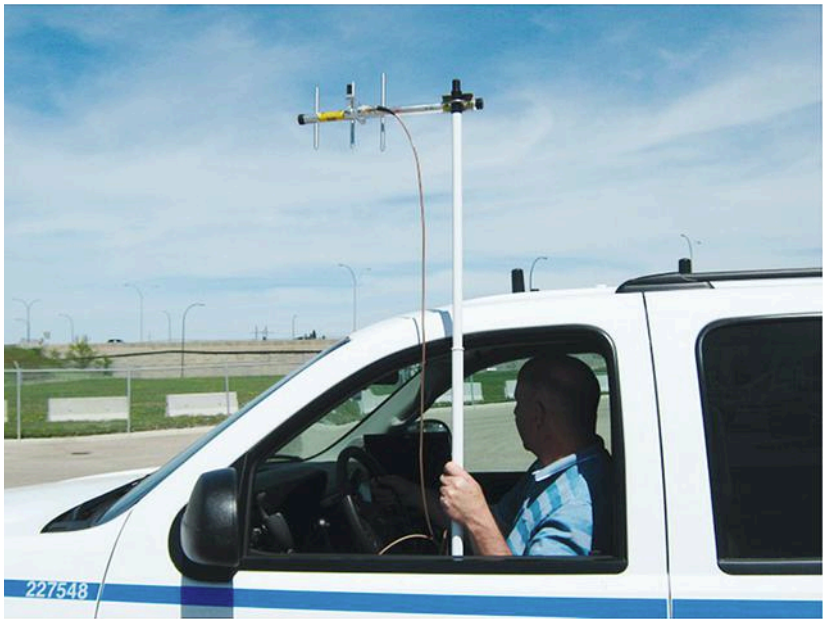
Turn to USB-Based Spectrum Analyzers to Conquer Interference

This article discusses how communications provider SaskTel is utilizing real-time spectrum analyzers to track down interference from European DECT wireless handsets.

DECT stands for Digital Enhanced Cordless Technology, although some might suggest that the "E" actually stands for European. And, in fact, the DECT standard for cordless telephone systems did originate in Europe. Due in part to this development path, there are slight differences in the frequency ranges for European DECT phones and their North American counterparts. The differences may be slight, but they are significant if you are an information and communications technology (ICT) provider like SaskTel.

Like other cell service providers across North America, SaskTel faces ongoing problems with European DECT phones. When people move from Europe to the Canadian province of Saskatchewan, where SaskTel supports more than 614,000 cell service customers, they often bring their DECT phones with them. From a consumer perspective the phones work fine, and they generally have no idea that approximately 10 MHz of the unlicensed spectrum used by their wireless handsets overlaps with SaskTel's licensed spectrum.

For SaskTel and its customers, however, it's a different story. "Interference shrinks the footprint of a cell site, it degrades the download and the upload speeds, and when it shrinks the footprint of the site, it's kind of a snowball effect," says John Davidson, technical assistant in SaskTel's technology division. "In some cases, the phones have to transmit with more power to get back to the site, and that in turn affects more and more phones in the area.

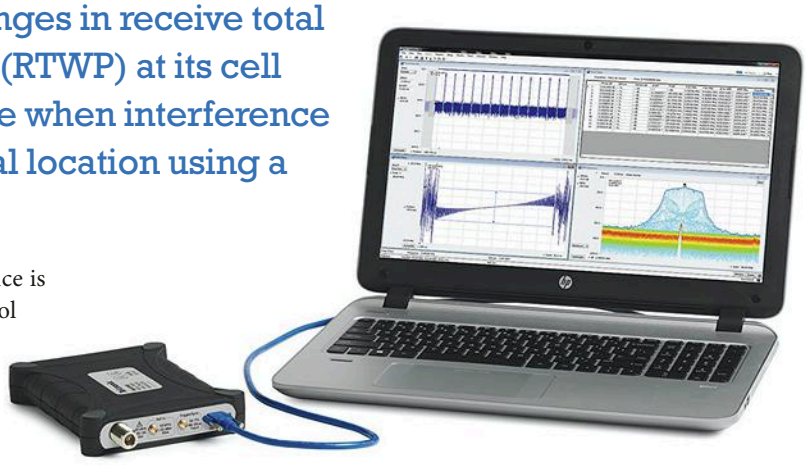


1. SaskTel interference hunters use "broomstick" antennas and USB-based real-time spectrum analyzers to track down sources of interference.

"And it might not just affect one site," Davidson adds. "Depending on the number of phones in the area it might affect a number of sites in a city setting. The ability to track down the source of interference and do it quickly and in a timely fashion is important."

By monitoring changes in receive total wideband power (RTWP) at its cell

By monitoring changes in receive total wideband power (RTWP) at its cell sites, SaskTel can determine when interference is occurring and the general location using a tool called splunk.



2. SaskTel is adopting USB-based real-time spectrum analyzers such as the Tektronix RSA306B shown here to track down sources of interference.

sites, SaskTel can determine when interference is occurring and the general location using a tool called splunk. They then dispatch Davidson or other engineers and technicians with test equipment and vehicles to start the hunt. The vehicles are typically equipped with traditional swept-tune spectrum analyzers along with a variety of directional antennas *(Fig. 1)*.

But when it came to European DECT phones, tracking down interference sources was hardly quick or timely using this equipment. The problem, according to Davidson, was that "if the phone was not transmitting at the time your spectrum analyzer sweeps across that frequency, you wouldn't know that it was there.

"The issue is that DECT phones change frequencies," he explains. "You could zoom in on what you thought was interfering frequency and it could change frequencies. We would lose a lot of time that way trying to figure out exactly where the DECT phone was, and why it wasn't on the frequency we thought it was. On top of it, if there was SaskTel phone in close proximity to the DECT phone, it would actually switch frequencies."

In one case a couple of years ago, Davidson was able to ascertain that interference was coming from an apartment building near a hospital, but from there found that it was impossible to pinpoint the location of the European DECT phones. "So, I ended up getting into the apartment building and knocked on every door, which was very time-consuming," he recalls.

HAPPY HUNTING

Looking for a better solution, Davidson and some colleagues attended a show in nearby Saskatoon where they attended a presentation on new USB-based real-time spectrum analyzers. These instruments combine high performance in a compact package and are operated via a software application running on a laptop or tablet.

"We were impressed with the USB instruments—especially the price point," Davidson says. "In our business, we don't need desktop spectrum analyzers anymore. We have a lab, and we can of course take our equipment in there, but mostly we travel around. The size was good and the price was good."

Davidson continued to be impressed once he added a USB-based analyzer to his interference hunting arsenal. "The real-time spectrum analyzer makes it easy to find DECT phones because you can see in real time what the phone is doing, as opposed to just recording or seeing the signal when your spectrum analyzer happens to sweep through it," he says. "The real-time spectrum analyzer is a real benefit to tracking these down easily," he says.

Gone too are the days of knocking on apartment doors. "Now we can tell by the graphs from the RTWP and splunk that interference is coming from a European DECT phone and you just get in the truck and basically drive right up to it," Davidson notes.

Going back to the hospital example, he says a real-time spectrum analyzer would have saved him many hours: "If I would have had the real-time spectrum analyzer at the time, it would have been real obvious where the signal was coming from. I could have then gotten access to the apartment building and gone right up to the apartment where it was coming from. At that point we didn't have it, and this took a long time."

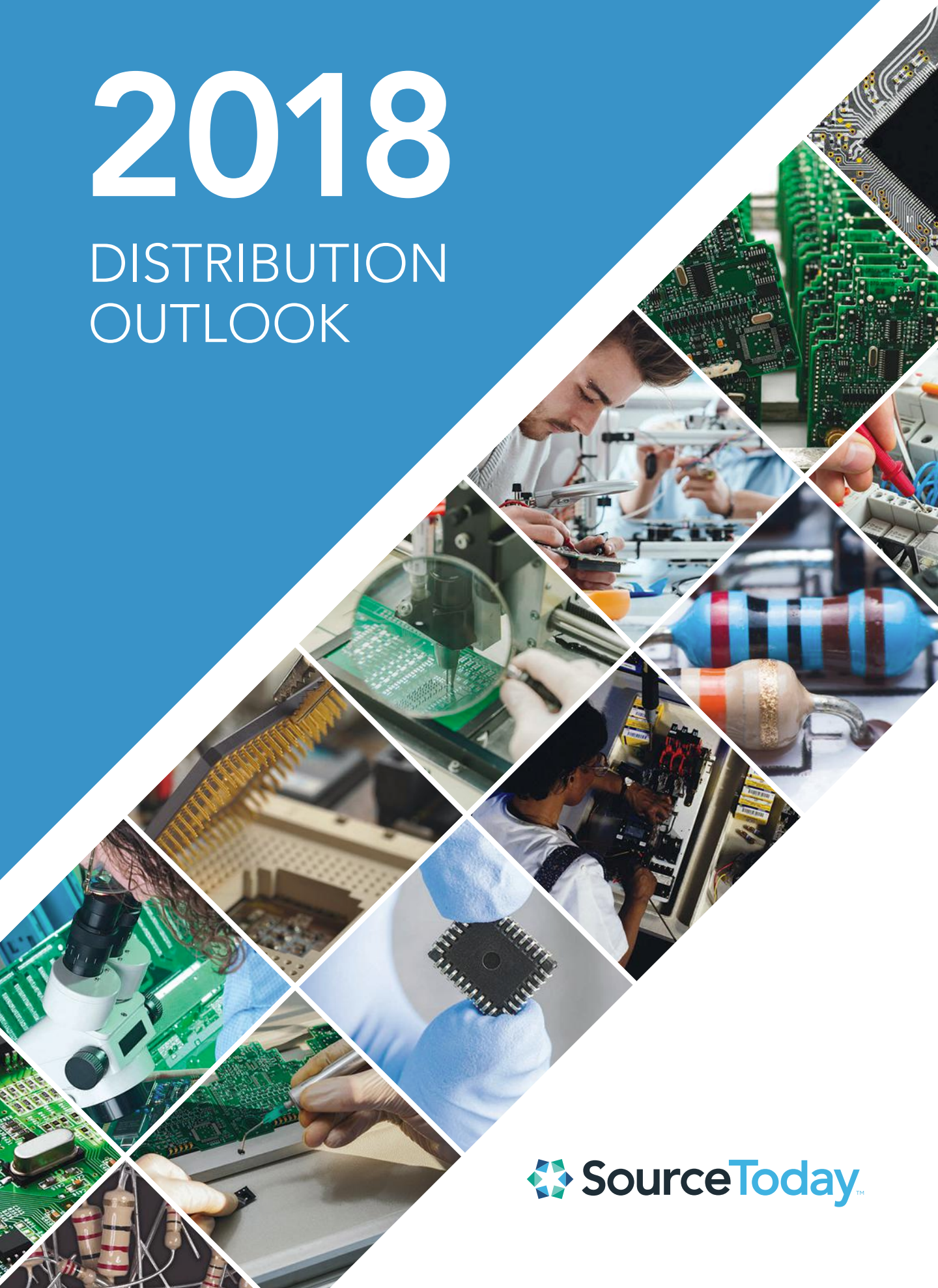
OTHER APPLICATIONS

USB-based spectrum analyzers such as the Tektronix RSA306B that SaskTel is using *(Fig. 2)* include displays like DPX and spectrograms. The team uses these features to track down other sources of interference that were previously hard to spot. One example was an intermodulation effect that was created when a couple of antennas in town were updated.

SaskTel is in the process of equipping more members of its interference hunting team with these instruments. From Davidson's perspective, it can't happen fast enough. "We also use these tools for other forms of interference, which could be anything from cellular amplifiers to internet cameras to garage door openers," he explains. "We currently have two units—one here in Saskatoon and one in the south. For the price of them, it would be nice for everyone to have one." mw

2018

DISTRIBUTION OUTLOOK



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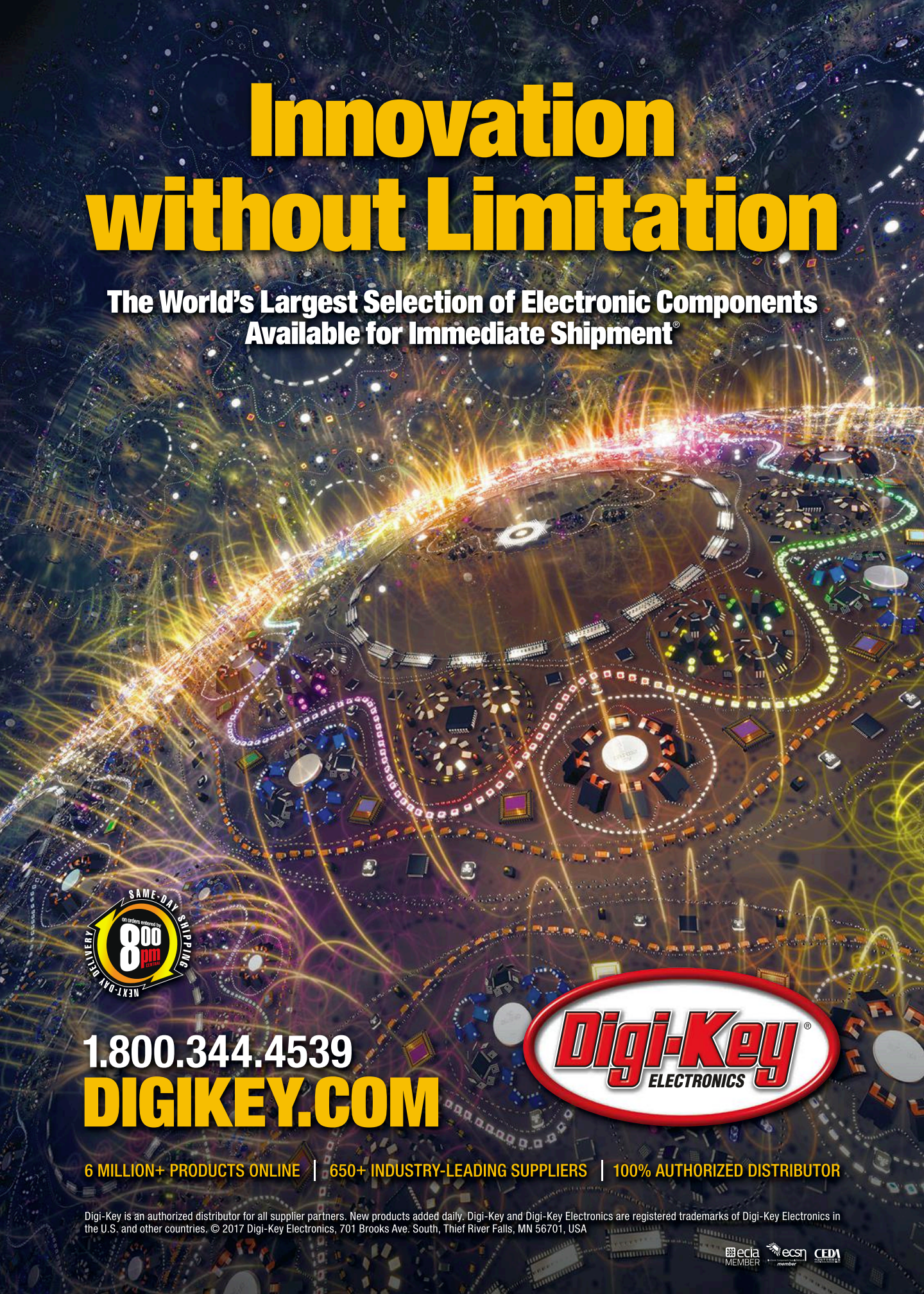
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Leading the Way to a Bright Future

In our annual Leaders coverage, we select key industries and applications and share what companies at the forefront are doing and what that means to the market overall.

We live in a time when technology is changing, improving, and revolutionizing the way we live and work every day. From how our vehicles operate to how we communicate and order parts, the world is quickly advancing. Tasks are becoming automated and intelligent with enhanced security. In our special Leaders issues, we spotlight key strategies, applications, and technologies across four of our core brands and look at the current landscape. We also pinpoint which companies are leading the charge into the future.

In *Electronic Design*, for example, we examine leading applications and technology solutions for wide-bandgap power—specifically, gallium nitride and silicon carbide. We also delve into the security issues around embedded devices, an issue that is becoming more critical as more devices and systems connect to the cloud.

When it comes to manufacturing and automation, the Industrial Internet of Things (IIoT)/Industry 4.0 is increasingly taking hold. As machine learning and artificial intelligence are increasingly leveraged, these networks will be self-learning and eventually largely self-managing. IoT also is discussed in our test and measurement article together with 5G, as we look at how those technologies are changing the test landscape. Similarly, an article on automotive electronics examines which automakers are furthest along on the road to the driverless vehicle and what technologies and developments are fueling their success.

Speaking of the electronics market, our *SourceToday Distribution Outlook* offers insight into why distributors are bullish about next year's outlook. This positive attitude is quite new, as electronics distributors have largely struggled amid generally soft market demand since the recession in 2008-09. Yet they're foreseeing brisk business across most markets, which hopefully will put an end to the slump. *SourceToday Distribution Outlook* also covers trends and features highlights of key interviews regarding expectations for electronics distribution in 2018.

Our *Machine Design* brand also focuses on key applications and technologies that are impacting the design universe now and going forward. A feature on 3D printing, for example, looks at how leaders in this area are looking to boost manufacturing speed. Industrial automation is, of course, a major focus here as well, with data and analytics being used to inform processes and other improvements. Also featured are "smart" motion systems and adhesive improvements, which are benefiting manufacturing. Even the seemingly simple fastener is discussed, as companies profiled have simplified installation using automated/robotic approaches, working with single-piece fasteners, or exploring various materials.

In *Microwaves & RF*, we cover a topic that connects with all of our readership in both their personal and work lives: 5G communications. These much-heralded, next-generation networks still may take different approaches, leaving millimeter wave's role still somewhat to be determined, as just one example. We look at the companies on the forefront of these network rollouts and those that must support them to track their moves and predict who will shape the 5G landscape. The Leaders section also takes a fun turn by exploring solid-state cooking to see who the players are and what its real near-term potential may be.

Stay tuned for more of this type of coverage going forward, as we strive to keep you informed of who is leading the charge of using new technology and solutions and how they are doing it. Happy reading!

JOHN SIMPSON | Contributing Editor

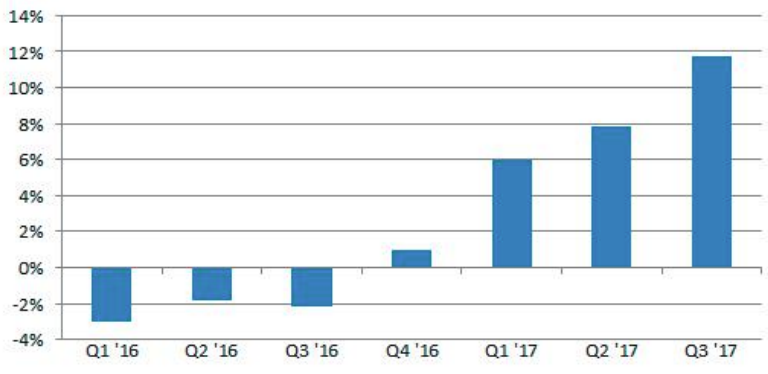
Electronics Distributors Bullish on Outlook for 2018

For the first time in years, electronics distributors are confidently predicting robust sales for the 12 months ahead. Credit brisk business across most market segments in the first three quarters of 2017 for their upbeat outlook.

North American distributor sales figures published in November by the Electronic Components Industry Association (ECIA) document solid growth for the third quarter of calendar year 2017, reaching their highest dollar value since the association began collecting the data in Q1 2015. Sales increased 2% quarter on quarter and 12% compared to a year ago (Fig. 1). Book-to-bill was a strong 1.29, making for four positive book-to-bill quarters out of the last five. Through the first three quarters of 2017, distributor sales are up 9% compared to year-earlier totals.

(Continued on page ST 6)

Figure 1. Distributor Sales % Change to Previous Year



Courtesy of ECIA

According to ECIA, sales increased 2% quarter on quarter and 12% compared to a year ago.

NON-TRADITIONAL COMPANIES VIE FOR A PIECE OF THE CATALOG BUSINESS

—A Question for Chris Beeson, Executive Vice President, Sales and Supplier Management, Digi-Key Corporation

What challenges do you see for your company on the horizon?

"I think the ecosystem is getting more demanding. There are a lot of creative people out there, and the barrier to entry to get into this business is so much less than what it used to be. You wake up every day and you have to be curious about, what should my model look like tomorrow? Is my content enough? How do I fit into the ecosystem?

"We have some very good competitors—and there are some non-traditional companies that are now trying to enter into a space that has [traditionally been occupied by] Digi-Key. We hope that's done in a means that is healthy and productive at the customer level. We're now seeing a lot more 'spend $200, get 50-dollar coupons; free shipping.' Many companies are coming in and they think it's best-price-wins. And it's really greater than that.

"For a lot of people who want to enter the space—with a web and digital orientation—it may look relatively easy from the outside. But when you get into it, you see the magnitude of details involved. We jokingly call it a thousand little things done right every day—a thousand is a big number—and it's *not* quite that easy. It's a different business model, a different P&L orientation than what a lot of traditional distributors have. And so that's really a change for them to try to enter the space."

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(Continued from page ST 4)

"The difference this year is that strength has continued all throughout the year," says Faris Aruri, vice president of supplier marketing at Sager Electronics. "The last three or four years, by this time, we were giving up a lot of the gains that we got earlier in the year. Just based on this momentum that we have in September and October, we're going to put up a similar or even higher number for 2018."

It wasn't always this way. Electronics distributors have struggled amid generally soft market demand for much of the period since the 2008-09 recession. Component manufacturers have responded to the conditions with consolidation and capacity cuts to help calibrate supply with demand. Still, in the relatively flat market of the past five years, customers have had the negotiating leverage afforded by relatively abundant component availability and short lead times.

"It's been a buyer's market for so long," says Michael Knight, executive vice president at TTI Inc. "It's a hard mindset to get out of—that parts are plentiful and I'm always going to be able to get a better price."

That situation began to turn around in earnest in the second half of 2016. Surging demand in a number of sectors, including automotive, industrial, and consumer electronics, has since stretched lead times and boosted prices of a number of components, including discrete semiconductors, resistors, and memory chips. ECIA data shows that, by the third week of September, passives and semiconductors both had average lead times of over 11 weeks. Discrete semiconductors and resistors carried lead times of over 16 weeks.

According to Tobey Gonnerman, executive vice president at Fusion Worldwide, in June and July 2017 his firm experienced a 20-fold increase in the number of resistor requests compared to those received over similar periods during the previous year. "This is noteworthy in that there are many players in the resistor space, plenty of manufacturers to regularly manage the risk," he wrote in a blog post. "When manufacturers start calling independent distributors like Fusion for such a readily available commodity, that means there is exceptional—and perhaps unprecedented—demand."

Growing demand, low inventories, long lead times, and higher component prices give hope for distributors that better margins are on the horizon. With shrinking part supplies, and reports of double-ordering, customers now increasingly face the prospect of purchasing certain components on an allocation-only basis. What a difference a year makes.

HIGH DEMAND IN 2018 FORECAST ACROSS MAJOR END MARKETS

Analysts predict continuing strong demand in 2018 in most growth markets for electronic components, including automotive, the Internet of Things (IoT), and consumer electronics. According to market research company IC Insights, demand is rising for electronic systems in new cars, particularly for autonomous vehicles, vehicle-to-vehicle and vehicle-to-infrastructure communications, on-board safety, convenience, and environmental features. IC Insights forecasts that the automotive segment will be the fastest-growing electronic system market through 2021 (Fig. 2), with automotive integrated circuit (IC) sales growing 22% in 2017 and 16% in 2018.

Market intelligence company TrendForce, meanwhile, has reported that in 2018 major automotive chip suppliers will begin shipping solutions that allow vehicles to achieve Level 4 "High Automation" technologies as defined by SAE International. Key applications that automakers will incorporate these components into include radar modules, image sensors,

(Continued on page ST 8)

AUTOMOTIVE, AFTERMARKET ELECTRONICS AMONG THE GROWTH DRIVERS FOR 2018

—A Question for Kevin Hess,
Vice President of Marketing, Mouser Electronics

What is the current outlook for Mouser and what do you see as the biggest growth drivers in 2018?

"Our forecast for 2017 a year ago was to grow, we were thinking, 10%. In fact, we're probably going to grow 21-24% this year. So things are going well. Europe and Asia are still outpacing the Americas; we're growing over 30% in both regions and 14% in the Americas, which is our biggest piece of the pie. Going into 2018, you're hearing a lot of people saying Q1 and Q2 should be strong and then we'll start seeing a flattening out. So what we're anticipating is probably a good first half of the year.

"What will to continue to drive growth, I think, are the automotive industry—all of the electronics that are now going into cars and into aftermarket products through automotive—as well as IoT, connected devices, wearables, etc. And it's not large-production-type stuff; it's smaller—thousands of pieces instead of millions of pieces.

"For Mouser, what's going to drive our business are new products. Just to give an idea: this year, 28% of our sales will be from components we introduced in the last four years. We need to keep adding those new products so that, three to four years down the road, they comprise 30% of our sales. If we stop bringing them out, that's going to negatively affect our future business."

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(Continued from page ST 6)

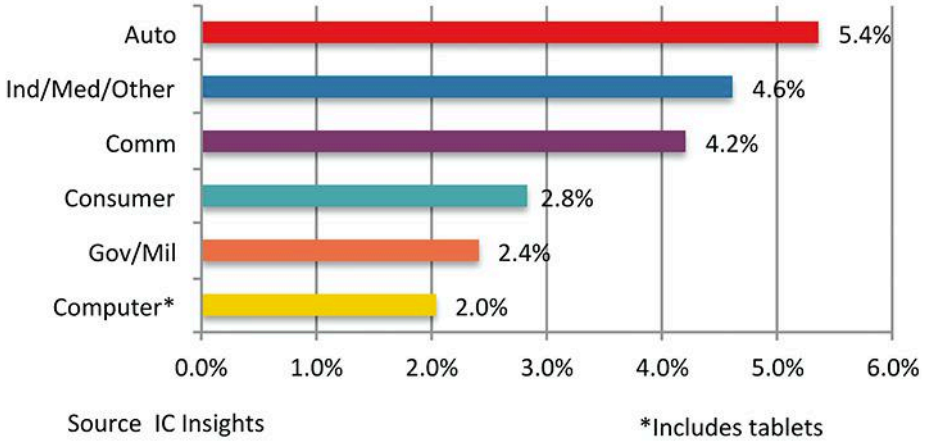
automotive processors, displays, advanced driver assistance systems, and connected-vehicle platforms.

"I think transportation remains a great growth opportunity for our industry," says Karim Yasmine, vice president of sales and marketing for Future Electronics. "It is a business that has been traditionally known as direct-oriented, but they're much more open now. Those tier 2 and tier 3 transportation and automotive companies are all interfacing with distribution looking for design support."

IoT will also get a boost in 2018, TrendForce says, with the commercialization of 5G in the new year in the U.S., China, Japan, and South Korea—as well as the emergence of the next-generation WiFi standard, 802, which will help with the bandwidth burden that more connected devices will bring. TrendForce predicts the global population of 5G subscribers will approach 500 million by the end of 2022; IHS Markit forecasts that the number of connected IoT devices worldwide will grow at a compound annual growth rate of 12%, from 27 billion in 2017 to 125 billion in 2030.

"It seems that at least in 2017 the dynamics of growth across the board are unbroken," says Georg Steinberger, chairman of the European Semiconductor Distribution Market, which like the U.S. Semiconductor Industry Association reported record quarterly sales during the year. "Newer designs in fields like IoT or e-mobility will see higher components content, so the future looks rather positive from a sales and volume perspective." *(Continued on page ST 10)*

Figure 2. Worldwide Electronic System CAGRs ($, 2016-2021F)



IC Insights forecasts that the automotive segment will be the fastest-growing electronic system market through 2021.

THE CHANGING SKILLS REQUIRED OF DISTRIBUTION PROFESSIONALS

—A Question for Karim Yasmine, Vice President, Sales & Marketing, Future Electronics

What kinds of knowledge, skills, and abilities are you looking for in new hires?

"In terms of skill sets, I think you need to aim for a balance. There is no doubt that you want to hire the millennial counterpart to the customer. So that means hiring young, dynamic, hungry people from outside the business who don't have all these ideas of what *can't* work in our industry. But at the same time, we continue to look for seasoned professionals who understand how things work—they're the best people to train these new people.

"So we're not in this 'uni-model' of scouting for only younger people who are going to be the answer to the changes in the industry. Because the reality is that there are still very strong purchasing and engineering communities that are looking for seasoned veterans who have seen many cycles and many situations—and there's good value in those people as well.

"Increasingly, though, I think the desired profile involves someone who is hungry and also has technical knowledge. I think in the past our industry didn't emphasize the technical side as much when it came to sales. Certainly FAEs had to have that [technical aptitude]. Now, what I think we're interested in on the sales side are people who are passionate about technology and are savvy enough to be able to introduce new products and solutions to our customers."

It All Started in 1887 as a Small Boston Storefront Selling Speaking Tubes.

130 years later, Sager Electronics has grown into a leading North American distributor of interconnect, power and electromechanical electronic components. Acquired 5 years ago by TTI, Inc., a Berkshire Hathaway, Inc. company, Sager continues to operate with the same dedication to its core values – integrity, service and adaptability.

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(Continued from page ST 8)

Mobile phone sales, meanwhile, are expected to return to year-over-year growth in 2018, with Gartner Inc. forecasting shipments totaling 1.9 billion units. Smartphones will represent 86% of total mobile phone shipments in 2018, up 6% from 2017, and Gartner expects Apple's iPhone X to be the sales driver in North America, China, and Western Europe despite its high price.

"Given the late November availability of the iPhone X, we expect the iPhone's replacement cycle to flow more strongly into 2018," says Roberta Cozza, research director at Gartner.

GLOBAL RISK INDEXES EASING

"It's interesting to see the diversity of industries that are doing well. We're encouraged from that perspective, and there's no indication that that's slowing down," notes Chris Beeson, executive vice president, supplier management and supply chain at Digi-Key. "A lot of us, going into the year, weren't anticipating this robust of a year," he adds.

Indeed, past performance is not necessarily the best predictor of the future, and a number of unknowns lurk in the political and economic arenas. In the short term, U.S. policymakers will grapple with tax reform, (likely) infrastructure legislation, and the confirmation of a new Federal Reserve chairman, Jerome Powell. Over the longer term, negotiations over NAFTA and Brexit loom as additional factors that could impact electronics component markets.

Assessing the effect of the current political and economic environment on global supply chains, Dun & Bradstreet (D&B) in mid-November reported that its Chartered Institute of Procurement and Supply (CIPS) Risk Index fell (i.e., improved) for the third consecutive quarter. However, the firm notes that despite recent improvement in the risk environment, the Q3 score is only slightly below the index's all-time high, recorded in Q4 2016 (see country-risk heatmap in Fig. 3).

The largest drop in risk was in Western and Central Europe, where a series of stabilizing political outcomes helped to reduce the region's contribution to global risk in Q3, according to D&B. The formation of a government in Macedonia following months of political deadlock and the abandonment of street protests by the opposition Democratic Party in Albania helped to stabilize the region and reduce risk.

In addition, the European Union's free trade agreement (FTA) with Canada came into force in September, eliminating many taxes and duties on goods traded between the EU and Canada. The EU also appeared to make progress in talks with Japan and Indonesia about FTAs in the future, D&B said.

However, political risk around the world could spill over into the economy and impact supply chains, D&B cautioned. This risk stems particularly from the U.S., where the lack of clarity from the Trump administration around trade—and threats to pull out of a major trade deal with South Korea—could impact Asia. Similarly, the renegotiation of the NAFTA trade agreement among the U.S., Mexico, and Canada could affect the stability of the North American region in the coming months, the business credit-reporting firm said.

"The outcomes of various ongoing negotiations, such as Brexit and NAFTA, could change the face of global trade and cause significant disruption to supply chains in the future," notes CIPS Economist John Glen. "This could cause delays, increase costs, or reduce the quality of supplies businesses have access to, so it is now more important than ever for businesses to have robust contingency plans in place."

(Continued on page ST 12)

HOW TECHNOLOGY IS TRANSFORMING THE DISTRIBUTION INDUSTRY

—A Question for Michael Knight, Executive Vice President, TTI Inc.

How is technology impacting electronics distributors—and is there a seismic shift under way?

"It's not a cataclysmic change—it's a gradual change and I don't think it's unique to our industry. Technology is changing the way we all interact in business—and actually making it less personal. That's been an ongoing trend that's been developing for a long time.

"At some point in the not-too-distant future, you're going to see a lot more computers buying from computers. You already have artificial intelligence out there today that can teach itself to play Go—which is infinitely more complicated than chess—and defeat a [human] grandmaster. So a computer buying from another computer seems ridiculously simple in context. And I think there's much more of a business case to spend money developing that than spending it to develop something that wins at Go.

"The primary purpose of the supply chain is to make sure your line doesn't go down—in the face of uncertain demand from your end customer, uncertain supply from component manufacturers, etc. So you want to make sure you have continuity of supply so you can build on time and ship on time. Today there are a lot of people involved in that. People are expense—and there is an ongoing push to take cost out. I think you're going to see more people being taken out of the equation—sales people, planning people, purchasing people."

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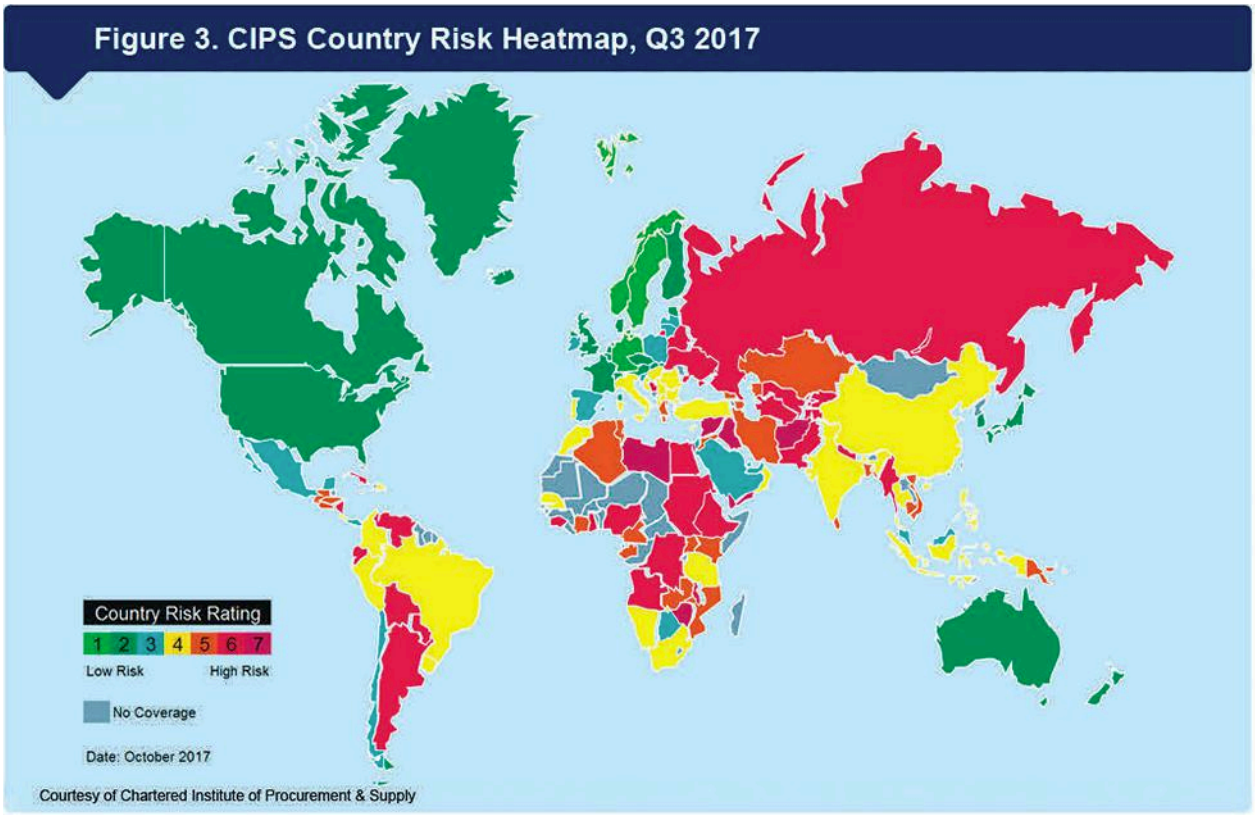

As the map above illustrates, the Q3 score is only slightly below the CIPS Risk Index's all-time high, recorded in Q4 2016.

ECONOMIC FORECASTS, LEADING INDICATORS PREDICT STRENGTH

In its October World Economic Outlook, the International Monetary Fund (IMF) reported that the worldwide upswing in economic activity is strengthening, projecting global growth to rise to 3.6% in 2017 and 3.7% in 2018. "Broad-based upward revisions in the euro area, Japan, emerging Asia, emerging Europe, and Russia more than offset downward revisions for the United States and the United Kingdom," the IMF says. But the recovery is not complete, IMF adds, noting that while the baseline outlook is strengthening, growth remains weak in many countries and inflation is below target levels in most advanced economies.

The Conference Board—which counts among its membership approximately 1,200 public and private corporations and other organizations across 60 countries—largely agreed with IMF in its mid-November outlook. The organization said that global GDP growth, which it predicted would grow at 2.8% a year ago, is likely to reach 3% for 2017 and carry on at that rate through 2018.

"Global growth has finally left the starting gate since the global economic and financial crisis," says Chief Economist Bart van Ark.

The Conference Board said 2017's growth uptick reflects a combination of "unique" events, including the stabilization of energy and commodities prices, improved business confidence based on hopes for fiscal stimulus and tax reforms by the U.S. administration, a cyclical recovery in Europe, and China's policy-driven growth stimulus. "These events are unlikely to provide sustained growth going forward," the Conference Board adds, however.

In the manufacturing sphere, purchasing managers index (PMI) data for October show that companies are operating amid the best global business conditions in six-and-a-half years, says Chris Williamson, chief business economist at IHS Markit. The JPMorgan Manufacturing PMI edged up to 53.5 in October, its highest level since April 2011 (Fig. 4).

While the current upturn remains weaker than the expansion of 2009-11, the broad-based nature of the expansion is "encouraging" in terms of its sustainability, Williamson said. Only three of the 29 countries covered by IHS Markit's manufacturing PMI surveys reported deteriorating business conditions.

(Continued on page ST 14)

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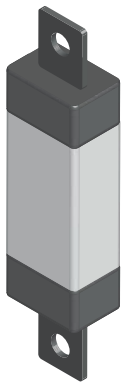

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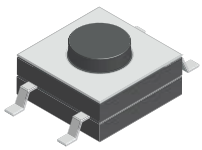

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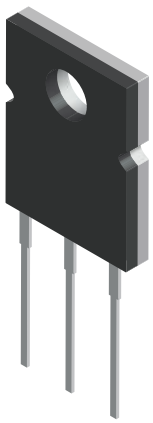

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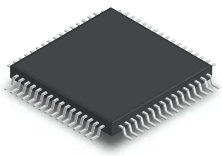

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(Continued from page ST 12)

Figure 4. PMI Is at its Highest Level in Over Six Years

Courtesy of IHS Markit

Purchasing managers index (PMI) data for October shows that companies are operating amid the best global business conditions in six-and-a-half years.

As for U.S. industrial production, the Institute for Supply Management's (ISM's) Production Index registered 61% in October which, although a decrease of 1.2 percentage points from September, nonetheless indicates the 14th consecutive month of growth. "Production expansion continues at a strong pace in spite of supply chain difficulties, including the reduction of inventory levels seen during the period," Timothy Fiore, chair of ISM's Manufacturing Business Survey Committee, says, alluding to Hurricanes Harvey and Irma.

"We're in what I think of as a period of sustainable growth," adds Dan Stewart, vice president of marketing at Allied Electronics. "Industrial production (IP) has been ticking along at 2-3-4% growth—that's a pretty sustainable rate. If IP were at 5-6-7%, that's not sustainable."

CONNECTED DEVICES, CORD-CUTTING COULD DRIVE FUTURE GROWTH

TTI's Michael Knight said that the emergence of new connected products that are now under development could help distributors power through a mild recession if one were to occur at some point beyond 2018.

"Everybody who makes anything electronic is trying to figure out how to connect to the cloud, how to collect data off it, and how to use the data," Knight says. "All that connected stuff is going to replace all of the currently unconnected stuff."

Moreover, new battery technology will allow customers to "cut the cord," creating incentive for them to replace corded products with cordless versions, he adds.

"They're going to be faster, smarter, smaller, and more energy efficient," Knight says. "It's going to take a long time to flush all the old things out and replace them with new ones—but it's going to happen."

MEETING CUSTOMERS' NEED FOR A SEAMLESS DIGITAL EXPERIENCE

—A Question for Dan Stewart,
Vice President of Marketing, Allied Electronics

How are customers' interactions with distributors changing with respect to how they research part availability, prices, etc.?

"If you talk to the engineer—regardless of whether they are board level, automation control, etc.—what he or she wants is access to good information, the ability to find parts easily, and a seamless experience with the distributors that they work with. And really what that boils down to is their digital experience.

"It's gone from the perspective of having a salesperson who can help you out with whatever you need to 'I want to be able to do things for myself.' So what we've got to figure out is how to create a simple but effective online experience, particularly for our engineers. That sounds relatively easy. But when you put it into practice and look at things like being able to receive back-order information from our suppliers all the way through to us and to our customers, it's a really demanding thing to achieve.

"So we've invested quite a lot into our search capabilities to allow us to use algorithms to much better connect our engineers with the parts that they're looking for based on that computer-generated intelligence. It's really about how we seamlessly communicate with our customers in a very integral fashion, which I think is just as big of a challenge for us as it is for everyone else."

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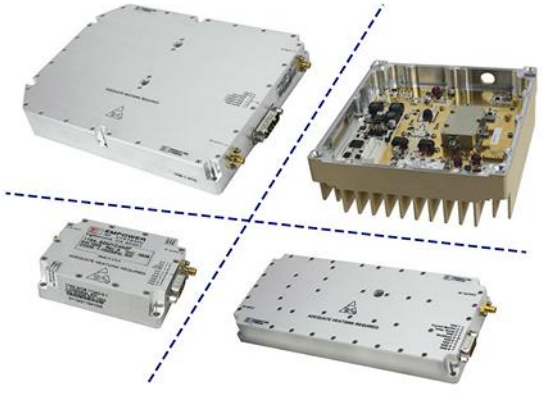

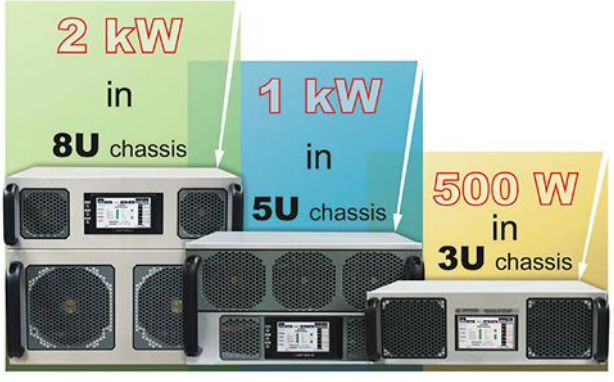

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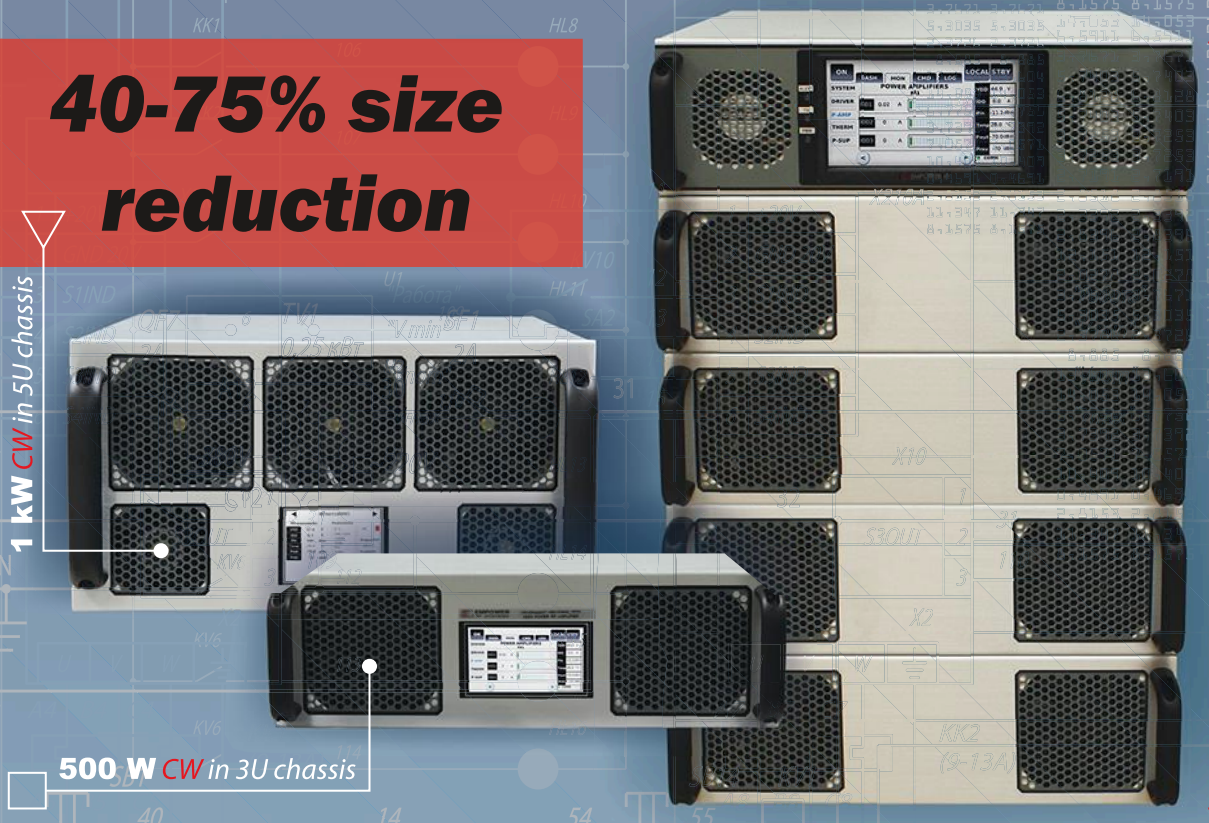

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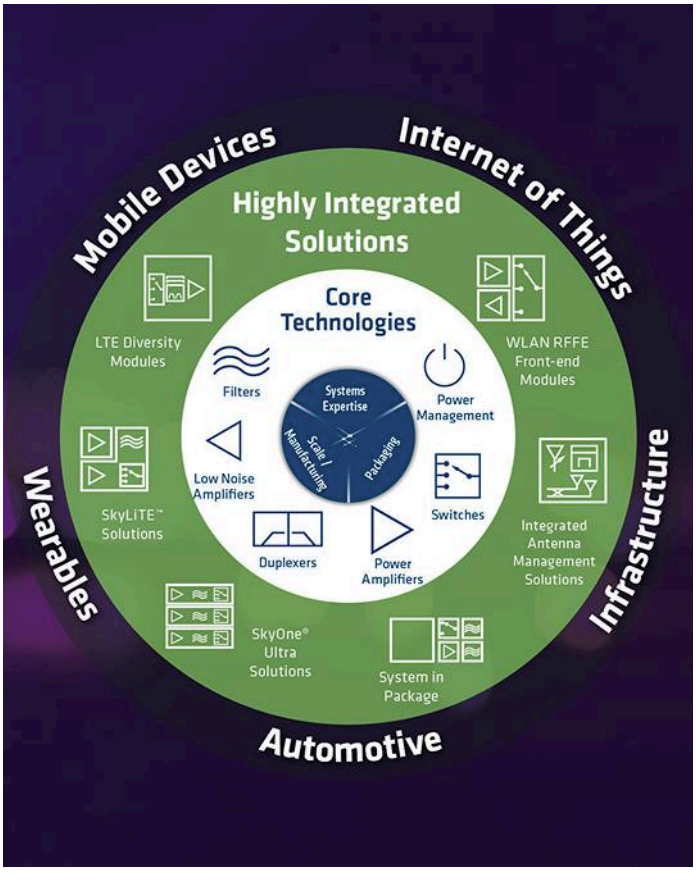

AS "ALWAYS-ON" CONNECTIVITY plays a bigger role in our daily lives—at home, in the office, or on the go—there is a commensurate level of analog and RF complexity that comes along with it. Solutions must preserve battery life, increase data rates, and ensure that connectivity technologies work seamlessly, all while occupying minimal space. Meeting these design challenges requires not only mixed-signal and broad RF competencies, but the ability to address signal transmission and conditioning, filtering, tuning, power-management, voltage regulation, and battery-charging challenges. These challenges play directly to Skyworks' strengths. Given our broad systems expertise, we innovate and create highly configurable and customizable solutions that reduce system complexity, delivering unparalleled levels of integration and superior analog performance.

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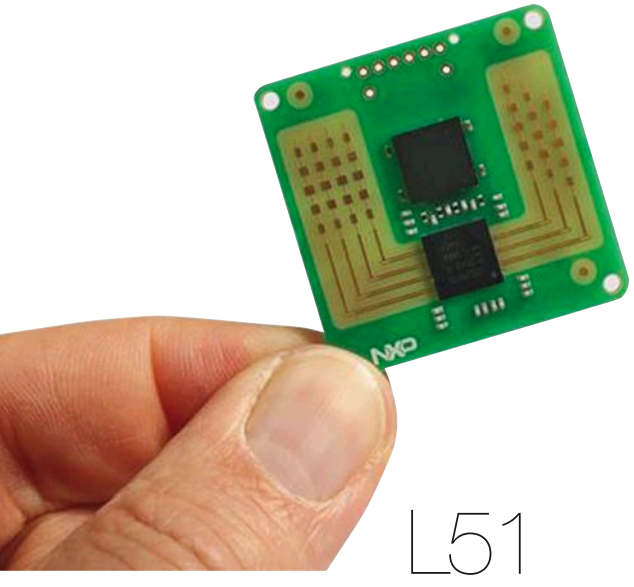

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Making 5G Happen

There's something in it for everyone.

5G IS BIG. Also known as 5G New Radio (NR), this new wireless technology will ultimately impact everyone in the electronics and telecommunications industries, not to mention the effect that it will have on us individually. 5G NR has been under development now for several years, and while progress is being made to finalize the standard, it is still years away before becoming what we call mainstream. Most estimates say 2020 is when we will ultimately see some real 5G deployments on a scale that will we will notice. In the meantime, companies are firming up their plans for whatever 5G products and services they will offer. Considerable hype still abounds, but real progress is being made. Here is a fresh assessment of 5G status.

WHAT'S THE HURRY? LTE IS GREAT.

Do we really need 5G right now? Our current 4G cellular standard Long Term Evolution (LTE) is adequately serving most of us right now. Are conditions so bad that we are anxious for the next generation to come along and relieve our suffering? I don't think so. Virtually all cellular carriers now implement LTE that is delivering megabit speeds over most of the developed world.

In addition, the carriers are regularly updating their systems to add capacity or boost data rates. Many have already implemented LTE Advanced and are on the path to LTE Advanced Pro. These advanced versions offer features like carrier aggregation (CA) that combines up to five 20 MHz channels, increased MIMO configurations to 8×8, and modulation to 256QAM. These provide the potential for gigabit speed, although in reality hundreds of megabits downloads are more likely. Isn't that enough? For some, probably not. Yet it is fine for the average masses. Video hogs always want more.

LTE is also now serving the need for some Internet of Things (IoT) applications. Yes, cellular is an option. The new LTE M1 and NB-IoT versions are being embedded into products. Most major carriers offer IoT or machine-to-machine (M2M) services that are typically manageable on existing networks. That application is growing.

Never satisfied, the industry is pushing ahead for something better. Isn't that what we always do? Once a technology standard like LTE is finalized and commercially implemented we typically rush to top it with a new and better standard. It keeps us busy and challenged and pushes us to develop better hardware and software. How do engineers stay interested if they are not brainstorming then designing the next chips, products, and programs? We invent stuff even if we don't need it, because revenue growth is a perpetual need.

LTE is more than satisfactory for now, and it will continue. 5G will not replace LTE.—it will serve a separate need and will complement LTE. Some call 5G an LTE overlay. You will not be wanting for good cellular service.

THE 5G RATIONALE

Those pushing for 5G cite two major needs. First, everyone wants faster mobile broadband services on our smartphones and tablets. The key driving force is video. Audio is another major application. More cord-cutting and streaming. 4K and even 8K high definition video content is now available. We have become a nation of watchers and listeners, not readers. The smartphone makers are giving us bigger and higher resolution screens and faster processors to deal with our video-intensified life. The cellular operators are continually gearing up to provide the major pipeline for this coming video/audio glut.

Then there is the looming Internet of Things threat. We are already experiencing a significant increase in IoT connectivity, but more is coming. The predictions says billions more devices will ultimately need connections, and the cellular folks want a piece of that IoT and M2M business. LTE is dealing with it now, but 5G will greatly expand the potential uses.

For example, 5G will offer increased capacity and decreased latency for some critical applications such as vehicle-to-vehicle (V2V) or vehicle-to-infrastructure (V2I) communications for advanced driver assistance systems (ADAS) and self-driving vehicles. A 5G-based cellular V2X communications system could very will replace the long-approved DSRC radios that use the 802.11p Wi-Fi-like standard.

Cellular operators are also looking at the broadband wireless market to deliver high-speed internet service. 5G will allow carriers to offer fast internet service in competition with cable and fiber ISPs. With 5G, wireless speeds will be on par with those hard-wired services, giving them a new revenue stream.

No, we are not desperate for 5G, as LTE is adequate for now. But we will love 5G once it gets here.

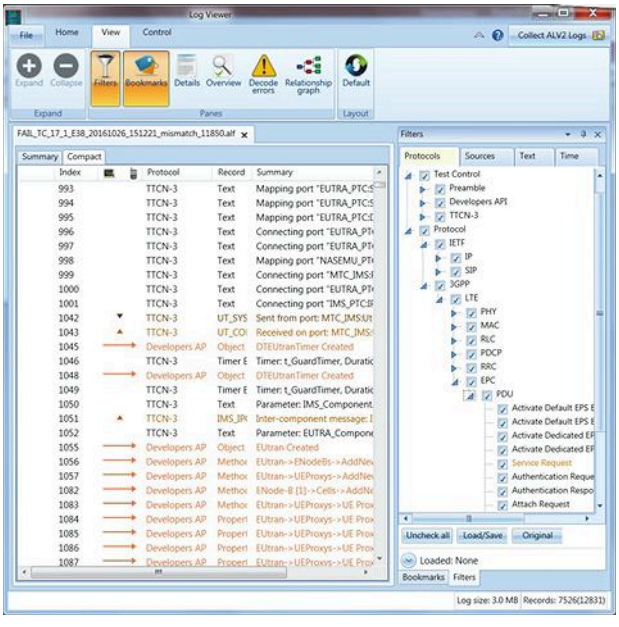
DEFINING 5G

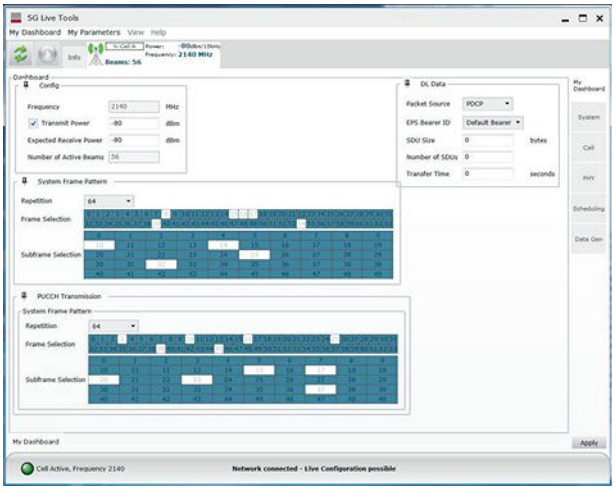
The 5G standard is not complete as this is written, but we do know some generalities. The overall goals are a user capacity of x100 over existing LTE capability, downlink data rates up to 10 Gb/s, and a latency of less than 10 ms. Here are the highlights of the proposed 5G standard to meet these goals.

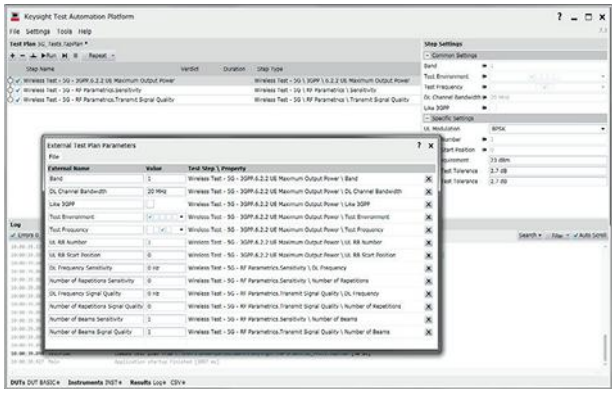
• A variety of spectrum will be used. Much of it will be below 6 GHz. Each carrier has its own spectrum licenses that vary widely. For example, T-Mobile bought some 600 MHz spectrum for 5G use. T-Mobile can also use some existing 1.7 and 2.1 GHz space. Sprint will use its extensive 2.5 GHz spectrum holdings. The 3.5 GHz Citizens Broadband Radio Service (CBRS) now used by the military may see some 5G usage on a shared basis. But the major trend is to move to the millimeter wave bands to gain more bandwidth to support that gigabit speed target. In the U.S. the 28 GHz and 39 GHz bands will be the new operational space. AT&T, T-Mobile, and Verizon have committed to this spectrum. This new spectrum provides the much wanted bandwidth up to 1 GHz. However, these frequencies offer new challenges of radio wave propagation and wireless circuitry. This industry as a whole is stepping up to make the mmWave bands workable.

• A dense collection of small cells will supplement traditional basestations. These miniature cell sites will attach to light poles, the sides of buildings, and on other structures to get the height needed for reliable connectivity. Getting permissions to install the small cells is turning out to be a major problem and will no doubt slow implementation of full 5G networks. Providing power and backhaul are related issues. While fiber backhaul is preferred for its speed, it is more costly to install, making microwave or mmWave backhaul a better choice for many installations. Otherwise, the dense small cell strategy is sound and will complement the existing LTE cell sites. Combined these sites should provide the coverage needed to make our 5G dreams come true.

1. Screenshots from Keysight's 5G DVT Toolbox software show applications: (a) Customizable filters allow different teams to investigate issues efficiently; (b) Key Performance Indicators (KPI) statistics ensure cost-effective development; (c) Real-time access to L1/L2 protocol parameters accelerate test programs; and (d) TAP (Test Automation Platform) allows the user to easily create and customize RF and RRM test cases with the highest degree of parametrization.







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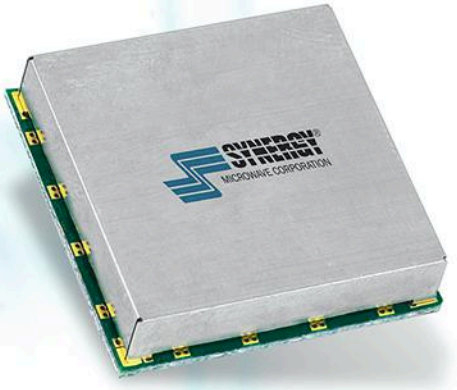

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HFSO600-5	600	0.5 - 15	+5 VDC @ 35 mA	-146
HFSO640-5	640	0.5 - 12	+5 VDC @ 35 mA	-151
HFSO745R84-5	745.84	0.5 - 12	+5 VDC @ 35 mA	-147
HFSO776R82-5	776.82	0.5 - 12	+5 VDC @ 35 mA	-146
HFSO800-5	800	0.5 - 12	+5 VDC @ 20 mA	-146
HFSO800-5H	800	0.5 - 12	+5 VDC @ 20 mA	-144
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	-138
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

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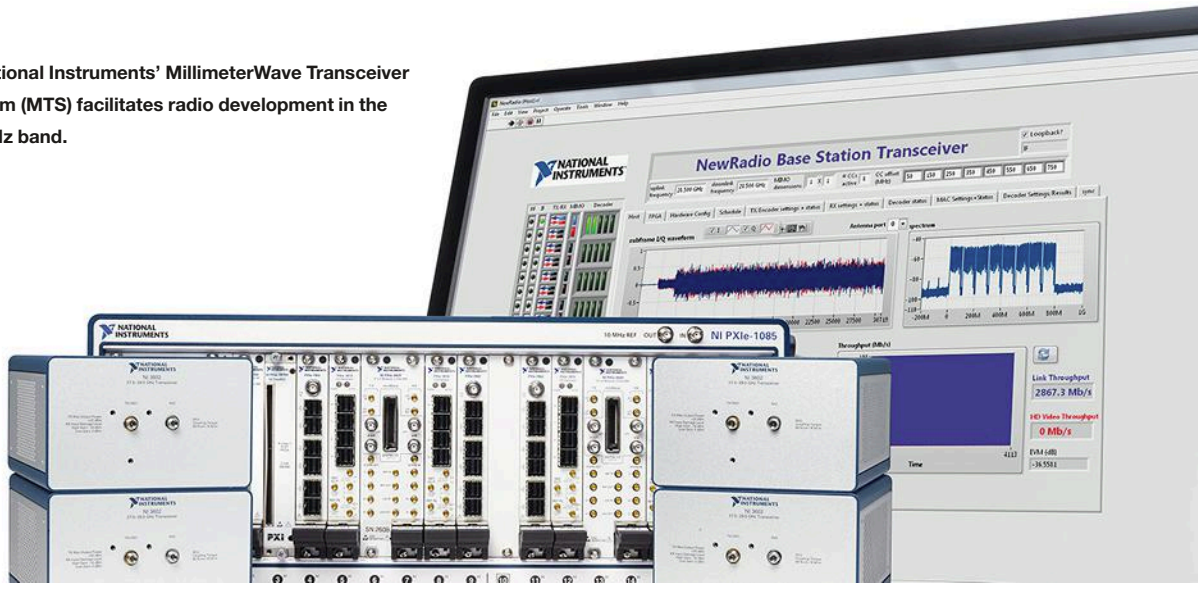


2. National Instruments' MillimeterWave Transceiver System (MTS) facilitates radio development in the 28 GHz band.

• The modulation will surely be some form of OFDMA, different from plain old LTE. The final variant has yet to be revealed. Also look for some other features like different OFDMA subcarrier bandwidths up from LTE's 15 kHz to 30, 60, 75, 120, or 240 kHz.

• Adaptive modulation to 256QAM will be adopted.

• Time division duplexing (TDD) replaces frequency division duplexing (FDD) that requires twice the spectrum.

• New channel coding includes low density parity check (LDPC) for data and polar coding for control.

• Massive, multiuser MIMO and antenna agile beamforming will be a standard feature.

• Some carriers like Verizon will offer their own technical variant of 5G.

BE THANKFUL FOR THE T&M COMPANIES

Let's all show our appreciation for the test-and-measurement companies that literally make it possible to create 5G. Without the ability to simulate and test new hardware and software, the 5G developers would be stalled or limited. We would not be nearly as far along in 5G development without frequency-related arbitrary signal generators, spectrum analyzers, vector signal analyzers, vector network analyzers, and oscilloscopes. The T&M companies are the real pioneers of 5G and their products make it possible for the rest of the developers to create, test, evaluate, and make final standards decisions. Some of the key challenges of 5G testing include the still-unknown version of the OFDM modulation, massive MIMO, channel simulation and estimation, and the clear need for extensive over the air (OTA) testing. Here are just a few of the many products that companies are offering to expedite the way to 5G.

Keysight Technologies' contribution to the 5G test effort is its 5G RF DVT Toolset, an addition to the company's network emulation solution (NES) portfolio. The Toolset is based upon Keysight's UXM 5G wireless test platform. Its purpose is to ensure measurement traceability from prototyping to acceptance and manufacturing. The DVT Toolset software uses Keysight's Test Automation Platform (TAP) to generate RF and radio resource management test cases. It is applicable to 5G NR, including mmWave frequencies and beamforming. *Figure 1* shows some example uses.

National Instruments is offering its line of 28 GHz radio heads that make it easy to experiment with and test 5G systems. These software-defined transceivers cover the 27.5 to 29.5 GHz range and can accommodate signals up to 2 GHz wide *(Fig. 2)*.

3. This is how National Instruments meets the challenge of testing massive MIMO systems.

Let's all show our appreciation for the test-and-measurement companies that literally make it possible to create 5G. Without the ability to simulate and test new hardware and software, the 5G developers would be stalled or limited.

Figure 3 shows how National Instruments test systems permit the evaluation of massive MIMO. This 128-antenna MIMO system was developed and tested by the University of Bristol in the UK for British Telecom.

Rohde & Schwarz helps to solve the 5G signal generation problem with its SMW200A vector signal generator. It produces signals up to 40 GHz and permits a bandwidth up to 2 GHz. It supports to 8x carrier aggregation. A companion instrument is the FSW spectrum and signal analyzer.

THE TECHNOLOGY THAT MAKES IT POSSIBLE

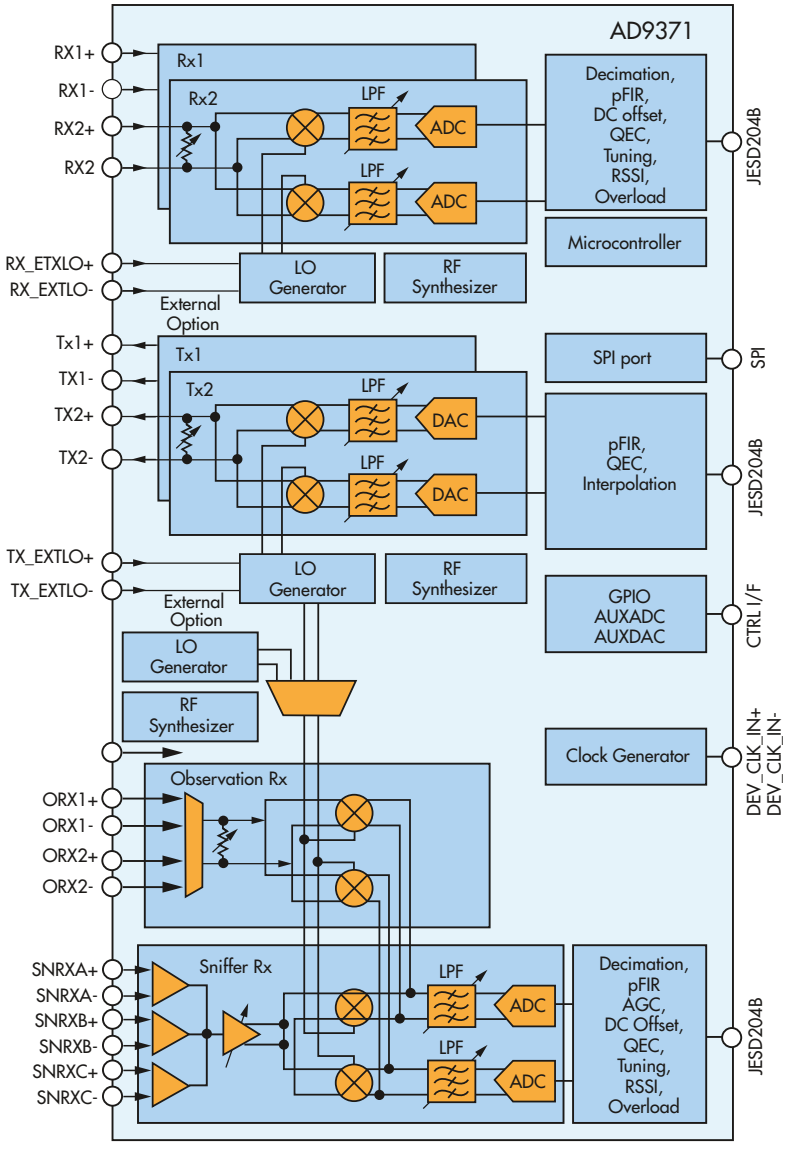
Chips that operate at the millimeter wave bands are making 5G possible. Some examples are chips from some major vendors.

Analog Devices' AD9371 dual RF transceiver is one chip that is making it easier to make phased arrays with beamforming. This device includes two transmitters and two receivers that operate at frequencies up to 6 GHz *(Fig. 4)*. It supports FDD and TDD operation. When combined with the phase shifters and amplifiers, this transceiver provides most of the circuitry to build large MIMO and beamforming phased arrays.

Qualcomm is a leader in supplying modems and radio chips to smartphone makers. Its latest modem is the Snapdragon X50 for 5G. It works in the 28 GHz band and can connect using up to 800 MHz of bandwidth. It supports download speeds to 5 Gb/s. It also incorporates MIMO and antenna techniques like adaptive beamforming and beam tracking. The X50 can pair with a Snapdragon processor with an integrated LTE modem to provide a complete 4G/5G solution for smartphones.

Chip companies like Qorvo and Skyworks are pushing their GaN and GaAs technologies to the limit to make mmWave power amplifiers (PAs), low noise amplifiers (LNAs), switches, and other components.

But when you dig a little deeper, you will discover that the technology that really brings it all home involves antennas. The unappreciated component of wireless products is the antenna, more of a mechanical device than an electronic device. It is actually both, as it is a transducer with full transmit-receive reciprocity. A new generation of antennas is being created to deal with the higher



4. Analog Devices' AD9371 dual transceiver operates up to 6 GHz and is finding a home is some 5G products.

operating frequencies, limited spectrum space, and need for higher speeds.

Most new 5G gear will incorporate antenna technology like multiple input multiple output (MIMO), including massive multiuser MIMO that will boost signal reliability as well as raise the data rate. Then there are the phased arrays that give us adaptive beamforming and high gain needed to propagate the mmWave signals over a practical distance with minimal interference to other users or cell sites. At mmWave frequencies, these multiple element antennas are small enough to use on the smallest basestations, as well as in our smartphones.

An example of a product that is making these antennas possible is the Anokiwave AWA-0134 that is used to implement a phased array with 256 radiating elements. *(Fig. 5)*. This antenna allows 4×4 MIMO operation with beamforming. The system uses 64 Anokiwave chips, each serving four antenna elements.

While MIMO and phased arrays are the solution to meeting 5G specifications, the antenna is ultimate challenge for handset designers. Smartphone engineers have continued to address the need for multiple antennas. The average smartphone has two main cellular radio antennas, plus antennas for Wi-Fi, Bluetooth, and GNSS/GPS. The question is how to add more antennas for MIMO needs as well as the 5G mmWave band antennas? A considerable amount of engineering is now in progress to solve this problem. Custom antennas that fit the packaging needs of the smartphones will no doubt be the solution.

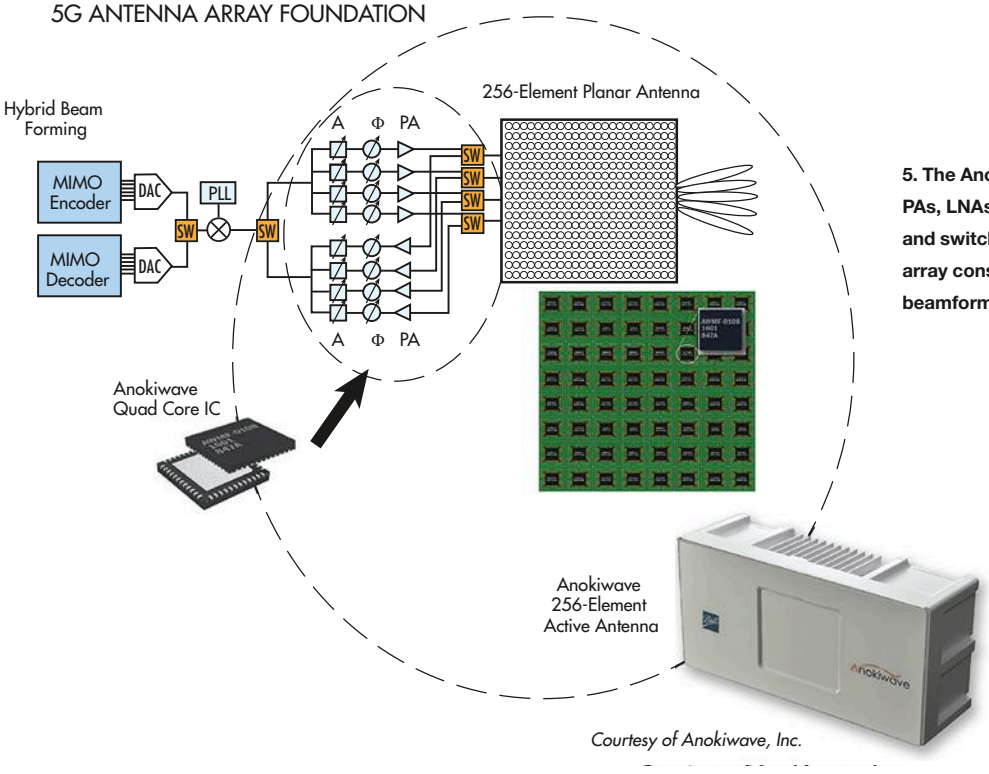
THE 5G TIMELINE

The Third Generation Partnership Project (3GPP) does its development work in stages and periodically introduces segments of the standards in documents called Releases. The 3GPP offers a projected time line but it regularly changes as the work progresses. On top of that, the industry is pushing for more detail sooner so chip, equipment, and software development can get on with it.

The latest word is that a complete 5G proposal will be submitted for review in the first quarter of 2018. We should see the first version Release 15 about that time. Ultimately, the long estimated final standard (Release 16) availability in the late-2019 to mid-2020 timeframe seems likely. Yet we are seeing lots of parallel development of hardware and software along with many field trials.

Aside from a few scattered initial installations around the world in the 2018 to 2019 period, the first real working deployments will probably be after 2020. Wireless internet access services are expected to be the first real application. It may take the smartphone manufacturers a while longer to figure out how to put 5G in a handset along with LTE and other backward-compatible features.

Go and enjoy your new iPhone X or iPhone 8 and prepare for the next LTE-A Pro iPhone 11. 5G probably won't show up until the iPhone 12. Perhaps it will be the iPhone 20/20 (or XX/XX). For now, learn to appreciate the LTE that serves us so well. Until the 5G formal introduction, watch the progress on the 3GPP website *(www.3gpp.com)*. mw



Courtesy of Anokiwave, Inc.

5. The Anokiwave AWA-0134 contains PAs, LNAs, phase shifters, attenuators, and switches that simplify phased array construction to meet MIMO and beamforming requirements.

BARRY MANZ | Contributing Editor

RF Energy Is Finally COOKING

Years in the making, RF cooking products have arrived—first for professional and high-end consumer kitchens, and soon for the rest of us as well.

1. A Raytheon Radarange was installed on the NS Savannah nuclear-powered cargo ship (now a museum ship) in 1961. *(Source: Wikipedia)*

SILICON VALLEY MAY be the acknowledged birthplace of high-tech, but the microwave oven—arguably one of most useful products ever created—was developed in Waltham, Mass. It put Percy Spencer in the history books, although this master of the magnetron would've wound up there anyway with more than 150 patents to his credit.

Unfortunately, it's the magnetron that has kept the microwave oven from becoming more than a way to make popcorn, defrost prepackaged foods, and reheat coffee. Fortunately, nearly three quarters of a century after Raytheon filed a patent covering Spencer's invention (for which he received the company's customary $2), the microwave oven is finally getting a thorough 21st Century overhaul.

Microwave ovens have come a very long way from the Amana Radarange that resulted from what (legend has it) was a candy bar melting in Spencer's pocket while he was tweaking a powered-up magnetron. The first Radaranges were nearly 6 ft. high, weighed 750 lb., and cost about $5,000 ($54,000 in today's dollars). They devoured 3 kW of power from 120 VAC, and had to be water cooled *(Fig. 1)*.

Today even a high-end microwave oven complete with fan-forced convection for crispy skin and assorted features like multiple cooking settings and a humidity sensor costs less than $500. The microwave oven state-of-the-art is exemplified by products like some from KitchenAid that also steam food based on its type and desired "doneness," and use the steam to help remove stains from the oven as well. They even have an acoustic sensor that listens to the sound of popping corn and turns off the magnetron when its fully popped.

But they still can't replace every type of cooking appliance, are too small to cook a turkey, heat unevenly, thaw foods disastrously, can cause a miniature firework display when a fork is left inside, steal moisture from food, and remove some of its original nutrients. In short, they don't do a great job of either defrosting or cooking.

WHAT IT TAKES TO BE BETTER

Turning a microwave into a full-fledged, cooks-anything device requires more and different ingredients—namely replacing the magnetron with a solid-state RF power amplifier and adding a receiver, sculpting the RF energy into beams that can be directed to specific foods on the turntable, more modern sensor integration, and proficient software that can orchestrate the process and cook several types of food simultaneously without intervention from the "chef." The result would be what the white goods and RF semiconductor industries like to call RF cooking, to reinforce that this is not simply a microwave oven. Browning would nevertheless still require an additional cooking method such as an electrical heating element.

Although the immense volume of microwave oven sales has reduced magnetron prices to the commodity level, they're still the same inflexible RF power source they have always been. A magnetron *(Fig. 2)* has two RF power states, on and off, and there is no way to vary its RF output. Its frequency is not tunable at least intentionally (it tends to drift) and phase and amplitude cannot be accurately controlled. These limitations effectively make the device incapable of adjusting cooking parameters—and limit their performance in the radar systems they were originally designed for, which is in part why solid-state devices have taken their place.

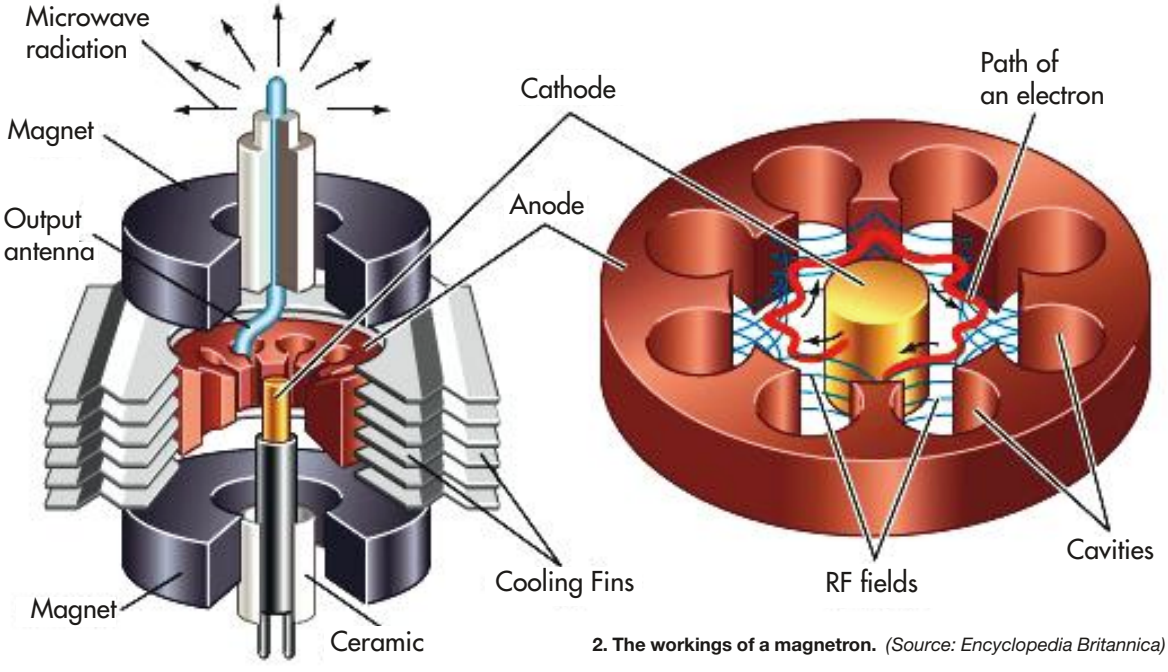
Defrosting is an excellent application illustrating the limitations of magnetrons for cooking. A magnetron-based oven basically blasts about 1 kW of energy into a cavity and "stirs" it to produce more uniform energy distribution. This energy cannot be varied, so defrosting is performed by turning the magnetron on and off. The result is that (for example) in a frozen hamburger patty, some portions will be fully defrosted, others fully cooked, and the rest somewhere in between.

In contrast, the power level of an amplifier powered by solid-state devices such as LDMOS RF power transistors can be infinitely varied, as can their frequency and phase, which along with real-time analysis of the food state is far more precise, resulting in uniformly-defrosted food. This same scenario applies equally to cooking, as faced with multiple items on a turntable, a magnetron-based oven will simply cook everything the same way (with predictable results).

The output of a magnetron also decreases time with time. This is rarely noticed in a home environment where a microwave oven is generally not the primary cooking appliance. However, commercial microwave ovens at fast-food restaurants operate almost continuously, as are those in the hundred-odd industrial applications ranging from curing wood to drying dog food.

In these applications, it's not uncommon for a magnetron to be replaced twice a year, and while the device itself isn't expensive, the truck roll definitely is. When multiplied by the thousands of restaurants in a major fast-food chain, each one having several ovens, the result is a noticeable impact on the bottom line. A solid-state oven will produce almost the exact same RF output power for its entire operating life, which is about 100 yr., while an industrial-grade magnetron has a lifetime of between 2,000 and 6,000 hr.

A reasonable question might be why, considering the enormous advantages of solid-state devices, have they not been



2. The workings of a magnetron. *(Source: Encyclopedia Britannica)*

There are no limitations on what can be placed in a Goji-based oven, such as utensils like forks and other metal items as well as metallic-coated cups. The oven can cook an entire meal, such as a steak, vegetables, a potato, and a dinner roll.

used for RF cooking before. There are several reasons, the first of which being that until relatively recently have RF power transistors been rugged enough to withstand the varying load conditions encountered in cooking. They also didn't have the overall performance characteristics.

Current LDMOS and most recently some gallium-nitride (GaN) RF power transistors meet all of these requirements, and can withstand impedance mismatches from 20:1 for GaN to 65:1 for LDMOS. Even though the RF cooking environment is comparatively well-controlled compared to applications like Magnetic Resonance Imaging, where LDMOS transistors are also used, it still presents challenges.

3. The components of a meal demonstrated by Goji can be cooked simultaneously. *(Source: Goji Food Solutions)*

The ability to vary their RF output power level allows solid-state devices to provide much more precise application of energy, and as they are also frequency agile, solid-state RF power amplifiers can be tuned to the meet the conditions of the load (that is, the target material). These characteristics are essential, as cooking inherently produces widely varying loads caused by changes in the properties of the food during the cooking process.

In addition, by sweeping the frequency range of the output, hot and cold spots within the material can be uniformly targeted. The switch-mode power supplies for amplifiers based on LDMOS RF power transistors are also far smaller, more reliable, and operate at tens of volts versus the thousands of volts required by magnetrons. For a given RF output, a solid-state amplifier is typically half the weight of one using a magnetron, and unlike magnetrons there is no need for complex electromechanical controls and sequencing.

WHAT'S COOKING

Israeli company Goji Food Solutions has made huge strides in creating the basis for a modern cooking appliance based on solid-state power sources, with a portfolio of hundreds of patented techniques, including software and solid-state heating modules. The environment within an oven is extremely complex with millions of points representing an entire oven and food, and varies with what's being cooked. This is why it's necessary to assess this environment in real time as the process unfolds, something a magnetron-based microwave oven cannot do.

A Goji-based oven uses a proprietary software tool it calls SARA that combines information about RF parameters is collects every 2 s with a priori data about food characteristics, in order to make decisions. There are no limitations on what can be placed in a Goji-based oven, such as utensils like forks and other metal items as well as metallic-coated cups.

The oven can cook an entire meal, such as a steak, vegetables, a potato, and a dinner roll *(Fig. 3)*. As Goji has frequently demonstrated, it can cook a frozen fish embedded in a block of ice with precision—without melting the ice. The company hopes to have its first product for commercial applications this year, with consumer versions to follow, and it licenses the technology as well. While the company has not yet introduced the product itself, it is licensing it to appliance manufacturers for use in their own products.

The first consumer RF cooking appliance that uses Goji's technology (which it calls M-Chef technology in its own product) was introduced by German high-end appliance manufacturer Miele. The product *(Fig. 4)*, which it calls the Dialog oven (as it communicates with the food) was demonstrated with huge fanfare at IFA, Europe's largest trade show, in August. It will reach the German and Austrian markets in April, followed by the U.S. later in the year. The Dialog is big in its current configuration as a wall oven, but as it's the first of its kind, the

(Continued on page L20)

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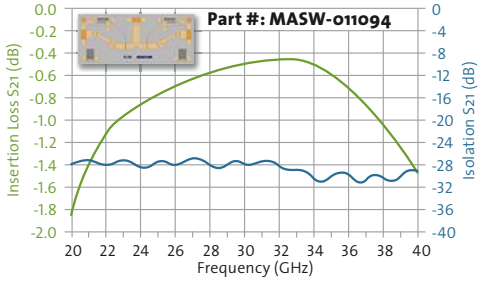

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(Continued from page L17)

implementation of higher functional integration and other advances as the market grows should allow size (and cost) to come down.

With a retail price of $10,000, the average consumer is obviously not the target market, but the Dialog oven represents what RF cooking appliances are likely to become for the broad market in the coming years. It combines solid-state cooking with steam and an electrical heating element and convection to deliver the benefits of each technology, while providing features such as a smartphone app that performs a variety of functions.

Miele says the Dialog oven reduces cooking time compared to conventional methods by up to 70%, and for example can cook pulled pork in 2.5 hr. versus 8 hr. for a conventional oven. As an example of what the Dialog can do, Miele suggests placing a leg of lamb on a bed of vegetables consisting of red peppers and green asparagus, with any remaining space consumed by potato wedges. After about 45 min., all the food will be evenly cooked to its different requirements, with the vegetables "slightly al dente" and the potatoes soft. This obviously couldn't be achieved in a microwave oven or even a conventional oven. When roasting is required, the oven automatically applies radiant heat.

The Dialog also pays tribute to the current trend toward "appliance connectivity." The oven will come with an updated version of its Miele@mobile smartphone app for Android and iOS that, along with food preparation videos and shopping lists, allows the parameters of a recipe to be transferred to the oven, and also allows the progress of cooking to be monitored from the phone (among other features).

The other RF cooking appliance currently available is the IBEX One created by the $14 billion manufacturing behemoth Illinois Tool Works (ITW), whose many divisions encompass everything from reflow chambers to consumer packaging and professional kitchen products through its Vulcan, Wolf, and Hobart subsidiaries. Hobart was an investor in Goji.

The IBEX One has a retail price of $18,000 and is designed for professional kitchens. It measures 26.6 in. high × 32 in. wide × 29 in. deep, and uses a real-time, adaptive, heat-sensing system that uses heating algorithms designed for custom menus and common kitchen operations. Programming and uploading of recipes and unique cooking functions is available via a USB port to expand menu offerings.

While these two products represent the entirely of the current RF cooking market, they're not likely to alone for too long. Chinese appliance manufacturer Midea is developing its Semiconductor Heating Magic Cube *(Fig. 5)* in partnership with NXP Semiconductors, which has been the most active semiconductor company in bringing RF cooking to fruition. The Magic Cube, which was announced last year at IFA, uses NXP's MHT1004N LDMOS RF power transistor and accompanying RF cooking module to produce a 300-W countertop appliance.

The major white goods manufacturers are also interested, as is the RF Energy Alliance, (which champions the use of RF and microwave technology for commercial, consumer, and industrial appliance lists), along with Midea and Miele, Whirlpool, Panasonic, and Cellencor as members. AFT Microwave, Ampleon, Anaren, Huber + Suhner, MACOM, Passive Plus, and Rogers represent the microwave industry. mw

4. Miele's Dialog oven provides some insight into what RF cooking appliances might become once the cost comes down. *(Source: Miele, Inc.)*

5. Midea has been working with NXP Semiconductors to create a mass-market RF cooking appliance. *(Source: Midea)*

CHRIS DeMARTINO | Technical Editor

2017 *Microwaves & RF* SALARY & CAREER REPORT

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

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

A CALL FOR YOUTH

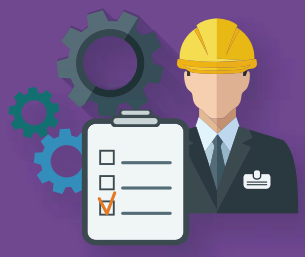
The striking similarities between the results from this year with the results from the last two years reveal another significant aspect of the industry. Specifically, 55% of respondents were age 55 and older in 2015. Last year, 40.2% of respondents were age 60 and older, while 44.2% of respondents in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

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

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

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

THE TYPICAL ENGINEER



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

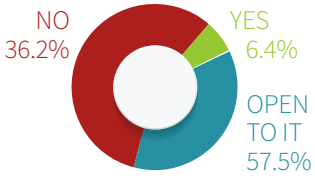
COMPENSATION

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

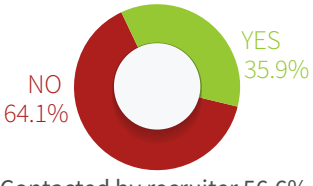
- SALARY INCREASE 53.4%
- SALARY DECREASE 13.6%
- SALARY EQUAL 32.9%

EMPLOYMENT OUTLOOK

Actively seeking a new position



Focused on employee retention



Contacted by recruiter 56.6%

YEARS IN THE PROFESSION

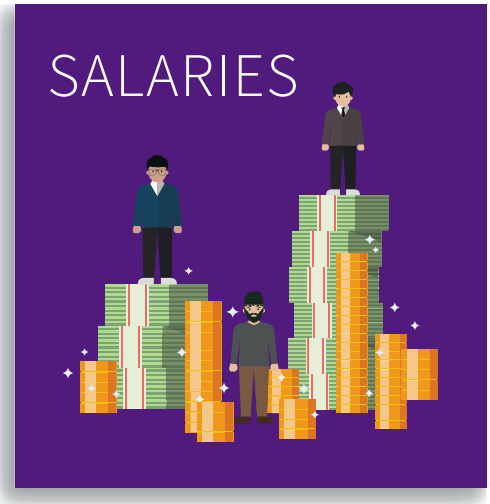
Less than 1 year	1.3%
1-4 years	3.2%
5-9 years	5.1%
10-14 years	4.5%
15-19 years	6.8%
20-24 years	9.6%
25-29 years	11.1%
30-34 years	20.2%
35-39 years	16.1%
40 years or more	22.2%

WORK LOCATION

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

YEARS AT PRESENT COMPANY

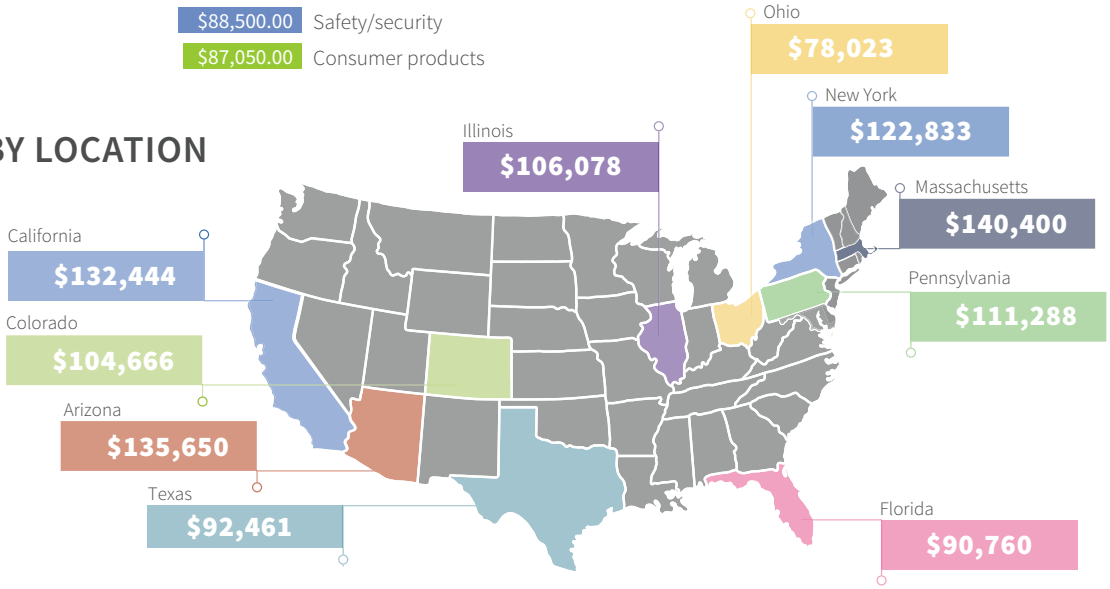
Currently unemployed	1.5%
Less than 1 year	8.1%
1-4 years	21.6%
5-9 years	17.6%
10-14 years	13.7%
15-19 years	11.6%
20-24 years	7.7%
25-29 years	5.5%
30-34 years	5.5%
35-39 years	4.5%
40 years or more	2.5%



BY INDUSTRY

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

BY LOCATION

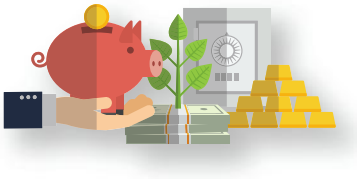


BY EXPERIENCE

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

BY JOB

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



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EMAIL | microwave@teledyne.com
TEL | 800-832-6869

YOUR SINGLE SOURCE FOR ALL THINGS MICROWAVE

For decades, the companies that now compose Teledyne Microwave Solutions (TMS) have been industry leaders in their own right, delivering sophisticated microwave product lines for the most demanding applications in many global markets. Over time, as these organizations became members of the Teledyne Technologies Inc. family of companies, they began to collaborate to deliver superior products and services as one entity: Teledyne Microwave Solutions. That collaboration has created new products ranging from remote body scanners to radar- and threat-detection systems to ultra-compact satellite communication amplifiers. We believe the alignment of our unsurpassed R&D, manufacturing, and support capabilities with the industry's most important, emerging trends makes TMS the logical "go-to" provider for your most demanding needs. With manufacturing sites and localized customer support spanning six continents, there is no challenge too great, no hurdle too high, to prevent us from delivering the best microwave solutions by working closely with our customers.

WITHIN OUR MULTIPLE MANUFACTURING SITES and their Clean Rooms, Machine Shops, Chemical and Analytical Labs, and other facilities, TMS possesses a comprehensive array of microwave manufacturing capabilities. Broadly defined, those capabilities include Hybrid Assembly, Environmental Testing, Laser Cutting, Autoclave Bonding, Element Evaluation, Inspection & Calibration, Bare Board Testing, HARASS (Highly Accelerated Rapid Stress Screening), Quick Turnaround Prototyping, Thermocompression Bonding, RF Test to 50 GHz, and State-of-the-Art Processing Equipment.

WE DELIVER THE most advanced microwave solutions to leading companies in multiple markets, including Aviation, Communication, EW/ECM/IED, Radar, Missile & UAV, Space, Satcom, and Test and Measurement. We collaborate closely to produce custom configurations or off-the-shelf solutions, including an extensive Amplifier/SSPA product line, TWTs, Filters, Receivers, YIG products, Microwave PCBs, MMIC Packaging, Integrated Assemblies, and components.

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Everywhereyoulook™

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Your Single Source for Advanced Microwave & RF Technologies

From microwave components to integrated assemblies, Teledyne Microwave Solutions (TMS) brings 50+ years of experience to the design, development, and manufacture of advanced microwave technologies.

SSPAs | Modems | Mixers

Receivers | Detectors

HPAs | Converters

Linearizers | Synthesizers

Integrated Assemblies

Circuit Board & Packaging

TWTs | Space | SATCOM

Filters | Amplifiers | YIG & BAW

Components | Isolators & Circulators

Attenuators | Value Added Services

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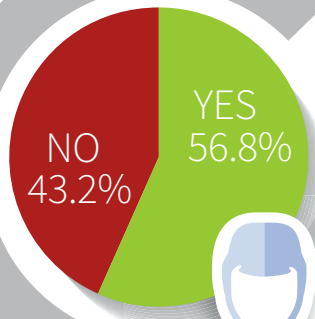
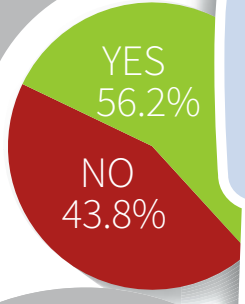
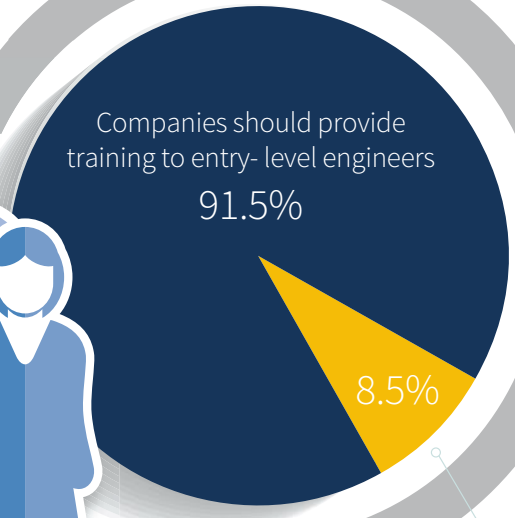
ENGINEERING LABOR FORCE

Is there an engineering shortage?



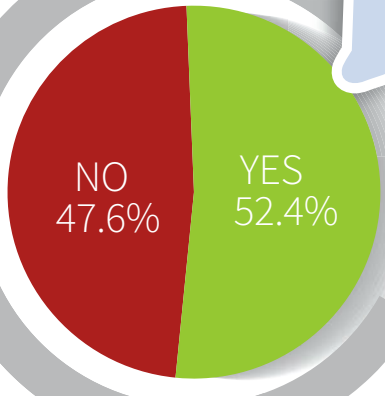
Do you think that engineering students are learning the right skills?





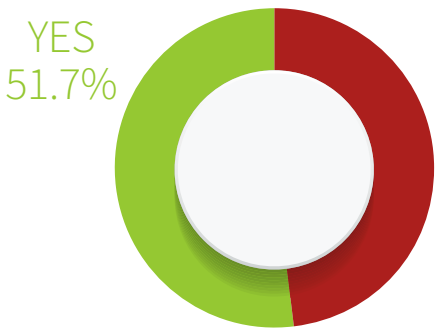
Companies should only hire skilled engineers

Do you think that companies should provide training to entry-level engineers - or only hire engineers that have already learned those skills?

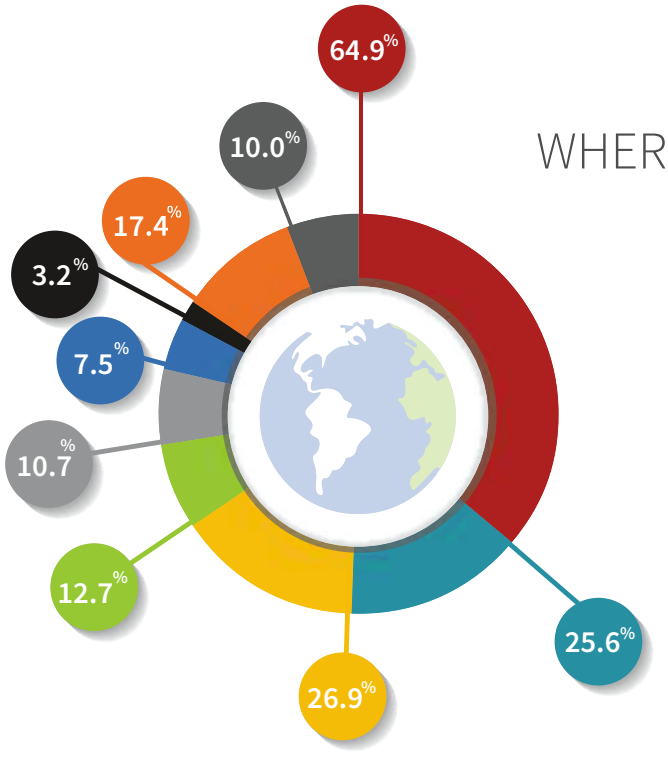


Do you find workers right out of school are bringing new skills to your company?

DOES YOUR COMPANY OUTSOURCE?

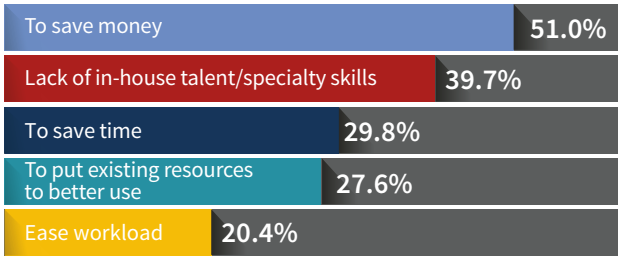


WHERE ARE JOBS GOING?



- OTHER LOCATIONS IN THE U.S.
- INDIA
- CHINA
- PACIFIC RIM
- OTHER COUNTRIES
- CANADA
- SOUTH AMERICA
- EUROPE
- MEXICO

REASONS FOR OUTSOURCING



WORK BEING OUTSOURCED

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

DS INSTRUMENTS

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BRINGING HIGH FREQUENCY AND SIMPLICITY TO ENGINEERS ON A BUDGET

DS Instruments was founded on the idea that by utilizing cutting-edge semiconductors and innovative designs, RF devices and test equipment could be made more compact and affordable, bringing high-frequency research into the hands of a wider audience. We have been developing equipment that provides universities, defense projects, and communications engineers intuitive, compact solutions at an amazing price point. Being an American manufacturer, we stand by our warranty. From concept to the day of shipment, we are 100% responsible for our devices and proudly outsource nothing. As a young, flexible small business, our engineering cycle is extremely fast-paced, resulting in cutting-edge semiconductors powering our products within months. Device customization and additional features are happily welcomed and refreshingly affordable.

FLEXIBILITY SETS US APART

OUR AFFORDABLE DUAL-CONTROL devices combine industry standard SCPI remote operation with simple and intuitive standalone front panel controls. DS Instruments currently specializes in developing compact signal generators, programmable digital attenuators, power meters, RF gain blocks, and phase shifters, with new products released regularly. Visit us online for updates!

2018 AND THE FUTURE

THE COMING YEAR will be even more exciting than the last for DS Instruments. Releasing to market new products and updated versions including: Ku-band amplifiers, a 12-GHz USB scalar network analyzer, new integrated-LO mixers, and Ethernet-enabled signal generators. Call us for a quote!

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Wideband Microwave Source

- Output covering 60MHz - 24GHz
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- Front control buttons and display
- Ultra-low phase noise (-94dBc@10K)
- Simple Windows control software
- Standard SCPI remote commands
- Compact and portable at 4 inches wide!

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Ku-Band Digital Attenuator

- Frequency Band: 1GHz - 18GHz
- Up to 60dB attenuation in 0.5dB steps
- USB powered / SCPI command support
- User display and step buttons
- Laser-etched aluminum construction
- Premium SMA connections
- Simple PC control application
- Stress-tested for absolute reliability!

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20GHz Integrated-LO Mixer

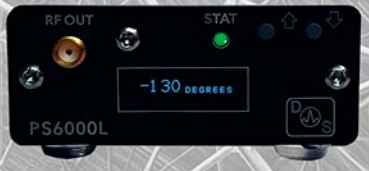
- 12 - 22GHz internal programmable LO
- Mixer RF 11-20GHz, IF up to 4GHz
- USB powered and controlled
- Compact aluminum enclosure
- Low phase noise and conversion loss
- 6&12GHz versions also available
- Extremely cost and space efficient!

Only $1149.00

Ku Signal Generator

- 12GHz - 22GHz Output (band 3)
- 25MHz - 6GHz Output (band 1)
- Internal / external 10MHz reference
- USB powered / automated control
- Bright OLED display and buttons
- High RF power output
- Incredibly portable!

Only $1049.00



6GHz Active Phase Shifter

- Covers 400MHz - 6GHz
- 1/2-degree phase resolution
- Full 360-degree range
- Output power from -20 to +10dBm
- USB powered / controllable
- Bright mini-display and step buttons
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Parsippany, NJ 07054

Wireless Telecom Group, Inc., comprised of Boonton Electronics, CommAgility, Microlab, and Noisecom, is a global designer and manufacturer of advanced RF and microwave components, modules, systems, and instruments. Serving the wireless, telecommunication, satellite, military, aerospace, semiconductor, and medical industries, Wireless Telecom Group products enable innovation across a wide range of traditional and emerging wireless technologies. With a unique set of high-performance products including peak power meters, signal analyzers, signal-processing modules, LTE PHY and stack software, power splitters and combiners, GPS repeaters, public safety monitors, noise sources, and programmable noise generators, Wireless Telecom Group supports the development, testing, and deployment of wireless technologies around the globe.

BOONTON ELECTRONICS is a leader in high-performance RF and microwave test equipment for radar, avionics, electronic warfare, satellite and wireless communications, and EMI/EMC applications. Used across the semiconductor, military, aerospace, medical, and communications industries, Boonton products enable a wide range of RF power measurements and signal analysis for RF product design, production, maintenance, and system integration. The Boonton product portfolio includes peak and average RF power meters, Real-Time USB Power sensors, RF voltmeters, modulation analyzers, and audio analyzers.

COMMAGILITY is a developer of embedded signal processing and RF modules, and LTE PHY/stack software, for 4G and 5G mobile network and related applications. Combining the latest DSP, FPGA, and RF technologies with advanced, industry-leading software, CommAgility provides compact, powerful, and reliable products for integration into high-performance test equipment, specialized radio and intelligence systems, and R&D demonstrators. CommAgility engineers work closely with customers to provide hardware and software solutions for the most demanding real-time signal processing, test and control challenges in wireless baseband, semiconductor processing, medical imaging, radar, and sonar applications.

MICROLAB is a leader in low PIM (passive intermod) RF and microwave products enabling signal distribution and deployment of in-building DAS (distributed antenna systems), wireless base stations, and small-cell networks. High-performance passive components such as power combiners, directional couplers, attenuators, terminators, and filters are developed for broadband applications to support public safety networks, GPS reference signaling, television transmitters, and aircraft landing systems. Active solutions from Microlab include GPS signal repeaters for cellular timing synchronization and passive safety monitors for real-time in-building DAS system diagnostics.

NOISECOM is a leader of RF and microwave noise sources for signal jamming and impairment, reference-level comparison and calibration, receiver robustness testing, and jitter injection. Electronic noise-generation devices from Noisecom come in a variety of product types, including noise diodes, built-in-test modules (BITE), calibrated noise sources, jitter sources, cryogenic noise standards, and programmable instruments. Calibrated noise sources are available from audio to millimeter wavelengths in coaxial or waveguide modules. Programmable instruments are highly configurable and able to generate precise carrier-to-noise, signal-to-noise, and broadband white noise. Noisecom products are customizable to meet the unique needs of challenging applications and can be designed for high power, high crest factor, and specific filter responses with a wide selection of input and output options.

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As a global provider of noise generators, modules, diodes and specialized test solutions we are ready to meet your present needs, as well as address your future applications.

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- Millimeter Wave Point-to-Point
- Satellite Communications (BER, Eb/No)
- Wireless (WiFi & LTE-A)
- >60 GHz Noise Figure
- Serial Data Compliance (Jitter, Rj)
- Wireless HD Testing
- Receiver & Antenna Calibration

Wireless Telecom Group
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Noisecom

JOB SATISFACTION

HOW SATISFIED ARE YOU IN YOUR JOB?

24.3%	Extremely Satisfied
32.9%	Very Satisfied
33.6%	Satisfied
7.3%	Not Very Satisfied
1.9%	Not At All Satisfied

MOST IMPORTANT FACTORS IN JOB SATISFACTION

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

[Based on a scale of 1 to 10]

REASONS ENGINEERS WOULD LEAVE THE PROFESSION

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

Recommend Engineering?

Feeling Challenged?

YOUR EDUCATION

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

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

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

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

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

NETWORKS INTERNATIONAL CORP.

Founded 1986

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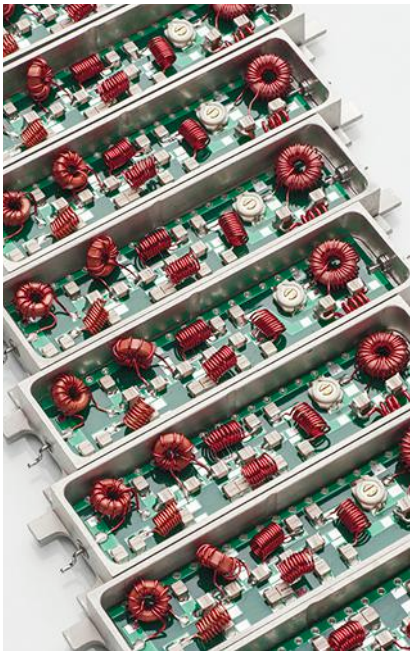
Overland Park, KS 66223

CUSTOM RF & MICROWAVE SOLUTIONS FROM DC TO 40 GHZ

Networks International Corp. (NIC) is a leading manufacturer of radio-frequency and microwave filters and assemblies that provides custom solutions for advanced communications systems. For over 30 years, NIC has partnered with its customers to transfer value through superior engineering design, manufacturing, and continuous support. NIC is a small business that serves the Military, Space, and Commercial markets. The company's heritage lies in the military market, where precision, high reliability, repeatability, and service are mission-critical.



Typical applications for NIC's products include communications, navigation, guidance, surveillance, point-to-point and multi-point radio systems, radar systems, and satellite systems.

NIC's product portfolio includes crystal filters, ceramic filters, cavity filters, LC filters, multiplexers & diplexers, TCXOs & VCXOs, switched filter banks, phase shifters, filter/amplifiers, filter/limiters, and low-noise amplifiers (LNAs).

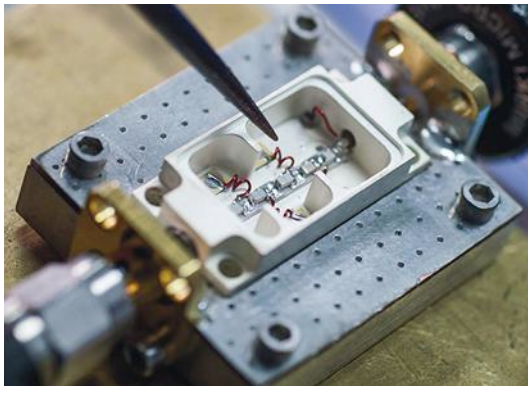
CAPABILITIES & TECHNOLOGY

NIC IS A vertically integrated company that maintains all assembly and testing in its 15,000 sq. ft. facility. NIC operates an advanced in-house suite of environmental testing that is compliant with MIL-STD-202, MIL-STD-883, as well as space-level screening.

NIC has consistently incorporated industry-leading design techniques and technologies to create practical, cost-effective, and repeatable solutions. NIC's staff engineers have >100 years in RF design experience and are staffed to provide quick-turn prototypes.

PRODUCT FOCUS: LOW-PROFILE LC BANDPASS FILTER

NIC INTRODUCES A low profile LC bandpass filter centered at 8000 MHz with a bandwidth of >50%. This filter offers low insertion loss of <1 dB @ Fc, high selectivity of 50 dBc in adjacent bands, and a compact package size of 0.90" x 0.30" x 0.10". Exceptional electrical performance in a small-profile package makes this filter a perfect fit for many X-band applications. Custom designs are available upon request.



NIC

Networks International Corporation

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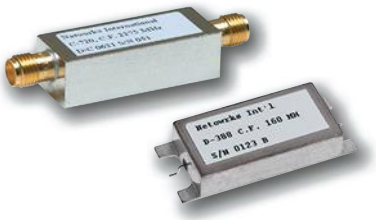
NIC

www.nickc.com

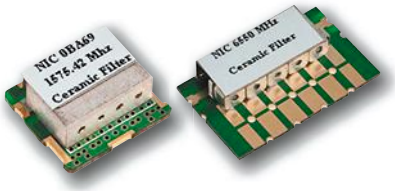
- Innovative Solutions: DC-40GHz
- 3-4 Week Prototype Delivery
- Preferred Supplier to Major OEMs
- 30+ Years of Success

LC Filters

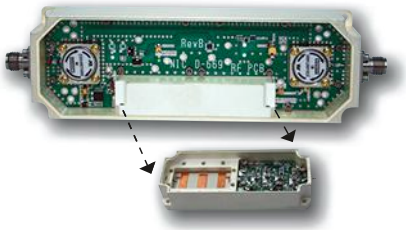


Discrete & Monolithic Crystal Filters

Ceramic Filters

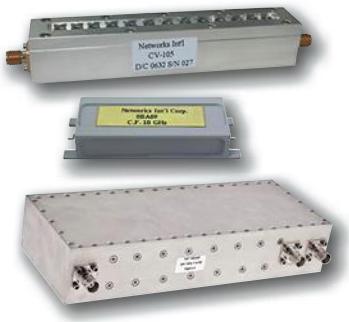


Integrated Assemblies



Switch Filter Banks

Cavity Filters & Diplexers



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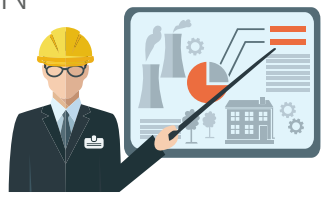
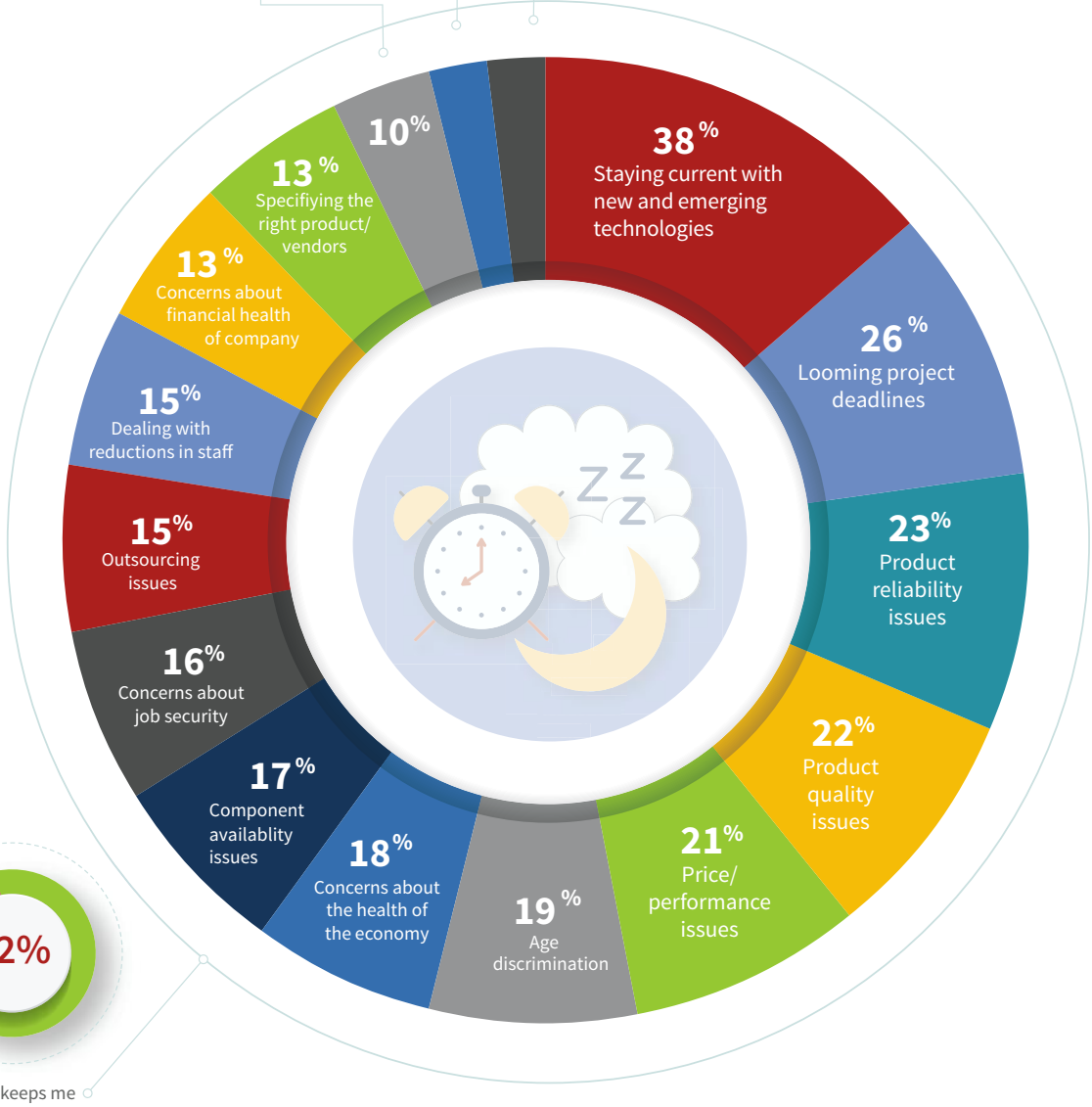
WHAT'S KEEPING ENGINEERS UP AT NIGHT?

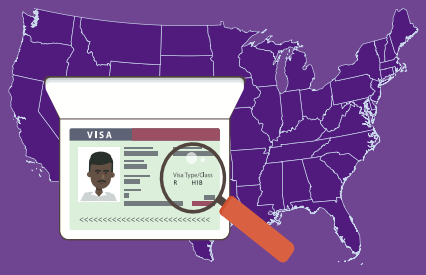
TOP CONCERN

38% Staying current with new and emerging technologies





ENGINEERING AND SOCIETY



DOES YOUR COMPANY HIRE EMPLOYEES ON H1-B VISAS?

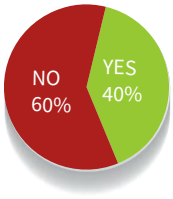
YES 37.2%

NO 62.8%

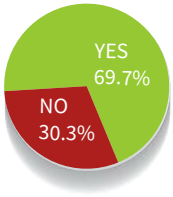
DOES H1-B HURT EMPLOYMENT OPPORTUNITES FOR ELECTRICAL ENGINEERS IN THE UNITED STATES?

YES 57.9% **NO 42.1%**

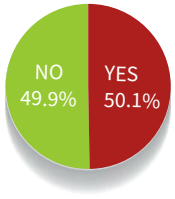
Are you worried about President Trump's trade policy, including his decision to withdraw from the Trans-Pacific Partnership and renegotiate the North American Free Trade Agreement?



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



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



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

YES 42.6%

NO 57.4%

68.6% YES

31.4% NO

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

JACK BROWNE | Technical Contributor

Managing the Coexistence of Multiple Wireless Systems

Many different wireless communications standards must often operate within the same frequency spectrum, requiring guidelines to allow them to work effectively with each other.

COEXISTENCE REFERS TO the functioning of different wireless devices and standards in the same frequency band. The various IEEE 802.11 wireless standards, for example, are packed into the 2.4-GHz unlicensed Industrial-Scientific-Medical (ISM) frequency band. IEEE 802.15.4 wireless sensor networks share the 2.4-GHz ISM unlicensed frequency band. Bluetooth is yet another wireless standard operating in that same frequency band.

While it be ideal to have different frequencies for each wireless standard, as with radio and television broadcast channels, frequency spectrum is limited. The growing number of wireless standards makes it difficult, if not impossible, to allocate separate frequency spectrum for each standard. In addition, new applications being added to the same crowded frequency spectrum, such as Internet-of-Things (IoT) wireless devices and machine-to-machine (M2M) devices in the 2.4-GHz ISM band, make the task of achieving wireless coexistence even more challenging.

Interference from intentional or unintentional electromagnetic (EM) radiators can disrupt the operation of wireless devices in the same or adjacent frequency bands. Interference can result in lost data, poor voice quality, and decreased operating range, depending upon the type of wireless device. Wireless devices may be designed for point-to-point communications; for access to a cellular base station; for communication to a satellite; or access to a network node, such as a wireless local area network (WLAN). Multiple devices must operate within the same or closely spaced frequencies without interfering with each other.

The ISM band is just one portion of the frequency spectrum in which spectrum sharing takes place. Coexistence issues can impact all different wireless applications in all market areas, including military, medical, and automotive applications, as well as in commercial electronics. Regulatory organizations such as the Federal Communications Commission in the United States are responsible for establishing acceptable transmitter standards for both licensed and unlicensed frequency spectrum. But when multiple wireless standards occupy the same portion of frequency spectrum, it is possible for one standard to comply with regulatory limits and still interfere with another wireless standard in that same frequency spectrum.

THE ROAD TO COEXISTENCE

Achieving coexistence among wireless standards starts with the design of the wireless protocol, such as the various IEEE standards for IEEE 802.11 WLANs, but then relies on modeling, design, and testing to ensure that a wireless product will operate as expected in the presence of existing wireless devices and networks. Device and circuit modeling can ensure proper electrical performance for a given set of circuit elements and parameters, but modeling for wireless coexistence is performed at a different level—more in terms of the operating environment.

Accurate models for wireless coexistence must anticipate the total number of radiators within a frequency band of interest and the waveform types for each. But they also must take into account the emissions that may occur as the result of second- and third-harmonic signals from lower-frequency sources that may fall within the band of interest, assuming they are at sufficient power levels to interfere with the subject of the modeling procedure.

Lessons learned from system-level modeling of a wireless operating environment can provide guidance on possible modifications for a prototype wireless product in preparation for achieving wireless coexistence. By modeling a device for electromagnetic compatibility (EMC), for example, the effects of both internal and external EM sources can be studied on the performance of the device.

A prototype wireless radio device may suffer excessive signal leakage from its local oscillator (LO), causing unintended EM emissions to reach the same device's antenna and resulting in self-interference with that device. Or instability in the LO may cause a shifting of that device's operating bandwidth, leaving it susceptible to interference from signals in adjacent frequency bands. Device and circuit modeling can help identify such problems at the device/circuit design stage, prior to modeling the device within the wireless operating environment for its capability to operate while surrounded by other EM sources.

Testing a prototype design for its own internal sources of radiated interference can be challenging, since even low-level leakage from a signal source such as an LO can couple to a nearby amplifier and result in EM energy that can be received by the device's own antenna. Isolating and measuring such internally generated interference requires eliminating the measurement of external sources of radiation, from outside emitters, and this can require the extreme of testing within an anechoic chamber.

Because of differences in transmission format among wireless standards (such as modulation), wireless coexistence especially in shared spectrum requires that a device with one transmission format not be affected by another device operating at the same frequency, but in a different transmission format. Test signals should be carefully chosen for wireless coexistence testing.

While a simple continuous-wave (CW) test signal can check the basic operation of a radio's performance, the device should be tested with waveforms representing both devices like it and other wireless devices with different transmission formats that are sharing the same spectrum. Resistance to these other waveforms sharing the same spectrum can reveal a great deal about the capabilities of a wireless design to operate effectively while surrounded by nearby EM emissions.

CREATING COEXISTENCE

Obviously, with the steady growth of wireless applications, and only limited frequency spectrum, wireless coexistence is an ongoing issue for radio designers in all application areas. In some operating environments, such as for medical electronic equipment in hospitals, failure to achieve wireless coexistence can be life-threatening. The frequencies and bandwidths may change, such as the millimeter-wave frequencies used for automotive radars and safety systems, but each part of the spectrum contains its own sets of interference issues and challenges for coexistence.

Circuit designers are increasingly aware of wireless coexistence as a design requirement, and such technologies as software-defined radios (SDRs) and cognitive radios provide the capabilities to dynamically change a radio's operating parameters in response to problems posed by interference in the operating environment.

As an example of a transceiver designed for coexistence, Mercury Systems *(www.mrcy.com)* recently introduced its Ensemble DCM-MU-4R2G-2T3G low-latency transceiver nominally for electronic-warfare (EW) applications. It can be applied as much for contested military signal environments as for congested commercial communications signal environments.

The Ensemble transceiver was designed according to OpenVPX high-speed interconnectivity standards for maintaining high performance in battlefield environments with potentially hostile signal threats, but it is also constructed according to the same requirements as shared spectrum within a congested signal environment. The transceiver is optimized for low probability of intercept (LPOI) RF signal detection in heavily contested and congested signal environments. It uses a multiple-channel, multiple-board configuration to instantly detect occupied (and available) bandwidth and respond by generating a timely response in terms of transmitting on available spectrum.

This transceiver follows a design trend established by SDRs, with heavy reliance on high-speed data converters for achieving flexible programmability in the realization of the radio transmit and receive functions. It incorporates four high-speed analog-to-digital converters (ADCs) sampling at 2 GSamples/s, with an option for two ADC channels operating at rates to 4 GSamples/s. On the transmit site, two low-latency digital-to-analog converters (DACs) operate at sampling rates to 3 GSamples/s to produce transmit waveforms types and frequencies as dictated by available spectrum.

To encourage SDR-based radio designs capable of dynamically achieving wireless coexistence even within a crowded portion of the spectrum, such as the 2.4-GHz band, manufacturers such as Pentek *(www.pentek.com)* and Texas Instruments *(www.ti.com)* offer free downloadable design handbooks and also designer's kits. These kits provide board-level SDRs with all components in place—including high-speed ADCs, DACs, and digital-signal-processing (DSP) integrated circuits (ICs)—for tuning and testing when developing a programmable radio design that can adapt to a changing EM environment, whether in the shopping mall or on the battlefield. mw

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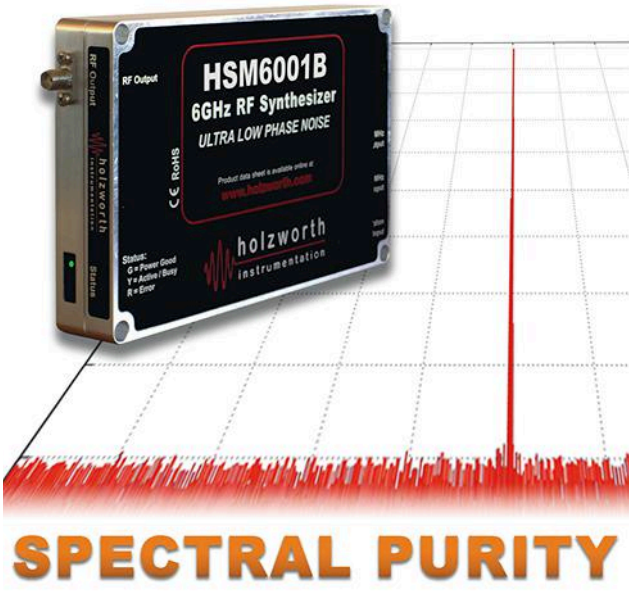

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- Switching Speed: 6 µs to 100 µs (0s settling time)

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- 1GHz Phase Noise: –142 dBc/Hz (10 kHz offset)
- Spurious: < –85 dbc
- Output Dynamic Range: –110 dBm to +20 dBm

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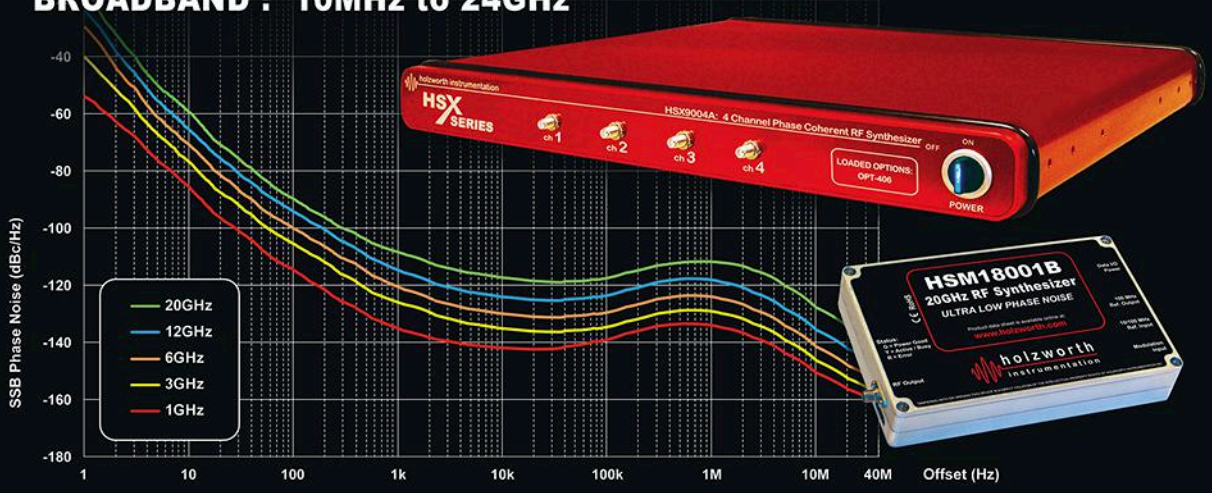

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How Smart Homes Can Deliver Sustainability as a Service

Smart-home services have the potential to impact households in a profound way.

WITHIN JUST THREE years, it's estimated that as many as five billion people and 50 billion devices could be connected. While those numbers alone are impressive, it's the potential of that connectivity to improve many aspects of our lives (including the health of our planet) that's truly eye-opening.

Many discussions surrounding the smart home focus on benefits that can be realized by the people living in them. But a truly smart, connected home—one that can independently assess and respond to real-time requirements for power, water, heating, and similar resources—is able to promote sustainability. In addition, it can avoid serious damage to the home by independently identifying waste and avoiding spillage.

The introduction of highly power-efficient chips that support multiple communications protocols—e.g., IEEE 802.15.4, ZigBee 3.0, Thread, and Bluetooth Low Energy (BLE)—is rapidly driving advances in smart-home networking.

1. These are the types of events and behavior patterns that a smart home will track and learn from to recognize what is going on in the home.

But in order to realize the environmental benefits of smart-home technology, we must first understand what a smart home really is (not just a collection of connected devices) and have insight into what consumers want from a smart home (services).

WHAT IS A SMART HOME?

Too often, the words "smart" and "connected" are used interchangeably when discussing the devices that power the Internet of Things (IoT). But they are not the same. Many of today's devices are essentially internet-enabled remote controls that require human action to be turned on and off.

The term "smart" implies intelligence with decision-making capabilities. A smart device and application can analyze incoming data and make a decision to control or activate a device without human intervention.

In the context of the home, "smart" refers to a network of sensors in the house that measures and monitors the environment. The network senses who is in the home, where they are in the home, and what the "normal" activity is in the home at that particular day and time.

By using intelligence and information that the system has learned about the residents, it makes decisions about whether to lock doors and windows; turn on or off the heater, air conditioner, lights or entertainment systems; activate the security system; and more *(Fig. 1)*.

For example, if a family was streaming a movie on a hot summer night, a smart-home system would turn off the lights and turn down the A/C in the empty parts of the home. In addition, if power-consuming devices are on but not in use, such as a computer or gaming console, the system turns those off as well.

After the family goes to bed, the system can then turn off the A/C or heating in the unused areas and keep it on only in the areas where people are sleeping. Since many people prefer cooler temperatures for sleeping, the system could be smart enough to slowly reduce the temperature at night and then raise it again in the morning. It could further reduce energy consumption by anticipating the falling outside temperature during the night.

The network learns from the people who live in the home to make predictions about future behaviors. It knows the number of household members, how rooms are used and when, bedtimes, who works from home and where, who gets up early, etc. Patterns are absorbed by the system and used to enhance comfort and convenience settings. These settings are also cost-saving and have the potential to significantly reduce energy consumption.

This type of sophisticated smart-home network requires specific capabilities:

1. It must connect to and communicate with other smart or connected devices in the home.
2. It must be intelligent, recognize what goes on in the home, and learn what is normal.
3. Residents must be able to manage functions with a single integrated application on a smartphone or other web-connected device.

Smart devices are essential to what consumers really want—namely, services. A 2016 study showed that consumers are not interested in simply having a bunch of connected devices that remotely control various things in the home. They desire services, and having these services without the hassle of investigating, purchasing, installing, and maintaining a system of disparate connected devices. In short, consumers want a smart home as a service.

WHAT IS SHaaS?

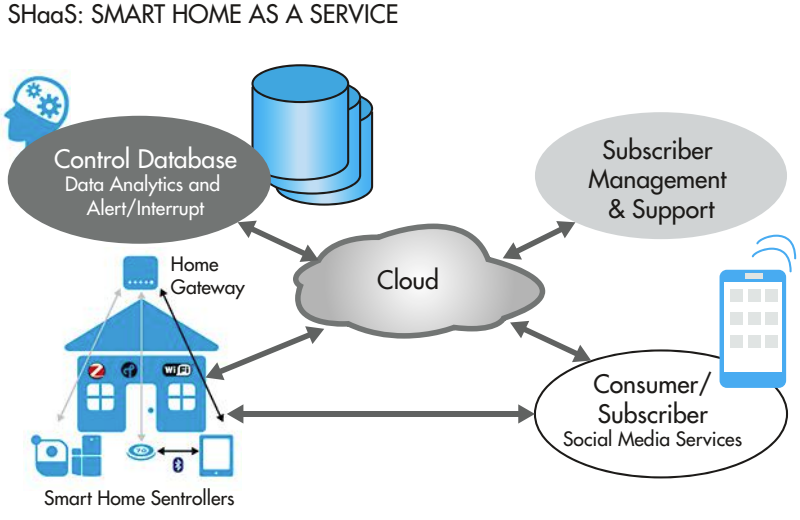
Smart Home as a Service (SHaaS) is a collection of services that analyzes input from the smart home's sensors, learns how the family lives and how the home is used, and can make intelligent decisions to make homes more comfortable, safe, and energy-efficient *(Fig. 2)*.

Instead of a consumer having to decide which hardware and software options or which wireless technology to implement in their home, they can simply leave it up to the providers of services they already use (e.g., internet access, security, and entertainment).

By opting for SHaaS, consumers don't have to be technologically savvy or care about the underlying wireless technology. Having one provider responsible for installation, setup, and management of the network makes it much faster to implement services, add new services, and ensure that controls and user interfaces are unified.

This is how the four basic components of a SHaaS work together:

1. A network of sensors in the home provides a general indication of when and where movement occurs in the home and whether the home is secure, what the environmental conditions are, and whether there are any issues (a leak, for example).
2. The information derived from these sensors is wirelessly collected by a local hub (gateway, set-top box, etc.) and securely transmitted to an intelligent cloud service that collects and analyzes the data, and sends alerts to family members when it detects changes.
3. A central management app enables the consumer to manage the network via a smartphone or any web-connected device in a single user interface.
4. The service provider is able to easily handle customer support, billing, and subscriber management, as well as software and service upgrades and changes.



2. A Smart Home as a Service (SHaaS) system consists of multiple services that leverage input from sensors.

(Continued on page L50)

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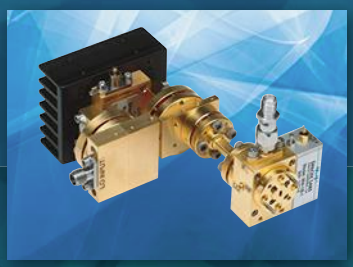

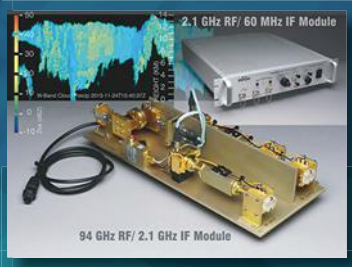

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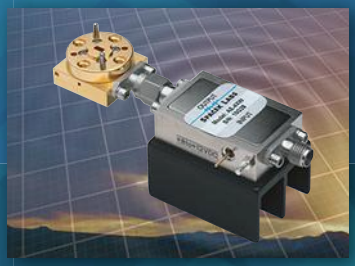

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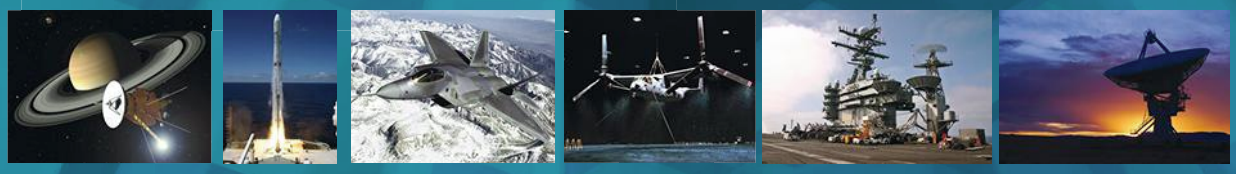

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Delta-Sigma, Inc., is a world leader in the design and manufacture of high-performance solid-state RF power amplifier modules, subsystems, and systems up to 350 kW for defense, commercial, and scientific applications. Our modular designs elegantly scale from 1-kW subsystems to the industry's highest-power, solid-state turnkey systems for fast turnaround, low system cost, reduced complexity, and exceptional reliability. And we specialize in helping our customers transition from legacy vacuum-tube amplifiers to modern solid-state designs.

OUR AMPLIFIERS SERVE APPLICATIONS INCLUDING:

- Electronic warfare
- Commercial and military communications
- Industrial RF heating
- EMC testing
- Synthetic aperture radar (SAR)
- Wind profiler radars to at least 60,000 ft.
- Particle accelerators
- Satellite communications

EXCEPTIONAL PERFORMANCE:

- Compact and lightweight
- Exceptionally reliable and rugged
- Highest efficiency: DC-to-RF greater than 70% and system AC-to-RF greater than 50%
- High linearity: Proprietary linearization circuitry delivers system-level third-order IMD as low as –91 dBc
- Rated for CW and pulsed operation
- Pulse width to 30 ns with zero droop and ringing
- Noise in receive mode near the thermal limit
- Switching speed typically less than 1 µs and isolation of 60 dB.

YOUR RF AMPLIFIER PARTNER SINCE 1995

For more than two decades, Delta-Sigma, Inc., has worked together with our customers to create some of the world's most impressive synergistic RF power amplifier systems. So please contact us with your requirements!

ΔΣ DELTA SIGMA Inc.

New! Compact 2-kW CW PA

The THEIA-H is the industry's smallest, lightest, best-performing 2-kW amplifier covering 1.5 to 30 MHz.

The new THEIA-H from Delta-Sigma, Inc. is our latest achievement in delivering high power and superb performance in a small package. Measuring only 4U high including the power supply and weighing only 57 lb., it delivers 2 kW CW from 1.5 to 30 MHz with 57% AC-to-RF efficiency. The THEIA-H is extremely rugged and designed for military communication system including QPSK, GMSK and OFDM, meteor scatter, and airborne platforms to 30,000 ft., as well as test systems and HF radar.

The amplifier has the high linearity required for digital modulation, a linearity-controlled loop for less than 0.5 dB compression at rated power, a hot-swappable amplifier module that weighs only 29 lb., and total weight of 57 lb. Extensive protection circuits are included and full control and monitoring are available via RS-232, RS-485, or Ethernet. **Can be upgraded to operate up to 45 MHz.

Frequency range (MHz)	1.5 to 30
RF output, CW (kW)	1.8, 2 typical
THD, 5 to 90% modulation (%)	<5
Gain (dB)	54
AC-to-RF efficiency at rated power (%)	57
Noise floor in transmit-disable mode (dBm/Hz)	-173
Harmonic suppression (dBc)	-10 second order -28 third order -60 with filter
Spurious rejection (dBc)	<-70
Third-order IMD (dBm)	+75
Input/output return loss (dB)	-22/-16
Phase flatness (±2 MHz BW) (deg)	<1
Maximum duty cycle (%)	100
Maximum VSWR	2:1, 30:1 with foldback
TX/RX isolation (option)(dB)	60
RX/TX switching time (option)(μs)	5, 2 typical
Prime power (VAC)	85 to 265
Control/Monitoring	RS-232 or RS-485, Ethernet
Altitude (ft.)	30,000
Dimensions (in. HWD)	7x19x20. Amplifier 5.25 H , power supply 1.25 H
Weight (lb.)	Amplifier (29), total (57)
Protection	Thermal overload, over/under voltage, temperature, fan
Monitoring	Forward/reflected power, gain, temperature, hours of operation, fan status, filter selection, BIT status, others

PLEASE CONTACT US FOR ADDITIONAL INFORMATION

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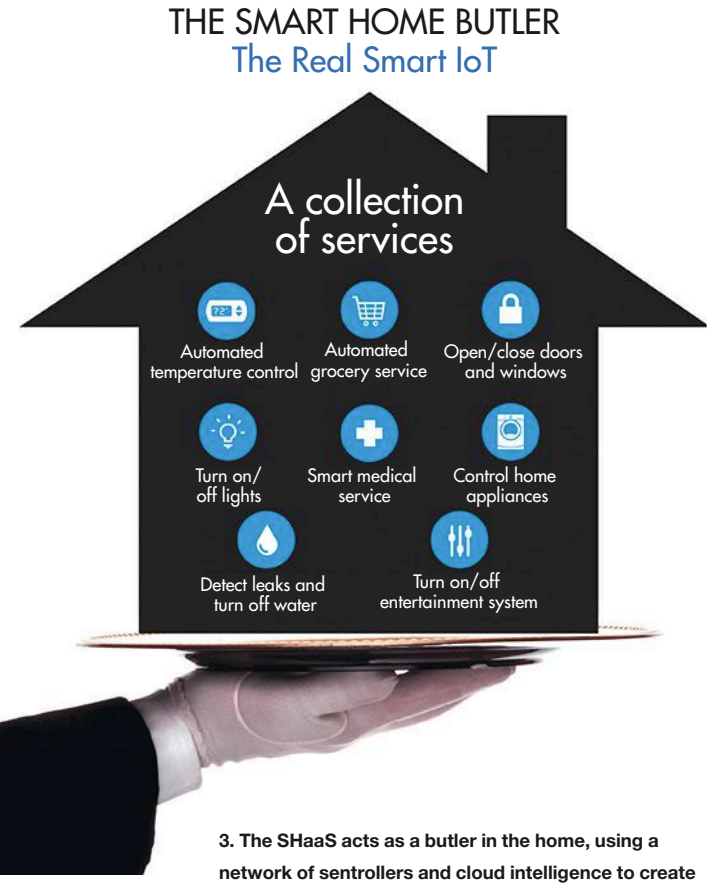
ΔΣ **DELTA SIGMA Inc.**

(Continued from page L45)

HOW CAN THE SHaaS REDUCE ENVIRONMENTAL IMPACTS?

It's easy to see how a SHaaS can increase efficiency, safety, and comfort within the home and help its occupants better manage and live their lives. But SHaaS benefits reach well beyond the walls of the home, helping to reduce the use of our planet's natural resources and our carbon footprint *(Fig. 3)*.



3. The SHaaS acts as a butler in the home, using a network of sentrollers and cloud intelligence to create an environment that benefits those who live in it—and also helps to support the health of our planet.

Water. Water conservation is one such example. Most everyone has experienced a leaking water heater. If the leak is not immediately detected, the water heater continues to run, inefficiently heating and wasting water, causing costly damage in the home, and resulting in high energy and water bills.

One fix is to install a leak detector that sends an alarm when the tank fails. But by taking that a step further and connecting that leak detector sensor to a smart-home network—one that includes actuators and controls on the power and water sources—the smart home can alert the home owner and control the power and water systems that feed it.

This same scenario applies to frozen water pipes. If the network notices that water is moving in the pipes with no one home, it can send a notice to the homeowner and turn off the water at the main valve. In daily applications, the smart home would recognize that water is flowing when no one is home, talk to the water meter, and turn off the flow.

Power. Power use is another area where the SHaaS delivers environmental benefits. A green smart home would monitor how and when power is consumed and manage power in the home based on that data. For example, the home would make sure A/C and heating systems are not in use until someone is home, and would automatically open and close window shades or curtains to adjust for the sun and the season.

The home's power-storage system can be charged during the day via solar panels on the roof, or at night when power is less expensive. That way, the home's power-hungry appliances can use "cheap" stored electricity instead of drawing from the grid during expensive rate times. These systems are already in use in industrial applications and will soon be moving to home use.

The smart-home power system can learn which devices are the worst power consumers when not in use and simply disconnect them. If the home network recognizes that the family is away on vacation, it can disconnect all devices that consume standby power.

People. A smart home can have environmental benefits in subtle ways, as well. Families with an older parent who lives alone can use the smart-home network to maintain awareness of their daily well-being without having to drive or take the bus across town, reducing CO_2 emissions.

An effective smart home makes its people smarter, too. When people are educated about how much appliances are actually costing in power, they are more likely to turn off the appliances when not in use and to be more conscientious in their use of energy.

HOME SENSORS AND ANALYTICS SUPPORT SUSTAINABILITY

On April 22, countries around the world will mark Earth Day. Our ideas about the role of home connectivity in environmental stewardship have been transformed since the first celebration of this event in 1970.

New technology, composed of sensors and analytics, is empowering smart-home solutions that learn from the people who live there. These systems use this knowledge to make predictions about future behaviors and take actions that enhance comfort and convenience, save money, and reduce environmental impacts. Smart Home as a Service enables consumers to practice sustainability and help ensure a cleaner future simply by exerting greater control over the way resources are used in their homes. mw

CHRIS DeMARTINO | Technical Editor

Driving the Future of Vehicular Technology

Electronic technologies, from basic temperature sensors to millimeter-wave radars, are playing more prominent roles in new car models.

AUTOMOBILES ARE BEING made smarter with each model year. Electronic technologies are playing major roles in enhancing vehicular safety, and that trend will continue. Cameras and millimeter-wave radar systems in newer car models, for example, can detect objects in front and rear and send warning and trigger signals to other subsystems within a car, such as the automatic braking system (ABS), to prevent an accident.

The interest of automotive manufacturers in producing fully autonomous vehicles has been well publicized, and the overall growth of electronic content within new-model automobiles represents a heartily growing market for electronic devices such as microprocessors and wireless transceivers, as well as software that can help build the road to the "driverless" vehicle of the future. But before we can all take our hands off the wheel, a better understanding of the industry's growing electronic needs is needed.

Cars are smarter due to their growing electronics content, starting with their computer networks—among them, those based on the controller area network (CAN), local interconnect network (LIN), and FlexRay protocols. The CAN protocol, for example, allows all electronic devices in an automobile to communicate. A vehicle's electronic control unit (ECU) can communicate by means of a single CAN interface, as opposed to utilizing separate analog and digital interfaces for different electronic components to save weight and complexity. The CAN protocol was first developed for automotive applications, but has been adopted by other industries (e.g., medical electronic equipment manufacturers) because of its reliability and effectiveness.

As vehicles gain more electronic content, an efficient communications and control protocol such as CAN is essential for orchestrating the sequences of messages among the networked devices. All devices on a CAN system first receive all transmitted messages from the ECU, then decide whether a message is relevant or should be filtered. Every message has a priority, and the device node with the higher priority has the opportunity to respond first. A CAN system includes cyclic redundancy code (CRC) that is used for error checking.

In addition to this communication of electronic devices within a vehicle's own network, future vehicles will also communicate with each other by means of wireless vehicle-to-vehicle (V2V) communications. A recent proposal by the U.S. Department of Transportation (DoT) outlined the benefits of V2V communications and a timeframe for its implementation in new model cars (by 2023). The proposal is under review by a number of other organizations, including the U.S. Federal Highway Administration and the Alliance of Automobile Manufacturers.

By having all vehicles communicating their locations, speeds, directions, and other parameters 10 times per second to other vehicles, all vehicles will have a 360-deg. situational awareness of the traffic volume and conditions around them (*Fig. 1*), both to avoid accidents and minimize traffic congestion.

1. The concept of vehicle-to-vehicle (V2V) communications involves a sharing of vehicular speed and location information among vehicles with V2V wireless technology, to avoid accidents as well as traffic backups. *(Courtesy of Car Talk)*

(Continued on page L56)

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A LEADING SUPPLIER OF STANDARDIZED GaAs AND GaN MMICs FOR MILITARY, AEROSPACE, AND SATELLITE APPLICATIONS

From next-generation long-range military radar systems, (including phased array and AESA radar) to advanced ground-, air-, and space- based communications, microwave signal chains are being pushed to new limits—and no one understands this more than Custom MMIC. Founded in 2006 as a fabless circuit designer, they've been entrusted by the biggest names in defense to resolve their microwave signal chain challenges with best-in-class MMIC design and manufacturing.

Today, they are a complete ISO-certified designer and supplier of active and passive MMICs through 50 GHz. They've recently invested in a new modern engineering, testing, and packaging facility, and are gaining recognition as one of the most responsive MMIC vendors in the RF and microwave industry. This new facility is enabling them to address higher volume demands and reduce lead times to better serve a growing global customer base. By turning around requests for pricing and application support quickly, and stocking evaluation boards for all their MMICs, the microwave engineering community is taking notice of Custom MMIC. Program and supply-chain managers have also been impressed, evidence to which is a recent 4 Star Supplier Excellence Award from Raytheon.

Custom MMIC has become extremely proficient in the selection of the best foundry facilities, and the GaAs or GaN processing expertise needed for each of their circuits. As a result, their application-driven line of standard products now exceeds over 120 high-performance MMICs that outperform the competition on many levels. Their continuously updated website includes fast and simple product navigation, and readily offers downloadable datasheets, S-parameter data, and a variety of technical resources.

APPROACH TO INNOVATION

CUSTOM MMIC'S APPROACH to innovation is driven by listening to customer's needs and challenges. Their system engineering focus enables clear definition of products which solve customer problems and ease the design process. Custom MMIC strives to add unique features such as positive gain slope and low phase noise in its amplifiers. The use of all positive supplies and the ability to handle high input powers are distinctive features of the company's low noise amplifiers. Working with customers enables Custom MMIC to save valuable size, weight, power and cost (SWAP-C), but sometimes even more importantly, save systems design time.

Custom MMIC

MMIC PRODUCT LINE

AMPLIFIERS: Custom MMIC's amplifier MMIC products provide industry-leading gain flatness and stability, noise figure, phase noise and linearity, and offer unique benefits such as positive gain slope, positive biasing, and 50-Ω matching. Models include low noise amplifiers (LNAs), driver amplifiers, power amplifiers, low phase noise amplifiers (LPNAs), and Broad Range distributed amplifiers.

CONTROL DEVICES: Their switching and frequency-conversion MMICs offer state-of-the-art insertion/conversion loss, bandwidth, and isolation for advanced signal chain design. These products include SPST to SP4T switches, RF phase shifters, and voltage variable attenuators.

MIXERS AND MULTIPLIERS: Their frequency control products provide the highest accuracy, along with low loss. Models include fundamental mixers, dual mixers, and I/Q / I/R mixers. And their RF multiplier MMIC family includes both passive and active solutions.

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OUR EXTENSIVE LINES of high-frequency, millimeter-wave interconnects encompass adapters, connectors, and cable assemblies that perform up to 65 GHz. Complete lines of 1.85mm, 2.4mm, 2.92mm, SMP, and Mini-SMP series products are among the largest in the industry. These product lines are also supported by a variety of components including attenuators, power dividers, terminations, waveguides, and many more. Fairview's components are in-stock, off-the-shelf, and available to ship the same day.

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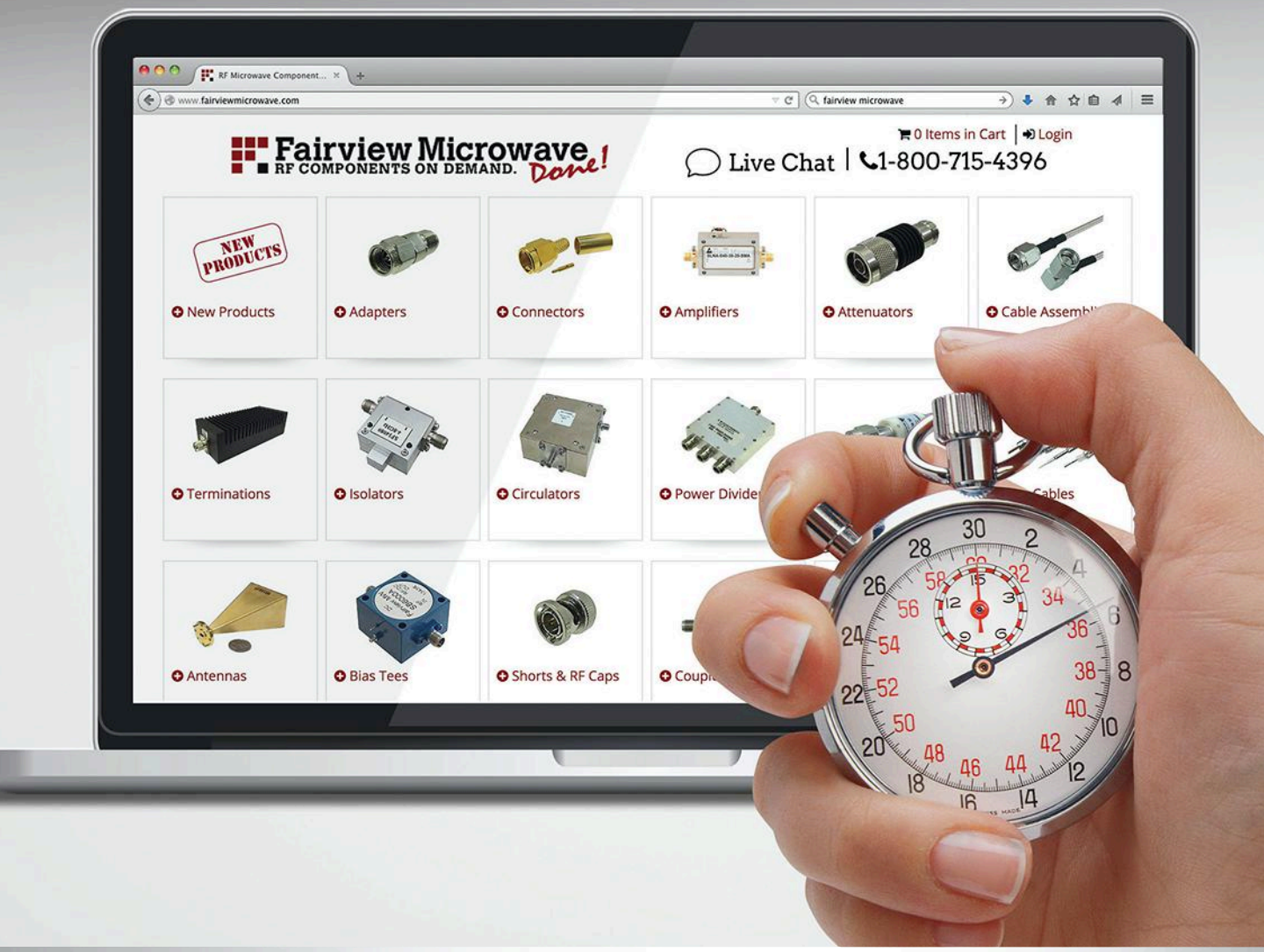

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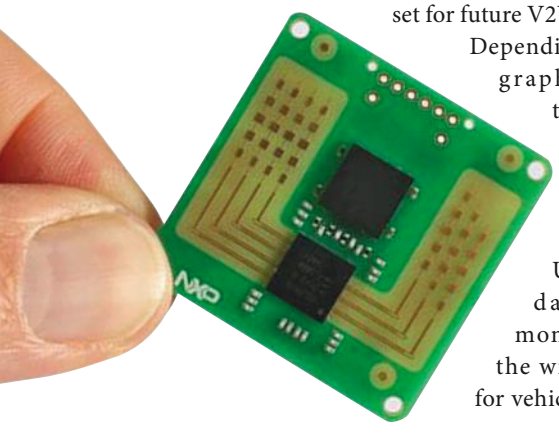
(Continued from page L51)

By having all vehicles communicating their locations, speeds, directions, and other parameters 10 times per second to other vehicles, all vehicles will have a 360-deg. situational awareness of the traffic volume and conditions around them, both to avoid accidents and minimize traffic congestion.

Existing vehicular electronic technologies, such as collision-avoidance systems, are seen as complementary to V2V systems and networks.

The DoT's proposal suggests that V2V technology can provide significant decreases in the number of accidents and significant decreases in the number of lives lost due to vehicular accidents. The 392-page proposal is aligned with the automotive industry's efforts to develop autonomous, "self-driving" vehicles that would employ GPS satellite receivers for position information and V2V networks for cars to "talk" to each other by means of various electronic components and devices. As a consequence, roads are made safer even with less local control exerted by human drivers.

Wireless communications within a single vehicle has traditionally been conducted within the Industrial-Scientific-Medical (ISM) frequency band, typically from 315 to 915 MHz, although much higher frequencies are used for automotive radar systems and will be used for V2V technology. For example, in the U.S., the FCC has allocated the frequency range normally associated with wireless local area network (WLAN) equipment for V2V applications: 5.850 to 5.925 GHz. While internet providers and other wireless users are hoping to gain the use of some of this bandwidth, the automotive industry is well aware of the need for bandwidth if it is to achieve the challenging goals set for future V2V networks.



2. The high level of integration used in a SiGe semiconductor process has enabled the production of this miniature 77-GHz automotive radar chip. *(Courtesy of NXP Semiconductors)*

Depending upon geographic regions, the V2V standards and frequencies will vary. The U.S. V2V standard is commonly known as the wireless access for vehicular environments (WAVE) standard. Europe has the vehicular ad hoc network (VANET) standard, which is a variation on the mobile ad hoc network (MANET) standard. While the FCC that governs frequency bandwidth in the U.S., it is the European Telecommunications Standards Institute (ETSI) in Europe that sets the requirements for V2V technology. The latter governing body has created a standard known as ITS-G5, which is based on the IEEE's 802.11p wireless networking standard.

DRIVING MORE CHIPS

Semiconductor manufacturers have been long at work developing and supplying wireless transceivers, sensors, and other forms of integrated circuits (ICs) for automotive electronics prior to the coming of V2V technologies. The list of well-established IC suppliers for automotive electronics is long, and includes Analog Devices (*www.analog.com*), Broadcom (*www.broadcom.com*), NXP Semiconductors (*www.nxp.com*), and Infineon Technologies (*www.infineon.com*). Not only are electronic sensors helping to meet stricter emissions standards for vehicles with internal combustion engines, but they are also being used to achieve low-emissions power trains in hybrid electric vehicles (HEVs).

The operating environment for automotive ICs is not unlike the specifications set for military electronic devices, with high reliability required over wide operating temperature ranges. To be considered "automotive-grade" electronic devices, such ICs must endure stress testing according to guidelines established by the Automotive Electronics Council (AEC) in the AEC Q100 specifications. Electronic devices for automotive use are qualified according to how rigorous the conditions of their particular applications and locations within the vehicle, with grades 0 through 4 assigned for different ambient operating temperature ranges: −40 to +150°C (Grade 0), −40 to +125°C (Grade 1), −40 to +105°C (Grade 2), −40 to +85°C (Grade 3), and −40 to +70°C (Grade 4).

Through its merger with Freescale Semiconductor, NXP (which is in turn about to be acquired by Qualcomm) fortified its already strong semiconductor design and fabrication capabilities to produce some of the industry's smallest 77-GHz radar ICs (*Fig. 2*). Based on a high-frequency sili-

con germanium (SiGe) semiconductor process, the single-chip, multiple-channel, 77-GHz radar transceiver measures just 7.5 × 7.5 mm2 and provides high-resolution radar performance for automotive advanced driver assistance systems (ADASs). The small size of the radar IC makes it easier to integrate into multiple locations within a vehicle. The IC provides the accurate, high-resolution radar returns needed for self-driving autonomous vehicles in addition to its support of collision-avoidance systems and adaptive cruise control systems.

Infineon, a long-time supplier of automotive electronic solutions, also relies on a SiGe semiconductor process for its radar system IC (RASIC) series of 77-GHz automotive radar devices that are fully qualified to AEC-Q100 requirements. The highly integrated devices require few, if any, additional external components.

NXP, which supports all three automotive network protocols, also makes a number of RF-based solutions for automotive electronics applications at ISM band frequencies, including a single-chip transceiver with programmable fractional-N phased-lock loop (PLL) frequency synthesizer. These lower-frequency devices are typically used for such applications as communicating data from tire pressure monitoring systems (TPMSs) and for keyless remote entry and other telemetry applications. The firm supplies a range of sensors for such functions as monitoring gas emissions and fluid temperature monitoring (such as for antifreeze and motor oil).

All automotive radar systems are not at millimeter-wave frequencies, as Analog Devices offers a frequency-modulated-continuous-wave (FMCW) radar chip for use at 24 GHz, along with a number of different sensors based on MEMS technology. The radar chipset includes a two-channel transmitter, a four-channel receiver, and a 13-GHz fractional-N PLL frequency synthesizer. The firm recently bolstered its position as an electronics component supplier for automotive safety systems by acquiring solid-state laser-beam steering technology from the privately held Vescent Photonics, Inc. of Golden, Colo. The nonmechanical technology is a good fit for automotive LIDAR systems with higher reliability than mechanical solutions.

Between the self-contained networks within each vehicle, such as a CAN system, and the expectations of widespread V2V wireless communications capabilities in future vehicles, modern wireless communications technologies will ensure that vehicles are as well connected as their owners. Whether a driver's hands are on or off the steering wheel, hopefully the end result is a safer driving experience for all. MW

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William Capogeannis / Founder, Omniyig, Inc.

YIG TECH

A BROAD REQUIREMENT of electronically tuned microwave components needed for use in numerous systems exists – radar, telecommunications, countermeasure, guidance, microwave receivers, and much more. The Yig is the only microwave component element that can be designed for those systems tuned in octave and multi-octave bandwidths.

Omniyig started pursuing the design and manufacture of Yig devices realizing the Yig can replace many microwave components, satisfying that broad requirement in a very small, very light footprint. Coupled with a reliable mean time between failure of over 200,000 hours, as well as multi-octave tuned in a single package, a star was born.

With the Yig material, Omniyig can manufacture many microwave components – Bandpass Yig Filters, Band-Reject Yig Filters, Yig Multipliers, Yig Oscillators, Phase-Lock Yig Oscillators, Phase-Lock Yig Filters, Tracking Yig Filters, Front End Tuners, as well as many other Yig components and systems – to thousands of custom requirements.

The bulk of Omniyig's sales are Yig components and Yig subsystems built to MIL-STD programs with very stringent MIL-STD QA guidelines. Some of the programs that Omniyig has manufactured Yig devices for are the ALQ-99, ALQ-117, ALR-172, ALR-56C, ALR-62, ALR-64, ALR-67, ALR-69, WLR-8, EF111, B1, and L-130… the list goes on.

R&D activities at Omniyig occur continually, with a dedicated R&D team fleshing out any particulars related to novel custom designs or requests on the client's part. They relish continuously developing new and improved Yig products in providing a deliverable product performing under all environmental conditions.

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OMNIYIG continues to further the design, development, and technology of Yig devices, subsystems, and more. With unending engineering passion, Omniyig welcomes future uncharted waters in advancing Yig technology even further.

"Delivering the Highest Quality of Technology Since 1973"

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YIG BAND REJECT FILTERS

Omniyig Model No.	Frequency Range (GHz)	Ins. Loss (dB)	Bandwidth at 40 dB (MHz)
M107RX	8.0 - 18.0	1.5	20
M104RX	4.0 - 18.0	2.0	8
M105RX	2.0 - 8.0	1.5	10

MIL-SPEC and High Reliability!
Integrated with Analog and 12 Bit Digital Drivers.
MANY other Multioctave designs available.

YIG MULTIPLIERS

Omniyig Model No.	Input Frequency (GHz)	Output Frequency (GHz)	Output Power (dBm)
YM1001	1.0 - 2.0	2.0 - 13.0	6
YM1002	0.1	1.0 - 12.0	-33
YM1003	0.2	1.0 - 12.0	-28
YM1004	0.5	1.0 - 12.0	-10
YM1026	1.0 - 2.0	2.0 - 18.0	-4
YM1027	0.1	1.0 - 18.0	-40
YM1028	0.2	1.0 - 18.0	-33
YM1029	0.5	1.0 - 18.0	-22
YM1087	0.1 - 0.2	1.0 - 12.0	-25

RF input power on all models 0.5 to 1.0 watts.
Fast switching, MIL-Spec Hi-Reliability and units integrated with drivers, oscillators or amplifiers also available.

STANDARD DETECTORS

Omniyig Model No.	Frequency Range (GHz)	k Factor	TSS (dBm)
Zero-Bias Schottky			
ODZ0004A	0.1 - 18.0	1200	-52
ODZ0328A	2.0 - 18.0	1200	-52
ODZ0441A	6.0 - 26.0	1000	-51

STANDARD COMB GENERATORS

Omniyig Model No.	Input Frequency (MHz)	Output Frequency (GHz)	Output Power (dBm)
OHG10118	100	0.1 - 18.0	-40
OHG20218	20	0.2 - 18.0	-35
OHG51026	500	0.5 - 18.0	-28
OHG81026	1000	1.0 - 18.0	-18

Let Omniyig help with any special Limiter or Detector requirements you may have - Zero Bias Schottky Detectors, Limiter-Detectors, Comb Generators and a broad line of YIG-tuned Filters, Oscillators and Multipliers.

WIDEBAND YIG FILTERS

Omniyig Model No.	Frequency Range (GHz)	Ins. Loss (dB)	Bandwidth at 3 dB (MHz)
4-STAGE			
M3064	6.0 - 18.0	6.5	500 min
M2997	6.0 - 18.0	6.0	400 min
M3513	8.0 - 18.0	6.5	500 min

Industry-leading bandwidths in multi-octave, YIG units providing the widest 3dB bandwidth available!

LOW PHASE NOISE YIG OSCILLATORS

Omniyig Model No.	Frequency Range (GHz)	RF Power Output (mW)	Second Harmonic (dBc)
YOM1517	0.5 - 2.0	20-60	16
YOM1518	1.0 - 4.0	20-60	16
YOM1514	4.0 - 12.0	10	15
YOM3719-5	2.0 - 15.0	20	13
YOM1679	2.0 - 12.4	20	13
YOM83	2.0 - 6.0	20	12
YOM137	2.0 - 8.0	20	12
YOM3719-4	8.0 - 18.0	20	14
YOM3719-2	6.0 - 18.0	20	14
YOM3719-1	4.0 - 18.0	20	13
YOM3719	3.0 - 18.0	10	12
YOM3676	2.0 - 18.0	20	15

We offer other models with Second Harmonic -60 dBc and Oscillators integrated with 2-stage YIG Filters.

STANDARD LIMITERS

Omniyig Model No.	Frequency Range (GHz)	Insertion Loss (dB)	Leakage Power (dBm)
Pin			
OLP2645A	8.0 - 18.0	2.0	+19
OLP2726A	2.0 - 18.0	1.2	+19
PL473	0.5 - 12.0	1.8	+19
OLP2652	2.0 - 18.0	2.5	+20
Schottky Turn-on			
SL048	2.0 - 26.0	2.5	+14
OLD2635A	4.0 - 18.0	2.5	+14
OLD2733A	0.4 - 18.0	2.5	+14

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Interview

CHRIS DeMARTINO | Technology Editor

Q&A: LoRa Alliance's Geoff Mulligan

The group's chairman discusses its mission and LoRa technology in general.

Can you tell us about LoRa technology for those who may not be so familiar?

The LoRa radio and LoRaWAN specification define an interoperable low-power and low-cost communications solutions for the Internet of Things (IoT). By using LoRaWAN, IoT devices can communicate over tens of kilometers but still be powered by batteries and utilize chips that cost below $2. It is prime technology where the application has both power and cost constraints, but still requires two-way communication over a wide area.

Besides incorporating low-cost chips in the end nodes, the overall operating expenditure (OPEX) and capital expenditure (CAPEX) costs for the base stations and infrastructure is 1% of the cost of most alternatives. The architecture is a star network, but has unique features that provide improved robustness. It has no single points of failure and can provide geolocation/localization without the need for GPS chips.

Additionally, the LoRa Alliance *(www.lora-alliance.org)* ecosystem is "open," meaning it is an openly available specification based on open standards (TCP/IP), [an] open certification program, and most importantly an open business model. The latter means that companies can choose to build their own network, partner with operators, or even become an operator themselves.

It seems like there are countless IoT wireless technologies. Where do you see LoRa in all of this?

LoRaWAN fills a gap for low-power wide-area connectivity. It is perfect for covering very large distances while still providing battery-powered solutions. It provides an extremely cost-effective and power-efficient bi-directional communication capability. A 30-square-kilometer farm could be covered for less than $10,000. And because LoRaWAN utilizes unlicensed spectrum, end-users, solutions providers, and operators can build their own networks. Furthermore, being based on open internet standards (TCP/IP) allows for future proofing and eliminates vendor lock-in.

I do not see any one technology as the panacea for all IoT communications. Just as Wi-Fi and cellular provide higher-speed data communications, so shall there be different technologies for interconnecting IoT devices. The LoRaWAN protocol is a good fit for applications requiring low-cost, low-power two-way communication over large distances. It is a particularly good solution when end-users want or need to operate their own network.

What applications do you see as the main beneficiaries of LoRa technology?

It can readily be used in areas like smart agriculture, intelligent transportation, smart cities (traffic management, air quality, smart parking, energy management, etc.), and oil/gas/water distribution condition monitoring. All of these require a large coverage area. But LoRa technology is equally capable of providing cost-effective connectivity for building control, perimeter monitoring, and energy and HVAC control.

Because of the extremely low CAPEX and OPEX costs, LoRa and the LoRaWAN protocol make it now possible to start deploying large-scale IoT applications. For example, a 1,000-acre farm or vineyard could deploy a moisture/crop sensor network for less than $10,000. Cities can start to deploy a LoRaWAN network immediately and scale it up as needed to increase coverage. A single gateway can cover a small downtown—though at least three gateways are required in order to provide geolocation/localization. MW

A 5G WORLD Requires Suitable MIMO Testing

Next-generation 5G networks are expected to represent a revolutionary change in wireless communications. Furthermore, multiple-input, multiple-output (MIMO) technology is primed to play an important role in these networks. Test systems must therefore account for this key technology. In the new technical brief, "Insights on Evolving 5G MIMO Networks and Test Methods," Vaunix Technology describes various MIMO implementations before discussing possible test solutions for these systems.

The technical brief begins by noting that the number of devices connected to the internet will exceed 20 billion in 2020, according to some predictions. Another point mentioned is how mobile phones are increasingly being used to connect to the internet. These points help to illustrate the need for better network performance, which is what 5G is expected to provide. These performance improvements include faster data rates, enhanced spectral efficiency, and lower latency.

Vaunix Technology Corp.,
7 New Pasture Rd.,
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(978) 662-7839;
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MIMO technology is expected to be utilized to overcome the challenges associated with 5G. The document examines MIMO by first discussing small cells, with an explanation of hardwired and mesh-network small cells. Millimeter-wave and massive MIMO are also discussed. The latter allows for a significant increase in spectral efficiency, which is a major requirement of 5G.

Linear processing and precoding are the next topics. According to the document, the preferred method for linear processing involves time-division-duplex (TDD) systems that leverage channel reciprocity, which is a property that allows channel state estimation (CSI) to be estimated at the transmitter. Furthermore, precoding techniques represent another challenge for engineers involved with 5G system development.

MIMO test solutions are then discussed. MIMO testing often requires digital attenuation and RF switching functionality. The document points out the benefit of utilizing USB-powered portable test equipment to meet MIMO test challenges. It also points out that vendors should offer products with a variety of frequency ranges and performance levels. Other factors mentioned are graphical-user-interfaces (GUIs) that are easy to use and install, as well as the capability to operate multiple devices directly from a PC or self-powered USB hub.

Program Your Attenuator System to Do the Job

PROGRAMMABLE ATTENUATOR SYSTEMS areneeded for a variety of applications. Programmable, or step, attenuators can be controlled by either analog or digital control signals. They can also be controlled either manually or via a computer. In the application note, "An Introduction to Programmable Attenuator Systems," JFW Industries describes various types of programmable attenuator systems and how they can be used to satisfy the requirements of different applications.

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Programmable attenuator systems can be used to test the performance of such wireless applications as first responder, Wi-Fi, and cellular networks. Important specifications of a programmable attenuator include frequency range, attenuation range and step size, maximum RF input power, and insertion loss. As an example, the application note shows a specification sheet for a presently available programmable attenuator assembly.

A few different programmable attenuator system architectures are discussed. The first one presented is the parallel test system architecture, which the document identifies as the simplest configuration. A block diagram is shown to illustrate how each attenuator in the system has an independent input and output, as well as the fact that there is no RF connection between attenuators. This parallel architecture is typically used to simultaneously test multiple independent receivers and transmitters in a production environment.

Handover test systems are also described, as these systems are well suited for cellular and Wi-Fi testing. Handover test systems include attenuators and power dividers, providing connections for multiple network access points and devices. A block diagram of a handover test system is presented to illustrate its functionality.

The final type of system presented is the transceiver test system, which the document describes as the most complex type of configuration. These systems can accommodate the largest amount of device combinations and can perform most types of RF testing. A block diagram of a transceiver test system is also shown. The document also explains the differences between full fan-out, limited fan-out, and hub fan-out transceiver test systems.

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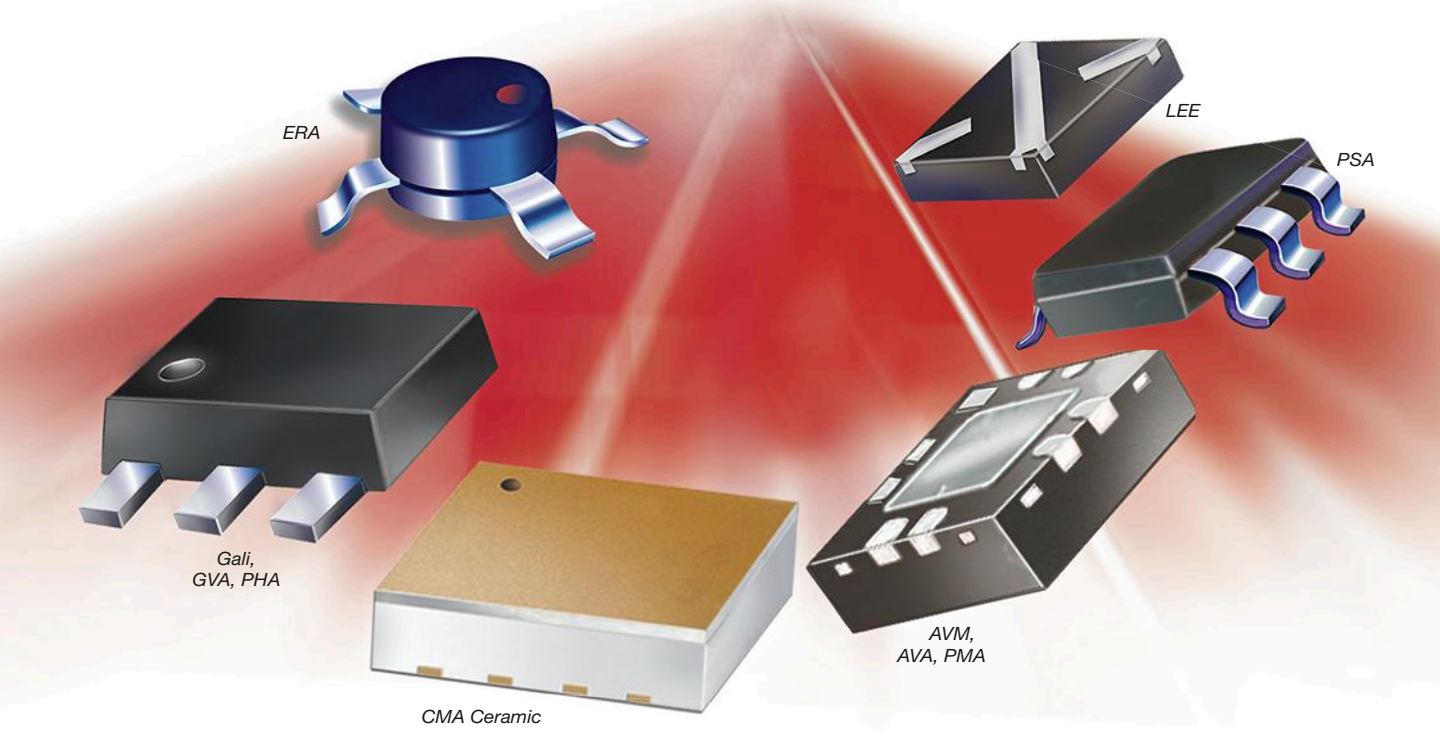

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BRAD HALL | RF Systems Applications Engineer, Analog Devices
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Need More Bandwidth for the Ka-Band? Here Are Three Options

To design a signal chain for satellite communications systems at Ka-band frequencies, the right system architecture must be chosen. This article discusses several signal-chain options that system designers can take advantage of.

As the demand for global connectedness increases, many satellite communications (satcom) systems are pushing toward higher data rates with an increased presence in the Ka-band spectrum. With high-performance signal chains now able to support multiple GHz of instantaneous bandwidth, and with potentially hundreds of transceivers in a system, the potential for very-high-throughput data rates is now a reality.

In addition, there is a trend in many systems to move away from static mechanically-steered parabolic antennas and move toward active phased-array antennas. This is driven by the enhanced technology and increased integration available to drive element spacing down to what is required at Ka-band frequencies. Phased-array technology also allows for improved interference mitigation by creating nulls in the antenna pattern in the direction of interfering signals.

The following overview describes some of the tradeoffs that exist among the transceiver architectures available, as well as what types of architectures may be appropriate for different types of systems. Included in this analysis is a breakdown of some of the key specifications for a satellite system and how these system-level specifications translate to transceiver signal-chain-level components.

SPECIFICATION FLOW-DOWN FROM SYSTEM-LEVEL ANALYSIS

Satcom systems at a high level are concerned with maintaining a certain carrier-to-noise ratio (CNR), which is a result of the link-budget calculation. Maintaining this CNR ensures a certain bit-error-rate (BER). The CNR required depends on many factors, such as error correction, information coding, bandwidth, and modulation type.

Once a required CNR is established, the individual receiver and transmitter specifications can flow down from the high-level system requirements. Typically, they will first flow down in the form of a required gain-to-system-noise-temperature (G/T) figure of merit for receivers, and effective isotropic radiated power (EIRP) for transmitters.

For the receiver, translating from G/T to a lower-level receiver signal-chain specification requires the system designer to know the antenna gain and system noise temperature, as shown in *Eq. 1* below. The receiver noise temperature can be determined from *Eq. 2*.

$$\frac{G}{T}(dB) = G_{ant}(dB) - 10\log(T_{sys}) \qquad (1)$$

$$T_{sys} = T_{ant} + T_{RX} \qquad (2)$$

The noise figure required of the receiver signal chain can then be found from *Eq. 3*:

$$NF_{RX}(dB) = 10\log\left(\frac{T_{RX}(K)}{290K} + 1\right) \qquad (3)$$

Once the receiver noise figure is known, a cascade analysis can be computed to determine if the signal chain is meeting these required specifications and if adjustments can be made as necessary.

For the transmitter, the EIRP needed is first determined based on how far away the receiver is (either ground-to-satellite or satellite-to-ground) and how sensitive the receiver is. Once the EIRP requirement is known, a tradeoff exists between the output power of the transmit signal chain and the gain of the antenna. With a higher-gain antenna, the power consumption and size of the transmitter can go down but at the expense of a larger antenna. The EIRP is given by *Eq. 4.*

$$EIRP\ (dBW) = P_{TX}(dBW) + G_{ant}(dB) \qquad (4)$$

Carefully selecting components in the signal chain allows the required output power to be maintained without causing degradation to other important parameters. Such parameters include output noise spectral density and out-of-band RF energy that can cause interference in other systems.

Other critical specifications for both the transmitter and receiver include:

Instantaneous bandwidth. How much spectrum the signal chain can digitize at any point in time.

Power handling. How large of a signal can a signal chain handle without degrading performance.

Phase coherency among channels. For emerging beamforming systems, ensuring predictable phase between channels to allow for simplified beamforming signal processing and calibration.

Spurious performance. Ensuring the receiver and transmitter do not produce RF energy at undesired frequencies that can impact the system or other system's performance.

Keeping these specifications and others in mind when designing a signal chain is critical to guarantee a high-performance system for any given application, whether a wideband multi-carrier-aggregation hub or an individual narrowband handheld satcom terminal.

GENERAL ARCHITECTURE COMPARISON

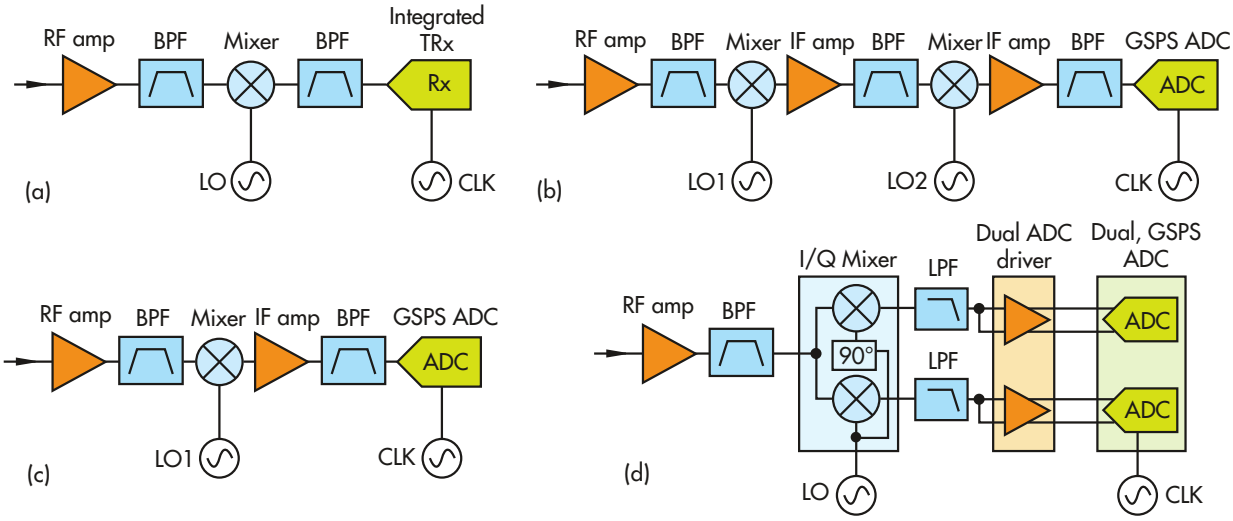
Once the high-level specifications are determined, the signal-chain architecture can be decided upon. One of the critical specifications previously listed that can have a big impact on the architecture is instantaneous bandwidth. This impacts the analog-to-digital converter (ADC) for the receiver and digital-to-analog converter (DAC) for the transmitter. To achieve greater instantaneous bandwidth, the digitizers must be sampled at a higher rate, which can generally drive up power consumption of the signal chain as a whole, but decrease power consumption if judged on a W/GHz basis.

For systems with less than 100-MHz bandwidth, a base architecture that is similar to the one shown in *Fig. 1a* is optimal in many cases. This architecture utilizes a hybrid approach, as it pairs a standard downconversion stage with an integrated direct-conversion transceiver chip. The integrated transceiver provides a high level of integration, drastically reducing size and power.

To achieve as much as 1.5 GHz of bandwidth, one can utilize a classic dual-conversion superheterodyne architecture in conjunction with the latest ADC technology *(Fig. 1b)*. With this well-established, high-performance architecture, conversion stages are used to filter out unwanted spurious signals. Depending on the receive frequency band, the first downconversion stage is utilized to downconvert to an intermediate frequency (IF).

Following the first downconversion stage, an additional downconversion stage is utilized to downconvert to a lower-frequency final IF that the ADC can digitize. The lower this final IF, the higher the ADC performance will be but at the expense of increased filtering requirements. Generally, due to the increased component count, this architecture is the largest and highest-power version of the four options presented.

Another similar option involves converting to a higher IF with a single-conversion stage followed by sampling using a gigasample-per-second (GSPS) ADC *(Fig. 1c)*. This architecture takes advantage of the increasing amounts of RF bandwidth that ADCs are able to digitize with very little perfor-



1. This figure shows four different architectures: High-IF with integrated TRx (a), dual-conversion superheterodyne with GSPS ADC (b), single-conversion superheterodyne with GSPS ADC (c), direct-conversion with I/Q mixer (d).

mance degradation. The latest GSPS ADCs on the market allow for direct sampling of RF frequencies as high as 9 GHz. In this option, the IF is centered somewhere in the range of 4 to 5 GHz to strike the best balance between filtering requirements for the signal chain and ADC requirements.

Figure 1d shows the final option. This direct-conversion architecture provides even greater instantaneous bandwidth, but comes at the expense of complexity and potentially decreased performance. This architecture uses a passive in-phase/quadrature (I/Q) mixer, allowing for two IFs at baseband that are 90 deg. offset from one another.

Each I and Q leg is then digitized using a dual-channel, GSPS ADC. In this case, as much as 3 GHz of instantaneous bandwidth is possible. The major challenge associated with this option is maintaining the quadrature balance between the I and Q paths, as the errors propagate through the mixer, low-pass filter, and ADC driver. This may be an acceptable tradeoff, depending on CNR requirements.

A general overview has been given here that describes, at a high level, the operation of these receiver architectures. The architectures presented here are not all inclusive by any means, as hybrids that use elements of each option are also possible. Although transmit signal chains were not covered in the comparison, each option from Fig. 1 has a corresponding transmit signal chain with similar tradeoffs.

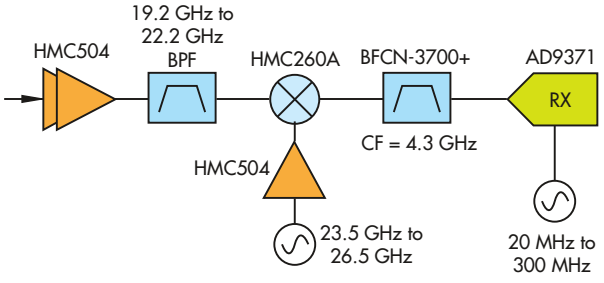
KA-BAND SATCOM RECEIVER EXAMPLES

Now that the pros and cons of different architectures have been discussed, the knowledge can be applied to real signal-chain examples. Many satcom systems are now operating in the Ka-band in order to decrease antenna size and increase data rates. This is especially relevant in high-throughput satellite systems. The following is a discussion of examples using different architectures along with a more detailed comparison.

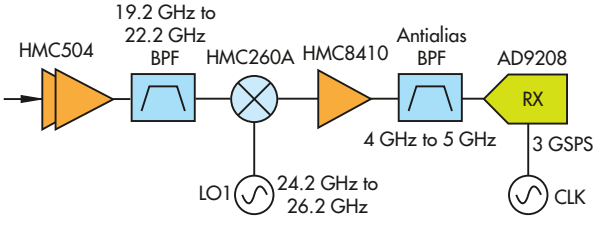
For systems that require instantaneous bandwidth below 100 MHz, such as is the case with very small aperture terminals (VSATs), the high-IF architecture with an integrated transceiver chip (AD9371) can be used *(Fig. 2)*. This design can achieve low noise figure, and because it has such a high level of integration, it offers the smallest design footprint. A summary of its performance can be seen in the *table*.

DETAILED COMPARISON OF KA-BAND RECEIVERS

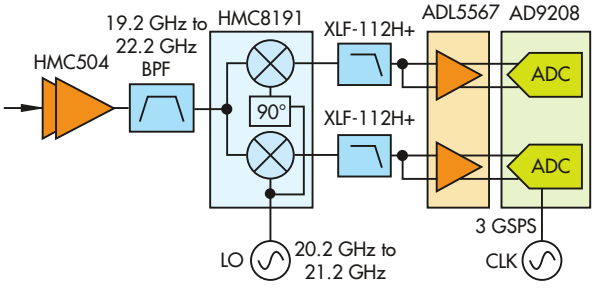
	High IF with Int.TRx	High IF with GSPS ADC	Direct Conversion
Digitizer	AD9371	AD9208	AD9208 (dual-channel)
Instantaneous Bandwidth	100 MHz	1 GHz	2 GHz
NF (dB)	2.5	2.3	2.3
IIP3 (dBm)	–19	–20	–20
Max Pin (dBm)	–38	–40	–41
Other Spurious (HD2, HD3, MxN)	65 dB	73 dB	45 dB
Image Rejection (dBc)	75	80	25
Filtering Difficulty	Low	Medium	Low
Power (W)	2.9	4.1	6.1
Power/GHz (W/GHz)	29	4.1	3.05
Package Size (mm^2)	300	510	580



2. This architecture utilizes a high-IF and has an integrated TRx. It allows for bandwidth up to 100 MHz.



3. This figure depicts a single-conversion-to-high-IF architecture that utilizes the AD9208 ADC.



4. Shown is an example of a direct-conversion architecture that includes an I/Q mixer and GSPS ADC.

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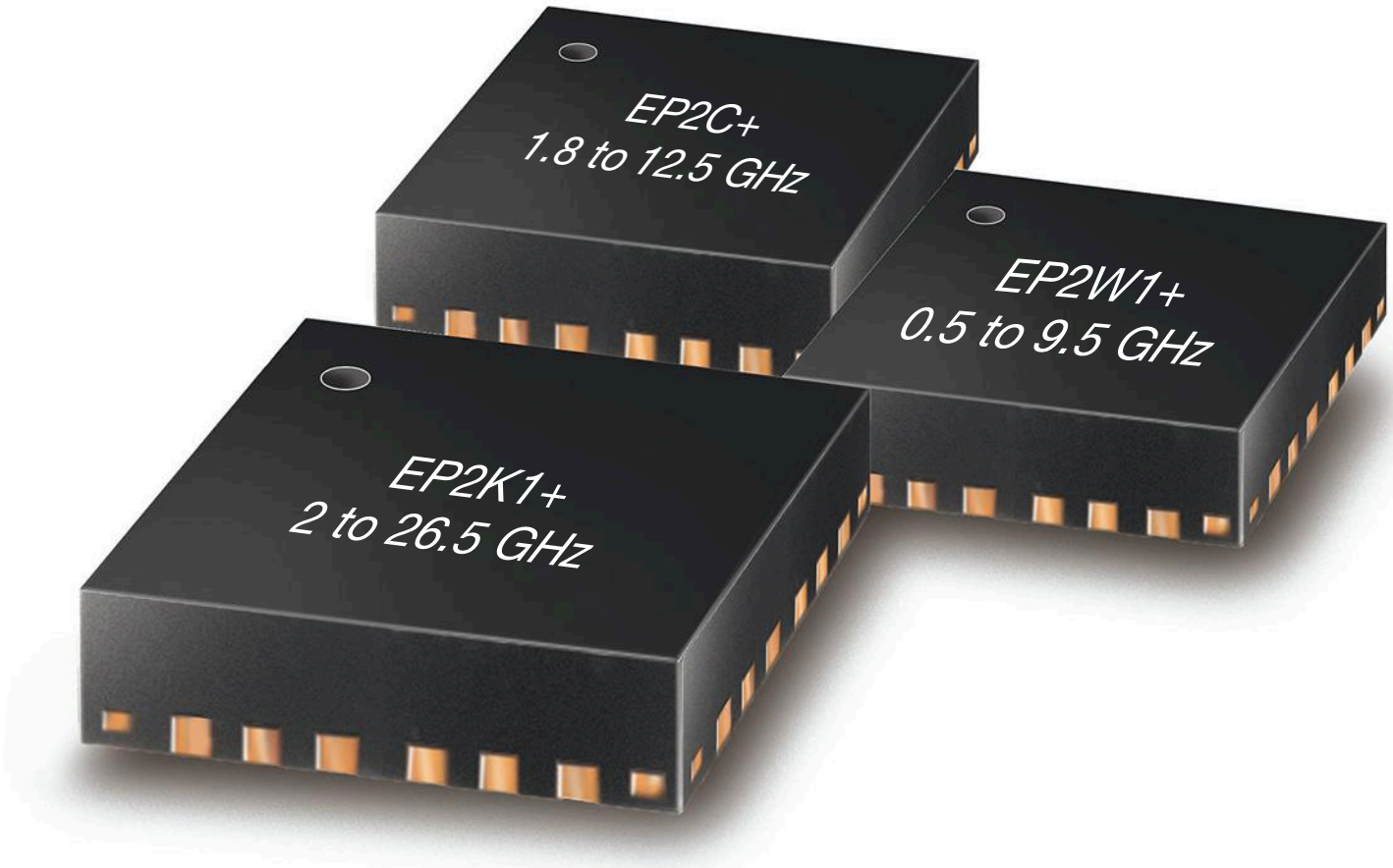

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Many satcom systems are now operating in the Ka-band in order to decrease antenna size and increase data rates. This is especially relevant in high-throughput satellite systems.

Some systems may be dealing with many carrier signals at a time if they are acting as a hub for multiple users in a satcom system. In this case, bandwidth per receiver or bandwidth/power become important factors. *Figure 3* shows a signal chain that utilizes a high-speed ADC. The ADC used here is the recently released AD9208, which is a high-sample rate ADC that can digitize as much as 1.5 GHz of instantaneous bandwidth. In this example, the IF is placed at 4.5 GHz to achieve 1 GHz of instantaneous bandwidth. The achievable bandwidth here will depend on filtering requirements for the anti-alias filter before the ADC, but is generally limited to approximately 75% of a Nyquist zone (half of the sample rate).

In systems that demand the highest instantaneous bandwidth and can give up performance in the form of CNR, the direct-conversion signal chain shown in *Fig. 4* may be desirable. This signal chain utilizes an I/Q mixer, the HMC8191, which has an image rejection performance of approximately 25 dBc. In this case, the image rejection is limited by the amplitude and phase balance between the I and Q output channels. This is the limiting factor for this signal chain without more advanced quadrature-error-correction (QEC) techniques.

A summary of the direct-conversion signal-chain performance is shown in the *Table*. Notably, the noise figure and third-order intercept (IP3) performance is similar to the other options, but the power/GHz metric is the lowest of the three. Size is similarly optimal for the amount of bandwidth that can be utilized at any instant.

While the three receive options presented here are shown in the table, it should be noted that this list is not meant as a comprehensive breakdown of all possible options. This summary overview is given in order to show differentiation among the various signal chain options. In any given system, the final optimal signal chain may be one of the three shown or a hybrid approach of any of these.

Additionally, even though only the breakdown for the receiver side is shown, many similar tradeoffs exist for transmitter signal chains as well.

(Continued on page 137)

JACK BROWNE | Technical Contributor

RF/Microwave Technology Helping Power EVs and HEVs

Electric and hybrid-electric vehicles are joining purely fossil-fuel-powered vehicles on modern roadways that were being made safer through the use of RF/microwave sensors and communications.

Electricity may one day rule the world's vehicles rather than gasoline. As fossil fuels become more expensive, and the technologies and manufacturing costs associated with electric vehicles (EVs) and hybrid electric vehicles (HEVs)—which combine electric and gas-powered engines—become more affordable, the prices for EVs and HEVs will drop, making such vehicles more widespread on the roads.

When drivers take the wheel of their new EV or HEV for the first time, they will also find that the drive system is not the only one powered by electricity. Rather, RF/microwave signals throughout each vehicle and beyond it are helping with the day's drive. That comforting invite to "leave the driving to us" may very well refer to those RF/microwave systems.

The disadvantages of EVs and HEVs compared to gasoline or powered vehicles have included the aforementioned relatively high costs, limited driving ranges (typically as much as 250 miles compared to a vehicle that can be refueled at any convenient gas station), and long recharge times required to bring a battery to full charge once it has been depleted of energy. But some companies, including Qualcomm (www.qualcomm.com), are exploring ways to recharge the batteries of EVs and HEVs while they are moving, without having to make long stops at recharging stations.

Both EVs *(Fig. 1)* and HEVs *(Fig. 2)* are growing in numbers worldwide—approaching or exceeding the number of fossil-fuel-powered vehicles in some places. For example, according to the Reuters news agency (www.reuters.com), more than half of all new car sales in Norway are EVs as of 2017, rather than vehicles with gasoline-powered internal combustion engines. Drivers are highly incentivized to own and drive electric vehicles in Norway since that country's government offers significant tax exemptions with the purchase and ownership of an EV.

A typical EV or HEV represents an impressive interconnection of electrical and mechanical subsystems that must communicate with each other as a form of miniature internet. These many subsystems in turn are designed to communi-

1. The 2018 Ford Fusion Energi plug-in hybrid has an electric motor with a high-voltage battery and a gasoline engine. Its estimated driving range is 21 miles. Braking the car provides more power: It uses kinetic braking energy captured from its Regenerative Braking System to capture and store energy in its battery for later use. *(Courtesy of Ford Motor Company)*

2. The 2018 Ford Focus Electric vehicle is all electric, powered by a 35-kWh liquid-cooled, lithium-ion battery (and shown here next to a recharging station). It also uses regenerative braking to capture energy during braking and store it in the battery for later use. It features a 107-kW electric motor and a 1-speed automatic transmission. *(Courtesy of Ford Motor Company)*

cate with the outside world via the internet and numerous on-board sensors and communications links. Wireless communications from a modern vehicle of any kind—including gas powered—can take place in a number of different ways, including vehicle to vehicle (V2V), vehicle to infrastructure (V2I), and vehicle to the cloud or Internet (V2C). There may also be communications from vehicle to pedestrian (V2P) and vehicle to everything (V2X).

MAINTAINING A CHARGE

Perhaps more important than inclusion of positioning systems, such as GPS or wireless communications systems in EVs or HEVs, is the integration of some means to provide long-term voltage-charging solutions. Such a subsystem will help improve the energy efficiency of each vehicle and perhaps reduce the "range anxiety" that is associated with EVs and HEVs—of having them run out of battery charge before reaching a destination.

A traditional solution exists, where available, in the form of a charging station and a long stop required to recharge an electric vehicle's battery at a charging station. A newer, more innovative, solution is in the form of a technology known as wireless power transfer (WPT), as proposed by Qualcomm and others.

Rather than using connected wires and conduction to charge an electric vehicle's depleted battery, WPT employs induction, in which electric power is transferred over an air gap. Inductive charging is less efficient than conductive charging. But it is very convenient for a user, with no mating of plugs, and is capable of high power charging levels.

In a WPT system, a transmitter coil transfers current from an input power source to a magnetic field. A receive coil transforms the magnetic field into power that can be stored in the rechargeable battery of an EV or HEV. WPT battery charging techniques can be used on EVs and HEVs whether they are stationary or in motion, depending upon how the WPT system is configured.

In the Qualcomm dynamic charging approach, the batteries of an EV or HEV can be recharged by means of inductive charging, as the vehicle is driving over roadways in which specially engineered charging pads have been embedded into the road's surface. It is a variation of the Qualcomm Halo wireless electric vehicle charging (WEVC) approach in which the charging pads are embedded into the road surfaces of parking spaces, so that an EV's battery can be recharged while it is stationary and parked for some time.

The Energy Dynamics Lab (EDL) of the Utah State University Research Foundation has explored the potential of inductive charging methods for EVs and HEVs in both stationary and vehicles in motion. The organization's current stationary inductive charging systems are designed for charging at 5-kW power levels and wireless charging frequency of 20 kHz; their systems are capable of operating at charging frequencies extending from 20 to 100 kHz.

For an air gap of 6.0 to 10.5 in. between magnetic transmit and receive antennas, current systems provide an output voltage to +300 V dc with better than 90% efficiency, although higher efficiency levels are possible. By developing systems with wider inductive air gaps, higher voltage charging levels will be possible, to as much as +1200 V dc.

In term of in-motion IPT, a section of Interstate 5 through Seattle is often cited as an example of an "electrified" portion of roadway that has been equipped for in-motion power transfer, with costs that are quite competitive to those required for ICE vehicles. Still, the costs of electrifying modern highways such as this for in motion charging of EVs and/or HEVs approaches $3 million per lane per mile, with many goals set on lowering that cost over time to $2 million or less per lane per mile. This experimental system integrated into a lane of I-5 provides 40 kW charging power at a vehicle speed of 75 mph, with more than 90% transfer efficiency.

CONNECTING ELECTRIC CARS

Of course, transferring energy from stations to vehicles is just one example of the massive amount of wired and wireless communications that will be taking place within and without EVs and HEVs. Within each vehicle is the equivalent of a miniature internet, with many electronic systems linked via multiple high-speed microprocessors to an advanced driver assistance system (ADAS) that is projected to be a key part of the autonomous vehicle of the future.

The ADAS for each vehicle will in turn be treated as an Internet of Things (IoT) device over the real Internet, allowing those with the proper credentials to track the location of a connected vehicle via internet access, even the amount of electricity left in a vehicle's battery before its next charge.

SAE International *(www.sae.org)* has established standards for EV and HEV terminology, including methods for conductive and inductive charge coupling and various approaches for testing fully integrated EV and HEV systems. The organization has also established a number of different levels of ADAS use on the road to the "driverless car." In SAE Level 0, there is no use of ADAS technology, and the driver operates all controls.

In SAE Level 1, the ADAS is available to assist a human driver with braking and accelerating. In SAE Level 2, the ADAS can control steering and braking and accelerating under some circumstances, but the human driver must be monitoring the roadway and perform the majority of the driving. In SAE Level 3, the ADAS does a bit more of the driving than the human driver, while in SAE Level 4, under some circumstances, the ADAS has full control of the vehicle. In SAE Level 5, the human passengers are essentially along for the ride.

Both EVs and HEVs will rely on RF/microwave technologies for charging and for wireless communications links to the internet as these vehicles are increasingly used on modern highways. In addition to such techniques as inductive charging, a great deal of research is being performed on different forms of lithium-ion batteries and solid-state batteries that are light in weight—but capable of storing the amount of power needed for an EV or HEV—and with the capabilities to survive numerous recharge cycles and to maintain required charge levels when operating within the wide ranges of environmental conditions in which an EV and HEV may be used.

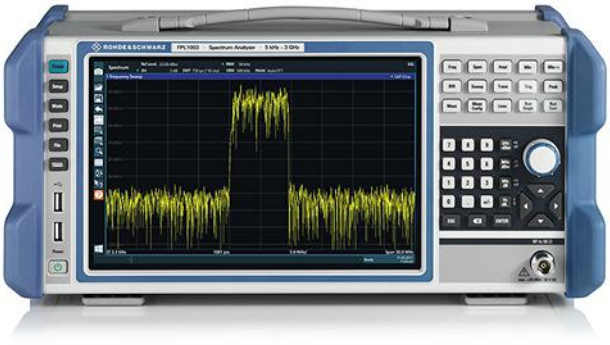
At present, the costs of EVs and HEVs are high relative to those of conventional internal-combustion vehicles, although those costs will drop as EVs and HEVs are mass-produced in larger numbers and as advances are made in the batteries used to store charge within those EVs and HEVs. The increasing number of EVs and HEVs appearing as IoT devices on the internet will literally drive the need for the additional wireless bandwidth provided by 5G wireless networks. The growing use of EVs and HEVs will contribute to a growing demand for 5G wireless communications as a result, with drivers and driverless users having wireless connections at any one time. mw

Product Feature

JACK BROWNE | Technical Contributor

Compact Spectrum Analyzer Packs Functionality to 3 GHz

This versatile instrument combines the extensive capabilities of a benchtop with the convenience and portability of a handheld spectrum analyzer.



The R&S FPL1000 spectrum analyzer, with a measurement range of 5 kHz to 3 GHz, packs a great deal of test power into a compact package. *(Courtesy of Rohde & Schwarz)*

Spectrum analyzers are among the most useful of RF/microwave test instruments for their capabilities to display a wide dynamic range of signals within a large frequency range. The R&S FPL1000 spectrum analyzer from Rohde & Schwarz *(www.rohde-schwarz.com)* provides such an extreme measurement value in a diminutive unit that supplies the accuracy of a benchtop machine and the versatility of a battery-powered portable for measurements from 5 kHz to 3 GHz..

The FPL1000 spectrum analyzer shows measured signals on a bright, 10.1-in. touchscreen with 1280- × 800-pixel resolution *(see figure)*. As many as six signal traces can be displayed at any one time, with as many as 1001 trace points. The standard displayed average noise level is −152 dBm, which can be reduced to −167 dBm with an optional preamplifier. The reference level can be set as low as −130 dBm plus the amount of added attenuation.

The spectrum analyzer captures signals within its frequency range using resolution-bandwidth (RBW) filters that can be set from 100 kHz to 10 MHz in a 1, 2, 3, 5 sequence (an option includes RBWs as narrow as 1 Hz). Signal traces can be displayed with impressive frequency resolution of 0.01 Hz. Sweep times range from as fast as 1 μs to as long as 8000 s for zero-span measurements.

The flexible spectrum analyzer features outstanding spectral purity, characterized by low single-sideband (SSB) phase noise. When measured in a 1-Hz bandwidth and a 1-GHz carrier, the SSB phase noise is typically −107 dBc/Hz offset 1 kHz from the carrier, −108 dBc/Hz offset 10 kHz from the carrier, −116 dBc/Hz offset 100 kHz from the carrier, and −136 dBc/Hz offset 1 MHz from the carrier. Spurious and harmonic levels are similarly low to support high sensitivity when detecting and analyzing low-level signals. To cover a wide dynamic range, the analyzer features a standard third-order intercept point of +20 dBm, and can be supplied with a step attenuator option to measure high-level input signals.

STOCKED WITH OPTIONS

An extensive number and variety of options are available with the FPL1000 spectrum analyzer, including for measurements of power and noise. A power measurement option, for example, enables the spectrum analyzer to be used with the R&S NRP series power sensors to make power measurements from −67 to +45 dBm at frequencies as high as 110 GHz. And the R&S FPL1-K30 noise figure and gain measurement option allows measurement of noise figure, gain, and Y-factor (in dB) across a selected frequency range. It is controlled by the analyzer's +28-V dc output and additional interface options on the back of the spectrum analyzer.

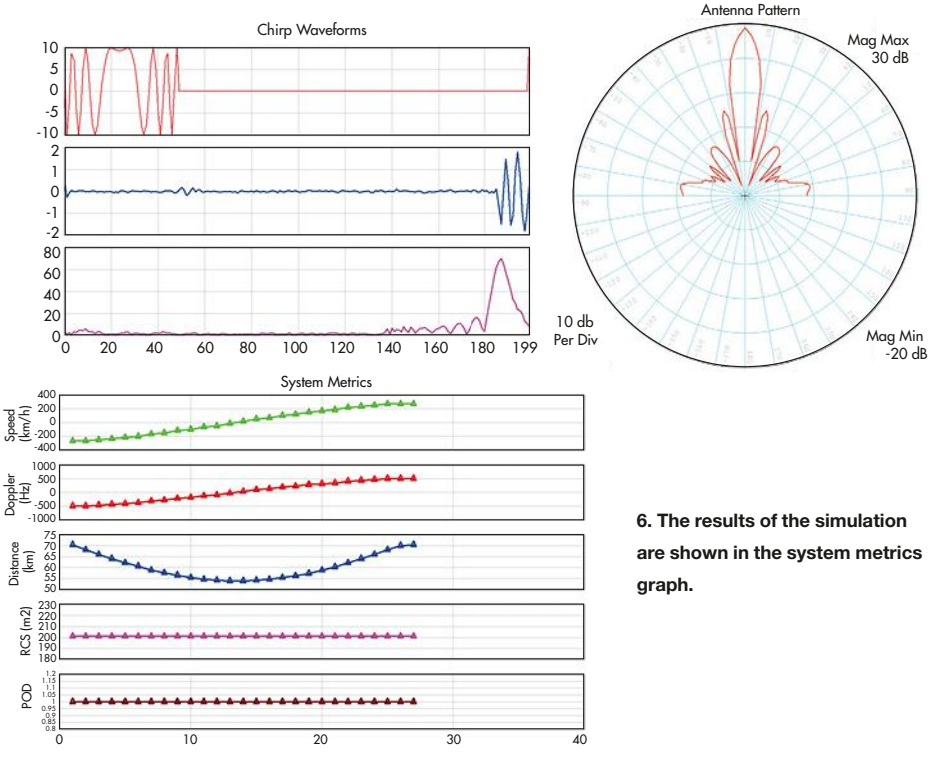
The spectrum analyzer is equipped with two Universal Serial Bus (USB 2.0) ports for ease of connecting accessories and memory devices for data storage. It has a two-year recommended calibration interval and an operating temperature range of 0 to +40°C. The analyzer weighs only 13.22 lbs (6 kg) without options and 16 lbs. (7.3 kg) with internal battery. It measures 16.06 × 7.32 × 9.25 in. (408 × 186 × 235 mm). MW

ROHDE & SCHWARZ GMBH & CO. KG, P.O. Box 80 14 69 81671, Munich, Germany; 888-TEST-RSA (1-888-837-8772); www.rohde-schwarz.com.

Design Software

(Continued from page 34)

velocity and distance. In this simulation, the distance to the target is swept to reflect a vehicle that approaches and passes by a stationary radar, resulting in Doppler frequency that reverses the sign from negative to positive (red curve) and produces a null in relative distance as the target passes by the radar. In an automotive radar for ACC, the velocity and distance information would be used to alert the driver or take corrective action (such as applying braking). MW



6. The results of the simulation are shown in the system metrics graph.

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Bandwidth for Ka-Band

(Continued from page 132)

Generally, there is a tradeoff between the bandwidth and performance as systems move from a superheterodyne-based architecture to a direct-conversion-based architecture.

DATA INTERFACE

Once the data has been digitized by the ADC or transceiver, it must be passed along through a digital interface to be processed by the system. All of the digitizers mentioned utilize the high-speed JESD204B standard, which takes the bits from the data converter and packages them into frames to be transmitted on a small number of traces. The data rate coming out of the chips will vary based on system requirements, but all of the mentioned parts have digital functionality to decimate and frequency shift to accommodate various data rates to suit different system requirements.

This specification allows for up to 12.5 GSPS speeds on the JESD204B lanes, which is fully taken advantage of for high-bandwidth systems passing large amounts of data. Detailed descriptions of these interfaces can be found in the datasheets for the AD9208 and AD9371. Furthermore, selection of the FPGA must take into account this interface. Many FPGAs from vendors such as Xilinx, Altera, and others now incorporate this standard into their part for easy integration with these data converters.

CONCLUSION

The analysis shown has broken down the various tradeoffs and given specific examples of signal chains appropriate for satcom systems operating in the Ka-band. Among the several options presented is a single-conversion-to-high-IF architecture that utilizes the AD9371 integrated transceiver. A similar architecture uses a GSPS ADC in place of the integrated transceiver to increase instantaneous bandwidth. Additionally, a direct-conversion architecture increases bandwidth, but comes at the expense of decreased image rejection.

Although the signal chains presented can be used directly, they are intended to be starting points in the design process. Depending on the system-level application, different requirements will emerge, and a clear path will likely be evident that will favor one signal chain over the other. MW

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Product Feature

CHRIS DeMARTINO | Technical Editor

Microsemi Provides Synchronization for Networks Far and Wide

This new gateway clock is intended to meet the needs of next-generation wireless communication networks while still maintaining the flexibility to support legacy ones.

Timing and synchronization are extremely important aspects of cellular communication networks. Frequency synchronization alone is enough to meet the requirements of older 2G and 3G networks, as well as LTE networks based on frequency-division-duplexing (FDD). However, LTE networks based on time-division-duplexing (TDD), LTE-Advanced (LTE-A) networks, and future 5G networks also require phase synchronization. Utilizing phase synchronization allows for efficient spectrum usage and interference mitigation, making it critical to satisfy the needs of higher-density networks.

One company that is addressing these challenges with its timing and synchronization solutions for current and future wireless networks is Microsemi (*www.microsemi.com*). The company recently introduced the TimeProvider 4100, which is an IEEE 1588 Precision Time Protocol (PTP) gateway clock that provides phase to 4G and 5G base stations (*see photo*). The TimeProvider 4100 offers multiple PTP profiles, and is designed to scale from the edge to the aggregation layers of both mobile infrastructure and access networks.

The TimeProvider 4100 can receive multiple global-navigation satellite-system (GNSS) signals, such as Galileo, GPS, GLONASS, and BeiDou. It also supports Synchronous Ethernet (SyncE) inputs and outputs, as well as 1588 PTP and E1/T1 digital transmission links. Timing flows are distributed to multiple end points, such as base stations.

One benefit of the TimeProvider 4100 is flexibility, as its multiple ports enable it to support current, legacy, and future networks. These ports include four building integrated timing supplies (BITS) ports (E1/T1) and two pulse-per-second/time-of-day (1PPS/ToD) ports. The TimeProvider 4100 also has two 1PPS/10 MHz ports, one GNSS port, and one craft (RS-232) port. The unit also features eight Ethernet ports: two RJ-45 ports and six small form-factor pluggable (SFP) ports.

In addition, the base unit can be upgraded with an optional expansion module that provides 16 additional E1/T1 synchronization ports. Taking advantage of this expansion module therefore brings the total number of E1/T1 ports to 20 (four in the base unit, plus 16 more in the expansion module).

RESILIENCY AND OTHER FEATURES

A layered approach to protection equips the TimeProvider 4100 with resiliency. The GNSS signal can be backed up with Microsemi's assisted partial timing support (APTS), which provides patented asymmetry compensation for time delay.

The next layer of protection involves upgrading the oscillator. Customers have the option of upgrading the standard oscillator to an oven-controlled crystal oscillator (OCXO) or a rubidium oscillator that improves holdover performance. Furthermore, users can take advantage of the dual dc power inputs for power redundancy. Microsemi also offers geographical redundancy through network topology and failover, as two units are deployed—one active and one passive.

System management is an additional feature. The TimeProvider 4100 can be deployed with Microsemi's TimePictra synchronization management system, enabling information monitoring and management capabilities for control of—and visibility into—the entire synchronization network. The solution can monitor both 1PPS and PTP traffic. TimePictra supports the standard fault, configuration, accounting, performance, and security (FCAPS) management functions. mw

The TimeProvider 4100 is an IEEE 1588 gateway clock that can adapt to a wide variety of use cases.

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CHRIS DeMARTINO | Technical Editor

A New Way to Defrost Food

This novel "smart" solution overcomes the drawbacks associated with traditional methods of defrosting.

It's time to defrost food from the freezer. Often, you'll leave it on the counter or in the sink to let it thaw at room temperature. But that usually takes a decent amount of time. Or if there's a need for speed, you'll resort to using the microwave oven, or other similar methods (conventional oven). But using a microwave oven has its drawbacks, as it can result in food with hot and cold spots.

Now there's another option. NXP Semiconductors (*www.nxp.com*) believes it has developed a more effective solution for defrosting food—an automated frozen-food defrosting and thawing reference design. Known as the smart defrost solution, it is intended for consumer and commercial applications. In its own words, NXP says it can "enable healthier frozen-food options for consumers without sacrificing convenience." *Figure 1* shows the RF module that is incorporated into the reference design.

The smart defrost solution is based on NXP's LDMOS (laterally diffused metal oxide semiconductor) technology. "What we've done is taken our solid-state RF power devices and built a solution to create warming energy for food," says Dan Viza, director of RF heating business at NXP.

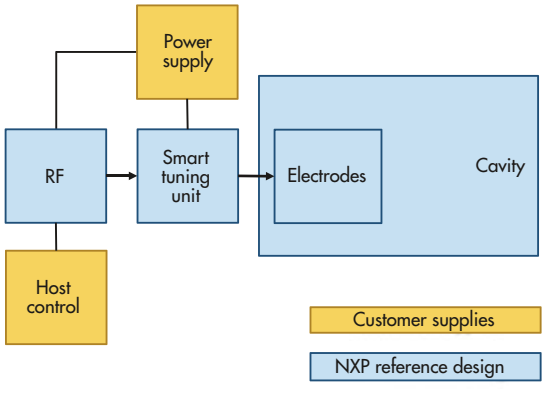
Figure 2 shows a simplified block diagram of the smart defrost solution. The RF module generates the energy used to raise food temperature. The smart tuning unit (STU) can intelligently adjust operation for properties of the food within the defrost chamber. Electrodes then deliver energy into the defrost cavity, which is a shielded, enclosed space for defrosting frozen food. The customer supplies the power supply and host control functionality.

NXP asserts that the smart defrost solution offers several benefits. For one, it defrosts food in minutes as opposed to hours. A wide range of RF power levels is available. The defrost solution can also penetrate food without developing hot or cold spots, retaining moisture and food quality. Another benefit is automatic single button operation that can intelligently stop at the targeted temperature.

The company also believes that its new defrost solution can reduce the amount of wasted food. Essentially, with this solution, more food can be frozen and saved to be eaten later rather than just simply being thrown away.

The smart defrost solution could have multiple implementations. It can be used as a standalone appliance. Alternatively, it may become integrated into appliances from consumer original equipment manufacturers (OEMs). "We have strong engagement with consumer OEMs and we believe our solution will be integrated into appliances within the next 12 to 24 months," says Viza. MW

1. Shown is the RF module that is at the heart of the defrosting solution.



2. This block diagram illustrates the functionality of NXP's smart defrost solution.

SPDT Switch Handles 400 W CW to 500 MHz

THE SSHPS 0.100-0.500-400 single-pole, double-throw (SPDT) switch is designed to handle as much as 400 W CW power from 100 to 500 MHz. It can also transfer signal power levels as high as 1.6 kW peak pulsed power across that frequency range. Insertion loss across its frequency range is low—typically 0.34 dB at 100 MHz, 0.18 dB at 300 MHz, and 0.32 dB at 500 MHz. The solid-state switch draws 550 mA current maximum from a +28 V dc supply and provides 3 µs switching speed. The typical isolation is 39 dB. The rugged switch can handle operating temperatures from –30 to +70°C and is specified to MIL-STD-202G, Method 213.

AETHERCOMM, INC., 3205 Lionshead Ave., Carlsbad, CA 92010; (760) 208-6002, *www.aethercomm.com*

Relay Switches Cover C through Ka Bands

A TOTAL OF 28 pelectromechanical waveguide relay switches have been developed and introduced for applications from 5.85 through 40.0 GHz. The switches, which are designed for systems at C-, X-, Ku-, K-, and Ka-band frequencies, provide signal control in space, test, electronic-warfare (EW), electronic-countermeasures (ECM), radar, and satellite-communications (satcom) systems. They are configured for single-pole, double-throw (SPDT) operation with latching actuators, self-shut-off operation, transistor-transistor-logic (TTL) programming, and position indicators with manual override. A shorting plate can be removed for optional double-pole, double-throw (DPDT) operation. The switches are assembled with a patented motor drive and integrated waveguide ports, with waveguide sides of WR137, WR112, WR90, WR75, WR62, WR42, and WR28. The switches feature insertion loss as low as 0.01 dB and isolation as high as 105 dB. They are designed for operating temperatures from –40 to +85°C.

FAIRVIEW MICROWAVE, 11792 Fitch, Irvine, CA 92614; (972) 649-6678, *www.fairviewmicrowave.com*

High-Q Lowpass Filter Has Passband of DC to 11 GHz

THE ZLSS-11G+ 50-Ω lowpass filter has a broad, low-loss passband of DC to 11 GHz with sharp cutoff and high-rejection stopband that extends to 33 GHz. Fabricated with reliable suspended-substrate-stripline circuit technology, the RoHS-compliant filter has typical passband insertion loss of 2 dB with typical passband VSWR of 2.0:1. Typical stopband rejection is 30 dB from 12.5 to 14.5 GHz and 90 dB or more from 14.5 to 33.0 GHz. The lowpass filter is suitable for rejection of unwanted harmonic signal content in transmitters and receivers. It is supplied in a compact coaxial package measuring 0.90 × 0.70 × 0.60 in. (22.86 × 17.78 × 15.24 mm) with female SMA connectors. The RoHS-compliant filter handles input power levels to 1 W (+30 dBm). It is designed for operating temperatures from -40 to +85°C.

MINI-CIRCUITS, P. O. Box 350166, Brooklyn, NY11235-003; (718) 934-4500, *www.mini-circuits.com*

GaN Chip Amplifier Powers 8 to 12.75 GHz

RICHARDSON RFPD IS NOW providing full design support capabilities for the CHA6710-99F GaN-based two-stage amplifier from United Monolithic Semiconductors S.A.S. The amplifier provides 5.5 W saturated output power from 8 to 12.75 GHz in a chip measuring 2.70 × 2.15 × 0.10 mm. It draws 0.2 A current from a +25 V dc supply. The amplifier exhibits 36% power-added efficiency and 23.5-dB linear gain and is manufactured with a proprietary 0.25-µm gate-length GaN HEMT process. It is available as a bare die.

RICHARDSON RFPD, 1950 S. Batavia Ave., Ste. 100, Geveva, IL 60134; (630) 262-6867, (630) 488-6184; *www.richardsonrfpd.com*

OCXO Locks Onto 100 MHz

MODEL OXO100-1-412 is a 100-MHz stable oven-controlled crystal oscillator (OCXO) constructed to provide low phase noise at that frequency. It is housed in a compact housing with connectors for ease of installation in many applications. It controls sinewave output harmonics to at least –30 dBc with good long-term stability. The crystal oscillator includes an electronic tuning port for making fine frequency adjustments and modulation purposes. This timing source is a good fit for wireless base stations and radar systems.

SYNERGY MICROWAVE CORP., 201 McLean Blvd., Paterson, NJ 07504; (973) 881-8800; *www.synergymwave.com*

Wideband I/Q Mixer Spans 20 to 42 GHz

SUITABLE FOR IMAGE-REJECT receivers and single-sideband (SSB) upconversion in transmitters, the HMC8192 is a passive in-phase/quadrature (I/Q) mixer with an RF/LO range of 20 to 42 GHz and IF range of DC to 5 GHz. It provides high image rejection of 25 dB and high LO-to-RF isolation of 45 dB, with high input third-order intercept point (IIP3) of +22 dBm. The mixer achieves low conversion loss of typically 8.5 dB without any power source. The mixer, which works with +15 to +22 dBm LO power, is fabricated with a GaAs MESFET MMIC process. It is available in a compact 4 × 4 mm 25-lead LGA package and has an operating temperature range of –40 to +85°C. An evaluation board is also available for the mixer.

ANALOG DEVICES, One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106; (781) 329-4700; *www.analog.com*

Meter Measures AC and DC Power

MODEL 5335B IS A compact, single-phase AC/DC bench power meter with 100 kHz bandwidth and measurement range to 600 V RMS and 20 A RMS. It shows measured results on a bright 4.3-in. color liquid-crystal-display (LCD) screen. It includes a bar graph display for harmonic analysis. An optional external current sensor can be used for power calculations on devices that exceed the 20 A RMS limit. An optional breakout box simplifies the AC line connection between the power meter and a device under test (DUT) by eliminating the process of cutting the power cord and stripping wires to connect to the power meter. The meter provides 0.1% basic accuracy for voltage and current measurements.

B&K PRECISION, 22820 Savi Ranch Pkwy., Yorba Linda, CA 92887; (714) 921-9095, *www.bkprecision.com*

Coaxial Adapters Feature Low PIM Levels

RFMW, LTD. HAS ANNOUNCED design and sales support for MECA low-PIM coaxial adapters. Adapters are available with right-angle, bulkhead, in-series, and between-series options. As an example, the ANF-DM-M01 is a Type N female to 7/16 DIN male adapter with a maximum VSWR of 1.25:1 for applications to 8 GHz. The adapters are usable in operating temperatures from –55 to +85°C.

MECA STOCKING DISTRIBUTOR, RFMW, LTD., 188 Martinvale Ln., San Jose, CA 95119; (408) 414-1450, *www.rfmw.com*

Fixed-Frequency PLOs Range 50 to 6,000 MHz

A LINE OF PHASE-LOCKED oscillators (PLOs) features low-noise signal sources suited for use as local oscillators (LOs) in communications and radar systems. Twenty new models covering 50 to 6,000 MHz include units with fixed output frequencies of 50, 100, 500, 1,000, 2,000, 4,000, and 6,000 MHz, and are capable of delivering +7 dBm buffered output power. These are low-noise sources, with typical phase noise of –105 dBc/Hz offset 10 kHz from the carrier, typical harmonics of –25 dBc, and typical spurious content of –70 dBc. They are designed to work with an external 10- or 100-MHz frequency reference and can be supplied in compact surface-mount packages or in housings with SMA connectors. The PLOs, which are built to handle MIL-STD-202 conditions, provide a TTL lock detect output to signify out-of-lock conditions and have an operating temperature range of –30 to +70°C.

PASTERNACK ENTERPRISES, 17792 Fitch, Irvine, CA 92614; (978) 682-6936, *www.pasternack.com*

Low-Noise VCO Tunes 910 to 1,190 MHz

THE MEC91119-10 is a voltage-controlled oscillator (VCO) designed for use from 910 to 1,190 MHz using a tuning range of 20 V dc. It draws maximum current of 29 mA from a +10-V dc bias supply. The VCO supplies at least +2 dBm output power and has tuning sensitivity typically ranging from 13 to 26 MHz/V. Harmonics are typically –3 dBc, while phase noise is typically –114 dBc/Hz offset 10 kHz from the carrier and –134 dBc/Hz offset 100 kHz from the carrier. The VCO is supplied in a RoHS-compliant package measuring 0.5 × 0.5 × 0.180 in. and is capable of handling operating temperatures from –40 to +85°C.

SYNERGY MICROWAVE CORP., 201 McLean Blvd., Paterson, NJ 07504; (973) 881-8800; *www.synergymwave.com*

Surface-Mount 75-Ω Coupler Directs 5 to 1250 MHz

Mini-Circuits' RDC-17-122-75X+ compact surface-mount directional coupler provides 17.6-dB typical coupling from 5 to 1250 MHz. The coupling flatness is an impressive ±0.25 dB across its wide frequency range. It maintains low insertion loss of typically 0.8 dB from 5 through 1000 MHz and typically only 0.9 dB from 1000 to 1250 MHz. The 75-Ω coupler features typical directivity of 20 dB with typical return loss of 24 dB at all ports. The miniature coupler measures just 0.25 × 0.25 × 0.140 in. (6.35 × 7.11 × 3.56 mm) and is well suited for a wide range of broadband applications, including for DOCSIS 3.1 and cable-television (CATV) applications. It handles as much as 1 W input power and is designed for operating temperatures from -40 to +85°C.

Adapter Mates 3.5-mm Connectors to 33 GHz

Mini-Circuits' 35FFL-35F50+ is a rugged coaxial adapter that mates 3.5-mm female to 3.5-mm female connectors and can also be used with SMA connectors. The 50-Ω adapter has a broad frequency range of DC to 33 GHz with typical insertion loss of 0.13 dB and low VSWR. The VSWR from DC to 18 GHz is 1.05:1, from DC to 26.5 GHz is 1.07:1, and from DC to 33 GHz is 1.08:1. The RoHS-compliant adapter has a built-in flange that simplifies connections to the panels of equipment cases without need for extra brackets or bulkhead adapters. The 0.76-in. long (19.3-mm-long) adapter fits in a flange area measuring just 0.5 × 0.5 in. (12.7 × 12.7 mm). It features durable, passivated stainless-steel construction and is designed for operating temperatures from -55 to +100°C.

LTCC Differential Lowpass Filter Passes DC to 540 MHz

Mini-Circuits' DLFCG-540+ is a differential lowpass filter with a passband of DC to 540 MHz and a stopband that extends to 8360 MHz. Based on low-temperature-cofired-ceramic (LTCC) technology, the 100-Ω filter is well suited for filtering signals on balanced 50-Ω lines, such as for analog-to-digital converters (ADCs) and digital-to-analog converters (DACs). The lowpass filter exhibits typical insertion loss of 1.2 dB across its passband with typical VSWR of 1.20:1. The insertion loss is typically 3.0 dB at the frequency cutoff point of 590 MHz. The stopband rejection is typically 26 dB from 720 to 8360 MHz, with typically 31-dB rejection from 890 to 4560 MHz. The RoHS-compliant filter, which handles input power levels to 1 W, is supplied in a ceramic 0805 package with wrap-around terminations measuring 0.079 × 0.049 × 0.033 in. (2.01 × 1.24 × 0.84 mm). It has an operating temperature range of -55 to +100°C.

Coaxial Phase Shifter Varies 360 deg. from 250 to 430 MHz

Mini-Circuits' ZXPHS-431+ is a coaxial voltage-variable phase shifter with 360-deg. phase-shift range across a frequency range of 250 to 430 MHz. The 50-Ω, RoHS-compliant phase shifter uses control voltages of 0 to 15 V dc and a voltage control bandwidth of DC to 50 kHz to vary phase across the full frequency range. Ideal for military communications and signal-processing applications, the phase shifter handles input signal power levels to +20 dBm. It features typical insertion loss of 2.0 dB from 250 to 280 MHz, 3.0 dB from 280 to 380 MHz, and 3.5 dB from 380 to 430 MHz. The typical VSWR is 1.25:1 from 250 to 280 MHz, 1.50:1 from 280 to 380 MHz, and 1.75:1 from 380 to 430 MHz. Supplied with female SMA connectors, the compact phase shifter measures 1.38 × 1.50 × 1.00 in. (35.06 × 38.10 × 25.40 mm) without the connectors. It is designed for operating temperatures from -40 to +75°C.

Power Amplifier Boosts 700 to 4200 MHz

Mini-Circuits' ZHL-15W-422+ is a coaxial high-power amplifier capable of 15 W saturated output power from 700 to 4200 MHz. A good match for communications, radar, and general-purpose test applications, the amplifier provides 46-dB typical gain with ±2 dB gain flatness and 10-dB typical noise figure. The typical output power at 1-dB compression is +39 dBm while typical saturated output power is +42 dBm. The typical output third-order-intercept point (OIP3) is +47 dBm. The RoHS-compliant amplifier, which draws 3.5 A maximum current from a recommended +28-V dc supply, can survive short- or open-circuit conditions at the output while delivering as much as 10 W output power. It includes self-protection for overheating, reverse polarity, and short-circuit conditions. It measures 7.25 x 4.33 x 1.18 in. (184.15 x 110.00 x 30.00 mm) without an optional heatsink with fan and is supplied in a rugged aluminum alloy case with SMA connectors. The operating temperature range is -20 to +50°C.

SMA Cables are Stable with Flexure to 18 GHz

Mini-Circuits' ULC-1FT-SMSM+ is an ultra-flexible test cable with minimum bend radius of 2 in. for applications from DC to 18 GHz. Available in a variety of standard lengths with stainless-steel male SMA connectors, the cables remain stable in amplitude and phase with flexure. For a 2.4-in.-radius flexure, the insertion loss changes typically by 0.01 dB from DC to 6 GHz and by 0.03 dB from DC to 18 GHz. For the same flexure, the phase changes typically by 0.21 deg. from DC to 2 GHz, by 0.69 deg. from 2 to 6 GHz, by 1.45 deg. from 6 to 12 GHz, and by 2.37 deg. from 12 to 18 GHz. For that same flexure, the VSWR changes typically by 0.02:1 across the full DC to 18 GHz bandwidth. The ultra-flexible cables exhibit low loss, with typical insertion loss of 0.2 dB from DC to 2 GHz, 0.3 dB from 2 to 6 GHz, and 0.7 dB or less from DC to 18 GHz. The return loss is 30 dB or better from DC to 18 GHz. The cables are rated for typical power levels as high as 210 W from DC to 2 GHz, to 82 W at 12 GHz, and as high as 67 W at 18 GHz. The operating temperature range is -55 to +85°C.

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DC-100	30	±0.5	0682-30F
DC-250	10	±0.5	0682-10F
Uncalibrated models			
DC-60	40	±1.0	0682-40
DC-100	20	±0.6	0682-20
DC-100	30	±0.5	0682-30
DC-200	30	±2.0	0682-30A
DC-250	15	±1.2	0682-15
DC-500	10	±0.25	0682-10

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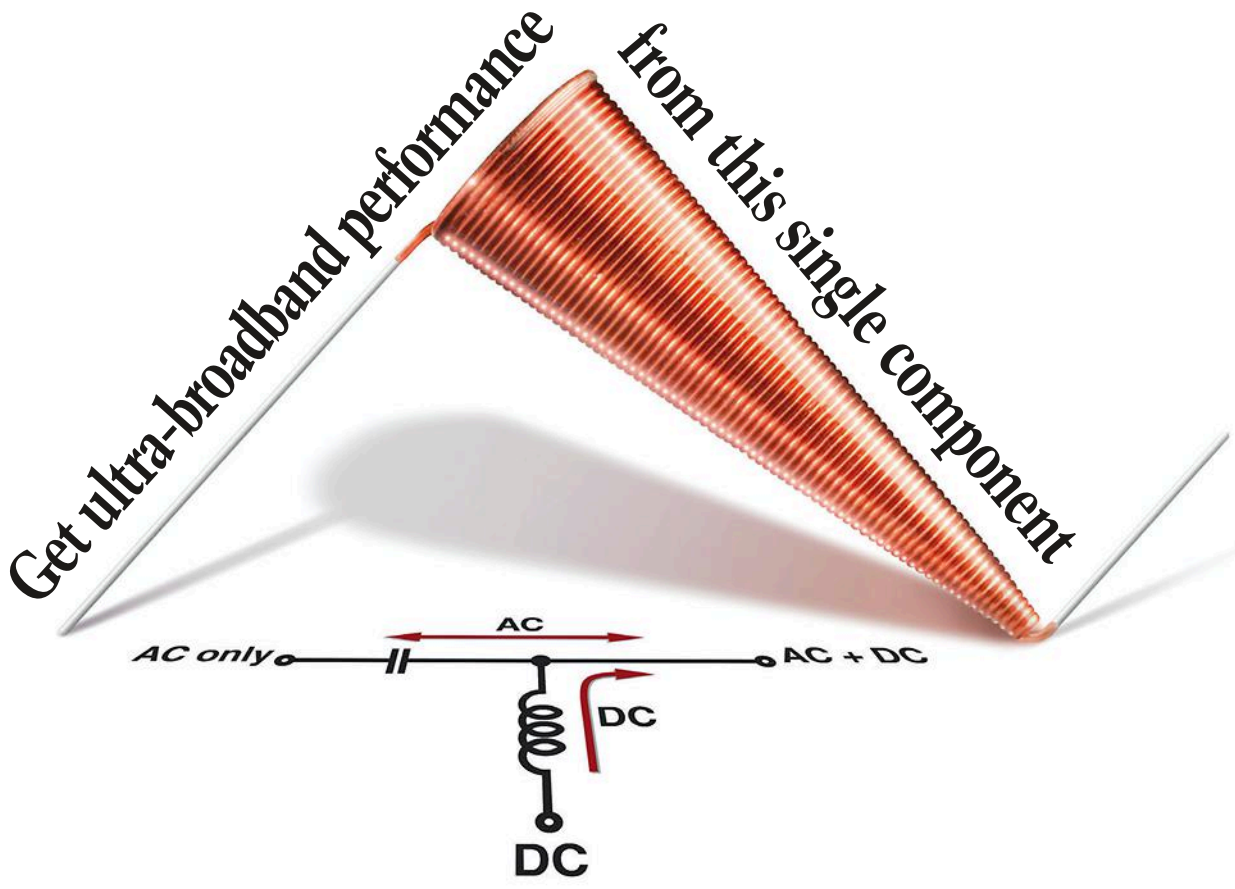

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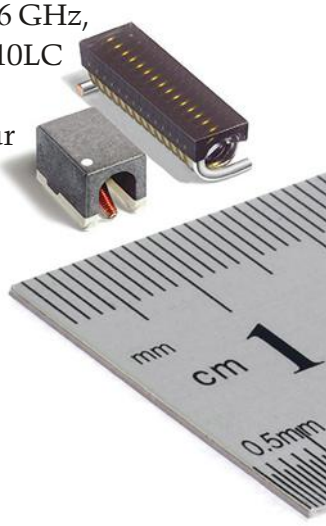

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