High-Speed Data Converters Create Complex Analog Voltage Waveforms p43

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Wideband Amplifiers Add Low Noise Figures to High IP3s p92

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EYE ON THE ENEMY

Unmanned aircraft reach new heights in military surveillance p46

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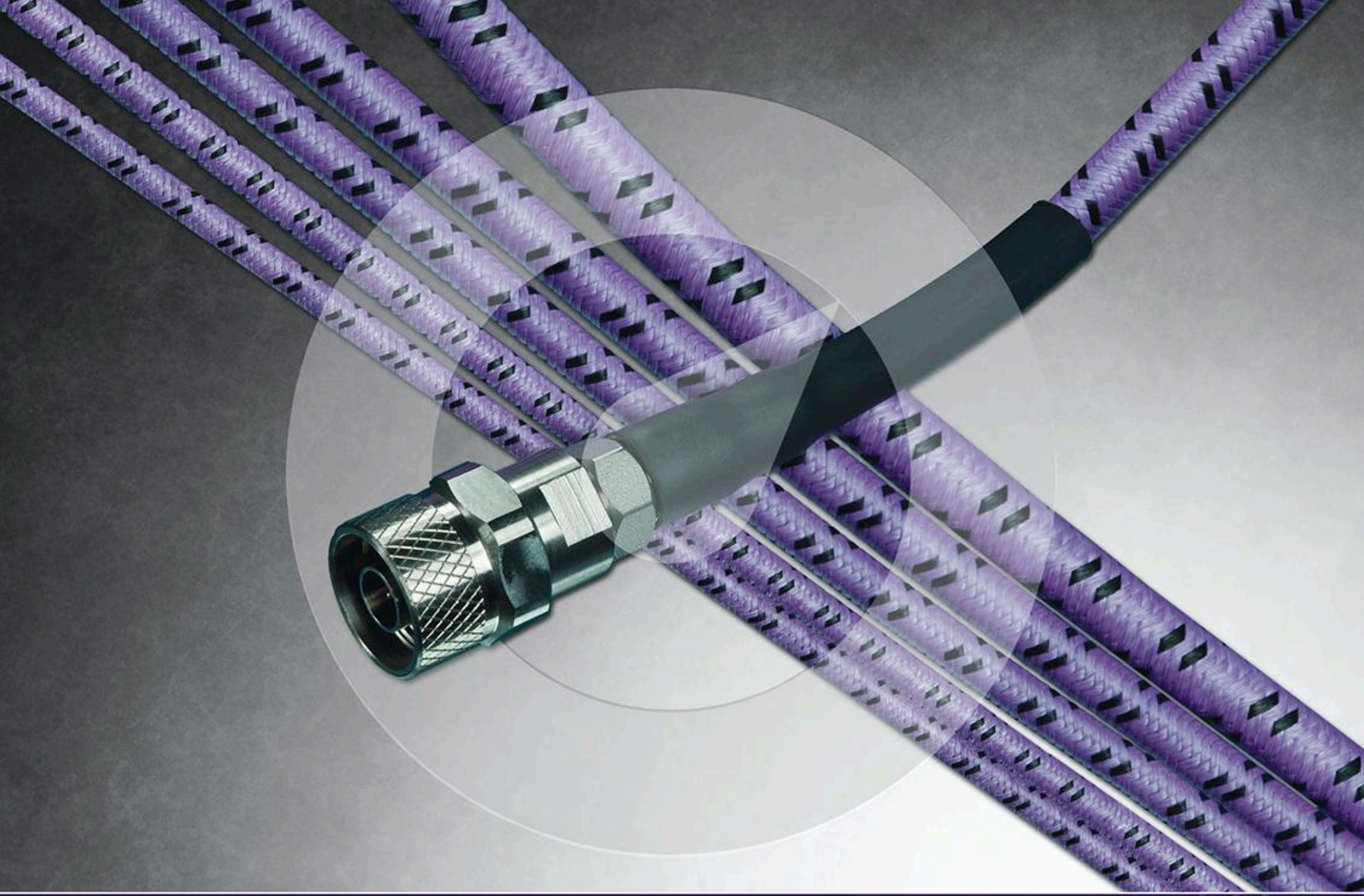

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Software Centricity Seeks to Make the Impossible Possible

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

http://www.mwrf.com/software/software-centricity-seeks-make-impossible-possible

Smart Homes Can Also Deliver Sustainability

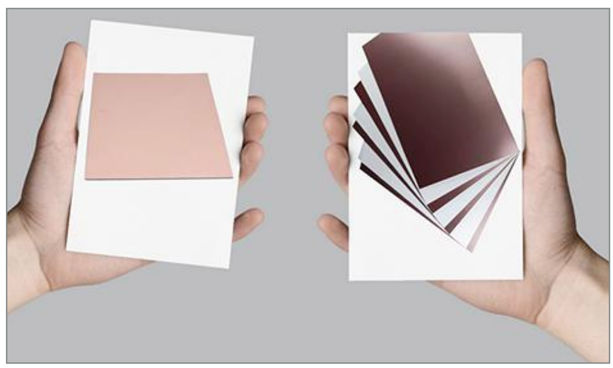
Many discussions surrounding the smart home focus on benefits that can be realized by the people living in them. But a truly smart, connected home is also able to promote sustainability. In addition, it can avoid serious damage to the home by independently identifying waste and avoiding spillage.

http://www.mwrf.com/systems/how-smart-homes-can-deliver-sustainability-service

Don't Let These Excuses Get in the Way of Antenna Testing

With the growing reliance on wireless communications systems, antennas are essential for keeping system users "connected," although they are also often one of the more taken-for-granted components in a wireless communications system. Even so, many design engineers ignore the importance of real-world antenna performance for a number of reasons or excuses.

http://www.mwrf.com/components/don-t-let-these-excuses-get-way-antenna-testing



Should You Choose Hard or Soft PCB Materials?

The number of circuit material choices has grown with time, although most of the materials can still be categorized as being hard/rigid or soft/flexible in nature. Reviewing some of the differences between the two basic types of RF/microwave circuit materials may help clarify when it makes the most sense to use one type or another for a particular high-frequency application.

http://www.mwrf.com/materials/should-you-choose-hard-or-soft-pcb-materials

Editorial

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

Are Print Magazines Less Important to Engineers?

The magazine industry is undergoing a transformation. How does this affect engineers?

It is clear that the way we consume information has dramatically changed. To be more specific, the magazine industry has been—and is being—significantly impacted by the internet coupled with social media. Proving this point, Time Inc. recently announced it will reduce the print issue frequency of prominent magazines, such as *Sports Illustrated* and *Fortune*. The moves were made "amid slumping financial fortunes across the print media industry as readers increasingly follow favorite magazines, newspapers, and other publications online." (The legendary print media company also was recently acquired by Meredith, pointing to more consolidation in the industry.).

Furthermore, the internet enables people to view video content, which can be very beneficial. It also allows people to consume content at any time instead of having to wait for a magazine to arrive in the mail. So with all of this being said, do print magazines still have a significant role in the RF/microwave engineering community? Do engineers still need them? Or can they just find everything online?

Surely, different people have different opinions when it comes to the usefulness of print magazines. I personally believe that they still have something to offer engineers. I know that if I see an article online that I want to read and then keep as a reference, chances are that I will actually print a hard copy. That means that I am essentially still reading something in "print."

The point mentioned is the root of why I think print magazines still have value for engineers. In other words, a very short article or news piece can be quickly read online—even on a smartphone. However, if one sees a longer technical article online and wants to read it and possibly use it as a reference, there is a good chance that person is going to want to have that article in paper to hold in his or her hands. An actual magazine allows one to have a number of technical articles in paper all at once.

So while it is true that print is declining in general, I still think it is beneficial to the RF/microwave engineering community. Hopefully you agree as well. Let us know your thoughts. mw

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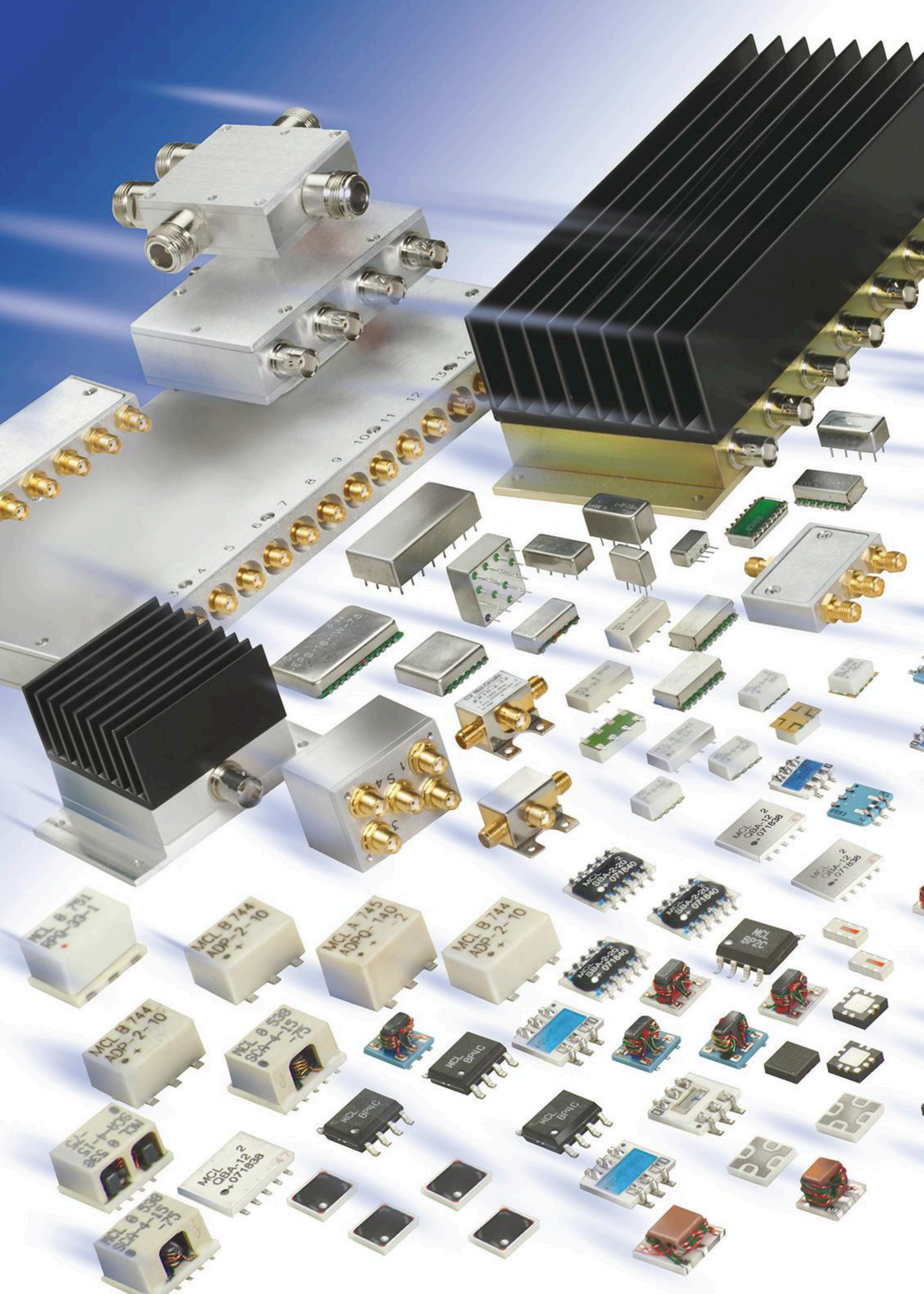
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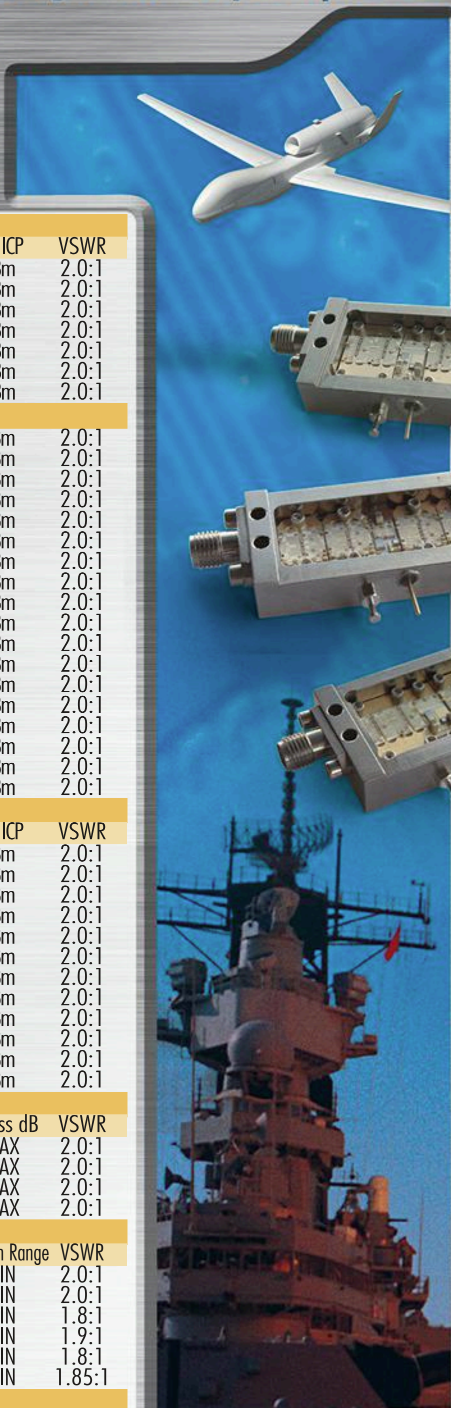

OCTAVE BAND LOW NOISE AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA01-2110	0.5-1.0	28	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA12-2110	1.0-2.0	30	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA24-2111	2.0-4.0	29	1.1 MAX, 0.95 TYP	+10 MIN	+20 dBm	2.0:1
CA48-2111	4.0-8.0	29	1.3 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA812-3111	8.0-12.0	27	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA1218-4111	12.0-18.0	25	1.9 MAX, 1.7 TYP	+10 MIN	+20 dBm	2.0:1
CA1826-2110	18.0-26.5	32	3.0 MAX, 2.5 TYP	+10 MIN	+20 dBm	2.0:1

NARROW BAND LOW NOISE AND MEDIUM POWER AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA01-2111	0.4 - 0.5	28	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA01-2113	0.8 - 1.0	28	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA12-3117	1.2 - 1.6	25	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA23-3111	2.2 - 2.4	30	0.6 MAX, 0.45 TYP	+10 MIN	+20 dBm	2.0:1
CA23-3116	2.7 - 2.9	29	0.7 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA34-2110	3.7 - 4.2	28	1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA56-3110	5.4 - 5.9	40	1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA78-4110	7.25 - 7.75	32	1.2 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA910-3110	9.0 - 10.6	25	1.4 MAX, 1.2 TYP	+10 MIN	+20 dBm	2.0:1
CA1315-3110	13.75 - 15.4	25	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA12-3114	1.35 - 1.85	30	4.0 MAX, 3.0 TYP	+33 MIN	+41 dBm	2.0:1
CA34-6116	3.1 - 3.5	40	4.5 MAX, 3.5 TYP	+35 MIN	+43 dBm	2.0:1
CA56-5114	5.9 - 6.4	30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6115	8.0 - 12.0	30	4.5 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6116	8.0 - 12.0	30	5.0 MAX, 4.0 TYP	+33 MIN	+41 dBm	2.0:1
CA1213-7110	12.2 - 13.25	28	6.0 MAX, 5.5 TYP	+33 MIN	+42 dBm	2.0:1
CA1415-7110	14.0 - 15.0	30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm	2.0:1
CA1722-4110	17.0 - 22.0	25	3.5 MAX, 2.8 TYP	+21 MIN	+31 dBm	2.0:1

ULTRA-BROADBAND & MULTI-OCTAVE BAND AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA0102-3111	0.1-2.0	28	1.6 Max, 1.2 TYP	+10 MIN	+20 dBm	2.0:1
CA0106-3111	0.1-6.0	28	1.9 Max, 1.5 TYP	+10 MIN	+20 dBm	2.0:1
CA0108-3110	0.1-8.0	26	2.2 Max, 1.8 TYP	+10 MIN	+20 dBm	2.0:1
CA0108-4112	0.1-8.0	32	3.0 MAX, 1.8 TYP	+22 MIN	+32 dBm	2.0:1
CA02-3112	0.5-2.0	36	4.5 MAX, 2.5 TYP	+30 MIN	+40 dBm	2.0:1
CA26-3110	2.0-6.0	26	2.0 MAX, 1.5 TYP	+10 MIN	+20 dBm	2.0:1
CA26-4114	2.0-6.0	22	5.0 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA618-4112	6.0-18.0	25	5.0 MAX, 3.5 TYP	+23 MIN	+33 dBm	2.0:1
CA618-6114	6.0-18.0	35	5.0 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA218-4116	2.0-18.0	30	3.5 MAX, 2.8 TYP	+10 MIN	+20 dBm	2.0:1
CA218-4110	2.0-18.0	30	5.0 MAX, 3.5 TYP	+20 MIN	+30 dBm	2.0:1
CA218-4112	2.0-18.0	29	5.0 MAX, 3.5 TYP	+24 MIN	+34 dBm	2.0:1

LIMITING AMPLIFIERS

Model No.	Freq (GHz)	Input Dynamic Range	Output Power Range Psat	Power Flatness dB	VSWR
CLA24-4001	2.0 - 4.0	-28 to +10 dBm	+7 to +11 dBm	+/- 1.5 MAX	2.0:1
CLA26-8001	2.0 - 6.0	-50 to +20 dBm	+14 to +18 dBm	+/- 1.5 MAX	2.0:1
CLA712-5001	7.0 - 12.4	-21 to +10 dBm	+14 to +19 dBm	+/- 1.5 MAX	2.0:1
CLA618-1201	6.0 - 18.0	-50 to +20 dBm	+14 to +19 dBm	+/- 1.5 MAX	2.0:1

AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	Gain Attenuation Range	VSWR
CA001-2511A	0.025-0.150	21	5.0 MAX, 3.5 TYP	+12 MIN	30 dB MIN	2.0:1
CA05-3110A	0.5-5.5	23	2.5 MAX, 1.5 TYP	+18 MIN	20 dB MIN	2.0:1
CA56-3110A	5.85-6.425	28	2.5 MAX, 1.5 TYP	+16 MIN	22 dB MIN	1.8:1
CA612-4110A	6.0-12.0	24	2.5 MAX, 1.5 TYP	+12 MIN	15 dB MIN	1.9:1
CA1315-4110A	13.75-15.4	25	2.2 MAX, 1.6 TYP	+16 MIN	20 dB MIN	1.8:1
CA1518-4110A	15.0-18.0	30	3.0 MAX, 2.0 TYP	+18 MIN	20 dB MIN	1.85:1

LOW FREQUENCY AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure dB	Power-out @ P1-dB	3rd Order ICP	VSWR
CA001-2110	0.01-0.10	18	4.0 MAX, 2.2 TYP	+10 MIN	+20 dBm	2.0:1
CA001-2211	0.04-0.15	24	3.5 MAX, 2.2 TYP	+13 MIN	+23 dBm	2.0:1
CA001-2215	0.04-0.15	23	4.0 MAX, 2.2 TYP	+23 MIN	+33 dBm	2.0:1
CA001-3113	0.01-1.0	28	4.0 MAX, 2.8 TYP	+17 MIN	+27 dBm	2.0:1
CA002-3114	0.01-2.0	27	4.0 MAX, 2.8 TYP	+20 MIN	+30 dBm	2.0:1
CA003-3116	0.01-3.0	18	4.0 MAX, 2.8 TYP	+25 MIN	+35 dBm	2.0:1
CA004-3112	0.01-4.0	32	4.0 MAX, 2.8 TYP	+15 MIN	+25 dBm	2.0:1

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ON THEIR OWN TURF

I read many of your articles with executives or representatives from different companies in the RF/microwave industry, often from the smaller, up-and-coming companies, like Charles Trantanella, the chief scientist at Custom MMIC. But there is also a fair share of interviews with people from the major companies, such as the interview in April with Greg Henderson, the vice president of the RF and microwave business unit of Analog Devices. While these interviews may provide some valuable insights into the operation of a high-frequency electronics company, they never reveal any secrets. Far too often, the person being interviewed is acting like something of a "cheerleader" for the company, and is not about to say anything critical about the company or reveal anything that might help another company's business or manufacturing processes. Especially not a competitor.

This leads me to the request for a different kind of article, not one where you interview someone from another company, but one where you visit the company and write your own observations about how they run their business, what their design area looks like, what their test-and-measurement area looks like, and even how their people behave toward having an outsider (albeit one from your magazine) walking through what might normally be considered a "secure" area.

There have been glimpses of this type of article in your magazine in the past, such as a recent report on an anechoic chamber installed at Synergy Microwave Corp., and those are the kinds of articles that can really set your magazine apart from the rest reporting on this industry. What is the chance that your readers will see more articles in 2018 about the insides of companies?

JONATHAN RAIMI

EDITOR'S NOTE

Thank you for your note and your thoughtful suggestions. The editors on *Microwaves & RF* (Chris DeMartino and Jack Browne) have spoken a great deal recently about "going out in the world" more in 2018. While it has been a practice to attend major trade shows, it is clear that visiting representatives from a company at a trade show is not the same as seeing them in their "own house." While writing about a company following a visit would require full acceptance by the company, and their review and clearance of anything written, such a series of "Inside the Company" reports would no doubt be well read by many, especially competitors and companies trying to emulate the success of a reported company. Keep an eye out in 2018.

JACK BROWNE
TECHNICAL CONTRIBUTOR

INTEL LAYS OUT AMMUNITION in Fight with Qualcomm Modems

Intel announced a new series of 5G wireless modems that will be available in around a year and a half. The new series of chips, called XMM 8000, will support multiple gigabits-per-second speeds.

Intel is laying out the ammunition with which it plans to challenge Qualcomm, which has been ironing out the kinks in its prototype 5G modem. Intel has already taken advantage of Qualcomm's woes with both customers and antitrust regulators, poaching orders of cellular modems that Apple previously sourced only from Qualcomm.

Intel declined to detail the performance of the new chips, which can connect everything from smartphones and tablets to sensors and cars. The silicon squares operate in both sub-6 GHz bands and millimeter waves like 28 GHz. They will support the 5G standard to be approved next month after a complex process led by Qualcomm engineer Wanshi Chen.

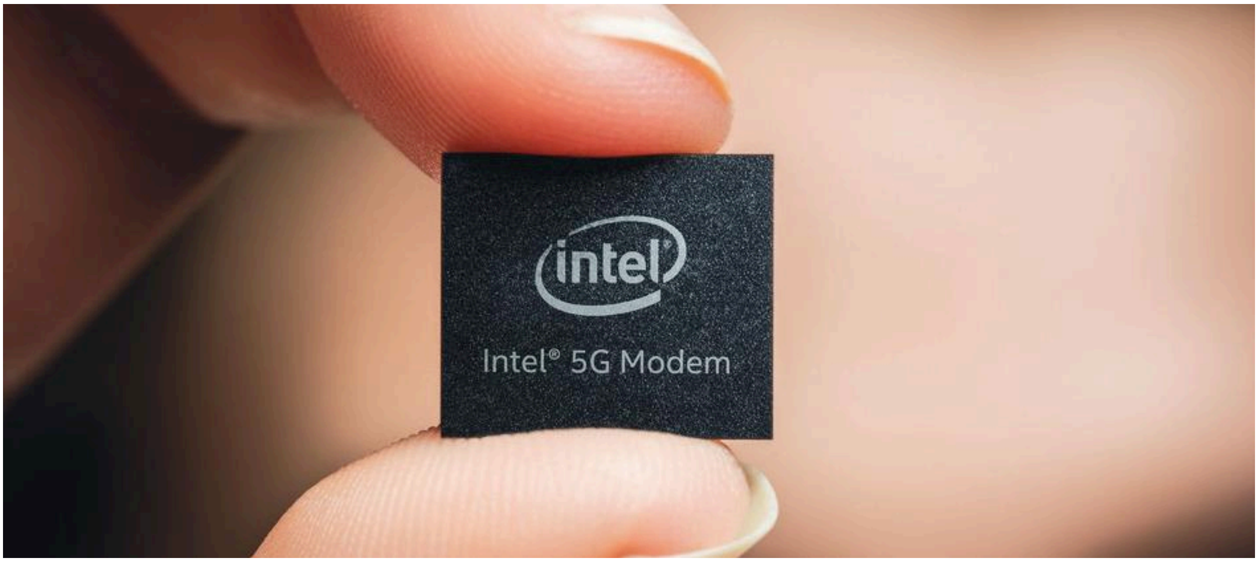
Intel's first chip, called XMM 8060, will be available in the middle of 2019, while the new network infrastructure for 5G networks is expected to be installed starting in 2020. But because it could take many years to create widespread coverage, Intel's modems can also fall back onto 2G, 3G, and 4G networks.

"Today's wireless networks are the equivalent of data driving down a single-lane highway; tomorrow's will need to serve as a multilane superhighway as data moves at warp speed with 5G," said Sandra Rivera, general manager of Intel's network platform group, in a statement. Intel has partnered with companies like Ericsson and Verizon in trials to properly prepare its chips for 5G.

Intel's announcement comes more than a month after Qualcomm trumpeted the performance of its own 5G modem, which it claims will start shipping in smartphones within two years. Qualcomm recently the modem at download rates around 1.2 gigabits per second amid months of legal volleyball with Apple.

Intel also provided the spark for Qualcomm's latest lawsuit against Apple, which allegedly roped an Intel engineer into a confidential email about source code that help in the integration of Qualcomm's basebands. Bloomberg reports that Apple is planning iPhones and iPads for next year without Qualcomm's modems, opting instead for Intel and Mediatek chips.

In the same announcement, Intel said that it had built a 4G modem that operates at 1.6 gigabits per second, and it will be used in commercial devices by 2019. For 5G, both Intel and Qualcomm are targeting a bandwidth of five gigabits per second, which would be around two orders of magnitude faster than what a typical smartphone does today. ■



KEYSIGHT REOPENS HEADQUARTERS Singed and Bruised by Wildfires

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 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.

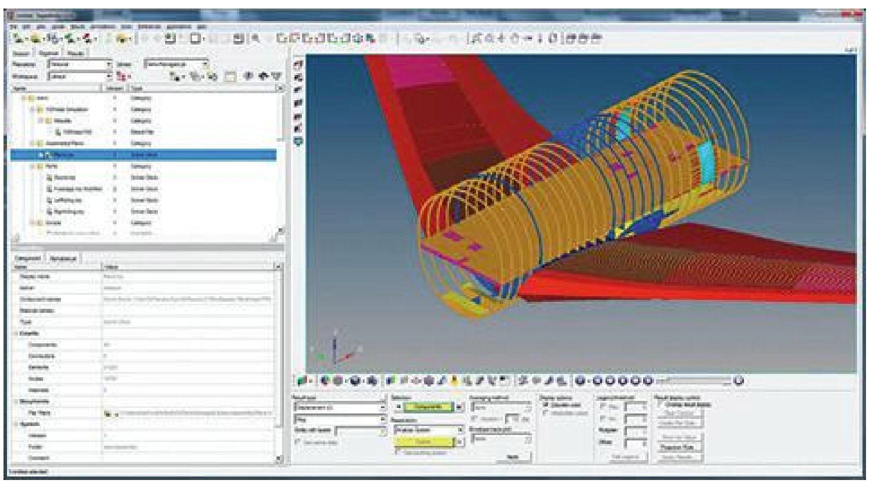
However, other lost property might not be easily replaced. Keysight, the former test division of Hewlett Packard spinoff Agilent Technologies, confirmed in a statement to trade publication *EETimes* that the flames had consumed a cache of historical documents from founders Bill Hewlett and Dave Packard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

ALTAIR ENGINEERING BLOOMS Eas Prototyping Shifts Toward Software

ALTAIR ENGINEERING, which sells simulation software for analyzing antenna interference, aerodynamics, and other effects, rounded off an initial public offering after raising almost $180 million from the sale of its first cache of stock.



The company, which is based in Troy, Mich., has bloomed as electrical engineers spend more time prototyping products from rockets to wearables in virtual software labs. The firm, which is profitable, sells simulation software to customers like SpaceX, Facebook, and Daimler, which run it on racks of high-performance servers.

Last month, Altair disclosed that it planned to raise $144 million in an initial public offering priced at $13 per share. Since the company went public in late November, its stock price has swelled. At press time, the stock was trading at around $19.40 per share, valuing the software firm at almost $1.2 billion.

Altair's software is an increasingly important tool for RF engineers, said Ulrich Jakobis, Altair's head of electromagnetic solutions, in a recent interview. The company's Feko software can be used for prototyping antennas and placing them on connected cars, airplanes, and ships where they are safe from wireless interference, he said.

"Almost everybody in the tech world actually is a customer," said James Scapa, Altair's chief executive, in an interview with TechCrunch. Last year, Altair's revenues were $313 million, up from $294 million the previous year. The company, which was founded in 1985 and employs around 2,000 employees worldwide, reaped profits of $10.2 million.

The company's competitors include France's Dassault Systèmes, which owns electromagnetic software maker Computer Simulation Technology. Another rival is Ansys, which recently updated its core software to simulate how wireless signals react to colliding with trees and buildings as well as hitting patches of interference and rainfall.

Over the last year, Altair has been expanding into tools that aid chip designers. In May, it bought the electronic design automation firm Modeliis, giving it a foothold in software dominated by the likes of Cadence and Synopsys. In September, it acquired RunTime Design Automation for tools that schedule simulation jobs run inside data centers. ■

REGULATORS CRIMP CONNECTED Vehicle Mandate, Report Says

THE TRUMP ADMINISTRATION may have shelved a mandate to require that cars share their location, speed, and other information wirelessly. The technology could detect when another vehicle brakes suddenly or speeds around a blind corner to warn the driver or avoid a collision.

The Associated Press reported that officials had stopped pursuing a rule that would require all news cars to be equipped with vehicle-to-vehicle communications, or V2V. The reversal would fit the Trump's hostility toward regulations but endanger technology that transportation officials have said could prevent or mitigate four out of every five accidents not involving drugs or alcohol.

The technology is based on dedicated short-range communications (DSRC) that enables cars to send messages to each other 10 times per second. It could be installed in traffic lights and stop signs, so that cars could leave alerts about slippery road conditions for vehicles out of its 1,000-foot range. It could be used in phones to give cars a map of pedestrians.

The proposed rule would require all new vehicles to be manufactured with V2V technology within four years, but with older cars still on the road, it would take years for the technology to make a significant impact. The Obama administration proposed the rule last December and expected a mandate to be released in 2019.

Without the mandate, it could take longer for V2V technology to catch on. In the meantime, other companies could move onto 5G communications to connect cars. The end of the mandate could also bolster cable companies lobbying to appropriate parts of the 5.9 GHz spectrum used by V2V technology.

The Associated Press report said that "decisions on the matter are being made at higher levels of the administration." The National Highway Transportation and Safety Administration denied that the rule is dead in a statement to technology news site ArsTechnica. The agency said it is still mulling over 460 public comments on the mandate. ■

CLIMACELL FORECASTS THE WEATHER by Dissecting Wireless Signals

CLIMACELL IS MAKING unusual use of the wireless networks that connect smartphones and other gadgets. The startup analyzes disturbances in wireless signals that could indicate rain, humidity, or other weather conditions, and it provides forecasts to businesses like airlines, shipping companies, and utilities.

ClimaCell partners with wireless companies that share massive amounts of data about the behavior of wireless signals as they travel over the air to and from base stations. Taking advantage of the sensitivity of these signals to interference, the company claims that it can predict the weather in an area as small as an individual city block.

The company, which was only founded in 2015, can refresh its weather models every minute, allowing it to forecast six hours into the future. But the company combines its conclusions with data from other sources like the National Oceanic and Atmospheric Administration, which operates a battalion of satellites and radar systems, to refine its forecasts.

"What we're accessing is signals and measurements from a variety of networks," said Shimon Elkabetz, chief executive and one of the founders of ClimaCell, in a blog post. "We are assembling the networks constantly, analyzing the signals very fast, integrating them with NOAA data, and then plugging everything together in a model."

The company, based in Boston, recently raised $15 million in funding to compete with IBM's The Weather Company and Monsanto's The Climate Corporation as well as startups like Spire, which wants to launch a constellation of weather satellites and sell what they see to the agriculture and transportation industries.

For ClimaCell, the new funding will be used to target customers outside the United States. Elkablatz also said in an interview with technology website Xconomy that the funding would be used to refine its software and double its employee ranks to around 50 people. It previously raised around $5 million, according to venture capital database Crunchbase.

ClimaCell lets customers either access its weather maps over the cloud or use a programming interface to integrate its software. The company already licenses software to airlines, which can use ClimaCell's forecasts to plan flight routes or instruct pilots not to taxi if inclement weather will prevent them from taking off.

Other industries like shipping and ride-sharing could also benefit. (Fortinalis, an investor in transportation start-ups like Lyft and Nutonomy, chipped into ClimaCell's funding round). The company's forecasts could also be used to help plan when to plant, harvest, and transport food. Or as another source of information for emergency management agencies.

And these industries stake billions of dollars on weather forecasts. Almost three-fourths of air traffic delays are caused by weather, at a cost of $6 billion per year to airlines, says the American Meteorological Society. Utilities generate electricity based on temperature forecasts, and in the United States that saves them more than $150 million per year.

"By shifting from forecasting to more accurate, granular, real-time predictions— 'what we call nowcasting'—ClimaCell is changing the way massive industries assess, manage and make decisions around weather risk," said Rich Boyle, general partner at investment firm Canaan, in a statement. ■

LEARN HOW TO CALCULATE the Phase Center of an Antenna

Wireless functions such as Internet of Things (IoT) devices continue to increase and fill the environment with electromagnetic (EM) waves. Antennas are needed in support of those growing wireless functions, and it can be helpful to know about the characteristics of different antennas, for example, how to find the phase center of an antenna. When performing a far-field approximation of an antenna far from the antenna itself, assuming that the phase center of the antenna occurs at the physical center may be adequate at a far enough distance from the antenna. But closer to the antenna, actual knowledge of the phase center and how to find it can be helpful for some applications.

The phase calculation method involves careful linear measurements to find the phase center of each antenna. Linear measurements were made across several axes of each antenna, with good agreement found between the measurements and simulations conducted to predict where the phase center of the antenna should be in each case. Although there were some concerns for using the measurement approach to find the phase center of highly directive antennas, the calculations are relatively simple and can be applied in situ to estimation the physical phase center of many different mechanical antenna types.

When the model for calculating the phase centers of the antennas was applied to a number of different types of antennas, the results were consistent with measured results and consistent is estimating the different antenna characteristics. The positions of the phase centers for each structure went through little variation in the overall results with consistency that implies the accuracy of the measurement and estimation method. The method is designed to be simple and straightforward and to be applied in real time while working on a particular antenna design.

See "Calculating the Phase Center of an Antenna," *IEEE Antennas & Propagation Magazine*, Vol. 59, No. 5, October 2017, p. 130.

MAKE RFID TAGS PRACTICAL Enough to Make Sense

IN THEORY, RADIO-FREQUENCY-IDENTIFICATION (RFID) tags provide the means of adding wireless labels to clothing or other merchandise almost anywhere and at any time, if those RFID tags can be made inexpensively enough to be practical. To find out, a research study took a look at four different ways to prototype flexible UHF RFID tags: based on ink-jet printing, wax-based ink deposition, cutting plotter shaping, and screen printing. An RFID chip from manufacturer Impinj (Seattle, WA) was used with the antennas as part of the evaluation.

The antennas were fabricated on layers of polyimide (PI) Kapton HN material from Dupont (Wilmington, DE) with all four fabrication processes used to form antennas. One of the antennas was a design recommended by the RFID chip manufacturer; the other antenna was designed just for the research project. A total of eight different RFID antennas were fabricated for the research project, two of each antenna design for each fabrication process, to evaluate the nuances of the different fabrication processes. Antenna designs described as thin propeller (TP), as recommended by the RFID chip manufacturer, and trapezoidal meandered (TM), as created for this research project, were fabricated with each process to study the effects of the process on each antenna's basic performance parameters.

The different RFID tags were evaluated for tag sensitivity and radiation pattern, which is useful when analyzing tag behavior when varying its angular position with respect to the RFID reader antenna. Measurements on the tags representing the four different fabrication processes were performed at both the European RFID standard frequency of 866 MHz and the U.S. standard frequency of 915 MHz. The metal traces for both antennas are 1 mm wide. The gaps between adjacent metal lines ranges from 1 to 2 mm in the TP antenna and always 0.76 mm for the TM antenna case.

In addition to sheet resistance measurements of the metal conductors, a commercial model E5071C vector network analyzer (VNA) from Keysight Technologies *(www.keysight.com)* was used to measure the scattering (S) parameters of the antenna circuits. A special differential test fixture and custom calibration kit were used with the VNA to make measurements on the eight different printed-circuit RFID antennas.

During the study, all of the fabrication processes were found to be suitable for constructing RFID antennas with acceptable performance for the U.S. and European RFID tag standards. The processing approaches in the number of circuit layers fabricated and thus the amount of printing materials required to assemble a given RFID tag antenna, so the cost of the different fabrication approaches will differ. But, as the researchers note, parameters other than electrical performance, such as cost, processing time, and robustness can be used as differentiators among the fabrication processes to determine which process makes the most sense for a particular RFID (or other) antenna application.

See "Comparison of Fabrication Techniques for Flexible UHF RFID Tag Antennas," *IEEE Antennas & Propagation Magazine*, Vol. 59, No. 5, October 2017, p. 159.

News

NANCY FRIEDRICH | Content Director

Inside TRACK with Hagit Messer

Professor at the School of Electrical Engineering, Tel Aviv University

In recent years, the U.S. microwave industry has put more emphasis on attracting and retaining women engineers. The Israeli industry faces many similar and yet some different issues.

In recent years, Women in Microwaves—a subset of the IEEE Women in Engineering (WIE)—has created networking opportunities, recognized accomplished women in the industry, and delved into why women do not enter or stay in microwave engineering. Typically, much of this effort is put into events during Microwave Week, when the International Microwave Symposium is held. This year, a special session on Women in Engineering is also being held at the IEEE Conference on Microwaves, Communications, Antennas, Electronic Systems, and Bio-Medical Engineering (COMCAS), which takes place in Israel. Nancy Friedrich, content director for *Microwaves & RF*, recently had a chance to talk with Hagit Messer, an endowed Professor at the School of Electrical Engineering, Tel Aviv University, about why she put together this event and the issues women in Israel in particular face that may cause them to leave engineering.

What do you think are the biggest issues faced by efforts to bring and keep more women in engineering?

Messer: Women in engineering are facing a three-pronged challenge:

1. Bringing girls/young women into STEM.
2. Breaking the glass ceiling by making sure women are promoted as men are.
3. Fixing the "leaky pipe," which is a term for how we successfully bring young women in via STEM, succeed in having them get engineering degrees and subsequently jobs, but then lose them about 10 years later when they leave for various reasons. This is a problem particularly in Israel, where relatively many women go into engineering, do brilliant work, do well in their careers, but still opt to change careers a decade or so into their work lives. It should be noted that according to Intel, this leaky pipe issue affects other diverse populations beyond women.

What do you think causes this phenomenon of the leaky pipe?

Messer: I'm not certain, but based on my experience I can suggest some reasons. They are of course important ones, as no one would lightly throw away all that investment—their own and from the university and industry—after 10 or so years. The first would be family, as engineering is hard to do part-time—especially in a startup environment, where you're often judged by the time you put in instead of what you accomplish. The second is that not all engineers feel fulfilled simply bringing more money to shareholders; they want to feel that they do more for people. Finally, women in particular will complain about the masculine culture. They complain that they have to raise their voices to be heard and if they don't, they won't be counted.

Do you think any of these issues are more pronounced in Israel?

Messer: It is common in Israel for families to have more children, typically three or more. So that certainly is a factor. If you feel the tension of career versus family, many women are not comfortable choosing career. When faced with missing your child's "firsts," for example, writing code is not very fulfilling emotionally. Israel is also a bit unusual because its society isn't necessarily considered to be polite. You can criticize your coworkers openly, but that may make some people feel more pressured. It should be noted that engineers make good money—up to five times more than a teacher—but still, successful women engineers choose teaching. And there is almost no unemployment in Israel.

Are there any initiatives in Israel that focus on Women in Engineering?

Messer: Yes, private initiatives, but most of them provide tools for women to be more like men, such as networking. I think it might work better to create a female culture at some companies, rather than help women fit into a male culture. Other initiatives have experienced women come in to mentor the younger women. Advantages like flexibility could keep a lot more women in engineering, but it's easier for established companies like Google, Microsoft, and Intel to provide that than it is for others.

What are you most hoping to get out of the Women in Engineering event at IEEE COMCAS?

Messer: The ultimate goal is to make team leaders, CEOs, etc. more aware of the experience women have in their groups. We have a panel of four women engineers to provide different points of view, which I hope will help us identify the issues preventing women from staying in engineering in Israel. One is a senior officer, so she can provide the management perspective. The second works at a high-demand company where she helped improve the situation for women in that company in various ways, eventually getting help and recognition from the CEO for those efforts. The next speaker chose a specific engineering job because she wanted to do meaningful work. The last panelist is one that left engineering, who can give her perspective on why she left and what could have prevented her from making that decision.

The event also will offer a talk from in the former head of HR at Microsoft Israel, who will address various efforts she has participated in regarding women in engineering. Sherry Hess from AWR will talk as well to give some international perspective. Finally, we will share the results from a survey we did, asking professional women if they were happy in engineering, why or why not, what changes would make them happier in their jobs, why they might think of leaving, and more.

Thinking about your own engineering career, how did you get your start?

Messer: Maybe from my father; he never had any gender bias. He was a self-made man, having come alone to Israel at 16 after losing his whole family in the Holocaust. He would say, "You can do whatever you want to do." So when I was serving in the Israeli Army and working in the radar unit, I became interested in electronics. From there, I studied electrical engineering at university.

I was always interested in everything and, when you're an engineer, you can do so many things: research and development, teaching, management, and more. If you're, say, a social worker, you can work with people but not do engineering. I realized I wanted to have my degree in engineering and do various things in and related to that field.

What are you working on these days?

Messer: I'm actually getting involved in new startup with a different structure that's more focused on an environment that better fits women.

I also understand you're doing some very interesting research to measure rainfall from the ground up using signal attenuation from records of telecom carriers. Can you describe this in more detail?

Messer: A large part of the cellular backhaul network is based on microwave links, which are sensitive to changing conditions in the propagation channel and mostly weather. In 2005, we pioneered the suggestion to use existing measurements taken by standard network management systems for environmental monitoring. Our first paper was published in Science on May 2006. It received much attention because with this technology, data from widespread cellular networks can be used for accurate, high tempo-spatial resolution weather monitoring.

How many students have participated in this weather monitoring to this point?

Messer: Our research group is as unique as it is cross-disciplinary, with graduate students ranging from EE to earth sciences. In any given time, we have about 10 members in the group. By now, we have had about 20 graduates, published more than 50 papers with manuscript citations, and do excellent research collaboration with other groups studying and applying our technology.

Anything else you want to add?

Messer: During my long career, which also includes high-level academic administrative positions, I was active in promoting women to science and engineering. I strongly believe that having and retaining more women in engineering is not only fair and good for them; it is also highly beneficial to science and engineering. Women do think differently than men. They therefore bring new ideas and innovative solutions. I think that my innovative idea for transforming commercial microwave links into virtual weather stations is one such example. mw

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CHRIS DeMARTINO | Technical Editor

See How This New VNA STACKS UP

Earlier this year, Tektronix introduced its new TTR500 Series. In this article, a bandpass filter measurement example is presented to demonstrate what this new VNA can do.

In past years, the oscilloscope was likely the first instrument that came to mind when thinking of Tektronix *(www.tek.com)*. This thinking was certainly justified, as the company's history with oscilloscopes dates back many years. However, while Tektronix is clearly still at the forefront of this area, the company now offers a wide range of other test-and-measurement instrumentation. These instruments include spectrum analyzers, vector signal generators (VSGs), arbitrary waveform generators (AWGs), and more.

However, one critical test instrument still had not been offered by Tektronix: the vector network analyzer (VNA). That finally changed earlier this year when the company released its new TTR500 Series of USB-based VNAs.

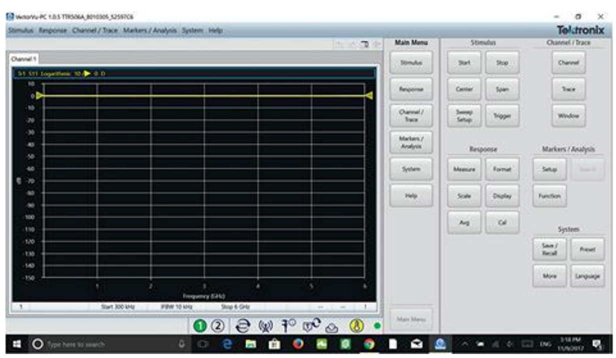
This article takes a firsthand look at a TTR500 Series VNA thanks to a demo kit the company provided. For purposes of the demonstration, a bandpass filter measurement is described here. While measuring a bandpass filter with a VNA may seem like something pretty basic to some engineers, the example presented is intended to illustrate how the TTR500 Series has a rightful place in the VNA arena.

GETTING STARTED

The TTR500 Series consists of two models: the TTR503A and the TTR506A. The TTR503A covers a frequency range of 100 kHz to 3 GHz, while the TTR506A covers a frequency range of 100 kHz to 6 GHz. A TTR506A VNA was used to perform the measurements that are discussed later in this article *(Fig. 1)*.

The TTR500 VNAs connect to a laptop or desktop computer via a USB cable. This connection allows measurement acquisition to be separated from analysis. The end result is a VNA that can easily be carried from one location to another.

1. Shown is a photo of the actual VNA used to perform the measurements described throughout this article.



2. The VectorVu-PC software is used in conjunction with the TTR500 Series VNAs.

To operate the TTR500 VNAs, one must download Tektronix's VectorVu-PC software. In a sense, VectorVu-PC is the VNA equivalent of Tektronix's SignalVu-PC software, which is used with the company's spectrum analyzers. *Figure 2* shows the VectorVu-PC software when first starting the program with the TTR506A VNA connected to the computer. Typical VNA functions can be seen.

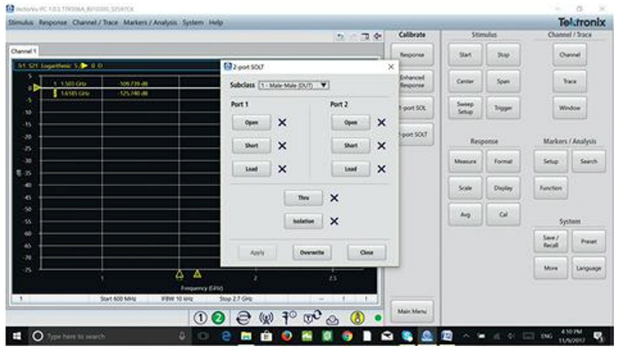
The device-under-test (DUT) in the measurement example that follows is Mini-Circuits' *(www.minicircuits.com)* NBP-1560+ bandpass filter *(Fig. 3)*. This filter has a passband from 1,500 to 1,620 MHz. It is built with a type-N male connector on one side and a type-N female connector on the other.

3. Shown is the actual bandpass filter that was used as the DUT.

TWO-PORT CALIBRATION

Of course, calibration is critical for making VNA measurements. For this example, calibration was performed over a frequency range of 600 MHz to 2.7 GHz. One can perform calibration by clicking the *Cal* button in the *Response* section of the VectorVu-PC user interface. Selecting *Cal Kit* then allows users to select from several built-in calibration kits. For this example, the BN533844 calibration kit from SPINNER *(www.spinner-group.com)* was used *(Fig. 4)*.

4. This figure shows the calibration kit used to calibrate the VNA.

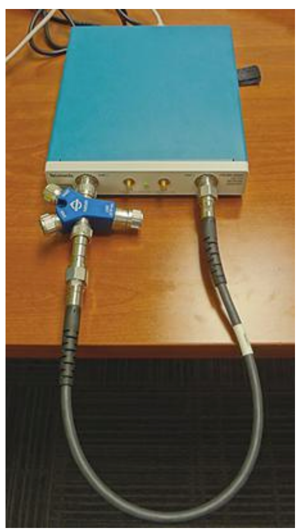


5. Users will see this interface upon selecting *2-port SOLT* calibration.

Next, by selecting *Calibrate*, users can choose from different calibration options. For this example, *2-port SOLT* was selected. *Figure 5* shows the user interface after clicking *2-port SOLT*.

The calibration procedure was then carried out in order. After directly connecting the *OPEN* port of the BN533844 calibration kit to *Port 1* of the VNA, the *Open* button was clicked. *Port 1 Short* and *Load* calibration steps were then performed by the same process of connecting the BN533844 *SHORT* and *LOAD* ports, respectively, to *Port 1* of the VNA. The same process was carried out for the *Port 2* calibration steps. The only difference is that a cable with type-N male connectors on both ends was actually connected to *Port 2* of the VNA. This cable was required to actually measure the filter. Thus, the calibration kit ports were not connected directly to *Port 2* of the VNA, but rather the end of the cable that was connected to *Port 2*.

After completing the *Port 2 Open, Short,* and *Load* calibration steps, a *Thru* calibration was carried out. Performing a *Thru* calibration required one of the *THROUGH* ports of the calibration kit to be connected to *Port 1* of the VNA while the other *THROUGH* port was connected to the cable connected to *Port 2 (Fig. 6)*. Once a calibration procedure is complete, users can save the calibration file by first clicking the *Save/Recall* button in the *System* section and then selecting *Save*.



6. This photo shows the test setup when performing a *Thru* calibration.

It also should be noted that an additional calibration step was needed to compensate for the connection change between the calibration and measurement setups. When performing the *Port 2* calibration steps, an adaptor with a type-N female connector on

both sides was used in order to connect the end of the cable to the calibration kit ports. However, that adaptor was not actually used in the measurement setup.

For the measurement setup, an adaptor with a type-N male connector on one side and a type-N female connector on the other side was used. This adaptor was placed between the end of the cable connected to *Port 2* and one side of the bandpass filter. *Figure 7* shows both adaptors (For the description that follows, the adaptor with a type-N male connector on one side and a type-N female connector on the other side is referred to as the “measurement adaptor.”)

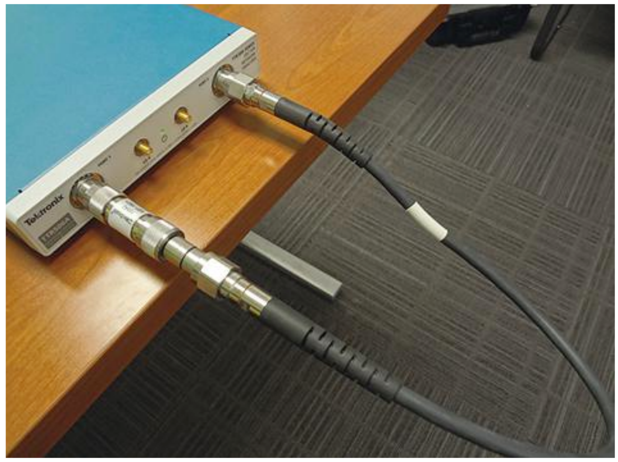
7. Shown are the adaptors used to perform calibration and measurements, respectively.

Because the two adaptors have different electrical lengths, an additional calibration step was needed. This additional step, known as *Port Extension*, was carried out by connecting one side of the measurement adaptor to *Port 1* of the VNA and the other side to the end of the cable connected to *Port 2*. After clicking Cal, the *Port Extension* button was selected. A delay time of 25 ps was entered, as this value is the approximate delay time that must be compensated for in this example.

MEASURING THE FILTER

Next, the filter was connected *(Fig. 8)*. Before discussing the actual filter measurements, it is helpful to first discuss some of the options that users can choose from when using VectorVu-PC. For one, clicking the *Format* button in the *Response* section subsequently displays a number of format types. These formats are *Log Mag, Phase (Deg), Phase (Rad), Group Delay, Lin Mag, SWR,* and *Real*. In addition, selecting the *More* button displays these additional formats: *Imaginary, Phase Units, Expanded Phase, Positive Phase, Smith,* and *Polar*.

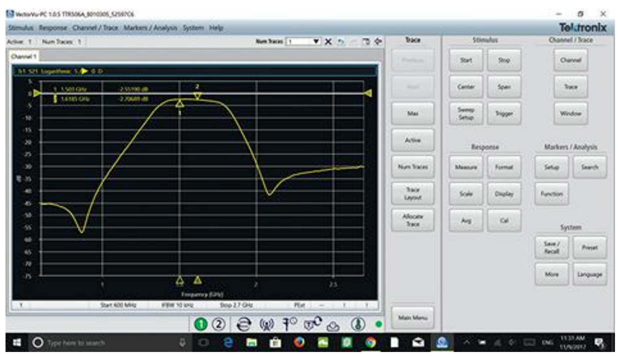
Also, clicking on the *Measure* button in the Response section subsequently displays *S11, S21, S12, S22*, and *Absolute*. *Figure 9* shows an *S21* measurement in *Log Mag* format of the bandpass filter over the calibrated frequency range.



8. This photo shows the DUT connected to the VNA.

A couple of additional points should be noted. First, while *Fig. 9* shows one trace being displayed, users have the option of displaying multiple traces by clicking the *Trace* button in the *Channel/Trace* section. One would then select *Num Traces* to specify the number of trace displays.

Furthermore, clicking the *Trace Layout* button subsequently allows users to select from a number of trace layout options. *Figure 10* shows four traces being displayed using the *D12_34*



9. This VectorVu-PC plot illustrates an *S21* measurement of the DUT.

10. The software allows multiple traces to be displayed simultaneously.

Although not demonstrated in this article, the TTR500 also includes bias tee input ports located on the rear panel. Applying dc bias to these ports allows dc voltage to be supplied to a DUT via the inner conductor of the VNA. This feature can simplify test setups by eliminating the need for additional external hardware.

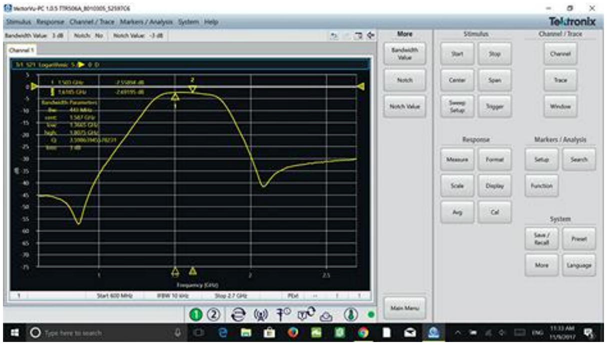
trace layout option. As can be seen, these settings can allow four S-parameter measurements to be viewed simultaneously.

Another notable point is the *Bandwidth* feature, which could be very useful when measuring filters. This feature can be accessed by first clicking the *Search* button in the *Marker/Analysis* section and then by clicking the *Bandwidth* button. Utilizing this feature displays a DUT's bandwidth, center frequency, low and high frequencies, and Q-factor. *Figure 11* shows the *S21* measurement of the filter with the *Bandwidth* function turned on. While *Fig. 11* displays a measurement with the *Bandwidth Value* option set to 3 dB, users can enter any desired bandwidth.

Of course, phase response is also significant in terms of VNA measurements. As stated earlier, *Phase (Deg)*, *Phase (Rad)*, and *Group Delay* measurements are made possible by clicking the *Format* button. Selecting *Phase (Deg)* displays a phase measurement in degrees that is bounded by ±180 deg. Alternatively, selecting *Expanded Phase* displays a phase measurement in degrees that is not bounded by ±180 deg. *Figure 12* shows both *Phase (Deg)* and *Expanded Phase* measurements of the bandpass filter.

TOUCHSTONE FILES AND OFFLINE ANALYSIS

Touchstone files and offline analysis are two additional features that should be mentioned. Essentially, when measuring a DUT, such as the filter used here, the measurement data can be saved in the form of a touchstone file. To create a touchstone file, one would click



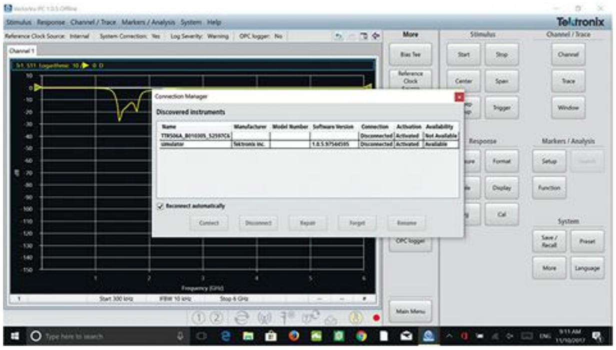
11. Shown is an *S21* measurement with the *Bandwidth* feature turned on.

12. This image shows both *Phase (Deg)* and *Expanded Phase* plots.

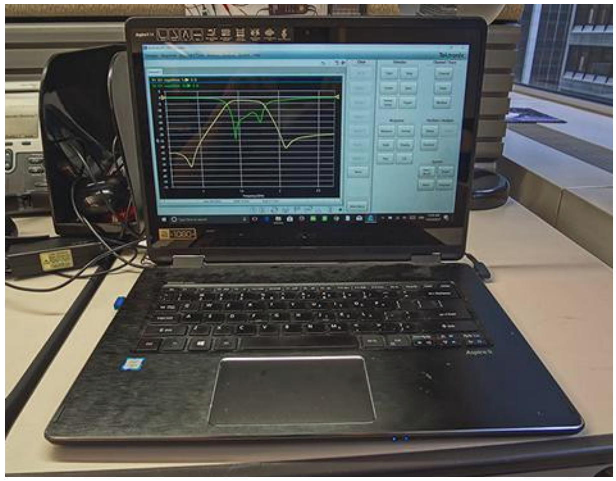
Save/Recall in the *System* section followed by *Save SnP*. This touchstone file, which could be saved in the form of an S1P or S2P file, could then be used in a software simulation tool.

In addition, creating a touchstone file allows for offline analysis, meaning the data contained in the touchstone file can be viewed in VectorVu-PC without even being connected to an actual VNA. Offline analysis can be performed by clicking *More* in the *System* section followed by *Connections*. *Figure 13* shows the resulting interface. After connecting to the simulator, the next step would be to click *Simulator* followed by *Load SnP* to load the touchstone file.

These steps enable the data contained in that touchstone file to be analyzed with VectorVu-PC—without an actual VNA being connected. *Figure 14* shows a laptop that is running VectorVu-PC with offline analysis enabled. In the figure, a touchstone file that was created when measuring the bandpass filter is being analyzed. As can be seen, the VNA is nowhere in sight.



13. With offline analysis, touchstone files can be analyzed in VectorVu-PC without a VNA connection.



14. Offline analysis is demonstrated in this photo, as the laptop is displaying data from a touchstone file.

BIAS TEE AND FINAL THOUGHTS

Although not demonstrated in this article, the TTR500 also includes bias tee input ports located on the rear panel. Applying dc bias to these ports allows dc voltage to be supplied to a DUT via the inner conductor of the VNA. This feature can simplify test setups by eliminating the need for additional external hardware.

To summarize, this article demonstrated Tektronix's new VNA with a bandpass filter measurement example. Some of the features were explained in an attempt to offer a better picture of the new VNA Series for anyone who has not had the opportunity to use one. In the end, it is clear that the new TTR500 Series is a worthy product in the VNA market. mw

JACK BROWNE | Technical Contributor

FREQUENCY SYNTHESIZERS, PART 2: Create Complex Waveforms Using Fast Digital Circuits

Modern high-speed data converters provide the performance and precision to create complex analog voltage waveforms from digital code representations of those waveforms.

HIGH-FREQUENCY SIGNAL WAVEFORMS flow through everything from communications systems to sophisticated test systems. They are often generated by analog sources, such as different types of oscillators. In recent years, however, as digital components such as digital-to-analog converters (DACSs) have improved in speed and performance, many signal waveforms can now be created, starting with digital code and hardware.

Signal generators based on digital architectures may be known as arbitrary waveform generators (AWGs), but they are often called direct digital synthesizers (DDSs). They may not be able to match all the performance levels of a good phase-locked analog frequency synthesizer, but they have some benefits in terms of the precision and frequency switching speeds of the waveforms they can generate.

In contrast to an indirect analog frequency synthesizer—which may use a PLL to lock a tunable frequency source such as a voltage-controlled oscillator (VCO) or a yttrium-indium-garnet (YIG) oscillator to the phase of a reference oscillator—a DDS generates an RF/microwave waveform directly from a high-speed DAC, using digital techniques. It stores the points of a signal waveform in digital form and then recalls a number of the stored points to generate a waveform, with the number of digital bits determining the amplitude resolution of the waveform.

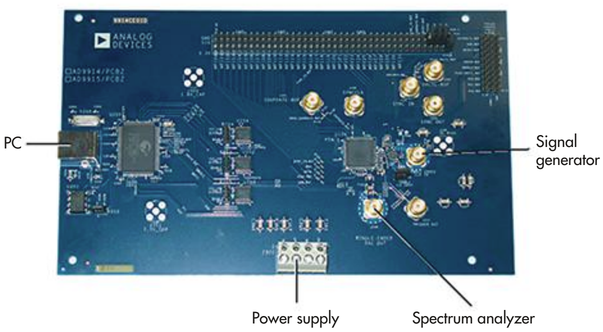
A DDS is also often referred to as a numerically controlled oscillator (NCO). A block diagram for a basic DDS would show a phase accumulator connected to some form of memory to store digital representations of different waveforms, such as a read-only-memory (ROM) or programmable ROM integrated circuit (IC). The phase accumulator is connected to a high-speed DAC capable of generating the frequency range of analog voltage outputs to serve an application of interest. The DAC is usually connected to a lowpass filter (LPF) to remove higher-order harmonic content.

1. The DDS-based NI PXIe-5451 arbitrary waveform generator operates at sampling rates to 400 MSamples/s and produces output waveforms to 160 MHz. *(Photo courtesy of National Instruments)*

A precision reference clock controls the timing of the phase accumulator and other components in the DDS. When there is more than one phase accumulator in a DDS, it can generate modulation, such as frequency-modulated CW (FMCW) signals used in automotive radar systems as part of advanced driver assistance system (ADAS) equipment.

In conventional Nyquist sampling operation, a DDS DAC generates output signals at fundamental frequencies that are less than one-half the frequency of the clock frequency. So, for a DDS DAC operating at a clock rate of 1 GHz, output fundamental tones produced by the synthesizer's DAC are no greater than 500 MHz in frequency—although usually somewhat less, such as 40% or 400 MHz, to minimize distortion. However, some DDS DACs function in what is known as a "super-Nyquist" means of operation, in which higher-order image frequencies are used as the output signals rather than fundamental tones.

Additional filtering, such as a bandpass filter, is needed to suppress any fundamental tones that are generated, and the amplitudes of the image or harmonic signals will be considerably less than those of the fundamental tones, requiring amplification. But in such a way, a DAC-based DDS can also generate output signal waveform frequencies that are considerably higher in frequency than the frequency of the DDS's clock source.



2. The AD9914 is a 3.5-GSamples/s DDS that is available on an evaluation board for ease of training and applications development. *(Photo courtesy of Analog Devices)*

Different forms of noise, such as phase noise, spurious signals, and harmonic signals, can be produced as part of the signal generation process in a DDS. Noise can originate from various sources, including jitter from the reference clock. Phase noise truncations occurs can occur as part of the sampling process when an insufficient number of bits are available to generate analog output waveforms with low phase noise. Even a high-resolution, high-performance DAC will contribute some noise of its own to the signal-generation process. DAC quantization or linearity errors can cause unwanted phase noise, as well as harmonic signals, although proper choice of output filtering (such as a lowpass filter) can significantly reduce harmonic signal levels in a DDS.

COMMERCIAL SOURCES

Signal sources based on DDS technology are commercially available in both instrument enclosures (as test signal generators) and as various forms of packaged ICs. When sorting through various product candidates for an application, some of the parameters and specifications to consider include the maximum clock frequency, the frequency tuning resolution, the bit resolution, the number of channels, spurious-free dynamic range (SFDR), and the power consumption. For system-level applications in which a large number of synchronized multiple channels may be needed, this capability may also be considered important.

A number of manufacturers offer DDS signal sources in board-level form, including as modular test instruments. One example of these is the NI PXIe-5451 arbitrary waveform generator from National Instruments (www.ni.com). The PXIe DDS-based generator has two channels with single-ended and differential output signals. Its 16-b DAC operates at sampling rates to 400 MSamples/s, resulting in output waveform frequencies to 160 MHz. It can run with an internal sampling clock or support a wide range of external clocking options for test signal flexibility.

In terms of DDS-based board-level instruments without the enclosure, Novatech Instruments *(www.novatech-inst.com)* offers its DDS9m four-channel signal generator as a small circuit board module. It can generate sinewaves and LVCMOS output signals simultaneously at frequencies to 170 MHz. The frequency tuning resolution is 0.1 Hz, and the frequencies of the four outputs can be set independently, with controllable phase offsets. The DDS source has an on-board voltage-controlled temperature-compensated crystal oscillator (VCTCXO) reference clock, and works with external clocks at frequencies as high as 500 MHz. An RS-232 interface allows for programmable control in automatic-test-equipment (ATE) applications. Spectral performance includes spurious levels of −50 dBc or better and harmonics of −35 dBc or better.

The majority of commercial DDS sources are available as packaged ICs, allowing users to surround the digital synthesizer chip with their own choices for supporting components, such as output filters and signal-boosting amplifiers. The AD9914 DDS from Analog Devices *(www.analog.com)*, for example, has a 12-b DAC and operates at sampling rates to 3.5 GSamples/s for generating low-noise, microwave output frequencies for use as agile local oscillator (LO) sources or for clock sources in frequency-hopped radios.

To simplify the use and understanding of the DDS technology, the company also offers the AD9914 DDS mounted on an evaluation board, so that the synthesizer is essentially ready to power up and connect to a spectrum analyzer for experimentation and observation. Additional suppliers of DDS sources in chip packages include Intersil *(www.intersil.com)* and Xilinx *(www.xilinx.com)*.

For those seeking to know more about the basics of chip-level DDS signal sources, Analog Devices offers an excellent tutorial lesson on the programming and specifying of DDS sources in the application note, "All About Direct Digital Synthesis," which is the 33rd installment of the company's "Ask The Application Engineer" series. mw

JACK BROWNE | Technical Contributor

UAVs Keep An Eye on Enemy Movements

Unmanned aircraft have become as much a part of military surveillance and intelligence gathering as the advanced electronic sensors they carry.

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. Put simply, as electronic devices increase in performance and capability within smaller-sized packages, long-distance surveillance capabilities increase in direct proportion.

Electronic surveillance devices, which are largely linked to remote-controlled, robotic vehicles, have become the long-distance eyes and ears of the military, with the U.S. Air Force coordinating most surveillance efforts as part of its Distributed Common Ground System (DCGS), also known as the AN/GSQ-272-SENTINEL system. It is the Air Force's main intelligence, surveillance, and reconnaissance (ISR) system for the purpose of critical data collection, processing, exploitation, analysis, and dissemination (CPAD) of intelligence data throughout the branches of the armed forces and allies.

Unmanned aerial vehicles (UAVs) are a large part of the Navy's DCGS, using advanced cameras and sensor arrays and secure communications systems to collect and disseminate ISR data. Nonetheless, other branches of the military have made significant investments in UAVs for ISR and tactical applications. The U.S. Army's Unmanned Aircraft Systems (UAS) program is a roadmap for UAV development for the next several decades, building upon the baseline success of the Pioneer UAV and its many successful combat missions in the early 1990s in Iraq and Afghanistan. The Army, Navy, and Air Force are guided by reduced size, weight, and power (SWaP) goals when developing future UAVs for surveillance or tactical use.

Tactical UAVs, whether for ISR or offensive missions, are classified by size and weight, which also tend to translate into range and endurance, or the total time a UAV can remain in flight per mission. They are categorized by tiers, with Tier III being the largest and highest-altitude UAVs and Tier I being the smallest and lowest in altitude.

Among the largest UAVs in use for tactical and ISR applications is the Global Hawk (*Fig. 1*) from Northrop Grumman (*www.northropgrumman.com*). Considered a high-altitude, long-endurance (HALE) UAV, it is designed to provide near real-time ISR over large geographic areas. The electronics on board the Global Hawk are designed to match its impressive flight capabilities, with run times exceeding 32 hours. It is designed to carry an Enhanced Integrated Sensor Suite (EISS) payload, as well as an Airborne Signals Intelligence Payload (ASIP) for long-range detection and intelligence gathering.

1. The Global Hawk is a Tier III UAV with long-endurance, long-distance surveillance capabilities. *(Photo courtesy of Northrop Grumman)*

The Global Hawk's EISS contains a synthetic-aperture-radar (SAR) system, a moving target indicator (MTI), an electro-optical (EO) digital camera, and an advanced infrared (IR) sensor. All of these detection systems operate using a common signal processor, with the on-board computer enabling simultaneous operation of the SAR and MTI, coupled with the capability of transferring ISR data to warfighters in real time.

As a large Tier III UAV, the Global Hawk has impressive physical features, with a wingspan of 130.9 ft. (39.9 m), a length of 47.6 ft. (14.5 m), and a height of 15.4 ft. (4.7 m). It is designed to reach a maximum altitude of 60,000 ft. with a payload of 3,000 lb. It is capable of endurance as long as 32 hours for long-range missions and can be equipped for flex-

2. The sensor suite on the Global Hawk was recently enhanced with the integration of the multiple-sensor MS-177 sensor payload. *(Photo courtesy of Northrop Grumman)*

3. An MQ-1 Predator UAV (at right) is shown next to an F-16 fighter, with both returning from a mission during Operation Iraqi Freedom. (*Photo courtesy of the U.S. Air Force)*

4. The U.S. Air Force plans to phase out the use of the Predator and rely on the MQ-9 Reaper for its ISR missions.
(*Photo courtesy of the U.S. Air Force)*

ible ISR duties, as well as for full-scale combat missions. Northrop Grumman recently upgraded the Global Hawk by developing and integrating the MS-177 sensor payload for the UAV (*Fig. 2*). The new sensor payload incorporates different sensor technologies for enhanced detection and tracking of targets even through crowded environments.

In comparison, the smaller Tier II MQ-1 Predator (*Fig. 3*) from General Atomics Aeronautical Systems (www.ga-asi.com) is about one-half the size of the Global Hawk. It has a wingspan of 55 ft., a length of 27 ft., and a height of 7 ft. With a maximum payload of 450 lb., it has a maximum altitude of 25,000 ft. It is equipped with two laser-guided AGM-114 Hellfire missiles for offensive missions and is capable of 24-h endurance; the Air Force refers to is as a medium-altitude, long-endurance (MALE) surveillance aircraft. The Predator can be disassembled and loaded into a container for travel.

The Predator is actually part of a remotely piloted aircraft system consisting of four sensor- and weapon-equipped aircraft, a ground control station, a primary satellite link, and trained crews for conducting 24-hour missions. A crew consists of a pilot and enlisted aircrew member to operate sensors and weapons, as well as a mission coordinator when required. The crew employs the aircraft from inside the ground control station via a line-of-sight data link or a satellite data link for beyond line-of-sight operations.

The Predator's Multi-Spectral Targeting System integrates an infrared (IR) sensor, color/monochrome daylight TV camera, image-intensified television (TV) camera, laser designator, and laser illuminator. Full-motion video from each of the imaging sensors can be fused or viewed separately. The UAV carries an ARC-210 two-way radio (30 to 512 MHz) and APX-100 identify-friend-or-foe (IFF)/selective-identification-feature (SIF) system.

The U.S. Air Force has successfully operated the Predator UAV for ISR operations for many years, in conjunction with the MQ-9 Reaper UAV, which is designed for a much larger payload and weapons-carrying capabilities. This branch of the military intends to transition in early 2018 to using just a single UAV—the Reaper—for surveillance and weapons deployment. The Reaper (*Fig. 4*) carries a nearly 4,000-lb. payload in contrast to the Predator's approximate 400-lb. payload. It is hoped that by consolidating to a single aircraft for surveillance, the costs of operating two different airframes will be greatly reduced.

Since the operating ranges of UAVs developed for ISR missions can vary from long-range to line-of-sight (LOS) operations, a variety of different communications systems are employed in these UAVs, often driven by modern SWaP requirements. Secure communications of critical intelligence data is a vital part of ISR missions, and the mobile radios that are installed on UAVs must be durable and dependable—not to mention, capable of operating effectively through severe and hostile environments (*see page 84*).

DIMINUTIVE DRONES

While Tier I, II, and III UAVs provide extensive ISR data across wide areas and from long distances, some surveillance efforts may be relatively close to base camp, requiring much smaller UAVs for an ISR mission. Several branches of the military, including DARPA, have invested in the development of micro air vehicles (MAVs) small enough to fit in the palm of the hand, and capable both of remote surveillance over short distances and carrying explosive warheads for offensive missions. Many of these MAVs are modeled on the mechanical configurations of birds or insects.

As an example, the PD-100 Black Hornet is a tiny flying robot developed by Prox Dynamics (*www.proxdynamics.com*) that can be remotely piloted or can fly with the aid of a GPS autopilot function. In spite of its miniature size, it is capable of flying for about 25 min. with a range of about two miles. The PD-100 personal reconnaissance system (PRS), which is commercially available, includes a remote control and monitoring handset which provides a user with immediate ISR capability. The electric-motor-powered MAV has a mass of 18 g, including cameras and steerable electro-optical (EO) cameras.

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Bandpass Filters Feature Wide Tuning Ranges

In this article, the design of second-order tunable lumped-element bandpass filters is considered with special attention given to circuit topology. Closed-form design equations are provided.

Classical LC filter design is becoming increasingly rare in much of the RF design community. This is in part due to the domination of direct-conversion in up- and down-converters along with the widespread availability of excellent off-the-shelf filter components, such as surface-acoustic-wave (SAW) filters. However, tunable bandpass filters are still required for many applications, whether for discrete designs or on-chip integrated-circuit (IC) designs. If insertion loss must be as low as possible, a peaked-response lowpass filter may be used in order to side-step the higher insertion loss of a true bandpass filter. If attenuation is required in both stopband regions, however, a bandpass filter is generally required.

Bandpass filters (BPFs) have an inherently higher insertion loss than lowpass filters (LPFs) given similar design requirements. A first-order BPF can be designed for low passband insertion loss, but it will suffer from poor stopband attenuation roll-off and rounded passband shape. A second-order BPF can be designed to have appreciably faster stopband transition regions and a reasonably flat passband shape, but normally exhibits higher passband insertion loss than the first-order filter. Only the second-order filter design case will be considered here, whereas extensive details for the first-order filter design can be found in ref. 8.

FILTER DESIGN PRELIMINARIES

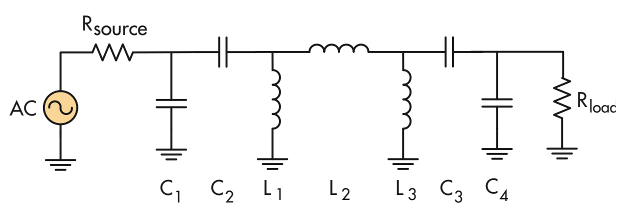
The author learned a great deal early in his engineering career from the book by Daniels.[1] It provided an early appreciation for filter pole/zero placement and was the primary motivation for thinking about the second-order filter design problem in the context of *Table 1*.

Good control of the internal impedance levels within a lumped-element LC filter is crucial for obtaining reasonable component values and keeping stray inductance and stray capacitance issues at bay. A filter's internal resistance level can be crafted in a fairly flexible manner in order to realize a range of filter bandwidth versus center frequency behaviors. Choosing series LC-resonators versus parallel LC-resonators is largely determined via the means by which the filter's center frequency is to be tuned—such as by varactor diodes, FET switches, PIN diodes, or microelectromechanical-systems (MEMS) devices—and having reasonable component values.

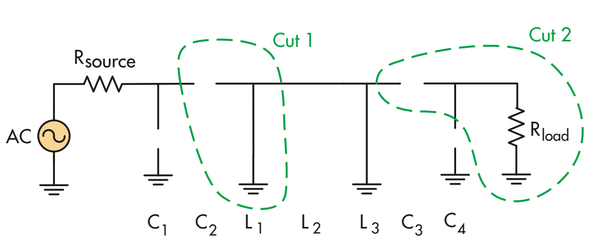
Parallel resonators are usually more advantageous for lower insertion loss since these are typically used with an internal filter impedance, $R_{internal}$, which is greater than the port impedances, R_{source} and R_{load}.

In order to make a filter tunable, its inductors and/or capacitors must be tunable. Since tunable inductors are rather intractable for traditional LC filters, the tuning elements are usually limited to capacitors. Since inductors also tend to be more lossy and larger than capacitors, it is desirable to minimize the number of inductors used—nothing new here.

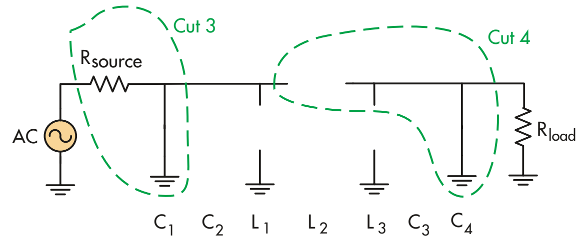
Pole and zero placement for a filter determine all of the behavior characteristics of the filter. It is generally desirable to have an equal number of transmission zeros at dc and infinity so that the lower and upper stopband behaviors can be made roughly symmetric. A representative filter to aid in this discussion is shown in *Fig. 1*. In order to determine the number of transmission zeros at dc in *Fig. 1*, it is helpful to think of each capacitor being replaced by an open-circuit and each inductor being replaced by a short circuit, as shown in *Fig. 2*. In the portion denoted as *Cut 1*, in a resistive divider sense, an impedance open (from C_2) is working against an impedance short (from L_1), thereby contributing two transmission zeros (*see footnote*).



1. Representative second-order bandpass filter.



2. Bandpass filter shown in Fig. 1 with impedance considerations at dc shown.



3. Bandpass filter shown in Fig. 1 with impedance considerations at infinite frequency shown.

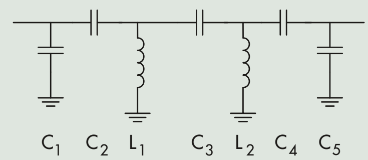
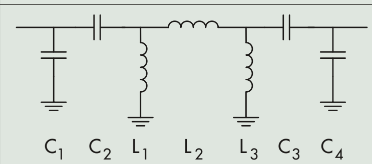
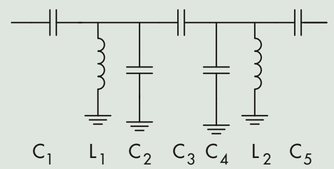
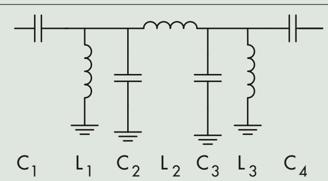
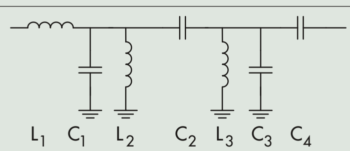
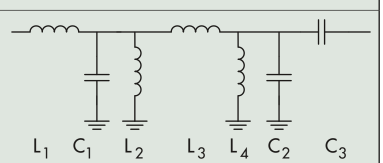
In the portion denoted as *Cut 2*, an impedance open (from C_3) is working against a non-zero impedance R_{load}, thus adding only one transmission zero. The filter consequently has three transmission zeros at dc.

In the case of transmission zeros at infinite frequency, each capacitor is replaced by a short circuit and each inductor is replaced by an open circuit, as shown in *Fig. 3*. For *Cut 3*, a short (from C_1) is working against a non-zero impedance, R_{source}, thereby contributing one transmission zero. For *Cut 4*, an open circuit (from L_2) is working against a short circuit (from C_4), thereby contributing two transmission zeros. The filter consequently exhibits three transmission zeros at infinite frequency, making for an equal number of transmission zeros in the lower and upper stopbands as desired.

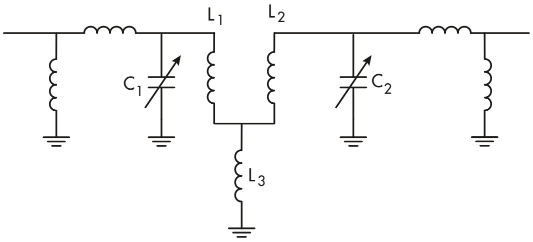
Of the second-order filter topology configurations shown in *Table 1*, having roughly equal numbers of transmission zeros at dc and infinite frequency helps assure good overall stopband performance as just explained. This criterion favors Configurations 2 and 4. Both topologies use parallel resonators, so that is not a discriminating factor. Configuration 2 is the more interesting of the two, however, because it permits $R_{internal}$ to be larger than the port impedances, whereas Configuration 4 is just the opposite. The design details behind both configurations will be presented shortly.

This type of tunable second-order BPF was earlier used in connection with an SBIR project.[2] Two circuit sketches from that report that make use of this filter type are shown in

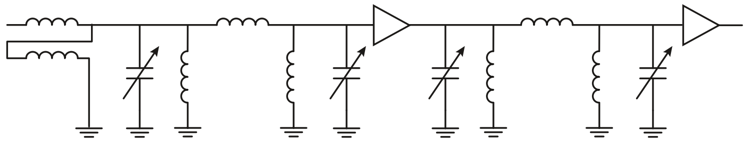
TABLE 1

Config #	Input Match	Resonator Coupling	Output Match	Zeros @ DC	Zeros @ ∞	Schematic
1	Tapped- C	C	Tapped-C	5	1	
2*	Tapped- C	L	Tapped-C	3	3	
3	HPF	C	HPF	5	1	
4*	HPF	L	HPF	3	3	
5	LPF	C	HPF	4	2	
6	LPF	L	HPF	2	4	

Several of the many possible second-order bandpass filter alternatives. Configurations 2 and 4 are preferred. Transmission zeros at dc and infinity provide an indication about the lower and upper stopband behaviors.



4. Second-order tunable bandpass filter from ref. 2 using inductive-tee coupling.

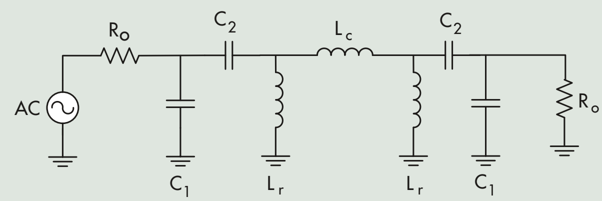
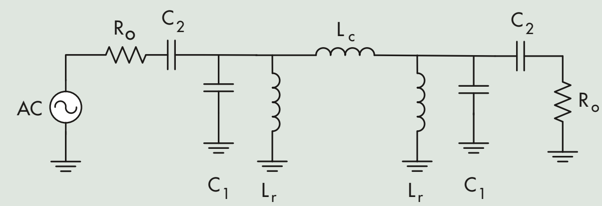


5. Second-order tunable bandpass filter from ref. 2 using inductive-pi coupling.

Figs. 4 and 5. Both make use of inductive-coupling between the two resonators based upon the tee-to-pi transformation. Note that inductive impedance transformations were used at the input and output of the filter, rather than capacitive transformers as used in Configuration 2 of Table 1.

The notion of admittance and impedance inverters is not new.[3, 4, 5] They were used in ref. 2 as the basis for *Figs. 4 and 5*.

Table 2 shows the filter topologies which are the focus for the remainder of this article. Two related topologies can be created by making use of the pi-to-tee network transformation for the inductor sections. The design of Configuration I in Table 2 begins by defining the following initial design parameters

TABLE 2: TUNABLE FILTER TOPOLOGY CANDIDATES		
I		$R_o < R_{internal}$ Inductor-pi
II		$R_o > R_{internal}$ Inductor-pi

f_{low} = Minimum tunable filter center frequency (Hz);

f_{high} = Maximum tunable filter center frequency (Hz);

B_{geo} = −3 dB RF filter bandwidth (in Hz) at the geometric center frequency;

R_{geo} = Internal filter impedance (in Ω) at the geometric center frequency of the filter;

R_o = Port impedance, usually taken as 50 Ω;

γ = Constant value. A value of $\gamma = 1.0$ results in a constant-Q filter design, while a value of $\gamma = 2.0$ results in a constant-bandwidth filter design. A value between one and two will yield a blend of the two filter characteristics. Inductor Q values will be more critical as the value of γ is increased.

The internal impedance level of the filter is represented by R_t, and is given by

$$R_t = R_{geo}(\omega/\omega_{geo})^{\gamma}$$

It is important to note that R_t should always be greater than the port impedance, R_o, at the band edges of the filter.

The geometric center frequency of the filter, ω_{geo}, is given by

$$\omega_{geo} = 2\pi\sqrt{f_{low} f_{high}} \text{ rad/sec} \quad (1)$$

while the coupling inductor, L_c, is given by

$$L_c = \frac{R_{geo}}{\omega_{geo}} \quad (2)$$

and the total tuning capacitance at the geometric center frequency is as follows

$$C_{tgeo} = \frac{1}{\pi\sqrt{2}R_{geo}B_{geo}} \quad (3)$$

$$L_{eff} = \frac{1}{\omega_{geo}^2 C_{tgeo}} \quad (4)$$

$$L_r = \frac{L_{eff} L_c}{L_c - L_{eff}} \quad (5)$$

Since the inductance values in the filter are fixed, the total tuning capacitance versus the center frequency is given by

$$C_t(\omega) = \left(\frac{\omega_{geo}}{\omega}\right)^2 C_{tgeo} \quad (6)$$

Tuning capacitances C_1 and C_2 are given by Eqs. 7 and 8

$$C_1 = \frac{1}{\omega R_o}\sqrt{\left(\frac{\omega_{geo}}{\omega}\right)^{\gamma}\left(\frac{R_o}{R_{geo}}\right) + \omega^2 C_t^2 R_o R_{geo}\left(\frac{\omega}{\omega_{geo}}\right)^{\gamma} - 1} \quad (7)$$

$$C_2 = \left[\frac{\omega^2 C_t}{\left(\frac{\omega_{geo}}{\omega}\right)^{2\gamma}\left(\frac{1}{R_{geo}}\right)^2 + (\omega C_t)^2} - \frac{\omega^2 R_o^2 C_1}{1+(\omega R_o C_1)^2}\right]^{-1} \quad (8)$$

The design for Configuration II begins with the same initial parameters as given for the first configuration. The design formulas are a bit more involved for this configuration. The coupling inductor value, L_c, is given by

$$L_c = \frac{R_{geo}}{\omega_{geo}} \quad (9)$$

$$L_{eff} = \frac{R_{geo}}{\pi\sqrt{2}B_{geo}} \quad (10)$$

with

$$L_r = L_{eff} - L_c \quad (11)$$

Continuing

$$C_{tgeo} = \frac{1}{L_{eff}\,\omega_{geo}^2} \quad (12)$$

$$C_t = \left(\frac{\omega_{geo}}{\omega}\right)^2 C_{tgeo} \quad (13)$$

Next, define the following quantities

$$R_t = \left(\frac{\omega}{\omega_{geo}}\right)^{\gamma} R_{geo}$$
$$a = -\omega^2 R_o R_t$$
$$b = \frac{1}{C_t} \quad (14)$$
$$d = \frac{R_t}{R_o}$$

and then compute α and β as follows

$$\alpha = \frac{d - \frac{b^2}{a}}{1 + \frac{b^2}{a} - d}$$
$$\beta = \frac{\left(b/a\right)}{1 + \frac{b^2}{a} - d} \quad (15)$$

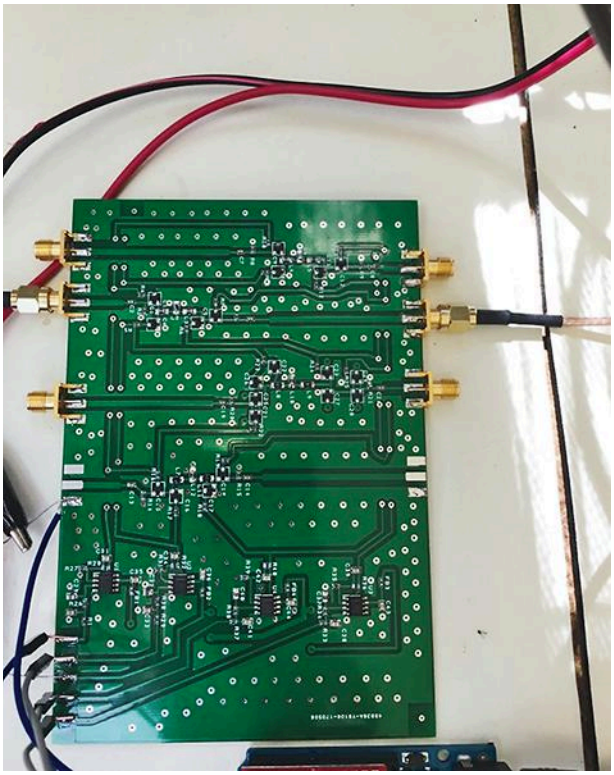
The solution for capacitance C_1 can be found by solving the quadratic equation

$$a\alpha C_1^2 + (a\beta + b + b\alpha)C_1 + (b\beta - 1) = 0 \quad (16)$$

from which C_2 follows as

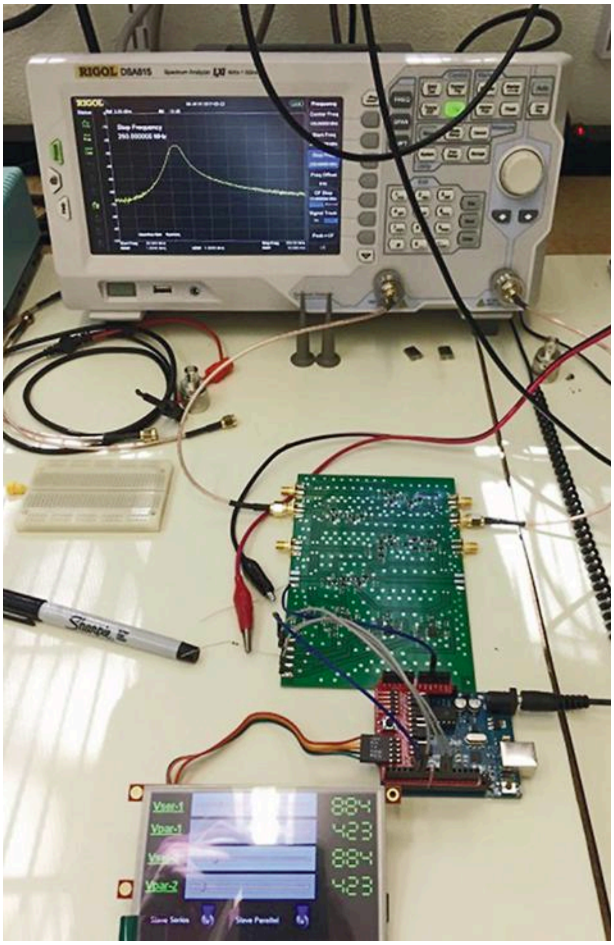
$$C_2 = \alpha C_1 + \beta \quad (17)$$

All of the capacitance values can be physically realized using varactor diodes and are therefore tunable. This makes it possible to tune the filter center frequency and adjust the port impedances as desired.

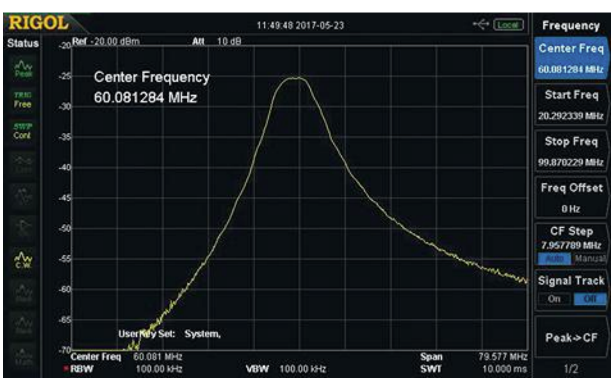


6. Close-up of prototype board with three of the four filters with SMA connectors visible. Op-amp tune voltage amplifiers at the bottom for two independent series-tune voltages and two independent parallel-tune voltages.

Good control of the internal impedance levels within a lumped-element LC filter is crucial for obtaining reasonable component values and keeping stray inductance and stray capacitance issues at bay.



7. Tunable prototype filter board, Arduino Uno, and LCD display with adjustable varactor voltages.



8. 40-to-80 MHz filter. 60 MHz center frequency.

FILTER PROTOTYPES

Using these design methods, filter prototypes were built and characterized that covered 10 MHz through 640 MHz (*Figs. 6 and 7*). Since each tunable filter requires as many as four individual tuning voltages, an Arduino Uno was used to create the four voltages that were then heavily filtered and scaled with the op-amp circuitry in the lower half of *Fig. 6.* This approach simplified the amount of test equipment needed while making direct-reads of the tuning voltages very convenient. *Figure 8* shows a spectrum analyzer measurement using this arrangement.

For interested readers, the original work papers in refs. 8-10 are available in their entirety (102 pages) upon request from filters@am1.us. The original materials include exhaustive design formula derivations, complete schematic details, additional characterization results, and a helpful filter design MATLAB script. mw

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FOOTNOTE: **NOTE** that parallel open circuits count as simply one open circuit, while parallel short circuits count as a single short circuit. The converse is true with series open and short circuits.

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Design Feature

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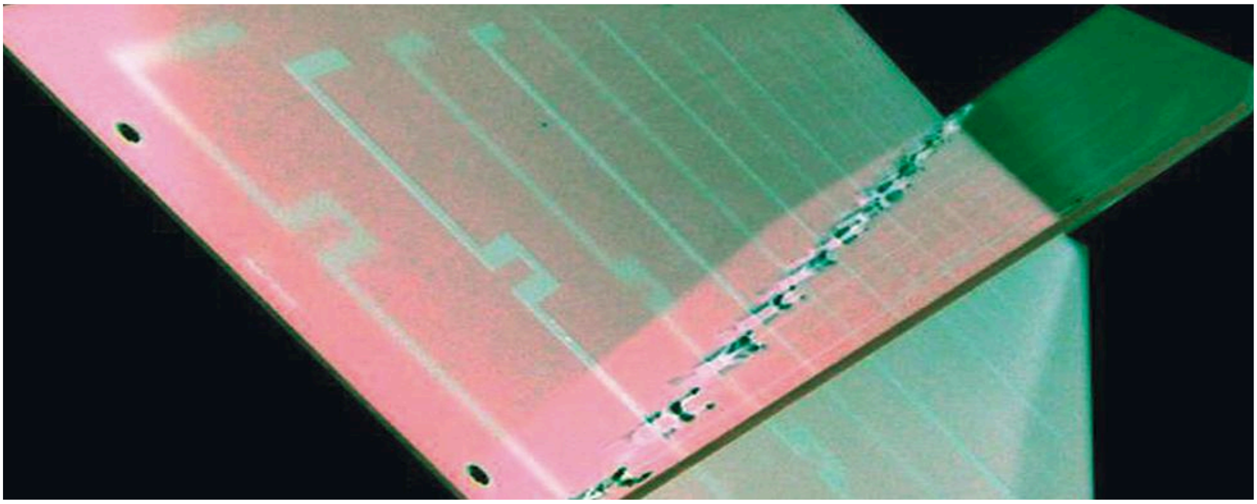
Choosing Circuit Materials for Low-PIM PCB Antennas

By designing RF/microwave antennas for production using 3D laser printers, size, time, cost, and complexity can be saved while gaining many performance benefits.



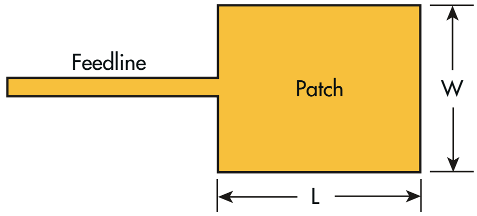
Antennas come in many shapes and sizes, although printed-circuit-board (PCB) antennas provide the capability of packing a great deal of performance into miniature footprints. Of course, many antennas—including those based on PCBs—must be designed and fabricated for minimum passive intermodulation (PIM) levels for maximum effectiveness in today's crowded signal environments. For PCB antennas, low PIM is a function of the antenna design and/or the system. The choice of RF/microwave circuit material can have an influence on PIM performance. However, PIM is a circuit or system property.

PIM is a nonlinear, diode-like effect that results in the creation of unwanted harmonic signals when two or more signals combine (such as from different transmitters). These extra signals can cause problems when they are at sufficient energy levels and when they fall within the frequency range of a receiver and can prevent the receiver from detecting its intended in-band signals. While PIM may not impact every application, it can disrupt the operation of wireless communications systems, especially those attempting to recover low-level signals.

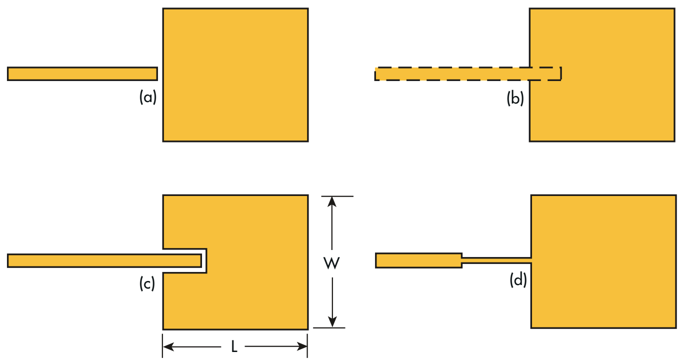
PIM can occur at any junction or interface with two different metals, such as connectors and cable assemblies or antennas and antenna feeds. Loose connectors and connectors with internal rust or oxidation can cause PIM. PCB materials can also influence PIM, whether from the materials themselves or at feed points. But by understanding how different circuit material parameters relate to PIM, it is possible to select circuit laminates that are less likely to contribute to PIM problems in PCB antennas.

PCB ANTENNAS

High-frequency antennas fabricated in PCB form can take on many configurations, from simple dipoles to more elaborate constructions based on ring resonators and Rotman lenses. One of the more popular PCB antennas is the microstrip patch antenna, which can be made simply and compactly for a given frequency range *(Fig. 1)*. Many applications employ multiple patches or resonant structures on a PCB to create a beam-forming network (BFN) or phased-array antenna with the capability of electronically steering the amplitude, phase, and direction of a low-profile PCB antenna structure for radar and communications systems. Compact planar PCB antennas are



1. Microstrip patch antenna elements are fundamental building blocks for larger antenna arrays.



2. Four different feedlines are used with microstrip patch elements: (a) loosely gap coupled, (b) bottom layer feed, (c) tightly gap coupled, and (d) with a quarter-wavelength transformer.

also of growing interest at millimeter-wave frequencies, such as for 77-GHz Advanced Driver Assistant Systems (ADAS) for automotive electronic safety systems, for such functions as blind-spot detection, automatic braking systems, and collision avoidance. Because signal power levels are low in such systems, ADAS receivers rely on high sensitivity to reliably detect radar returns reflected from targets such as pedestrians and other vehicles.

Although PIM is usually the result of inhomogenous materials in circuit junctions such as solder joints or connectors, circuit material characteristics, such as rough copper conductor surfaces and different types of plating finishes, can favor either lower or higher PIM levels. A number of circuit material parameters can be used as guidelines for achieving lower PIM in PCB antennas.

Dielectric constant (Dk) is a starting point for many engineers when selecting a circuit laminate for a design, such as a microstrip patch antenna. The effect of circuit material Dk on circuit dimensions are detailed for the four examples of the *table*, showing how the size of a microstrip patch antenna for a given frequency shrinks with increasing Dk value. The table was created with the help of the MWI-2017 software, which is available for free download from the Rogers Corp. website (*www.rogerscorp.com*). The length (L) and width (W) of a microstrip patch antenna can be found from a pair of simple equations:

$$W = (c/2f_r)[2/(Dk_{eff} + 1)]^{0.5}$$
$$L = \lambda/[2(Dk_{eff})^{0.5}] - 2\Delta L$$

where

Dk_{eff} = the effective dielectric constant of the microstrip circuit;
λ = the wavelength based on the microstrip circuit;
f_r = the resonant frequency of the patch radiating element;
c = the speed of light in free space; and
ΔL = the extension of the patch due to electric field fringing.

A microstrip patch antenna element radiates EM energy to free space upon transmission and returns EM energy to a connected circuit (e.g., a receiver) upon reception. But the patch is just one component in a PCB antenna, with the feedline comprising another important part. The feedline transfers EM energy between the connected microstrip circuitry and the radiating patch for transmission and reception. Ideally, the patch should exhibit high radiation while a feedline should exhibit low radiation, achieving efficient transfer of energy from the circuit to the patch.

Four different feedline configurations (*Fig. 2*) are available for connection to a microstrip patch: loosely gap coupled, bottom layer feed (where the feedline in a multilayer circuit is beneath the patch), tightly gap coupled, and via a quarter-wavelength ($\lambda/4$) transformer. The feedlines differ in complexity and flexibility. With the bottom layer fed, for example, a designer has the option to select the best circuit material on the outer layer for optimum patch radiation and a different circuit material for the inner layers, so as to minimize radiation and insertion losses for the feedline.

Thicker circuit materials are more prone to radiation. As a result, in gen-

SOME MICROSTRIP PATCH ANTENNAS FOR DIFFERENT DK CIRCUIT LAMINATES

Dk	Antenna patch dimensions			Reduction in area (%)	50-Ω feedline width (mils)
	Length (in.)	Width (in.)	Area (in.^{2})		
3	1.342	0.835	1.1205	0	76
4	1.162	0.747	0.8680	23	62
6	0.952	0.632	0.6017	31	45
10	0.742	0.504	0.3740	38	29

eral, circuit materials for radiating antenna elements such as microstrip patches should be relatively thick and with low Dk value (2.2 to 3.5, for example). Circuit materials with higher Dk values can be used when it is necessary to create smaller patch antennas, although materials with higher Dk values are less prone to radiate and PCB antennas are more challenging when using circuit materials with high Dk values.

POLICING PIM

Antennas guilty of high levels of PIM can cause loss of data in wireless telecommunications systems, such as 4G LTE wireless networks. Such networks rely on distributed antenna systems (DAS) for extended wireless coverage, and the same is expected to be true for emerging 5G wireless networks—albeit at higher frequencies.

For two in-band carrier signal frequencies f1 and f2 in a transceiver system, PIM can occur as mixing products of nf1 – mf2 and nf2 – mf1, where n and m are integers. The generated PIM products are categorized by order numbers, with the order determined by the sum of m and n, such as third-order PIM products of 2f1 – f2 and 2f2 – f1 (*Fig. 3*). Third-order products are problematic because they can fall within the receiver's frequency band and can block reception if at suitably high levels.

The amplitudes of the PIM products is a function not only of the amplitudes of f1 and f2 but of the PIM order number, with the amplitudes of PIM products decreasing with increasing order numbers. As a result, fifth-, seventh-, and ninth-order PIM products are usually at power levels that do not affect receiver performance.

What is considered low PIM? An acceptable value varies from system to system, with –145 dBc often considered low enough for the DAS equipment used in 4G-LTE systems, which include other passive components, such as connectors and cables. In general, a level of –140 dBc or worse is considered poor PIM performance, while –150 dBc is considered good and –160 dBc is excellent.

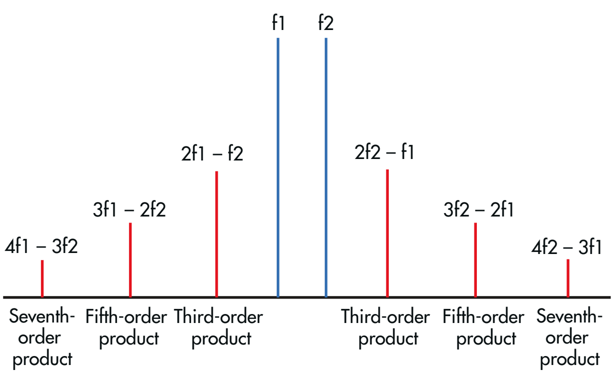
The PIM levels of antennas and other passive components are measured in specially designed anechoic chambers in which a level as low as –170 dBc is likely beyond the ambient noise of the test chamber. A more realistic noise level for most PIM test chambers is –165 dBc when performing measurements with two +43-dBm test tones.

Low PIM is especially important when the same antenna is used for transmit and receive functions with a

Circuit treatments can be beneficial to achieving low PIM levels for antennas and other passive components fabricated on those treated circuits. Circuits with soldermask over bare copper typically provide better PIM performance than circuits with bare copper.

common feedline. Whenever transmitters and receivers are co-located in a system, any unwanted nonlinear mixing of multiple transmitted signals can result in PIM at amplitudes sufficient to degrade receiver performance. Some contributions on the part of a PCB antenna to poor PIM performance can be influenced by understanding the circuit design, current density differences, and the influence which some material characteristics can play in the generation of PIM.

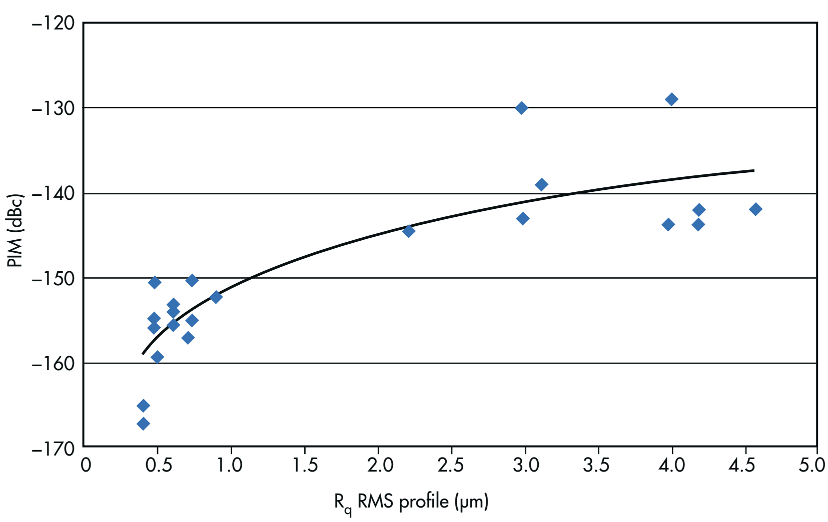
The dielectric portion of a laminate, such as ceramic or PTFE material, has less impact on a laminate's contributions to PIM than the relative surface roughness of the copper conductor layer. For circuits based on the same dielectric material (e.g., PTFE with woven-glass or ceramic filler), a circuit with rough copper conductor surface will have worse PIM performance than the same circuit with a smoother copper surface.



3. Mixing carrier harmonics results in different orders of intermodulation distortion (IMD).

To better understand the relationship of laminate copper surface roughness to PIM, a circuit material with good PIM performance was analyzed with copper foils having much different surface roughness characteristics. The surface roughness of each copper foil was measured prior to making the circuit laminates with the foil, and the PIM performance of each of the laminates was then measured by forming a microstrip transmission-line test circuit on each laminate. The PIM was found to rise steadily with increasing copper surface roughness (*Fig. 4*).

The plated finish used on a PCB material can also affect the PIM performance of antennas and other passive components fabricated on the material. Ferromagnetic materials, such as nickel, are not good material ingredients for achieving low PIM levels. Studies of circuits with immersion tin as the final plated finish typically have better PIM performance than bare-copper circuits, while circuits using electroless-nickel-immersion-gold (ENIG) plated finishes provide poor PIM performance because of the nickel content.

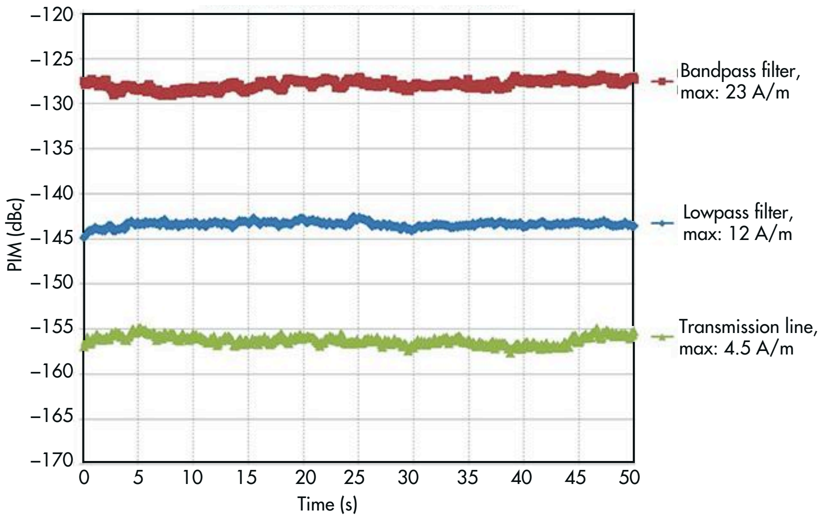


4. Copper surface roughness was found to directly contribute to the PIM levels of circuit materials.

Circuit treatments can be beneficial to achieving low PIM levels for antennas and other passive components fabricated on those treated circuits. Circuits with soldermask over bare copper typically provide better PIM performance than circuits with bare copper. Clean circuits, without residues left behind by wet chemical processing, are important foundations for low PIM performance. Circuits with any form of ionic contaminate residue can yield poor PIM performance.

Similarly, the etching quality of a circuit is also important for good PIM performance. If a conductor has been under-etched, small copper dendrites left along the edges of the circuit can cause degraded PIM performance.

The level of PIM exhibited by a passive component can be influenced through a careful choice of circuit material, although even a low-PIM material will not cure every PIM ill for some circuits. Certain types of circuits are more susceptible to PIM than others, as an experiment with 30.7-mil-thick RO4534 circuit material from Rogers Corp. revealed. The antenna-grade laminate features a Dk of 3.4 with a tolerance of ±0.08 and low dissipation factor (low loss) of 0.0027 at 10 GHz.



5. Three different circuits were fabricated on low-PIM material, with the circuits having higher current densities exhibiting higher PIM levels.

The same sheet of material was used to fabricate three different circuits: a transmission line, a bandpass filter, and a lowpass filter (*Fig. 5*). PIM is impacted by current density, and even though these circuits were formed on the same circuit material, the differences in PIM were significant; the filters and their higher current densities suffered much higher PIM levels than the simpler transmission-line circuit. The RO4534 material is specified for low PIM of −157 dBc when evaluated with two +43-dBm test tones using a microstrip transmission-line test vehicle.

As the experiments show, simple transmission-line circuits, as might be used for antenna feeds, can achieve close to the rated PIM levels of the material. Nontheless, PIM is also very dependent upon circuit configuration. mw

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Generate Complex Radar Signals with AWGs

Arbitrary waveform generators leverage the capabilities of high-performance digital-to-analog converters to directly produce radar waveforms to 20 GHz for measurement and simulation.

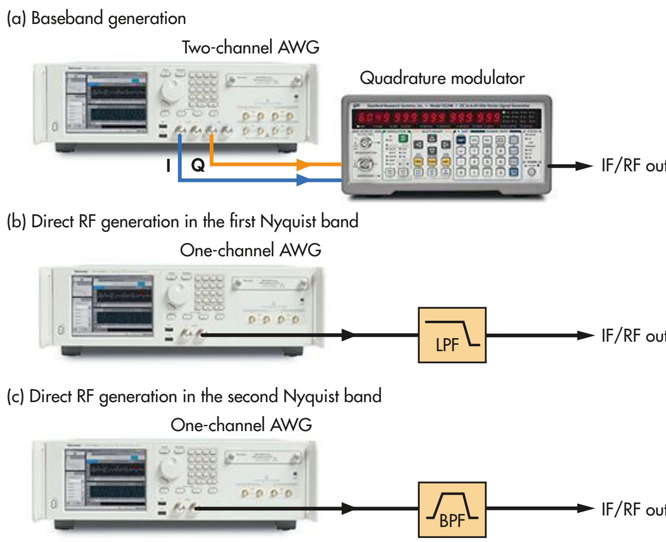
Generating radar signals can be challenging for any test signal generator. Radar technology, which was once primarily used for military applications, is becoming a standard feature in the collision-avoidance systems of an increasing number of commercial vehicles. Testing these systems requires a signal source capable of combinations of carrier frequency, modulation bandwidth, and tightly controlled pulses that can be difficult to produce.

The need to emulate multiple-antenna radar systems based on phased-array antennas—or, more recently, multiple-input, multiple-output (MIMO) antenna architectures—makes it necessary for a radar test signal source to generate multiple signals with tightly controlled timing and phase alignments.

Radar signals have traditionally been produced by means of a baseband signal generator and an RF/microwave modulator. However, with the emergence of high-speed, high-frequency arbitrary waveform generators (AWGs) based on high-speed digital-to-analog converters (DACs), it is now possible to directly generate radar signals with carrier frequencies to 20 GHz (beyond Ku-band frequencies). In contrast to the baseband/modulator approach, the use of an AWG delivers higher signal quality, greater repeatability, and much better cost-effectiveness than traditional radar signal generation options.

Before looking at how AWGs can be applied to radar signal generation requirements, however, it's helpful to review typical radar and electronic warfare (EW) signal characteristics.

Radar systems are simple in concept, although often complex in function and implementation. They operate by transmitting short pulsed signals to "illuminate" or bounce off a target and then receive the signals that have been reflected by the target. Information from the radar returns can tell a great deal about a target, such as its distance from the radar's transmit antenna, its relative size or radar cross section (RCS), and even its Doppler motion relative to the transmitted radar system.



1. AWGs generate signals using three basic methods: (a) baseband generation, (b) direct RF generation in the first Nyquist band, and (c) direct RF generation in the second Nyquist band.

UNDERSTANDING RADAR SIGNALS

Carrier frequencies used in radar systems cover most of the usable radio-frequency (RF) spectrum, from the low frequencies used in long range and over-the-horizon (OTH) surveillance radar systems to the shorter millimeter-wave signals used in high-resolution military and civilian radars. Most radar systems operate below Ku-band frequencies (below 18 GHz).

Radar systems operate according to the radar range equation, which can be written in various forms. In one of the most common formats, the maximum detection range of a radar, Rmax, is defined according to

$$R_{max} = \{(P_t G^2 \lambda^2 \sigma)/[(4\pi)^3 P_{min}]\}^{0.25}$$

where

P_t = the transmit power;
P_{min} = the minimum detectable signal;
G = the gain of the antenna;
λ = the transmit wavelength; and
σ = the radar cross section (RCS) of the target;

While this depiction of the radar range equation provides only a rough idea (no units of measure) of how the concept of reflected signal frequencies can provide information about an illuminated target, it offers an idea of how the different variables—such as transmit frequency and power and target RCS—contribute to the operation and performance of a radar. The radar range equation implies that the detection range is maximized as power increases, while spatial resolution improves as radar pulses become narrower. Since these two requirements are contradictory, pulse-compression techniques are often used to achieve optimized performance.

Radar signal characteristics can be described by two broad categories: pulsed RF and continuous-wave (CW) signals. In pulsed RF operation, the signal consists of periodic bursts of an RF carrier, which may or may not be modulated in terms of one or more signal characteristics, such as amplitude modulation (AM), frequency modulation (FM), or phase modulation (PM). The rate at which the pulses is generated is referred to as the pulse repetition frequency (PRF), while the period at which the pulses is generated is called the pulse repetition interval (PRI).

In CW radars, the RF signal is continuous and the range of the radar system is established through time markers carried on by a transmitted signal. The use of FM is the typical way to measure distance to target, since the instantaneous frequency detected from an illuminated target is dependent upon distance.

For pulsed RF radars, transmissions may be fixed or variable in frequency, using various frequency-hopping patterns. These patterns are complex by design, meant to be repeating by nature and difficult to predict. The carrier frequency may also change for each transmitted pulse. Some of the reasons that designers vary PRF over time are as follows:

- Echo ambiguity: Unambiguous ranging of targets is limited by the PRI, and targets located beyond that distance can be mistakenly positioned. One way to identify this behavior is to change the timing of consecutive pulses such that their position relative to nearby pulses will change.
- Doppler dilemma: The physics of the Doppler effect produce “blind speeds” for specific target velocities. Changing the PRF can change the location of blind speeds and detect previously unseen targets. Some radar systems switch between a high PRF optimized to obtain blind speeds greater than the expected target velocities and a slower PRF optimized for increased range.
- Protection against jamming: Variable PRI, often combined with complex stagger sequences, allows easier differentiation of signal echoes across radar systems. Some stagger sequences are also designed to confuse jammers based on digital-signal-processing (DSP) techniques.

Pulse compression techniques can increase the range of a radar system by transmitting longer pulses for increased average power. Echo processing at the receiver can deliver much better spatial resolution by “compressing” the pulse through correlation or dispersion processing. The two main pulse compression methodologies are as follows:

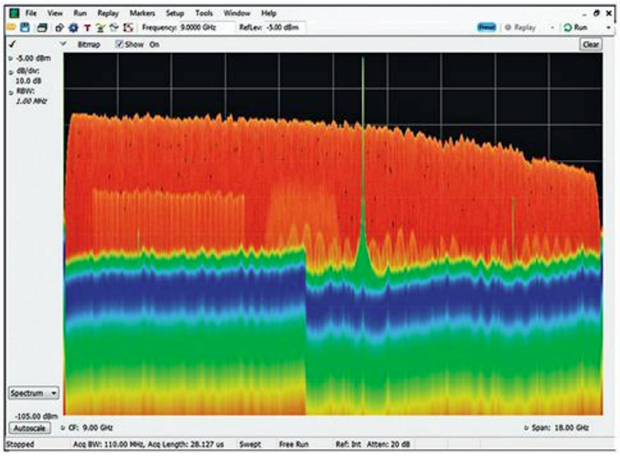
- FM chirp, which consists of fast frequency sweeps that can be linear frequency modulation (LFM) or nonlinear frequency modulation (NLFM). NLFM has some advantages compared to LFM in terms of efficient use of bandwidth, signal sensitivity, and receiver noise levels.
- Phase modulation, in which each pulse is composed of a series of shorter pulses where the carrier phase is controlled by a low-autocorrelation binary sequence of symbols. In binary-phase-coding modulation, the carrier phase changes between 0 and 180 deg. Polyphase pulse compression applies the same basic idea of changing phase, but the carrier phase is switched among more than simply two phase states.

Carrier phase coherence is an important issue for certain radar systems. In certain radar systems, such as high-performance coherent moving-target-indication (MTI) radar systems—where the phase of each pulse provides details about the precise position of a moving target—the phase coherence between consecutive pulses must be preserved to ensure precise positioning of the target.

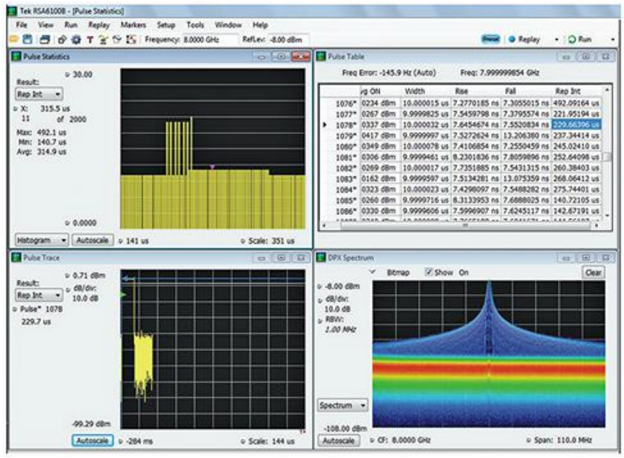
Radar receivers detect target echo signals consisting of multiple superimposed signals returning from the same target. Some of the relative phase differences may be due to different signal reflections, different multipath signal delays, and different Doppler-related signal clutter and frequency shifts. While the transmitted signal may exhibit complex timing and modulation, the reflected signal will be much more complex due to environmental effects.

GENERATING RADAR SIGNALS

As *Fig. 1* shows, AWGs can generate radar signals using three different basic methods: baseband generation, intermediate-frequency (IF) signal generation, and direct RF signal generation. When creating radar signals through baseband generation, an AWG generates a time-domain signal to be applied to an RF modulator. For simple signals, a single-channel AWG output is applied to an amplitude modulator (AM).



2. With its high-speed digital-to-analog signal conversion architecture, a modern AWG is capable of producing a wideband signal environment suitable for radar system testing.



3. This test result evaluates PRI on a set of 2,000 pulses constructed as a staggered PRI CW pulse waveform on a commercial AWG (a model AWG70001A from Tektronix).

For more complex signals with complex forms of digital modulation or fast frequency sweeps (FM chirp), both the amplitude and the phase of the carrier must be instantaneously controlled. In such a case, the easiest and most flexible solution is a quadrature modulator with two baseband signals.

When creating radar signals by means of IF generation, an AWG generates a modulated signal at a relatively low carrier frequency. Often the signal can be applied directly to a signal-processing function block in the receiver or transmitter. In situations involving the final RF/microwave frequency, a frequency upconverter block may be needed to achieve the final required carrier frequency.

When creating radar signals by means of the final method, through direct RF/microwave generation, an AWG generates the modulated carrier at the final RF/microwave frequency. No additional signal-processing blocks aside from the expected filters and amplifiers are required to achieve the required radar signals.

Each radar signal generation approach has benefits and shortcomings. For most baseband and IF signals, an AWG with a sample rate of a few gigasamples per second (GSamples/s) is sufficient to achieve the required output frequencies. However, the modulation bandwidth of the final RF/microwave signal will be limited by the modulator or frequency upconverter.

In addition, wideband quadrature modulation is sensitive in in-phase/quadrature (I/Q) amplitude and phase imbalance or quadrature errors. Accurate alignment after a careful calibration is required to produce signals of sufficient quality using the baseband or IF radar signal generation approach.

Direct signal generation requires an extremely fast AWG with a sample rate at least 2.5 times higher than the maximum frequency component of the signal to be generated. These speeds are now possible with the latest generation of AWGs that can deliver quality signal generation beyond Ku-band frequencies (12 to 18 GHz).

An AWG can generate both undistorted or intentionally distorted signals according to their programming. The use of intentional distortion can compensate for distortion caused by external effects or components (such as connectors, cables, and other components) and can be used, for example, to improve amplitude flatness or group delay of a test setup.

Such compensation takes the form of a pre-emphasis filter to correct the signal-generation system's overall lowpass frequency response. As high-frequency components are boosted, the low-frequency components of the signal must be attenuated to maintain a peak-to-peak value that fits within the available DAC dynamic range.

An AWG's maximum sampling rate greatly influences signal quality. It is good practice to set the AWG sampling rate well above the minimum Nyquist requirement for generating a given signal frequency. Such oversampling increases signal quality in various ways, including providing flatter frequency response, greater image rejection, lower quantization noise, and lower pulse-to-pulse jitter. In fact, the main drawback to oversampling is the need for more memory—a reason why long record lengths are important to high-speed AWGs.

Generating test signals that closely resemble radar system signals can provide a tremendous boost when designing a radar system. For example, when one of the subsystems of a radar system is being designed, the remaining parts of the system are often unavailable for testing. By using off-the-shelf, general-purpose test equipment to simulate other subsystems within the full system, the device under test (DUT) can be tested under controlled signal conditions.

A test signal source capable of generating signals that closely match the signals that will be used by an actual radar system provides the means of characterizing that system under actual operating conditions. A wideband AWG, for example, can be used to simulate a cluttered open-air signal environment, as represented by *Fig. 2*.

The signal environment includes wide- and narrowband chip signals, narrowband signals, CW signals, and frequency-hopped radar signals, all captured by a real-time spectrum analyzer. Several communication signals and other interferers can also be seen in the same frequency bands as the radar signals.

Radar transmitter testing includes extensive evaluation of a wide variety of test signals. In many cases, the evaluation involves hundreds or thousands of pulses that are then analyzed using statistical techniques. As an example, *Fig. 3* evaluates the PRI on a set of 2,000 pulses constructed as a staggered PRI CW pulse waveform using a high-speed AWG. The histogram provides a statistical view of the distribution of the PRI measurements, while the pulse table and pulse waveform can be used to view measurements for each pulse.

DIRECT CARRIER GENERATION

An ideal AWG can generate output signals from DC to within one-half the sampling rate. Given a sufficiently high sampling rate, an AWG can directly generate a modulated RF/microwave test signal. Prior to current-generation AWGs, available AWGs suffered from relatively low sampling rates and poor spurious-free dynamic range (SFDR), which limited the generation of output signals for radar tested to a few GHz.

Direct signal generation with an AWG offers several advantages over traditional baseband/external modulator signal generation approaches. Among them:

- Baseband generation and quadrature modulation are performed mathematically;
- No additional equipment is required;
- A single AWG can generate multiple dissimilar carriers or wideband noise so that more realistic test scenarios can be provided by a single instrument; and
- Direct signal generation can be achieved using a simplified calibration procedure.

Although these advantages are significant, actual implementations of this architecture can reveal some drawbacks as well. One important issue is record length requirements. For a given record length, RL, the maximum time window, TW, that can be implemented is inversely proportional to the sampling frequency, f_s, or $TW = RL/f_s$.

Since sampling rates for direct RF generation must be higher than those for baseband signal generation, a given record length translates into a shorter TW for direct RF generation than for baseband signal generation. The RL is crucial for realistic emulation of complex radar systems incorporating staggered pulse sequences, frequency-hopping patterns, or time-varying echo characteristics caused by target movement or antenna vibration.

Generation of wideband signals may require the controlled addition of linear distortion to correct for amplitude flatness problems and phase linearity issues, such as those stemming from coaxial cables and connectors. Applying corrections based only on the amplitude response improves modulation quality performance, although phase response compensation is also required for optimal performance. Direct carrier generation also requires excellent sampling clock jitter performance because this translates directly to phase noise in the generated carriers.

Some applications, such as MIMO radar generation, require multiple test signal channels. The channels must also be synchronized, so they must share the same sampling clock and be time-aligned. Any timing difference among channels or channel-to-channel jitter will result in a reduced-quality radar test signal. When more than one instrument must be synchronized, standardized synchronization methodologies can simplify the alignment tasks while dramatically improving repeatability and reliability.

Continuous signal generation with an AWG is made possible by seamlessly cycling the contents of the waveform memory through the DAC. To obtain useful signals, consistency of the signal around the wrap-around event must be preserved. Timing characteristics of radar signals are especially important for the following reasons:

- PRI: An integer number of PRIs must be stored in the waveform memory. Otherwise abnormal pulse timing (longer or shorter than required) will occur every time the waveform is cycled.
- Carrier phase: For coherent radar emulation, carrier phase must be preserved. This condition can be met if record length and sampling rate are selected so that the resulting time window is an exact multiple of the carrier frequency period.
- Echo consistency: Multipath, filtering effects, and echoes beyond the unambiguous range must propagate from the end of one cycle to the next. The previous effects are seen as the convolution between the transmitted signal and the target system impulse response. Applying circular convolution to a consistent transmitted data set will create an echo emulation signal without any discontinuity or abnormal behavior.

In short, the latest AWGs allow for the direct generation of complex radar signals to carrier signals as high as 20 GHz in frequency. Such performance capabilities are made possible by recent breakthroughs in DAC technology and DAC components. Even the most complex frequency-agile or MIMO radar systems can now be emulated through direct RF/microwave generation—either coupled with deep waveform memory and time alignment between channels within a single signal generator, or else by means of multiple synchronized sources. mw

defense electronics

A Special Section to PENTON'S DESIGN ENGINEERING & SOURCING GROUP DECEMBER 2017

JACK BROWNE | Technical Contributor

Australian Defense Learns Through Simulation

Rockwell Collins is providing dome and desktop simulation tools to enhance the training efforts of the Australian Defense Force (ADF).

ROCKWELL COLLINS *(www.rockwellcollins.com)* will be supplying and installing simulation training systems for the Australian Army and Air Force Joint Terminal Attack Controllers (JTAC) and Joint Forward Observer (JFO) communities. The gear includes eight customized domes and 11 desktop trainer simulation solutions.

"The JTAC/JFO simulators, coupled with the Rockwell Collins FireStorm targeting solution, provide a true train-as-you-fight and fight-as-you-train experience for the users," said Jim Walker, vice president and managing director, Asia Pacific for Rockwell Collins. "This scalable solution allows students to transition from a desktop environment to high-fidelity visual realism in a fully immersive environment in the dome systems."

The Rockwell Collins JTAC/JFO simulators have been built from the ground up, utilizing innovative technologies from within the company and also by teaming with Australian companies Virtual Simulation Systems (VSS) and Titan IM Pty on core components for the simulators.

Virtual Simulation Systems *(www.virtualsimulationsystems.com)*, which develops commercial-off-the-shelf (COTS) as well as custom software simulation tools, offers a variety of innovative training

(Continued on page 70)

A new version of Rockwell Collins' SimEye helmet mounted display (HMD) will improve optical performance and decrease life cycle costs for the U.S. Army's Aviation Combined Arms Tactical Trainer (ACATT) systems.

U.S. Army Looks to Helmet Display for Improved Training

THE U.S. ARMY has selected a new version of Rockwell Collins' SimEye Helmet Mounted Display (HMD) for its Aviation Combined Arms Tactical Trainer (AVCATT) systems. A total of 332 HMDs will be upgraded for the training systems as part of a contract issued to Rockwell Collins *(www.rockwellcollins.com)* by the U.S. Army Program Executive Office for Simulation, Training, and Instrumentation (PEO STRI). The new display enhancement is expected to improve HMD optical performance, increase availability, and provide substantial life cycle cost savings due to lower maintenance requirements.

"We worked very closely with the PEO STRI to fine tune the

(Continued on page 70)

Surveillance is Becoming Less a "Manned" Operation

BATTLEFIELDS CHANGE has technologies evolve, and the combatants must adapt to the capabilities of available tools and weapons. Surveillance provides a means of knowing about those threats in advance, using the latest technologies to spy on the enemy. And for both sides performing surveillance, it is more and more becoming a matter of machines spying on machines, with the humans working from a distance.

Surveillance once involved infiltration, which often meant trying to sneak troops or individuals behind enemy lines in order to gather information about an enemy's plans. Advances in technology, such as spy satellites, helped to improve the efficiency of spying efforts. These led to the development of technologies devoted to intelligence, surveillance, and reconnaissance (ISR) using various information-gathering electronic devices, such as visual and thermal cameras and sensors. One of the keys to successful ISR efforts was slipping these cameras and sensors behind enemy lines, and unmanned vehicles. In particular, unmanned aerial vehicles (UAVs), were found to be an effective means of keeping an "eye" on an enemy without putting humans at risk. While humans were still involved, they stayed behind at a control station to monitor and control the motions of the UAV during its ISR mission.

The use of UAVs for ISR has now become standard practice for most military forces (see p. 46), with many of the vehicles used for ISR missions capable of impressive flight times and long endurance. Since these vehicles and their collections of sensors and cameras are not inexpensive, the global market for ISR-based UAVs is quite healthy, and expected to grow at a steady pace for the next decade.

These ISR vehicles are becoming more "intelligent," with tremendous computing and communications assets that allow them to process data from multiple sensors and cameras and transfer large amounts of intelligence at high data rates for dissemination across multiple armed forces and allied forces. Humans are still involved, but they are more and more keeping their distances from the battlefield. de

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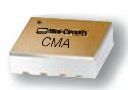

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Model	Freq. (GHz)	Gain (dB)	P_{OUT} (dBm)	IP3 (dBm)	NF (dB)	DC (V)	Price $ ea. (qty 20)
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CMA-82+	DC-7	15	20	42	6.8	5	8.95
CMA-84+	DC-7	24	21	38	5.5	5	8.95
CMA-62+	0.01-6	15	19	33	5	5	7.45
CMA-63+	0.01-6	20	18	32	4	5	7.45
CMA-545+	0.05-6	15	20	37	1	3	7.45
CMA-5043+	0.05-4	18	20	33	0.8	5	7.45
CMA-545G1+	0.4-2.2	32	23	36	0.9	5	7.95
CMA-162LN+	0.7-1.6	23	19	30	0.5	4	7.45
CMA-252LN+	1.5-2.5	17	18	30	1	4	7.45

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Pakistan Navy Upgrades Subs with Solid-State Radar

FOLLOWING AN announcement in February 2017 that Kelvin Hughes *(www.kelvinhughes.com)* will be supplying the SharpEye Doppler submarine radar system for the Pakistan Navy's Agosta 90B-class submarine—also known as the Khalid class diesel electric attack submarine—as part of a middle-of-life systems upgrade, the company received an order to equip the next Pakistan navy submarine with a SharpEye radar system. Kelvin Hughes is working with Turkish defense contractor STM as the prime contractor on the refurbishment program, and is scheduled to supply the first SharpEye system in 2018 and the second in 2019.

"We have a long-standing relationship with the Pakistan Navy and STM and I am very pleased to be working with STM to supply the state-of-the-art SharpEye radar system to the Khalid class submarines," said Barry Jones, regional sales manager for Kelvin Hughes.

The SharpEye I-band (X-band) radar transceiver (see photo) is based on a down mast transceiver housed in a compact enclosure within the submarine pressure hull. It makes use of the existing bulkhead infrastructure in the pressure hull, removing the need to replace the antenna mast system by using the existing external antenna, rotational drive, and waveguide connections. It serves as a retrofit for in-service submarines and high-performance solid-state radar for new classes of submarines, delivering performance and capabilities similar to SharpEye radar systems installed on naval surface ships. The upgrades are being performed at the Karachi Naval Shipyard in Pakistan.

The SharpEye solid-state radar transceiver module is being installed on two Pakistan navy submarines as part of an upgrade program.

(Photo courtesy of Kelvin Hughes)

The SharpEye solid-state radar system operates without a vacuum-tube magnetron to generate high-power pulsed Doppler signals. The high-reliability system does not require fault-finding training. It features low mean time to repair (MTTR), and is a readily line replaceable unit (LRU), not requiring trained technicians to performance a system replacement. ■

Australian Defense Learns Through Simulation

(Continued from page 67)

including its Complete Aircrew Training System (CATS) and Tactical Airlift Crew Trainer (TACT). Titan IM Pty Ltd. provides virtual reality (VR) software for the visualization of terrain and airspace for the purpose of combat training *(see figure)*.

"We are pleased to have been part of the Rockwell Collins team in providing this world-class training capability to the Australian Defence Force (ADF)," said David Lagettie, CEO of Titan IM Pty Ltd. "The past four years of collaborative development with Rockwell Collins has allowed us to fuse our industry-leading technologies together in a single, focused solution for the ADF."

Rockwell Collins has been committed to the Australian defense for more than five decades. This latest development effort will involve tools installed in seven locations across Australia over the next 24 months. These latest tools provide the capabilities to conduct JTAC and JFO missions true to the ADF processes within a highly immersive environment. ■

U.S. Army Helmet Display

(Continued from page 67)

HMD as technology continues to evolve," said Nick Gibbs, vice president and general manager, Simulation and Training Solutions at Rockwell Collins. "This next-generation solution will provide the Army with the highest fidelity simulation available and at a lower cost to maintain."

The SimEye HMD will be refined to include display and optical improvements to visual symbology, providing a boost to the already unprecedented level of realism. Along with a software update, the HMD upgrade will ensure the Army's continued success in using the AVCATT to train their helicopter crews effectively. ■

Raytheon Teams with MetTel Against Cybersecurity Threats

RAYTHEON CO *(www.raytheon.com)* and MetTel *(www.mettel.net)* have established a global security alliance to protect government and commercial communications networks against an increasing number of cybersecurity threats, including those using the Internet of Things (IoT) technology. The companies will work together to ensure that cybersecurity is designed into the government's telecommunications infrastructure. The alliance supports the current presidential administration's information technology (IT) modernization and cybersecurity priorities.

"Security is foremost on everyone's mind today, especially with the constant emergence of new threat forms compounded by the exploding array of devices and network access points," said Ed Fox, vice president of Network Services for MetTel. "The world needs a network that meets the highest government security standards and together, MetTel and Raytheon are committed to delivering that network."

The MetTel-Raytheon alliance will provide a range of managed security services, professional consulting services and technologies to detect, assess and defeat potential intrusions on MetTel-owned or managed customer networks. The principal elements of the agreement include MetTel and Raytheon building and operating managed trusted IP services for federal government agencies through the GSA's Enterprise Infrastructure Solutions (EIS) contract.

MetTel was named as a vendor for the $50 billion, 15-year GSA award in August 2017. As part of MetTel's team on the EIS contract, Raytheon will offer cybersecurity experts on a contractual basis to federal agencies for custom consultations. MetTel will also employ Raytheon's Automated Threat Intelligence Platform (ATIP) and other advanced security services as part of the EIS work. ■

Mercury Systems Supplies MCMs for Airborne EW System

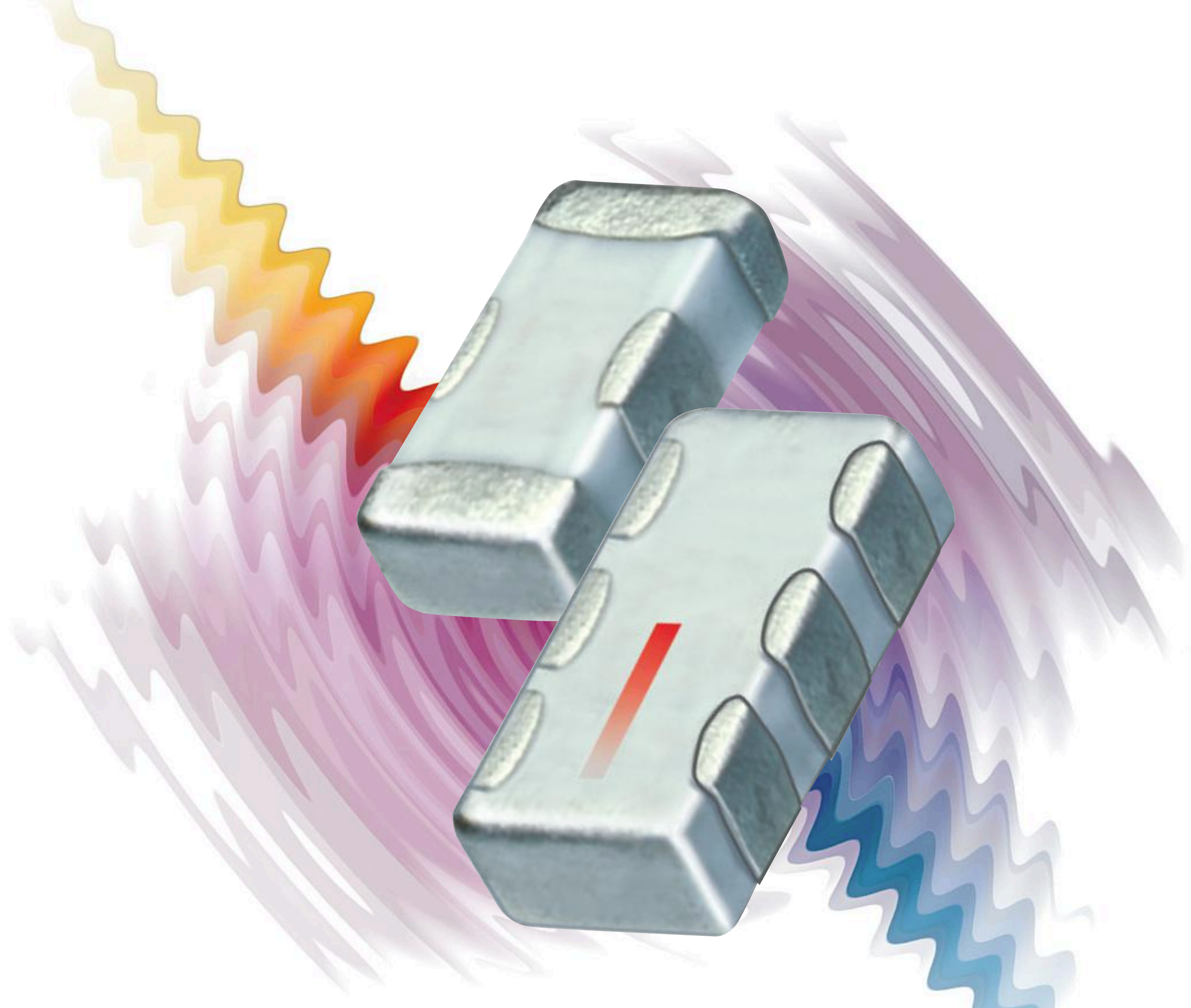
MERCURY SYSTEMS *(www.mrcy.com)* has received a follow-on $3.8 million order from a leading defense prime contractor for multichip modules (MCMs) integrated into an advanced airborne electronic warfare (EW) system. The order was booked in the second quarter of the company's fiscal 2018 business year and is expected to be shipped over the next several quarters.

The microelectronic devices are manufactured in Mercury's Defense Microelectronics Activity (DMEA) Advanced Microelectronics Center (Phoenix, Ariz.). The company's technology includes rugged 3D ball-grid-array (BGA) packaging designed for harsh military environments.

"We are honored to continue supplying trusted microelectronics enabling our military forces' most advanced airborne platforms to dominate the electromagnetic spectrum," said Iain Mackie, vice president and general manager of Mercury's Microelectronic Secure Solutions group. "Defense prime contractors and our military forces can count on Mercury's next-generation business model for long-term supply continuity of the most affordable, compact, and high-performance microelectronics solutions." ■

Lockheed Martin Recognizes Dedicated Computing for Award

LOCKHEED MARTIN Rotary and Mission Systems (RMS) nominates and selects partners each year that persistently provide outstanding support and products. This year, Dedicated Computing *(www.dedictaedcomputing.com)* received the RMS Small Business Award by designing, manufacturing, and delivering a large quantity of complex image-rendering computers to different RMS customer training facilities, on tight schedules. ■



Navy Eyes Advanced Telemetry System for Range Support Aircraft

THE U.S. NAVY has awarded Raytheon Co. (www.raytheon.com) a $79 million contract to develop a new telemetry system for the U.S. Navy's Range Support Aircraft. The advanced aircraft will replace the Navy's aging telemetry test aircraft, in service since the 1970s. The new aircraft, which will be based on the subsystem within the Gulfstream (www.gulfstream.com) G550 airborne early warning airframe, will offer multi-role capabilities in telemetry data collection, range safety and surveillance, and communications relay.

"It's like replacing your old eight-track tapes with streaming digital music—there's simply no comparison," said Todd Callahan, Raytheon Naval and Area Mission Defense vice president. "Our new Range Support Aircraft will use the latest technology to support advanced weapons testing and other missions for the next 25 years." Raytheon will draw upon a wide portfolio of products, technology, and expertise to develop the new system. Once operational, the Range Support Aircraft will collect and process telemetry data from missiles, aircraft, unmanned aerial vehicles (UAVs), and ships. Raytheon will perform system design, fabrication, and aircraft integration as part of the contract award. ■

A U.S. Navy Range Support Craft (RSC) is accompanied by an MH-60S Sea Hawk helicopter during training sessions. *(Photo courtesy of the U.S. Navy)*

Increasing Cyberthreats Boost Growing Cybersecurity Spending

COMPUTER VANDALS work at all levels and in all markets in their attempts to steal secure data. As a result, according to leading research firm VisionGain *(www.visiongain.com)*, the need to invest in protection against cyberthieves is growing, and the global cybersecurity market will reach a level of $83.5 billion in spending in 2017. The firm's 289-page report, "Cyber Security Market Report, 2017 to 2027," projects massive growth in spending to protect against computer thieves at all levels.

One current trend in cybersecurity is a growing awareness on the part of businesses and organizations of the dangers of hackers and a steady rise in the use of ransomware against small businesses, nonprofit organizations, and government agencies. Because of this, organizations are witnessing a general increased level of investment by every company trying to protect their sensitive data.

Another trend is the increase in the number of devices being used to protect against cyberthreats and the amount of bandwidth enterprises are leveraging for protection. Larger organizations have been slower to adopt cloud-based technologies because of concerns over security and compliance issues. These firms require a more flexible solution that allows them to use the cloud when appropriate and also have the option of onsite hardware when necessary. The study includes a 10-year forecast of the cybersecurity market for aerospace and defense companies, and includes profiles of a variety of companies, including Cisco Systems, Dell, Lockheed Martin, Northrop Grumman, and Verizon Communications. ■

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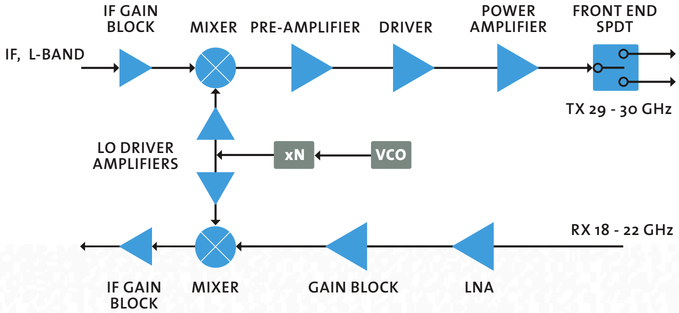

BOB LAZARAVICH | Technical Director, Mercury Systems, Inc., 50 Minuteman Rd., Andover, MA 01810; (978) 256-1300
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Secure Solid-State Drives Safeguard Critical Data

Data protection is an important design aspect of many defense electronics systems and can be effectively managed through the use of secure solid-state storage drives.

DATA SECURITY is an important if not always achievable goal for military electronics systems. Those systems are acquiring large amounts of data from multiple sensors simultaneously, at rates sometimes exceeding 30 GB/s. With flash memory as the only practical permanent storage media, solid state drives (SSDs) are now a common system- level component in military systems. System-level designers may specify low-cost, commercial-off-the-shelf (COTS) SSDs to store data in military systems, but are often challenged with providing enough data security in the final system.

As low-cost data storage solutions, COTS SSDs may represent budget savers for advanced military electronics systems. But they then fail to meet nearly all of the performance criteria required by the other electronic components in the system: predictable performance under stressful operating conditions, physical ruggedization, long-term availability from a Defense Microelectronics Activity (DMEA)-accredited supply-chain partner, and trusted security. To avoid catastrophic consequences, security must be incorporated into a military-grade SSD from a system's design phase—not "bolted-on" as an afterthought to a mass-market consumer data storage product.

Modern military-grade SSDs use advanced encryption standard 256 (AES 256) to encrypt data. The standard was established by the National Institute of Standards and Technology (NIST) in 2001. Protection of stored data in a military electronic system is directly linked to the strength of the data encryption key (DEK), how the DEK is generated, and how the DEK is filled into the SSD.

DEKs used by most COTS SSDs are internally generated. It provides data security, but the internal generation does not permit verification of the randomness or entropy of the DEK. An alternative to using internal, self-generated DEKs for an SSD is to generate the DEK values externally. This can be done by means of systems and algorithms known to create highly random values and using these externally generated DEK values to fill the SSD.

External key fill also provides a very strong security feature. Because the DEK is filled by the host system at every power-on event, an unpowered SSD contains no discoverable key value. COTS SSDs with internally generated and stored DEK values must obscure or encrypt the self-generated DEK. Since the method used to secure the DEK is unknown, it may well be secure, but it is nearly impossible to verify that a COTS SSD is properly protecting the DEK. It might be stored in plain text!

While recovering even a plain-text DEK stored somewhere inside a COTS SSD is most likely beyond the abilities of an everyday computer hacker, it may not be beyond the abilities of state-sponsored cryptographic professionals. Military-grade SSDs encrypt self-generated DEKs and accept password lengths to 64 characters to fully secure them.

Additionally, a military-grade SSD will erase the entire contents of the drive after just a few incorrect password or key fill attempts. Since the requirements for defense applications vary considerably, an SSD that supports several key management techniques, strong passwords, and programmable security features can greatly simplify the security implementation of a defense system.

Unlike consumer or enterprise-grade storage devices used in climate-controlled environments, SSDs used in military systems are deployed in manned and unmanned air, land, and shipborne platforms. The use case for unmanned vehi-

End-user devices (EUDs) implemented under the CSfC program use two or more layers of CSfC-compliant components and are approved to provide protection for classified, secret, and top-secret data. Part of the protection comes from being powered, and an unpowered CSfC EUD is actually considered unclassified.

This is an example of a military-grade, FIPS 140-2 certified solid-state-drive (SSD) data storage device for mission-critical applications.

cles presents a unique security challenge: If an unmanned vehicle is captured, no personnel will be available to physically destruct or initiate a process to eliminate the sensitive data valued by the adversary. In this scenario, the contents of the drive should be quickly and automatically erased as soon as a threat is detected.

DEK purge, fast clear, sanitize, and destruct operations triggered by sensors in the host system or anti-tamper circuitry in the SSD are very good ways to assure that highly sensitive data remains protected, provided that the SSD supports these capabilities. While common on military grade SSDs, these features are rare to nonexistent in COTS SSDs.

PROTECTING DATA

Highly sensitive data has historically been protected using Type 1 security memory devices certified by the U.S. National Security Agency (NSA; *www.nsa.gov*) for securing classified government information. However, the Type 1 security certification process can require several years and millions of dollars to implement. In seeking a better way, the NSA and the Central Security Service (CSS) of the NSA launched the Commercial Solutions for Classified (CSfC) Program.

End-user devices (EUDs) implemented under the CSfC program use two or more layers of CSfC-compliant components and are approved to provide protection for classified, secret, and top-secret data. Part of the protection comes from being powered, and an unpowered CSfC EUD is actually considered unclassified. Validation under the CSfC program provides the system architect with assurance that cryptographic algorithms in the SSD are certified and have passed rigorous testing at an approved NIST and National Information Assurance Partnership (NIAP) laboratory *(www.niap-ccevs.org)*.

Although CSfC validation of a secure SSD represents the pinnacle of third-party testing, various certification approaches can be used to determine the suitability of an SSD for mission-critical applications. At the very minimum, the encryption algorithm should be certified by NIST as properly conforming to the AES algorithm as specified in Federal Information Processing Standard (FIPS) Publication 197, Advanced Encryption Standard *(https://csrc.nist.gov/Projects/Cryptographic-Algorithm-Validation-Program/Validation/Validation-List/AES)*. The next level of certification is validation under the NIST Cryptographic Module Validation Program (CMVP) FIPS 140-2. FIPS Publication 140-2 *(https://csrc.nist.gov/csrc/media/publications/fips/140/2/final/documents/fips1402.pdf)* defines a rigorous set of security requirements for cryptographic devices that has gained worldwide acceptance *(see photo)*.

Certainly, for some applications, a COTS SSD may provide the performance, ruggedness, and security required to protect the data. But if a COTS SSD lacks the ruggedness, security, and the properly implemented crypto algorithms required to protect data under the many challenges faced by a military electronics system, a military-grade SSD and its high level of encryption may make a better choice for protecting data in a sensitive military application.

Additional information on protecting sensitive data through the use of secure SSDs is available by downloading the white paper "Safeguarding Mission Critical Data with Secure SSDs," available at the Mercury Systems website *(www.mrcy.com/SSD)*. In addition, more information on SSD encryption technology can be found in an eight-page white paper, "Demystifying Hardware Full Disk Encryption Technology for Military Data Storage," also available for download from the Mercury Systems website.

JACK BROWNE | Technical Contributor

TWTs Power Instrument Amplifiers to 40 GHz

Equipped with many field-friendly features, these rugged TWTAs are available for frequency bands to 40 GHz with as much as kilowatts of power.

DEFENSE SYSTEMS contain a great deal of hardware that requires high-power RF/microwave signals for testing, whether in communications systems, electronic-warfare (EW), or radar systems. In addition, high-power test signals are often needed for electromagnetic-compatibility (EMC) or radio-frequency-interference (RFI) testing of high-frequency components and systems.

For robust power levels, instrumentation amplifiers based on traveling-wave-tube (TWT) active devices can provide the necessary output-power levels across the required bandwidths. TMD Technologies Ltd. (www.tmd.co.uk) has just unveiled its PTCM line of TWT-based instrumentation amplifiers that provide as much as kilowatts of power for selected bandwidths to 40 GHz, but are more than "just" amplifiers, with many self-monitoring and self-protection features that ensure long and reliable service lives for these TWTAs.

The PTCM TWTA instrumentation amplifiers (see photo) are housed in a standard, 6-u-high 19-in. rack-mount enclosure that allows multiple units to be combined in an instrument rack to achieve required frequency ranges and power levels. Amplifiers are available for total frequency coverage of DC to 40 GHz and as much as 50 kW peak output power, although the output levels of individual, standard units are much more conservative and for more limited bandwidths.

As an example, model PTCM1004 is a rack-mount TWTA for applications from 2 to 6 GHz. It provides 200 W minimum output power across that frequency range, with typical output power of 250 W for pulsed or CW signals. For somewhat higher frequencies, model PTCM1008 covers a frequency range of 6 to 18 GHz, with 300 W minimum output power and 320 W typical output power for pulsed or CW signals. At the high-frequency end of the total frequency range, model PTCM1018 delivers 40 W minimum output power, and typically 80 W output power from 18 to 40 GHz, for pulsed or CW signals.

The instrumentation amplifiers are quite robust, weighing 47 kg and with a length of 800 mm. The company's long history in electron tube technology, including klystrons and TWTs, is apparent in the thermal design of the PTCM instrumentation amplifiers, which incorporate heat-pipe technology to spread the heat produced by each TWT over large areas within the enclosure. The advanced thermal management reduces peak temperatures and minimizes opportunities for "hot spots," improving the mean time before failure (MTBF) of the amplifiers in the process. The TWTAs are designed for an operating temperature range of 0 to +40ºC.

The PTCM Series of TWT-based instrumentation amplifiers (such as the PTCM1001 shown here) provide high output-power levels across a total frequency range of DC to 40 GHz in 19-in. rack-mount enclosures. They are well suited for a wide range of test purposes for communications, ECM, EW, and radar applications.

The high-power instrumentation amplifiers are built to last, with a host of self-diagnostic routines and built-in over-VSWR protection. They are also equipped with plug-and-play field-replaceable power supplies to simplify the task should repairs be needed. They include Ethernet interfaces for wired or wireless connection to a PC for monitoring and remote control, and are fortified by a PC-based software tool that monitors and displays primary operating parameters, such as VSWR, pulse width, pulse repetition frequency (PRF), duty cycle, TWT temperature, and power-supply temperature. The amplifiers meet the standards for RTCA/DO-160, MIL-STD-810G, EUROCAE, and AIRBUS ABD 100.

TMD TECHNOLOGIES LTD., Swallowfield Way, Hayes, Greater London UB3 1DQ, United Kingdom; +44 (0) 20 8581 5116; *www.tmd.co.uko.*

JACK BROWNE | Technical Contributor

Smart Radios Connect Army's Ground Robots

These modular, highly computerized tactical radios are being installed as the communication devices on a large squad of UGV robots for the U.S. Army.

ROBOTS ARE PLAYING larger roles in military efforts, and even robots need reliable radios to communicate. What better way for them to connect with each other and with humans than by using a "smart" radio, such as the MPU5 smart radio from Persistent Systems (*www.persistent.com*)? This mobile ad hoc networking (MANET) radio will provide communications links for ground robots being supplied to the U.S. Army MTRS Inc II program by Endeavor Robotics (*www.endeavorrobotics.com*). A total of 2,400 MPU5 smart radios are being supplied for 1,200 robots as part of a $100 million IDIQ contract.

With the compact MPU5 smart radios (*Fig. 1*) installed on the MTRS Inc II ground robots, they are connected to each other and to their human operators, who will have wireless control of the unmanned ground vehicles (UGVs). This contract expands the number of participants in Persistent Systems' networked ecosystem, which includes unmanned aerial vehicles (UAVs), UGVs, fixed sensors, and even legacy radios. This news comes on the heels of Persistent's September $8.9 million contract win to support Army National Guard counter-WMD civil support teams by networking their chemical, biological, radiological, nuclear, or explosive (CBRNE) sensors.

The MPU5 is based on software-defined-radio (SDR) technology and the company's own Wave Relay transmission algorithms. It is computer-intensive, with 1-GHz quad-core ARM, 2 GB RAM, and 128 GB of flash memory storage for flexibility when adapting to changing network communications conditions in the field. The phone can run Android Tactical Assault Kit (ATAK) software and other programs. In spite of the computing power, the radio is small enough to fit in the palm of the hand and won't slow down the robotic UGVs on which they are installed.

1. The MPU5 smart radios are highly computerized tactical radios with interchangeable frequency modules for L-, S-, and C-band frequencies that are being installed in the Endeavor Robotics ground robots being supplied to the U.S. Army MTRS Inc II program. *(Photo courtesy of Persistent Systems, LLC)*

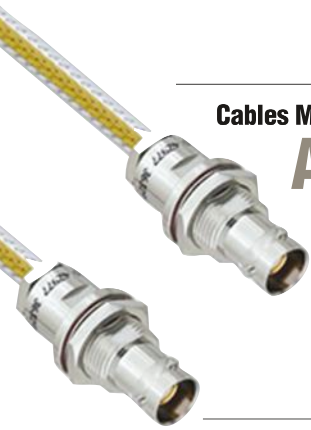
These small tactical radios are modular in terms of frequency, and can operate over three frequency bands: L-band, S-band, or C-band. As much as 6 W transmit power is available for any of the three frequency bands, which can be exchanged in the field for networking flexibility. The MPU5 is a true MANET solution with Cloud computing capability; it supports 3×3 multiple-input, multiple-output (MIMO) communications with data throughput of better than 100 Mb/s. It has a built-in GPS receiver which is updated every 1 s for navigational and locational precision.

The three interchangeable frequency modules are the RF-1100, which covers the L-band frequency range of 1,350 to 1,390 MHz; the RF-2100 module, which operates at S-band frequencies of 2,200 to 2,500 MHz; and the RF-4100 module, which operates over the lower C-band frequency range of 4,435 to 4,980 MHz. The radios and their modules feature software configurable bandwidths of 5, 10, and 20 MHz.

The Army's UGVs will have full wireless and wired connectivity options, since the radios include USB host and RS-232 serial ports, Ethernet, and USB-on-the-Go connections. The MPU5 smart radios also include multiple power-charging options, with an end-user-device (EUD) data/charging port, a charging downstream port (CDP) port rated for 1500 mA, and a standard charging port (SDP) rated for 500 mA. The radios require 8 to 28 V dc for operation. They are MIL-STD certified and designed for use by both men and machines (*Fig. 2*) over an operating temperature range of −40 to +85°C.

2. The MPU5 smart radios will provide the means for men and machines to communicate securely in the field, as part of a new U.S. Army IDIQ contract. *(Photo courtesy of Persistent Systems, LLC)*

PERSISTENT SYSTEMS, LLC, 303 Fifth Ave., Ste. 306, New York, NY 10016; (212) 561-5895; *www.persistentsystems.com*.



Cables Make High-Temperature Connections

A LINE OF Teflon-jacketed cable assemblies has been developed for high-temperature RF/microwave and instrumentation applications from –55 to +200ºC. Available with a variety of termination combinations, such as TRB jacks and TRB plugs, the 50-Ω cable assemblies are supplied in standard lengths of 1, 3, 10, and 20 ft. The cable assemblies feature a silver-plated copper braid with 0.236-in. outside diameter (O.D.).

MILESTEK

17792 Fitch, Irvine, CA 92614; (978) 682-6936; www.milestek.com

X-Band PA Hits 8-kW Peaks

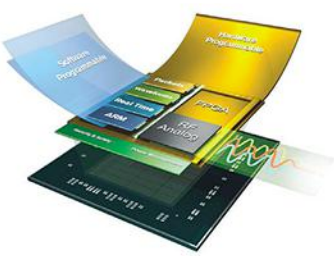
THE BMPC9X89X8-8000 power amplifier is designed for pulsed X-band radar applications from 9.0 to 9.9 GHz. Based on GaN solid-state technology, the rugged Class AB linear amplifier provides 8 kW peak output power across an instantaneous bandwidth of 500 MHz with less than 1 dB pulse droop. It is designed to operate with pulse widths from 0.25 to 100 µs with typical pulse rise/fall time of 50 ns and 10% duty cycle. The amplifier delivers 69-dB nominal power gain with phase noise of –100 dBc/Hz offset 100 Hz from the carrier and harmonics of –60 dBc. The input and output VSWRs are less than 1.50:1. The rack-mountable amplifier, which is supplied with an internal AC power supply and Ethernet control interface, weighs 90 lb. and measures 19 × 12.25 × 24. with female SMA connectors. It is designed for operating temperatures from 0 to +50ºC.

COMTECH PST

105 Baylis Rd., Melville, NY 11747; (631) 777-8900, www.comtechpst.com

RF SoC Integrates Radar Components

THE ZYNQ ULTRASCALE+ RF system on a chip (SoC) family includes versatile integrated solutions that are as well suited for radar systems as for 5G wireless networks. These SoCs include high-performance analog and digital components, including analog-to-digital converters (ADCs), digital-to-analog converters (DACs), 16-nm programmable logic, memory, and forward error correction (FEC) in low-power devices. Available devices can be supplied with as many as eight 4-GSamples/s or 16 2-GSamples/s 12-b ADCs and eight to 16 6.4-GSamples/s 14-b DACs and as many as 930,000 logic cells. They provide the high level of performance and integration needed for multifunction-phased-array-radar (MPAR) systems, making it possible to incorporate the functions of several radar networks into a single system for aircraft and weather surveillance.

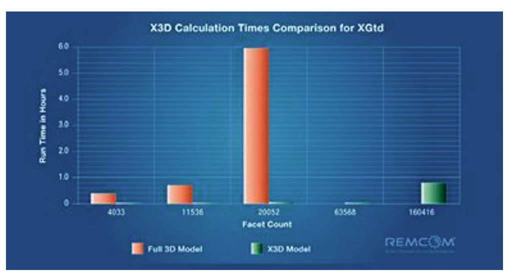


XILINX, INC.

2100 Logic Dr., San Jose, CA 95124-3400; (408) 559-7778, www.xilinx.com

Antenna EM Simulator Boosts Speed and Accuracy

THE LATEST VERSION of XGtd ray-based electromagnetic (EM) simulation software for antenna analysis features a GPU accelerated radar-cross-section (RCS) model with fast processing speed and high accuracy. The software is well suited for assessing the effects of a vehicle or vessel on antenna radiation, predicting coupling between antennas, and predicting the RCS of an antenna—especially for higher-frequency systems with large volumes and complex geometries. The new software version uses multithreading techniques to reduce computational times from hours or days to minutes while enhancing the computational accuracy.



REMCOM, INC.

315 South Allen St., Ste. 416, State College, PA 16801; (814) 861-1299, www.remcom.com

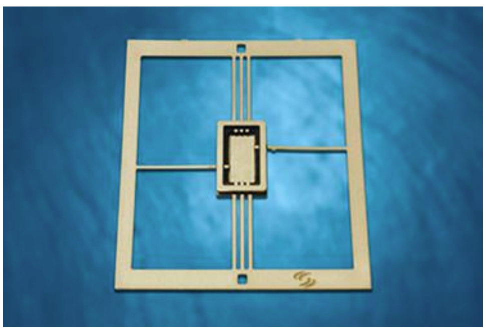
AlGaAs Switch Reaches 100 GHz

THE MASW-011029 is a single-pole, three-throw (SP3T) switch usable for applications from 75 to 110 GHz and usable across a total frequency range of 60 to 110 GHz. It suitable for satellite communications, 77-GHz automotive radar, and 94-GHz commercial and military imaging and security applications. The switch is fabricated on GaAs substrate material, with an AlGaAs PIN diode MMIC process, including an additional protective layer for scratch protection that enables the devices to handle pick-and-place assembly. Each RF port contains DC blocking capacitors and a DC bias circuit consisting of high-impedance lines and RF bypass capacitors. The RoHS-compliant switch exhibits typical insertion loss of 1.3 dB from 75 to 110 GHz, with 33-dB typical isolation. It draws 10 mA typical forward bias from +1.15 to +1.40 V dc. Its typical 10-to-90% switching speed is 2 ns. The AlGaAs switch is designed for operating temperatures from –25 to +85ºC and can handle input power levels to +23 dBm.

MACOM

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

Ceramic Packages Protect GaN Devices to 18 GHz



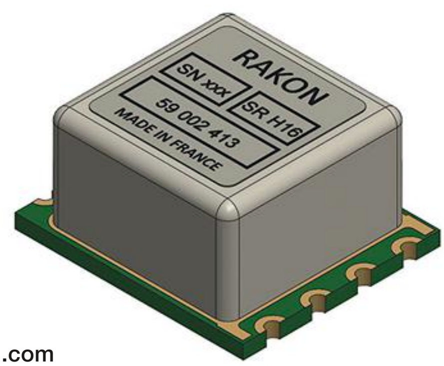
A LINE OF off-the-shelf molded ceramic packages can be configured to meet the requirements of high-frequency devices, including those based on GaN, at frequencies through 18 GHz. The molded ceramic packages are supplied in more than 200 standard outlines, providing a tremendous array of options for packaging GaN devices. The molded ceramic packages serve as a lower-frequency alternative to copper-molybdenum-copper (CMC) packages used for devices through 63 GHz. In the molded ceramic packages to be used for GaN, the standard Kovar base can be replaced with CMC for better thermal dissipation. For frequencies of 18 GHz or less, using a molded ceramic package provides the advantages of hermeticity and lower cost, while the CMC provides the thermal dissipation needed to manage heat in critical applications, such as in aerospace systems. For surface-mount-technology (SMT) packages, the ceramic packages can be manufactured with gull-wing formed leads.

STRATEDGE

6335 Ferris Square, Ste. C, San Diego, CA 92121; www.stratedge.com

Ovenized SAW Oscillators Trim Noise in Tight Spots

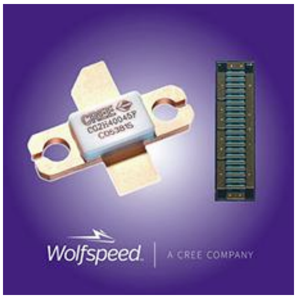
A LINE OF small-form-factor oven-controlled surface-acoustic-wave (SAW) oscillators is a good fit for applications requiring stable frequencies with low phase noise. These OCSOs are suitable for instrumentation, radar, and electronic-warfare (EW) applications. Models are available with frequencies of 400 MHz, 500 MHz, 600 MHz, 800 MHz, 1 GHz, and 1.2 GHz, supplied in miniature surface-mount-device (SMD) packages measuring 25.4 × 22 × 12.7 mm and designed for connection by means of solder reflow. As an example, model LNO800E1 is an oven-controlled, voltage-controlled SAW oscillator (OCVCSO) that operates at 800 MHz. It is powered by a +5-V dc supply with its output generated from a 400-MHz fundamental frequency resonator followed by a low-noise frequency doubler. The signal sources are useful for applications where size and weight are critical. Typical phase noise is –137 dBc/Hz offset 1 kHz from the carrier and –160 dBc/Hz offset 10 kHz from the carrier, with a noise floor of –167 dBc/Hz.



RAKON LTD.

8 Sylvia Park Rd., Auckland 1060, New Zealand; +64-9-571-9216, www.rakon.com

GaN HEMTs Provide Power to 8 GHz



SUITABLE FOR BOOSTING signals at frequencies to 8 GHz, several lines of GaN-on-SiC HEMT devices provide high output power at high efficiency in chip and packaged forms. Suitable of military communications, radar, ECM, and EW applications, these high-power transistors are fabricated on a 0.25-μm GaN-on-SiC process that provides devices with high gain and high efficiency. The transistors are available as packaged devices in the CG2H400 line and bare die, in the CG2H800 line. For example, in the packaged series, model CG2H40010 provides 10 W saturated output power with 70% efficiency. It offers 18-dB small-signal gain at 2 GHz and 16-dB small-signal gain at 4 GHz and is usable to 8 GHz. Model CG2H40025 delivers 25 W saturated output power with 65% efficiency, 17-dB small-signal gain at 2 GHz, 15-dB small-signal gain at 4 GHz, and is usable to 6 GHz. Model CG2H40045 generates 45 W saturated output power with 60% efficiency, 18-dB small-signal gain at 2 GHz, and 14-dB small signal gain at 4 GHz. Transistors available as bare die include model CG2H80015 with 15 W output power and 65% efficiency at 8 GHz; model CG2H80030 with 30 W output power and 65% efficiency at 8 GHz; and model CG2H80060 with 60 W output power and 65% efficiency at 8 GHz.

WOLFSPEED, A CREE CO.

13028 East Cornwallis Rd., Research Triangle Park, NC 27709; (866) 924-3645, (919) 287-7888, www.wolfspeed.com

Weatherproof Dividers Go 6, 8 Ways to 500 MHz

OUTDOOR APPLICATIONS REQUIRE rugged components that not only provide the required electrical performance, but can withstand the effects of radio frequency interference (RFI) and moisture from humidity and adverse weather. Several additions to a line of six- and eight-way Wilkinson power dividers with SMA and Type N connectors for applications from 5 to 500 MHz. The typical VSWR for these components is 1.20:1, with typical isolation between channels of 25 dB. The Wilkinson power dividers are built to handle high levels of shock and vibration and maintain excellent amplitude and phase balance between channels. As an example, model 806-4-0.252WWP is a weatherproof six-way power divider with female Type N connectors for applications from 5 to 500 MHz. It has 1.20:1 typical VSWR and 1.30:1 maximum VSWR. The typical insertion loss is 0.7 dB. The six-way power divider/combiner handles power levels to 2 W and maintains typical amplitude balance of 0.5 dB and phase balance of 8 deg. Typical isolation between ports is 25 dB.

MECA ELECTRONICS, INC.

459 East Main St., Denville, NJ 07834; (866) 444-6322, (973) 625-0661, www.e-MECA.com

Programmable Pads Span DC to 2 GHz

A LINE OF relay-controlled programmable attenuators with coaxial connectors covers a total frequency range of DC to 2 GHz and a total programmable attenuation range of 0 to 127 dB. Attenuation steps are as small as 0.25 dB and as large as 64 dB. Insertion loss spans 0.8 to 0.35 dB, depending upon frequency and model. Attenuation accuracy for all models is ±0.5 dB. The programmable attenuators are rated to handle as much as 1 W input power. Models are available with characteristic impedance of 50 or 75 Ω. The RoHS-compliant attenuators are constructed of nickel-plated brass with female SMA or Type F coaxial connectors and have operating temperature ranges of -20 to +85ºC. They are suitable for commercial and military satellite and ground communications systems. As an example, model PE70A8002 is a 50-Ω attenuator that operates from DC to 2 GHz with 0 to 63.75 dB attenuation. Attenuation can be adjusted in steps of 0.25, 0.5, 1, 2, 4, 8, 16, or 32 dB. The insertion loss ranges from 3.0 to 3.5 dB. The attenuation is controlled via bias of 30 mA from a supply of +12 V dc. The relay-controlled attenuation is supplied with female SMA connectors.

PASTERNACK ENTERPRISES, INC.

17802 Fitch, Irvine, CA 92614; (949) 261-1920, www.pasternack.com

ORDER FROM THE MENU of IoT Wireless Technologies

WITHOUT QUESTION, THE number of wireless Internet of Things (IoT) standards seems too numerous to count. With so many in existence, how can one decide which to use for a given application? Doing just that is the objective of Keysight Technologies' new application note, "The Menu at the IoT Café: A Guide to IoT Wireless Technologies." The application note discusses several topics, such as both short- and long-range wireless, unlicensed and licensed bands, and more.

The application note first discusses the various short-range wireless technologies, such as Bluetooth and ZigBee. Bluetooth and ZigBee devices operate in the unlicensed industrial-scientific-medical (ISM) bands; specifically, the 2.4-GHz band is the most commonly used ISM frequency band. The document also associates short-range wireless standards with personal area networks (PANs), which typically have ranges of about 10 to 30 meters.

Wi-Fi is then discussed in greater detail. Since Wi-Fi has existed for a long time, there are many suppliers of chip and modules. Designers therefore have many options in terms of hardware components. The application note describes various forms of Wi-Fi: 802.11b, 802.11g, 802.11a, 802.11n, and 802.11ac.

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

Next, long-range wireless standards are discussed. One technology described is LoRa, which uses sub-1-GHz frequencies in unlicensed spectrum. The application note points out how LoRa signals can penetrate deep into buildings and reach locations not accessible when using higher frequency equipment. Another technology described, Sigfox, is a proprietary radio protocol that operates in the sub-1-GHz frequency bands.

The next topic presented is licensed spectrum, which in this case refers to cellular data networks. These networks involve spectrum and control access that have been purchased by operators to provide voice and data connections. Two IoT technologies mentioned that use licensed spectrum are narrowband-IoT (NB-IoT) and Cat-M1. NB-IoT is a low-data-rate, long-range technology. Cat-M1 offers higher data rates than NB-IoT. Finally, hybrid networks are discussed, as these networks combine short-range PAN and long-range protocols into a single network.

Consider These Factors When Selecting an LNA MMIC

LOW-NOISE AMPLIFIERS (LNAS) are vital components in any system. While an LNA's noise figure is generally considered the most important parameter, other factors are also significant. In the tech brief, "5 Key LNA MMIC Factors that Can Make or Break a Receiver Design," Custom MMIC discusses five aspects other than noise figure that should be considered when selecting an LNA monolithic microwave integrated circuit (MMIC) for a system design.

The amount of input power that an LNA can withstand, or input power survivability, is the first point presented. A common approach to reduce the impact of high-power signals arriving at an LNA's input is to place a limiter or circulator in the receiver chain prior to the LNA. However, this approach has the drawback of degrading the overall system noise figure. Some LNAs can withstand input signals with higher power levels, thereby potentially eliminating the need for a limiter.

Custom MMIC,
300 Apollo Dr.,
Chelmsford, MA 01824;
(978) 467-4290;
www.custommmic.com

Gain flatness over frequency and gain stability over temperature are the next topics discussed. The tech brief explains how gain flatness over frequency is important for both wideband communication systems and radar systems. Gain stability over temperature is also of importance, as some applications have operating temperatures that can vary significantly within a short time period.

The third factor is supply voltage, as properly biasing a MMIC amplifier is critical for achieving adequate performance. Additional circuitry may be required to condition an LNA's supply voltages. This circuitry requires assembly real estate and consumes power. It also increases size, weight, and costs, as well as design and test time. The document explains the benefit of utilizing an LNA that only requires a single positive voltage supply.

The fourth factor is power consumption, which the tech brief emphasizes by noting that some applications may require numerous LNAs. The final topic is time savings, as design, assembly, test, qualification, support, and documentation all require some amount of time. Selecting insufficient LNA MMICs for a given application could create delays in one or more of these areas.

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US patent 6,943,629

**Low frequency cut-off determined by coupling cap.*
For GVA-60+, GVA-62+, GVA-63+, and GVA-123+ low cut off at 10 MHz.
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NOTE: GVA-62+ may be used as a replacement for RFMD SBB-4089Z
GVA-63+ may be used as a replacement for RFMD SBB-5089Z
See model datasheets for details

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JACK BROWNE | Technical Contributor

Wideband Amplifiers Add Low Noise Figures to High IP3s

With extremely wide dynamic ranges from 1 MHz to 2 GHz, these broadband MMIC E-PHEMT amplifiers provide versatile signal gain for both transmitters and receivers.

Amplifiers are characterized by many parameters, including gain, bandwidth, and output power. One of the more subtle amplifier performance parameters is dynamic range: when it is lacking in a receiver, for example, the signal amplification stages can saturate and shut down when hit with a high-power incoming signal, even when it is as brief as a short pulse. Wide dynamic range in an RF/microwave amplifier is often hard to come by because it requires two characteristics that are not often found together in an amplifier: low noise figure and high third-order-intercept point (IP3). Such an amplifier can boost low-level signals without overwhelming them with noise, and still respond dynamically to high-level input signals without producing excessive distortion. Such an amplifier is now available from Mini-Circuits (*www.minicircuits.com*), as part of a line of enhancement-mode, pseudomorphic high-electron-mobility-transistor (E-PHEMT) monolithic-microwave-integrated-circuit (MMIC) amplifiers covering a total frequency range of 1 MHz to 2 GHz with low noise figures (some below 1 dB) and high IP3s (approaching or exceeding +40 dBm)—for outstanding wideband, wide-dynamic-range performance for receivers and early-stage transmitter applications.

The wide-dynamic-range amplifiers require very little printed-circuit-board (PCB) space since they are supplied in multipin plastic SOT-89 packages (*Fig. 1*). In fact, they conserve PCB real estate without compromising thermal stability. Versions of the packaged amplifiers are available for supply voltages of +3 to +5 V dc and for +8 V dc, with the lower-voltage units rated for maximum operating temperatures to +105°C and the +8-V dc amplifiers rated for maximum operating temperature to +95°C.

The first four models of these high-power-density E-PHEMT MMIC amplifiers have been designed for 50-Ω applications, covering frequency ranges of either 1 MHz to 1 GHz or 30 MHz to 2 GHz with low noise figure, high gain, high output power at 1-dB compression (for their size), and high output IP3. Two of the four package leads serve as ground connections, with the RF output lead doubling as the DC bias input connection.

As an example, model PHA-13LN+ operates from 1 to 1000 MHz with noise figure that is generally below 1 dB for most of the frequency range. The noise figure is typically 0.8 dB at 20 MHz, 0.7 dB at 250 MHz, rising back to 0.8 dB at 500 MHz, and only reaching 1 dB at 1 GHz. Such low noise levels support outstanding signal sensitivity in a broadband receiver (*Fig. 2*).

1. The wide-dynamic-range E-PHEMT MMIC amplifiers are supplied in thermally stable SOT-89 packages and don't require additional impedance-matching components.

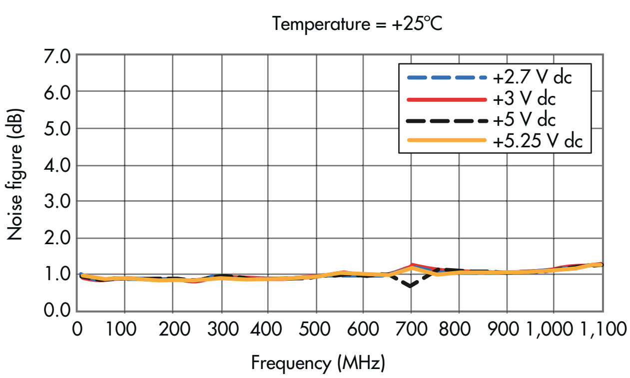
Wide dynamic range in an RF/microwave amplifier is often hard to come by because it requires two characteristics that are not often found together in an amplifier: low noise figure and high third-order-intercept point (IP3).

This amplifier operates from +3 or +5 V dc bias supply, providing greater output power and higher intercept point when a higher bias supply is available. It features an output IP3 of typically +40.2 dBm at 20 MHz, dropping to +39.0 dBm at 500 MHz, but a still-respectable +36.4 dBm at 1 GHz when running on the +5-V dc bias. The output IP3 and output power at 1-dB compression are both less when the source voltage is less, and the amplifier offers an output IP3 of typically +33.3 dBm at 20 MHz, +32.3 dBm at 500 MHz, and +28.6 dBm at 1 GHz when running on +3-V dc bias. The typical output power at 1-dB compression when operating from a +5-V dc supply is +23.0 dBm at 20 MHz, +24.5 dBm at 500 MHz, and +24.2 dBm at 1 GHz, compared to +16.9 dBm at 20 MHz, +19.5 dBm at 500 MHz, and +18.7 dBm at 1 GHz for a +3-V dc supply.

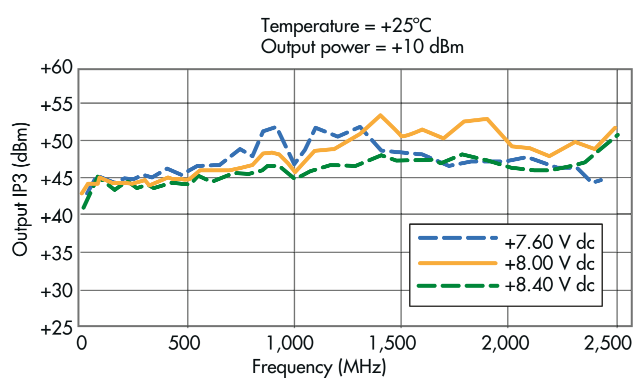
The miniature amplifier has an operating temperature range of -40 to +105°C and draws typical current of 138.9 mA at +5 V dc and 71.2 mA at +3 V dc. The gain is consistently high at either bias, with typical gain of 24.0 dB at 20 MHz, 22.8 dB at 250 MHz, 22.4 dB at 500 MHz, and 20.1 dB at 1 GHz for a +5-V dc supply and typically 23.3 dB at 20 MHz, 22.1 dB at 250 MHz, 21.5 dB at 500 MHz, and 18.7 dB at 1 GHz for a +3-V dc supply.

As good as the dynamic range of the PHA-13LN+ is over its 1000:1 bandwidth, the model PHA-13HLN+ (with its "H" added as part of the model number) is a wider-dynamic-range version for the same frequency range, designed for use with a higher bias voltage of +8 V dc. It provides an output IP3 of typically +41.7 dBm at 20 MHz, increasing to +43.0 dBm at 500 MHz, and +42.2 dBm at 1 GHz. The output power at 1-dB compression is typically +27.3 dBm at 20 MHz, +28.7 dBm at 500 MHz, and +27.4 dBm at 1 GHz. For the high output levels, it still manages to achieve low noise figures, typically 1.0 dB at 20 MHz, 0.9 dB at 500 MHz, and 1.2 dB at 1 GHz. The gain at +8 V dc is typically 24.3 dB at 20 MHz, 22.7 dB at 500 MHz, and 20.4 dB at 1 GHz.

The high typical output IP3 of the PHA-13HLN+ designates it as an amplifier with excellent linearity. While its output levels do not mark it a power amplifier by any means, its low noise figures at one time might have identified it as a low-noise amplifier (LNA). Certainly its high output levels and low noise figures reveal a wide dynamic range between the smallest signal it can boost and the largest signal it can process without distortion. This is a difference of about 43 dB between the typical IP3 and the output power at 1-dB compression, which provides a good deal of



2. The lower end of the wide dynamic range begins with outstanding noise figure across the frequency range, at all bias voltages.



3. The high end of the dynamic range is marked by high output third-order intercept point (OIP3) across the frequency range and bias voltages.

Because of the low noise figures, these amplifiers can boost signal waveforms prior to the input of a receiver mixer while still providing the high dynamic range needed to handle complex modulation formats.

tolerance when handling bursts or occasional signal peaks without loss of data in a communications system. The wide dynamic range also identifies an amplifier that can operate without saturation even in a signal environment characterized by strong interfering signals.

Both the PHA-13LN+ and PHA-13HLN+ are E-PHEMT amplifiers supplied in plastic SOT-89 packages with good thermal stability. Both are RoHS compliant, with amplifiers intended for +3 to +5 V dc supplies designed for operating temperatures from -40 to +105°C and amplifiers for +8 V dc supplies designed to handle operating temperatures from -40 to +95°C.

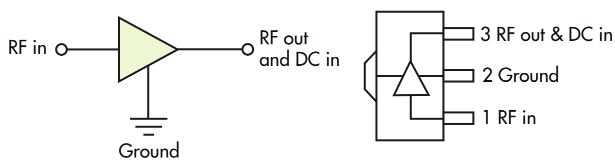
FOR WIDER BANDWIDTH

When more bandwidth and a higher frequency range are needed, the models PHA-23LN+ and PHA-23HLN+ are E-PHEMT amplifiers designed for use from 30 MHz to 2 GHz with similar differences in biasing arrangements providing greater dynamic range as needed. The PHA-23LN+ E-PHEMT amplifier is housed in a SOT-89 package and meant for use with supply voltages of +3 to +5 V dc. It has low noise figures across its almost 2-GHz bandwidth, typically 1.1 dB at 30 MHz, 1.0 dB at 500 MHz, 1.2 dB at 1 GHz, and 1.6 dB at 2 GHz. The noise figures are the same for either a +3- or +5-V dc supply.

The large-signal end of the dynamic range is indicated by typical output IP3 of +40.9 dBm at 30 MHz, +39.3 dBm at 500 MHz, +37.4 dBm at 1 GHz, and +35.6 dBm at 2 GHz when operating at +5 V dc. The IP3 numbers will drop with a lower-voltage supply, with IP3s of +34.7 dBm at 30 MHz, +33.3 dBm at 500 MHz, +30.9 dBm at 1 GHz, and +29.7 dBm at 2 GHz expected for a +3-V dc bias supply.

For applications capable of a higher +8-V dc bias, the PHA-23HLN+ E-PHEMT amplifier also covers 30 MHz to 2 GHz with wider dynamic range than its lower-voltage counterpart. Its noise figures are similar to those of the +3/+5-V dc amplifier, typically 1.3 dB at 30 MHz, 1.2 dB at 500 MHz, 1.4 dB at 1 GHz, and 1.9 dB at 2 GHz, but it provides a wider dynamic range by merit of output IP3 of typically +43.6 dBm at 500 MHz, +44.4 dBm at 1 GHz, and +42.5 dBm at 2 GHz. For its +8-V dc supply, the PHA-23HLN+ provides typical gain of 23.2 dB at 30 MHz, 22.1 dB at 500 MHz, 21.3 dB at 1 GHz, and 19.5 dB at 2 GHz, with typical output power at 1-dB compression of +26.2 dBm at 30 MHz, +28.1 dBm at 500 MHz, +28.4 dBm at 1 GHz, and +27.8 dBm at 2 GHz (*Fig. 3*).

These four amplifiers are good fits for wired and wireless communications applications in which signals can typically occupy wide dynamic ranges, such as in cable-television (CATV) as well as HF, VHF, and cellular communications networks. These amplifiers can be considered as having wide dynamic ranges because of their having output IP3 levels that are somewhat higher than their output power levels at 1-dB compression. With a high output IP3 level, an amplifier can more readily handle amplification of complex waveforms without adding or increasing the distortion levels of the waveforms.



4. The packaged MMIC E-PHEMT amplifiers feature simple connections and pin assignments.

Given the simple circuit interconnections and an effective choice of three different bias levels across the two frequency ranges, designers have several options for tradeoffs between performance and power consumption. The multiple pins of the SOT-89 package provide for secure circuit and (multiple) ground connections (*Fig. 4*) without requiring additional external matching components in 50-Ω circuits. Because of the low noise figures, these amplifiers can boost signal waveforms prior to the input of a receiver mixer while still providing the high dynamic range needed to handle complex modulation formats. mw

MINI-CIRCUITS, P.O. Box 350166, Brooklyn, NY 11235-0003; (718) 934-4500, sales@minicircuits.com, www.minicircuits.com.

CHRIS DeMARTINO | Technical Editor

The Top Products of 2017

Covering everything from 5G communications to military applications, the industry delivered a number of impressive products in 2017.

IN 2017, many companies in the RF/microwave industry introduced new products that propelled them to greater heights. To meet the needs of today's commercial, military, and industrial markets, companies are setting the bar higher in terms of product performance. Here, Microwaves & RF presents our picks for the top products of 2017.

TEST & MEASUREMENT SOLUTIONS

No question, suppliers of test-and-measurement equipment delivered a number of cutting-edge products in 2017. In a sense, one could say that some of the newest high-frequency test-and-measurement equipment is changing the perception of traditional test instrumentation. For example, instruments such as spectrum analyzers and vector network analyzers (VNAs) have traditionally been built in the form of bulky boxes. However, some suppliers are now offering smaller, portable versions.

One product line that was launched in 2017 that exemplifies the trend of smaller test instruments is Anritsu's Spectrum Master MS2760A (*Fig. 1*). This line of portable spectrum analyzers consists of six different models, with the highest-frequency version covering frequencies as high as 110 GHz. At 110 GHz, greater than 100 dB of dynamic range is achieved. Furthermore, the MS2760A spectrum analyzers measure only 6.1 × 3.3 × 1.1 in. (155 × 84 × 27 mm) and weigh just 9 oz. (255 g).

1. The Spectrum Master MS2760A portable spectrum analyzers are USB-powered and offer performance to 110 GHz.

Another company known for smaller test instruments is Copper Mountain Technologies. In 2017, the company added to its selection of VNAs by introducing the R180 1-port VNA. The R180 1-port VNA covers a frequency range of 1 MHz to 18 GHz. It offers the benefit of being able to directly connect to a device-under-test (DUT), thereby eliminating the need for test cables. The R180 is well suited for cable testing, antenna testing, and more.

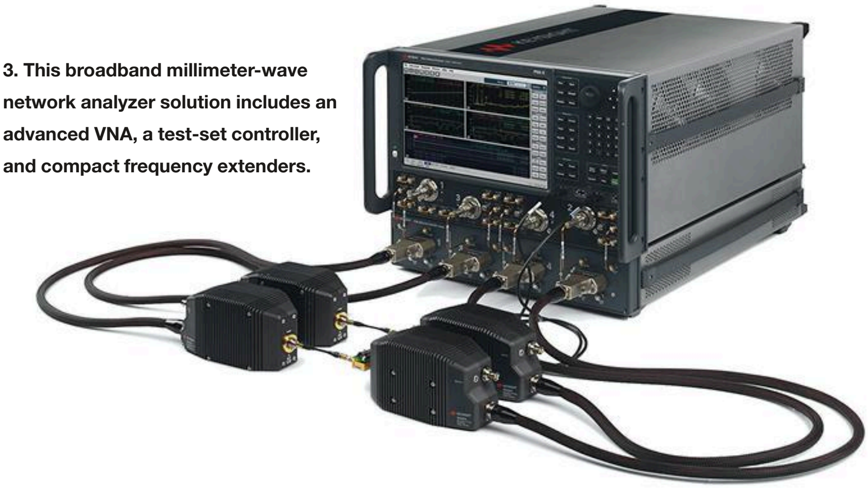
Speaking of VNAs, one established company actually made its debut in the VNA arena in 2017. That company is Tektronix, which introduced the TTR500 Series this year (*Fig. 2*). This series of USB-based VNAs consists of two models: the TTR503A and the TTR506A. The TTR503A covers a frequency range of 100 KHz to 3 GHz, while the TTR506A covers a frequency range of 100 kHz to 6 GHz. The TTR500 VNAs achieve greater than 122 dB of dynamic range. Furthermore, they measure just 11.25 × 8.125 × 1.75 in. (285.8 × 206.4 × 44.5 mm) and weigh only 3.5 lb. (1.59 kg).

Not to be outdone, Keysight Technologies unveiled its new VNA test system to meet the growing need for millimeter-wave testing. The N5290A and N5291A millimeter-wave systems allow for testing at frequencies over 100 GHz (*Fig. 3*). The N5290A/N5291A test solutions consist of an advanced VNA, a test-set controller, and compact frequency extenders.

While the products mentioned are on the analysis side, some notable products were introduced in 2017 on the signal-generation side as well. For example, Tektronix made headlines in more ways than one in 2017, as the company also introduced the AWG5200 Series of arbitrary wave generators (*Fig. 4*). These AWGs can achieve sample rates as high as 5 GSamples/s (and as high as 10 GSamples/s with 2× interpolation). Textronix offers two-, four-, and eight-channel models.

Also making this list are the R&S SMA100B signal generators from Rohde & Schwarz (*Fig. 5*). Four models are available, offering performance to 3.0, 6.0, 12.75, and 20.0 GHz, respectively. For a 1-GHz signal, phase noise is -152 dBc/Hz at 20-kHz offset. For a 10-GHz signal, phase noise is -132 dBc/Hz at 20-kHz offset. The R&S SMA100B signal generators also deliver high output power, as the 6-GHz model can provide signals with a power level as high as +38 dBm.

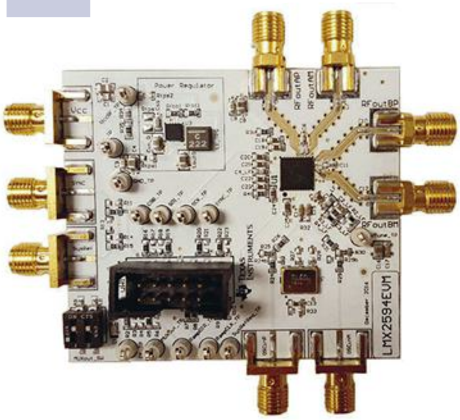
2. The TTR500 VNAs achieve a dynamic range greater than 122 dB.


3. This broadband millimeter-wave network analyzer solution includes an advanced VNA, a test-set controller, and compact frequency extenders.

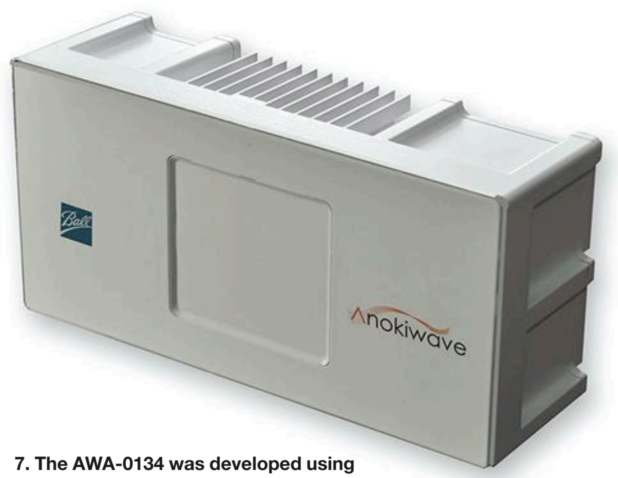
4. An AWG5200 Series AWG can have as many as eight independent waveform generation channels.


5. The R&S SMA100B signal generators are available in four frequency ranges, with the highest-frequency model covering 8 kHz to 20 GHz.

To meet the needs of today's commercial, military, and industrial markets, companies are setting the bar higher in terms of product performance.



6. The LMX2594 (shown on an evaluation board) is supplied in a 40-pin VQFN package that measures only 6.0 × 6.0 mm.



7. The AWA-0134 was developed using planar antenna technology.

A couple more test-and-measurement products are worthy of recognition. One is the PXIe-5820 baseband vector signal transceiver (VST) from National Instruments (NI). The PXIe-5820, which follows last year's PXIe-5840 RF VST, is well suited to meet the needs of next-generation wireless communications, such as 5G and IEEE 802.11ax. The PXIe-5820 can achieve 1 GHz of in-phase/quadrature (I/Q) instantaneous bandwidth for generation and analysis.

Last but not least, Focus Microwaves unveiled its MPT-110200 tuner system. This system provides impedance tuning functionality via three independently controlled tuning probes. The system covers a frequency range of 20 to 110 GHz.

COMPONENTS AND MORE

Test-and-measurement companies weren't the only ones that demonstrated innovation in 2017, as several components suppliers introduced some impressive products as well. For instance, Analog Devices introduced the AD9375 RF transceiver, which followed the release of last year's AD9371. The AD9375 covers a frequency range of 300 MHz to 6 GHz. It integrates a digital pre-distortion (DPD) solution, multiple receivers and transmitters, and on-board frequency synthesizers.

Another notable product from 2017 is Texas Instruments' LMX2594 wideband synthesizer, which can generate any frequency from 10 MHz to 15 GHz (*Fig. 6*). The phase detector frequency can be as high as 400 MHz in integer mode and as high as 300 MHz in fractional mode. The LMX2594 is also equipped with phase synchronization capability.

Continuing the theme of frequency synthesis, the Luxyn frequency synthesizers from Micro Lambda Wireless were introduced at this year's International Microwave Symposium (IMS). The Luxyn frequency synthesizers cover a frequency range of 50 MHz to 21 GHz, with frequency steps as small as 0.001 Hz. For a 5-GHz carrier, the typical phase noise is -131 dBc/Hz at 10-kHz offset. For a 10-GHz carrier, typical phase noise is -125 dBc/Hz at 10-kHz offset. In addition, these synthesizers are built in a package that is only 4.0 × 3.6 × 0.9 in. and weighs just 15 oz.

Another product unveiled this year is one that is intended to improve driver navigation. That would be Broadcom Limited's BCM47755 single-chip, dual-frequency global navigation satellite system (GNSS) receiver. According to the company, the BCM47755 is the first mass-market, dual- frequency GNSS receiver device. While traditional GNSS receivers have only used the L1 signal, the BCM47755 actually uses both L1 and L5 signals. The end result is 30-cm accuracy that essentially allows "lane-level" accuracy to be achieved on highways.

5G millimeter-wave systems are something we can expect to hear more of in the very near future. One company that is making headlines in this realm is Anokiwave. In 2017, the company introduced the AWA-0134, which is a 256-element reconfigurable active antenna kit for 5G applications that was developed with Ball Aerospace (*Fig. 7*). The AWA-0134, which is driven by Anokiwave's AWMF-0108 5G quad-core integrated circuit (IC), covers a frequency range of 26.5 to 29.5 GHz. The AWA-0134 can be used as a single 256-element array or as a 4 × 64 multiple-input multiple-output (MIMO) system. mw

JACK BROWNE | Technical Contributor

Synthesizer Paves Way for 28-GHz 5G Converters

These clock sources are available with LVCMOS outputs from 1 to 141 MHz, using several programmable operating parameters to significantly reduce EMI levels.

Fifth-generation (5G) wireless networks may be a year or two away, but the growing demands for wireless functionality from current fourth-generation (4G) Long Term Evolution (LTE) wireless communications systems are creating near-supernatural expectations for 5G wireless networks. To handle massive amounts of data along with their voice and video services, 5G networks will need to occupy spectrum at 28 GHz and higher and use advanced transmission formats, such as time-division-duplex (TDD) techniques, to transfer information-laden signals.

Wireless systems built to meet these high expectations will need stable and quiet frequency synthesizers operating at these higher frequencies. One such example is the model KSFLO27T50-12-100 phase-locked oscillator from Synergy Microwave Corp. It has been designed to provide stable, low-noise mixing signals for frequency translation of 28-GHz 5G signals, as well as for mixing with signals from Ka-band radar systems. The device delivers low-phase-noise signals from a miniature coaxial package with very low power consumption to meet the needs of 5G and other emerging millimeter-wave system applications.

The KSFLO27T50-12-100 frequency synthesizer (*see figure*) provides robust +10.5-dBm output-power signals with ±2-dB output-power flatness at 27.5 GHz. It works with a 100-MHz reference oscillator capable of providing input reference levels from −3 to +3 dBm to generate its 27.5-GHz output signals, consuming less than 400 mA current from a +12-V (±0.5 V) dc supply in the frequency-synthesis process.

The synthesizer suffers less than −60-dBc reference sidebands from the 100-MHz reference input signals, and exhibits maximum phase noise of −72 dBc/Hz offset 100 Hz from the carrier, −80 dBc/Hz offset 1 kHz from the carrier, −82 dBc/Hz offset 10 kHz from the carrier, −84 dBc/Hz offset 100 kHz from the carrier, and −94 dBc/Hz offset 1 MHz from the carrier.

Output spurious levels are typically −60 dBc and as good as −70 dBc, while harmonic levels are typically −30 dBc or better. Typical subharmonic levels, whether from $1/2f_0$ or $3/2f_0$ multiples of the f_0 fundamental-frequency signal, are −30 dBc or better. The miniature coaxial frequency synthesizer incorporates female SMA connectors for its reference input port and frequency output port, on a metal package measuring 2.250 × 2.250 × 0.500 in. The synthesizer is designed to remain stable across operating temperatures from −20 to +50°C.

The model KSFLO27T50-12-100 phase-locked oscillator provides frequency-synthesized output signals at 27.5 GHz for use in 5G frequency-conversion applications.

LOCKED IN

The frequency synthesizer includes internal voltage regulation for good power-supply isolation and stability, along with a CMOS lock-detect logical output for built-in-test (BIT) capability. This unit is plug-and-play ready to be used with just a single power supply and external frequency reference applied to the synthesizer ports. Once powered on, frequency lock to 27.5 GHz is almost instantaneous.

Though the low-noise 27.5-GHz frequency synthesizer is designed for low power consumption and good thermal stability, it must be surrounded with realistic heat-sink protection. That will isolate it from thermal gradients from nearby lossy passive components, such as filters, or heat-generating active components, such as amplifiers. SMA coaxial connectors can serve as funnels for thermal gradients from surrounding heat sources, and the added heat energy can disrupt the output flatness of the frequency synthesizer.

Packaging includes at least four through-hole locations for mounting to an enclosure or printed-circuit board (PCB) to provide an enhanced thermal flow away from the synthesizer's active devices, and ensure good amplitude flatness with temperature. mw

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JACK BROWNE | Technical Contributor

Versatile VNAs

Bring 6-GHz Measurements to the Masses

These compact VNAs work with external PCs and software to provide S-parameter measurements from 400 MHz to 4 and 6 GHz, with or without internal bias generators.

1. The VNA-0460 (left) and VNA-0460e are compact bidirectional two-port 6-GHz VNAs without and with a built-in bias generator, respectively.

Vector network analyzers (VNAs) are essential test instruments for firms that need to characterize RF/microwave components. However, fully equipped, rack-mounted VNA systems can carry hefty price tags. Fortunately, the economical VNA-0440 and VNA-0460 VNAs from MegiQ *(www.megiq.com)* provide two-port bidirectional VNA measurements from 400 MHz to 4 and 6 GHz, respectively, and at a fraction of the cost of full-sized VNA systems.

These VNAs are based on an innovative architecture, and leverage the processing power of an external PC running Windows XP through 10 and dedicated software. They deliver highly accurate, calibrated, 12-term, error-corrected S-parameter measurements on active and passive devices under test (DUTs).

The VNA-0440 and VNA-0460 VNAs *(Fig. 1)* are ruggedly built with two SMA test ports for making two-port S-parameter measurements, such as S_{11}, S_{21}, S_{12}, and S_{22}. The measurement ports are fully calibrated at the factory for direct measurements on suitable DUTs with an SMA connector. For measurements involving coaxial cables and connectors or on-board connectors, the VNAs are supplied with measurement software that guides an operator through a reliable short-open-load-through (SOLT) calibration process. With their dedicated software, the compact VNAs can make swept-parameter measurements with as many as 20,000 data points.

The VNAs feature internal test-signal generators covering their respective frequency ranges and capable of power level adjustments from –30 to +5 dBm with ±1 dB accuracy and 0.5-dB power adjustment resolution. The test signals are quite clean, with harmonic levels of less than –35 dBc.

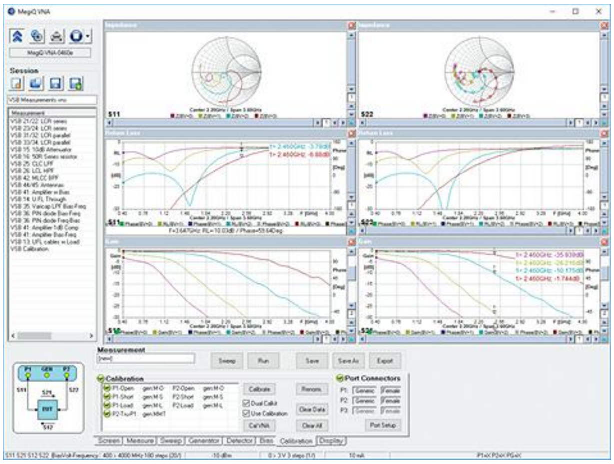
The VNAs are equipped with wide-dynamic-range detectors for measuring a DUT's port power, with ranges of –75 to +20 dBm from 400 MHz to 4 GHz and –60 to +20 dBm from 4 to 6 GHz. The detectors are supported by an input attenuator with attenuation range of 0 to 30 dB, as might be used for measuring higher-power DUTs, such as amplifiers.

Versions of the VNAs are available as models VNA-0440e and VNA-0460e which also operate from 400 MHz to 4 and 6 GHz, respectively, but these are 2.5-port bidirectional VNAs which also provide measurements of S_{13} and S_{23}. In addition, they include a signal generator output port, as well as a precision bias generator for powering active devices (such as transistors and amplifiers). It provides a voltage range of –12 to +12 V dc and a current range of 0 to 100 mA.

The compact VNAs are operated by means of intuitive measurement software, which shows test results on a PC screen in various formats, including on Smith charts and as x-y plots *(Fig. 2)*. The software, which was written for use with a computer having a touchscreen, includes several preset routines for quickly and automatically performing regular and routine one- and two-port measurements, such as insertion loss, insertion gain, phase, and group delay.

The software includes a sweep manager that allows an operator to combine multiple measurement parameters, such as frequency, power, and bias, into a parametric sweep. For antenna tuning and matching, the software also features a handy match calculator that provides circuits designed to match 50 Ω to a specific impedance point on a Smith chart.

The test software incorporates a Session Manager that allows an operator to store several measurements in a session file. This way, it is possible to follow a trail of measurements and reconstruct a measurement strategy. All calibration and measurement data are stored, enabling a user to return to an earlier measurement and use that test setup for additional measurements.



2. The compact VNAs are operated through flexible measurement software that collects data and shows test results in multiple formats.

For large-scale automated measurements, an Application Programming Interface (API) is available to use these VNAs with the major measurement programs, including Visual Basic (VB) from Microsoft, LabVIEW from National Instruments *(www.ni.com)*, and C++ programming language.

For those seeking to explore the capabilities of their compact VNAs, the VNA Sandbox is a circuit board constructed with many different experiments. It contains many different one- and two-port circuits for testing, including antennas, filters, and amplifiers, and all the adapters and connectors needed for making measurements with one of the VNAs. It is supplied with an extensive tutorial lesson on calibration and VNA measurements to help someone get started on making RF/microwave active and passive S-parameter measurements.

VNA kits supplied with the VNA Sandbox greatly simplify PC-based RF/microwave test development. It helps make these VNAs attractive additions to the test capabilities of small and large companies alike. **mw**

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Product Feature

CHRIS DeMARTINO | Technical Editor

FreeWave Delivers IIoT Solutions on Different Fronts

By introducing a new embedded radio and app server software, the company shows why it's at the forefront of industrial wireless applications.

One company on the front lines of military unmanned systems and industrial wireless applications is FreeWave Technologies (*www.freewave.com*). Quite literally—millions of FreeWave's radios have seen action in harsh and dangerous environments throughout the world. One notable product line offered by the company is the ZumLink 900 Series (*Fig. 1*). This series of 900-MHz radios is intended for a wide range of Industrial Internet of Things (IIoT) applications, such as agriculture, oil and gas, utilities, and many more.

FreeWave recently introduced the ZumLink Z9-PC radio module, which is the newest addition to the ZumLink 900 Series (*Fig. 2*). The company actually calls the ZumLink Z9-PC its "most advanced embeddable radio to date." In addition, FreeWave announced its ZumIQ app server software, which enables developers to program ZumLink 900 Series radios with their own applications. This capability allows for intelligent control and automation of remote sensors and devices.

The ZumLink Z9-PC joins the other ZumLink 900 Series products: the Z9-P, Z9-PE, Z9-C, and Z9-T. Like the other radios in the series, the ZumLink Z9-PC operates in the 902-to-928 MHz frequency band. Its output power level is user-selectable and can range from 10 mW to 1 W. Furthermore, the ZumLink Z9-PC can cover a range as great as 60 miles. Five data rates are supported, with throughput reaching as high as four Mbps.

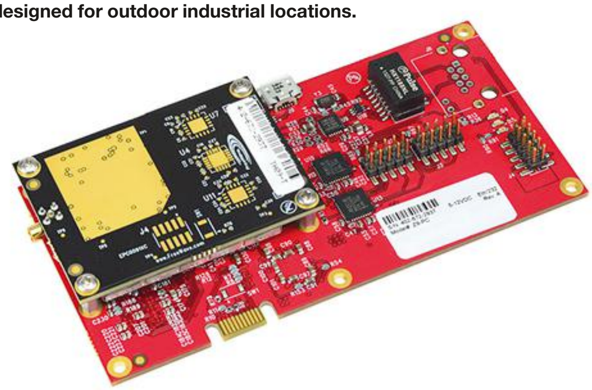
The ZumLink Z9-PC takes advantage of FreeWave's ZumBoost technology to enhance performance. This technology consists of four algorithms that can be used either independently or together to improve throughput in demanding RF environments. These four techniques are defined as packet compression, packet aggregation, forward error correction, and the patent-pending Adaptive Spectrum Learning technology. The ZumLink Z9-PC radio module is available now.

As mentioned, FreeWave also recently announced the ZumIQ app server software platform. This platform brings another aspect to the ZumLink 900 Series, as it enables developers to create and host open-source third-party applications. In essence, the ZumIQ platform combines 900-MHz wireless communications with app programmability, ultimately allowing sensor data at the network edge to be monitored, collected, and controlled. The ZumIQ app server software platform is also available now.

FreeWave's vision can basically be described in its own words as an "iPhone strategy." "Smartphones introduced a new realm of innovation," said Scott Allen, CMO of FreeWave. "That's similar to what we're doing with ZumLink radio." mw

FREEWAVE TECHNOLOGIES, 5395 Pearl Pkwy., Boulder, CO 80301; (866) 923-6168, www.freewave.com.

1. The Z9-PE, one of the radios in the ZumLink 900 Series, is designed for outdoor industrial locations.



2. The Z9-PC is a board-level radio for original equipment manufacturers (OEMs).

CHRIS DeMARTINO | Technical Editor

Q&A with Peter Gammel

Chief Technology Officer, Skyworks Solutions, Inc.

Skyworks' CTO Peter Gammel gives his take on 5G and addresses the company's technological roadmap in this arena.

Obviously, 5G is something we constantly hear about. Will it live up to the hype?

It is important to point out that 5G is being driven by market pull, and not technology push. Ubiquitous connectivity is gaining significant momentum and enhancing the way we live, work, play, and educate, creating an immediate and insatiable demand for higher speed and lower latency data. While millimeter-wave frequencies will unlock a massive swath of new spectrum for 5G and cellular communications, we believe 5G will see rapid adoption as a dual-connectivity solution at sub-6-GHz and even sub-1-GHz frequencies.

Ultimately, this data throughput and low latency will enable a host of new applications, from autonomous vehicles to artificial intelligence, augmented and mixed reality, and much more, with some of the most exciting applications not yet envisioned.

What semiconductor technologies will be most significant in enabling 5G networks?

The move toward increasing band complexity and RF content through both carrier aggregation and MIMO will accelerate as we migrate to 5G. The initial phase of 5G in higher-frequency bands—between 2.7 and 6 GHz—for 5G cellular communications will have a significant impact on RF front-end complexity and the technologies utilized.

There will be a need for new RF technologies to address signal transmission, conditioning, filtering, tuning, voltage regulation, battery-charging, and packaging, creating a perfect storm of complexity. In short, the goal of a 10X increase in battery life, simultaneous output power increase for enhanced cell user experience, and linearity for 5G new radio data rates have resulted in a re-evaluation of the entire RF transmit chain.

As the second phase of 5G takes us into millimeter-waves, a new suite of technologies will be ramped up to augment the use of gallium-arsenide (GaAs) heterojunction-bipolar-transistor (HBT), silicon-on-insulator (SOI), and acoustic-wave filters.

Can you tell us a little bit about expected filter technology solutions for 5G—especially at millimeter-wave frequencies?

The initial 5G rollout, or below 6 GHz, will increase complexity in the RF chain, including an explosion in the number and types of filters. With filters, as with semiconductors, complexity and product footprint are driving a wide range of innovative system architectures and packaging technologies. By looking at the entire RF front-end as a system, it will enable some exciting and differentiated ways of resolving transmit-chain efficiency, linearity, and isolation.

The primary challenges associated with utilizing the millimeter-wave spectrum have to do with the path loss in comparison to signals using spectrum below 6 GHz. This path loss impacts power-amplifier (PA) efficiency on the transmit side and noise figure on the receive side. With today's technologies,

Product SPOTLIGHT

The latest product information presented by

Mini-Circuits®

www.minicircuits.com

Two-Way 90-deg. Power Splitter Handles 200 W from 2 to 6 GHz

Mini-Circuits' model QCH-63+ is a two-way, 90-deg. power splitter that can handle as much as 200 W input power from 2 to 6 GHz. It maintains excellent amplitude unbalance of ±1.0 dB and phase unbalance of ±1.5 deg. across its wide frequency range, making it ideal for I/Q quadrature systems. The RoHS-compliant, 50-Ω power splitter provides at least 18-dB isolation and typically 26-dB isolation between ports. Insertion loss is low, at typically 0.2 dB, while the VSWR across the full frequency range is typically 1.15:1. The compact power splitter measures 0.56 × 0.35 × 0.091 in. with wrap-around terminations for good solderability, with an operating temperature range of -55 to +105°C.

Cavity Bandpass Filter Screens 3845 to 3905 MHz

Mini-Circuits' ZVBP-3875+ cavity bandpass filter provides high selectivity for extracting desired signals from wide sections of spectrum. Well suited for communications transmitter and receiver front ends, the RoHS-compliant filter features a 3875-MHz center frequency and passband of 3845 to 3905 MHz with typical passband insertion loss of 0.6 dB and VSWR of 1.30:1. It has a lower stopband of DC to 3785 MHz and upper stopband of 3970 to 8500 MHz, both with typical rejection/loss of 43 dB. The 50-Ω cavity bandpass filter measures 3.86 × 2.64 × 0.98 in. (98 × 67 × 25 mm) with female SMA connectors and is designed for operating temperatures from -40 to +85°C.

High-Q Surface-Mount Bandpass Filter Passes 329 to 335 MHz

Mini-Circuits' BPHI-332+ is a high-selectivity surface-mount bandpass filter ideal for radio communications, defense, and aviation applications. It features a narrow passband of 329 to 335 MHz. Passband insertion loss is no more than 5.0 dB and typically 4.5 dB, while the passband VSWR is no more than 2.0:1 and typically 1.50:1. The RoHS-compliant, 50-Ω filter handles as much as 1.5 W RF input power. Rejection in the lower stopband is at least 40 dB and typically 50 dB from DC to 313 MHz and at least 20 dB and typically 30 dB from 300 to 313 MHz. Rejection in the upper stopband is at least 20 dB and typically 25 dB from 343 to 370 MHz and at least 40 dB and typically 50 dB from 370 to 2600 MHz. The compact filter measures 0.365 × 1.360 × 0.35 in. (9.27 × 34.54 × 8.89 mm in a shielded surface-mount package with an operating temperature range of -40 to +85°C.

2.4-mm Coaxial Termination Handles 1 W to 50 GHz

Mini-Circuits' ANNE-50V+ is a 2.4-mm 50-Ω coaxial termination with wide bandwidth of DC to 50 GHz. The RoHS-compliant termination can absorb signal power levels to 1 W across the full frequency range with excellent return loss, typically 28 dB to 18 GHz and 20 dB to 50 GHz. Suitable for measurement laboratories and in defense and aerospace applications, the termination is supplied in a brass case measuring 0.67 in. long and 0.31 in. in diameter with a male 2.4-mm coaxial connector which is mechanically compatible with 2.4-mm and 1.85-mm female connectors. The broadband termination has an operating temperature range of -55 to +100°C.

Surface-Mount Diplexer Separates DC to 2150 MHz

Mini-Circuits' RDP-2150+ is a diplexer that combines low-loss lowpass and highpass filters covering DC to 2150 MHz in a compact, surface-mount 50-Ω package. Well suited for multiband radio and video system applications, the RoHS-compliant diplexer delivers lowpass performance that includes typical insertion loss of 0.5 dB and return loss of 29 dB from DC to 10 MHz. The highpass performance includes typical insertion loss of 0.9 dB and return loss of 16 dB from 40 to 2150 MHz. The lowpass stopband isolation is typically 31 dB from 40 to 2200 MHz and 44 dB from 50 to 2150 MHz, while the highpass stopband isolation is typically 33 dB from DC to 18 GHz and 61 dB from DC to 10 GHz. The diplexer has an operating temperature range of -40 to +85°C and is supplied in a shielded package measuring just 0.500 × 0.500 × 0.180 in. (12.7 × 12.7 × 4.572 mm).

75-Ω RF Transformer Tackles 10 to 1400 MHz

Mini-Circuits' TCM2-142-75X is a compact, 75-Ω surface-mount RF transformer with wide bandwidth of 10 to 1400 MHz. With low typical insertion loss of 1.3 dB and high typical input return loss of 17 dB across the full frequency range, the transformer is suitable for a wide range of transmission-line balancing chores. It handles input power levels to 0.4 W with typical amplitude unbalance of 0.5 dB and typical phase unbalance of 10 deg. The RoHS-compliant transformer measures just 0.15 × 0.15 × 0.15 in. for use in high-density circuits. It features core-and-wire construction and Mini-Circuits' Top Hat® feature for ease of assembly and inspection. It has an operating temperature range of -40 to +85°C.

As a leader in unwiring the planet, we plan to continue leveraging our extensive technology breadth and depth, strategic partnerships with all leading smartphone and IoT customers, and differentiated architectures to deliver 5G solutions that lead to unmatched levels of integration and performance.

these both lead to reduced battery life. Given the proliferation of frequency bands and the addition of LTE, the need for filters that address the low-, mid-, and high-band performance requirements for emerging 5G applications has never been higher.

As 5G migrates to millimeter-waves, acoustic filtering is no longer an option. The good news is that the size and performance of traditional dielectric, ceramic, and transmission-line filters used in infrastructure applications today become appropriate for many handheld and battery-powered devices. The same need for scaling will permit the use of steered beam and other antenna-array technologies in consumer electronics.

Lastly, what is Skyworks (www.skyworksinc.com) doing now—and plans on doing in the future—in terms of 5G?

Our innovative analog semiconductors are already enabling connectivity across new and previously unimagined applications in mobile and the Internet of Things (IoT). You can find our solutions in numerous markets spanning the connected home, car, wearables, military, industrial, and cellular infrastructure.

In 5G, complexity will grow and system architectures will require significantly more powerful connectivity engines to ensure that intense performance challenges are realized. As a leader in unwiring the planet, we plan to continue leveraging our extensive technology breadth and depth, strategic partnerships with all leading smartphone and IoT customers, and differentiated architectures to deliver 5G solutions that lead to unmatched levels of integration and performance. Our ambitious vision of connecting everyone and everything, all of the time, has never been more relevant and exciting. mw

MORE ABOUT 5G FROM SKYWORKS

INTERESTED READERS MAY also want to visit Skyworks' 5G page *(www.skyworksinc.com/5G),* which has some good resources. One of them is a video titled, "5G in Five Minutes." In this video, Peter Gammel provides a simple explanation of 5G and discusses how it will affect our daily lives.

Also featured is the white paper, "5G in Perspective: A Pragmatic Guide to What's Next." In this 26-page white paper, Skyworks discusses the current state of LTE before diving into 5G in detail. Among the vast amount of information presented is an explanation of 5G spectrum, as both sub-6-GHz and millimeter-wave spectrums are illustrated.

The white paper also talks about new technologies that are required to serve 5G. Technologies needed to implement power amplifiers (PAs), low-noise amplifiers (LNAs), RF switching, filtering, and antenna integration functionality are presented. Readers can view the white paper for more information on these and many other topics.

Precision Connector Gauge Kits Check Contact Tolerances

EACH CONNECTOR GAUGE KIT in the ACUDIAL Series includes precision hardware for measuring center pin and dielectric location or outer conductor mating surfaces of the most popular high-frequency coaxial connectors, including BNC/TNC (ACUDIAL-BNC/TNC kit), SMA (ACUDIAL-SMA kit), and N Type (ACUDIAL-N kit) connectors. Each kit contains a dial indicator assembly, female and male master gauges for the appropriate connectors, an instruction manual, and a wooden instrument case. ACUDIAL Series connector gauges feature 0.0001-in. resolution and repeatability for calibration of each type of coaxial connector to MIL-PRF-39012 class 2 requirements in compliance with ASME and ANSI/NCSL standards. The easy-to-use kits are suitable for ensuring proper compliance for each kit's connector type(s) for both laboratory and production applications.

MINI-CIRCUITS, P.O. Box 350166, Brooklyn, NY 11235-003; (718) 934-4500, *www.minicircuits.com*

Programmable Attenuator is Four Pads in One

MODEL 50BA-032-31 packs four individually controllable programmable attenuators in a miniature benchtop enclosure well suited for testing applications. It provides a total of 0 to 31-dB attenuation in 1-dB steps at frequencies from 100 MHz to 18 GHz. It includes SMA connectors for RF/microwave signals and Ethernet and RS-232 links for digital control. The 50-Ω programmable attenuator exhibits maximum VSWR of 2.0:1 and typically 1.70:1. The typical insertion loss is 2.0 dB at 100 MHz, 3.2 dB at 3.0 GHz, 4.0 dB at 6.0 GHz, 6.6 dB at 12.4 GHz, and 6.6 dB at 18.0 GHz. The attenuator, which has typical switching speed of 1 μs, is rated for +20 dBm average input power and as much as +25 dBm input power without damage. It runs on a +12 VDC supply and is supplied with a 100 to 240 VAC/DC transformer.

JFW INDUSTRIES, INC., 5134 Commerce Square Dr., Indianapolis, IN 46237; (877) 887-4539, (317) 887-1340, e-mail: sales@jfwindustries.com, *www.jfwindustries.com*

Synthesizer Generates 500 to 1,200 MHz

THE KFSW50120-50 4000-8 INTELLIGENT interactive synthesizer tunes from 500 to 1,200 MHz using a 10-MHz frequency reference to produce 500-kHz frequency steps with low phase noise. A 3.3-V CMOS signal provides lock-detect indication. The RoHS-compliant synthesizer produces at least 0-dBm output power across its frequency range with –15 dBc typical harmonic suppression and -85 dBc typical spurious suppression. The phase noise is –96 dBc/Hz offset 1 kHz from the carrier and –118 dBc/Hz offset 100 kHz from the carrier. The frequency settling time is typically 3 ms. The synthesizer is designed for operating temperatures from –40 to +85°C. The synthesizer is supplied in a compact package measuring 2.75 × 2.0 × 1.0 in. with SMA connectors and with graphical user interface (GUI) software for fast product integration.

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

Sampling Scopes Extend Bandwidths to 25 GHz

THE LATEST MEMBERS of Pico Technology's PicoScope 9300 family of sampling oscilloscopes is now available from Saelig Co. With bandwidths as wide as 25 GHz, the oscilloscopes are well suited for testing at rates to 10 Gb/s and beyond in digital circuits and telecommunications systems. The oscilloscopes offer timing resolution as fine as 64 fs. Previous 12-GHz models in the 9200 series are being replaced by 15-GHz models in the 9300 series at lower prices. As an example, model 9301-15 provides two measurement channels with 15-GHz bandwidth and prescaled trigger to 14 GHz. It has a 16-b sampling rate of 1 MSamples/s for fast-update eye diagrams and statistical analysis. The 9302 15 version adds a clock recovery trigger to 11.3 Gb/s, with RMS jitter of typically 1.0 ps + 1% of the data interval.

SAELIG CO. INC., Fairport, NY, 888-7SAELIG, *www.saelig.com*

EMI/RFI Finger Stock Gaskets Are Cut to Length

STAINLESS-STEEL AND BERYLLIUM-COPPER (BE-CU) finger stock EMI/RFI shielding gaskets can be supplied in strips ranging from 16 to 24 in. in length and as continuous coils with lengths to 35 ft. They can be cut to requested lengths, supplied as single fingers, or formed into contact rings. The gaskets are suitable for a wide range of mounting options, including snap-on, stick-on, clip-on, track, and welding methods. More than 100 standard profiles are available, with BeCu gaskets offering 100-dB shielding effectiveness (SE).

TECH-ETCH, INC., 45 Aldrin Rd., Plymouth, MA 02360; (508) 747-0300, *www.tech-etch.com*

Module Adds Dual-Band Wi-Fi Connectivity

THE SKY85812-11 SKYONE MODULE is a dual-band Wi-Fi IEEE 802.11ac front-end module that simplifies the addition of Wi-Fi wireless connectivity to electronic devices and systems. The module includes a 2.4-GHz low-noise amplifier (LNA) with bypass and single-pole, three-throw (SP3T) switch and a 5-GHz LNA with bypass and a single-pole, double-throw (SPDT) switch. It also contains an integrated diplexer with a 2.4-GHz coexistence filter. The module provides fully 50-Ω impedance-matched input and output ports in a miniature 16-pin package measuring just 3 × 3 × 0.8 mm. It operates on a nominal supply voltage of +3.3 V dc and provides receive gain of 10 dB.

SKYWORKS SOLUTIONS, INC, 20 Sylvan Rd., Woburn, MA 01801; (781) 376-3000; *www.skyworksinc.com*

Radio Test Sets Gain TETRA Capabilities

TETRA BASE STATION TEST CAPABILITIES aare now available on the 8800SX digital radio test set and the 3550R touchscreen radio test sets. The instruments now offer cost-effective methods for performing full TETA base station field tests, including transmitter and receiver testing. Transmitter testing for TETRA base stations includes measurements of critical modulation parameters, including error vector magnitude (EVM), peak EVM, frequency error, and signal power. Measurement results can be shown on easy-to-read constellation diagrams.

COBHAM PLC, Brook Road, Wimborne, Dorset, BH21 2BJ, UK; *www.cobham.com*

Radio Modules Ease Wireless System Designs

COMPACT ANAREN INTEGRATED RADIO (AIR) modules are available for popular Industrial-Scientific-Medical (ISM) radio bands, such as 433, 868, 915, and 2,400 MHz. The proprietary solutions allow equipment manufactures to develop, implement, and deploy low-power wireless communications networks using simple wireless protocols or their own proprietary communications protocols. For example, 915-MHz CC1101-based modules are designed and qualified for use in the United States and Canada, while the dual-band CC110LR modules operate at 868 and 915 MHz and are certified to ETSI for use in Europe. Depending on their intended environment, both the CC1101 and CC110L modules are particularly well-suited for long-haul, low-data-rate applications.

ANAREN MICROWAVE, INC., 6635 Kirkville Rd., Syracuse, NY 13057; (315) 701-6751, *www.anaren.com*

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(ISSN 0745-2993)
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