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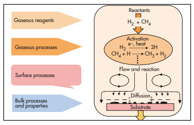

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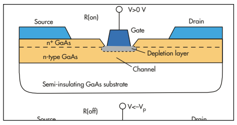

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TEST & MEASUREMENT ISSUE

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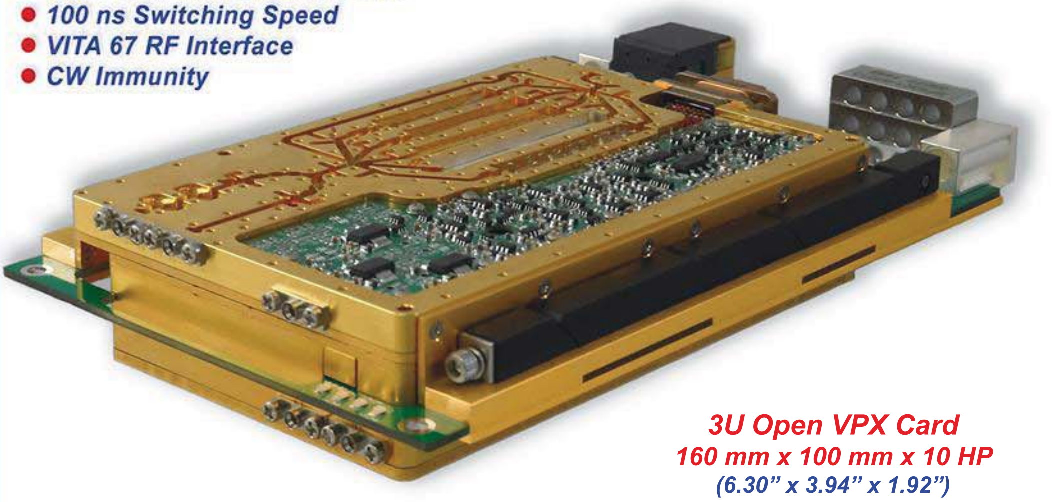

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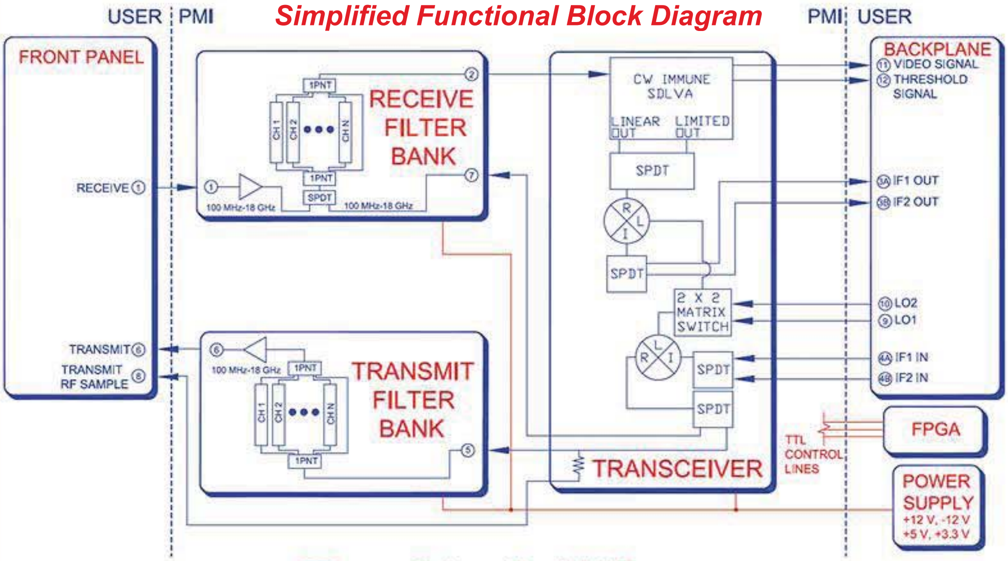
Simplified Functional Block Diagram



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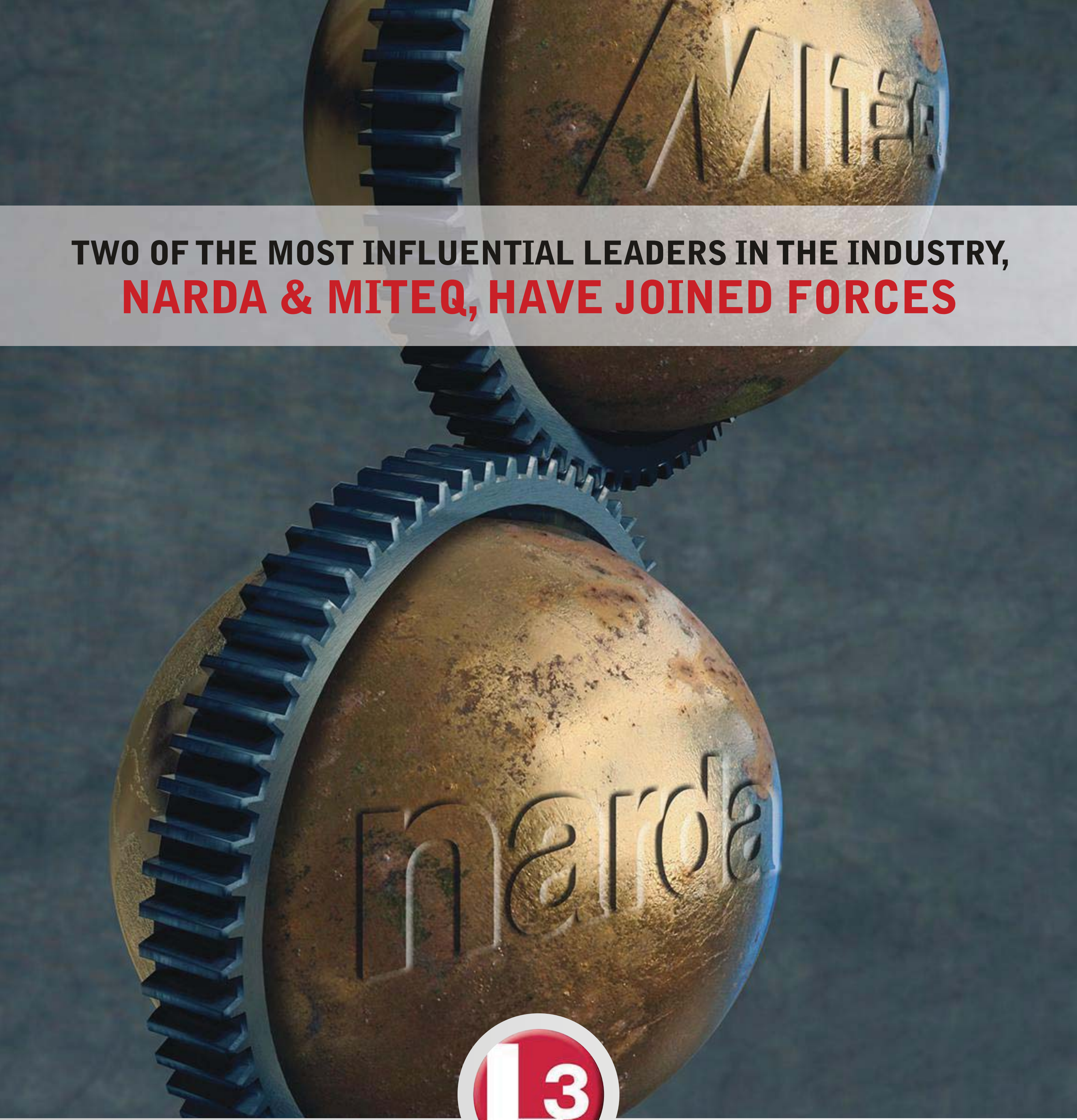

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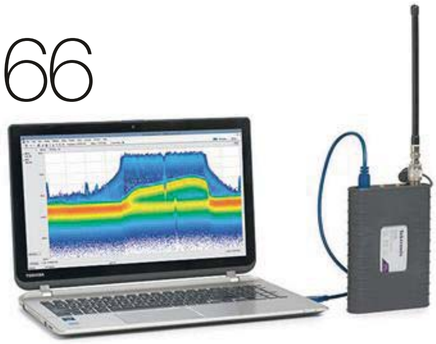

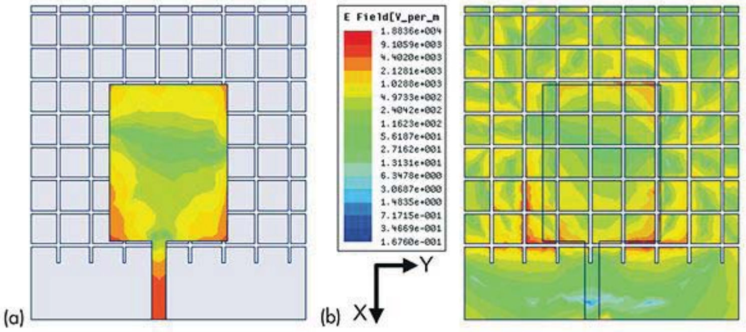

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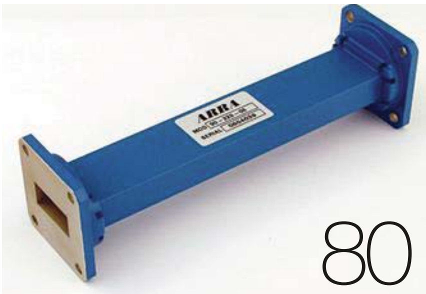

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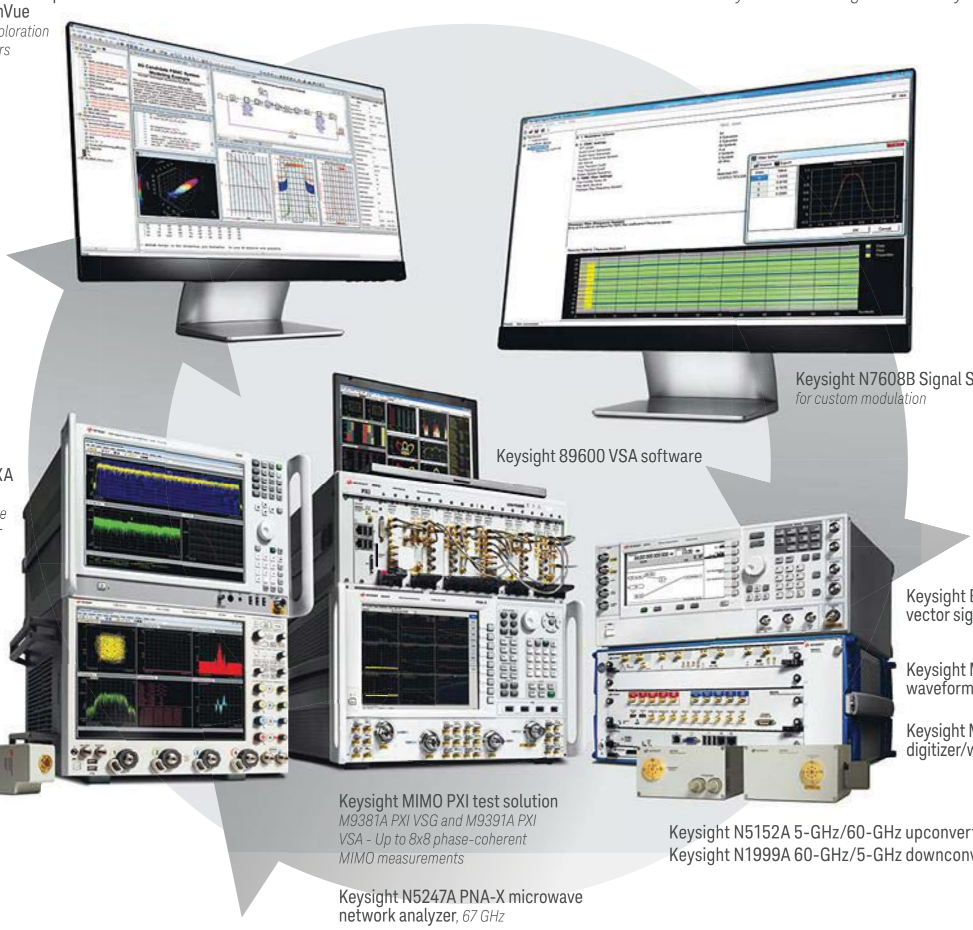

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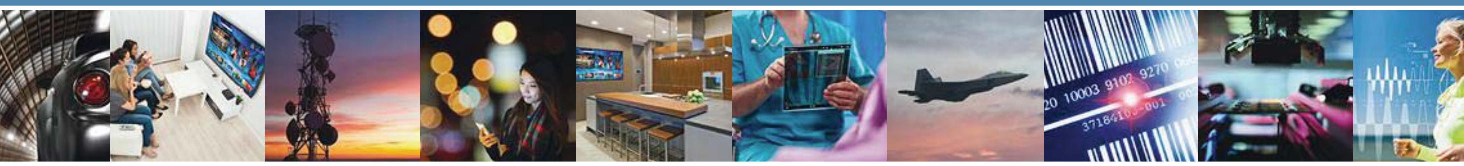

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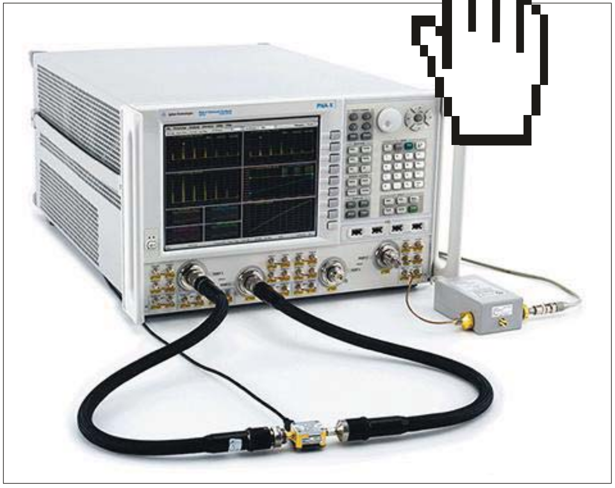


KNOW WHEN TO ADD ATTENUATION

http://mwrf.com/active-components/know-when-add-attenuation

Attenuators are found in an array of high-frequency systems, from the lowest-frequency designs through millimeter-wave communications networks. Although they perform a function—reducing signal levels—that would seem contrary to the usual design goals in an RF/microwave system, attenuators of all types serve invaluable functions in those systems.

WHY SUCH HIGH COSTS FOR TEST EQUIPMENT?

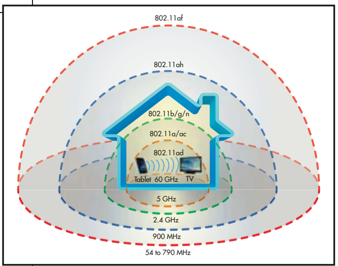
http://mwrf.com/blog/why-such-high-costs-test-equipment

At any engineering facility worth its salt, test equipment will usually be in demand, and there is always the "engineering complaint" of there not being enough test equipment "in the house." Many of us have asked, "Why doesn't the company simply invest in more test gear so that the engineering staff can work more efficiently and effectively?"

7 WAYS TO ATTACK DYNAMIC-RANGE MEASUREMENT THREATS

http://mwrf.com/active-components/7-ways-attack-dynamic-range-measurement-threats

By enhancing the dynamic range of a spectrum/signal or network analyzer, an instrument can discover signals well below its typical noise floor. However, maintaining adequate dynamic range in test-and-measurement applications can be a persistent headache. Several techniques help overcome those noise, distortion, high-power level, and ADC imbalance hurdles.



WHAT'S THE DIFFERENCE BETWEEN IEEE 802.11AF AND 802.11AH?

http://mwrf.com/active-components/what-s-difference-between-ieee-80211af-and-80211ah

The emerging Internet of Things (IoT) and machine-to-machine (M2M) communication markets demand wireless networking standards that operate in the sub-1 GHz spectrum, providing long-range and low-power operation. The IEEE 802.11af and 802.11ah standards aim to solve these challenges, offering a Wi-Fi-like experience with reasonable data rates up to and beyond a kilometer.

REFERENCES & TOOLS

http://mwrf.com/references-tools

Visit our online References & Tools section to quickly and easily download tables covering topics such as Connector Frequency, which include Coaxial and Waveguide; Frequency Nomenclature: Kilohertz to Terahertz; Frequency Spectrum & Allocations; and Wireless Coexistence: From 300 MHz to 6 GHz.

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US patent 6,943,629

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Editorial

JACK BROWNE
Technical Contributor
jack.browne@penton.com

Recovering from a Week in Phoenix

While a week in Phoenix, Ariz. sounds like a vacation of sorts, for many industry members, the week from May 17-22 will hardly be a holiday. After all, this is the IEEE's 2015 International Microwave Symposium (IMS), a densely packed schedule of exhibits and technical sessions in which it is possible to catch up with old friends, maybe avoid old enemies, and absorb lots of technology in a very short time.

Without a doubt, IMS is the single-most anticipated technical event in the RF/microwave industry. It draws thousands of visitors in search of new products on the exhibit floor and new technologies in the seminars, and is a wonderful opportunity for company representatives to meet with visitors. Whether the visitors are customers or potential customers, much can be learned by those on both sides of the booth. Visitors to the IMS exhibition often bring thoughts and requests for companies to modify existing products or to design and fabricate new products.

At an exhibition booth, company reps can learn by listening to these visitors and keeping track of the different requests for product modifications and refinements. Of course, some requests may be coming "from left field" and usually they're related to price. Certainly, many test-and-measurement company representatives can attest to the times they were asked to design and manufacture something that may simply not be possible, such as that $50 microwave spectrum analyzer. Patience is a virtue when listening to certain visitors' lists of needs and wants regarding RF/microwave hardware and software. Often, though, buried amongst those wishful-thinking requests are ideas that could transform into next-generation products (and solutions for the person making the requests).

Of course, to benefit from the many visitor interchanges that occur at an IMS exhibition booth, one must keep track of the suggestions and requests and remember the source of a given suggestion. Many times, anyone who is willing to discuss design information on a particular product will expound further if given the opportunity. New product development often starts with a customer's comments or requests and well-organized IMS exhibitors can turn those comments into new circuit-design approaches, or new ways to perform a test, or some method that will help the company meet that visitor's expectations.

The IEEE IMS exhibition floor has long been an annual three-day opportunity for industry members to exchange ideas. It's one of the rare times that an engineer working on, say, a waveguide bend or attenuator can share thoughts with a system-level designer working on a high-power pulsed radar system. This year, more new industries (*e.g.*, medical and automotive) are engaging in IEEE IMS. The show floor is a chance to find what these potential new customers need for their applications. Overall, IEEE IMS presents a wealth of opportunities for all those in attendance. mw

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*All models have 2.4 mm (M) input connector
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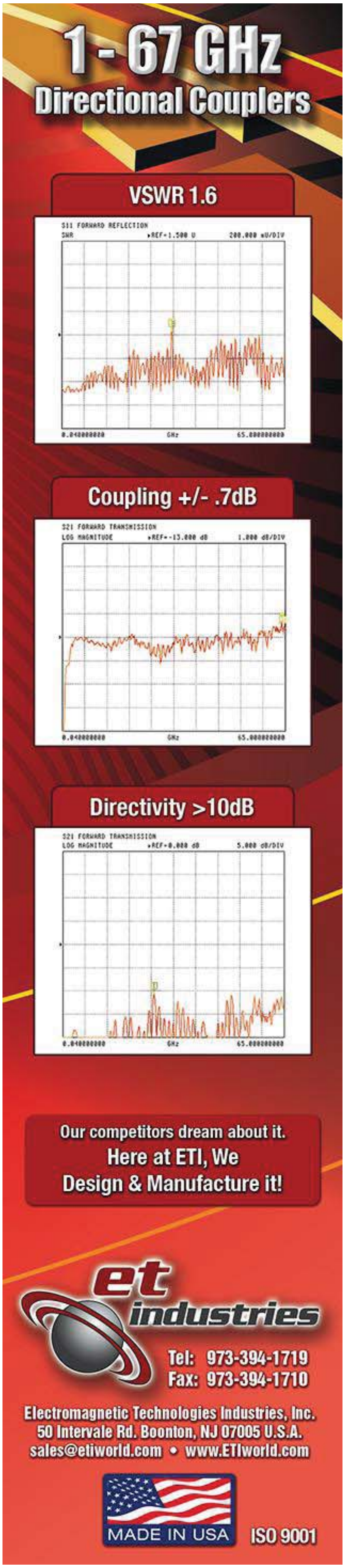

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EDITORIAL

CONTENT DIRECTOR: **NANCY K. FRIEDRICH** nancy.friedrich@penton.com
TECHNICAL CONTRIBUTOR: **JACK BROWNE** jack.browne@penton.com
TECHNICAL ENGINEERING EDITOR: **JEAN-JACQUES DELISLE** jean-jacques.delisle@penton.com
CONTENT PRODUCTION DIRECTOR: **MICHAEL BROWNE** michael.browne@penton.com
PRODUCTION EDITOR: **JEREMY COHEN** jeremy.cohen@penton.com
CONTENT PRODUCTION SPECIALIST: **ROGER ENGELKE** roger.engelke@penton.com
ASSOCIATE CONTENT PRODUCER: **ILIZA SOKOL** iliza.sokol@penton.com
ASSOCIATE CONTENT PRODUCER: **LEAH SCULLY** leah.scully@penton.com

ART DEPARTMENT

GROUP DESIGN DIRECTOR: **ANTHONY VITOLO** tony.vitolo@penton.com
SENIOR ARTIST: **JIM MILLER** jim.miller@penton.com
CONTRIBUTING ART DIRECTOR **RANDALL L. RUBENKING** randall.rubenking@penton.com

PRODUCTION

GROUP PRODUCTION MANAGER: **CAREY SWEETEN** carey.sweeten@penton.com
PRODUCTION MANAGER: **VICKI MCCARTY** vicki.mccarty@penton.com
CLASSIFIED PRODUCTION COORDINATOR: **LINDA SARGENT** linda.sargent@penton.com

AUDIENCE MARKETING

USER MARKETING DIRECTOR: **BRENDA ROODE** brenda.roode@penton.com
USER MARKETING MANAGER: **DEBBIE BRADY** debbie.brady@penton.com
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LIST RENTALS:
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sarah.nowowiejski@penton.com

ONLINE

PRODUCT DEVELOPMENT DIRECTOR: **RYAN MALEC** ryan.malec@penton.com

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CHIEF FINANCIAL OFFICER: **NICOLA ALLAIS** nicola.allais@penton.com
SENIOR VP, DESIGN ENGINEERING GROUP: **BOB MACARTHUR** bob.macarthur@penton.com
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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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MANAGING THE MEASUREMENT POWER

In reference to your "Measuring Progress" test blog on the *Microwaves & RF* website, "Why Such High Costs for Test Equipment?," first I wanted to thank you for your enlightening articles on the changes in the test equipment world. Remember when an "engineering-capable" personal computer cost $3,000? This was true for many years during the 1990s and first decade of the 2000s. Feature/performance creep kept the price constant, even as volumes rose. Prices only dropped once a "lightweight" application emerged: Internet browsing.

Vendors for vector network analyzers (VNAs) seem to be playing the same game: adding more capability for about the same price (even in PXIe format), which may make sense because the devices under test (DUTs) are changing quickly.

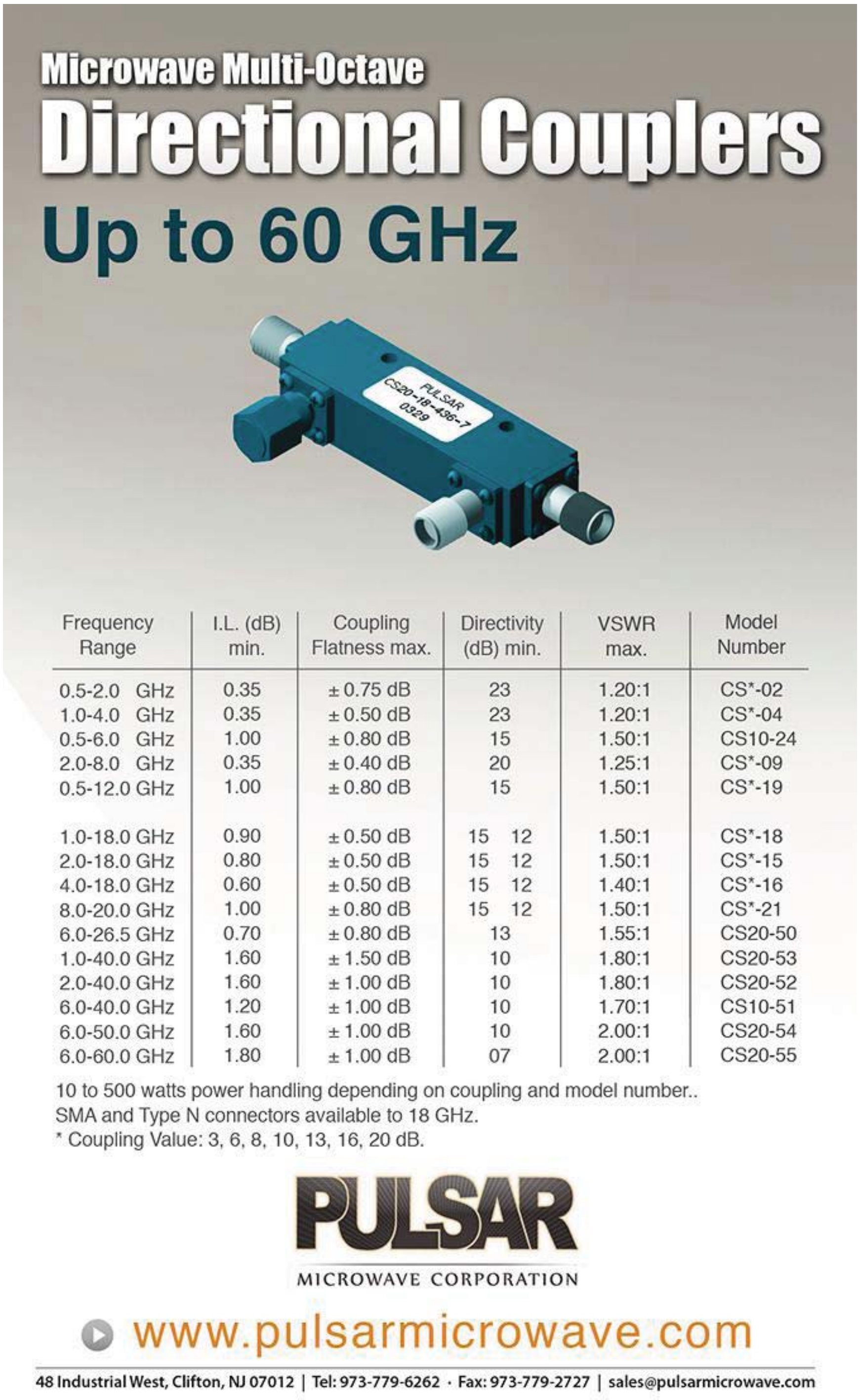
But, I wonder if there is an unserved "lightweight" market segment: simple, inexpensive, limited-functionality test equipment for high-volume production applications. With the growth in the number of components being produced, I am surprised that no one has yet brought out a "throwing knife" VNA rather than a "Swiss Army knife" VNA for manufacturing applications. Any thoughts or comments would be appreciated.

MATT CHERESH
AKELA, INC.

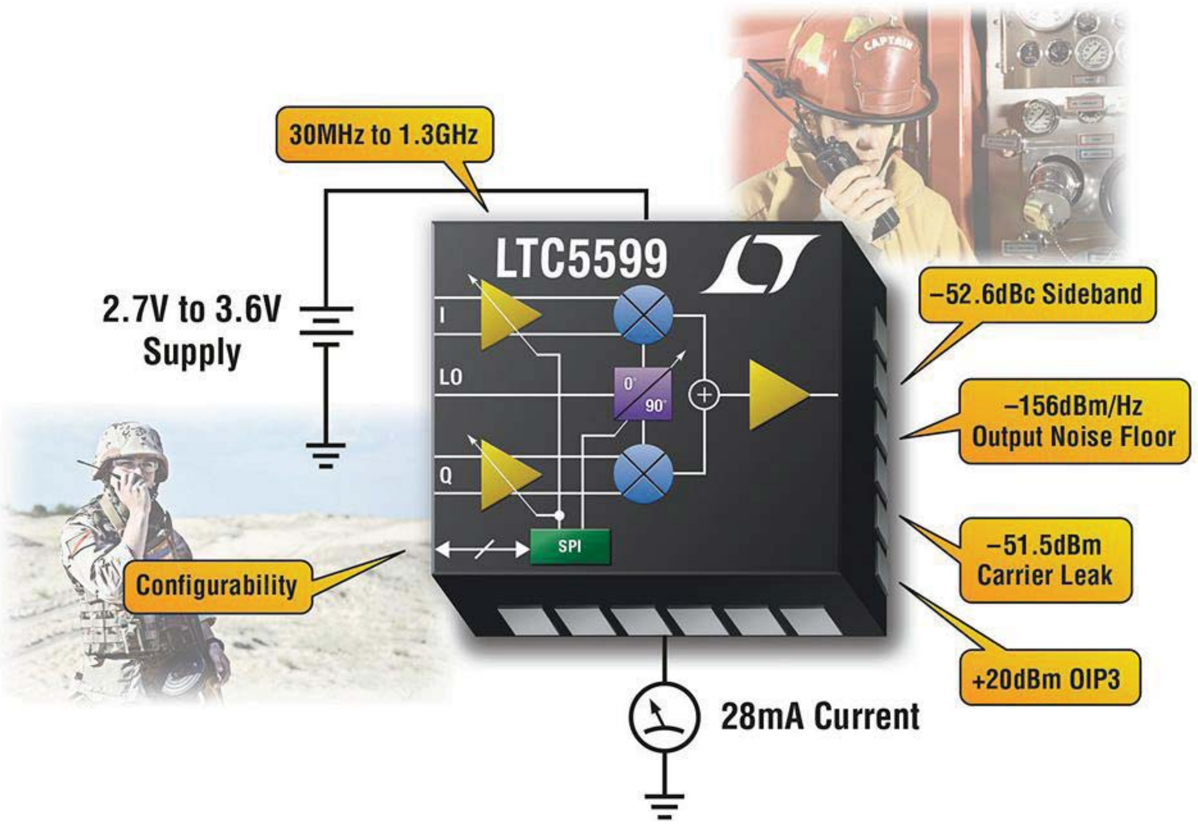
EDITOR'S NOTE

One of the problems with getting a low-cost VNA out there is all the service that must go with such a complex receiver. Signal generators and scopes have come down in price, but VNAs are complex and take some skill to work properly. And they do need a service plan—more than other instruments. It is possible to make a lower-cost VNA, but then you better be ready with that service plan. Still, we at *Microwaves & RF* will be watching for new test-and-measurement developments, and we will be covering new instruments and test software, trying to be as fair as possible in our coverage.

Some companies not known as test-and-measurement equipment suppliers, such as Mini-Circuits, are pursuing economical test solutions that are also accurate and effective, using such formats as modular PXI configurations to save money. This is a company with a history of developing economical RF/microwave solutions, and its number of low-cost test-equipment solutions is growing.



90mW I/Q Modulator



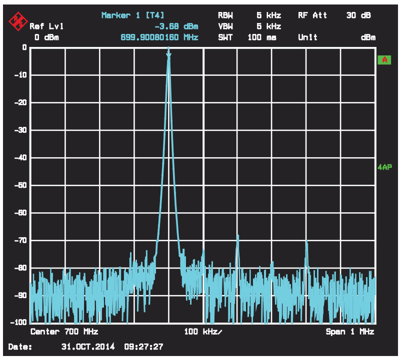
Powered from a single supply from 2.7V to 3.6V, the LTC®5599's 28mA supply current extends battery run time. The modulator offers superb –52.6dBc sideband and –51.5dBm carrier suppression—without the need of calibration. Its low noise floor of –156dBm/Hz and 20dBm OIP3 capability ensure outstanding transmitter performance. The LTC5599's built-in configurability allows users to optimize performance from 30MHz to 1.3GHz, minimizing external components and saving costs.

Features

Built-in Configurability Features:

- Gain Adjustable from 0dB to –19dB, with Supply Current Change from 35mA to 8mA
- Improves Sideband Suppression from –52.6dBc to –60dBc
- Reduces Carrier Leakage from –51.5dBm to –60dBm

Output Spectra (Optimized)



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LINEAR TECHNOLOGY

News

SATELLITE PAYLOAD to Further Augment GPS-Focused Aviation System

To help make air travel safer and more efficient, the Federal Aviation Administration (FAA) released the Wide Area Augmentation System (WAAS) to improve the availability and accuracy of Global Positioning System (GPS) signals. To further support the WAAS system, the FAA recently awarded Raytheon a $103 million contract to develop a payload to incorporate into a new geostationary (GEO) satellite and two associated ground uplink stations.

WAAS helps improve GPS accuracy from 100 m to about 2 m, and enables more direct flight routing, precision landing approaches, and even access to airports and remote landing sites without depending on ground-based infrastructure. Raytheon's WAAS GEO 6 payload will be hosted aboard the commercial host satellite, receiving processed signals from GEO 6 ground stations and re-broadcasting them to the user aircraft.

The FAA simultaneously operates three WAAS GEO satellite payloads to ensure continuous system availability. The sixth system, along with the previous incarnation GEO 5 (also awarded to Raytheon back in 2012), will replace two WAAS payloads that are approaching the end of their service leases. The sixth payload is expected to launch during the second quarter of 2017, with the system entering its 10-year operational phase in 2019. Raytheon represents the FAA's prime contractor for WAAS. ■

RFID USED IN... Automatic Vehicle Registration?

THE BREADTH OF RFID applications continues to widen, now spreading into the "next frontier" of automotive electronics. One of the latest innovations comes from STAR Systems International, which recently introduced the ASTRIA RFID Vehicle Decal for automatic vehicle registration and identification applications—a "3rd License Plate." ASTRIA is based on Alien Technology's HIGGS chip with its flexible memory architecture.

The decals are able to print and program secure RFID and bar-coded data on-demand using STAR's printing software and

Integrated flight decks, like Garmin's G5000, provides WAAS compatibility in-flight, with support from the GEO satellites and stations. *(Image courtesy of Garmin)* a qualified RFID thermal-transfer printer. End users can generate their own customized registration decals, but all vehicle information is printed and programmed at the point of distribution. Potential applications for the decals are numerous: electronic vehicle registration, electronic toll collection, secure parking and access control, fleet management, and other vehicle-tracking endeavors.

Decals conform to both the ISO 18000-6C and EPC C1G2 standards, and incorporate STAR's VENUS antenna transponder that's specifically designed for use on vehicle glass. User memory can be secured via the chip's read-lock and/or write-lock features to support a variety of models, and the factory-programmed, permanently locked 64-bit serial number cannot be altered. A combination of terminal-identification (TID) serial number, electronic-product-code (EPC) data bank, and open-source algorithms helps further enhance security by generating unique access codes for each tag.

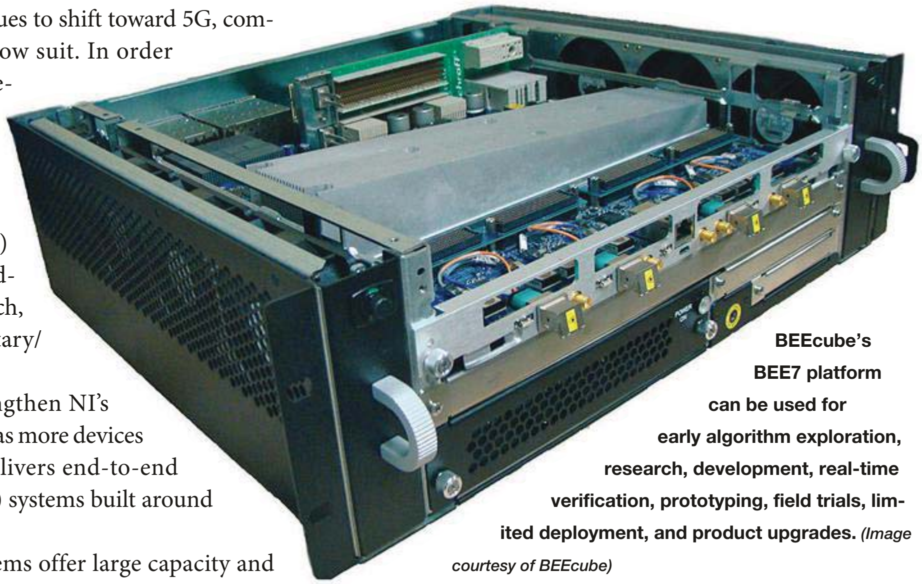
Designed to provide reliable readings even in extreme weather environments, the decals incorporate a non-removable, non-transferrable (NRNT)/break-on-removal (BOR) tamper-evident feature. ■

NI'S BEECUBE ACQUISITION Drives 5G Communications

AS THE MOBILE LANDSCAPE continues to shift toward 5G, components themselves have to follow suit. In order to strengthen its devices for telecommunications applications, National Instruments recently acquired BEEcube. The company supplies high-performance field-programmable-gate-array (FPGA) prototypes and deployment products for advanced wireless research, wireless infrastructure, and military/defense applications.

This acquisition aims to strengthen NI's Internet of Things (IoT) offerings as more devices become connected. BEEcube delivers end-to-end commercial-off-the-shelf (COTS) systems built around FPGA microchips.

The FPGA-driven COTS systems offer large capacity and high-speed interfaces to facilitate the real-time prototyping of deployable systems. The technology is well-suited for a variety of applications, including multi-core computer architectures, wireless communications, networking solutions at 100-Gb/s levels and higher, high-definition video processing, signal intelligence, radar/sonar arrays, bioinformatics, data mining, and medical imaging.



BEEcube's BEE7 platform can be used for early algorithm exploration, research, development, real-time verification, prototyping, field trials, limited deployment, and product upgrades. *(Image courtesy of BEEcube)*

BEEcube will operate as a wholly owned NI subsidiary under the leadership of Chen Chang, the former company's founder and CEO. It will continue to sell and support products under the BEEcube name through direct and distributor channels. The acquisition is reportedly not material to NI's consolidated financial statements. ■

STREAMLINED DATA RETRIEVAL Boosts Remote Health Monitoring

AMONG THE INDUSTRIES most closely tied to the Internet of Things (IoT) ecosystem, the medical market seems likely to reap the greatest benefits. New devices and technologies have the ability to do what doctors lack the bandwidth for—constant, remote monitoring of patients in near real time. A collaboration between Cerner Corp., a supplier of healthcare IT systems, and Qualcomm Life (a subsidiary of Qualcomm Inc.) aims to extend the reach of these services.

According to the agreement, Cerner will implement Qualcomm Life's 2net Platform and Hub, which seamlessly captures data from medical devices and sensors within a patient's home. It then transmits the data to Cerner healthcare clients through the company's CareAware device connectivity platform. Qualcomm's platform will make possible prescribable, turnkey monitoring capabilities that can be tailored to each patient's needs.

The 2net Platform is able to collect, store, and aggregate data from a variety of devices, including weight scales, blood-pressure monitors, and pulse oximeters.

Those values, transmitted via CareAware to the Cerner Millennium electronic health record (EHR), are then viewable through a patient engagement solution. Such comprehensive viewing can help with chronic condition management, as well as reduce readmissions and improve overall patient satisfaction. ■

QuickSyn Synthesizers Now Extended to mmW

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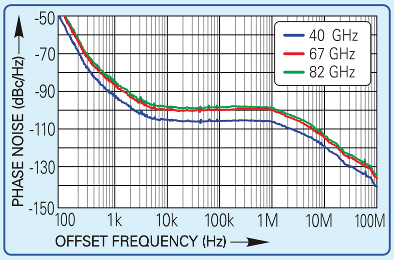
Feature	FSL–2740	FSL–5067	FSL–7682
Frequency GHz	27 to 40	50 to 67	76 to 82
Switching Speed µs	100	100	100
Phase Noise at 100 kHz	-108 dBc/Hz at 40 GHz	-105 dBc/Hz at 67 GHz	-103 dBc/Hz at 82 GHz
Power (min) dBm	+17	+17	+10
Output Connector	2.92 mm	1.85 mm	WR-12



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NOKIA TO ACQUIRE Alcatel-Lucent in $16.6 Billion Deal

WITH AN EYE TOWARD capitalizing on the Internet of Things (IoT) and cloud service markets, Nokia and Alcatel-Lucent are looking to merge their collective talents. The memorandum of understanding states that Nokia will make an offer for all of Alcatel-Lucent's equities (valued at approximately $16.6 billion), with the new company to be called the Nokia Corporation.

According to Adam Ewing and Marie Mawad at Bloomberg, the takeover allows Nokia to add products that are used to transmit landline and Internet traffic. This will give it a more complete offering to sell to carriers as the amount of data traveling on networks increases with the popularity of Netflix and other video and music services. It doesn't end there, as devices from cars to refrigerators are also getting connected to wireless networks.

This will allow the Nokia Corporation to uniquely position itself in order to help telecom operators, Internet players, and large enterprises.

The company will direct its efforts toward the United States, China, Europe, and Asia-Pacific, focusing on fixed and mobile broadband, IP routing, core networks, and cloud applications and services. Risto Siilasmaa will serve as chairman and Rajeev Suri as chief executive officer. The Nokia Corporation's headquarters will be established in Finland, with the firm also maintaining a strong presence in France. The transaction is expected to close in the first half of 2016. ■

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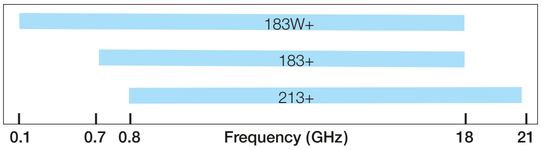
Model	Frequency (GHz)	Gain (dB)	P1dB (dBm)	IP3 (dBm)	NF (dB)	Price $ * (Qty. 1-9)
NEW ZVA-183WX+	0.1-18	28±2	27	35	3.0	1345.00
ZVA-183X+	0.7-18	26±1	24	33	3.0	845.00
ZVA-213X+	0.8-21	26±2	24	33	3.0	945.00

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

Wideband Performance



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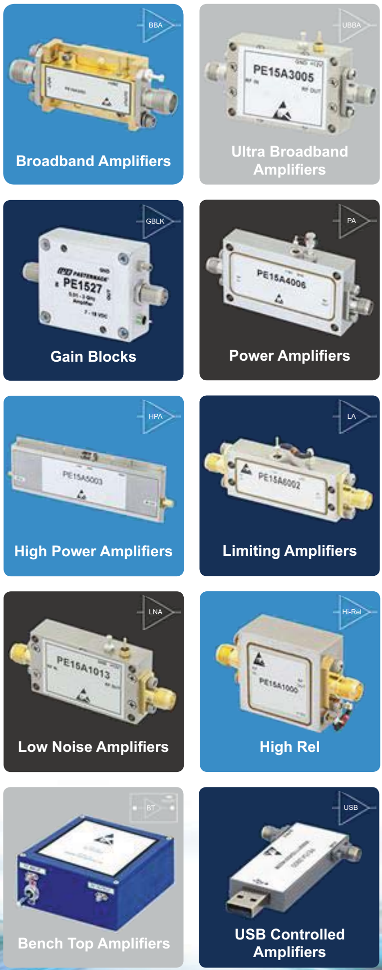

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A four-channel digital modular radio (DMR) from General Dynamics successfully completed data-transmission testing with a Mobile User Objective System (MUOS) satellite. *(Image courtesy of General Dynamics)*

DIGITAL MODULAR RADIO Tunes into MUOS Communications

MOBILE USER OBJECTIVE SYSTEM (MUOS) satellites leverage smartphone technology to elevate military communications to next-generation levels. While those satellites launch periodically, General Dynamics continues to test radios that will help elevate their efficacy further by driving secured communications to warfighters at the tactical edge. In fact, at the MUOS test facility in Scottsdale, Arizona, the company recently completed testing of a four-channel digital modular radio (DMR).

> "Expectations are the DMRs will help improve functionality and interoperability while paving the way for next-generation communications waveforms, including MUOS."

DMRs are currently used as the U.S. Navy's networking radios, operating on Navy vessels and on-shore locations. In conjunction with MUOS satellites and ground station simulators, voice calls and data transmission were successfully completed to and from the DMR to an Army AN/PRC-155 two-channel Manpack radio. Expectations are the DMRs will help improve functionality and interoperability while paving the way for next-generation communications waveforms, including MUOS and the Integrated Waveform.

DMR was the first software-defined radio used by the U.S. military, with 500 secure four-channel radios currently supporting Navy operations. Its digital functionality and open architecture enables updates to be completed via software, as opposed to hardware changes. This will help keep the radios operationally current and capable of being upgraded to waveforms that as of now don't even exist. ■

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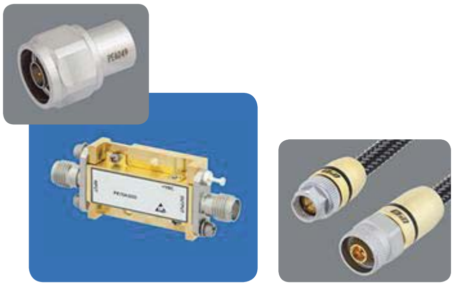

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KA-BAND TECHNOLOGY SPEEDS In-flight Connectivity

LONG GONE ARE the days when pilots urged passengers to turn off their devices. Now two companies are working to bring faster connectivity and higher-quality broadband service to all aircraft.

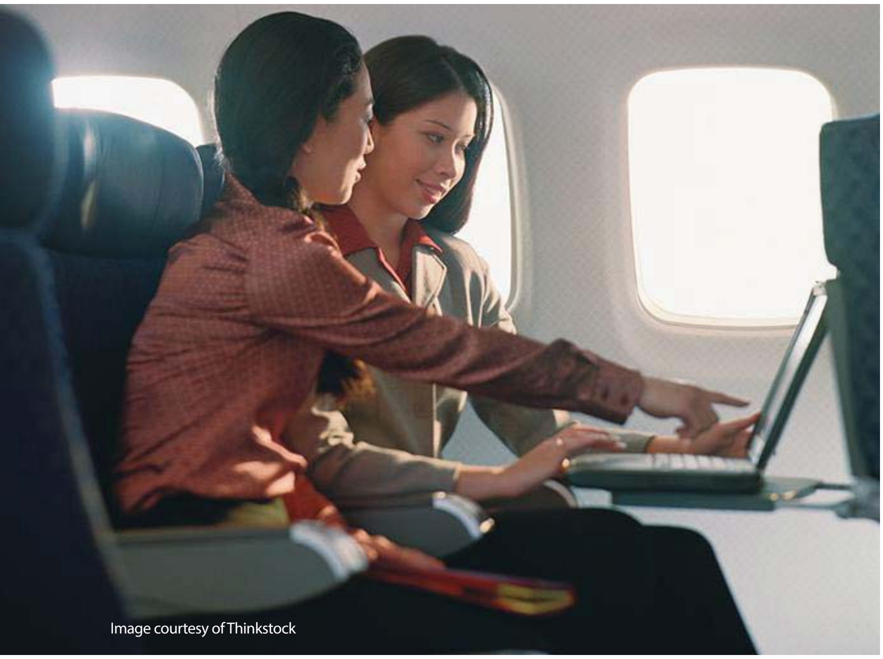
Image courtesy of Thinkstock

Kymeta and Honeywell Aerospace are developing and testing a new antenna that will bring Ka-band wireless services to commercial aircraft and business jets. The flat-panel design is light and reduces drag, helping to reduce overall costs.

Kymeta will deliver its mTenna antenna products to Honeywell, which will then test and integrate the antenna into its JetWave aviation product line. The line of satellite communications hardware exclusively supports Inmarsat's GX Aviation service. Driving the mTenna is a combination of electromagnetic metamaterial technology, which uses a holographic approach to steer and lock satellite beams without moving parts, and thin-film-transistor (TFT) LCD technology for a scalable solution.

According to Kymeta, "The direction of the beam is defined by the specific elements that are electronically activated—a design that allows for both continual and instantaneous changes in direction." This is made possible by the suite of tunable elements placed in a precise, calculated pattern. The antenna is just part of the companies' goals to bring faster in-flight connectivity to passengers and pilots. ■

QI-BASED KIT CONVERTS Any Smartphone for Wireless Charging

WHILE COMPLETE WIRELESS CHARGING of devices will certainly become the norm, the technology isn't yet available for all smartphones and gadgets. A new Kickstarter campaign aims to simplify the process with a wireless-charging conversion kit. Based on Qi technology, the NeverDed Cordless Charging Conversion Cystem (C4) includes a home dock, car charger, and portable charger, and will be compatible with almost every device.

Qi technology, which is backed by the Wireless Power Consortium, uses electromagnetic induction technology to charge devices. The C4 kit comes with a wireless receiver adapter connected to the device, specified to the phone's make and model (Micro USB for Android, Lightning for Apple, etc.) All pieces in the kit operate in the 110- to 205-kHz range.

As the NeverDed team says, "Mobile phones were made to be mobile, not tethered. Free your phone, and help us rid the world of charging cords forever." For more information and to back the project, check out *http://neverded.com/kickstarter/*. ■

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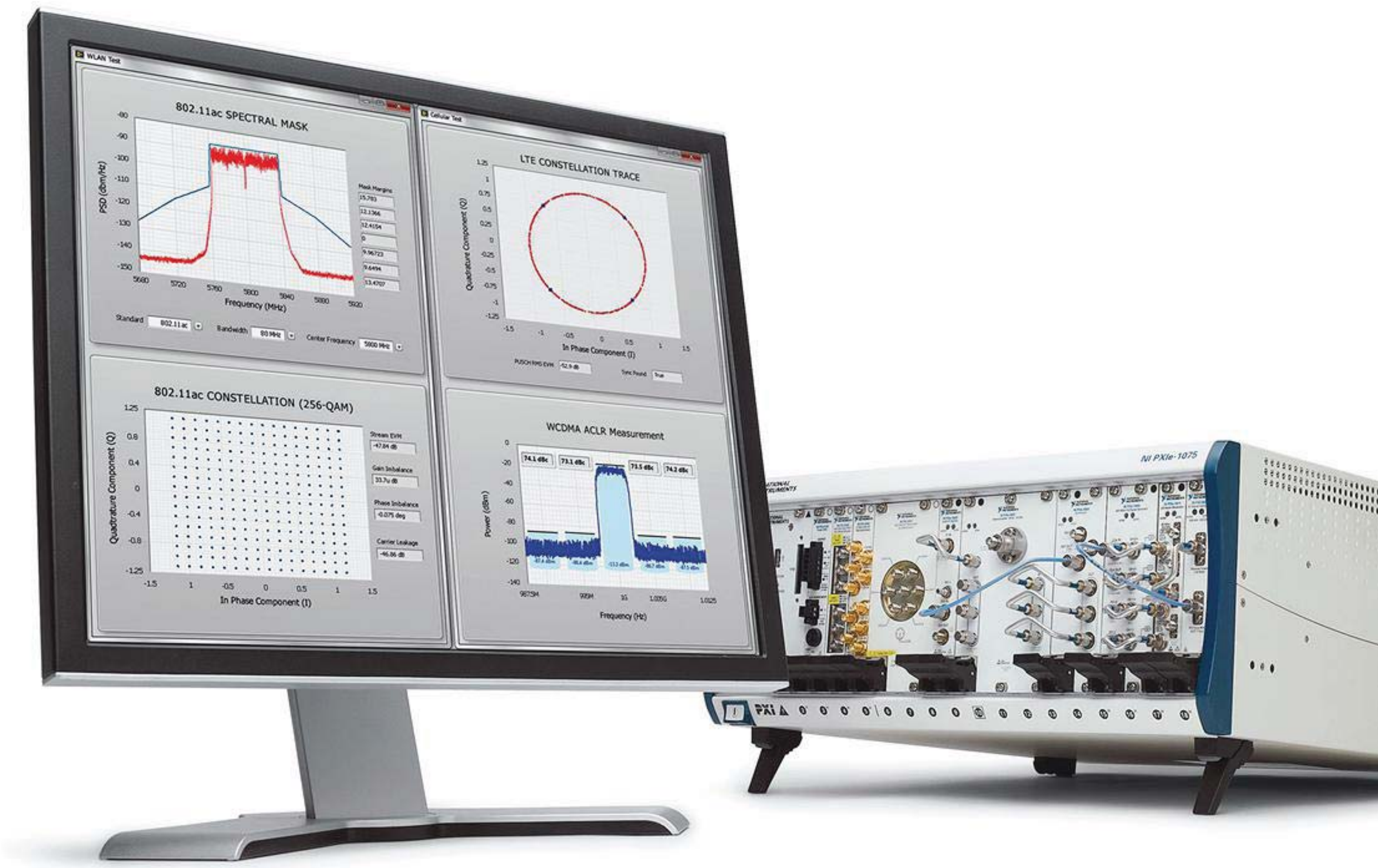

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NATIONAL INSTRUMENTS™

Company News

CONTRACTS

ETL Systems—Was chosen by CP Communications to support its new line of mobile production vehicles. A range of ETL's RF equipment including switch matrix / routers and RF combiners and splitters has been used to provide broadcasting capability to CP Communications' six RF mobile units. ETL Enigma matrices are housed in the production trucks and allow CP Communications to seamlessly switch the RF-over-fiber mini-sites for 18-hole coverage of a live golf tournament.

M/A-COM Technology Solutions Holdings Inc. (MACOM)—Announced that Blackmagic Design is utilizing its 12G-SDI equalizer with reclocker and crosspoint solution for the latest upgrade to the Videohub Routing and Distribution product line. In other MACOM news, the company announced that Utah Scientific, a global manufacturer of routing and master control switchers, has chosen MACOM's M23554 Adaptive Equalizer, M23145 Reclocker, and M23428 Cable Driver for the 12G-SDI interconnects of its UDS-4K Universal Distribution System.

Infrastructure Networks Inc. (INET)—Signed a substantial multiyear contract with a large independent exploration and production company to provide wireless connectivity in the Permian Basin, which will improve worker safety, productivity, and efficiency. Under this new contract, the large independent will be utilizing INET's industrial LTE network, which is the first open-standards-based wireless network dedicated to critical infrastructure, which includes the oil and gas industry. The network currently covers 18,000 square miles of the Permian Basin and will be expanded to 25,000 square miles in 2015.

ETL Sale Is Hole-in-One

Double Deals for MACOM

Mercury Systems Inc.—Received a $1.5 million order from a leading defense prime contractor for high-performance server-class ATCA signal-processing subsystems for a radar application. The order was booked in the company's fiscal 2015 third quarter and is expected to be shipped by its fiscal 2016 first quarter.

Norsat International Inc.—Received an order from the Defense Media Activity (DMA) to purchase Norsat's GLOBETrekker 2.0 portable satellite terminals, along with Norsat's 50W ATOM series Block Upconverters (BUCs) to enable satellite uplink of live high-definition or standard-definition video from the field, as well as data transfer and email access.

FRESH STARTS

Arrow Electronics Inc.—Signed a global distribution agreement with Silex Technology, a supplier of reliable Wi-Fi connectivity solutions. Under the agreement, Arrow will distribute Silex Technology Wi-Fi modules to its broad base of customers. Silex Technology is a Freescale Proven Partner and created the Freescale-recommended Wi-Fi solution for i.MX6-based products.

Averna—Announced that Tandem Expansion Fund, a Canadian growth-equity investor, has acquired a majority interest in the company. The transaction provides Averna, a developer of test solutions and services for communications and electronics device-makers worldwide, with the financial resources to accelerate organic and strategic growth as well as to expand its international presence.

AT4 wireless—Has completed the setup of a new laboratory for Over the Air (OTA) Testing MIMO measurements at its Malaga, Spain, headquarters. This facility will conduct radiated performance measurements for cellular and wireless devices in a multipath environment simulating a wide range of real world scenarios. The new facility consists of a fully anechoic chamber supplied by ETS-Lindgren Model AMS-8700, supporting a 16-antenna ring designed to generate single and multi-cluster environments, along with Anite's Propsim F32 Channel Emulator. AT4 wireless has worked closely with both ETS-Lindgren and Anite for many years.

u-blox—Has become a member of the CAR 2 CAR Communication Consortium, which is dedicated to the development and deployment of Cooperative Intelligent Transport Systems (C-ITS). As its ultimate goal is to improve road traffic safety and efficiency, the Consortium is working to develop roadmaps for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications and to harmonize related standards. Lane-accurate positioning and short-range communication technology, both a focus of u-blox, play an important role for ITS applications.

Maury Microwave—Has completed the acquisition of Anteverta-mw. This strategic move is expected to further strengthen Maury Microwave in the nonlinear measurement and modeling device characterization market and accelerate innovation for the betterment of markets served by both parties.

Advanced Defense Technologies Inc.—Announced that it is engaged in continued discussions toward a Statement of Work (SOW) order with a global leader in the technology enhancement, manufacturing, and testing of the sophisticated antenna systems. The antenna company has been actively seeking the new technology to electronically steer the RF beam (at a reasonable price) for multiple antenna system applications including Positioners/Controllers; Wideband Antennas; Airborne/Missile/Space; SATCOM; and Commercial Communications and GPS systems. Management believes that this opportunity, which has been generated under the company's revised business plan is a significant step toward ADTI's Generation #2 and the technology productization plans.

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NEW USB-1SP4T-A18	1 (SP4T)	0.25	1.2	85	2	795.00
USB-1SPDT-A18	1	0.25	1.2	85	10	385.00
USB-2SPDT-A18	2	0.25	1.2	85	10	685.00
USB-3SPDT-A18	3	0.25	1.2	85	10	980.00
USB-4SPDT-A18	4	0.25	1.2	85	10	1180.00
USB-8SPDT-A18	8	0.25	1.2	85	10	2495.00

NEW USB and Ethernet Control Switch Matrices

Model	# Switches (SPDT)	IL (dB)	VSWR (:1)	Isolation (dB)	RF P_{MAX} (W)	Price $ (Qty. 1-9)
RC-1SP4T-A18	1 (SP4T)	0.25	1.2	85	2	895.00
RC-2SP4T-A18	2 (SP4T)	0.25	1.2	85	2	2195.00
RC-1SPDT-A18	1	0.25	1.2	85	10	485.00
RC-2SPDT-A18	2	0.25	1.2	85	10	785.00
RC-3SPDT-A18	3	0.25	1.2	85	10	1080.00
RC-4SPDT-A18	4	0.25	1.2	85	10	1280.00
RC-8SPDT-A18	8	0.25	1.2	85	10	2595.00

*The mechanical switches within each model are offered with an optional 10 year extended warranty. Agreement required. See data sheets on our website for terms and conditions. Switches protected by US patents 5,272,458; 6,650,210; 6,414,577; 7,633,361; 7,843,289; and additional patents pending.

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PWR-4GHS	CW	0.009 to 4000	USB	795.00
PWR-6GHS	CW	1 to 6000	USB	695.00
PWR-8GHS	CW	1 to 8000	USB	869.00
NEW! PWR-8GHS-RC	CW	1 to 8000	USB & Ethernet	969.00
PWR-8FS	CW	1 to 8000	USB	969.00
PWR-4RMS	True RMS	50 to 4000	USB	1169.00

*Measurement speed as fast as 10 ms for model PWR-8-FS. All other models as fast as 30 ms.

†Dynamic range as wide as -35 to +20 dBm for model PWR-4RMS. All other models as wide as -30 to +20 dBm.
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532 rev B

Splitting Signals

JEAN-JACQUES DeLISLE
Technology Editor

RF Instrument Fusion Embraces PC-Driven and Modular Architectures

These days, even high-end test and measurement instruments are beginning to fuse into Frankenstein-like combinations of classical instruments. Just as Apple's new Apple Watch is an amalgamation of a timepiece, speakerphone, fitness hub, multi-pass, GPS, MP3 player, and possibly your next girlfriend, traditional RF/microwave instruments are getting smaller/portable and more feature rich.

Over-the-air upgrades are also a trending option, as well as instruments ditching the box and embracing PC-driven connectivity. Recently, several test-and-measurement companies have released box instruments—specifically oscilloscopes—with built-in SA functions or even SA modules incorporated into the box. Also, there are fusions of NAs and SAs in individual modular instruments with software-defined functions that enable full PC-driven transceiver tests.

Interestingly, this instrument melding is creating many new test opportunities to lower testing time, cost, and footprints. A major enabling factor is increased speed and more compact components with the ability to digitize RF/microwave signals with custom designed application-specific-integrated-circuits (ASICs), and even commercially available analog-to-digital (A/D) and digital-to-analog (D/A) converters.

One significant challenge these compound instruments may be able to meet involves the extremely complex testing of high-bandwidth wireless standards and emerging electronic warfare (EW) applications. The bandwidth requirements are extremely high for these applications. Plus, the latest wireless standards incorporate features—such as carrier aggregation, MIMO, digital-predistortion, and envelope tracking—that traditional spectrum analyzer technology isn't able to keep up with (especially at millimeter-wave frequencies).

With 5G coming up, possibly all the way up in the 60 GHz spectrum, there is a race for bandwidth in SAs with the necessary performance to meet these highly complex modulation schemes. Oscilloscopes with sophisticated FFT functions could bridge the gap, even more so by advancing the ability of using processing algorithms to more accurately recreate the frequency domain data. These types of solutions are more likely in a modular or PC-driven architecture, as box instrument computation capabilities likely won't be able to keep up with the pace of growth of signal complexity and the demand for even greater computing.

There have been PC-driven oscilloscopes, network analyzers (NAs), and spectrum analyzers (SAs) for several years. Generally, these instruments were relegated to the low-performance range and were only helpful for a select few applications. With the advancement of a high-speed serial bus, USB 3.0 at 5 Gbps, it became viable to do the initial digitization and processing of an RF/microwave signal in external hardware and transport the several gigabits per second of data to a powerful PC over USB. Additionally, commercial PC hardware has stepped up with affordable Intel i7 processors that can crunch a considerable amount of streaming RF data.

I am inclined to believe that with the release of USB-C, USB's new 10 Gbps standard with power-over-data-line technology, a new regime of PC-driven instruments will become possible. Yes, the USB-C standard also supports up to 100 watts of power over the same 10 Gbps interface, with a fully symmetric cable even an undergrad couldn't mess-up. I am unsure of how well USB-C could be used to sync several modular instruments, but I suspect that it may be up to the task.

Instantly I thought of combining USB-C's high-speed data transfer mechanism with an RF/microwave calibrated digitizer, throwing in a GPU-based computation engine for good measure. You would have an incredibly powerful PC-driven instrument that could function as a high-speed mixed-signal oscilloscope and advanced SA. You would only need a calibrated and synced generator, which could even be a separate component, and you would have just created a nearly-complete RF/microwave test-bench for a fraction of the cost of a box instrument. mw

LOU FRENZEL
Contrbuting Editor

5 New Things to Do with a Single-Chip Radar

In case you didn't know, you are living in the age of the single-chip radar. These chips are now widely used in automobiles, so volume is increasing—thereby reducing the price. This makes them ever more practical for other applications, which got me to thinking: What are these other apps? Here are a few thoughts.

The single-chip radars come in a variety of forms. You can get them in the 24, 60, 76-77, and 94 GHz bands. Some research-lab chips operate at 120 GHz. As for modulation, there are CW and pulse types—but most seem to use FM-CW. There are even some impulse UWB units available. Maximum range is about 10 to 60 meters. Most are made with SiGe, but there are some CMOS devices emerging. Prices are still in the high single digits, but coming down. A number of companies offer complete modules, especially for auto use.

What radar traditionally does is measure distance, direction, and speed. And the new single-chip devices are no exception. However, one good way to look at these chips is as sensors. They can still measure distance and speed, but they also indicate presence or motion. For example, one popular use is a liquid level sensor in a tank.

Single-chip radar's greatest success so far is its use for automotive safety and convenience. Some examples are adaptive cruise control, collision mitigation with automatic braking, lane-departure sensing, and even backup object detection. While most of these accessories are primarily found in high-end cars, they are showing up more and more in mid-range and low-priced cars. They are so effective that I half suspect the government will soon mandate all cars have them—not a bad idea. And, of course, single-chip radar is absolutely essential to the success of the driverless car.

So what else can you do with a single chip radar? One approach is to use the "find a need and fill it" method of product development. But another approach is one engineers love: Here is a cool, new chip, what new product can I make with it? Marketability and need are secondary factors. Here are my thoughts on this.

1. *Drone safety.* Use the chips as a cheap altimeter to ensure meeting the 400-foot ceiling now imposed by the FAA. Or why not use the chips to prevent drone collisions with one another or other objects? This could be one way that the FAA will eventually bless commercial drones.

2. *Automatic door openers.* How about a garage door opener that senses when your car gets close and opens automatically? This would also be good for gates. No button to push. But what if a moose walks in front of your garage door and it opens? Uh oh, back to the drawing board.

3. *Bug zapper.* Maybe it is possible to make a radar that tracks flies, mosquitoes, or other nuisance bugs and vaporizes them with a low-power laser. A great new consumer product for use on picnic tables or in the backyard. But then will everyone need to wear eye protection or other safety devices or risk getting zapped by the laser? Oooops….

4. *Security.* Security is a major need and app these days. Video cameras are everywhere. But sometimes all you need is a presence sensor or motion detector to set off an alarm. IR is used for this now, but radar would increase the range. A related need is to sense the presence or movement of animals.

5. *Bicycle safety.* If radar is so effective with automobiles, maybe it should be used on bikes—where personal safety is always an issue. This could cut deaths and accidents significantly if implemented correctly. Maybe the radar would be a wearable on a helmet or on the body like in a vest. The prices are right at last.

Single-chip radars are also perfect for robots, and I suspect someone will invent a toy using radar. But you tell me: What would you do with a single-chip radar? mw

BARIUM STRONTIUM TITANATE TUNES VARIABLE PATCH ANTENNA REFLECTARRAYS

REALIZING BEAMSTEERABLE REFLECTARRAY antennas in millimeter-wave frequencies is a challenge drawing much interest from the space antenna market. As the demand is increasing for electronically reconfigurable antenna arrays with high data rates and fast switching speeds, designers are looking beyond traditional switches and MEMS technology. Researchers Kalyan K. Karnati, Parveen F. Wahid, Xun Gong, and Michael E. Trampler of the University of Central Florida, Ya Shen, along with TriQuint Semiconductor (now Qorvo) and Intellectual Ventures' Siamak Ebadi, have developed integrated and tunable reflectarray unit cells in the Ka- and X-bands using barium strontium titanate (BST) tunable capacitors.

When the DC-bias of a thin-film of BST is adjusted, the dielectric properties of the material are changed. When monolithically integrated beneath the patch antenna element, a tuning mechanism for the antenna is possible without significant packaging and bonding parasitics and manufacturing challenges.

When operating in a maximum phase range mode, the unit cells reached a phase range of 298 deg. and 263 deg. with a maximum reflection loss of 16 dB and 8.8 dB in the Ka- and X-bands. At frequencies of minimum reflection loss, 30.7 GHz and 10.27 GHz, reflection losses of 5.6 DB and 5.8 dB were achieved with a phase angle of 250 deg. See "A BST-Integrated Capacitively Loaded Patch for Ka- and X-band Beamsteerable Reflectarray Antennas in Satellite Communications," *IEEE Transactions on Antennas and Propagation*, April 2015, p. 1,324.

DIFFERENTIAL GROUP DELAY MODULES AID INSTANTANEOUS MICROWAVE MEASUREMENTS

OPTOELECTRONIC TECHNIQUES APPLIED to RF technologies is a growing trend, and with good reason. The benefits optoelectronics provide are immunity to electromagnetic interference and extremely wide bandwidth transmissions. Now, researchers Songnian Fu, Junqiang Zhou, Perry P. Shum, and Kenneth Lee of the Network Technology Research Centre and Temasek Laboratories of the Nanyang Technological University, Singapore, have demonstrated a photonic technique to create an adjustable microwave frequency measurement system.

After a microwave signal of interest is received, the signal is modulated on an optical carrier using a Mach-Zehnder modulator (MZM). A dual pair of programmable differential group delay (DGD) modules then receives the optically modulated microwave signal. The DGD pair introduces unique microwave power fading effects on the optically modulated signals. These effects enable a fixed relationship between the frequency and power of the signal to be derived after the signals are coupled into separate photodetectors for electrical conversion.

DGD module adjustment can be used to vary both the frequency measurement range and the resolution range. The research team experimentally verified their design with continuous-wave microwave frequency signals from 15 dBm to 3 dBm of power. The measured errors of the signal were below 0.04 GHz for the entire range of 4.5 to 6.5 GHz. See "Instantaneous Microwave Frequency Measurement Using Programmable Differential Group Delay (DGD) Modules," *IEEE Photonics Journal*, Dec. 2010, p. 967.

TUNABLE OPTOELECTRONIC OSCILLATORS ENABLE ARBITRARY WAVEFORM GENERATORS

WITH THE INCREASED availability of optoelectronic technology, optical techniques for microwave waveform generation have become more and more viable: The limitations of frequency and bandwidth present with traditional microwave waveform generation technologies are not present with optical methods. Recently, researchers Wangzhe Li, Fanqi Kong, and Jianping Yao at the Microwave Photonics Research Laboratory of the University of Ottawa, Canada, developed an arbitrary microwave waveform generation technique using a tunable optoelectronic oscillator.

The goal of the research was to develop a phase-coded or frequency-chirped microwave waveform generator using photonic techniques. To generate the signal, a tunable optoelectronic oscillator (OEO) is used to output a microwave signal and an optical sideband. A polarization modulator (PolM) is then used to modulate the incoming optical sideband and light waves from the OEO laser source. After the application of an electrical signal to the PolM, two complementary phase-coded or frequency-chirped photonic signals are generated. Using a photodetector, these signals are then converted to electrical signals using a high-speed photodiode.

Without using a microwave source, the experimental system was built and verified at 10 GHz and 15 GHz with binary- and polyphase-coded microwave waveforms. Linearly frequency-chirped waveforms were produced with a chirp rate of 20.98 GHz/ns at 10 GHz and 22.5 GHz/ns at 15 GHz. See "Arbitrary Microwave Waveform Generation Based On A Tunable Optoelectronic Oscillator," *Journal of Lightwave Technology*, Dec. 2013, p. 3,780.

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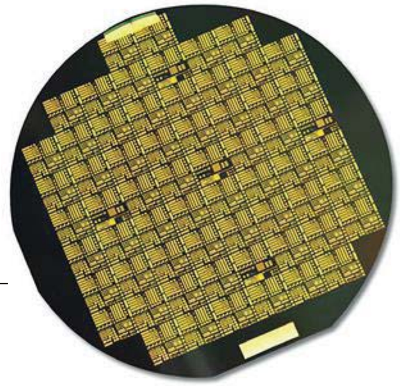
JEAN-JACQUES DeLISLE | Technical Editor

Diamonds Are a GaN PA's Best Friend



CVD diamond materials exhibit significant performance-enhancing potential for active and passive RF components.

SOLID-STATE POWER AMPLIFIERS (PAs) continually push the boundaries on power density in ever-smaller package sizes. Though that's desirable from a cost, size, and weight perspective, the thermal energy for gallium-nitride (GaN)-based devices operating at high power levels is magnitudes greater than prior technologies. Such thermal-energy density in and around these devices significantly strains the transistors and surrounding components. So, to get the most out of these new materials, GaN and passive-device manufacturers are now turning to diamond substrates as a next-generation material *(Table 1)*.

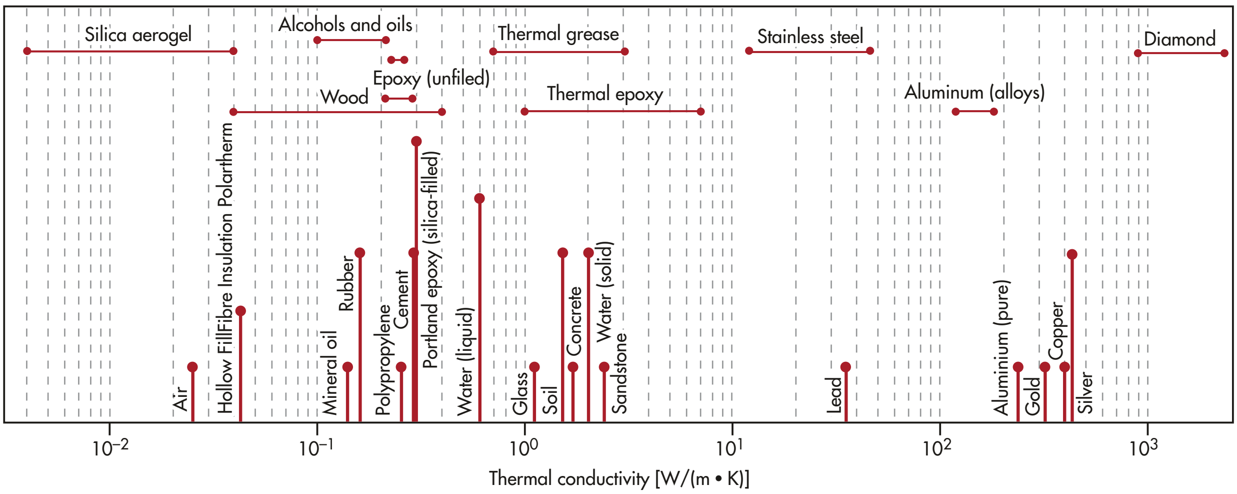
Diamond maintains the highest thermal conductivity of any material at room temperature *(Fig. 1)*. Alongside its extreme hardness and optical transmittance, these characteristics make diamond a highly attractive material for power electronics. High-performance RF amplifiers and laser-diode devices are the two main applications for diamond materials. For RF applications, the primary interest surrounds telecommunications and electronic-warfare (EW) amplifiers and passives.

However, natural diamonds and high-pressure high-temperature (HPHT) synthetic diamonds aren't suited for electronics manufacturing. In this industry, the dominant form of diamond is the chemical-vapor-deposition (CVD) diamond.

HOW IS CVD DIAMOND MADE?

Creating a material that's produced through application of Earth's heat and pressure over millions of years doesn't come easily or cheaply. Either those extreme conditions have to be replicated, or it requires the use of clever physics and chemistry. The CVD diamond process does that the latter. Using carbon dioxide, methane, and high-energy microwave plasma, a molecule-by-molecule construction of a diamond wafer is possible *(Fig. 2)*.

"There are several inputs that have to be controlled carefully to achieve the highest purity diamond. Those inputs are power, pressure, gas selection, and the temperature of the substrate the diamond is grown on," says Bruce Bolliger, head of sales and marketing for Element Six. These control parameters can influence the properties of the diamond to a high degree. Bolliger continues, "This includes engineering imperfections, thermal grade, and different optical characteristics. As the process grows



1. Alongside precious metals and alloys, diamond has the highest thermal conductivity of all known materials at room temperature.

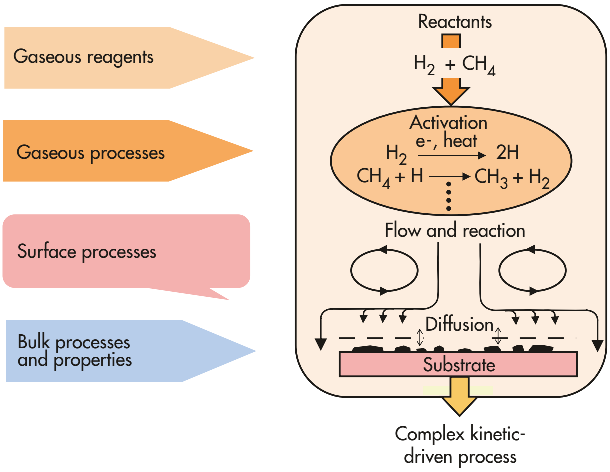
the diamond material molecule by molecule, the process allows for very refined control."

Most of the diamond material for RF applications is polycrystalline, and it's targeted mainly for thermal applications *(Fig. 3)*. Single-crystal diamond, predominantly used for its optical properties, has higher thermal conductivity than polycrystalline—roughly 3000 W/mK compared to 2000 W/mK. But the increased cost and limited 8- by 8-mm size reduces its viability for RF applications.

Diamond growth rate determines the grain size of the polycrystalline diamond. If the CVD diamond is grown more slowly, the diamond will have a larger grain size, which is typically a higher-performing material. For example, a 1000-W/mK quality CVD diamond is basically half the cost of a 2000-W/mK diamond, as its growth time is roughly half the time of the lower-quality diamond. In general, the variable growth rate enables quality control over the diamond substrate.

In addition, the polycrystalline diamond method can produce larger wafers that are at most 140 mm in diameter and 2 mm thick. For thermal applications, substrate thickness typically measures between 300 and 500 µm. Post-processing polishing and cutting can form the diamond into different grades and sizes, depending on the application.

2. Combining streams of hydrogen and methane with an extremely dense, high-energy plasma produces a diffusion process that deposits carbon atoms in a diamond matrix.



USING CVD DIAMOND AS HEAT SPREADERS

For RF technologies, CVD diamond's first main app has been as a heat spreader. The heat spreader is inserted between the RF die and substrate to channel thermal conduction away from the die material *(Fig. 4)*. "Good thermal transfer demands that the interface between the die and the diamond be as thermally optimal as possible," says Bolliger. "If this interface is fabricated incorrectly, the diamond heat spreader is ineffective."

Poor interface characteristics can reduce the thermal conduction gain of any heat spreader material. With diamond, however, any loss of thermal transfer is dramatic compared to the benefits *(Fig. 5)*. Bolliger continues, "If done right, the diamond heat spreader could reduce the thermal resistance by 25-30%. We recommend keeping the solder layer between the heat spreader and die as thin as possible to minimize its degradation of the thermal conductivity of the stack."

A metallization step helps with the interface characteristics between the die and the diamond

TABLE 1: COMPARISON OF IDENTICAL GaN-ON-DIAMOND VS. GaN-ON-SILICON HEMTs

Metric	GaN-on-diamond		GaN-on-silicon	
	Average value	Standard deviation	Average value	Standard deviation
R_c (Ωmm)	0.36	0.11	0.49	0.09
R_{sh}(Ω/sq)	441	39.4	429	17.8
IISO@50 V (µA)	89	103	226	186
G_m peak (mS/mm)	238	18.6	214	5.3
V_{th} (V)	−3.58	0.04	−3.81	0.05
I_{max} (mA/mm)	813	56.3	697	39.6
I_{dss} (mA/mm)	707	58.6	617	57.3
I_{gl} (µA/mm)	−5.66	5.49	−0.56	0.84
V_{bk} (V)	25.75	10.64	27.94	5.02
G_{Lag} @5 V (%)	7.9		7.1	
D_{Lag} @5 V (%)	10		10.6	

* Data from the Air Force Research Lab (AFRL)

TABLE 2: THERMAL/ELECTRICAL/PHYSICAL PROPERTIES OF SEVERAL BULK SUBSTRATE MATERIALS FOR GaN SEMICONDUCTORS

	Silicon (Si)	Gallium arsenide (GaAs)	Silicon carbide (SiC)	Gallium nitride (GaN)	Sapphire	CVD diamond
Thermal conductivity @300K (W/mK)	142.5 ± 7.5	42.5 ± 7.5	420 ± 30	200 ± 50	35	1500 ± 500
Electrical resistivity @300K (Ωcm)	2.3×10^5	10^4 to -10^8	10^4 to -10^6	10^6	10^{17}	10^{13} to 10^{16}
Young's Modulus @300K (GPa)	130	83	545 ± 155	190 ± 10	325 ±75	1,100
Maximum available wafer diameter (inch)	12	6	6	1.2	4	6

heat spreader. Generally, it entails layers of titanium, platinum, and gold. Platinum is used because a few metals will adhere well to titanium—a thin titanium layer is sputtered on, followed by platinum. The platinum also prevents die material from bonding to the titanium. A layer of gold is deposited on top to help with adhesion as the wire bonds are attached during soldering.

"BeO [beryllium oxide] is a good heat spreader, but has a thermal conductivity as much as 10 times lower than CVD diamond," says Bolliger. "Diamond doesn't collect any heat within the material itself, and so its thermal transfer is extremely rapid." With polycrystalline diamond, the larger crystals make it possible for phonon thermal transfer to move more rapidly through the material. He continues, "For example, comparing the TM100 (1000-W/mK thermal conductivity with smaller crystals) CVD diamond at 0.3 mm compared to BeO led to a 30% reduction in thermal resistance."

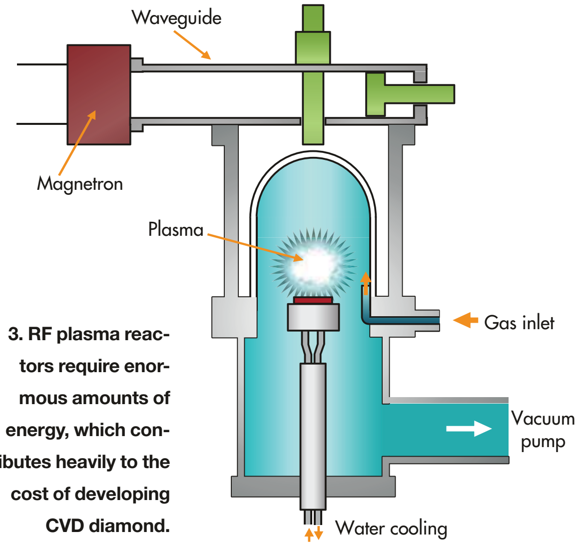
There are diminishing returns with using ever higher-quality CVD diamond, though. Once the thermal conduction can remove most of the heat, less benefit can be attained by using higher grades. Bolliger says, "With the same comparison with BeO using TM180 (1800 W/mK thermal conductivity), we only experienced a 37% improvement."

Diamond as a heat spreader does aid the thermal transfer. Even so, the further away the diamond material is from the die, the less likely it is to increase thermal conduction. When using a heat spreader, the diamond is still separated from the die substrate by 100 to 300 μm. Having the diamond within a micron of the heat source can reduce thermal resistance by as much as 50%.

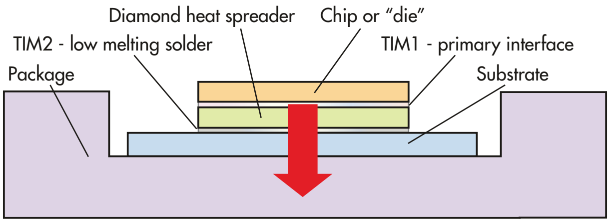
HOW IS GaN-ON-DIAMOND MADE?

Using a diamond substrate will ensure that the GaN and diamond are as close as possible. Though no process exists to grow GaN directly on top of CVD diamond, a specialized process has been developed. Bolliger explains, "The work of developing GaN-on-diamond technology has been going on for about 10 years. I would say many years of which have been spent on optimizing the interface between the materials."

Initially, GaN is grown on a silicon wafer, but the silicon is later etched away *(Table 2)*. The transition layers added to the GaN are etched away prior to the deposition of an interface layer on the GaN *(Fig. 6)*. Next, diamond is grown on the interface layer. That interface layer is one of the most critical aspects



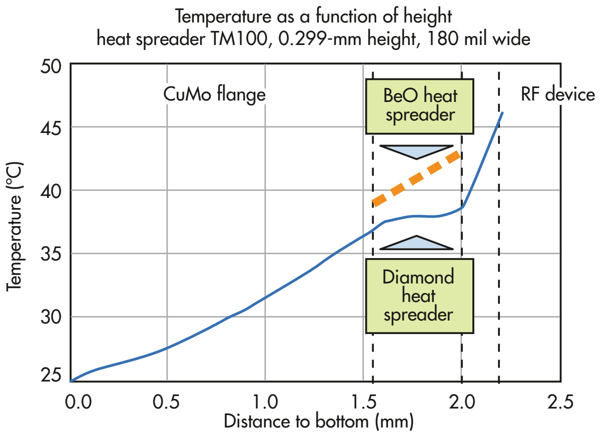
3. RF plasma reactors require enormous amounts of energy, which contributes heavily to the cost of developing CVD diamond.



4. Using a diamond heat spreader to increase the effective thermal wicking surface area aids in reducing temperature extremes near GaN transistors.

TABLE 3: NOMINAL CONSTITUENT THERMAL PROPERTIES

Property	Units	Value (T in Kelvin)
GaN conductivity	W/mK	$490560*T^{-1.41}$
GaN-on-diamond thermal infrared spectroscopy (TIR)	mm^2K/GW	47.6
Diamond conductivity (in plane)	W/mK	$27287*T^{-0.55}$
Diamond conductivity (through plane)	W/mK	$34109*T^{-0.55}$
AuSn solder R_{th}	mm^2K/W	0.45
Spreader conductivity	W/mK	140
Epoxy R_{th}	mm^2K/W	5.5
CuMo conductivity	W/mK	167



5. The diamond heat spreader displays a much higher thermal transportation characteristic than legacy materials.

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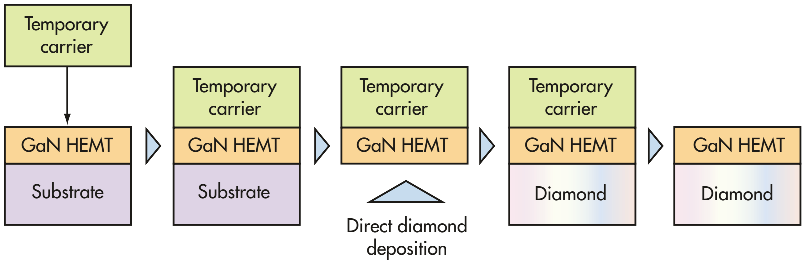

6. Using temporary and transition layers to create GaN-on-diamond enables diamond deposition extremely close to the GaN transistors.

of the process, as its quality can dramatically diminish the benefits of a diamond substrate *(Fig. 7)*.

GaN-ON-DIAMOND JUSTIFICATION

Diamonds offer lots of promise for GaN PAs. Although the PAs create very small hotspots, diamond spreads heat equally in all three dimensions. Thus, for a very small hotspot, diamonds are particularly effective. Companies like Raytheon and TriQuint (now Qorvo), with funding from DARPA, have researched the potential benefits of diamond substrates *(Fig. 8)*.

"Raytheon demonstrated that the space between the GaN-on-diamond gates can be reduced by as much as 4X, with the device running at comparable temperatures as with GaN-on-SiC mate-

GAN-ON-DIAMOND COULD REDUCE THERMAL NOISE

CVD DIAMOND SUBSTRATES can dramatically reduce the thermal energy near signal-conditioning and amplifying transistors. This reduction, in turn, may significantly lower a signal's thermal noise. Applications from telecommunications to EW and SIGINT can benefit from high-powered, low-noise devices.

For example, the amount of noise introduced by power amplifiers limits the latest modulation techniques at high constellation levels. This burden is usually borne by the receivers. In addition, there's demand for low-noise amplifiers (LNAs) that can handle a wide range of voltages, powers, and frequencies.

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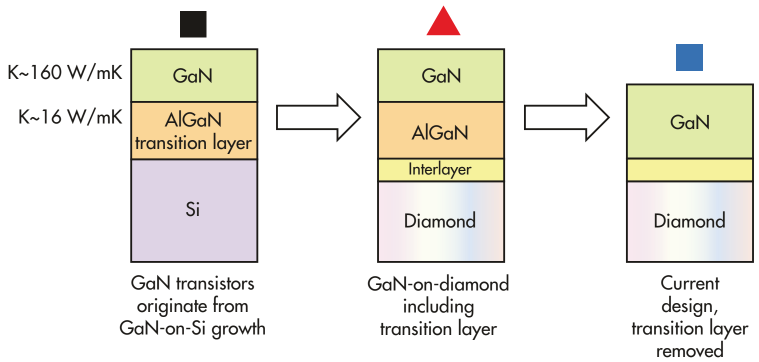
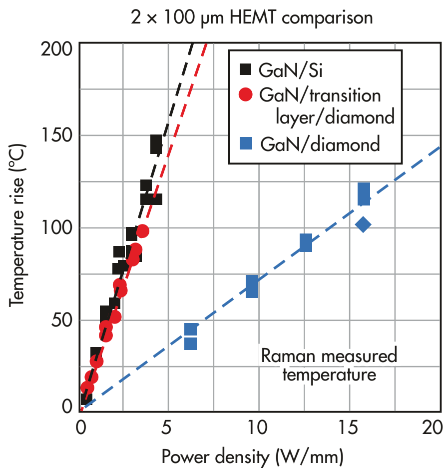


7. The process of eliminating the layers between GaN and diamond dramatically increases a stack's thermal-transfer properties.



rials," says Bolliger. Reducing thermal resistance near a PA's transistors can provide headroom to reduce the device size. Bolliger continues, "Also, the peak power and peak temperature are nearly the same. The enhanced thermal conductivity led to certainly more than a three times increase in power density."

Several advantages to GaN-on-diamond outweigh some of the initial cost considerations. For instance, the watts-per-meter of wafer space is much lower with a diamond substrate. The smaller chip leads to much less in handling costs, and could translate to smaller device sizes. Overall, higher performance in a smaller space could substantially lower system costs.

"As TriQuint's tests of RF performance of GaN-on-diamond to GaN-on-SiC show, GaN-on-diamond doesn't require a sacrifice in performance," says Bolliger. In addition, diamond negligibly changes shape under a wide thermal range, which benefits optical applications *(Fig. 9)*. This lack of thermal expansion and contraction cycles could reduce device wear.

Bolliger adds, "Secondly, in dc reliability tests compared with GaN-on-Si, we ran devices from both materials for many hours at 200°C. Neither the GaN-on-Si nor the GaN-on-diamond devices failed, so we cranked up the temperature to 350°C and the GaN-on-diamond devices still ran strong for over 1000 hours, while the GaN-on-Si devices began to degrade over the same time period."

The benefit of lowering a device's thermal resistance is that manufacturers can choose between a few optional enhancements. For example, they can run devices at lower temperatures and double their lifetime. Or, they can run the devices at higher power and at the same temperature. Device manufacturers can even run the device hotter, at similar lifetimes, and spend less on device cooling costs.

Because the hydrogen and methane gases are relatively inexpensive, only two main costs are incurred when creating CVD diamonds. The most significant costs lie in the equipment and energy used to strip the carbons from the gases. The plasma reactors need very consistent power over the hours and days it may take to grow a diamond wafer. Few locations have the electrical infrastructure to support such an operation. Growing large amounts of diamond material requires multiple reactors, so the costs scale linearly with the demand of CVD diamond.

CVD DIAMOND MEETS RESISTIVES

Like GaN PAs, high-power and high-frequency resistives are limited by thermal challenges. For resistors and attenuators, most of the energy lost is dissipated as heat. Removing this heat typically increases the size, weight, and cost of the resistive, as well as the surrounding assembly *(Table 3)*.

"Over the last decade, we came to realize that RF passive component technology has matured significantly," says Kai Loh, Senior Product manager for EMC Technologies and Florida RF Labs. "Though there are techniques for enhancing component performance in certain bands, the manufacturing techniques are mostly matured."

To avoid being the limiting factor, however, resistives have to keep pace with the performance of other components in an RF assembly. In response, Loh says, "We came to the conclusion that innovation would have to come through materials. As we analyzed material options, we came to CVD diamond as the ideal platform for next-generation resistives."

DIAMOND AS A SEMICONDUCTOR

WHEN CONSIDERING CVD diamond's impressive properties as a substrate, one wonders how it could be used as a semiconductor. Research into development of synthetic diamond as a semiconductor material revealed it to have a very wide bandgap and very low parasitics. Its other material benefits all point to diamond's potential as a high-performing semiconductor. Due to a lack of applications and high cost, however, few organizations are working on advancing the material for future use.

TABLE 4: SUBSTRATE MATERIAL COMPARISON FOR THIN-FILM RESISTORS

Device	82-3031	82-7176	CT1310D
Substrate material	Beryllium oxide	Aluminum nitride	CVD diamond
Substrate thickness (mm)	1.016	1.016	0.381
Length (mm)	5.842	4.064	1.727
Width (mm)	3.048	3.302	1.727
Area (mm)	0.711	0.5334	0.127
Capacitance per watt (pF/W)	0.305	0.1778	0.076

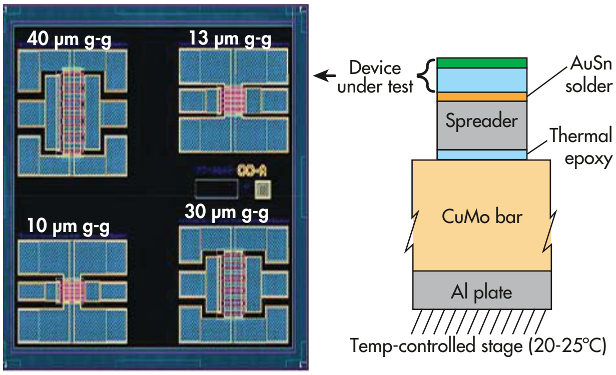
* Data from EMC Technology

Although conventional materials may be cheaper, CVD diamond has roughly 6X higher thermal conductivity than beryllium oxide (BeO) *(Table 4)*. In addition, it outperforms aluminum nitride (AlN) by about 7X or 8X. Conventional materials cannot conduct heat away quickly enough, which usually leads to a thermal bottleneck. Thermal conduction away from the part is also crucial for the part's operational lifetime and reliability.

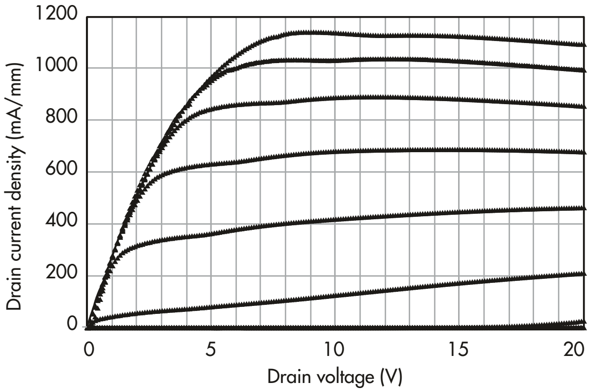
A resistor's power-handling capability depends on size. "A 0.25- by 0.25-in. resistor using traditional materials can be shrunk to a 1310 diamond chip capable of handling 150 W," says Loh. Using CVD diamond, the size of a resistive chip can be reduced. Loh adds, "To make a resistor that can handle 300 W would take a 0.375-by-0.375 footprint. There is a 2010 resistor chip made with CVD diamond that can handle 300 W."

CVD diamond also helps enhance the electrical performance of resistives. The dielectric constant of a CVD diamond is much lower than other materials, which reduces the parasitic capacitance *(Fig. 10)*. For thin-film resistors, this leads to higher-frequency operation.

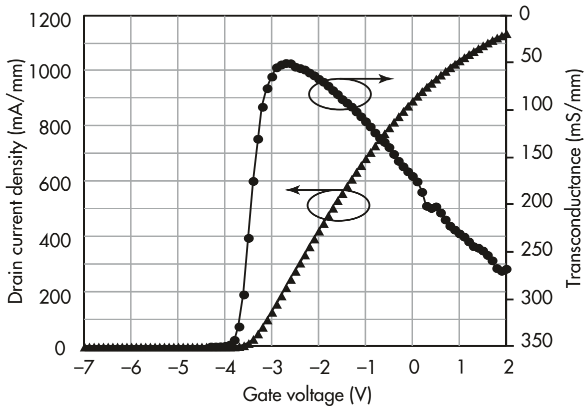
Another benefit of smaller resistive components is their decreased susceptibility to CTE mismatch issues. The hardness and tensile strength of diamond reduces the likelihood of cracking or fracturing under high CTE mismatch stresses.

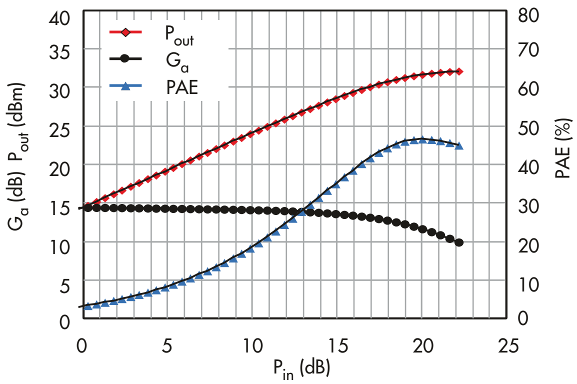


8. Micro-Raman measurements are used to measure the temperature at the optically accessible locations on the GaN-on-diamond HEMTs.



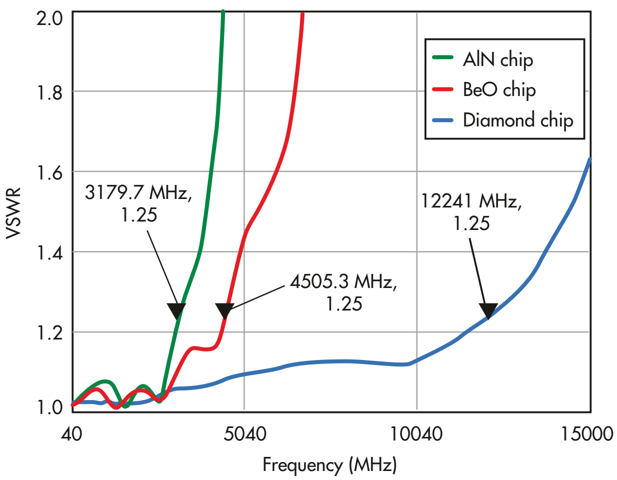
9. A DARPA-funded project led to the development of a 10-GHz, GaN-on-diamond power amplifier with 7.9 W/mm of power density at less than 46% PA efficiency.





The combination of small size and higher-frequency performance opens up opportunities for satellite-communications and telecommunications applications, such as point-to-point radio and backhaul. In addition, diamond resistives are seeing increased adoption in weight- and space-constrained applications. Examples include phased-array radars, Wilkinson power dividers, and combiners, which require many resistives (thus increasing both weight and volume). However, space applications might be the most weight- and volume-critical, where an estimated $10,000 to $100,000 is paid per pound of payload.

"At higher volumes, there is roughly a 30% cost difference between diamond and conventional passives," says Loh. "Though more expensive initially, in practical applications there is an opportunity to realize reduced resistive real estate and reduce the envelope size of the system." Potentially, these reductions could lead to value that is beyond what would be saved in the up-front cost of materials. Loh continues, "Additionally, the 30% figure is comparing standard components to standard components. If high reliability or space testing is involved, the screening costs are the same."



10. The extreme low capacitance per area of a diamond-chip thin-film resistor leads to very low VSWR ratings over a wide range of frequencies.

In summary, using CVD diamond as a heat spreader or substrate for active components and resistives has tremendous performance-enhancing potential in terms of increased power density, decreased size/weight, or higher reliability. Though the cost of CVD diamond may limit the material's penetration into many high-volume, low-cost markets, reasonable justifications can be made for those added system-level costs in high-performance markets. Further research and development could eventually lead to lower-cost CVD diamonds and even diamond-as-semiconductor. Undoubtedly, the diamond's footprint will continue to grow in high-performance RF applications. mw

DIAMOND IN OPTICS

OPTICALLY, DIAMOND CAN be transmitted over a very broad range of frequencies, including infrared (IR). For applications with high-powered lasers, a lens must be able to handle a large amount of power without changing shape or expanding. CVD diamond is well-suited to this application as well as others. However, high costs and a lack of mainstream applications may hinder diamond research.

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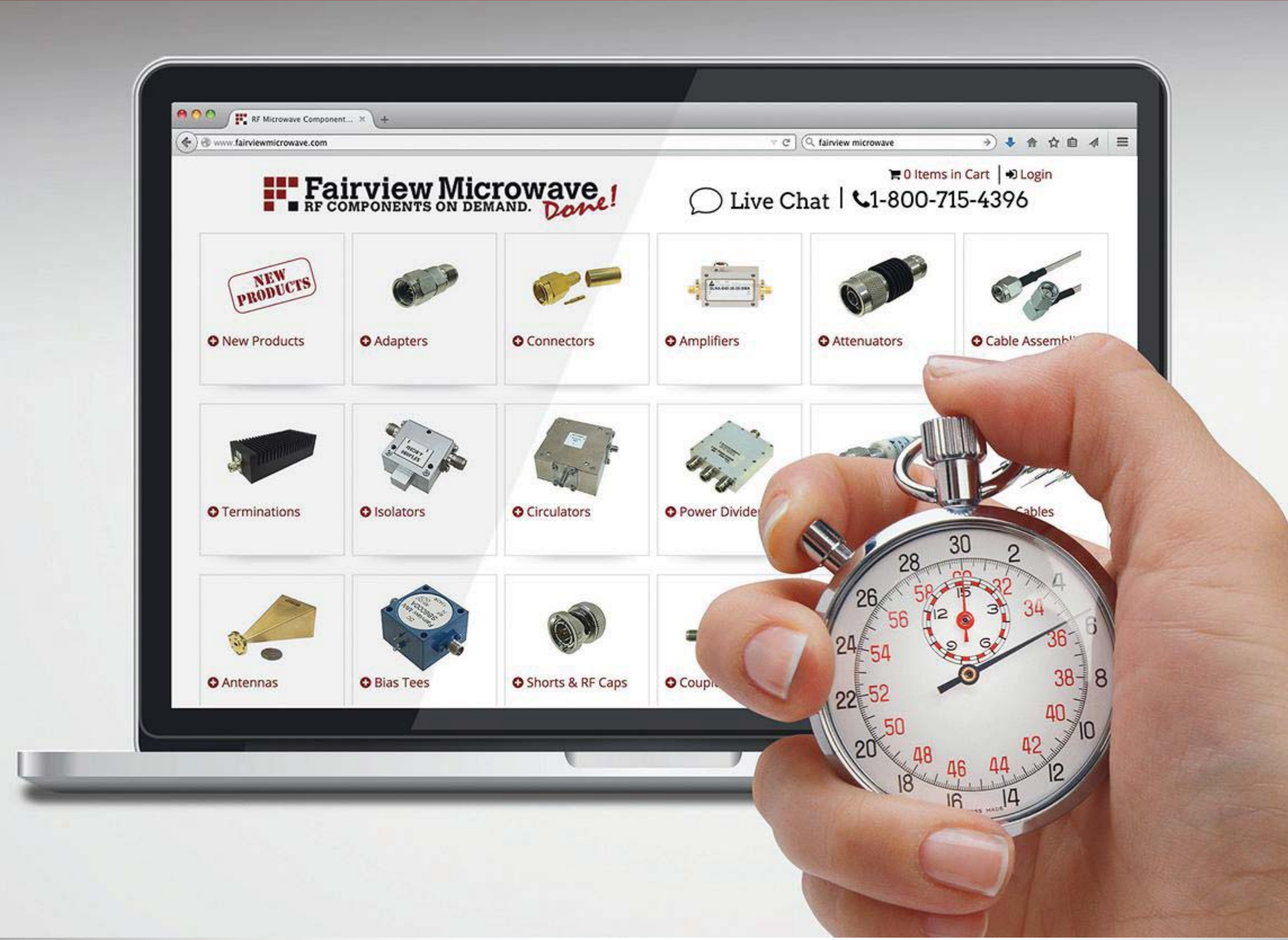

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JEAN-JACQUES DELISLE | Technical Editor

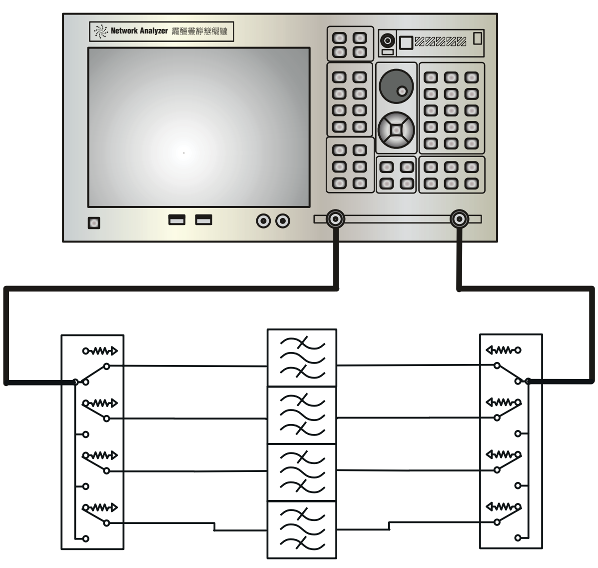
6 Degrees of Microwave and RF/Microwave Switch Separation

The RF/microwave switch, a fundamental component in many telecommunications, automated test and measurement, and electronic-warfare systems, helps reduce assembly complexity and cost.

BEFORE ELECTRONIC CONTROL and actuation, mechanically actuated RF switches were used to re-route RF energy to different subsystems. Out of necessity, these switches were often custom, expensive, slow, and prone to failure. But they could handle significant amounts of RF energy.

Maturation of electronic actuation and control led to RF switching with faster, more reliable electromechanical switches. Nonetheless, electrically actuated switches still were limited in their ability to handle high frequencies, due to limits in the mechanical tolerances of fabrication technology. In the 1950s, solid-state switches emerged when it was found that semiconductor materials could be used to channel RF energy. These switches were notably smaller and faster and could operate at much higher frequencies.

In the years since, a growing number of applications have benefited from higher-performance, smaller, and more integrated RF switches *(Fig. 1)*. Such demand has driven advances in solid-state and electromechanical materials and fabrication technologies. The latest switches from these two groups are reaching ever-smaller sizes, greater switching speeds, lower costs, and higher frequencies.



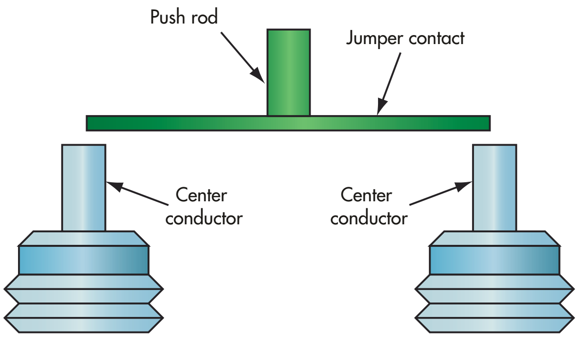
1. RF/microwave switches are used in testing complex multipath devices, antenna-array applications, telecommunications, and more.

1. ELECTROMECHANICAL SWITCHES

As the successors of purely mechanical switches, electromechanical switches use electrical actuators to make a physical connection between RF-path conductors. These RF paths can be waveguides, or coaxial or stripline transmission lines. The electrical actuators are often small solenoids connected to insulating plungers *(Fig. 2)*. When force is applied to a metallic member, the RF paths are connected. High-performance electromechanical RF switches, which benefit from enhanced machining technologies, can reach into the millimeter-wave frequencies with very high isolation and very low insertion loss. Electromechanical switches also excel in the areas of high-power handling, linearity, and low harmonics. In addition, they exhibit no compression region. As a function of the electrical actuation and mechanical connection design, electromechanical switches are limited to tens of milliseconds in the highest-precision designs. Any contaminants in the electromechanical switch can also reduce device performance *(Fig. 3)*.

2. RF MEMS SWITCHES

Technologies that can create extremely small and high-tolerance mechanical features have been developed to overcome the



2. Coaxial electromagnetic switches use an insulating push rod, which is attached to a transmission-line electrical connection between two coaxial lines.

limitations of traditional machining. Known as microelectromechanical systems (MEMS), they use processing that's similar to semiconductor device fabrication. MEMS devices can be made smaller, lighter, and more precise with the potential to be integrated alongside control electronics.

These new techniques have led to microwave and millimeter-wave devices that are less prone to mechanical wear, vibration, and repeatability issues. They also suffer from less parasitic effects, making them a more ideal solution for millimeter-wave applications. The two most common typologies of RF MEMS switches are ohmic and capacitive contact switches.

Using capacitive contact typology, MEMS fabrication techniques have been implemented to develop commercially available switches that operate into the low millimeter waves. MEMS switches are much faster than traditionally manufactured RF switches, but have yet to reach the speeds of PIN-diode or even FET-based switches. For some applications, however, the cost reductions and power savings derived from RF MEMS switches make them a viable alternative.

Ohmic switches have previously been seen as less reliable and more costly than capacitive contact switches, hindering their adoption. But, enhanced RF MEMS fabrication capability has made ohmic contact switches become more realizable. Instituting these new fabrication capabilities helps push the ohmic contact typology toward lower insertion loss and greater isolation and linearity.

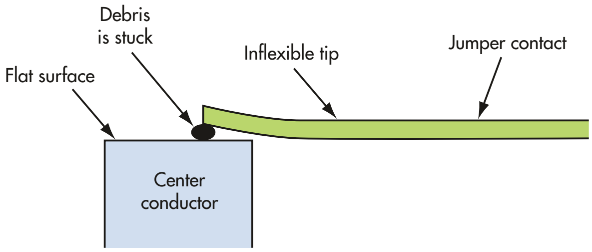
3. FIELD-EFFECT-TRANSISTOR (FET) SWITCHES

Dominating the realms of FET switches is the heterostructure FET (HFET) or high-electron-mobility transistor (HEMT) using gallium arsenide (GaAs) and aluminum gallium arsenide (AlGaAs). The heterostructure technology increases the FET switch's upper-frequency response *(Fig. 4)*.

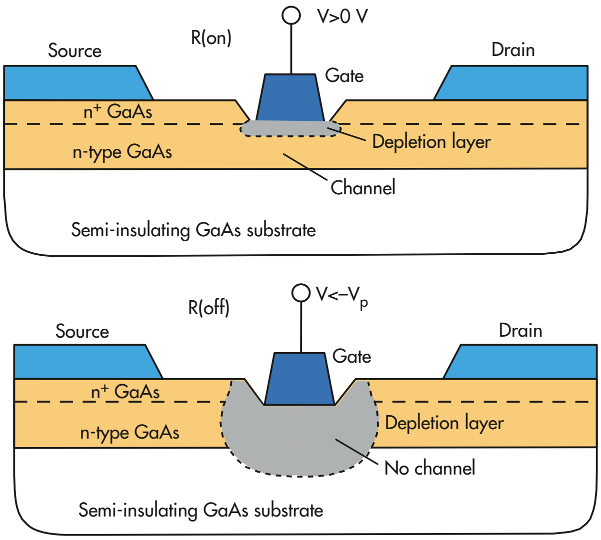
FET-based switches exhibit high isolation at low frequencies and operation down to direct current (dc). When the transistor is in reverse-biased condition, resistance from drain to source is extremely high. At high frequencies, the parasitic capacitance between the drain and source degrades the switches' isolation. To note, the FET's parasitic capacitances lead to switching speeds in the tens of nanoseconds. Yet hundreds of microseconds of additional gate lag prevent faster switching.

The signal path or on resistance of a FET switch is generally high enough to reduce insertion-loss performance compared to other switch technologies. High on resistance tends to negatively impact insertion loss. In addition, the voltage-controlled on resistance is very stable and repeatable. Such voltage control leads to low current consumption for switching, which in turn fosters low-power operation.

Advances in silicon-on-insulator (SOI) technology have produced FETs that perform at higher frequencies while retaining low cost and silicon-based CMOS integration. SOI exceeds GaAs in terms of power handling and electrostatic-discharge (ESD) survivability. For example, SOI-based switches can integrate control electronics and memory on the same substrate as the FETs. Recently, RF SOI switches reached performance levels like that of GaAs-based switches, leading



3. Electromagnetic switch performance can suffer from debris caused by metal wear, oxidation, and contamination.



4. Field-effect-transistor (FET) -based switches use an input voltage to create a region depleted of carriers. In doing so, they can "pinch off" the conductive channel within the device.

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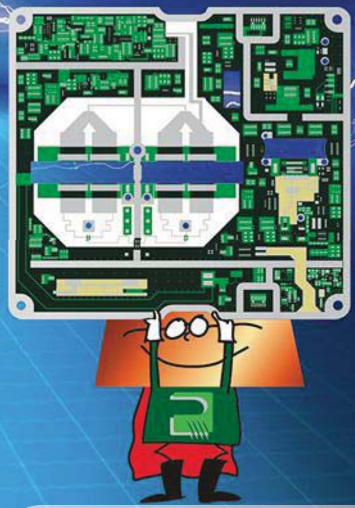
6.15 Dk High Frequency Laminates



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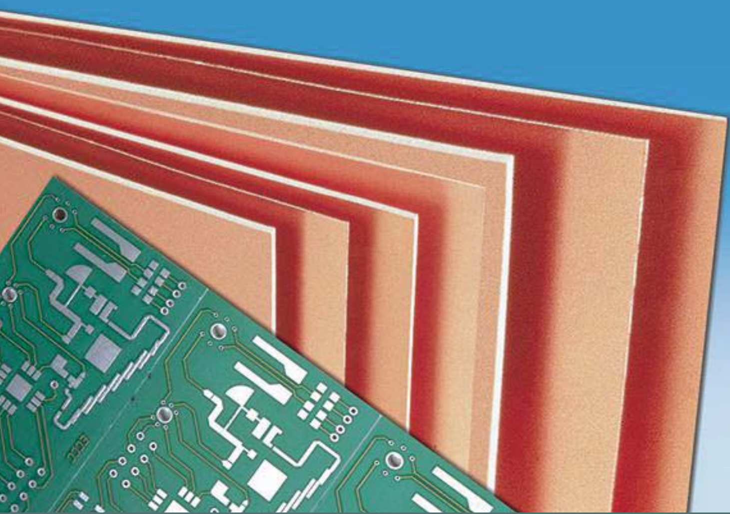
- Low fabrication cost

Ease of Fabrication

- Ideal for multilayer circuits
- Suitable for automated assembly lines
- Processes similar to FR-4
- Lead free, RoHS compliant



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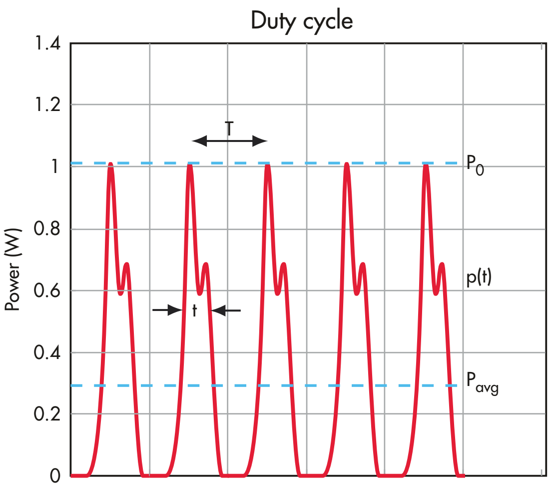


5. RF stress and damage to a switch can be caused by high instantaneous peak power or a prolonged power level, which is lower than the peak power-handling level.

to their extensive use in high-volume applications (e.g., cellular handsets).

TABLE 1: RF SWITCH COMPARISON				
Switch type	Electro-mechanical	Solid-state		
		FET	PIN	Hybrid
Frequency range	DC to max frequency		1-10 MHz to max frequency	From kHz
Insertion loss	Low	High	Medium	High
Isolation	Good across all frequencies	Good at low-end frequencies	Good at high-end frequencies	
Return loss	Good			
Repeatability	Good	Excellent		
Switching speed	Slow	Fast		
Settling time	Slow	Good <350 microseconds	Excellent <50 microseconds	Good <350 microseconds
Rise/fall time	Milliseconds	Microseconds	Nanoseconds	Microseconds
Switching time on to off	Milliseconds	Microseconds	Nanoseconds	Microseconds
Power handling	High	Low		
Operating life	Medium	High		
ESD immunity	High	Low	Medium	Low
Susceptible to	Mechanical vibrations	Temperature extremes and RF power extremes		

TABLE 2: COAXIAL CONNECTOR TYPE FREQUENCY LIMITS			
Frequency (GHz)	Connector type	Frequency (GHz)	Connector type
0.1	BNC TWINAX	12.4	SSMB, ZMA
0.2	TWINAX, FME	18	SMA, APC-7, 7 mm, QMA, N-P, TNC-P, ZMA-P
0.3	UHF	22	OSP
1	LC, 1.6/5.6, BNC-75, TNC-75	26.5	SMA-P, 3.5 mm
1.5	N-75	28	OSSP
2	10-32	34	3.5 mm-P
2.4	MINI UHF	38	SSMA
3	F	40	2.92mm, K, SMP, GPO, OSMP, OS-50P
4	BNC, SMB-75, MINI SMB-75, HN, SMB, FAKRA	50	2.4mm
6	MMCX, OSX, PCX, MCX, MCX-75, UMCX, 7/16, OSMT	60	MINI SMP, V
9	GR874	67	1.85 mm
10	1.0/2.3, SMC	110	1 mm
11	C,SC, N, TNC		

4. SOLID-STATE SWITCHES: PIN-DIODE SWITCHES

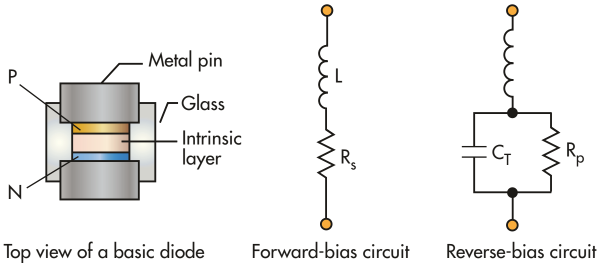
Unlike FET switches, a PIN diode acts as a variable resistance with a low on resistance (usually below 1 Ω) and a high off-state resistance (generally in the tens of kilohms). The intrinsic region's thickness dictates the attenuation of the lower frequencies and the power necessary to forward-bias the diode. Variations in the intrinsic layer thickness can change the lower frequency capability of the diode from tens of kilohertz to tens of megahertz at the lower limit.

The characteristics of the semiconductors used—silicon (Si), GaAs, AlGaAs, and now gallium nitride (GaN)—dictate both the frequency and power-handling capability of a switch constructed from PIN-diode components. A PIN-diode switch's diodes also must be dc-biased, which requires capacitive, inductive, and RF choke components. The circuit typology—either series or shunt—dictates the isolation, insertion loss, and bandwidth operation of the PIN-diode switch.

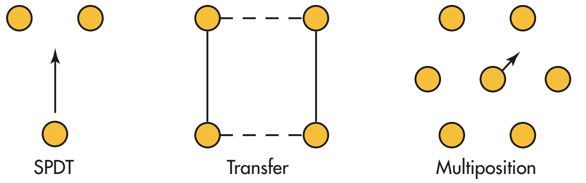
Series PIN-diode switches often display low isolation with wide bandwidths, which are only limited by the dc blocking capacitors and biasing inductors. The bandwidths of shunt PIN diodes, on the other hand, are limited by the transmission lines used to interconnect the common junction to each PIN diode.

The shunt typology generally exhibits much higher isolation, though, which requires a tradeoff of insertion loss. Often, hybrid typologies are used to deliver a balance of isolation, bandwidth, and insertion loss depending on the application.

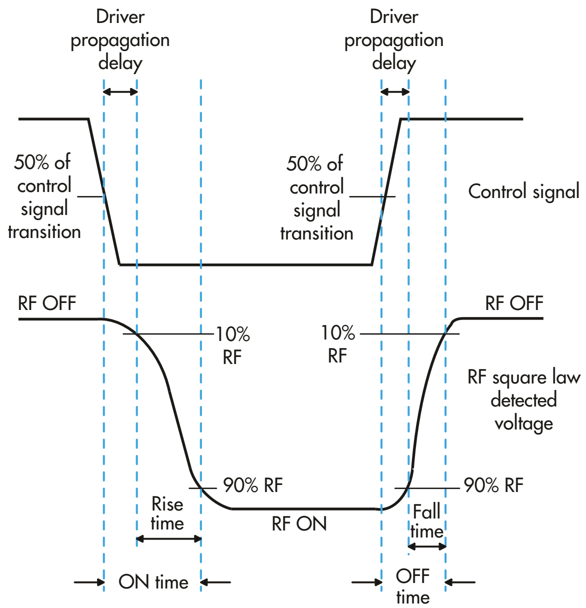
PIN-diode switches are generally a low-cost RF/microwave switching option ranging from milliwatts to tens of kilowatts of average power handling, depending on size. As the frequen-



6. Diodes operate in a forward- or reverse-bias condition that exhibits different electrical behavior according to the bias.



7. The three main types of RF/microwave switch typologies—single-pole, double throw (SPDT), transfer, and multiposition—lend themselves to different applications, depending on the routing complexity of RF signals.

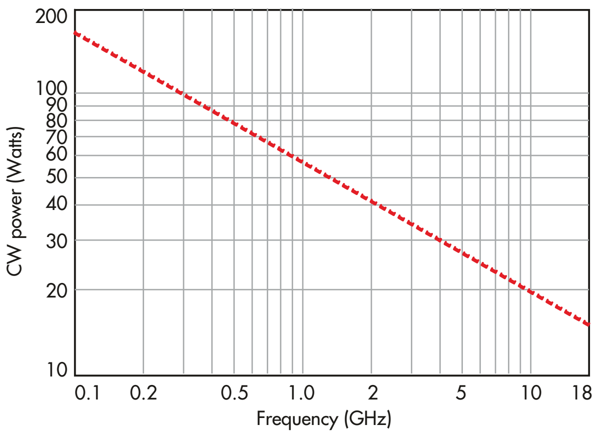


8. Depending on the application, the transient behavior of an RF/microwave switch can be critical in determining the switch technology and manufacturer.

cy increases, the average power-handling capability of these switches will decrease with size. PIN-diode switches differentiate themselves from FET-based switches in terms of their extremely fast switching speed, which can reach nanosecond transition times.

5. HYBRID SOLID-STATE SWITCHES

PIN-diode and FET switches have intrinsic benefits and drawbacks. Yet hybrid combinations of both technologies can potentially mitigate each technology's drawbacks. Such hybrid approaches are possible with certain semiconductors, and particular topologies will be able to leverage both bandwidth and isolation advantages.



9. The continuous-wave power-handling capability of switch devices decreases with increasing signal frequency.

For example, a hybrid switch combines series FET devices and shunt PIN-diode devices *(Fig. 6)*. Consequently, the PIN-diode switch's frequency response lowers to dc, while the high-end frequency isolation response of the FET-based switches receives a boost.

As shunt PIN diodes are used, there will be current draw in order to bias these diodes. This leads to slightly less power efficiency than with purely FET typologies. In addition, the RF paths and biasing should be isolated. Otherwise, the potential exists for RF leakage into the dc biasing path.

6. SWITCH TYPOLOGIES/CONFIGURATIONS

There are several different switch topologies and configurations. Failsafe and latching are the most common *(Fig. 7)*. Failsafe switches will return to the default state after the control signal is removed. Generally, solid-state switches are failsafe or normally open switches. The default position of the normally open switches is disconnected. In contrast, latching switches maintain the position that was last set after the control signals aren't present.

Aside from types of switches, RF/microwave switches will employ one of three main configurations. Single-pole, double-throw (SPDT) switches are used to route an RF signal input to two outputs or two outputs to a single input. Double-pole, double-throw (DPDT), or transfer switches, redirect the RF signal from two inputs and two outputs. And multiport switches, which have several output/input positions, redirect an RF signal from one input to more than three outputs or vice versa. These switch configurations can also be a sub-component of larger switch matrices to form a configurable RF path. mw

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Model #	Frequency (MHz)	Insertion Loss (dB) [Typ./Max.] ◊	Amplitude Unbalance (dB) [Typ./Max.]	Phase Unbalance (Deg.) [Typ./Max.]	Isolation (dB) [Typ./Min.]	VSWR (Typ.)	Input Power (Watts) [Max.] ▫	Package
2-WAY								
CSBK260S	20 - 600	0.28 / 0.4	0.05 / 0.4	0.8 / 3.0	25 / 20	1.15:1	50	377
DSK-729S	800 - 2200	0.5 / 0.8	0.05 / 0.4	1 / 2	25 / 20	1.3:1	10	215
DSK-H3N	800 - 2400	0.5 / 0.8	0.25 / 0.5	1 / 4	23 / 18	1.5:1	30	220
P2D100800	1000 - 8000	0.6 / 1.1	0.05 / 0.2	1 / 2	28 / 22	1.2:1	2	329
DSK100800	1000 - 8000	0.6 / 1.1	0.05 / 0.2	1 / 2	28 / 22	1.2:1	20	330
DHK-H1N	1700 - 2200	0.3 / 0.4	0.1 / 0.3	1 / 3	20 / 18	1.3:1	100	220
P2D180900L	1800 - 9000	0.4 / 0.8	0.05 / 0.2	1 / 2	27 / 23	1.2:1	2	331
DSK180900	1800 - 9000	0.4 / 0.8	0.05 / 0.2	1 / 2	27 / 23	1.2:1	20	330
3-WAY								
S3D1723	1700 - 2300	0.2 / 0.35	0.3 / 0.6	2 / 3	22 / 16	1.3:1	5	316
4-WAY								
CSDK3100S	30 - 1000	0.7 / 1.1	0.05 / 0.2	0.3 / 2.0	28 / 20	1.15:1	5	169S

▫ With matched operating conditions

HYBRIDS RoHS

Model #	Frequency (MHz)	Insertion Loss (dB) [Typ./Max.] ◊	Amplitude Unbalance (dB) [Typ./Max.]	Phase Unbalance (Deg.) [Typ./Max.]	Isolation (dB) [Typ./Min.]	VSWR (Typ.)	Input Power (Watts) [Max.]	Package
90°								
DQS-30-90	30 - 90	0.3 / 0.6	0.8 / 1.2	1 / 3	23 / 18	1.35:1	25	102SLF
DQS-3-11-10	30 - 110	0.5 / 0.8	0.6 / 0.9	1 / 3	30 / 20	1.30:1	10	102SLF
DQS-30-450	30 - 450	1.2 / 1.7	1 / 1.5	4 / 6	23 / 18	1.40:1	5	102SLF
DQS-118-174	118 - 174	0.3 / 0.6	0.4 / 1	1 / 3	23 / 18	1.35:1	25	102SLF
DQK80300	800 - 3000	0.2 / 0.4	0.5 / 0.8	2 / 5	20 / 18	1.30:1	40	113LF
MSQ80300	800 - 3000	0.2 / 0.4	0.5 / 0.8	2 / 5	20 / 18	1.30:1	40	325
DQK100800	1000 - 8000	0.8 / 1.6	1 / 1.6	1 / 4	22 / 20	1.20:1	40	326
MSQ100800	1000 - 8000	0.8 / 1.6	1 / 1.6	1 / 4	22 / 20	1.20:1	40	346
MSQ-8012	800 - 1200	0.2 / 0.3	0.2 / 0.4	2 / 3	22 / 18	1.20:1	50	226
180° (4-PORTS)								
DJS-345	30 - 450	0.75 / 1.2	0.3 / 0.8	2.5 / 4	23 / 18	1.25:1	5	301LF-1

◊ In excess of theoretical coupling loss of 3.0 dB

COUPLERS RoHS

Model #	Frequency (MHz)	Coupling (dB) [Nom]	Coupling Flatness (dB)	Mainline Loss (dB) [Typ./Max.]	Directivity (dB) [Typ./Min.]	Input Power (Watts) [Max.] ▫	Package
KFK-10-1200	10 - 1200	40 ±1.0	±1.5	0.4 / 0.5	22 / 14	150	376
KDS-30-30	30 - 512	27.5 ±0.8	±0.75	0.2 / 0.28	23 / 15	50	255 *
KBS-10-225	225 - 400	10.5 ±1.0	±0.5	0.6 / 0.7	25 / 18	50	255 *
KDS-20-225	225 - 400	20 ±1.0	±0.5	0.2 / 0.4	25 / 18	50	255 *
KBK-10-225N	225 - 400	10.5 ±1.0	±0.5	0.6 / 0.7	25 / 18	50	110N *
KDK-20-225N	225 - 400	20 ±1.0	±0.5	0.2 / 0.4	25 / 18	50	110N *
KEK-704H	850 - 960	30 ±0.75	±0.25	0.08 / 0.2	38 / 30	500	207
SCS100800-10	1000 - 8000	10.5 ±1.5	±2.0	1.2 / 1.8	8 / 5	25	361
KBK100800-10	1000 - 8000	10.5 ±1.5	±2.0	1.2 / 1.8	8 / 5	25	322
SCS100800-16	1000 - 7800	16.8 ±1.5	±2.8	0.7 / 1.0	14 / 5	25	321
KDK100800-16	1000 - 7800	16.8 ±1.5	±2.8	0.7 / 1.0	14 / 5	25	322
SCS100800-20	1000 - 7800	20.5 ±2.0	±2.0	0.45 / 0.75	12 / 5	25	321
KDK100800-20	1000 - 7800	20.5 ±2.0	±2.0	0.45 / 0.75	14 / 5	25	322
KEK-1317	13000 - 17000	30 ±1.0	±0.5	0.4 / 0.6	30 / 15	30	387

* Add suffix - LF to the part number for RoHS compliant version.
▫ With matched operating conditions

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Special Report

JEAN-JACQUES DeLISLE | Technical Editor

13 Key Considerations for Aerospace RF/ Microwave Devices

To ensure RF/microwave component reliability in aerospace applications, temperature and other environmental extremes need to take advantage of the latest technologies and well-studied standards.

BE IT AN AIRPLANE, DRONE, JET, SATELLITE, OR SPACECRAFT, aerospace platforms put their solid-state electronic components through an extreme range of temperatures and g-forces. Combine those factors with shock, vibration, and pressure changes, and the resulting environment makes it challenging for highly sophisticated RF/microwave devices to perform reliably. Future aerospace platforms will rely even more on RF/microwave telecommunications, geolocation, imaging, and electronic-warfare (EW) technologies. Fortunately, a wealth of ruggedization standards and qualifications have been developed since radios first took to the air. Now, new methods of employing analysis tools in conjunction with accelerated tests could take RF/microwave aerospace systems to the next level of reliability.

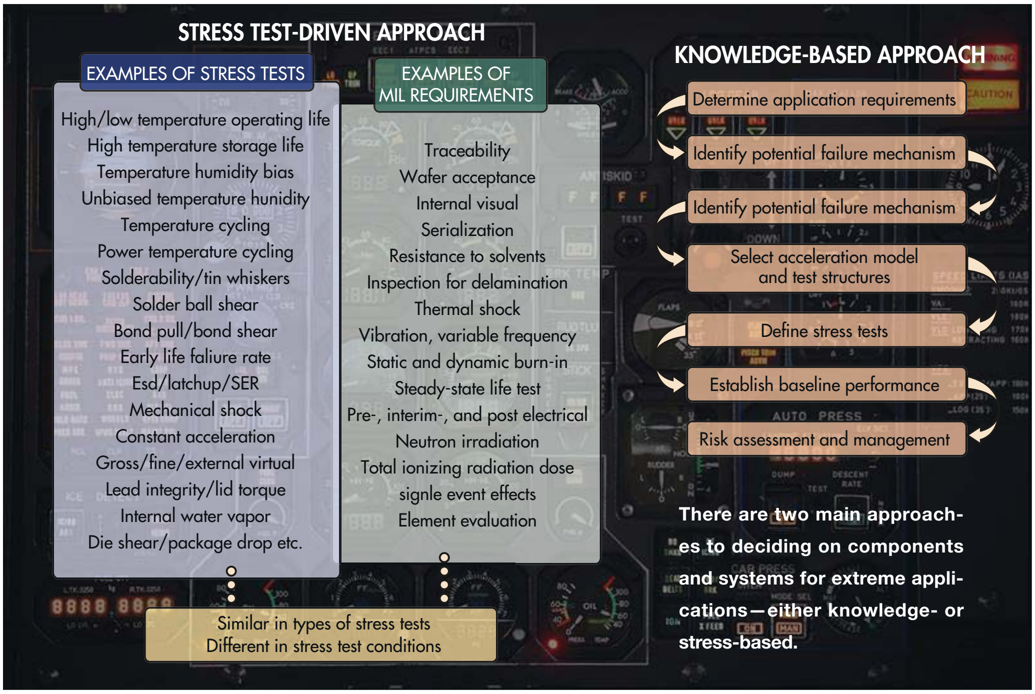
BREAKDOWN CONSTRAINTS

RF/microwave components in the aerospace channel have to be able to withstand extreme conditions, of course, but beyond simply functioning in survival mode, these components must continue to satisfy stringent performance criteria. RF/microwave components tend to be mission-critical. It is therefore necessary that these components be designed with breakdown constraints in mind.

1. SPACE-BREAKDOWN MECHANISMS

For RF/microwave technology designers who are familiar with space applications, the enormous differences in temperature and pressure are a given. Temperature operation ranges have been designed for, simulated, and predicted with a good level of accuracy. Though they are challenging, it also is possible to account for temperature extremes. Physical stressors, such as vibration, shock, and pressure differentials, are familiar enemies as well. A greater

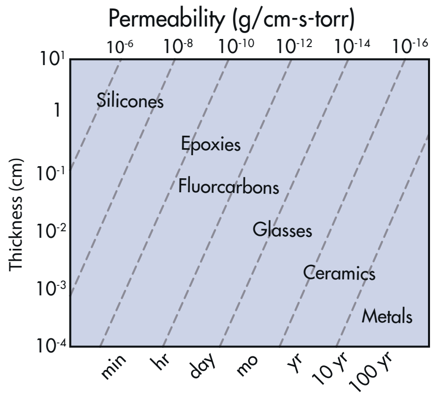
challenge is predicting unique material, radiation, and electrical phenomena, which can lead to component degradation and, later, system failure.



There are two main approaches to deciding on components and systems for extreme applications—either knowledge- or stress-based.

2. OUTGASSING

Many materials that are developed in a pressurized atmosphere trap various liquids and gases in their structure. When encountering a high-vacuum environment, these gases and liquids may begin to creep out of the material. Occasionally, this significantly changes the material properties. The level of outgassing exhibited by a material and its effects are difficult to model or simulate. Therefore, NASA has developed a database of materials and their estimated outgassing behavior through batteries of experiments.



Materials steadily allow liquids and gases to permeate when there is a pressure differential.

3. MULTIPACTION

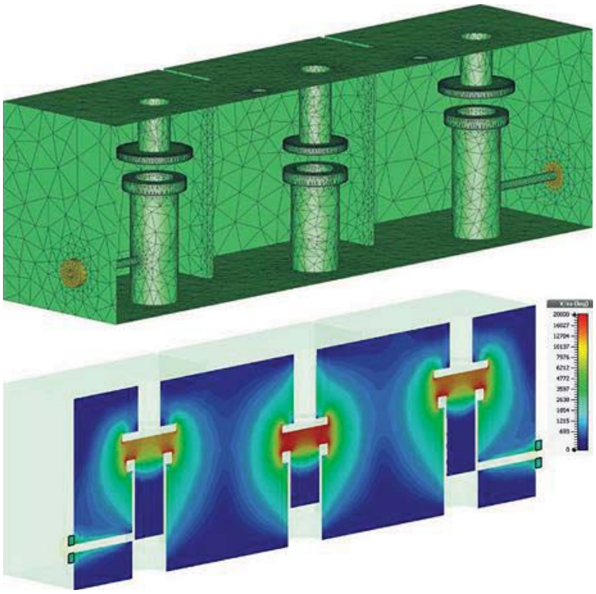
Hazardous-free electrons can become trapped in metallic structures under high-vacuum conditions—especially when these devices are open to radiation and electromagnetic field emission from celestial bodies. If they develop a resonant cascade with the RF signal, these free electrons are particularly troublesome for RF/microwave electronics. This effect occurs when high-energy electrons impact metallic structures with enough deposited energy to induce secondary electron emissions.

When resonant, these electrons can quickly cascade due to self-amplification. They will then create significant, and potentially damaging, electric discharge. The wall material can be characterized for its potential to induce secondary electron emission yield (SEY), which defines its potential as a space-grade material.

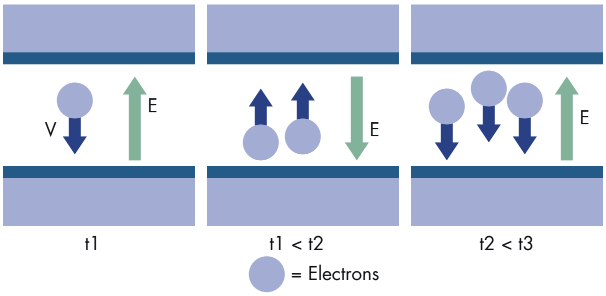
4. CORONA

Free electron emissions in space can also wreak havoc when interacting with the ionized atmospheric gas trapped with RF/microwave devices. If the energy of these electrons increases because of a spacecraft's RF/microwave electronics, the electrons can excite the gaseous molecules within the devices. If the energy of the excitation is high enough, additional electrons may be released. This local electron population growth could exceed the diffusion rate and subsequently cause coronal discharge of radiation.

Additionally, the high concentration of electrons could lead to RF reflections—potentially damaging the sensitive RF devices. Increased power density and component inte-



Multipaction can be induced in RF components that are unshielded from free space electron emissions.

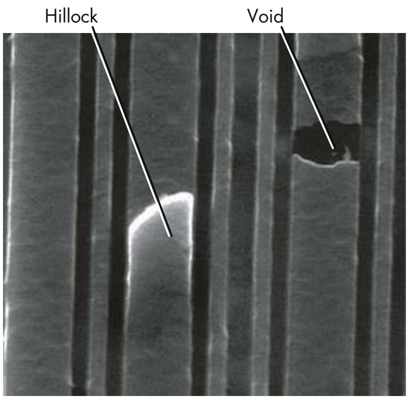


Amplified by the RF signal energy within a component's metallic channel, multiplication electrons can cause a cascade leading to discharge and damage.

gration also make RF/microwave assemblies more susceptible to corona effects.

5. SOLID-STATE-TRANSISTOR BREAKDOWN MECHANISMS

Because many RF parts are now solid state, these systems are subject to the breakdown mechanisms that are inherent to semiconductor technology. In most aerospace applications, RF/microwave devices need to be rated for survivability under all environmental conditions spanning several years and up to decades. Each solid-state failure mechanism must therefore be identified, designed against, and verified under the strictest standards.



Electromigration can cause adverse effects on the metallization of an IC, including breaks in the metal and metallic deformation.

6. STRESS MIGRATION

Hydrostatic stress gradients can drive electromigration, thus inducing voids in integrated-circuit (IC) metallization. This stress-induced-voiding (SIV) phenomenon can lead to cracks, fractures, and warping of the metallization layers, corrupting performance. Mechanical stresses, which arise from coefficient-of-thermal-expansion (CTE) mismatches, can add further stress to IC metallization. The end result is an increase in metallization failures.

7. ELECTROMIGRATION

Under high-current conditions, ions within a conductor can gradually travel in response to momentum transfer by electrons and diffusing metal atoms. Higher current density increases the likelihood of electromigration. As is the case with stress migration, electromigration can induce voiding-related failures.

8. HOT CARRIER INJECTION

When an electron or hole gains a sufficient amount of kinetic energy, it may be able to overcome the potential barrier at an interface. If the carrier is injected into the gate dielectric of a metal-oxide-semiconductor field-effect transistor (MOSFET), however, it may become trapped. As a result, the electrical characteristics of the device may be permanently changed. Hot carrier injection (HCI) is one of the most significant limiting factors affecting the reliability of a MOSFET device.

9. NEGATIVE-BIAS TEMPERATURE INSTABILITY (NBTI)

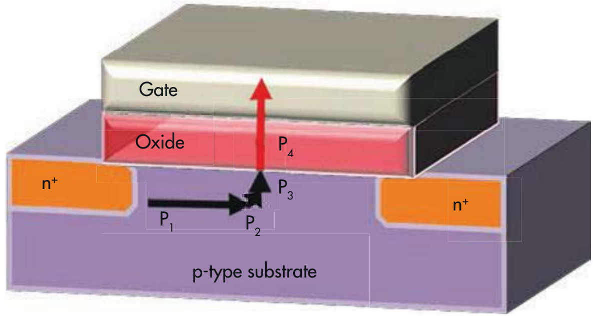
Also affecting MOSFETs, NBTI can lead to transconductance degeneration of the transistor. Over time and under negative voltage-bias conditions, the device's material property changes can result in increased threshold voltage. Both temporary traps and permanent interface traps can develop in the material, which induces silicon-hydrogen breaks. The migrating hydrogen can later merge with oxygen, leaving dangling silicon bonds and increasing threshold voltage. It is believed that nitrogen—used to retard boron penetration—may be responsible for increased NBTI in both p- and n-type MOSFETs.

10. TIME-DEPENDENT DIELECTRIC BREAKDOWN (TDDB)

When a steady voltage is applied across them, many high-performance dielectric materials experience time-related degradation. TDDB is thought to occur when conductive paths are formed through the gate-oxide substrate as electrons tunnel through the material. Higher densities of electrons tend to accelerate TDDB—an inevitability with MOSFETs. Accelerated statistical testing is used to develop reliability plots to predict TDDB failures.

11. MILITARY & AEROSPACE STANDARDS

Aerospace organizations have high reliability expectations. Therefore, many standards and qualifying tests have been developed to ensure that only high-reliability parts are used in



6. The "lucky electron model" is used to demonstrate a carrier traveling from within the depletion zone of a CMOS transistor and into the gate material.

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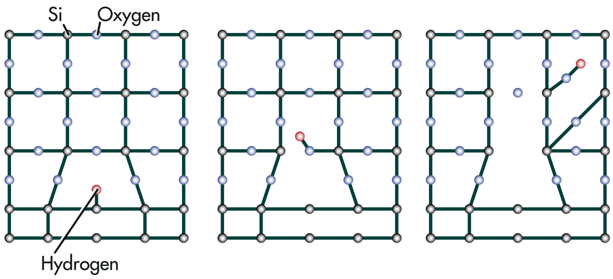
real systems. These qualifications cover virtually every component of an RF/microwave system with a battery of requirements.

For example, the U.S. Department of Defense has developed a wide range of "mil standards" to prevent the inclusion of unqualified parts. Additionally, NASA has performed many qualifying tests in order to recommend parts that are known to have performed well in prior space applications. Yet many part failures still occur, prompting greater investigation into how to effectively analyze and predict breakdowns.

12. SIMULATING RF BREAKDOWN

Testing for device breakdown vectors traditionally requires huge numbers of tests and many layers of qualifications. Rising costs and shrinking design cycles are hampering the deployment of the most effective technology available in real-world applications. In the hunt for methods to accelerate the analysis and prediction of breakdown mechanisms, designers are increasingly relying on advanced electromagnetic, mechanical, and environmental simulators.

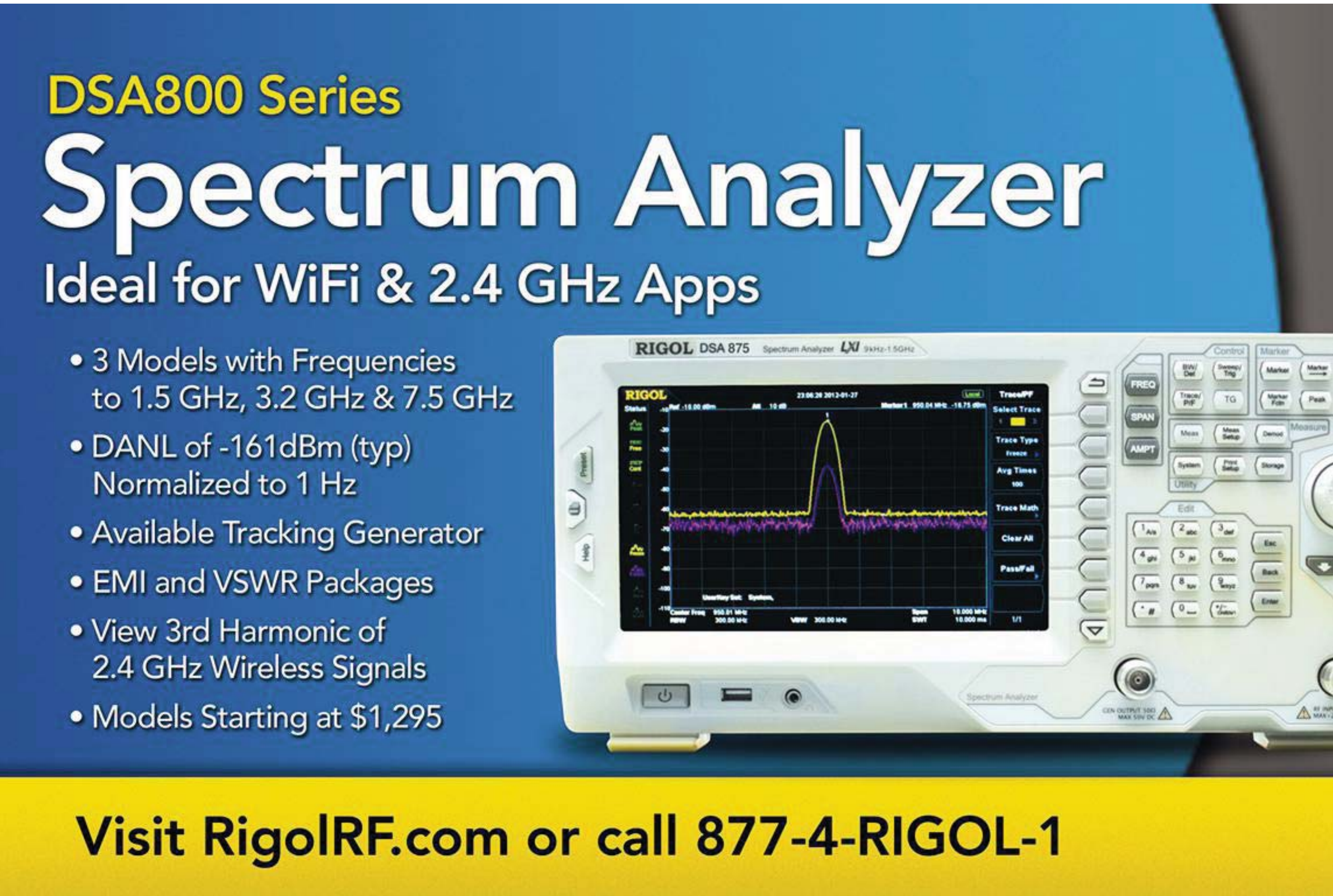
These integrated simulation environments, such as CST Studio Suite and ANSYS Multiphysics, have the potential to replicate real-world conditions. In some cases, the simulations can be more illuminating than real-world tests. The simulation environments can include models of different



Hydrogen atoms escaping from a silicon bond may leave silicon with a free-floating bond, thereby increasing the threshold voltage and degrading device performance.

physical interactions to reveal their impact on highly detailed three-dimensional structures. As a result, previously masked internal failure modes may become apparent. Such modes can be hard to detect/analyze in real tests, and could reduce the number of tests needed.

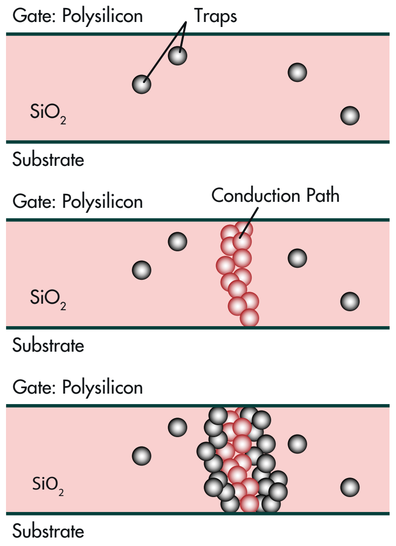
For example, a recent application note details the use of CST Studio Suite and Spark3D to predict multipaction and coronal discharge within a two-pole L-Band filter for space applications. A difference of roughly 25% was determined between the tested and simulated breakdown power levels. As shown, simulation tools may have reached a level of sophistication



necessary to reduce the need for costly, time-consuming qualification testing.

13. DARPA IRIS

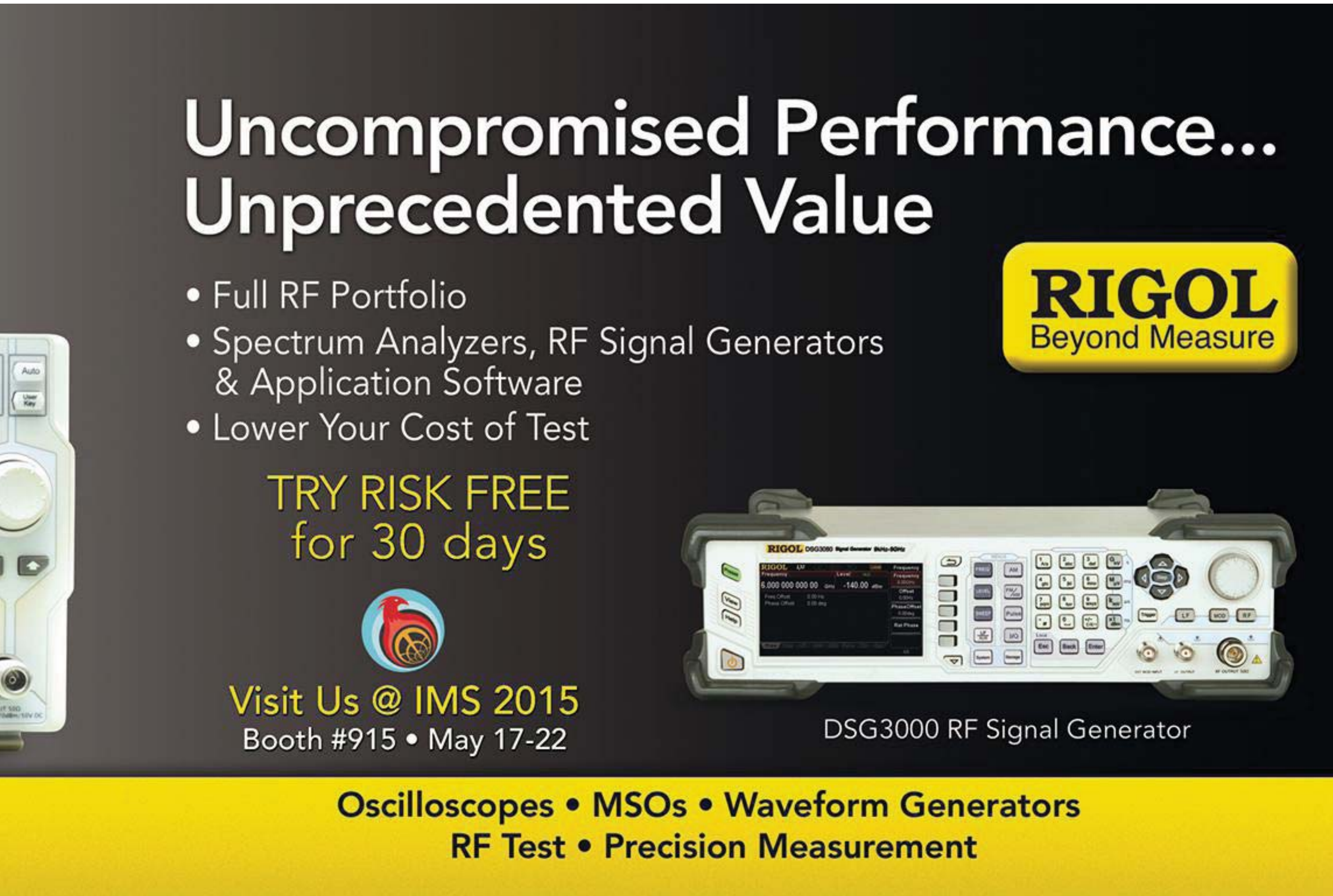
Even if all the right qualification steps are performed, the industry's reliance on offshore foundries for IC manufacturing still leaves room for counterfeiting and device performance below expectations. In light of such scenarios, DARPA has begun its Integrity and Reliability of Integrated Circuits (IRIS) initiative. This initiative is designed to develop techniques for determining the exact function and behavior of ICs. Through advanced imaging and the device recognition of complementary-metal-oxide-semiconductor (CMOS) circuits, DARPA hopes to use non-destructive computational methods to determine device connectivity. Beyond device modeling and analysis tools, other aspects of the initiative aim to derive reliability information from a small number of IC tests using unique diagnostic techniques.



The increase in traps due to thermal breakdown results in a bottleneck of trapped charges and eventually device failure.

The potential breakdown mechanisms in RF/microwave devices are increasing with the adoption of higher-performance criteria and more complex levels of integration. Rigorous qualification processes and testing can hopefully ensure that these complex devices operate reliably. Yet such steps are leading to significant cost and time requirements. In the meantime, counterfeiting and out-of-spec devices are contributing to assembly and system failures.

To combat these challenges, research and design techniques for aerospace devices are steadily being enhanced. For example, integrated simulation environments sporting electrical, thermal, mechanical, and other environmental models are now being leveraged to more rapidly gain insight into device failure modes. Additionally, DARPA and other organizations are actively developing advanced techniques to combat counterfeiting. Their goal is to confirm any component before use to avoid unexpected component-related catastrophes. mw



XUE-SHI LI | Researcher
Guangdong University of Technology, Guangzhou, PRC

KAI-DA XU | Researcher
EHF Key Lab of Fundamental Science, University of Electronics Science and Technology of China, Chengdu, PRC

ZHI-MIN LIU | Researcher
Guangdong University of Technology, Guangzhou, PRC

DONG-YUE ZHOU | Researcher

FEI DU | Researcher

METAMATERIAL Extends Patch

Patch antennas serve many different wireless applications, both for voice and data communications. When based on a metamaterial with reactive impedance surface (RIS), these antennas can achieve extended bandwidths of 1.70 to 5.26 GHz, and even more. By using an RIS metamaterial, a patch antenna with that bandwidth and peak gain of 7.24 dB was fabricated, with excellent radiation characteristics.

The antenna features a single structure of a one-layer substrate. It boasts a compact footprint that is only $0.408\lambda_0 \times 0.357\lambda_0$ at the lowest operating frequency (1.70 GHz). The antenna's wide bandwidth makes it well suited for a wide range of applications, including Bluetooth (2400 to 2480 MHz), Wibro (2300 to 2390 MHz), and WiMAX (3300 to 3700 MHz).

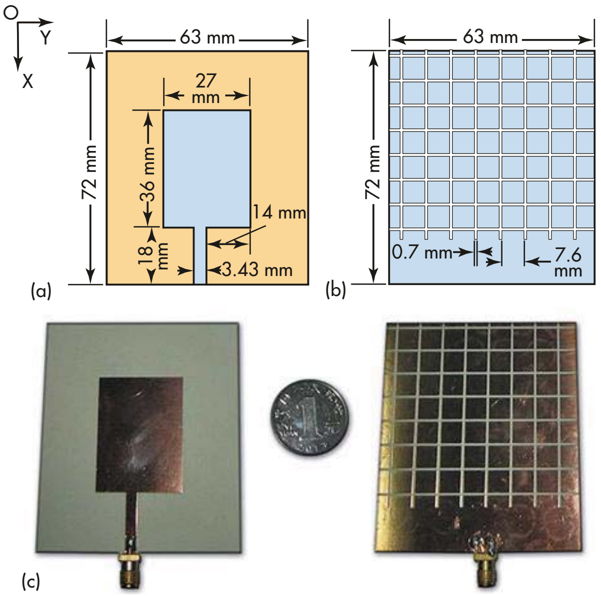
Metamaterials are essentially materials that began in the laboratory, rather than in nature. They are engineered to provide material characteristics that cannot be found in nature. Metamaterials include composite formulations of materials with improved electromagnetic (EM) or photonic characteristics or improved mechanical traits, such as enhanced flexibility.

Metamaterials can support a wide range of applications, and have been used as building blocks in antenna designs, as microwave absorbers, and even to counteract the effects of seismic waves during earthquakes, as a form of seismic material protection. The behavioral patterns of different types of metamaterials have been simulated on computers by means of three-dimensional (3D) models and with the aid of modern computer-aided-engineering (CAE) software programs, and the availability of these advanced EM metamaterials offers RF/microwave engineers a new frontier for the design of some traditional passive components, such as antennas, and the wideband patch antenna described herein.

Patch antennas based on metamaterials offer many benefits, including wide bandwidths, miniaturization, and well-controlled radiation characteristics. Because of their many benefits, metamaterial antennas have been used for many applications, including the aforementioned Bluetooth, Wibro, and WiMAX, as well as WCDMA operating from 1920 to 2170 MHz.[1,2] Still, improvements need to be made to these antennas, which typically involve complex structures with low gain as tradeoffs for the wide bandwidths.

To improve metamaterial antenna performance levels, novel metamaterial structures like multiple split ring resonators (MSRRs), reactive impedance surface (RIS) designs, partial reflective surface (PRS) designs, and mushroom-like electromagnetic bandgap (EBG) structures have been developed in recent years.[3-7] The composite-split-ring-resonator (CSRR) structures etched on the patch along with the substrate, and the ground plane can be optimized for miniaturization.[8]

To change an antenna from linear to circular polarization, the chiral patterned metamaterial placed over the radiation patch of an antenna was proposed.[9] The RIS has a simple pattern that is composed of periodic metallic patches. It is good for expanding the operating bandwidth and enhancing the radiation gain.[10,11] In recently published reports on metama-



1. The diagrams show (a) the top view and (b) bottom view of the antenna, along with (c) the fabricated antenna.

By leveraging a reactive impedance surface (RIS) metamaterial, this patch antenna design covers a wide bandwidth with high gain, serving a number of different wireless applications.

Antenna Bandwidth

terial antennas, an RIS-like pattern was etched on the ground with a one-layer substrate, and metamaterial inspired structures were being etched on the patch.[12-14]

This type of metamaterial antenna is a good example of extending the bandwidth while keeping the radiation performance attractive. It could be made even more valuable using a simpler structure while maintaining the relatively high operating frequencies (above 3 GHz). This is helpful for portable applications at lower frequencies, such as WCDMA, Bluetooth, or Wibro.

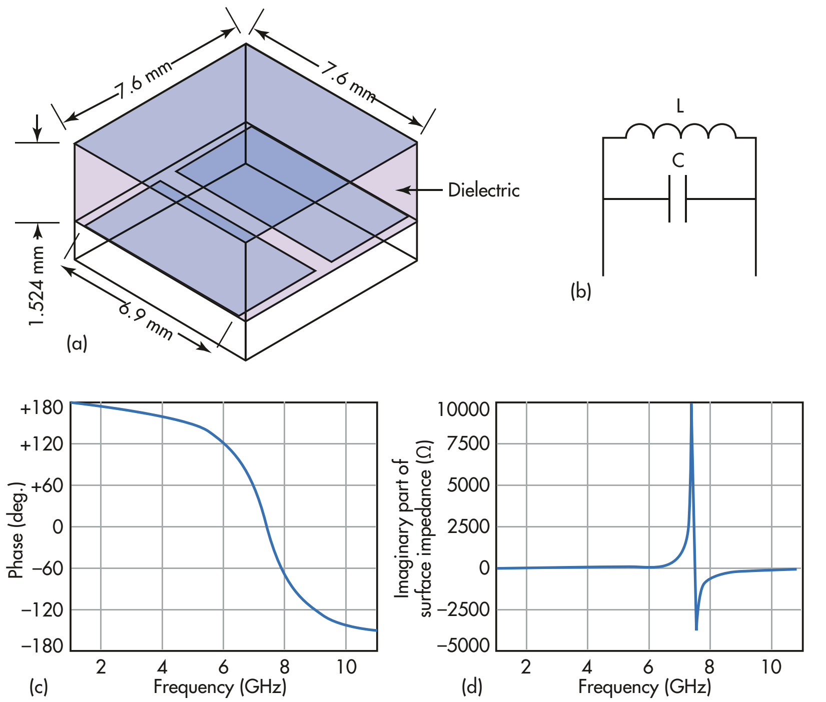
From a practical point of view, it might be desirable to simplify the antenna structure for ease of fabrication while shifting the operating frequency of the antenna in ref. 12 to a lower band. To meet these requirements, a one-layer patch antenna was developed based on the RIS metamaterial approach. The RIS structure is formed by means of an etched ground as well as the patch.

The metamaterial-inspired antenna employs simple structures since there is only one substrate layer and an intact patch applied in the antenna. The antenna achieves a wide operating frequency band at the lower frequencies. It is attractive for multiple-band applications, including WCDMA, WiMAX, Bluetooth, and Wibro.

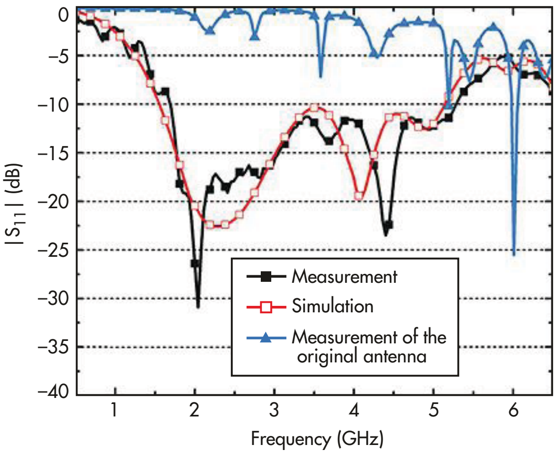
To achieve broadband coverage with a simple structure, an antenna was developed using RIS metamaterial. The antenna configuration is based on a one-layer patch design. It was constructed by etching strip gaps on the ground while leaving the patch intact, thus forming a RIS structure. The antenna is excited by a microstrip line that connects the patch and the input port.

The RIS metamaterial is employed to broaden the operating frequencies and enhance the radiation performance of the antenna via its reactive coupling with the patch and substrate. The antenna's performance was simulated by the electromagnetic (EM) High-Frequency Structure Simulator (HFSS) software from Ansoft (www.ansoft.com), and the simulations yielded results that were quite in keeping with the measured performance of the fabricated antenna.

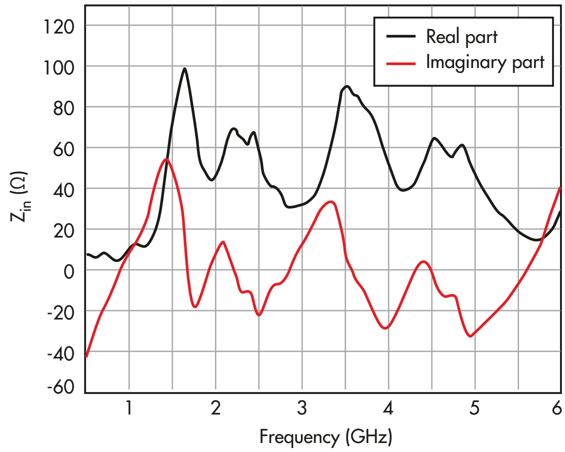
Figure 1 shows the structure of the antenna. To extend the operating bandwidth, the RIS is formed by the patch and the strip-gap etched ground. It is used to enhance the radiation performance as well as broaden the bandwidth of the antenna. It should be noted that there are some distinct differences between the antenna presented here and the antenna in ref. 12. The slots etched onto the patch



2. The diagram shows (a) a unit cell next to (b) a simple circuit model, (c) a phase response, and (d) a plot of the imaginary surface impedance.



3. These plots show measured and simulated reflection coefficients for the antenna.



4. These curves show the real and imaginary measured input impedance responses for the antenna.

of the antenna in ref. 12 have been eliminated while maintaining favorable performance. By using an intact patch, the structure of the antenna is further simplified, for ease of fabrication. In addition, the operating band is shifted towards lower frequencies than the design of ref. 12 (above 5.3 GHz) to cover the frequency bands of WiMAX, WCDMA, Bluetooth, and Wibro.

Figure 1(c) shows the fabricated antenna. It is formed on RO4350B printed-circuit-board (PCB) material from Rogers Corp. (www.rogerscorp.com) with a relative dielectric constant, $\varepsilon_r = 3.66$ in the z-axis (thickness) at 10 GHz. The thickness (h) of the substrate was fixed to be as small as 1.524 mm. The overall antenna footprint was only $0.408\lambda_0 \times 0.357\lambda_0$ at the lowest operating frequency of 1.7 GHz.

The strip-gap etched ground together with the antenna patch above it can be considered a type of metamaterial—namely, RIS. To analysis the influence of the RIS on the performance of the antenna, one unit cell of the RIS was built up and then the periodic boundary condition is applied on the four lateral walls of the unit cell. In this way, an infinite array of the unit cell forming the RIS structure is constructed for analysis. The dimension of the unit cell is the same as the RIS structure employed in the antenna of *Fig. 2*. The periodicity of the RIS structure is much smaller than the effective wavelength of the substrate.

The EM model of the unit cell is shown in *Fig. 2(a)*, while the circuit model of the unit cell is shown in *Fig. 2(b)*. Gaps between the small patches on the ground could be modeled as a capacitor placed at a distance h (1.524 mm) from the short-circuited, dielectric-loaded transmission line. The antenna patch that is placed at a distance h from the small RIS patch can be modeled as a lumped shunt inductor parallel to the capacitor.

Circuit analyses and EM simulations were performed to investigate the effects of the RIS structure on a plane wave impinging on it, much like the analysis performed in ref. 15. For the incident plane wave, the surface impedance of the RIS is found as:

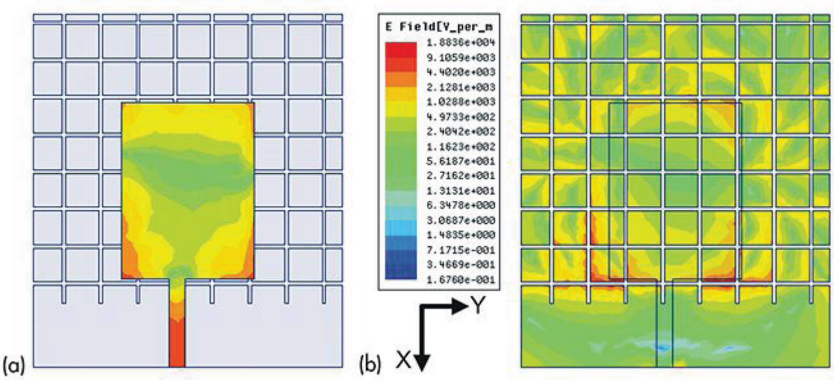
$$Z_{RIS} = j[(X_L X_C)/(X_C - X_L)] \quad (1)$$

where

$$X_L = Z_d \tan(kh) = Z_d \tan(k_0(\varepsilon_r)^{0.5}h \quad (2)$$

$$X_C = 1/(\omega C_{RIS}) \quad (3)$$

where



5. These simulated near-field distributions show (a) the E-field on the patch and (b) the E-field on the ground.

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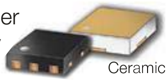

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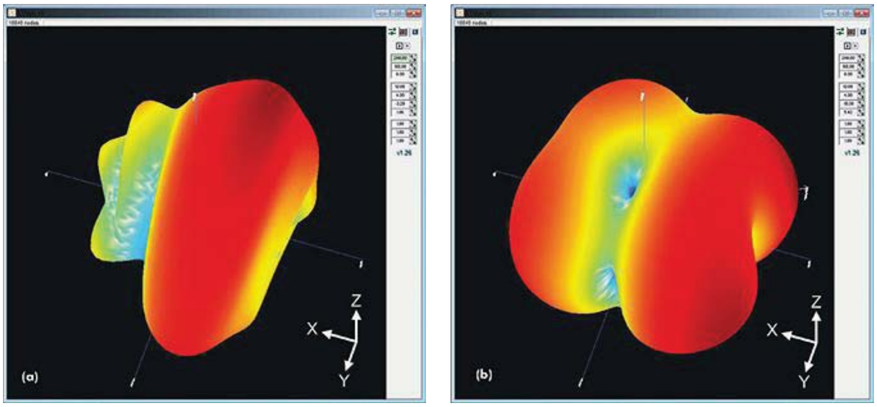


6. These plots offer far-field radiation patterns: (a) for the 3D gain pattern at 1.8 GHz, (b) the 3D gain pattern at 4.2 GHz, (c) the XOY and XOZ planes at 1.8 GHz, and (d) the XOY and XOZ planes at 4.2 GHz.

X_L and X_C are the reactances of the inductor and capacitor, respectively, shown in *Fig. 2(b)*. Detailed calculations of these two parameters can be found in ref. 15. The gap between the two adjacent small patches of the RIS structure mainly changes the capacitance value, while the dielectric permittivity and the substrate thickness mainly impact the inductor value. This combines for the resonant frequency of the RIS. The phase of the reflection coefficient of the plane wave was simulated and plotted in *Fig. 2(c)*.

The imaginary part of the surface impedance of the RIS structure was also simulated, as shown in *Fig. 2(d)*. As can be seen, the resonant frequency is located at 7.4 GHz. The RIS unit cell is inductive below the resonant frequency and capacitive above the resonant frequency. This is meaningful for the expansion of the operating frequency range of a patch antenna employing the RIS structure.

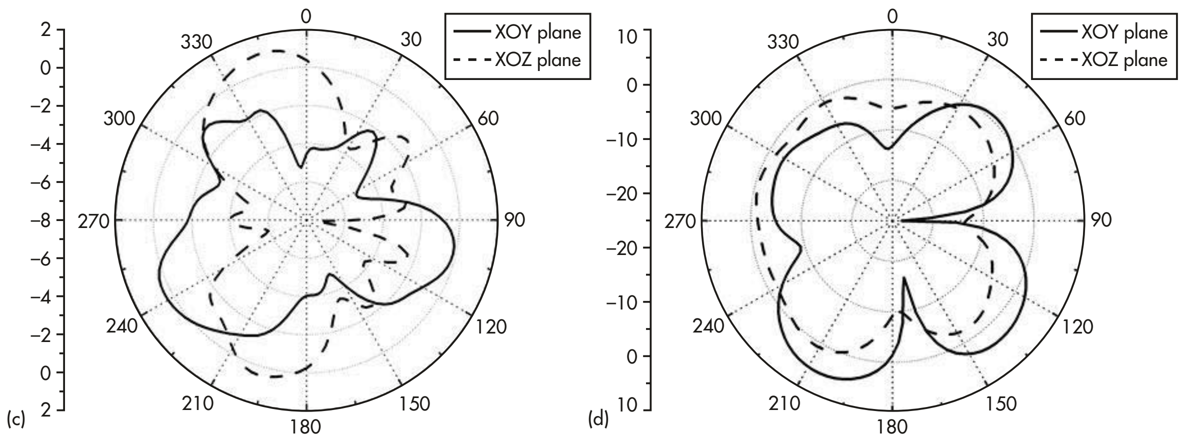
Since a patch antenna is capacitive below its resonant frequency, f_{patch}, by setting the resonant frequency of the RIS structure, f_{RIS}, higher than f_{patch}, the magnetic energy stored in the RIS structure compensates for the electrical energy stored in the near field of the patch antenna. This results in additional resonances at lower frequencies and a compact antenna size.

It should be pointed out that since the waves radiated by the patch are not plane waves and the number of RIS unit cells is finite, this analysis is just an approximation to provide physical insights into the mechanism of the RIS employed in the antenna.

Figure 3 shows the antenna's reflection coefficient. The operating bandwidth where the reflection coefficient is less than −10 dB ranges from 1.70 to 5.26 GHz. The reflection coefficient of this proposed antenna was compared with the reflection coefficient of the original antenna having the same dimensions as this proposed antenna, except that the patch and ground are intact. For the original patch antenna, *Fig. 3* shows that there is a resonance at 6.01 GHz.

Meanwhile, *Fig. 2(c)* shows that the resonant frequency of the RIS structure for the proposed antenna is located at 7.4 GHz. The inductive energy stored in the RIS below 7.4 GHz collaborates with the capacitive energy of the patch, forming the expanded operating band below 7.4 GHz. The relative bandwidth of the proposed antenna is approximately 100%, which is significantly wider than the original patch antenna. This demonstrates that the RIS structure can impact antenna resonance and extend its bandwidth.

Figure 4 shows the impedance characteristics of the antenna. There are several resonant frequencies where the imaginary part of the impedance crosses zero. The inductive energy stored in the RIS



compensates for the capacitive energy of the patch antenna, thus forming several additional resonances below the resonance frequency of the original patch antenna.

This also has the effect of maintaining the real part of the impedance close to 50 Ω at these resonant frequencies, as the real part of the impedance of *Fig. 4* shows. By introducing these resonant frequencies, the operating bands of the metamaterial antenna have been extended beyond its earlier version.

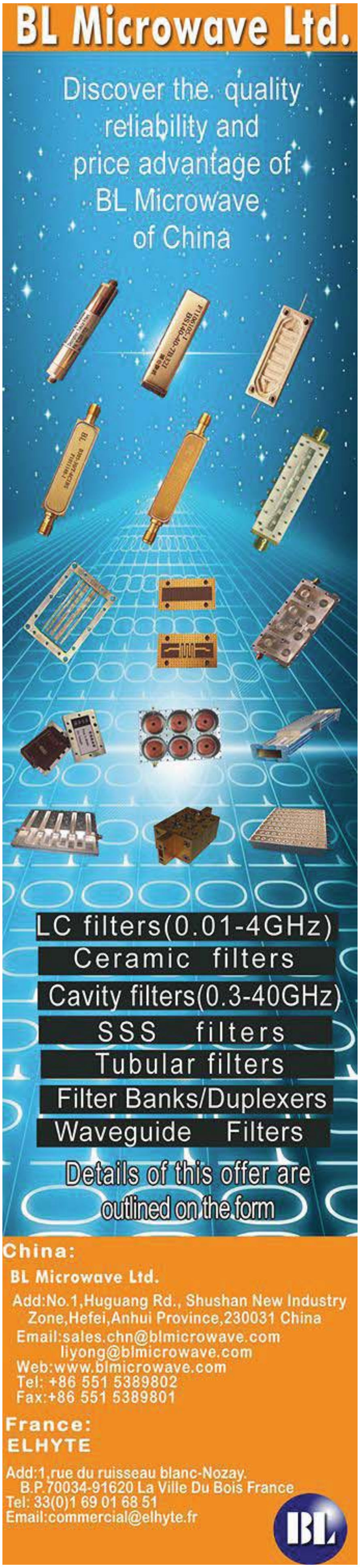
Figure 5 provides simulations of the near-field distribution of the antenna. It shows the electric fields on the patch and the ground at an arbitrary frequency (3 GHz). *Figure 5(a)* shows the electric field on the patch while *Fig. 5(b)* shows the electric field on the ground.

Figure 5(a) shows that the feed energy to the antenna is effectively coupled to the patch through the microstrip line and then radiated by the edges of the patch. *Figure 5(b)* shows that the RIS structure formed by the patch and etched ground also plays a key factor in the antenna's near-field radiation, since the electric fields are distributed regularly along the edges of the strip gaps etched on the ground. This helps to form multiple radiation routes for the antenna, enhancing its radiation strength.

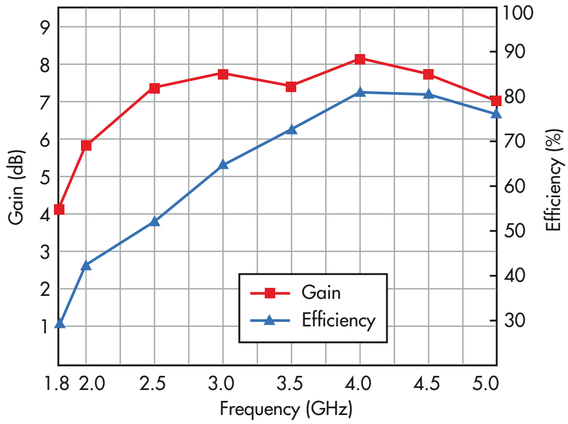
The far-field radiation property of the antenna was measured in terms of its radiation patterns and shown in *Fig. 6*. Two frequencies, 1.8 and 4.2 GHz, were arbitrarily chosen to verify the radiation performance of the antenna. The three-dimensional gain patterns are shown in *Fig. 6(a) and (b)* in the dB scale. The patterns of the XOY and XOZ planes at 1.8 and 4.2 GHz are also plotted in *Figs. 6(c) and 6(d)*.

As shown in *Fig. 5*, the RIS employed on the antenna affects the near-field distribution on the ground, thus making the radiation patterns of the antenna different from those of an ordinary patch antenna. At 1.8 GHz, the metamaterial-based antenna tends to radiate in the direction perpendicular to the axis of the feeding microstrip of the antenna.

The radiation pattern at 4.2 GHz also has three main lobes in the XOY plane and one main lobe in the XOZ plane. The position



7. These lots show the measured gain and efficiency for the antenna.



of the antenna could be adjusted so that the antenna is feasible for radiating or receiving signals in the desired direction.

Figure 7 offers the radiation gain and total efficiency of the antenna, at frequencies from 1.8 to 5.0 GHz. As can be seen, the peak gain is 7.24 dB at 4.0 GHz. The gain remains above 1.06 dB from 1.8 to 5.0 GHz. The near-field radiation from the patch, as well as that from the etched ground, help enhance the radiation gain *(Fig. 5)*. The radiation gain is in the range of 1.06 dB (at 1.8 GHz) to a maximum value of 7.24 dB (at 4.0 GHz).

From *Fig. 7*, it can be seen that the total efficiency is in the range of 54.8% (1.8 GHz) to 88.7% (4.0 GHz). This shows that the antenna can achieve efficient radiation over a wide frequency range, using a relatively simple structure in a physically compact size. mw

ACKNOWLEDGMENTS

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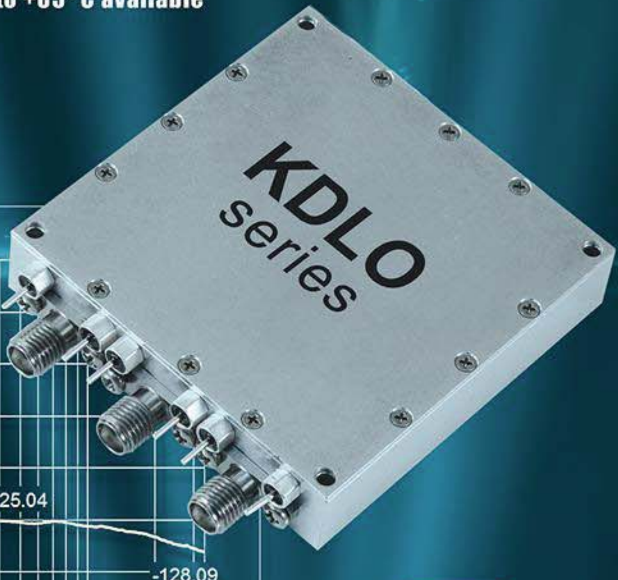

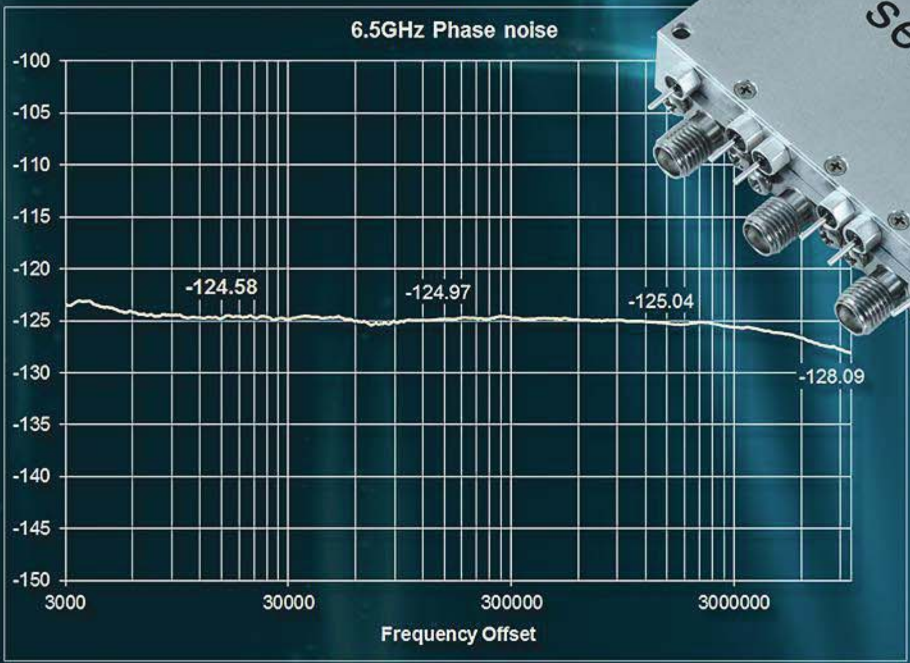

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SPOT UNLICENSED SPECTRUM with a Real-Time Analyzer

When planning for unlicensed band use for wireless systems, a real-time spectrum analyzer makes it possible to scan frequency spectrum for signals.

Wireless activity continues to increase as more and more frequency bands are occupied by popular applications—among them Bluetooth, ZigBee, IEEE 802.11, and Wi-Fi. With the emergence of the Internet of Things (IoT), demand is growing for low-cost, easy-to-implement chipsets to enable wireless connectivity.

These chipsets are attractive because they utilize unlicensed radio spectrum, and many solutions are available with reference designs which have already achieved regulatory approval. Managing the many different electronic devices soon to be communicating by means of IoT connections will require reliable knowledge of occupied frequency bands. Such knowledge can be provided by the versatile measurement capabilities of a real-time spectrum analyzer.

The 2.4-GHz spectrum is arguably the most popular unlicensed frequency band for low-cost communications applications, and even applications like microwave ovens (where the only communication occurs when the final buzzer sounds for a meal). Thousands of radios are operating in the 2.4-GHz band, making use of the unlicensed (free of charge) frequency spectrum.

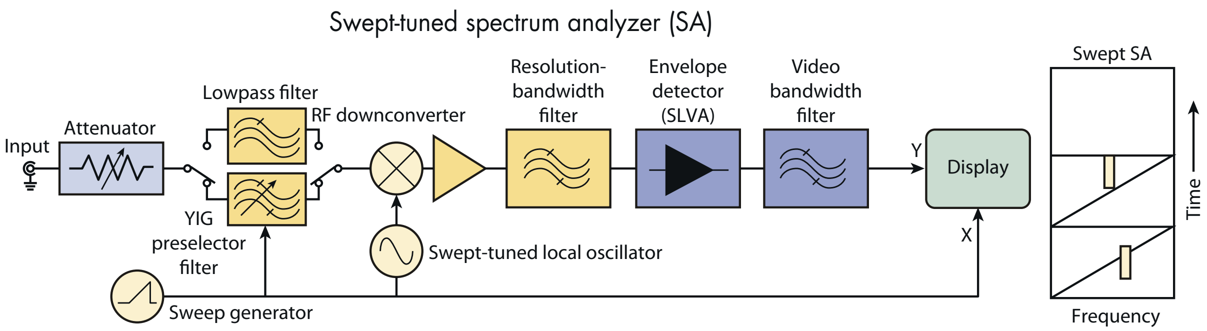
Of course, with many different radios and applications in the same frequency band, effective spectrum sharing is necessary. This is usually performed by means of advanced hardware and software within a radio, including:

Time-domain multiple access (TDMA) techniques that enable transmitting and receiving on the same frequency channel;

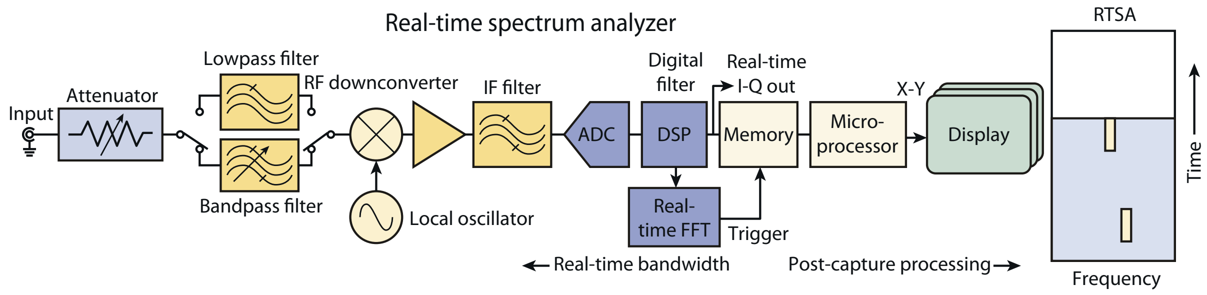
Clear channel assessment, by which a radio can monitor the activity in its designated band to find the optimum timing for a transmission; and

Adaptive frequency control, such as frequency hopping, to make efficient use of available frequency spectrum. This is accomplished by changing to portions of a frequency band as they are available, and free from interference from other signal sources in the band.

Engineers are finding that even when they use a "certified"



1. This simplified block diagram represents the essential functions of a traditional swept-tuned spectrum analyzer.



2. This block diagram shows the basic functions of a real-time spectrum analyzer (RTSA).

solution, they are still having problems establishing a radio link and maintaining communications within a particular portion of the radio spectrum. The challenge becomes how to troubleshoot a radio link for its activity and how to work a new application into that frequency band.

Spectrum analyzers have long been the instruments of choice for monitoring and measuring signal activity in the radio spectrum (see the sidebar, "Sorting Through Spectrum Analyzer Specifications," to gain a better understanding of the key parameters used for comparing analyzer models). A number of different architectures are available for commercial spectrum analyzers, including swept-tuned and real-time spectrum analyzers.

Figure 1 offers a simplified block diagram of a traditional swept-tuned spectrum analyzer. It employs a superheterodyne radio architecture that can process and measure a wide range of frequencies by translating them to lower intermediate frequencies (IFs) for processing and analysis.

When attempting to characterize modern signals like Wi-Fi, the challenge in using the superheterodyne spectrum analyzer lies in the "sweeping" nature of its operation. What is measured on the analyzer's spectrum display is disjointed in time and may not provide an accurate representation of the spectral information as a function of time (especially for TDMA signals). Even the fastest swept-tuned spectrum analyzers only provide a limited view of a frequency-hopped transmitter.

In addition to the basic frequency versus amplitude display, some superheterodyne spectrum analyzer manufacturers provide spectrogram information. In a swept-frequency spectrum analyzer, this information is derived from multiple sweeps; the timing information on display can only approximate what may be happening with a pulsed or frequency-agile transmitter.

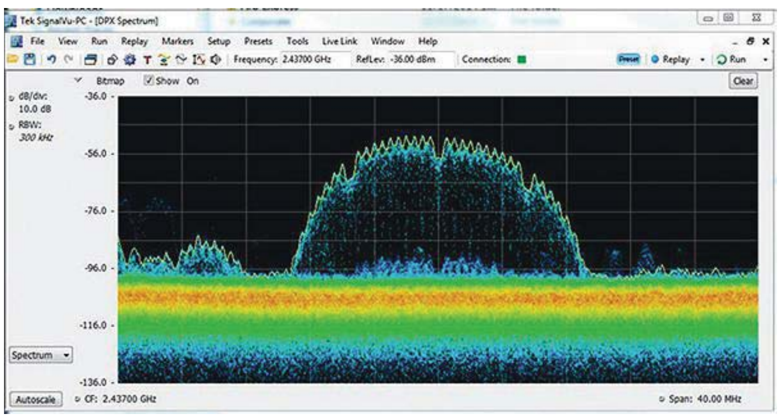
In contrast, a real-time spectrum analyzer (RTSA) provides the same basic functionality as a traditional swept-tuned superheterodyne spectrum analyzer, but with a number of added benefits. *Figure 2* shows a block diagram of a basic RTSA. One of the key differences between an RTSA and a basic swept-tuned spectrum analyzer is in the RTSA bandwidth specification.

For any span up to the maximum real-time frequency span of the instrument, an RTSA does not sweep and can continuously capture spectrum information. The Tektronix RTSA family also is not limited to a single display at one time. Rather, spectrum, spectrogram, and modulation information can be simultaneously measured in a time-correlated display, since this data has been captured from the continuous acquisition of the signal within the span of interest.

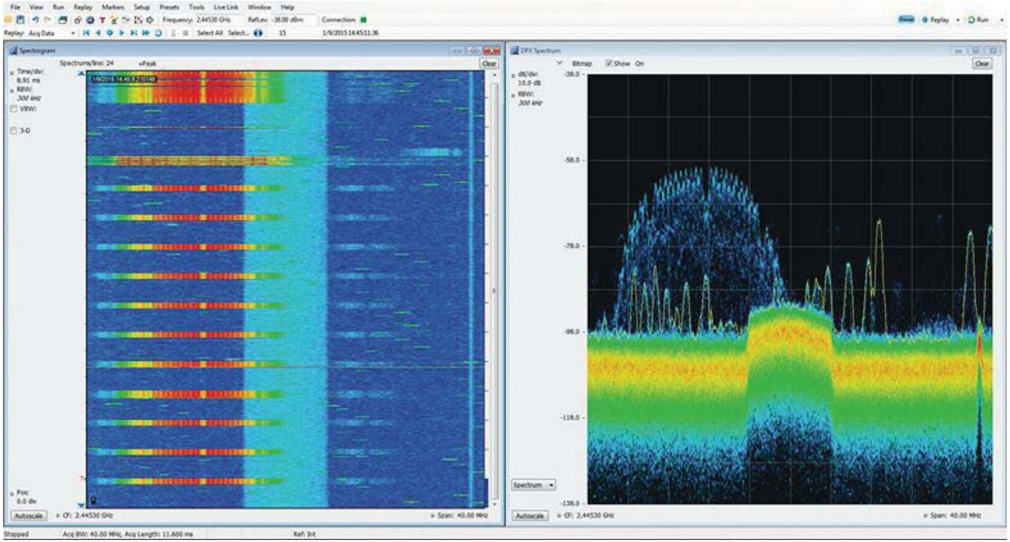
Important RTSA features include:

- Fast spectral analysis rates from 10,000 to 3,400,000 spectrums per second;
- Seamless recording of an RF/microwave signal environment over time;
- Triggering by means of time, frequency, amplitude, and RF density; and
- The capability to make measurements that are correlated in terms of time, frequency, and modulation.

A RTSA is particularly useful when analyzing systems that



3. A digital phosphor spectrum display, such as this captured using a Tektronix RSA306 USB spectrum analyzer, lets the user "see" what the receiver "sees."



4. An RTSA provides complete domain correlation allowing information in the spectrogram on the left to be directly correlated with other measurements.

employ a TDMA protocol, such as Wi-Fi and Bluetooth systems. One of the biggest problems for devices that operate in license-exempt frequency bands is managing the effects of multiple transceivers sharing the same spectrum. Regulatory requirements almost always require that devices operating in unlicensed frequency bands to not cause interference, and must

SORTING THROUGH SPECTRUM ANALYZER SPECIFICATIONS

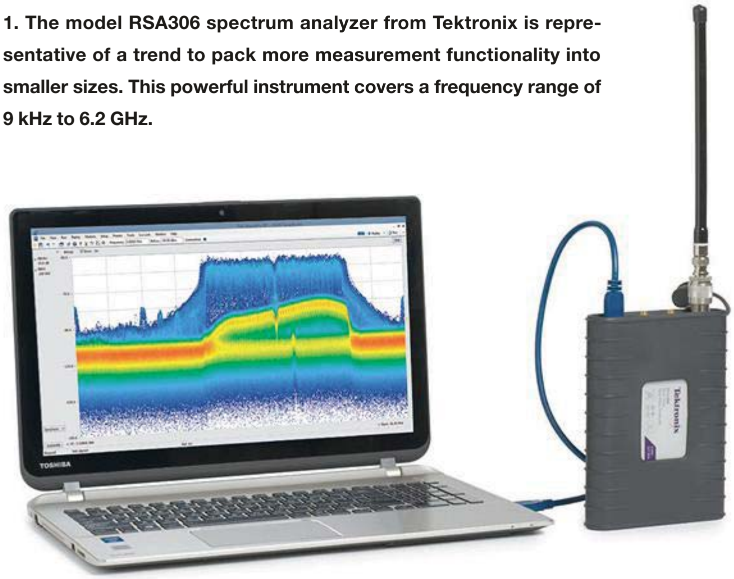
JACK BROWNE | Technical Contributor

SPECTRUM ANALYZERS ARE extremely versatile and useful test instruments that have long been used to study RF/microwave signals. The display screen has often served as a “window on a wireless world,” allowing users to capture and identify different signals within a bandwidth of interest.

Commercial spectrum analyzers are available with many different performance levels, frequency ranges, and operating features. And as with any powerful tool, knowing the essential capabilities of a spectrum analyzer is a good starting point for building the skill needed to benefit from its massive measurement power.

Spectrum analyzers are available in many shapes and sizes, from full-sized rack-mount instruments to more compact, battery-powered, portable analyzers. As the accompanying article explains, the instrument architectures can vary as well. Among the options are swept-tuned and real-time spectrum analyzers, providing different techniques for viewing a particular segment of frequency spectrum.

1. The model RSA306 spectrum analyzer from Tektronix is representative of a trend to pack more measurement functionality into smaller sizes. This powerful instrument covers a frequency range of 9 kHz to 6.2 GHz.



Because they are essentially receivers with a display screen, spectrum analyzers among all RF/microwave test instruments are well suited for on-site measurements, which have encouraged an evolution of “shrinking” spectrum analyzers over the past few decades.

Many may recall the 492/492P and 496/496P series of spectrum analyzers from Tektronix (www.tek.com) as starting points for RF/microwave spectrum analyzers, since they could be carried with accept any interference that is present. An RTSA is an ideal tool for quantifying the effects of interference, since as it is capable of continuously capturing spectrum information.

In addition, with newer RTSAs capable of being controlled over a standard Universal Serial Bus (USB), they can easily be connected to laptop computers and other computing devices. As an example, *Fig. 3* shows a digital phosphor spectrum display from a USB-based RTSA well suited to spectrum characterization and management applications. As with the display of a traditional swept-tuned superheterodyne spectrum analyzer, the RTSA display provides signal amplitude as a function of frequency, for a portion of bandwidth of interest.

One of the most important features of an RTSA is the capability of the instrument to employ color to show how RF energy is measured at a particular pixel (the pixel occupancy). The digital phosphor spectrum measurement makes it possible to specify a decay function, providing a phosphorescent effect which mimics the display effects found in older CRT-based oscilloscopes. These features add the dimension of periodicity to a display, making it possible to display how often a signal is being measured during a span of interest.

This type of real-time display in a RTSA makes it possible to graphically present what a classic RF receiver sees, providing

their built-in handles to a remote test site and quickly set up for spectrum measurements to about 26.5 GHz. Although these were battery-powered, portable spectrum analyzers that brought the accuracy and performance levels of larger rack-mount instruments to the field, they are relatively large by today's standards for portable spectrum analyzers.

Modern portable spectrum analyzers are considerably smaller than the 492/492P and 496/496P analyzers—more typically represented by the model RSA306 real-time spectrum analyzer from Tektronix *(Fig. 1)*. This spectrum analyzer resembles a hand-held portable radio and leverages an additional computer, such as a laptop computer, for processing power and display capabilities.

During the era of the 492/492P and 496/496P series of spectrum analyzers, the compact RSA306 would hardly be recognized as an RF/microwave test instrument, but it is quite capable of highly accurate spectrum measurements from

Continued on p. 72

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> “An RTSA is an ideal tool for quantifying the effects of interference, since it is capable of continuously capturing spectrum information.”

greater insight into what is taking place over a frequency span of interest. But it doesn't provide enough information about the potential effects of interfering signals. By their nature, spectrum displays cannot show the time interleaving of different signals. Employing a “zero-span” measurement capability would provide good detail about pulse amplitude and duration, but not about frequency information.

The spectrogram measurement is designed to address this type of problem. Like a traditional spectrum display, it will show low-frequency information on the left-hand side and higher-frequency information on the right. Unlike a basic spectrum-analyzer display, color is used to represent amplitude, and all of this information is plotted versus time on the y-axis. The spectrogram is effectively a strip chart recorder showing spectrum activity over time.

In a swept-tuned spectrum analyzer, the spectrogram will be disjointed in time as the instrument is sweeping. The spectrum analyzer sweeps through frequency, meaning that trace points on the left-hand side of the span occur at earlier times than trace points on the right-hand side of the span. As such, there can be no timing relationships within a spectrogram captured by a swept-frequency analyzer.

In contrast, a spectrogram created by a RTSA is comprised of continuously recorded spectral data, without sweeping a bandwidth of interest. The RTSA has the added benefit of complete domain correlation, so information in the spectrogram can be directly correlated with other measurements (i.e., modulation, power, and CCDF).

Figure 4 offers an example of a digital phosphor display in conjunction with a spectrogram. The digital phosphor display shows a great deal of detail on signals that are present. In the center of the display, a lower-level wideband signal exhibits a large crest factor. Given the bright, or “hot,” coloring for this display, this signal has a high level of channel occupancy (nearly continuous).

A Wi-Fi signal can also been seen in the display, operating at 2.437 GHz (Wi-Fi channel 6). There are also more than 10 other signals in the display at varying frequencies and power levels. Given the spectrum shape and frequencies in use, these signals are probably from a Bluetooth device.

At first glance, it appears that there would be a great deal of co-channel and adjacent-channel interference among the various devices operating in this monitored frequency span. However, the analyzer's digital phosphor display is not showing the complete picture. In order to provide a source of synchronization, a basic power trigger was employed to synchronize signal acquisition with the large amplitude of the Wi-Fi signal. The instrument was set up to acquire 10 ms of continuous RF signal information each time a trigger was generated.

An RTSA makes it possible not only capture real-time spectrum data, but to also record (and play back) seamless blocks of spectrum information. The spectrogram on the left-hand side

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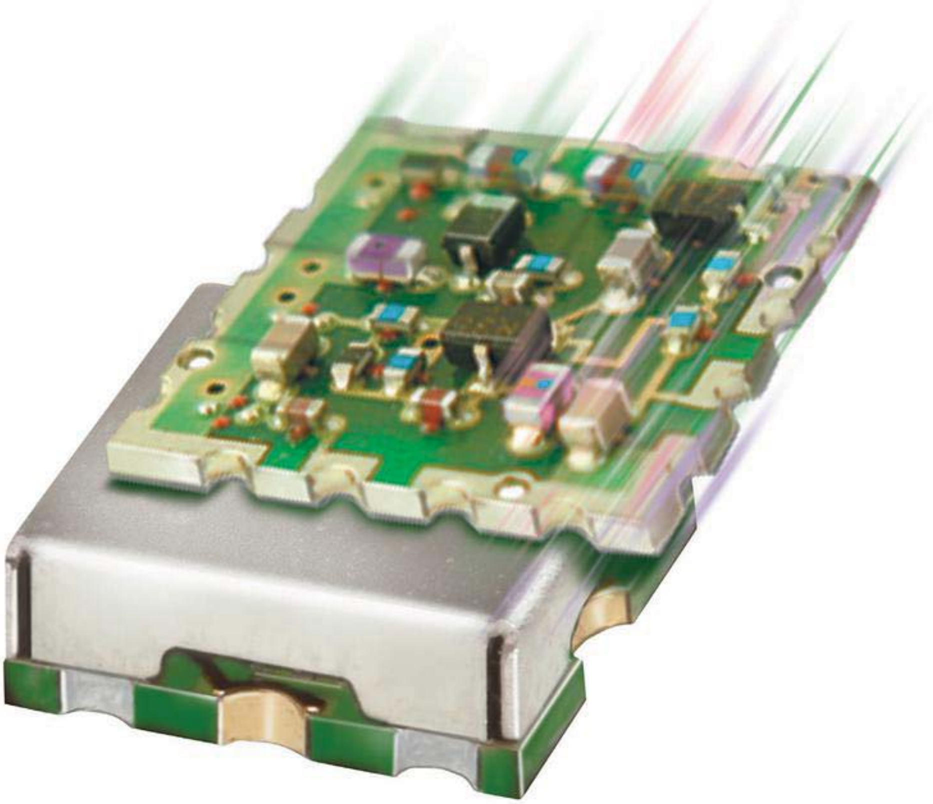

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of *Fig. 4* shows multiple 10-ms acquisitions. With the added dimension of time, it is possible to clearly observe the time interleaving occurring between various wireless systems sharing this portion of frequency spectrum.

The Wi-Fi signal is a short-duration pulse, unchanging either in frequency or power level. Centered on or about 2.4453 MHz, there is a lower-amplitude continuous signal with a root-cosine ("square-top") spectral shape. Multiple signal bursts (approximately 1 MHz wide and Gaussian shaped) can also be seen in the frequency span.

These signals are exhibiting the behavior of Bluetooth signals, and it can be seen how these signals are time-interleaved with other emissions in the span. In addition, it is possible to observe some adjacent-channel interference which can be directly correlated to the Wi-Fi signal on channel 6.

As can be seen in this analysis, there are a number of co-channel services utilizing the same RF spectrum. By using active spectrum-sharing techniques, the different signals are time interleaved so that they can co-exist within the same frequency spectrum, and there is little or no loss of link quality. Because of the growing number of services sharing different unlicensed frequency bands, it is easy to see why measurement tools such as RTSAs are needed for monitoring and measuring these crowded frequency bands. mw

Continued from p. 68

9 kHz to 6.2 GHz. Similarly, the FieldFox portable analyzers *(Fig. 2)* developed by Agilent Technologies (now Keysight Technologies) provided clear views of captured signals over a large screen, with simple-to-use controls underneath.

Spectrum analyzers show signals in the frequency domain (with signal amplitude levels displayed as a function of frequency), in contrast to an oscilloscope (which displays signals in the time domain, with signal levels shown as a function of time. Spectrum analyzers are typically used to track signal activity across a portion of spectrum; they can be used to measure signal frequency and power, but will typically not be as accurate as a frequency counter for measuring frequency or a power meter for measuring power.

A spectrum analyzer is useful for following signal behavior in a given bandwidth, and can follow other signals that may be related to the main signal of interest, such as signal harmonics and spurious content. Spectrum analyzers are excellent tools for tracking noise within a bandwidth of interest, as well as signal interference that may exist within a communications channel.

To be effective, a spectrum analyzer should have the frequency range to cover an application or group of target applications. In a conventional spectrum analyzer, it should have the swept measurement range to cover a suitable bandwidth (such as 50 or 100 MHz) within the total frequency range (such as 10 MHz to 6 GHz). The resolution bandwidth of the spectrum analyzer defines how finely a captured signal can be viewed, such as a 1-Hz resolution bandwidth to display a signal center frequency.

In a real-time spectrum analyzer, the real-time bandwidth is the instantaneous measurement bandwidth of the instrument, which can be tuned across a wider total bandwidth of interest for capturing and studying different signals. It enables an instrument to show all signal activity within that bandwidth at the same time, for a relatively short capture time, which is typically related to the amount of digital memory within the instrument for storing the digitized versions of the captured signal bandwidth.

Spectrum analyzers can also be compared for their amplitude capabilities, with displays typically adjustable for different dynamic ranges, or the minimum to maximum levels of amplitude that can be displayed at one time. The minimum level defines the sensitivity of the analyzer, while the maximum level is usually just below the damage level.

One of the more important amplitude-related specifications for a spectrum analyzer is the maximum input signal level that can be accepted to an instrument without causing damage. Amplitude specifications also include the maximum signal level at which an instrument will meet its specifications, and the amplitude accuracy of the spectrum analyzer at all displayed center frequencies.

2. Another example of powerful portable spectrum analysis capabilities is the FieldFox line of instruments from Keysight Technologies, with wide frequency ranges and long battery life.

Both benchtop and portable spectrum analyzers may be designed for use with an external frequency reference source in addition to their built-in frequency reference source, when increased levels of amplitude and frequency accuracy may be required. The frequency reference accuracy of a built-in reference is usually defined to meet a certain value after a certain warmup period.

The internal reference is also characterized in terms of aging rate, in ppm, usually defined for the first year and then for each consecutive year. Spectrum analyzers may also define an input frequency or frequency range and amplitude level range for an external frequency reference, to simplify connections when using a spectrum analyzer with an external frequency reference.

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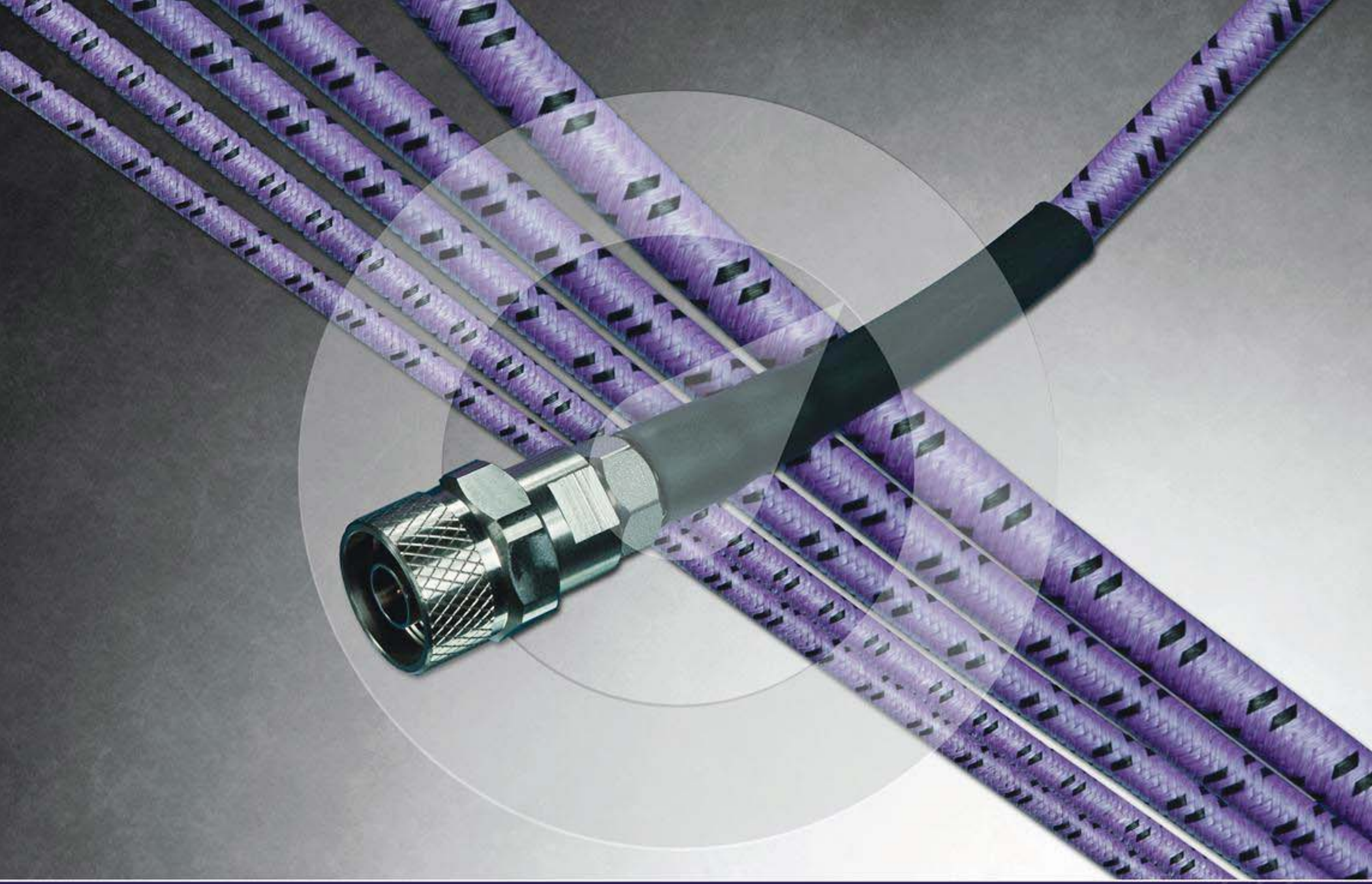

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Make the Most of MICROWAVE MIXERS

Frequency mixers provide a reliable means of translating signal frequencies higher or lower as needed, and across the wide bandwidths required in many RF/microwave systems.

Frequency conversion or translation serves a wide range of electronic systems, and the frequency mixer has long been the component of choice to accomplish this function. Frequency mixers can be specified for many different frequency ranges and bandwidths, to shift signals upward (upconversion) or downward (downconversion) in frequency. They come in a number of different package configurations, including with coaxial connectors and in surface-mount-technology (SMT) type miniature packages.

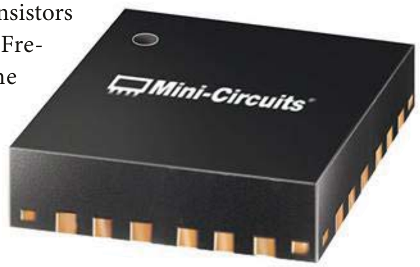
Frequency-mixer circuits feature three ports: radio frequency (RF), local oscillator (LO), and intermediate frequency (IF). Two function as input ports, with the remaining port serving as the output port. The LO port always involves an input signal. The RF and IF ports, on the other hand, can switch functions—it depends on whether a mixer is being used for upconversion, with the IF port as an input port and the RF port as an output port, or for downconversion, where the roles reverse.

For upconversion, lower-frequency IF signals are mixed with higher-frequency LO signals to produce higher-frequency signals at the RF port (the output port). For downconversion, higher-frequency RF signals mix with high-frequency LO signals to produce lower-frequency signals at outputs at the IF port. Downconversion is typically performed in high-frequency receivers while upconversion normally takes place in high-frequency transmitters.

Mixers are fabricated as either passive devices, with signal mixing taking place in Schottky diodes, or as active devices, typically based on GaAs field-effect transistors (FETs) for the signal mixing. Frequency translation follows the simple addition and subtraction of signal frequencies at the mixer RF port (f_{RF}) and the mixer LO port (f_{LO}) to produce sum and difference IF signals (f_{IF}):

$$n(f_{RF} \pm f_{LO}) = f_{IF}$$

The "n" in this relationship refers to the harmonic number of the signals being mixed. By means of different types of filtering, different mixing products can be selected and/or suppressed to accomplish a designed frequency translation.



1. This surface-mount housing packs a mixer IC, LO amplifier, and IF amplifier. *[Photo courtesy of Mini-Circuits (www.minicircuits.com).]*

A BROAD MIX OF MIXERS

Various types of frequency mixers are commercially available in different chip and package formats, including single-balanced mixers, double-balanced mixers, image-reject mixers, single-sideband mixers, double-sideband mixers, and in-phase/quadrature (I/Q) mixers. Single-balanced mixers can be realized with simple circuits implementing a single diode, while double-balanced mixers are typically formed with four Schottky diodes in a quad ring configuration. Two balanced transformers are used as transformers to achieve high isolation for the LO and RF ports. A triple-balanced mixer incorporates two well-matched quad diode rings to typically operate with wider LO and RF bandwidths than double-balanced mixers, with higher dynamic range and lower distortion.

"Mixers continue to evolve from simple frequency-conversion components to multiple-function components with additional pre-selection and IF filters, and even active circuitry like amplifiers."

Frequency mixers are characterized by a number of parameters that describe their frequency-translation performance, including conversion loss or gain, port-to-port isolation, VSWR, noise figure, 1-dB compression point, and third-order intercept point. An excellent introduction to the basic mixer parameters can be found in "Mixer Basics Primer: A Tutorial for RF & Microwave Mixers," a 12-page application note available for free download from Marki Microwave (www.markimicrowave.com).

The firm also provides an advanced mixer search tool on its website for performing a search by means of LO, RF, and IF frequency ranges. In addition, the text *Microwave Mixers* by Stephen A. Maas and available from Artech House (www.artechhouse.com) is an industry-standard information source on RF/microwave mixers.

Most searches for mixers begin by finding a unit with suitable RF, LO, and IF frequency ranges, usually with the lowest conversion loss. In a passive mixer, such as a diode mixer, conversion loss results from impedance mismatches and circuit junctions (e.g., diode connection points) that can cause signal reflections and losses in the circuit. For an upconversion mixer, conversion loss is evidenced by the difference in signal amplitude between the IF input signal and the RF output signal. For a downconversion mixer, conversion loss is the difference in signal level between the RF input signal and the IF output signal.

Ideally, with no conversion loss, and the appropriate LO signal level, the amplitude of the RF and the IF signals in both of the above cases would be the same. But any variation in impedance in a mixer circuit will contribute to conversion loss and result in some loss of signal from input to output ports. With active circuitry, such as the biasing of transistors in a GaAs FET mixer, it's possible to achieve conversion gain in a mixer, although additional bias energy must be consumed in the mixer in order to account for the signal gain through the component.

Isolation is a measure of the power leakage from one port to another. The isolation from the LO to the RF port indicates the leakage of LO power into the RF port. High LO-to-RF isolation minimizes the contamination of RF signals by LO power and/or noise. Isolation from the LO to the IF port provides insight into the amount of leakage of LO signal power into the IF port. When this form of isolation is low, it can contribute to saturation of an IF amplifier and cause deviations in a mixer's conversion-loss response.

Isolation from the RF to the IF port represents the amount of leakage that occurs from one port to the other. While it may not have the impact of maintaining high isolation between the LO and other two ports, high isolation from the RF to the IF port is usually a sign that the mixer will exhibit low conversion loss with good conversion loss flatness.

Dynamic range is the difference between the maximum amplitude of signals, usually denoted by the 1-dB compression point or where compression begins, and the lowest practical signal level (typically the mixer noise figure). The 1-dB compression point represents a difference in a linear relationship between input and output signal levels for a mixer, where the output power level drops by 1 dB relative to the power level applied at the input port. Since the 1-dB compression point is related to the available LO power level, mixers with higher dynamic range will also typically be specified for higher LO drive levels while exhibiting low conversion loss.

Mixers come in many different package formats, with and without coaxial connectors, and even in die form for mounting on printed-circuit boards (PCBs). The model HMC1106, a GaAs MMIC double-balanced mixer from Hittite Microwave Corp. (www.hittite.com), is supplied in die form. It can be used as an upconverter or a downconverter, with 10-dB typical conversion loss in either direction. The broadband chip mixer is designed for an RF range of 15 to 36 GHz, an LO range of 20 to 50 GHz, and an IF range of dc to 24 GHz.

A HIGHER FREQUENCY OF HIGH-FREQUENCY MIXERS

With increasing use of millimeter-wave frequencies for such applications as high-data-rate communications links, medical electronic systems, and vehicular radar safety systems, more mixers are being designed for higher-frequency purposes. Marki Microwave, for example, has stressed the importance of maintaining linearity in these higher-frequency mixers, working with commercial simulation software suppli-

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ers to develop physics-based nonlinear mixer models that can accurately predict the performance of its different high-frequency mixers in various applications. On that front, model MM1-2567LS from Marki Microwave is a double-balanced passive mixer with a specified RF and LO frequency range of 25 to 67 GHz and an IF range of dc to 30 GHz. It has typical conversion loss of 9 dB across that wide frequency range, with a 1-dB compression point of +1 dBm.

At millimeter-wave frequencies, mixers generally incorporate waveguide ports. Such is the case with many of the higher-frequency mixers from Spacek Labs (www.spaceklabs.com). The company's model MW-1B-6X broadband mixer features RF and LO ports spanning 75 to 110 GHz in WR-10 waveguide. The mixer simplifies LO connections by in- cluding a 6× LO W-band active multiplier on the LO port, thereby making it possible use LO signals from 12.5 to 18.33 GHz to reach the required 75- to 110-GHz LO frequency range for mixing. It accepts those LO signals at levels ranging from +13 to +18 dBm, and reduces IF signals to a range of 10 MHz to 3 GHz, available at a port with a female coaxial SMA connector. Typical conversion loss is 7 dB and no greater than 12 dB across the wide frequency range. In addition, broadband mixers with lower conversion loss are available for reduced bandwidths.

2. The MAC series of surface-mount mixers makes use of LTCC technology and monolithic active devices to achieve high-performance mixers in tiny hermetic packages. *[Photo courtesy of Mini-Circuits (www.minicircuits.com).]*

Spacek Labs also recently introduced its model MV-1B with V-band coverage of 50 to 75 GHz for the RF and LO ports in WR-15 waveguide. By using dc bias (10 mA at +12 V dc), the required LO power is only 0 to +5 dBm, with IF signals from 10 MHz to 3 GHz made available at a female SMA connector. Typical conversion loss is 6 dB and no more than 9 dB across the frequency range.

BUILT-IN MULTIFUNCTIONALITY

Mixers continue to evolve from simple frequency-conversion components to multiple-function components with additional preselection and IF filters, and even active circuitry like amplifiers. This ultimately provides more of a receiver's or transmitter's circuitry within a rather compact mixer housing.

For example, model MDA4-752H+ from Mini-Circuits (www.minicircuits.com) is a multichip module (MCM) supplied in a 4- × 4-mm MCLP package, which is essentially a quad-flatpack-no-lead (QFN) type package. The small package *(Fig. 1)* includes a mixer integrated circuit (IC), an LO amplifier, and an IF amplifier. It has LO and RF frequency ranges of 2.2 to 7.5 GHz and an IF range of 0.03 to 1.6 GHz. By integrating the amplifiers, it achieves conversion gain and enables operation with an LO power level of 0 dBm. The packaged mixer/amplifier combination suits commercial communications, defense radar systems, and satellite-communications (satcom) systems.

The firm, which supplies frequency mixers with coaxial connectors and in different types of drop-in and surface-mount packages (fitting applications through millimeter-wave frequencies), aids visitors to its website with a versatile "Yoni2" search-engine program. The search engine locates a mixer product based on key mixer search parameters, such as RF/LO frequency range, conversion loss, LO power level, and package style.

The company has extensive lines of surface-mount mixers employing a number of different mixer circuit technologies. For example, its "MAC" lines of mixers combine semiconductor devices with low-temperature-cofired-ceramic (LTCC) circuit materials to achieve high-performance levels in miniature hermetic surface-mount packages *(Fig. 2)*. One model in this line, the MAC-113H+, features an RF/LO frequency range of 3.8 to 11.0 GHz and IF range of dc to 2 GHz. It has a relatively high LO level requirement of +17 dBm and provides 6.5-dB typical conversion loss. The LO-to-RF isolation is typically 28 dB, and the rugged LTCC mixer is designed to handle operating temperatures from –55 to +125°C.

Synergy Microwave Corp.'s (www.synergymwave.com) Galaxy series of wideband surface-mount mixers includes the SGS-5-10 double-balanced mixer, which builds on the firm's SYNSTRIP multilayer circuit technology and REL-PRO patented technology to achieve low conversion loss over broad bandwidths. This mixer has an RF/LO frequency range of 3 to 19 GHz and an IF range of dc to 4 GHz, with typical conversion loss of 7.5 dB.

The SGS-5-10 operates with +10-dBm LO power for a –2-dBm 1-dB compression point, and features 25-dB typical LO-to-RF isolation, 12-dB typical LO-to-IF isolation, and 25-dB typical RF-to-IF isolation. The surface-mount device measures only 0.275 × 0.200 in. and maintains its performance over an operating temperature range of –40 to +85°C.

As evidenced by this small sampling of technologies and products, frequency mixers are very much a significant part of the electronic systems in the RF/microwave industry, and will be even more so as technology and design advances further boost their performance. Currently, mixers are making millimeter-wave links and applications possible and affordable whether in chip or packaged forms. Eventually, the continued trend of integration with other components should foster even more affordable RF/microwave mixers in the not-too-distant future. mw

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Comparing Commercial and Military Components

High-frequency components may be designed and fabricated in similar ways, but typically it's screening and special features that determine how they will be used.

Components for RF/microwave systems differ in many ways, including functionality, package styles, performance levels, and even in the way that they screened or qualified for commercial applications compared to aerospace and military applications.

System designers may develop a high-frequency electronic system through the old-fashioned practice of drawing a block diagram on a piece of paper. In the case of a receiver, they may start with antennas and filters, then work through low-noise amplifiers (LNAs), mixers, intermediate-frequency (IF) amplifiers, and analog-to-digital converters (Adcs). Or they may reach for a trusted system simulation computer-aided-engineering (CAE) software tool to put the components together, then predict what level of system performance is possible with them.

The industry provides a healthy choice of different active and passive components for many different application areas, including commercial, industrial, military, and aerospace systems. But how is it possible to differentiate components suited for commercial use versus those developed for military applications?

Often, very little in a component's specifications will immediately declare that it is a better fit for a commercial or a military application (other than price). Some components may simply be designed for particular performance characteristics, such as for high power levels at L-band and S-band frequencies, which suggest that they are suited for military (radar) applications.

Other components may also be designed for high power levels, but for frequency ranges of 85 to 110 MHz that are more in line with commercial frequency-modulated (FM) broadcast systems. Often, there simply may not be any design or manufacturing differences between components earmarked for commercial use and those developed for military applications.

For an active component such as an amplifier, for example, typical performance specifications such as gain, gain flatness versus frequency, output power at 1-dB compression, noise figure, and VSWR may appear quite good and within limits that satisfy both commercial and military requirements. Mechanically, the packaging may be rugged and reliable, whether in chip, drop-in, surface-mount, or coaxial format.

But a key difference between components for commercial applications versus components for military applications is their behavior under somewhat different sets of environmental conditions. Commercial component applications are generally assumed to be environmentally stable and predictable, with components for a commercial application projected to be used within fairly reasonable operating temperatures, and with performance specifications often referred to room temperature (+25°C).

Even in the case of a component as straightforward as a rectangular waveguide section *(see figure)*, there may be no discernable differences between models offered for commercial versus military use. In the case of an older technology such as rectangular waveguide, however, these components tend to be used more readily in military systems than in commercial systems. This is typically because of price.

It is also due to the fact that this older technology and component configuration often exceeds the performance levels of more-recent component alternatives (such as flexible or semi-rigid coaxial cable assemblies) in certain critical areas (like insertion loss and power-handling capabilities). Although physically larger than more-recent component alternatives, such a waveguide section is often referred to as a “legacy component”; the physical format has been an accepted part of the mechanical design of a military system for some time.

At the semiconductor or chip level, there is very little to differentiate a component that is designed for military circuits and systems from one that has been developed for commercial use. As an example, a recent product introduced by TriQuint Semiconductor (www.triquint.com) is perhaps as well suited to commercial communications as it is to military communications, radar, and electronic-warfare (EW) applications.

Model TGA2237-SM is a wideband distributed amplifier which provides more than 13-dB large-signal gain and more than 10 W saturated output power from 0.03 to 2.50 GHz. It is fabricated with the company’s 0.25-μm gallium-nitride (GaN) on silicon-carbide (SiC) semiconductor process and supplied in a low-cost, surface-mount 32-lead, 5 × 5 lead AIN QFN package.

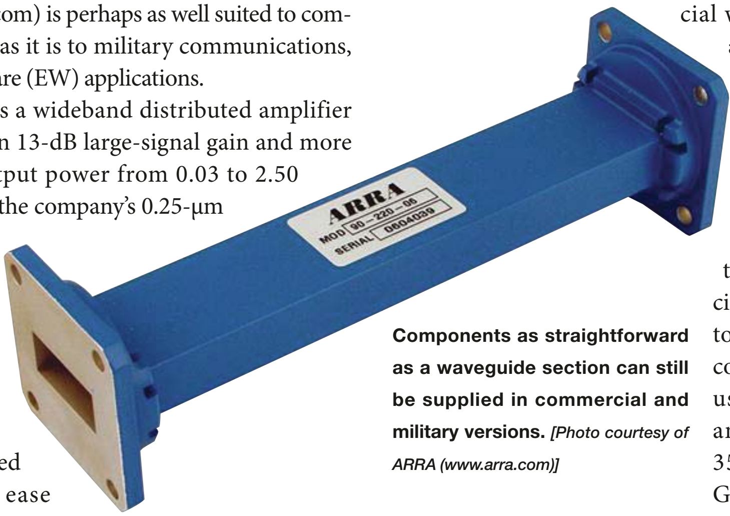
The amplifier is matched to 50 Ω impedance for ease of integration in 50-Ω circuits and systems. It is an RoHS-compliant, lead-free design that achieves better than 50% power-added efficiency (PAE). At this component level, however, the same chip amplifier is as well suited (and priced) for commercial as well as for military applications.

In some cases, it may be clear from the ruggedized design and construction of a component that it is specifically intended for the severe conditions of a military or aerospace application. The ZHL-100W-352+ and ZHL-100W-43+ amplifiers from Mini-Circuits (www.minicircuits.com) are clearly housed in large, heavy-duty packages that are designed for rough handling and severe environmental conditions.

These are Class-AB (very linear) amplifiers that are designed to provide unconditionally stable performance, even with changing temperatures and poor load conditions. Model ZHL-100W-352+ provides 100 W saturated output power from 3.0 to 3.5 GHz, while model ZHL-100W-43+ delivers 100 W saturated output power from 3.5 to 4.0 GHz. Both amplifiers are designed to deliver typical gain of 50 dB across their frequency ranges, with gain flatness of ±1.5 dB across the full operating bandwidths.

Although these are components that target both commercial and military applications, they have been designed and equipped with numerous additional safety features to improve reliability under harsh operating conditions. These features include protection against excessive signal drive levels, high case temperatures, reverse polarity connections, and the ability to operate under short-circuit conditions.

For instance, the amplifiers are built to survive without damage accidentally being put into short- or open-circuit operation even when delivering output signals as high as 100 W. Both amplifiers are supplied in rugged aluminum alloy cases with metal coaxial connectors and optional heat sinks. By their construction, they are clearly designed and fabricated for military applications, although they may also be suitable for commercial wireless communications applications.



Components as straightforward as a waveguide section can still be supplied in commercial and military versions. *[Photo courtesy of ARRA (www.arra.com)]*

MITEQ (www.miteq.com) recently introduced its model AMFW-6F-18004000-29-8P low-noise amplifier (LNA). It boasts a compact design that employed advanced circuit and packaging design to make it as well suited for commercial and for military use. The RoHS-compliant amplifier, which achieves 35-dB gain from 18 to 40 GHz, employs an aluminum housing that is only 1.32 × 0.88 in. with field-replaceable 2.92-mm coaxial connectors. The housing contributes to excellent thermal management to enable maintaining the noise figure below 3 dB across a wide operating-temperature range (–40 to +75°C). For this amplifier, the single design fits both commercial and military needs.

Military system designers operate with the assumption that a specified component will meet its own performance specifications, maintaining those specifications over time and over a variety of other conditions spelled out in numerous military standards. Perhaps one of the better known of these standards is MIL-STD-883, which defines a series of mechanical, environmental, and electrical tests for microelectronic devices intended for aerospace and military use.

MIL-STD-883 covers mechanical and electrical tests; the tests are essentially meant to measure a component’s resistance to the natural elements and conditions that may be found in military and space operations. They ensure that a component will continue to provide its specified performance levels even when subjected to harsh operating conditions.

The tests can even be used for services and training programs in relation to the components. The comprehensive standard uses the term “device” to refer to a wide range of electronic components, including monolithic components, multiple-chip components, hybrid components, and the materials from which the components are formed [such as printed-circuit-board (PCB) materials].

MIL-STD-883 is hundreds of pages long and is quite comprehensive in its definitions of requirements needed for designing and testing components and circuits appropriate for military and government use. The standard is so comprehensive that it includes numerous other standards and reference documents within it. Among these are several specifications from the U.S. Department of Defense: MIL-PRF-19500 for semiconductor devices, MIL-PRF-38534 for hybrid microcircuits, and MIL-PRF-38535 for integrated circuits. These define requirements for various component circuit formats.

MIL-STD-883 in its different forms is just one standard developed to ensure that RF/microwave components are designed and constructed with long-term reliability in mind. This even holds true for apparently simple RF/microwave components such as a waveguide bend or section. ARRA (www.arra.com), to cite one example, offers components with the firm's distinctive blue coating applied according to the guidelines of the MIL-C-22750 standard.

MIL-C-22750 defines the type of coating needed to provide the environmental protection required by different military and industrial applications. The standard even denotes what types of primer materials can be used with the topcoat material, such as primers meeting the requirements of MIL-PRF-23377 or MIL-PRF-53022 primer standards.

The many military standards represent the major difference between components designed and built for commercial applications versus those for military and aerospace applications. Depending upon the application and the system, the requirements set forth by the applicable standards can be quite challenging. Certainly, the testing employed to determine a component's adherence to these requirements can certainly drive up the component's cost.

ENVIRONMENTAL EXTREMES

Some military standards, such as MIL-STD-810, have proven so effective in evaluating a component's operation under severe environmental conditions that they are often applied to commercial and industrial components, as well. MIL-STD-810 checks a component at different temperature extremes; with such environmental conditions as rain and humidity; with shock and acceleration; and with random (and even gunfire) vibration.

Components that survive the minimal requirements of the standard are well equipped for almost any application, and it has been used when components are anticipated to be subjected to harsh environments and operating conditions, regardless of the application area.

Some military standards are very focused and will only apply to a limited group of components. For example, MIL-STD-704 refers to aircraft electrical power characteristics and defines a standard power interface between a military aircraft and its systems and components. It covers power-supply issues, including voltage, frequency, phase, power factor, power-supply ripple, maximum current, and electrical noise for both ac and dc systems.

COMMON GROUND

Other standards are more universal in their relevance, such as MIL-STD-461F. This standard sets conducted and radiated electromagnetic-compatibility (EMC) requirements, such as for power amplifiers, and has as much relevance for commercial components as for military and aerospace components.

Military electrical standards have become so diverse that individual components and groups of components are now defined by individual standards. For example, MIL-PRF-55365 is a standard that defines the performance of tantalum dielectric chip capacitors in terms of voltage, capactance, and various other parameters. MIL-DTL-38999 standards (which were formerly MIL-C class standards) relate to electrical connectors in terms of requirements for construction, dimensions, and contact types and expected performance under different environmental conditions. From the sheer number of these military standards, the appearance of a commercial-grade component and a military-grade component may be similar, but it is clear that considerable testing must be performed to qualify a component for military and aerospace use.

Military electronic systems may often have special requirements for components, above and beyond the requirements outlined in a particular standard. Multichannel communications systems and phased-array radar systems, for example, may rely on the close matching of amplitude and phase among the channels in the system; and the components within the signal-processing path for each channel must often provide fairly tight tolerances in amplitude and phase matching (e.g., amplitude matching).

One of the challenges in achieving amplitude and phase matching between and among components of a particular type—such as filters and amplifiers—is maintaining that tight amplitude and phase matching tolerance across a wide frequency bandwidth and under severe environmental conditions. The latter includes the wide temperature ranges specified by military applications.

Even in terms of military standards, measuring amplitude and phase across a wide bandwidth and for a wide temperature range can be time consuming and difficult, the presence of modern test software and automated test equipment notwithstanding. Such components may appear similar to standard commercial units, but are usually offered as custom models—whether for military or commercial use. mw

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HOW NOT TO BREAK YOUR NETWORK ANALYZER

PROPER TECHNIQUE CAN ensure that a highly sensitive and expensive instrument is put to use making quality measurements instead of sitting on a repair bench.

Network analyzers are one of the core instruments used in RF/microwave device development, characterization, and verification. As these instruments are necessarily very sensitive machines, they are prone to mechanical and electrical damage if improperly handled. In an application note by Keysight Technologies, tips for avoiding long repair cycles or costly equipment replacement requisitions are suggested.

Ensuring proper electrical power and grounding is essential for analyzer operation. If the machine is improperly grounded, charge could build, injuring the user or damaging the machine. The note reminds that these instruments tend to be supplied with a variety of warning labels and instructions in the datasheets and manuals in order to prevent mishaps.

The ports of a network analyzer are also sensitive to electrical and RF power at the inputs. Having an understanding of the range of power the ports can handle will aid in preventing damaging the internal measurement circuitry. Ensuring that during power cycles the instrument ports only experience the minimum safety level will also prevent startup or shutdown voltage swells or sags.

Mechanically speaking, the RF port connectors are precision parts that can easily be damaged at the connection to the instrument body or internally. To ensure RF connector safety, proper cable handling, inspection, cleaning, and electrostatic discharge (ESD) protections are valuable. ESD is an especially important consideration when packing the equipment for relocation, as it could come into contact with electric fields outside of a protected facility.

Keysight Technologies, 1400 Fountaingrove Pkwy., Santa Rosa, CA 95403, (707) 577-5030, www.keysight.com

Especially during operation, adequate ventilation in a low humidity environment will not only prevent catastrophic failure, but also increase equipment lifetime. As higher performance network analyzers are often rather large and heavy pieces of equipment full of electronic components, proper physical transport is also critical. The vibrations and jarring that regularly occur during transporting packages can easily damage a network analyzer. Therefore, proper packing materials are necessary. Finally, the note indicates that styrene pellets should never be used due to static generation and inadequate device protection.

RF DESIGN MADE SIMPLE FOR OTHER INDUSTRIES

RF/MICROWAVE TECHNOLOGIES ARE penetrating virtually every industry. The use of these technologies as tools, or for telecommunications purposes, is a growing trend worldwide. However, knowledge of fundamental and practical aspects of RF design is widely lacking in most industries. To help aid in providing the basics to those new to RF/microwave systems, Rohde & Schwarz prepared a white paper sharing system-level fundamentals.

The basics of an RF communication system involve taking information, processing it, and transporting it over a RF medium to information processing systems at the information destination. This requires the ability to input information electrically and convert that information to an RF signal for propagation.

Electromagnetic energy in the RF spectrum is used to transport information over long distances or at high data rates. Different standards, frequencies, and methods of transporting the data over an RF signal are used for a variety of different applications and industries. The basics components necessary for this process are transmitters, receivers, and antennas. True to their names, transmitters send data out through carrier RF signals, where receivers take that previously transmitted data and convert it to useful electrical signals. Antennas are the coupling mechanisms that enable RF energy to be sent in a controllable fashion over the "air."

Transmitters, receivers, and antenna are constructed of conductive/metallic components, as well as filters, amplifiers, frequency mixers, and modulators/demodulators. Filters block out certain signals from traveling further along the signal chain, where amplifiers increase the signal energy for either transmission or signal processing. Frequency mixers are used to shift the information carried in an electrical or RF signals to different frequency regimes. Modulators and demodulators convert electrical signal information into a format that is more readily transmitted and received over an RF signal path.

The operation of these devices needs to be confirmed and verified. Test-and-measurement equipment is used to analyze their behavior. For measuring unknown power signals, signal/spectrum analyzers are used. In order to provide a known test signal, a signal generator is employed. When an unknown systems frequency response needs to be illuminated, vector network analyzers detail system/component behavior. If a simple power measurement is needed, power meters/sensors are viable options.

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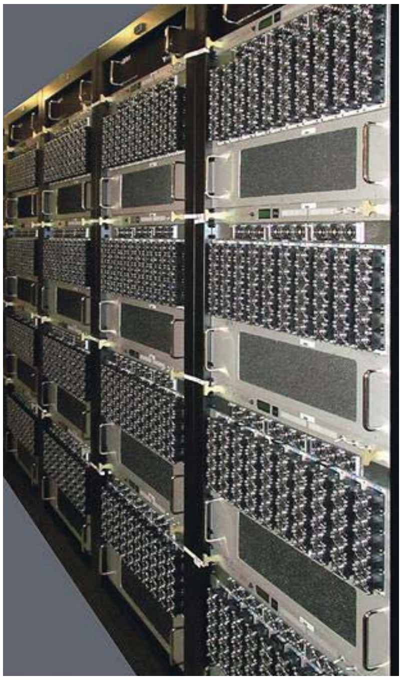
SOLID-STATE HF WIND PROFILER Transmits 250 kW

The power required by NASA to produce accurate radar wind profiling led to the development of the first solid-state HF wind profiler in the U.S.



1. The Doppler Radar Wind Profiler (DRWP) transmitter consists of 20 16-kW amplifier subsystems rated to deliver RF output power of more than 250 kW at 49.25 MHz.

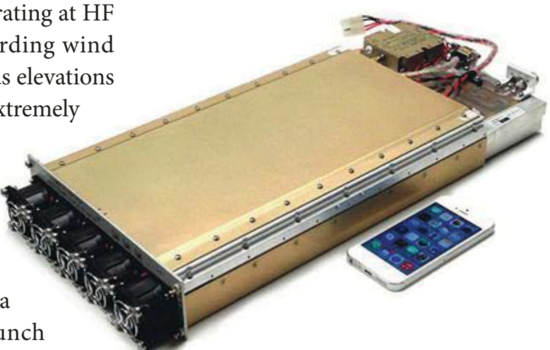
GENERATING VERY high RF power levels within the high-frequency (HF) range has always been the domain of vacuum tubes. Solid-state devices such as silicon LDMOS or bipolar junction transistors lacked the efficiency, ruggedness, or output power to make them viable solutions.

However, times and technologies change—Delta-Sigma Inc. leveraged solid-state technology to design and build a transmitter for NASA's Doppler Radar Wind Profiler (DRWP) at the Kennedy Space Center, Merritt Island, Fla. The system produces more than 250-kW HF signal power with ac-to-RF efficiency of nearly 50% and ruggedness surpassing that of vacuum tubes.

Radar wind profilers operating at HF provide accurate data regarding wind strength and speed at various elevations above Earth, making them extremely useful for assisting spaceflight, aviation, and meteorological applications. In spaceflight applications, for example, wind profiles are critical to the success of a mission. Even though a launch vehicle is quite strong, high winds can break it apart if loads are exceeded. Winds can also push it off course as it ascends, which can lead to a vehicle being ditched in the ocean. In either case, the result is a disaster, with people's lives potentially at stake and launch costs typically escalating to hundreds of millions of dollars.

Many solid-state radar wind profilers operating at UHF and lower microwave frequencies are deployed throughout the world for applications other than spaceflight. Thus, they're required to provide returns from relatively low altitudes.

HF radar profilers must profile winds to 60,000 ft., which demands megawatts of effective radiated power to produce detectable return signals from weak reflections from tiny atmospheric particles. As a result, the few HF wind profilers in existence are powered by vacuum tubes, a paradigm the new solid-state system is dedicated to changing. It will be able to deliver results every five minutes to altitudes of 10 miles above a launch site in increments of 150 m.



2. Delta-Sigma Inc.'s Valiant amplifier modules measure 2.25 × 8.5 in. × 18 in. They deliver 1.8 kW using Freescale MRFE6V61K25 LDMOS RF power transistors in the final amplifier stage.

BEYOND BALLOONS

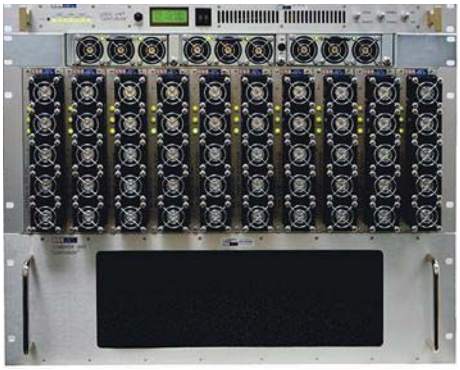
Although they might seem archaic, weather balloons (jimspheres) continue to be the sole determinant of wind conditions for spaceflight applications because previous radar profilers used decades-old technology. It goes to say, then, that NASA never considered those radar profilers to be reliable enough to replace jimsphere-generated measurements. Sensors on jimspheres are very precise and provide very accurate data, but jimspheres have significant disadvantages when compared to a radar profiler.

For example, multiple jimspheres must be launched at various times before each launch and require a crew to maintain and operate them, which means high operating costs. Once airborne, they typically drift as much as 60 miles away, where conditions may differ from those at the launch site. Conversely, a radar profiler is stationary and remains near the launch site.

In addition, jimspheres provide updated information only once per hour, making it unlikely that the latest data will be available at launch time. In contrast, the DRWP provides updated information every five minutes. Finally, because jimspheres continuously ascend, it's impossible for them to repeatedly provide data at 150-m increments of altitude like the profiler.

INSIDE THE DRWP TRANSMITTER

The transmitter developed by Delta-Sigma feeds an electronically steered array of three-element Yagi antennas covering several acres of area *(Fig. 1)*. The beam created by the array is sent straight up or at multiple angles, and its signals are reflected from particles in the atmosphere. Since signal returns from tiny atmospheric particles are quite faint compared to those from an aircraft or other solid structure, the system employs an extremely sensitive, low-noise receiver. The radar system processes the returns using custom software, and results are displayed at a control center for analysis.



3. The Centurion amplifier subsystem contains a 10-way power-combiner unit with filters, power monitoring, and T/R switch; a 240/208-V ac, three-phase power supply; 10 Valiant RF power-amplifier modules; and a logic unit to monitor and control.

The DRWP's transmitter is a modular system. At its core are 10 1.8-kW Delta-Sigma Valiant amplifiers *(Fig. 2)* that are mounted together in a rack. When combined, they form a Centurion amplifier subsystem *(Fig. 3)*. The 20 Centurion amplifiers in the transmitter each produce 16-kW power and are accompanied by a logic unit, three-phase power supply, 10-way power combiner, filter, patented high-speed transmit/receive (T/R) switches, and other components.

The DRWP transmitter operates in Class-AB bias conditions and produces 250-kW output. It's conservatively rated to meet NASA's requirements for redundancy and desired RF output power. However, the transmitter has demonstrated the ability to reliably generate 350 kW or more output power in the same configuration. While in the DRWP, it transmits a pulse-modulated signal, but the system can deliver the same output power in continuous-wave (CW) mode with a modified power supply.

The system employs a total of 400 model MRFE6V61K25 LDMOS RF power transistors from Freescale Semiconductor (www.freescale.com). They were selected for their ruggedness and reliability, even when exposed to large impedance mismatches and 3-dB overdrive conditions. A table with detailed specs is in the online version of this article at mwrf.com.

To ensure the transistors would meet the system's reliability requirements, Delta-Sigma performed three months of testing under pulsed and CW conditions, and subjected the devices to IR thermal imaging to detect hotspots. No failures were experienced during development or production.

System design required tight control of variations in gain, phase, and impedance among the hundreds of devices. This was done using advanced materials and proprietary design techniques, which made it possible to optimize performance within the overall size constraints imposed by the equipment shelter.

Each 2.25- × 8.50- × 18.00-in. Valiant amplifier module consists of one predriver device, one driver device, and two final amplifiers. Every final amplifier stage employs two MRFE-6V61K25 transistors capable of 1-kW CW output power that, when combined, produce 1.8 kW. Each module has five fans.

Since the DRWP's receiver is extremely sensitive, it was essential that the transmitter be designed to prevent current from flowing through the transistors when in receive mode (gating). No ringing is present when the amplifiers are gated on and off, and there's no effect on pulse shaping. The gating circuitry has rise and fall times of 30 ns, a transmit and receive switching speed of 3 μs, 60-dB isolation between the antenna and receive ports, and 0.3-dB insertion loss. The switch operates from a single +5-V dc supply, eliminating receiver interference caused by voltage spikes.

The logic unit uses software tailored for the DRWP that allows for system monitoring at several points down to the device level, with temperature resolution of 0.1°C when monitoring, say, the power combiners. Sensors are placed at critical points throughout the Valiant modules and Centurions to detect potentially damaging conditions, and the logic unit can send alerts to the operator via RS-232, RS-485, or Ethernet. The system also features hot-failover capability—if a module fails, power is somewhat reduced and the load is spread throughout the other modules.

The new DRWP was built by Detect Inc. (www.detect-inc.com) under contract to Vencore Inc. (www.vencore.com). The DRWP, under test since Dec. 2014, was used in several test launches. NASA will test the DRWP until later this year, at which time it should be certified as a key determinant of "go/no-go" launch decisions. When this occurs, it will be the only solid-state radar wind profiler in the U.S. with this distinction. mw

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	RCDAT-6000-30	0-30 dB	±0.4 dB	0.25 dB	✓	✓	-	$495
	RUDAT-6000-60	0-60 dB	±0.3 dB	0.25 dB	✓	-	✓	$625
	RCDAT-6000-60	0-60 dB	±0.3 dB	0.25 dB	✓	✓	-	$725
	RUDAT-6000-90	0-90 dB	±0.4 dB	0.25 dB	✓	-	✓	$695
	RCDAT-6000-90	0-90 dB	±0.4 dB	0.25 dB	✓	✓	-	$795
NEW	RUDAT-6000-110	0-110 dB	±0.45 dB	0.25 dB	✓	-	✓	$895
NEW	RCDAT-6000-110	0-110 dB	±0.45 dB	0.25 dB	✓	✓	-	$995
NEW	RUDAT-4000-120	0-120 dB	±0.5 dB	0.25 dB	✓	-	✓	$895
NEW	RCDAT-4000-120	0-120 dB	±0.5 dB	0.25 dB	✓	✓	-	$995

*120 dB models specified from 1-4000 MHz.
†No drivers required. DLL objects provided for 32/64-bit Windows® and Linux® environments using ActiveX® and .NET® frameworks.

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523 Rev D

JEAN-JACQUES DeLISLE | Technical Engineering Editor

Signal and Spectrum Analyzers Flex Bandwidth and Memory

To meet the needs of the latest industry demands, signal and spectrum analyzers are increasing in bandwidth, frequency, portability, and memory.

FLEXIBLE AND WIDER-BANDWIDTH signal/spectrum analyzers are being manufactured to meet the latest techniques, such as carrier aggregation, massive multiple input multiple output (MIMO), 5G, and the growth of automated test. As RF-to-digital conversion electronics have been separated from the processing or display devices, low-cost and highly versatile signal/spectrum analyzers have emerged that are either PC-controlled or PC-driven. Meanwhile, electronic-warfare (EW) and defense applications are moving far beyond telecommunications applications in their demands for performance and capabilities. These applications are demanding a shift in performance and versatility that is changing the face of signal/spectrum analyzers as we know it.

ANALYZING DEEPLY

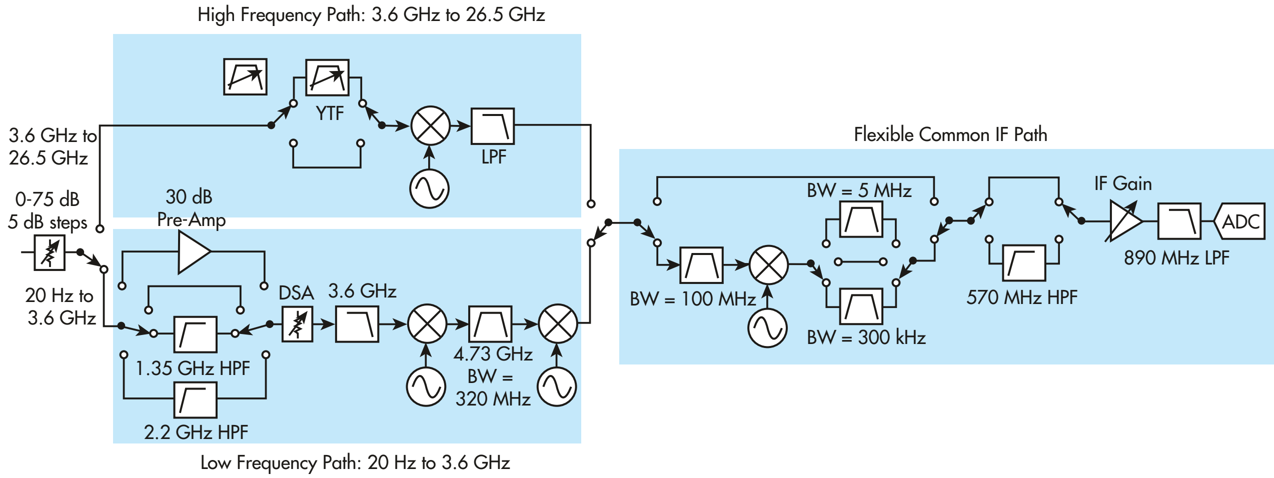
Without post-analysis, events or anomalies of interest in EW system integration or real-world testing are often long-term or very difficult to catch. This type of analysis also requires the use of sophisticated tools, such as MATLAB, and other computer-driven vector-signal-analysis tools. Deep-memory systems—with the ability to record, search, analyze, simulate, and replay over long periods—are becoming more necessary when analyzing and validating the latest EW technologies. For example, X-Com has developed a signal-analyzer-based system, the IQC91000A, with 1000 MHz of I/Q data record and playback from 0.5 to 18 GHz. This rack-mount device set works with commercially available signal analyzers and records up to 90 minutes continuously with 30 Terabytes of data storage.

The amount of memory needed to store the RF signal records increases with the record sample rate and resolution.

HIGHER HIGHS

Widening the analysis bandwidth of signal/spectrum analyzers is a growing necessity for industries ranging from telecommunications to EW. In addition, many cutting-edge technology developers are looking to extend native frequency coverage into the millimeter-wave bands. For 5G

The latest millimeter-wave projects often include the unlicensed bands between 57 and 64 GHz.



PCI-based test and measurement instruments are increasing in functionality and adoption. To support the latest wireless modulation techniques, bandwidths approaching 1 GHz or more are needed in a modular package.

research and millimeter-wave backhaul applications, frequencies must extend into the 60-GHz unlicensed bands as well as the lightly licensed 70-GHz, 80-GHz, and 90-GHz bands. Meeting these needs requires signal/spectrum analyzers with several gigahertz of analysis bandwidth and native frequency range beyond 60 GHz. High-quality and wideband harmonic mixers also are in demand, as they will extend the frequency range into the upper-millimeter waves.

In response to these trends, Rohde & Schwarz's R&SFSW67 signal and spectrum analyzer spans 2 Hz to 67 GHz while providing 2 GHz analysis bandwidth and 160 MHz real-time analysis bandwidth. The instrument boasts phase noise of -137 dBc/Hz at a 10-kHz offset with a 1-GHz carrier.

INCREASING MODULARITY

Modular instruments based on the AXI or PXI platforms have the ability to upgrade the processing and measurement components as the latest technologies become available. All of the system components—the display, digitizer, processor, memory, digital signal processor, mixers, and amplifiers—can be user replaced and upgraded as needed. Moreover, different programming and processing architectures can be used on these modular systems. For example, MATLAB, Labview, GNU Radio, and other tools can often be used alongside modular instruments to create custom modulation, demodulation, or analysis features. Another key aspect of the modular architecture is the opportunity to have a massively scalable system that can be expanded at a reasonable cost.

As an example of such systems, the PXIe-5668R modular vector signal and spectrum analyzer from National Instruments operates to 26.5 GHz with 765 MHz of instantaneous bandwidth over 3.6 GHz. It performs with a phase noise of -129 dBc/Hz at 10 kHz offset (800 MHz) with an average noise floor of -166 dBm/Hz at 1 GHz. These features enable quality measurements at 12 bits of maximum resolution. The 5668R uses a dual-signal path architecture with low- and high-frequency measurement paths working in tandem. As a result, low- and high-frequency performance is achieved without the compromises that would otherwise be necessary to cover the full range of frequencies.

New technology enables portable signal analyzers that offer advanced processing features for the signal-analyzer software and extremely deep recording capability.

RECORD, ANALYZE, AND CARRY

Designers are calling for increased portability and ruggedness in test equipment, a trend partially enabled by the hardware required to perform high-quality measurements, which is decreasing in size, weight, and cost. With their lower cost and smaller form factors, these devices are enabling more applications in telecommunications, EW, and signal-intelligence (SIGINT). For instance, standalone portable instruments can now feature ruggedized, commercially available computers and specialized signal/spectrum-analyzer hardware.

Defense Electronics serves electronic design engineers working in defense and aerospace markets with the latest technology-based news, design, and product information. It reviews the latest advances in electronics technologies related to military and aerospace electronic systems, from the device and component levels through the system level, also covering the latest developments in the software needed to simulate those defense/aerospace systems and the test equipment needed to analyze and maintain them. It is the industry's most trusted source of technical information for electronic engineers involved in military/aerospace circuit and system design.

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An example of a fully portable signal/spectrum analyzer is Aeroflex's CS9000SM broadband signal analyzer and recorder. Combining a portable signal/spectrum analyzer and a deep memory recorder, the CS9000SM can record to 12 GHz while providing 40 MHz of instantaneous bandwidth. Because the analyzer is also a portable computer, the analysis of real-time and recorded signals is possible with the multi-threaded system application software.

PC-controlled portable signal/spectrum analyzers have the benefit of being able to operate even with computing units with limited processing.

MASTERMIND PC CONTROL

PC-controlled signal/spectrum-analyzer units have digital-signal-processing (DSP) capability onboard, but rely on a PC for control and display. The device configurations are generally set by the computer control. The data requested by the computer is sent in pre-formatted data units, which the custom software translates into display data. An example is Aaronia AG's Spectran HF-60100 V4 X, which spans 9 kHz to 9.4 GHz with 50 MHz resolution bandwidth. The HF-60100 comes with custom software that operates on Windows, Linux, and Macintosh computers. It communicates to the computer via USB 2.0.

Another example is Berkeley Nucleonics Corp.'s RTSA7500. With 100 MHz of real-time bandwidth and a range to 27 GHz, the RTSA7500 can use its triggering—which is based on field-programmable gate arrays (FPGAs) for custom time-varying signal detection. The RTSA ships with several open-source application programming interfaces (APIs) for MATLAB, LabView, Python, C/C++, and SCIP/VRT. These APIs enable user-customizable and programmable control over 10/100/1G Ethernet.

PUMPING RF DATA

If the signal/spectrum analyzer's computational processing is removed to an external computer, a much lower-cost and smaller-form-factor analyzer will result. These PC-driven devices pass RF digitized signal data to an external computer, which analyzes, demodulates, and displays the outgoing signal data. The data for these instruments streams at extremely high rates for most common data bus architectures—in the hun-

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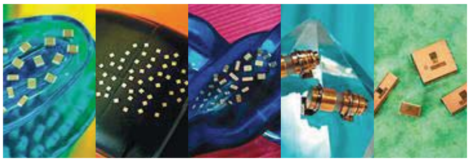
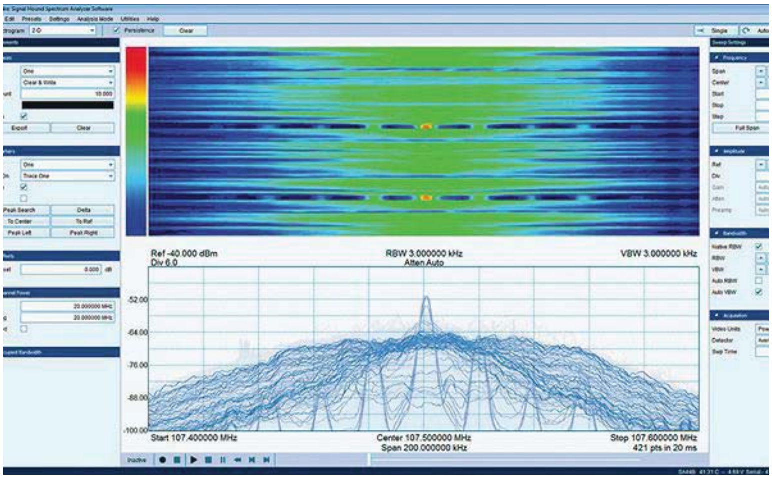


dreds of megahertz. As a result, powerful multicore processors are needed to analyze and demodulate the data. The most common databus option for these devices is USB 3.0 and Ethernet. Future versions may use the greater data pipe of USB 3.1 with the USB C variant, which can transfer both tens of watts of power and 10-Gb/s data-transfer speeds.

The RSA306 real-time spectrum analyzer from Tektronix, for example, covers 9 kHz to 6.2 GHz. The company claims that it provides 100% probability of intercept (POI) of 100 µs signals. With 40 MHz of bandwidth and an uncorrected analog-to-digital-conversion (ADC) rate of 112 MSamples/s at 14-bit depths, the RSA306 can stream an average of 224 MB/s to the PC. To make full use of the device's acquisition capability, common commercial Intel i7 processors (third generation and above) are recommended with 8 GB of RAM. Tektronix offers its SignalVu-PC software free for use with the RSA306 for both display and processing.

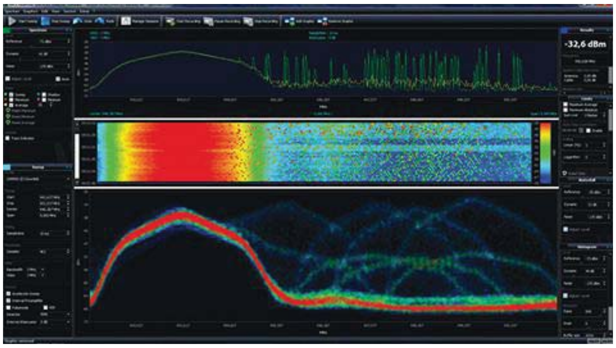


A lot of PC-driven signal/spectrum-analyzer software is shared free-of-charge and is often updated with new features requested by the user community.

Signal Hound's BB60C also offers USB 3.0 streaming of digitized RF data. Spanning 9 kHz to 6 GHz, the analyzer can stream 140 MB/s of sustained calibrated I/Q data with a sweep speed of 24 GHz/sec. With 27 MHz of instantaneous bandwidth and 75% overlapping Fast Fourier Transforms (FFTs),the BB60C also promises 100% POI of 1 µs signals. Due to commerce control (ECCN=3A002.c5), however, the analyzer does not natively offer frequency mask triggering (FMT). However, the BB60C is paired with a compiled API and open-source signal/spectrum-analyzer software that is open for community modifications and development.

DOUBLE-DUTY OSCILLOSCOPE

Some PC-driven oscilloscopes also can offer FFT-based spectral-frequency responses, such as the Picoscope 6000 series. This analyzer can operate from previously captured data to the full-frequency coverage of the instrument at 350 MHz of bandwidth and with operation to 1 GHz. The PicoScope software has controls for the spectrum-analyzer functions. However, this software is not as sophisticated as dedicated spectrum-analyzer software with waterfall displays, an API, or modulation functions.



PC-controlled signal/spectrum analyzers rely on the software that is bundled with the tool, as the user interface defines the experience and functionality of the equipment.

SMARTPHONE OR SPECTRUM ANALYZER?

The smartphone-sized spectrum analyzers from SAF Tehnika range to 40 GHz by taking advantage of the shrinking costs and footprints of microwave and millimeter-wave components. Using battery power, the Spectrum Compact displays up to 100 MHz of bandwidth at sweep speeds of 0.5 seconds. It can be paired with free PC software for saving, comparing, and analyzing spectrum data. The small size and weight limit the Spectrum Compact to low-resolution tests, as the processing power and footprint are too small for extreme performance. This isn't an issue for tower technicians and remote verification applications, which benefit more from portability and rapid data acquisition.

Throughout the signal/spectrum-analyzer market, several common themes are clearly developing: increasing frequency coverage, bandwidth, customization, and modularity. For EW and SIGINT applications in particular, deep memory and sophisticated analysis tools are also increasing in importance. To tackle the latest telecommunications standards, such as 5G, the focus is on carrier aggregation, MIMO, and cognitive radio. Signal/spectrum analyzers must also become more scalable while raising bandwidths into the gigahertz. Automated manufacturing and low-cost tests take a different angle, relying on external processing and storage units to decrease the cost and complexity of signal/spectrum analyzers. Here, there is also more focus on software-development environments to enhance features. mw

JACK BROWNE | Technical Contributor

Power Dividers/Combiners Help Minimize Losses

Whether by themselves or with other components, these RF/microwave power dividers/combiners help halve signal power in a wide range of systems, while also saving physical space.

COMBINING AND DIVIDING signal power has long been an important function in electronic systems ranging from commercial communications networks to space-based systems—essentially, wherever signals must be summed or distributed. Power dividers and combiners can be as simple as compact two-way components that split an input signal into two equal output signals each at one-half the power level of the input signal. They also can be quite complex, as evidenced by the multiway power combiners and dividers used in such applications as commercial in-building wireless communications networks and military phased-array radar systems.

Model 10A3NB-8S is an eight-way power divider with tapered output levels for use in L-band systems from 1100 to 1500 MHz.

By meeting some of the more complex requirements by squeezing power combiner/divider performance into compact housings, Renaissance Electronics & Communications (REC) is able to supply RF/microwave power dividers/combiners that meet a wide range of needs, while also saving space.

As an example, model 10A3NB-8S is an eight-way power divider *(see figure)* with tapered output levels, as might be used for phased-array applications. Designed for L-band use from 1100 to 1500 MHz in radar and communications systems, it works without attenuators, but divides input signals into outputs that are reduced by 18.4 dB, 12.4 dB, 8.6 dB, 6.7 dB, 6.7 dB, 8.6 dB, 12.4 dB, and 18.4 dB across the eight output ports.

Isolation between ports is 18 dB, and the eight-way divider exhibits VSWR of 1.43:1. It is designed to feed a fixed antenna with those eight staggered output signal levels. The unit handles 35 W CW input power and 350 W peak input power, and saves space by packing eight channels of power division into a housing measuring just 8.0 × 5.0 × 0.5 in.

Signals often must be processed across a range of frequency bands, so having a single power combiner that can handle multiple frequency bands can save the spaces for several components within the system. One example of this design approach is the model 16A4NAR multiple-band power combiner, designed for low passive-intermodulation (PIM) performance. It covers frequency bands of 806 to 960 MHz, 1,710 to 1,880 MHz, and 1,920 to 2,170 MHz with low loss and high isolation. The maximum insertion loss is 0.2 dB through 960 MHz and 0.5 dB from 1,710 through 2,170 MHz.

This wireless communications systems combiner handles power levels to 240 W average power. The frequency bands are well isolated from each other, with 65-dB separation from the band at 806 to 960 MHz and the bands at 1,710 to 1,880 MHz and 1,920 to 2,170 MHz. The band from 1710 to 1880 MHz is separated by 70 dB from the band at 806 to 960 MHz and by 65 dB from the band at 1,920 to 2,170 MHz. The band from 1,920 to 2,170 MHz is isolated by 70 dB from the 806-to-960-MHz band and by 65 dB from the 1,710-to-1,880-MHz band.

Although somewhat larger than the eight-way power divider, at 300.0 × 168.0 × 59.0 mm, this combiner can save space in a system by processing signals from multiple communications bands. It is designed for operating temperatures from −30 to +65°C and weighs 2.5 kg.

When space is tight, the firm offers multiple functions within a single housing. One such example is the model 10A4BV integrated switch and power divider, which operates from 380 to 2850 MHz with 120-dB isolation from the input to the output port. The unit measures 4.00 × 4.00 × 1.13 in. mw

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JACK BROWNE | Technical Contributor

Portable Analyzers Bring More Power to the Field

This family of spectrum analyzers and combination analyzers, which covers frequency ranges to 26.5 GHz, offers several new options that help ease in-field cable measurements.

SEVERAL LINES OF portable FieldFox handheld analyzers from Keysight Technologies now come with options that help improve measurements of high-frequency cables and cable assemblies. The analyzers include compact, portable vector network analyzers (VNAs) and combination instruments with frequency ranges starting at 30 kHz and reaching 4.0, 6.5, 9.0, 14.0, 18.0, and 26.5 GHz. There are also spectrum analyzers with full-band tracking generators for frequency coverage of 5 kHz to 4.0, 6.5, 9.0, 14.0, 18.0, and 26.5 GHz. The two new options deliver time-domain-reflectometry (TDR) cable measurement capability (Option 215) and extended range transmission analysis (Option 209). Option 215 is available for VNA and combination models, while Option 209 comes with the combination and spectrum-analyzer models.

Finding faults in communications cables requires a measurement tool that can help isolate and identify the fault under a wide range of environmental conditions *(see figure)*. Option 215 for the complements existing measurement capabilities within the FieldFox analyzers—the return-loss and distance-to-fault (DTF) measurement functions—to help isolate and identify coaxial cable faults.

The battery-powered FieldFox portable analyzers are available for use at frequencies to 26.5 GHz. Their combination of measurement functions make them suitable for harsh environmental conditions.

The TDR measurement option for the FieldFox cable and antenna analyzers measures the impedance changes along a cable and helps identify specific faults. The return-loss measurement function looks for impedance mismatches along the cable and at cable/connector junctions, while the DTF measurement capability identifies the distance from the analyzer to an identified fault. With the TDR option, the portable VNA instruments can simultaneously perform TDR and frequency-domain-reflectometry (FDR) measurements on coaxial cables.

Performing measurements on long runs of coaxial cable in the field is aided by a portable spectrum analyzer that features a built-in tracking generator and capabilities such as wide dynamic range, suitable frequency range, and fast processing speeds. The second option for the FieldFox analyzers (Option 209), Extended Range Transmission Analysis, enables in situ measurements on systems with long cable runs, including lossy microwave cables.

Thanks to their built-in tracking generators, a pair of FieldFox spectrum analyzers can perform cable fault measurements without calibrations or long warmup times. The two portable analyzers are step-synchronized with hardware triggers to perform an accurate analysis of long cable runs.

In addition, Option 209 can be configured with a frequency-offset function to measure communications cable runs with frequency-translation devices, such as RF/microwave mixers. The measurements exploit the spectrum analyzers' high selectivity to reject out-of-band signals and interference while providing a wide dynamic range to measure signals of interest (from the tracking generator). The instruments use a proprietary InstAlign spectrum-analysis technique to make accurate measurements on long cable runs with a pair of spectrum analyzers/generators without the need of calibration or warmup.

P&A: $1,000 added to the price for all combination analyzers and VNA models with Option 215 and $5,000 added to the price for all FieldFox combination analyzers and spectrum-analyzer models with Option 209. mw

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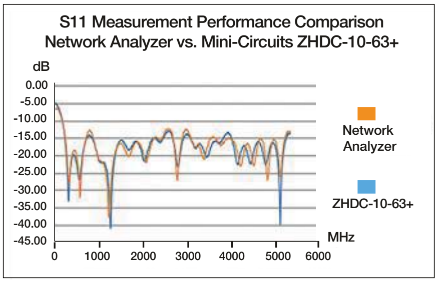

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538 rev A

JACK BROWNE | Technical Contributor

Switches Handle Heat of Automotive Applications

These broadband RF/microwave switches can operate as high as 6 GHz with AEC-Q100 Grade 2 certification to deal with the temperature extremes of automotive applications.

APPLICATIONS FOR HIGH-FREQUENCY COMPONENTS, such as switches, once meant systems in the home or a wireless-communications base station outside the home. But wireless components are increasingly taking to the road, i.e., automotive electronics. In that vein, a pair of broadband, high-speed switches from Peregrine Semiconductor meet Grade 2 AEC-Q100 requirements for applications ranging from –40 to +105°C.

Model PE423422 is a single-pole, double-throw (SPDT) switch with frequency range of 100 MHz to 6 GHz, while model PE423641 is a single-pole, four-throw (SP4T) switch with bandwidth of 50 MHz to 3 GHz. These low-cost RF/microwave switches join the firm's earlier model PE42359 SPDT switch (10 MHz to 3 GHz) in meeting Grade 2 AEC-Q100 automotive environmental requirements. And with their excellent electrostatic-discharge (ESD) ratings, they suit automotive-infotainment and traffic-safety applications.

The three automotive switches *(see figure)* draw upon Peregrine's UltraCMOS semiconductor process, a patented variation of silicon-on-insulator (SOI) technology using a sapphire substrate. UltraCMOS was developed to provide the high-frequency performance levels of gallium-arsenide (GaAs) semiconductor technology and high level of integration plus low cost of silicon CMOS technology. In addition, the PE423422 and PE423641 switches benefit from the company's HaRP technology for enhanced linearity and harmonic performance through their wide frequency ranges.

These three switches, which operate to 6 GHz with excellent electrostatic-discharge (ESD) ratings, also meet Grade 2 AEC-Q100 requirements for automotive-electronics applications from –40 to +105°C.

The earlier introduced 10-MHz to 3-GHz PE42359 SPDT switch features typical low insertion loss of 0.35 dB at 1 GHz and 0.5 dB at 2 GHz. Isolation between ports is typically 35 dB to 1 GHz and 21 dB to 2 GHz. This SPDT switch, with a typical 1-dB compression point of +33.35 dBm, runs on supply voltages as low as +1.8 V dc and achieves 2-μs typical switching time, from 50% control to 10% or 90% RF signal. The PE42359 squeezes into a six-lead SC-70 package and features high ESD tolerance of 2 kV per the human body model (HBM).

The new model PE423422 SPDT switch operates from 100 MHz to 6 GHz with low insertion loss of 0.25 dB to 1 GHz, 0.40 dB to 3 GHz, 0.65 dB to 5 GHz, and 0.90 dB to 6 GHz. The isolation between ports is typically 41 dB to 1 GHz, 28 dB to 3 GHz, 20 dB to 5 GHz, and 16 dB to 6 GHz. The switch, which runs on a +2.3- to +5.5-V dc supply range, offers 2-μs switching speed, from a 50% control signal to a 10% or 90% RF signal level. It handles input signals to +34 dBm with typical input compression of only 0.1 dB. The switch comes in a 12-lead 2- × 2-mm QFN package and is rated for ESD of 1 kV per the HBM on all pins.

The new SP4T model PE423641 controls 50 MHz to 3 GHz with low insertion loss of 0.5 dB to 1 GHz and 0.65 dB to 2.2 GHz. It achieves isolation between ports of 32 dB to 1 GHz and 25 dB to 2.2 GHz. The typical switching speed from 50% control to 10%/90% RF signal is 1 μs. The switch, which operates on +1.8- and +2.75-V dc levels, offers a +37-dBm typical input 0.1-dB compression point. It's supplied in a 16-lead 3- × 3-mm QFN package.

These three low-cost, RoHS-compliant packaged switches are control components that, unlike conventional CMOS devices, will be immune to latch-up conditions. In addition, blocking capacitors aren't required on the RF ports if dc isn't present. Although all three switches feature high ESD ratings, they should be handled with the precautions used for any ESD-sensitive device. With their wide frequency and temperature ranges, they should fit more than a few emerging automotive applications. mw

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Affordable Analyzers Bring Real-Time Measurements

The RTSA7500 real-time spectrum analyzers include models spanning 100 kHz to 8, 18, and 27 GHz.

REAL-TIME SPECTRUM ANALYZERS can add a great deal of measurement power and versatility to a test setup, but often are beyond the limits of many budgets. Fortunately, the RTSA7500 real-time spectrum analyzer series from Berkeley Nucleonics includes four models—with frequency ranges to 27 GHz and real-time bandwidths as wide as 100 MHz—all at reasonable price points.

As with many newer spectrum analyzers, the RTSA7500 instruments are supplied in compact housings *(see figure)*. They leverage the processing and display capabilities of personal computers (PCs) to process and show measurement results while helping to save customers on the final price.

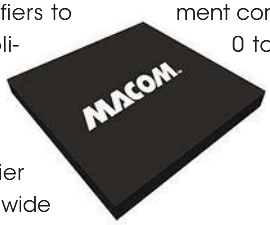
The four models are the RTSA7500-8B, with measurement range of 100 kHz to 8 GHz and maximum real-time bandwidth of 10 MHz; the RTSA7500-8, with measurement range of 100 kHz to 8 GHz and maximum real-time bandwidth of 100 MHz; the RTSA7500-18, with measurement range of 100 kHz to 18 GHz and maximum real-time bandwidth of 100 MHz; and the RTSA7500-27, with measurement range of 100 kHz to 27 GHz and maximum real-time bandwidth of 100 MHz.

The spectrum analyzers include a +12-V dc power input port for running on automotive and vehicular power supplies. Also, they can work with 10-MHz external references as well as their own internal frequency reference. The analyzers can be used locally as well as remotely, via software and Internet control. The RTSA7500 real-time spectrum analyzers are also available from Saelig Co. (www.saelig.com), Berkeley Nucleonics' U.S. technical distributor.

BERKELEY NUCLEONICS CORP., 2955 Kerner Blvd., San Rafael, CA 94901; 415-453-9955, FAX: 415-453-9956, *www.berkeley-nucleonics.com*

Wideband Amplifier Drives DC to 50 GHz

BOOSTING COMMUNICATIONS SIGNALS across wide bandwidths usually suggests a number of amplifiers to cover multiple bands. But a single compact amplifier in die form from MACOM Technology Solutions, the model MAAM-011109-DIE, covers the full bandwidth of dc to 50 GHz and provides a number of flexible controls that enable this low-noise amplifier (LNA) to tailor performance as needed across that wide frequency bandwidth.



MACOM's new offering is a broadband LNA capable of 15-dB gain from DC to 50 GHz.

Model MAAM-011109-DIE *(see figure)* is fully matched to 50 Ω and exhibits better than 15-dB return loss and more than 15-dB gain across the full frequency range. The typical noise figure of the MAAM-011109-DIE is 3.5 dB. The amplifier delivers +21 dBm output power at 1-dB compression. It has a third-order intercept point of +29 dBm.

The RoHS-compliant component has gold-plated contact pads and backside and is 100% on-wafer dc and RF tested. It measures 1.97 × 1.30 × 0.1 mm and draws 190 mA from a +5-V dc supply. It includes a gate-bias adjustment control that provides 15-dB gain control (from 0 to −1 V dc) and includes a temperature-compensated power detector that provides a dc voltage relative to the output power for consistent performance over changing environmental conditions.

"The DC-50 GHz operation, adjustable bias control for power and gain, and low noise performance make the device a highly versatile solution for multiple wideband applications," says Paul Beasly, a MACOM product manager. "The amplifier is well suited for diverse broadband applications, including in electronic-warfare (EW) systems and in test-and-measurement equipment.

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

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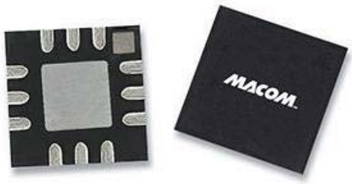
Amp Powers 6 to 18 GHz

MODEL BHE69189-50 is a rack-mountable broadband amplifier capable of 50 W saturated output power from 6 to 18 GHz. It typically provides more than 40 W output power into a 2.0:1 VSWR load with 45 dB typical gain. The amplifier exhibits second harmonics of less than –12 dBc and third harmonics of less than –22 dBc; spurious levels are better than –60 dBc. The amplifier is based on power gallium-nitride (GaN) device technology and designed for operating temperatures from –20 to +50°C. It measures 19.0 × 22.0 × 2.4 in. and weighs 40 lbs.

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

PIN Switch Runs 30 MHz to 3 GHz

RICHARDSON RFPD is now supporting a single-pole, double-throw (SPDT) PIN diode switch from MACOM Technology Solutions (www.macom.com) for applications from 30 MHz to 3 GHz. The switch, model MASW-011055, is supplied in a common-



anode configuration and can handle continuous-wave (CW) power levels to 100 W. Suitable for high-power pulsed and CW signals, the switch exhibits low insertion loss of 0.35 dB at 2 GHz and high isolation of 51 dB at the same test frequency. The switch is RoHS-compliant and +260°C reflow-compatible. It is ideal for use in land mobile radio and MIL-COM applications that require high CW and pulsed power operation. The switch achieves 500 ns typical switching speed and is supplied in a lead-free 5-mm HQFN 12-lead plastic package.

RICHARDSON RFPD, 1950 S. Batavia Ave., Ste. 100, Geneva, IL 60134; (630) 262-6837, *www.richardsonrfpd.com*

Board-Level Material Beats Heat and EMI

COOLZORB 400 is a unique board-level material that functions both as an absorber of electromagnetic interference (EMI) and a conductor of thermal energy. The silicone-based material can improve the signal integrity and thermal stability of electronic circuits. It is applied like a traditional printed-circuit-board (PCB) thermal interface material; it is placed between a source of heat, such as a power transistor, and a heat sink or metal package or chassis. The material meets requirements of the UL94 V0 flammability standards. Standard sheet sizes are 12 × 12 in. in standard thicknesses of 0.020, 0.040, and 0.100 in., although other thicknesses can be made to order.

LAIRD, 3481 Rider Trail South, Earth City, MO 63045; (636) 898-6000, FAX: (636) 898-6100, *www.lairdtech.com*

Coaxial Adapters Link DC to 65 GHz

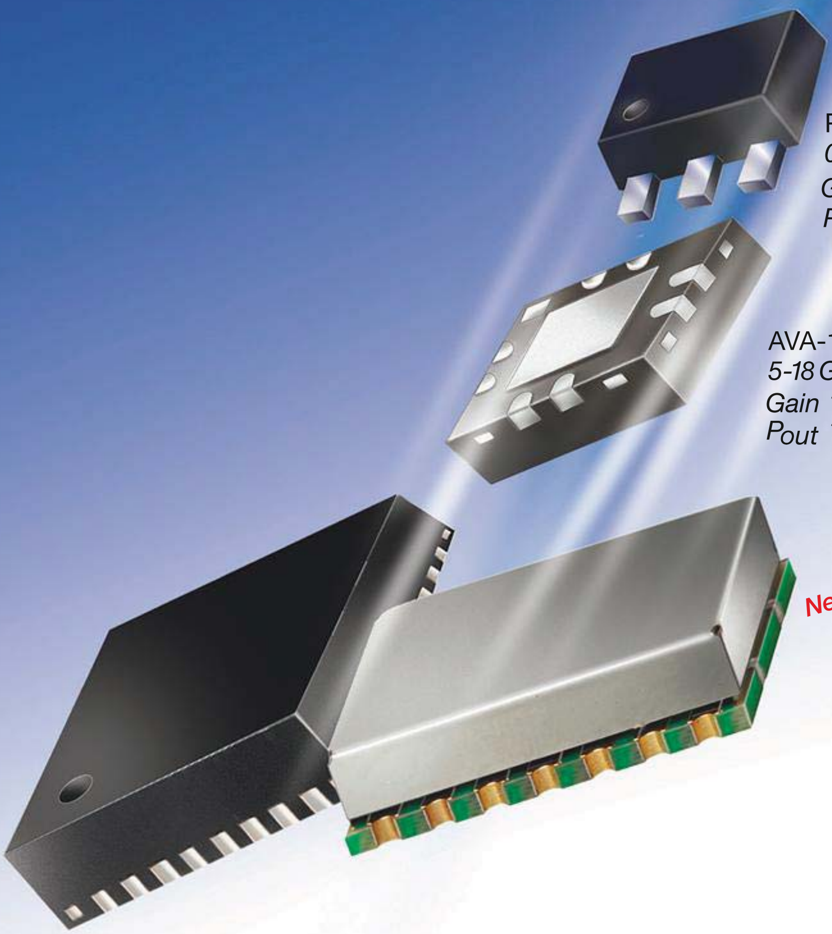
THE RMAD.BS.NMDXX between-series adapters include interface combinations in Type-N, 3.5-mm, 2.92-mm, 2.4-mm, and 1.85-mm connector types with a total frequency range of dc to 65 GHz to facilitate measurement applica-

tions. The adapters are usable over operating temperatures from 0 to +85°C with stainless-steel bodies and gold-plated BeCu center contacts. Typical insertion loss includes 0.20 dB with typical VSWR of 1.15:1. Custom combinations of connectors are also available.

RESPONSE MICROWAVE INC., 94 Jackson Rd., Ste. 110, Devens, MA 01434; (978) 772-3767; e-mail: info@responsemicrowave.com, *www.responsemicrowave.com*

50 MHz to 26.5 GHz

MICROWAVE MMIC AMPLIFIERS



Mini-Circuits' New AVM-273HPK+ wideband microwave MMIC amplifier supports applications from 13 to 26.5 GHz with up to 0.5W output power, 13 dB gain, ±1 dB gain flatness and 58 dB isolation. The amplifier comes supplied with a voltage sequencing and DC control module providing reverse voltage protection in one tiny package to simplify your circuit design. This model is an ideal buffer amplifier for P2P radios, military EW and radar, DBS, VSAT and more!

The AVA-183A+ delivers 14 dB Gain with excellent gain flatness (±1.0 dB) from 5 to 18 GHz, 38 dB isolation, and 19 dBm power handling. It is unconditionally stable and an ideal LO driver amplifier. Internal DC blocks, bias tee, and microwave coupling capacitor simplify external circuits, minimizing your design time.

The PHA-1+ + uses E-PHEMT technology to offer ultra-high dynamic range, low noise, and excellent IP3 performance, making it ideal for LTE and TD-SCDMA. Good input and output return loss across almost 7 octaves extend its use to CATV, wireless LANs, and base station infrastructure.

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478 rev Q

USB Controls Amps to 40 GHz

A LINE of RF/microwave amplifiers features Universal Serial Bus (USB) 2.0 interfaces for control and programming by means of a computer connection. They can be operated by means of easy-to-use downloadable software running on any Windows-based computer. Amplifiers are available for bandwidths of 50 MHz to 18 GHz or 50 MHz to 40 GHz, with typical noise figure of 4.5 dB, gain of 12 dB, and 1-dB compression point of +10 dBm. The firm also offers USB-controlled single-pole, double-throw (SPDT) switches and attenuators with similar bandwidths to 40 GHz. All models operate over temperatures from –40 to +85°C and, depending upon frequency, are available with SMA or 2.92-mm coaxial connectors.

PASTERNACK ENTERPRISES, INC., 17802 Fitch, Irvine, CA 92614; (866) PASTERNACK, (866) 727-8376, (949) 261-1920, FAX: (949) 261-7451, e-mail: sales@pasternack.com, *www.pasternack.com*

Relay Switches Run to 10 Million Cycles

A LINE of electromechanical relay switches includes models covering frequencies from dc to 40 GHz and rates for 2 to 10 million cycles of use. They are available in a wide range of configurations, from single-pole, double-throw (SPDT) switches to single-pole, 12-throw (SP12T) switches. Qualified to MIL-STD-202 requirements, the switches handle power levels from 5 to 700 W with low insertion loss of 0.15 dB at 1 GHz and high isolation, as much as 85 dB depending upon frequency. The switches are available for operating voltages from +12 to +30 V dc.

FAIRVIEW MICROWAVE, INC., 1130 Junction Dr., No. 100, Allen, TX 75013; (800) 715-4396, (972) 649-6678, FAX: (972) 649-6689, e-mail: sales@fairview-microwave.com, *www.fairviewmicrowave.com*

Small Signal Generators Spare Cost, Not Performance

A LINE of miniature signal generators provides excellent performance for reasonable cost. The ASG Series signal generators, which are available with Ethernet or USB control (and also available with an RS-232C interface), cover frequency ranges of 25 to 300 MHz and 25 to 6000 MHz with 1-Hz frequency resolution. The compact signal generators deliver as much as +13 dBm output power to 3 GHz and as much as +10 dBm output power to 6 GHz. Phase noise is –96 dBc/Hz offset 10 kHz from a 1-GHz carrier, –94 dBc/Hz offset 10 kHz from a 3-GHz carrier, and –85 dBc/Hz offset 10 kHz from a 6-GHz carrier. Spurious content is no greater than –50 dBc and typically only –70 dBc, while harmonic levels are typically –25 dBc. The ASG series signal generator modules measure just 21 × 72 × 100 mm and weigh only 300 g.

ATLANTECRF, A DIVISION OF ATLANTIC MICROWAVE LTD., 40A Springwood Dr., Braintree, Essex CM7 2YN England; (+44) (0) 1376 550220, FAX: (+44) (0) 1376 552145, e-mail: sales@atlantecrf.com, *www.atlantecrf.com*

Low-Noise Amps Drive Cells to 2600 MHz

A COLLECTION of eight low-noise, variable-gain-amplifier (VGA) modules has been developed for Long-Term-Evolution (LTE) and WCDMA infrastructure applications. The models SKY65369-11, SKY65370-11, SKY65371-11, SKY65372-11, SKY65373-11, SKY65374-11, SKY65375-11, and SKY65376-11 operate from 700 to 2600 MHz with low return loss and high gain. As an example, model SKY65369-11 operates from 832 to 862 MHz with 42-dB small-signal gain, a better than 35-dB gain-control range, and better than 20-dB return loss. It has a noise figure of 0.85 dB and is well suited for small cells operating in this frequency range. Each unit in the amplifier series is supplied in a compact 16-pin MCM 8 × 8 × 1.3 mm package.

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

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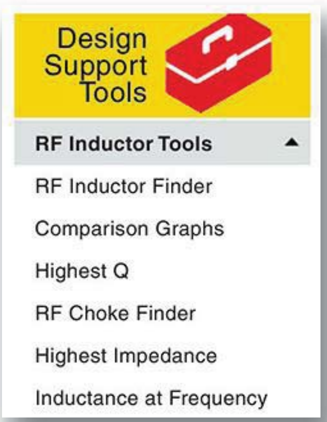

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