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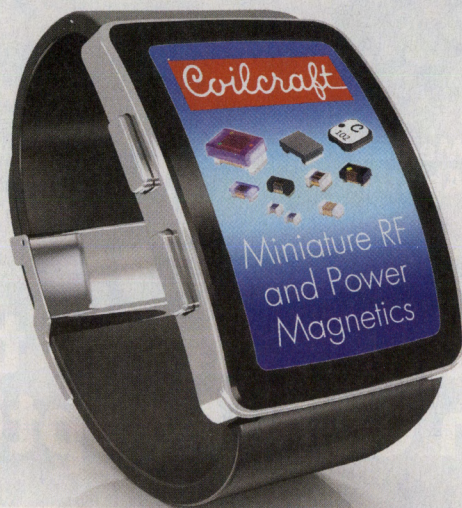
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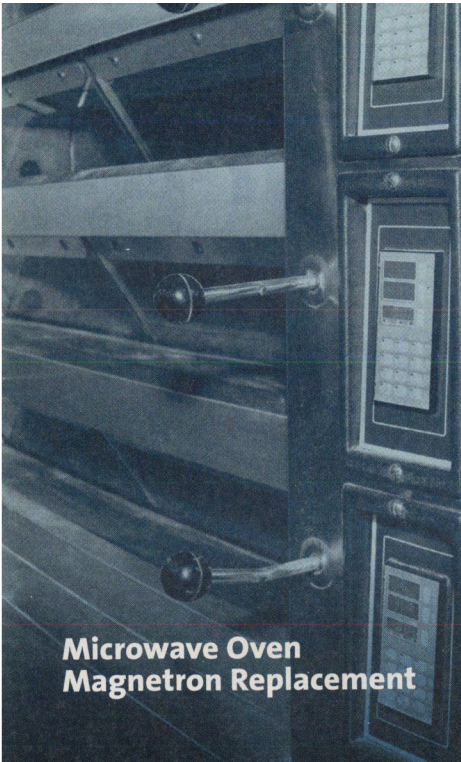
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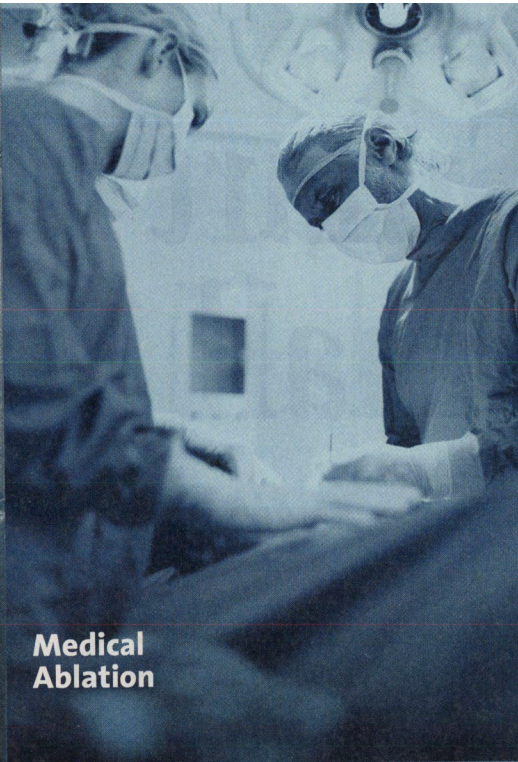


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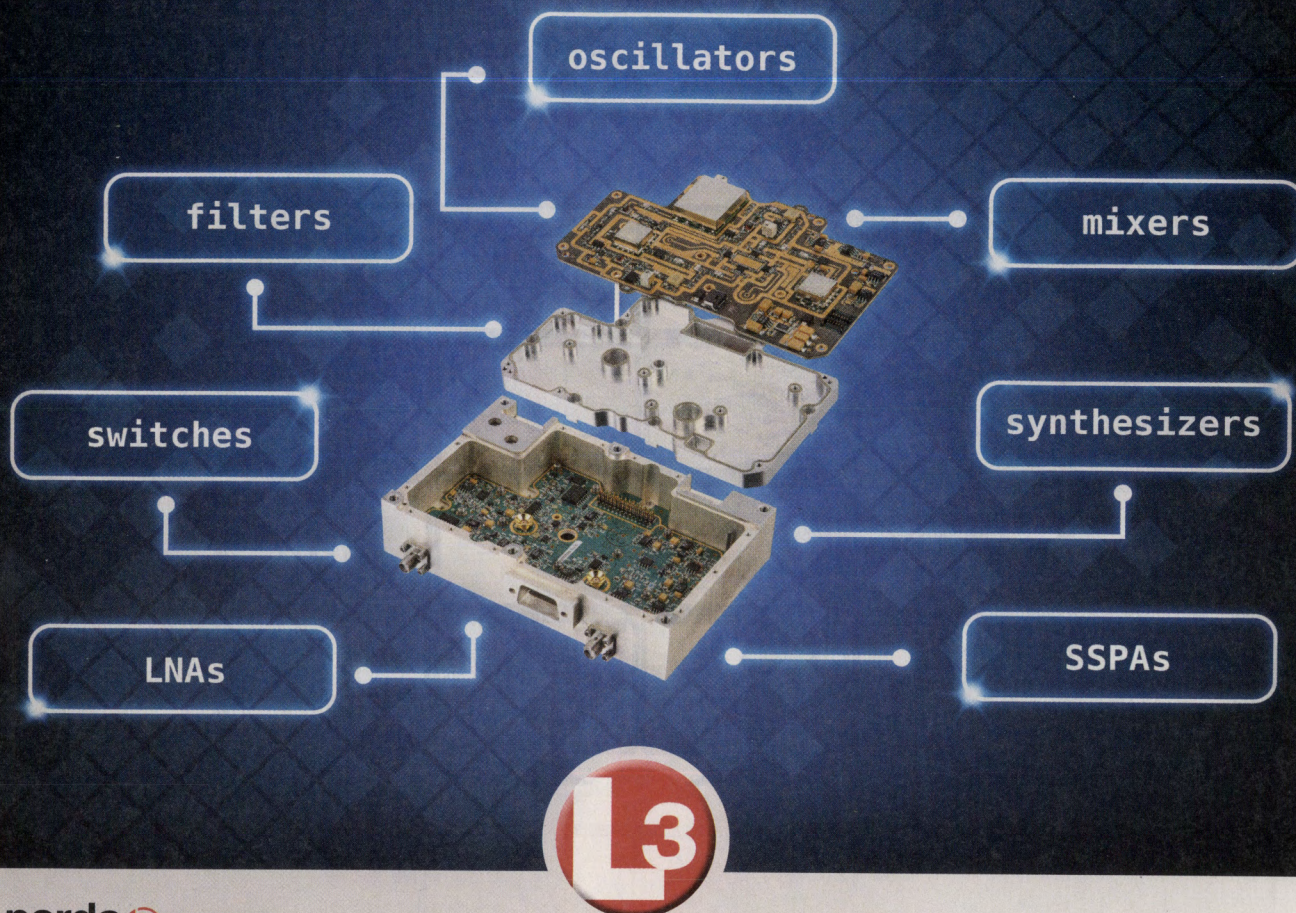
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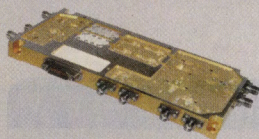
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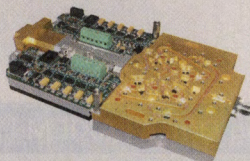
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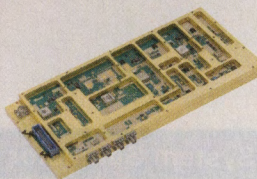
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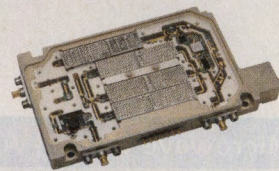
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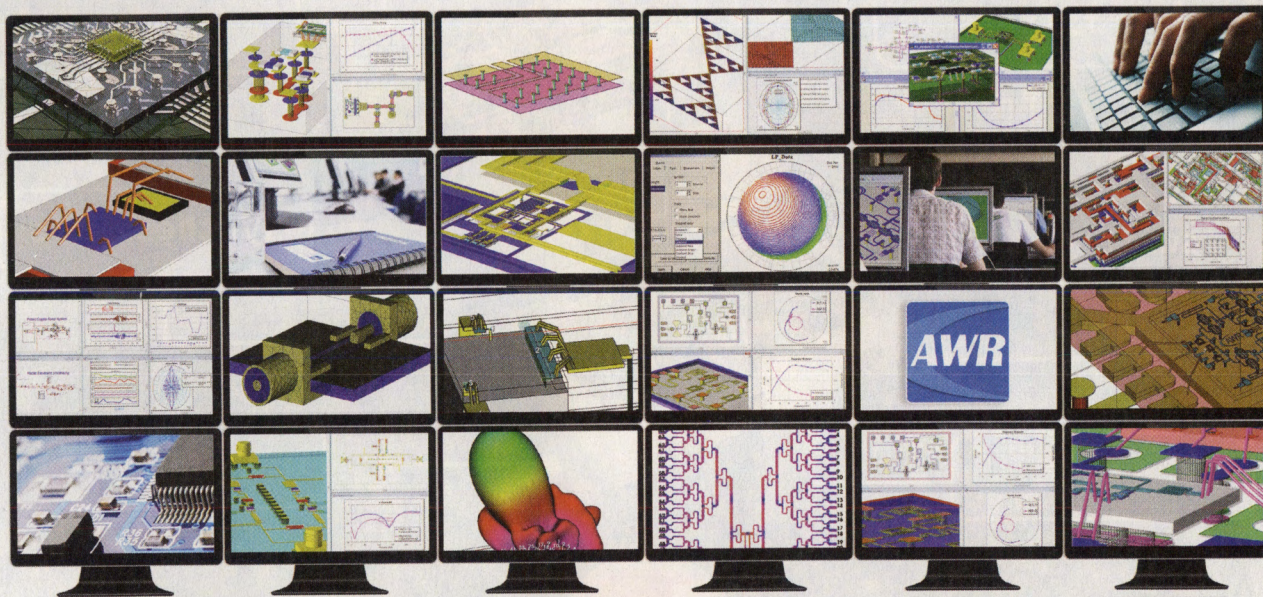
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In This Issue

FEATURES

63 COVER STORY:

MODULAR VSA PUSHES TO 50 GHZ

A 50-GHz PXIe vector signal analyzer is just one of the latest additions to a growing lineup of modular test instruments for RF/microwave signal generation and analysis.

48 VSA HELPS SIMPLIFY HARMONIC MEASUREMENTS

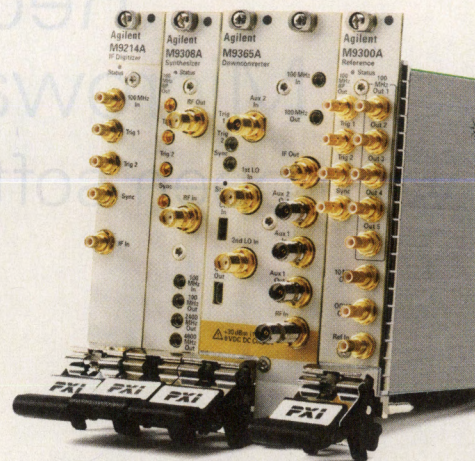
A vector signal analyzer is a powerful tool for measuring the harmonic signal levels of wireless communications standards with wideband modulation formats.

55 DECODING DISCRETE POWER TRANSISTORS

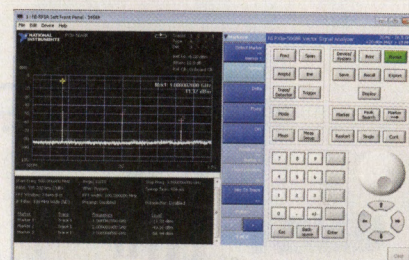
GaN discrete transistors are filling many higher-frequency requirements for high output power.

58 UNTANGLE THE MYSTERIES OF TRANSMISSION LINES

Transmission lines vary, creating challenges during the fabrication process when using different active- and passive-circuit components.



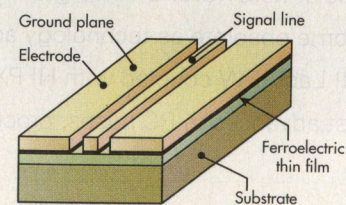
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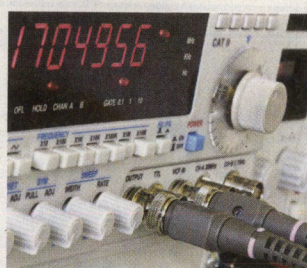
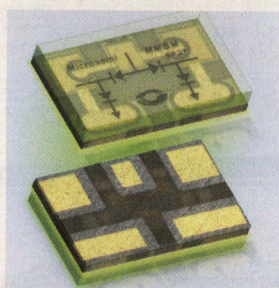


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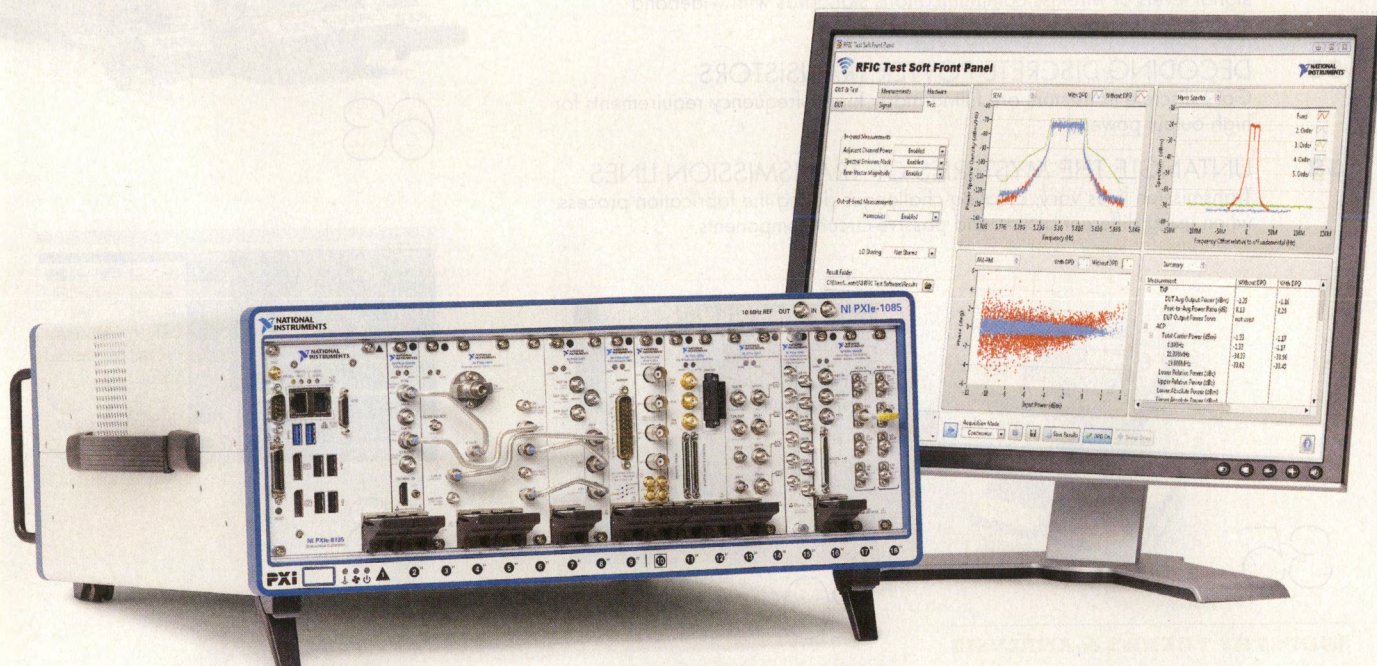
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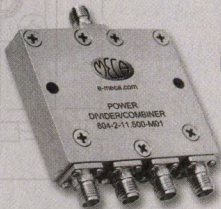
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BNC, RPSMA, RPTNC & 7/16
Up to 150 watts

Low PIM Attenuators



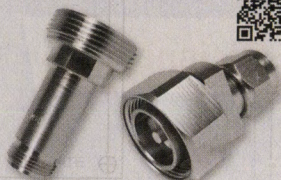
50 & 100 Watt
6, 10, 20 & 30 dB
N, 4.1/9.5 / 4.3/10.0 & 7/16 DIN

Low PIM Terminations



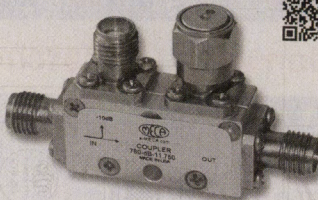
380 MHz - 2.7 GHz
10 watts - 250 watts
N, 4.1/9.5 & 7/16 DIN

Low PIM Adapters



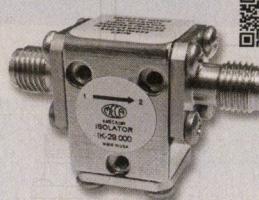
Up to 18 GHz
SMA, N, 4.1/9.5 & 7/16
RG, LMR & T-flex

Directional Couplers/Hybrids



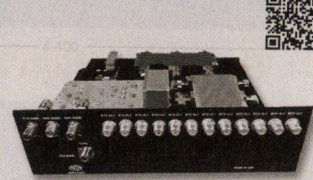
0.4 - 40 GHz
SMA, 2.92, QMA, N,
TNC, BNC, RPTNC & 7/16
Up to 500 watts

Circulators/Isolators



Up to 40 GHz
SMA, 2.92, N, & 7/16
Up to 250 watts

Low PIM & D.A.S. Equipment



Terminations, Attenuators,
Splitters, Adapters & Jumpers
N, 4.1/9.5 & 7/16

BETTER BUILDINGS / BETTER NETWORKS



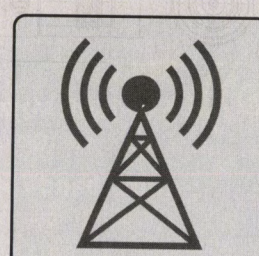
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& Military



Aeronautical/Space
Transportation

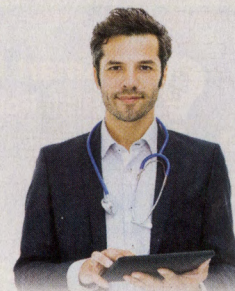


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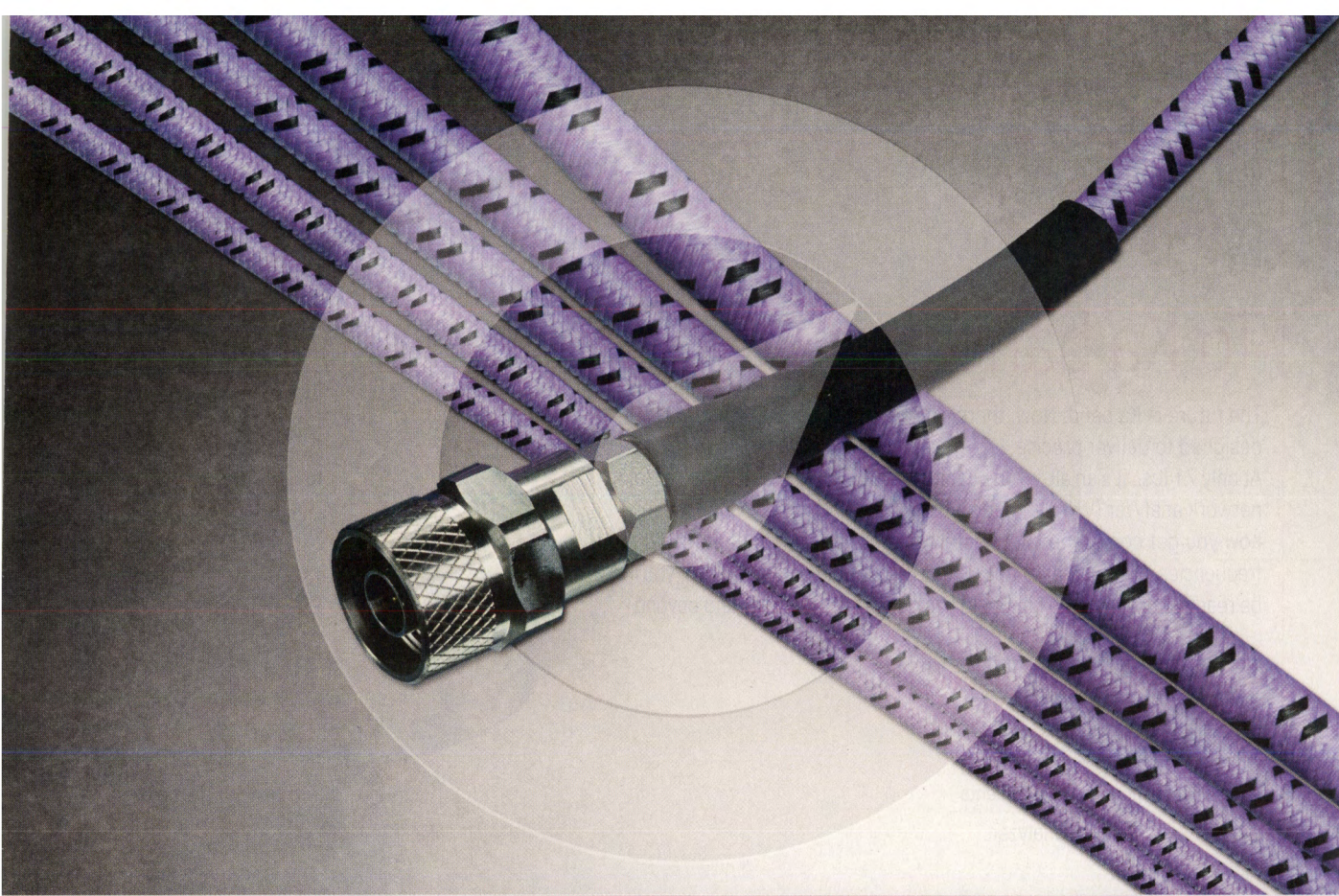
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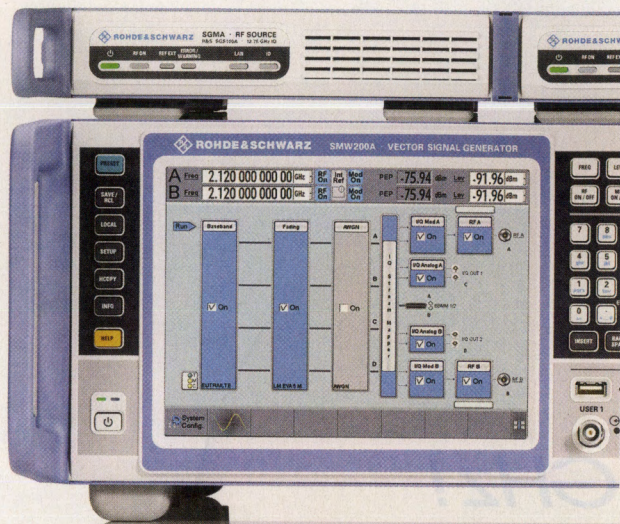


IMAGE GALLERY: SIGNAL GENERATORS

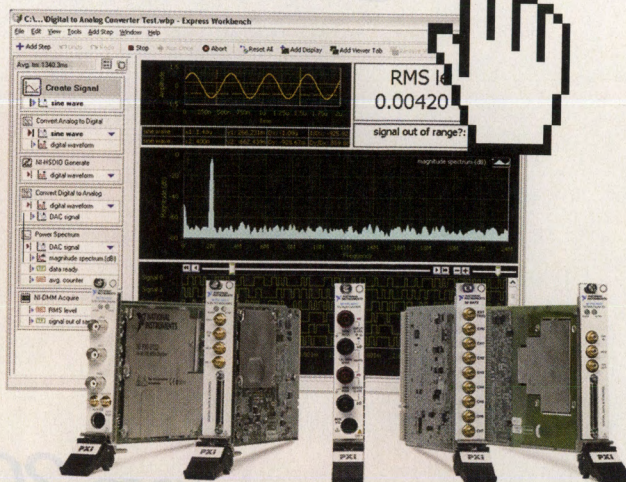
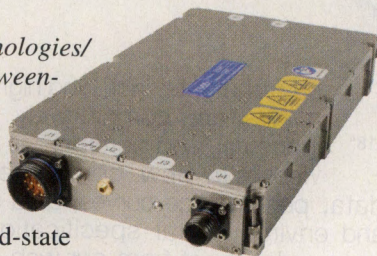
http://mwrf.com/test-measurement-generators/gallery-10-signal-generators-testing-microwave-and-rf-systems#slide-0-field_images-38091

Microwave and RF testing requirements are pushing the development of signal generators with wider bandwidths, greater flexibility, and more advanced capabilities. This *Microwaves & RF* image gallery takes a look at some of the latest signal generators for testing wireless components, devices, and systems.

WHAT'S THE DIFFERENCE BETWEEN TWTAs AND SSPAs?

<http://mwrf.com/technologies/what-s-difference-between-twtas-and-sspas>

Where size and weight were once clear differentials between tube and solid-state amplifiers, traveling-wave tubes and their power supplies have become considerably more compact.



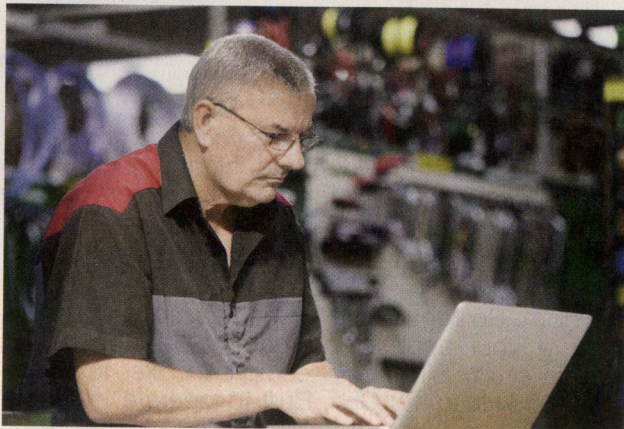
IS MODULAR REALLY MORE FOR LESS?

<http://mwrf.com/blog/modular-really-more-less>

Technical Contributor Jack Browne's latest blog notes that many of the major test-instrument suppliers have embraced newer modular instrument formats and are offering many different measurement functions in modular form. But are they that much better than the old benchtop format of RF/microwave test instruments?

OPTIONS FOR RF CIRCUIT-LEVEL DESIGN

<http://mwrf.com/software/assessing-options-rf-circuit-level-design>



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Editorial

CHRIS DeMARTINO

Technical Editor

chris.demartino@penton.com



MILCOM 2015 Showcases Technology Innovations

I recently had the opportunity to attend MILCOM 2015 in Tampa, Fla. A large number of companies participated in the exhibition, with exhibitors ranging from defense contractors to components suppliers—and much more in between. Given the circumstances of our world today, it is important to realize the significance of military communications, and the technology required to enable it.

The Internet of Things (IoT) was a major theme, and the subject of a number of technical panels. Specifically, the IoT's impact on the defense industry was a main topic of discussion: Technologies required for IoT deployment, as well as various challenges concerning the IoT were focal points of the panels. It is clear that the IoT will have a significant impact in the defense realm. The weight of this impact, as well as the weight of the IoT's impact in general, is something that will take form as we head into the future.

The exhibition itself was the center of a great deal of activity, as a wide range of products was displayed. Software-defined-radios (SDRs), for instance, were showcased by several companies. Ettus Research (www.ettus.com), a National Instruments company, was on the floor with its USRP E310, a pocket-sized, stand-alone SDR that covers 70 MHz to 6 GHz. Ancortek (www.ancortek.com), a Virginia-based startup, demonstrated the SDR-KIT 2500B, which is a 25-GHz SDR evaluation kit. And Spectranetix (www.spectranetix.com)—another supplier of SDRs—also participated in the exhibition.

A variety of amplifiers was presented by several exhibitors, such as AR Modular RF (www.arwww-modularrrf.com). The company's new AR-20KT model is a portable boost-amplifier that operates from 30 to 512 MHz. Ramona Research (www.ramona-research.com) was promoting its PAUK-20 quad-band power amplifier (PA). This PA can provide high-power outputs in four different frequency bands. And Comtech Xicom Technology (www.xicomtech.com) showcased the SuperPower Series of traveling-wave-tube-amplifiers (TWTAs), which can provide output power as high as 2 kW.

Many other products and services were presented at MILCOM. Various devices, components, and systems were prominently displayed. Design software also had a strong presence thanks to companies like Remcom (www.remcom.com), Computer Simulation Technology (www.cst.com), and Altair Engineering (www.altair.com).

MILCOM clearly demonstrated some of the innovative technology in the RF/microwave industry. However, the event also served as a grim reminder of the volatility in today's world. Because of our present-day conditions, the technology that the RF/microwave industry can provide will be especially needed. **mw**

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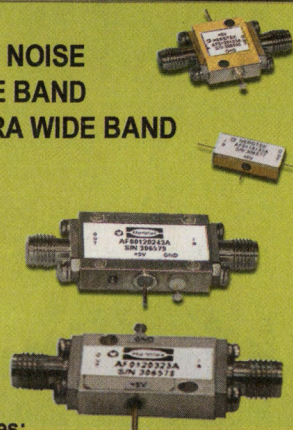


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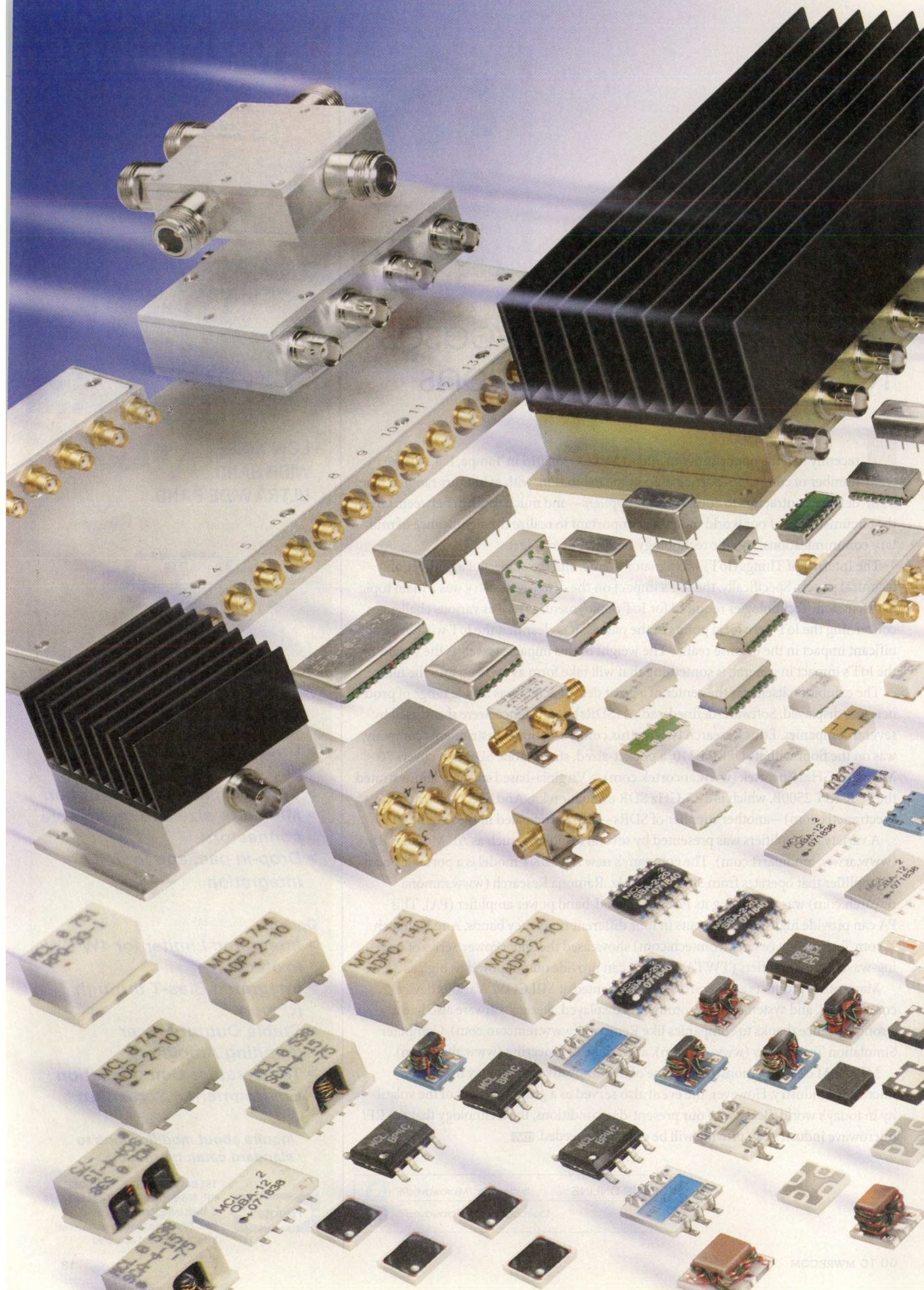
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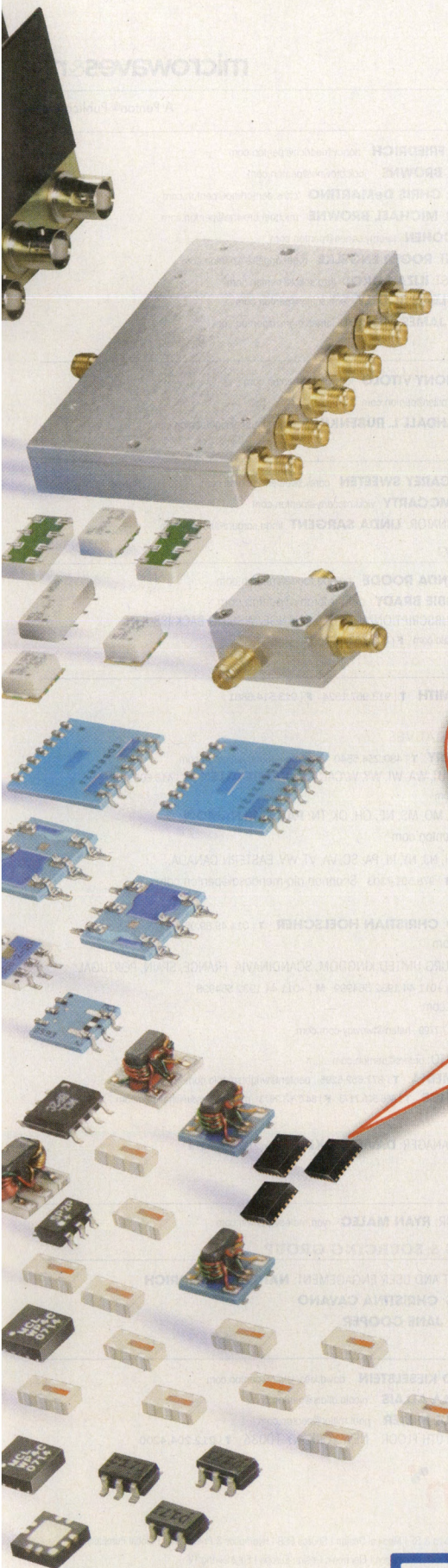
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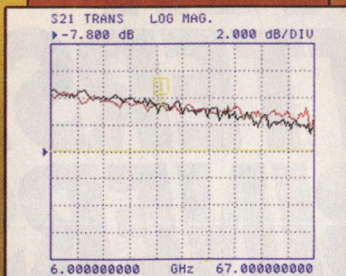
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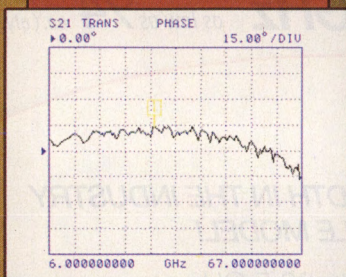
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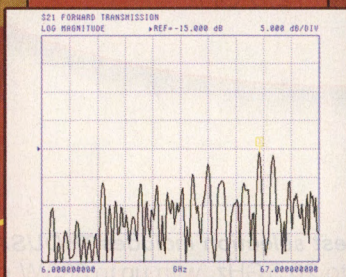
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OCTAVE BAND LOW NOISE AMPLIFIERS

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

NARROW BAND LOW NOISE AND MEDIUM POWER AMPLIFIERS

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
LA001-2110	0.01-0.10	18	4.0 MAX, 2.2 TYP	+10 MIN	+20 dBm	2.0:1
LA001-2211	0.04-0.15	24	3.5 MAX, 2.2 TYP	+13 MIN	+23 dBm	2.0:1
LA001-2215	0.04-0.15	23	4.0 MAX, 2.2 TYP	+23 MIN	+33 dBm	2.0:1
LA001-3113	0.01-1.0	28	4.0 MAX, 2.8 TYP	+17 MIN	+27 dBm	2.0:1
LA002-3114	0.01-2.0	27	4.0 MAX, 2.8 TYP	+20 MIN	+30 dBm	2.0:1
LA003-3116	0.01-3.0	18	4.0 MAX, 2.8 TYP	+25 MIN	+35 dBm	2.0:1
LA004-3112	0.01-4.0	32	4.0 MAX, 2.8 TYP	+15 MIN	+25 dBm	2.0:1

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MODULAR MUSINGS

I enjoyed your article "Is Modular Really More for Less?" [Note: This is the Nov. 4 installment of Technical Contributor Jack Browne's "Measuring Progress" blog, and can be found on mwrf.com.] I'm one of those Old Engineers! Modular instrumentation can be compelling if

your DUT has a large number of inputs/outputs, or if size and mobility of the test setup are stringent requirements.

Life-cycle cost, ROI, compatibility risk, etc., need to be well-understood before revolutionizing a test system. Depending on the age and architecture of the legacy software, writing new soft-

ware that retains lessons learned, trade secrets, etc., and leverages the greater performance of the new instrumentation, will consume a large majority of the budget and schedule of the project.

Until recently, all of the modular RF/microwave instruments topped-out at 6 GHz (which is fine for RF), but makes them irrelevant when the functional requirement is up to 50 GHz. Except for low-power requirements, power supplies will continue to have either a half-rack or full-rack form factor. For measurements with triggering requirements, migrating from GPIB to LXI may be a more economical approach.

It will be interesting to see how modular instrumentation evolves. I appreciate your focus on test-and-measurement topics.

DOUGLAS STROTHER

EDITOR'S NOTE

Thank you for your kind words. I have long enjoyed visiting and working with some of the top test-instrument providers in this industry, as well as sharing feedback with them on what users need most. The same is true for those of us who write about technology for a living: We rely on readers such as yourself to let us know if we are on the mark or not.

But the most important thing is that we are writing about something that is useful to you, the reader. Thank you again for your interest.

JACK BROWNE

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Microwaves & RF welcomes mail from its readers.

The magazine reserves the right to edit letters appearing in "Feedback."

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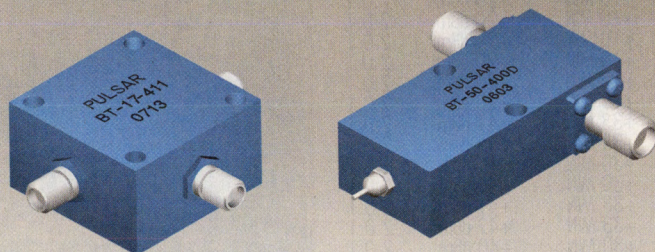
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10-1000 MHz	25	0.5	1000	1.20:1	BT-20
800-1000 MHz	30	0.5	5000	1.50:1	BT-21
1700-2000 MHz	30	0.5	5000	1.50:1	BT-22
500-2500 MHz	25	1.0	200	1.20:1	BT-02
10-3000 MHz	25	1.8	3000	1.50:1	BT-06-411
500-3000 MHz	25	1.0	500	1.20:1	BT-05
500-3000 MHz	30	1.8	2000	1.50:1	BT-23
10-4200 MHz	25	1.2	200	1.20:1	BT-03
1000-5000 MHz	35	1.0	1000	1.50:1	BT-04
100-6000 MHz	30	1.5	500	1.50:1	BT-07
0.5-10 GHz	30	1.0	200	1.50:1	BT-26
100 KHz - 12.4 GHz	40	1.5	700	1.60:1	BT-52-400D
100 KHz - 18.0 GHz	40	2.0	700	1.60:1	BT-53-400D
0.3-18.0 GHz	25	1.5	500	1.60:1	BT-29
30 KHz - 27.0 GHz	40	2.2	500	1.80:1	BT-51
30 KHz - 40.0 GHz	40	3.0	500	1.80:1	BT-50
30 KHz - 70.0 GHz	30	3.5	500	2:00:1	BT-54-401
30 KHz - 85.0 GHz	30	4.0	500	2:00:1	BT-55-401

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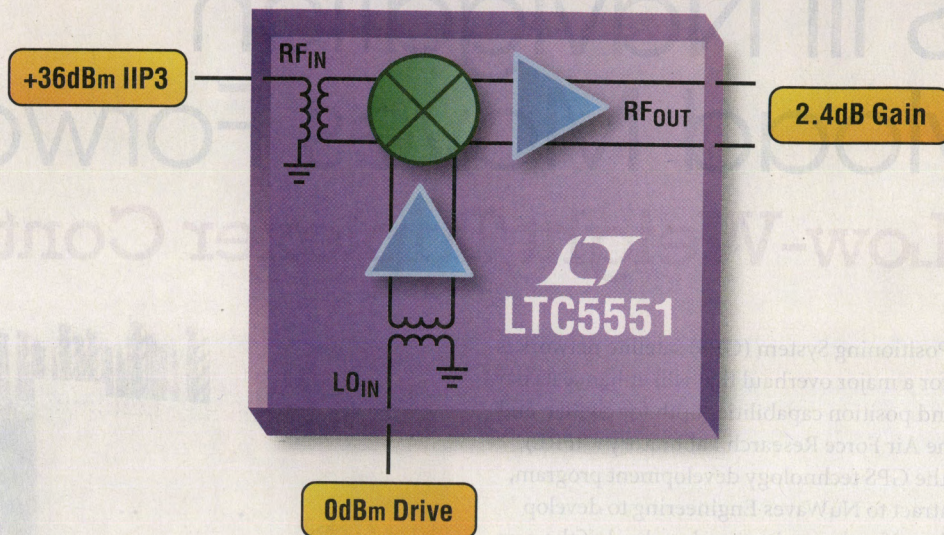
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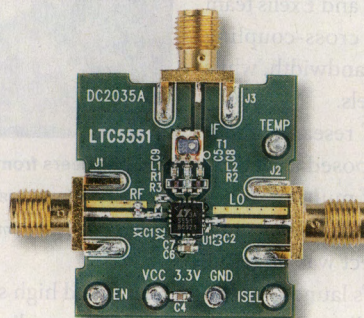
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News

GPS III Navigation Payload Moves Forward with Low-Weight Triplexer Contract

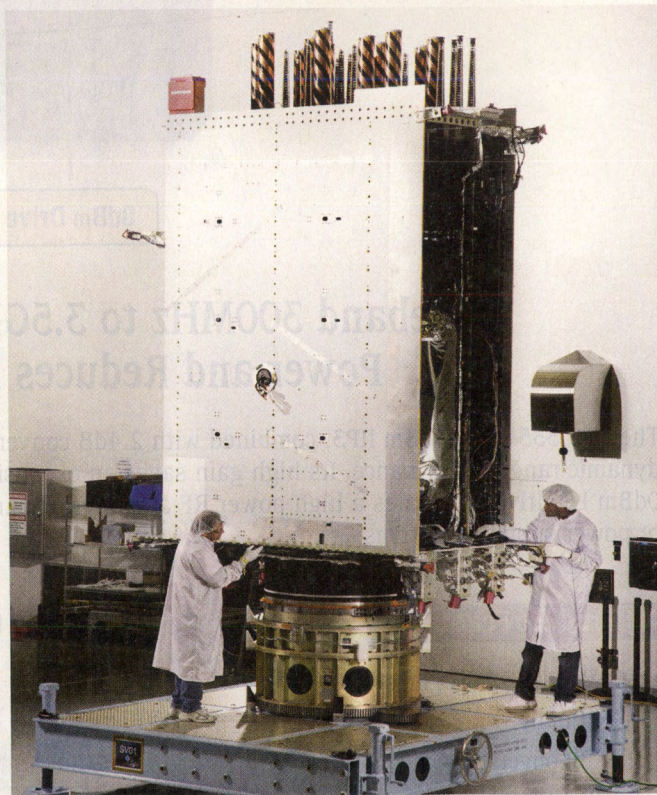
The Global Positioning System (GPS) satellite network is preparing for a major overhaul that will enhance its navigation, timing, and position capabilities both for civilian and military users. The Air Force Research Laboratory (AFRL), which is leading the GPS technology development program, has granted a contract to NuWaves Engineering to develop an advanced triplexer for the navigational payload of the new GPS III satellites.

NuWaves, which supplies RF and microwave components to the Department of Defense (DoD) and commercial satellite companies, recently received an extension on its Small Business Innovation Research (SBIR) contract, which was originally issued last year. The company completed the first phase of the contract with support from Exelis Geospatial Systems' Positioning, Navigation and Timing division, and will again work with Exelis engineers on the triplexer project.

The contract entails the design and testing of a new broadband triplexer that not only exhibits high-power handling but also delivers low insertion losses over the L-band—the primary spectrum range for GPS carriers. The NuWaves and Exelis team will also incorporate advanced filtering and cross-coupling technologies to minimize loss and maximize bandwidth, while also maintaining high isolation between channels.

The triplexer project builds upon NuWaves' research under the first phase of the contract. The team proposed a method to significantly reduce the size and weight of multiplexers—diplexers, triplexers, and quadplexers—for multi-carrier radio frequency (RF) signal transmission. The project was targeting “a significant reduction in the GPS III satellite's launch weight, reducing cost to orbit,” according to Jeff Wells, president of NuWaves.

To that end, NuWaves developed a prototype of a GPS L1-band cavity filter and subjected it to a series of multipaction tests. The approach involved using specialized inserts within the filter cavities, resulting in a design that supports wider band-



Two engineers from Lockheed Martin prepare the first GPS III satellite for system-level testing at the company's Denver-area satellite facility earlier this year. (Image courtesy of Lockheed Martin)

widths and high signal power levels. The results of the research project are guiding the design of the new triplexer, according to a statement from NuWaves.

The attempt to reduce the size and weight of the navigational payload aligns with the AFRL's broader development program. Based out of the Wright-Patterson Air Force Base in Ohio, the AFRL program is focused on exploring advanced L-band signal

options and manufacturing components that reduce the size, weight, power, and cost of the GPS satellite payload. According to Colonel David Goldstein, director of the AFRL's space vehicles directorate, the laboratory has thus far targeted new L-band antenna concepts, gallium-nitride (GaN) amplifiers, on-orbit waveform generators, and signal combining methods.

For Exelis, which was acquired by Harris Corp. earlier this year, the triplexer project is simply a footnote to its long history with the GPS satellite constellation. Joe Rambala, vice president and general manager of the GPS division at Harris Corp., notes that the company has built technology for every GPS navigation payload ever launched. According to recent reports, Harris is competing for a new series of contracts that will be issued next year, once the Air Force determines whether subsequent GPS III satellites will have a fully digital navigational payload.

The fully digital payloads, however, will not make it onto the first eight GPS III satellites, which Lockheed Martin is building

under contract at its GPS III Processing Facility near Denver. The evolution of the GPS constellation is being led by the Global Positioning Systems Directorate at the U.S. Air Force Space and Missile Systems Center. Lockheed Martin says that the GPS III satellites will deliver signals that are three times more accurate than the aging Block IIF satellites, assimilating legacy signals from the current satellite network and new types of signals. These include the jam-resistant military M-code and civil signals such as L1C, L2C, and L5.

The GPS III satellites were originally scheduled for launch in 2014, but significant delays have pushed back this timescale to around 2017. According to Rambala, the AFRL has given out L-band contracts to Ball, Boeing, and Northrop Grumman, in addition to Exelis and NuWaves. Lockheed Martin's website notes that the GPS III satellites will have an operational life of longer than 15 years—about 25% longer than the latest Block IIF vehicles. ■

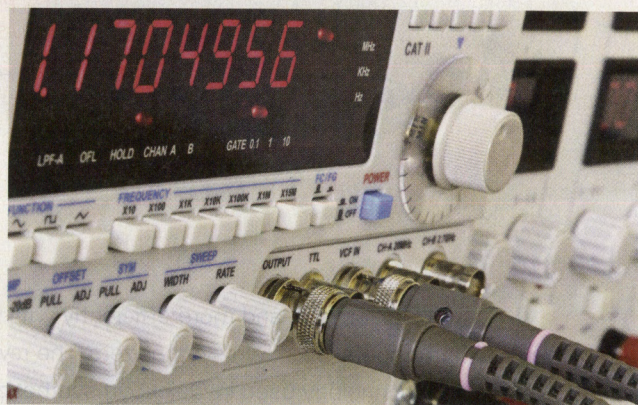
MODERN COMMUNICATIONS DRIVES Demand for Signal Generators

THE EVOLUTION OF wireless standards, such as LTE-Advanced and IEEE802.11ah, has increased demand for signal generators that can accurately test telecommunications equipment and electrical components, according to a recent report from the research firm Markets and Markets. These new standards in wireless communications are causing significant growth in the signal-generator market, the report says.

The market for signal generators is expected to earn revenues of approximately \$1.22 billion in 2020, up from the \$755 million earned last year, the report says. The report analyzes the entire market, from general-purpose and function generators to microwave and RF instruments. The main reason for the market's growth, the report says, is the growing need to test complex communication systems. Specifically, the report underlined the complex modulation techniques and communications standards that are emerging around 5G wireless networks.

The telecommunications industry, the report states, will remain the largest customer for signal generators over the next five years, followed closely by electronics manufacturing. In North America, which will hold the largest share of the global market, signal generators remain a necessary tool in aerospace, defense, and telecommunications testing. In Asia, on the other hand, the growth of electronics manufacturing is expected to bolster demand for these instruments.

For communications, there are two main types of signal generators. In general, RF signal generators operate below 6 GHz and are geared toward testing telecommunications equipment. While older RF signal generators are still necessary to test equipment using 2G and 3G signals, many wireless operators are starting to phase out or recycle the bands reserved for these networks. The other kind, microwave signal generators, operate in



As wireless protocols have become more complex, signal generators have been pushed to wider bandwidths and more automated functions. (Image courtesy of Thinkstock)

higher frequencies and are mostly used for testing radar systems, satellite and aerospace equipment, and electronic warfare (EW) components.

The report notes that one of the main restraints on the market comes from the intense competition among companies to keep prices down. Several RF signal generators, such as the DSG800 Series from RIGOL Technologies and the Windfreak SynthNV, have starting prices under \$2,000. On the other hand, certain RF vector signal generators, which can accurately replicate signals recorded by an analyzer in the field, can command prices over ten times that amount. Keysight's N5172B EXG RF vector signal generator, for instance, costs \$22,295.

In an interview with *Microwaves & RF*, Riadh Said, platform manager for Keysight's Microwaves and Communications division,

noted that the cost of signal generators also varies with phase noise, bandwidth, output power, and modularity. In response, manufacturers are releasing software upgrades that not only target wireless standards but also control the power, frequency, and modulation of the instrument. The report notes that manufacturers have

also started to design custom equipment for specific industries.

The report notes that signal generators have the most potential for growth in the development of human-machine interfaces, especially as technology within the Internet of Things (IoT) becomes more automated with software and embedded processors. ■

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WI-FI NETWORK MAKING Progress in NYC Subway Stations

IN 2010, the New York Metropolitan Transit Authority (MTA) announced that it would begin to roll out Wi-Fi and cellular voice and data service in New York City subway stations. The announcement launched an infrastructure project that would involve feeding miles of optical cable under the city streets and building a wireless network that supported several major wireless carriers. An independent benchmarking firm, Global Wireless Solutions (GWS), recently evaluated the current status of the project. The firm tested which stations commuters



With the New York City subway serving almost 1.7 billion people per year, city officials have been moving to expand wireless access in underground stations. (Image courtesy of Matias Garabedian via Wikimedia Commons)

could expect to successfully connect to Wi-Fi and cellular networks and what kind of quality they could expect.

The wireless infrastructure is being installed by Transit Wireless, a New York-based company formed explicitly to design Wi-Fi and cellular coverage in the New York City subway. The firm—a subsidiary of Broadcast Australia—won the contract from the MTA in 2007 to build out the network and maintain the infrastructure for 25 years. Once the network is installed, commuters will be able to connect to AT&T, Sprint, T-Mobile USA, and Verizon Wireless networks, or sign on to Wi-Fi via the Transit Wireless network.

The tests showed that the project, which is scheduled for completion in 2018, is still a work in progress. GWS tested 67 underground stations with access

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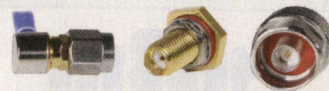
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to the public transit network and revealed that stations on the Q line provide the highest quality of experience on mobile phones. On the other hand, the 4 line was the worst-performing for Wi-Fi connections, with only 2 of 22 stations having access to Wi-Fi networks. In addition, the tests confirmed that six stations had no detectable Wi-Fi signals.

The underground network is based on the concept of a distributed antenna system (DAS). RF nodes are installed in each station

and send out signals to other antennas in the station, providing cellular voice and data coverage through the carrier networks, or Wi-Fi service through the Transit Wireless network. According to Nathan Cornish, director of RF engineering at Transit Wireless, the RF nodes are connected back to the Transit Wireless base station hotel via optical fiber. In the base-station hotel, the major cellular carriers each operate a separate base station and equipment supporting 3G, 4G, and LTE networks.

To test the availability and quality of these networks, GWS used a portable benchmarking system, the QualiPoc Freerider from SwissQual, a subsidiary of Rohde & Schwarz. Using five Samsung Galaxy S5 smartphones as measurement channels, the instrument examined voice, video, and message data from carrier networks. The metrics included upload and download speeds and task attempts and completions. For Wi-Fi, the average upload speed was 7.8 Mbits/s and the average download speed was 8.7 Mbits/s. Using mobile data, on the other hand, the average upload speed was 5.6 Mbits/s and the average download speed was 12.8 Mbits/s.

With the New York City subway serving almost 1.7 billion commuters per year, city officials have been committed to expanding wireless access into stations. "The city of New York has not been shy with its intentions to dramatically increase Wi-Fi and mobile connectivity for city dwellers and visitors over the past few years," says Dr. Paul Carter, chief executive of GWS.

"Adding and improving wireless service at more subway stations provides a much-anticipated boost to riders' experience in one of the world's busiest and oldest subway systems," said New York Gov. Andrew Cuomo last year, when the Transit Wireless project expanded into the borough of Queens. He added that cellular and Wi-Fi services could also improve responses to emergencies in the subway and provide more accurate train information to commuters.

According to the Transit Wireless website, about 120 of 279 stations in the subway system have been outfitted with cellular and Wi-Fi services. Transit Wireless anticipates a complete rollout of Wi-Fi services to all stations by 2017, ahead of the 2018 schedule. ■

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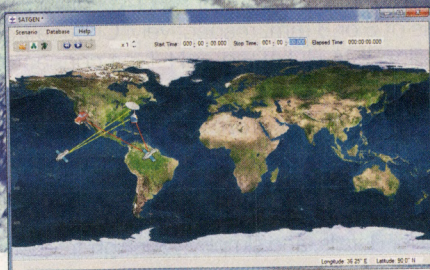
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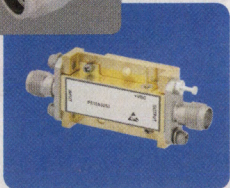
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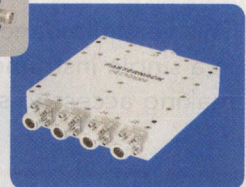
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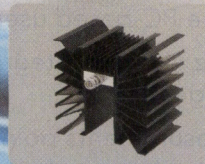
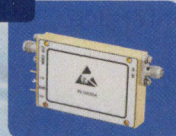
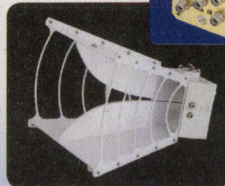
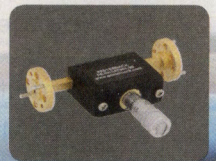
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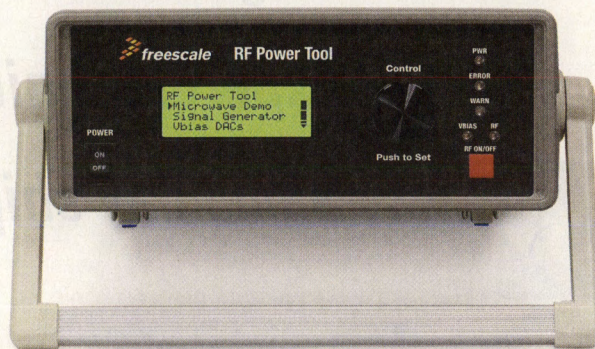
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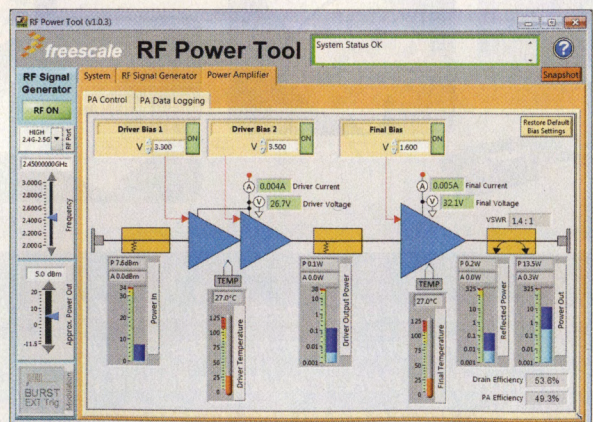
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Inside TRACK

with
Jiyoun Munn,

Technical Product Manager of RF, COMSOL

Interview by CHRIS DeMARTINO

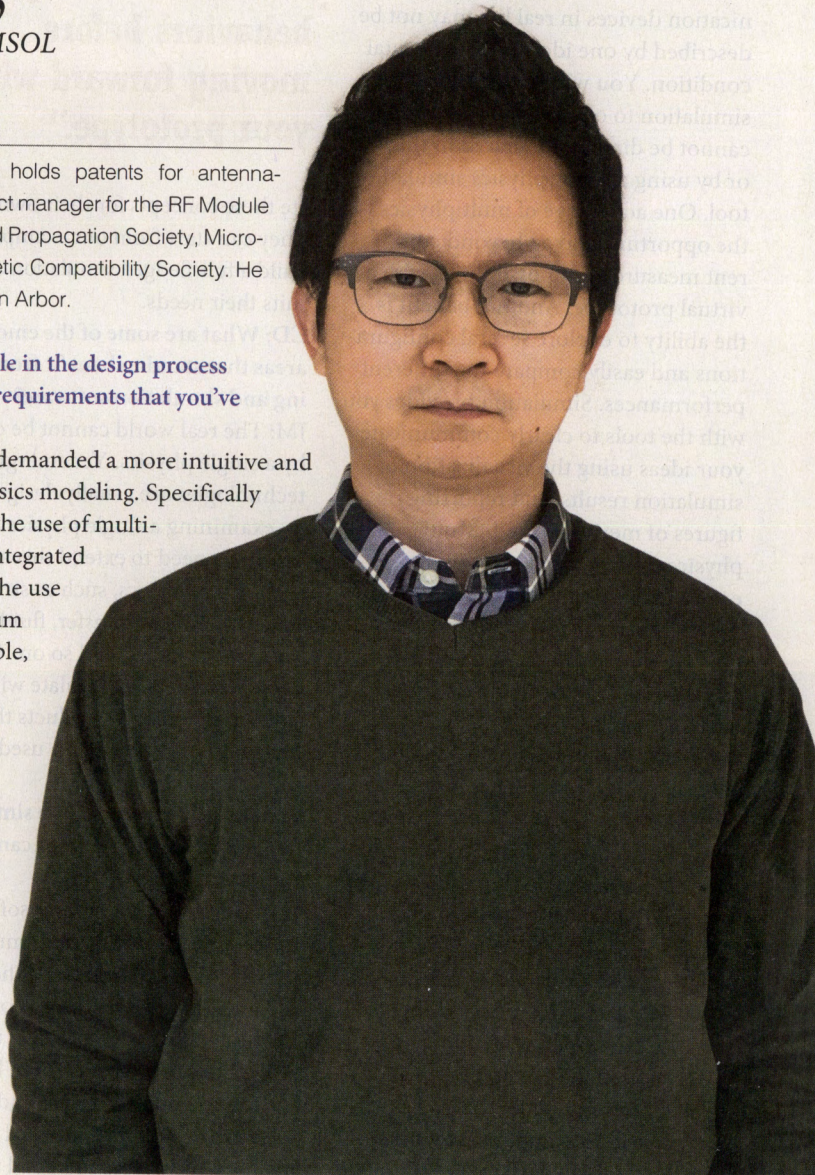
JIYOUN MUNN has published several papers and holds patents for antenna-interrogating systems. He is currently the technical product manager for the RF Module at COMSOL. Munn is a member of the IEEE Antennas and Propagation Society, Microwave Theory and Techniques Society, and Electromagnetic Compatibility Society. He received his M.S.E.E. from the University of Michigan, Ann Arbor.

CD: RF/microwave simulation plays a much larger role in the design process today than in the past. What are some of the specific requirements that you've received from customers in recent years?

JM: Over the past several years, our customers have demanded a more intuitive and easy-to-use, yet powerful user interface for multiphysics modeling. Specifically among our RF customers, we've seen an increase in the use of multiphysics simulation for studying metamaterials and integrated plasmonics (i.e., when researchers want to examine the use of metamaterials beyond the electromagnetic spectrum of microwaves and optics—to incorporate, for example, acoustics and fluid flow).

Additionally, we need to support the experts who often have to serve the entire organization while covering a diverse range of simulation needs. To do this, we are bringing simulation to a larger group of people. The latest version of COMSOL Multiphysics and its Application Builder provides simulation experts with the tools needed to turn their detailed physics and mathematical models into easy-to-use simulation apps for use by everyone in their organization and beyond.

Using COMSOL Multiphysics, for example, microwave and RF designers can couple electromagnetic (EM) simulations with heat transfer, structural mechanics, fluid flow formulations, and other physical phenomena, allowing them to solve systems of



equations representing coupled physics effects as they would occur in nature. As a result, they are able to accurately investigate use cases.

CD: What pitfalls can users avoid by utilizing electromagnetic (EM) simulation software?

JM: If, for example, you are building an Internet-of-Things (IoT) device, you'll need to study the interference between each device to design it in a way that allows for efficient communication under different circumstances. Of course, the integration of communication devices in real life may not be described by one ideal environmental condition. You will need multiphysics simulation to observe the effects that cannot be directly measured in the lab or by using a single physics simulation tool. One advantage of multiphysics is the opportunity to go beyond current measurement possibilities with a virtual prototype. Another benefit is the ability to explore several configurations and easily compare the different performances. Simulation provides you with the tools to clearly communicate your ideas using the visualization of simulation results, and reporting on all figures of merit involved. Multiphysics simulation allows you to examine unexpected behaviors before moving forward with your prototype.

CD: How will 5G and the Internet of Things impact simulation requirements?

JM: Current finite-element-analysis (FEA) tools will need substantially more computational power. To overcome this challenge, a full simulation model may have to be combined with state-of-the-art asymptotic methods.

In a simulation app called "Slot-Coupled Microstrip Patch Antenna Array Synthesizer," we built a very accurate model of a single antenna. We then used the Method Editor in the Application Builder to write a code to represent its asymptotic solution in order to combine the two. We wanted to

show how to efficiently evaluate many antenna components by running a 90-sec. analysis that provides very accurate results, rather than running the analysis for about two days, which is what would happen if a different approach was used.

Designers working on prototypes for 5G can copy and paste the code in the Method Editor used in the app to evalu-

"Multiphysics simulation allows you to examine unexpected behaviors before moving forward with your prototype."

ate these concepts for their own designs. They can start from our example and build a full-fledged simulation app that suits their needs.

CD: What are some of the emerging areas that stand to benefit from modeling and simulation software?

JM: The real world cannot be described by a single physics. Yet emerging RF technologies are usually designed by examining a single physics first. There's a need to extend this approach with other physics, such as structural mechanics, heat transfer, fluid flow, plasma, acoustics, and so on. This will allow designers to simulate with high fidelity and deliver products that will behave as expected when used in real-life situations.

CD: What are some of the simulation capabilities that you think can be realized in the future?

JM: Developing computer software for physics modeling and simulation is about implementing the laws of nature that have been discovered by the greatest scientists over the last several hundred years. Those laws are the foundations for useful and reliable software programs to be used by leading high-tech companies and individu-

als that produce advanced devices and processes. Because R&D and production costs are high and failure can be catastrophic, product requirements and expectations are extremely high. We also believe that simulation should be accessible to a larger group of people by providing experts with the tools to easily share their knowledge. For this reason, we've added the Application Builder to COMSOL Multiphysics for creating simulation apps and introduced COMSOL Server to distribute them via a COMSOL Client or browser.

The future is happening now, so to speak, with the adoption of simulation apps and engineers in product development and manufacturing. Even consumers will benefit greatly from this.

CD: How has COMSOL responded to the needs of colleges and universities that are utilizing simulation software more heavily than in the past?

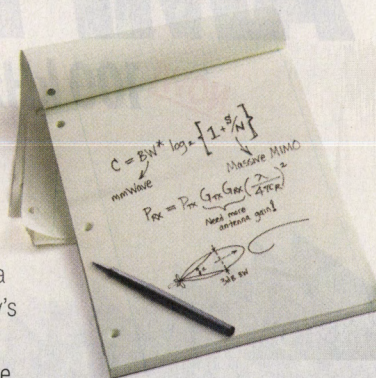
JM: Many technical colleges and universities around the globe use COMSOL software. COMSOL Multiphysics is a very flexible tool that caters to an array of users within academia as well as industry—from mathematicians and physicists who want to implement their own equations to those who benefit from our predefined physics interfaces. Additionally, the release of the Application Builder has introduced students at the undergraduate level to simulation earlier in their curricula. Professors now have the tools available to teach the fundamentals of physics and engineering in an interactive environment through the use of simulation apps.

COMSOL further supports the needs of colleges and universities with a generous licensing offering, such as a Class Kit License that allows as many as 30 students to simultaneously use the software for a class over a school network. Similarly, as instructors build simulation apps to support their course lectures, an Academic Server License will allow up to 300 concurrent users to run those simulation apps. **TMV**

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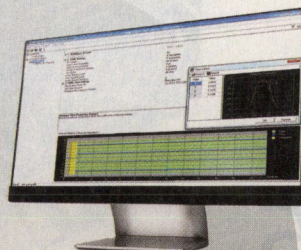
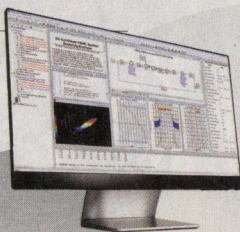
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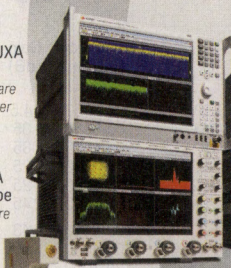
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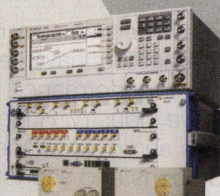
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ZHL-5W-2G+	800-2000	45	5	5	995
ZHL-10W-2G+	800-2000	43	10	12	1295
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• ZHL-20W-13+	20-1000	50	13	20	1395
• ZHL-20W-13SW+	20-1000	50	13	20	1445
LZY-22+	0.1-200	43	16	30	1495
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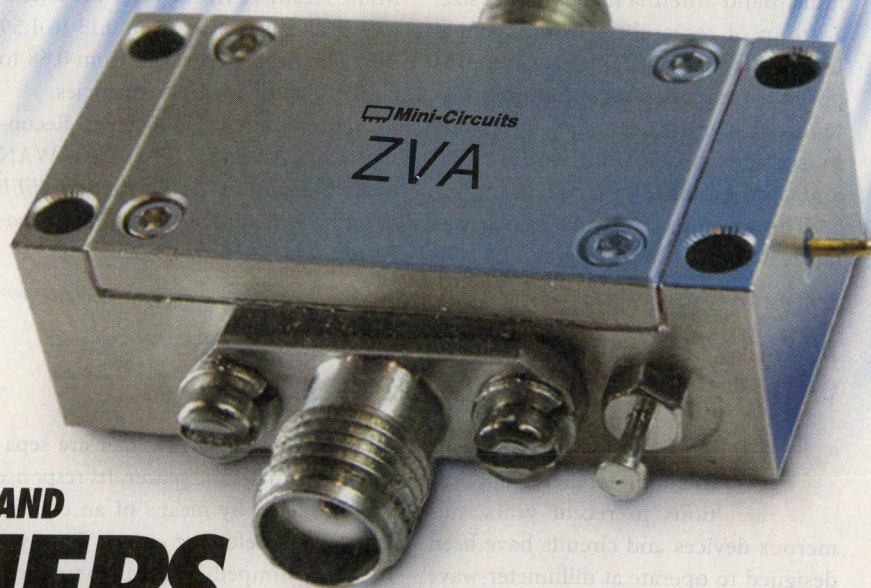
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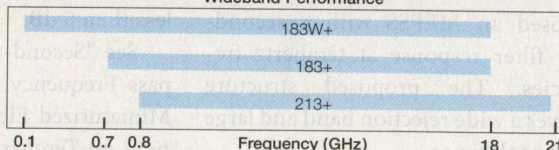
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TO ACHIEVE WIDEBAND performance, a number of multi-band antennas have been investigated. However, many of these antennas were unable to cover 700-MHz LTE bands because of the additional space required to operate at this frequency range. Although the coupled-feed technique is a typical solution to this problem, this approach is not suitable for mobile devices that require a compact size and low profile. To meet the goal of developing a multi-band antenna in a compact size, a group of researchers from Kyonggi University in South Korea have proposed a frequency-reconfigurable antenna. It has the capability to operate in six modes, allowing various LTE and GSM bands to be covered.

The proposed antenna, which was fabricated on a 1.6-mm-thick FR4 sub-

strate, comprises radiating elements and two PIN diodes. The antenna operates as three separate antennas—each of which generates its own resonant frequency. This enables performance in the lower-frequency 700-MHz LTE bands and the 850- and 900-MHz GSM bands, as well as the higher-frequency 2,300- and 2,500-MHz LTE bands and 1,800- and 1,900-MHz GSM bands. In addition, it operates in the Universal Mobile Telecommunications System (UMTS) band from 1,920 to 2,170 MHz. At lower frequencies, the antenna's peak gain varies from 0.13 to 1.59 dBi. The peak gain varies from 0.68 to 3.85 dBi at the higher frequencies.

See "Compact Frequency Reconfigurable Antenna for LTE/WWAN Mobile Handset Applications," *IEEE Transactions on Antennas and Propagation*, Oct. 2015, p. 4,572.

ATTAIN TERAHERTZ BANDPASS RESPONSE WITH MINIATURIZED ELEMENTS

WITH THE RAPID development of terahertz applications in recent years, numerous devices and circuits have been designed to operate at millimeter-wave and terahertz frequencies. Frequency-selective-surface (FSS) structures, for example, have been proposed for bandpass filtering at these frequencies. A new class of FSS structures, known as miniaturized-element FSSs (MEFSSs), is constructed of multilayer arrays of non-resonant metallic elements with much smaller dimensions than the operational wavelength.

Researchers from Australia recently proposed an MEFSS with a second-order filter response at terahertz frequencies. The proposed structure achieves a wide rejection band and large angular tolerance.

The structure is composed of two

periodic metallic arrays that are separated by a dielectric spacer. Its response was modeled by means of an equivalent lumped-element circuit. The synthesized lumped-element component values were mapped to the geometrical dimensions of the FSS.

The performance of the fabricated FSS was then measured, demonstrating good agreement with the simulation results. A center frequency of 0.42 THz was achieved along with a 3-dB bandwidth of approximately 45%. Out-of-band signals to 1.5 THz were attenuated by more than 25 dB. In addition, the maximum loss in the passband was less than 5 dB.

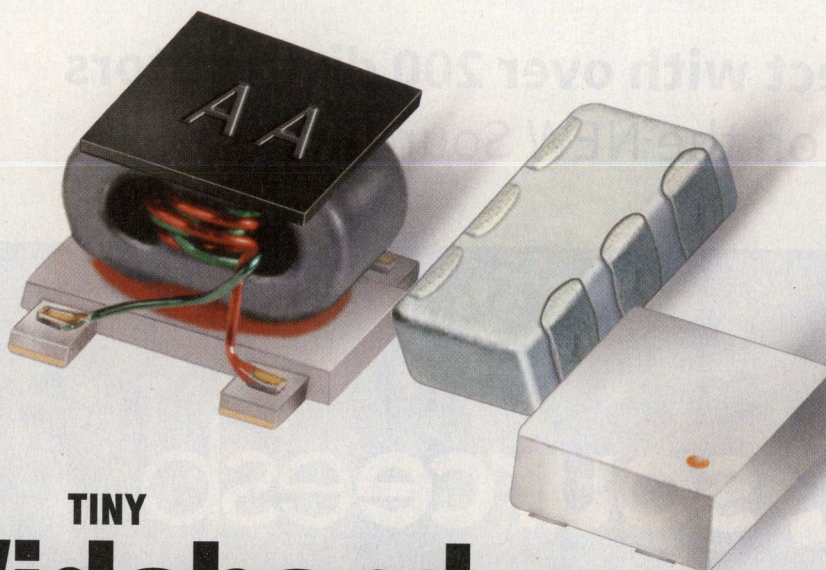
See "Second-Order Terahertz Bandpass Frequency Selective Surface With Miniaturized Elements," *IEEE Transactions on Terahertz Science and Technology*, Sept. 2015, p. 761.

FILTER INTERFERING SIGNALS WITH RECTANGULAR SLOT ANTENNAS

ULTRAWIDEBAND (UWB) COMMUNICATION SYSTEMS require compact, inexpensive antennas. Because the enhanced impedance bandwidth of UWB antennas is an important aspect, several different methods have been investigated. Filtering is also required in UWB systems to avoid interference with other communication systems. This interference can occur with wireless local-area-networking (WLAN) systems operating at 5-GHz frequencies. It is therefore desirable to design UWB antennas that incorporate notch filtering to avoid potential interference. A group of researchers from Iran have proposed a compact rectangular slot antenna that incorporates dual-band notch filtering. It can also achieve an enhanced impedance bandwidth.

The proposed antenna was fabricated on a 1.6-mm-thick FR4 substrate. A 50- Ω coplanar-waveguide (CPW) transmission line serves as the feedline for the slot antenna. By cutting the corners of the structure's rectangular patch while inserting semi-circular slots into the ground plane, the team significantly improved the antenna's bandwidth. An elliptical-ring-slot (ERS) was etched into the rectangular patch to achieve notch filtering in the 5-GHz WLAN frequency range. To implement notch filtering in the 3-GHz range, two S-shaped slits were incorporated into the ground plane.

See "Very Small Dual Band-Notched Rectangular Slot Antenna With Enhanced Impedance Bandwidth," *IEEE Transactions on Antennas and Propagation*, Oct. 2015, p. 4,529.



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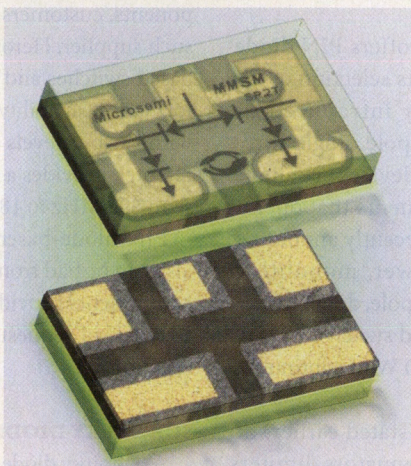
The performance of RF/microwave systems depends on the performance of the diodes that are incorporated into the system. These devices are available in many shapes and sizes, providing customers with numerous options.

Diodes play an important role in RF/microwave applications, as they are used to design a wide range of components. They enable various functionalities to be achieved, such as frequency conversion, power-level monitoring, amplitude control, and many others. Diode types that are commonly used to design RF/microwave components include PIN, Schottky, varactor, and step-recovery. The actual components that can be designed with these devices include switches, attenuators, limiters, detectors, mixers, and more. Such components are obviously required to enable systems, thus demonstrating the significant role that diodes play in high-frequency applications.

PACKAGING OPTIONS

Diodes for high-frequency applications are available in various packaging options. These can include plastic surface-mount-technology (SMT) packages, ceramic packages, unpackaged chips, and beam-lead devices. Plastic SMT diodes offer a generally inexpensive option, making them suitable for low-cost, high-volume applications. However, plastic SMT packages suffer from parasitic reactances, which limit their frequency capability.

RF/microwave diodes are also available in ceramic packages; these have lower parasitic reactances than plastic SMT packag-



1. This PIN diode-based switch can handle as much as 100 W of continuous-wave input power. (Courtesy of Microsemi)

es. In addition, their hermetic sealing can protect the die from environmental contaminants. However, ceramic packages are more costly in comparison to plastic SMT packages.

Diodes can also be purchased as unpackaged chips. These eliminate the parasitic reactances associated with a package, enabling them to be used with higher-frequency applications. Obviously, diode chips require die-attach and wire-bonding assembly capabilities. Flip-chip diodes, however, eliminate the need for wire-bonding, as these devices can be soldered or epoxied directly to a printed-circuit board (PCB).

Beam-lead diodes provide another option for higher-frequency applications. Their metal beams can be attached to a PCB by a bonding technique (e.g., thermocompression bonding), or with conductive epoxy. Thus, beam-lead devices remove the need to perform wire bonding.

PIN DIODES AND THEIR APPLICATIONS

In basic terms, a PIN diode is a device that is essentially a variable resistor at RF/microwave frequencies. The resistance value is determined by the diode's forward-biased dc current. This characteristic enables PIN diodes to be utilized to build components like switches and attenuators.

Switches, for example, are commonly designed with PIN diodes. Various topologies can be implemented when designing

a PIN diode-based switch. Insertion loss, isolation, and switching speed are a few of the parameters that determine the performance of these components.

PIN diodes intended for switching applications are available from various suppliers. MACOM Technology Solutions (www.macom.com), for example, offers a large selection of PIN diodes. The company provides silicon, gallium-arsenide (GaAs), and aluminum-gallium-arsenide (AlGaAs) PIN diodes in various packaging options.

In addition to discrete PIN diodes, MACOM offers actual switches that incorporate multiple PIN diodes into a single chip. The company is utilizing its heterolithic-microwave-integrated-circuit (HMIC) process to fabricate these components. Three new products were recently introduced that were fabricated with this process: the MASW-002103-1363, MASW-003103-1364, and MASW-004103-1365.

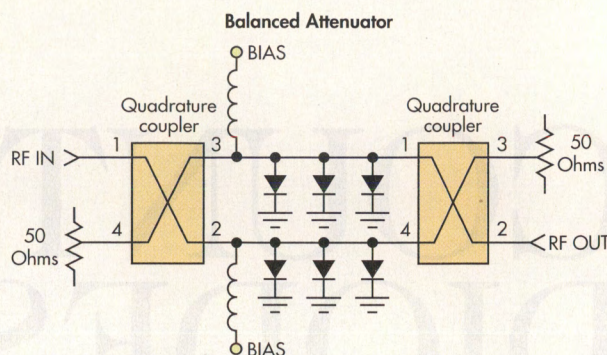
"Our new PIN diode switches utilize our patented HMIC process, which enables low loss and high isolation through low millimeter-wave frequencies," says Paul Wade, product manager at MACOM. "As such, these monolithic, rugged devices are ideally suited for use in broadband, low-to-moderate-signal switch applications."

Microsemi (www.microsemi.com) also offers PIN diode-based switching solutions. In addition to its selection of discrete PIN diodes, the company recently introduced the MPS4101-012S and MPS4102-013S single-pole, single-throw (SPST) switches. These PIN diode-based devices are single-chip, silicon-monolithic, series-shunt elements that operate from 50 MHz to 40 GHz. Microsemi also recently announced the MPS2R10-606, which is a high-power, monolithic-microwave-surface-mount (MMSM) single-pole, double-throw (SP2T) switch (Fig. 1). This PIN-diode-based switch covers 0.1 to 1.0 GHz. It can also handle as much as 100 W of continuous-wave (CW) input power.

In addition to switches, PIN diodes (as stated earlier) are used to design other components like attenuators, limiters, and phase shifters. Like their switch counterparts, PIN-diode-based attenuators can be implemented in various topologies. One often-used implementation is the balanced attenuator, as this approach has the benefit of impedance matching across all levels of attenuation (Fig. 2). This configuration also allows higher power-handling capability to be achieved. Skyworks (www.skyworksinc.com), for example, offers a selection of PIN diode-based attenuators.

Limiters are intended to protect components from damage to high-power signals. For instance, limiters are often times employed to protect the low-noise amplifier (LNA) in a receiver. PIN diodes are commonly utilized to create diode limiters. A diode limiter can be implemented by shunting a PIN diode to ground.

A selection of limiter diodes is offered by Skyworks. In addition, the company offers the SKY16602-632LF and SKY16601-



2. Balanced PIN diode attenuators utilize quadrature hybrids to achieve low voltage-standing-wave-ratio (VSWR) and greater power handling capability.

555LF limiter modules. These modules are comprised of integrated PIN limiter diodes and dc blocking capacitors. The SKY16602-632LF spans 200 MHz to 4 GHz, while the SKY16601-555LF spans 500 MHz to 6 GHz. Both components are offered in SMT packages.

When searching for connectorized PIN-diode-based components, customers can choose from a range of suppliers. One such supplier, Herotek (www.herotek.com), offers PIN-diode-based switches and limiters. The company's limiters offer performance capability to 40 GHz. These limiters are also offered with various levels of power-handling capability. In addition, Herotek provides a selection of PIN diode-based switches that span 500 MHz to 18 GHz.

PIN-diode-based attenuators, switches, and phase shifters also can be had from Waveline (www.wavelineinc.com). These components provide performance capability to 20 GHz. Customers can request custom designs to meet specific requirements, too.

SCHOTTKY DIODES, DETECTORS, AND SENSORS

A Schottky diode is another device commonly used to design RF/microwave components like detectors and mixers. They are created from a contact between a metal and a semiconductor. The metal is typically sputtered or evaporated onto the semiconductor's surface, thus forming the Schottky-diode junction. Both silicon and GaAs Schottky diodes are available from numerous suppliers.

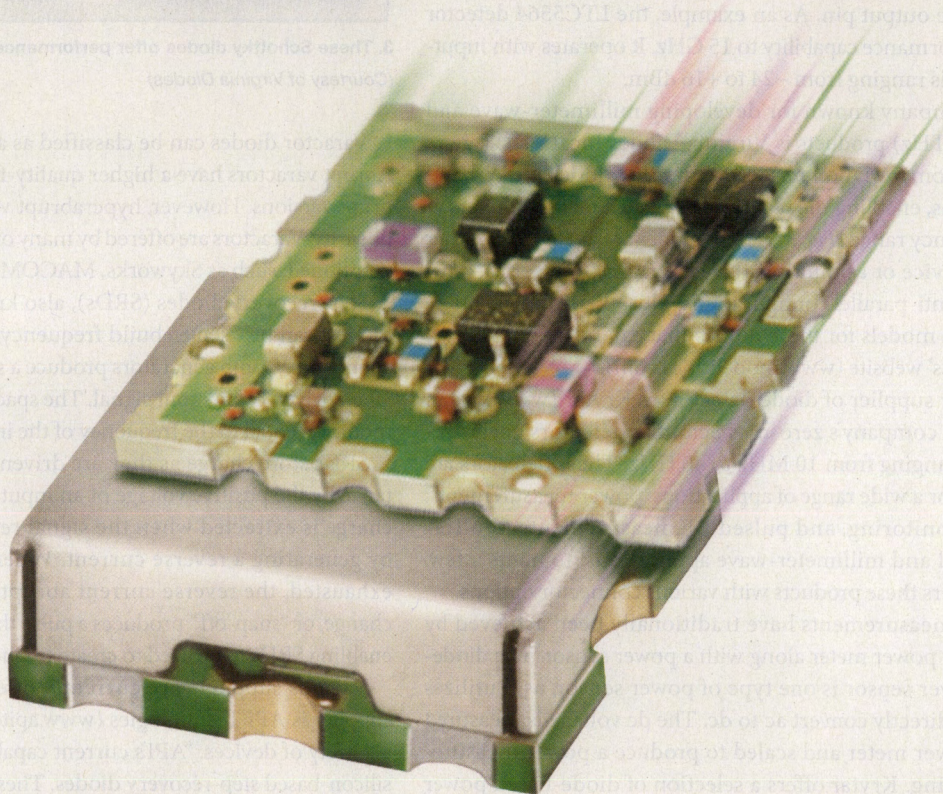
Detectors are typically employed with Schottky diodes. The diode rectifies the RF input signal, thereby producing an output that is proportional to the magnitude of the input signal. Detectors are often used for power monitoring, radar equipment, lab testing, and more.

One supplier of Schottky diodes is Avago Technologies (www.avagotech.com). Its devices are offered in a variety of packaging options and configurations. For example, customers can purchase diodes in configurations that include single diodes, ring-quads, bridge-quads, and several others. The company's

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plastic SMT diodes are well-suited for low-cost, high-volume commercial and consumer applications.

RF Schottky peak detectors are provided by Linear Technology (www.linear.com). These detectors combine a temperature-compensated Schottky diode and buffer amplifier in a single package. The RF input signal is peak-detected by an on-chip Schottky diode. The detected voltage is then buffered and supplied to the output pin. As an example, the LTC5564 detector offers performance capability to 15 GHz. It operates with input-power levels ranging from -24 to $+16$ dBm.

One company known for developing millimeter-wave and terahertz (THz) products is Virginia Diodes Inc. (VDI) (www.vadiodes.com). VDI offers GaAs Schottky diodes for W-band applications, enabling the realization of detectors and mixers in this frequency range (Fig. 3). These diodes are available as either a single device or as multiple devices arranged in series, anti-series, or anti-parallel configurations. Plus, the company offers simulation models for these diodes that can be obtained from Modelithics' website (www.modelithics.com).

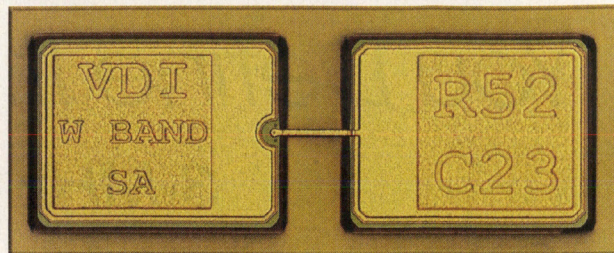
Another supplier of diode detectors is Krytar (www.krytar.com). The company's zero-bias Schottky detectors cover frequencies ranging from 10 MHz to 40 GHz. These detectors are intended for a wide range of applications: power measurements, system monitoring, and pulsed RF measurements in ultra-broadband and millimeter-wave applications, to name a few. Krytar offers these products with various connector options.

Power measurements have traditionally been achieved by means of a power meter along with a power sensor. The diode-based power sensor is one type of power sensor, as it utilizes diodes to directly convert ac to dc. The dc voltage is measured by the power meter and scaled to produce a power measurement reading. Krytar offers a selection of diode-based power sensors to satisfy power-measurement requirements as well. The company's 9500A-series power sensors offer measurement capability to 40 GHz.

Power sensors are also offered by Boonton (part of the Wireless Telecom Group) (www.boonton.com). The company provides diode sensors that utilize balanced diode detectors. Several of these dual-diode sensors have a dynamic range that spans from -70 to $+20$ dBm. Customers can select from a variety of frequency ranges, including models that can operate to 40 GHz.

MORE DEVICES: VARACTORS AND STEP-RECOVERY DIODES

Varactor diodes are often incorporated into the design of components like oscillators, filters, and phase shifters. These devices behave as voltage-varying capacitors, with the capacitance changing as the bias voltage applied to the varactor is varied. This property enables these devices to be utilized as tuning elements in RF/microwave circuits. For instance, varactors are often implemented as tuning elements in voltage-controlled oscillators (VCOs).



3. These Schottky diodes offer performance at W-band frequencies. (Courtesy of Virginia Diodes)

Varactor diodes can be classified as abrupt or hyperabrupt. Abrupt varactors have a higher quality-factor (Q) than hyperabrupt versions. However, hyperabrupt varactors provide better linearity. Varactors are offered by many of the companies already mentioned, such as Skyworks, MACOM, and Microsemi.

Step-recovery diodes (SRDs), also known as snap-varactor diodes, can be used to build frequency multipliers and comb generators. Comb generators produce a set of harmonic outputs when driven by an input signal. The spacing between these harmonics is equal to the frequency of the input signal.

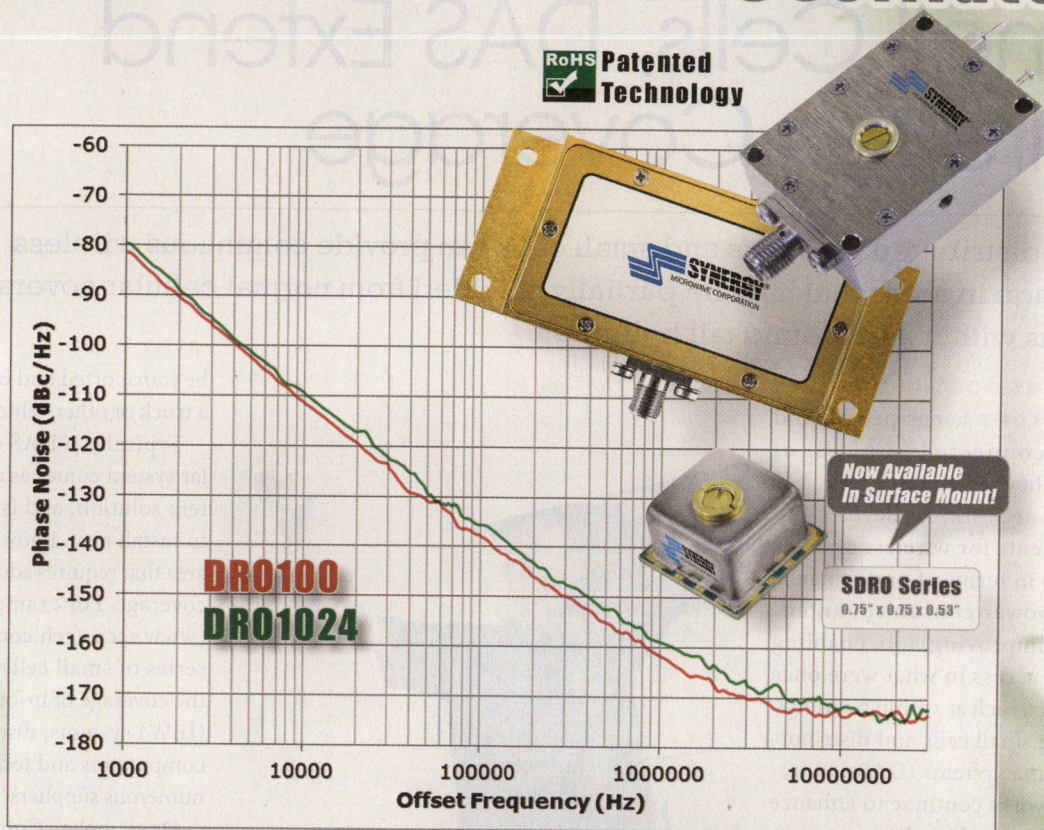
SRDs store charge as they are driven into forward conduction by the positive voltage of an input sinusoidal signal. This charge is extracted when the signal reverses polarity, thereby generating a reverse current. When the charge has been exhausted, the reverse current abruptly ceases. This abrupt change, or "snap-off," produces a pulse that is rich in harmonics, enabling SRDs to be used to create frequency multipliers.

Various suppliers are currently offering SRDs. One such supplier is API Technologies (www.apitech.com), which offers a variety of devices. "API's current capability allows us to offer silicon-based step-recovery diodes. These snap-varactor diodes find application in high-efficiency multipliers, up/down converters, comb generators, and in a variety of high-reliability, science-based space applications," says David Sims, product manager at API Technologies. "These devices can provide a cleaner output signal in comparison to monolithic-microwave-integrated-circuit (MMIC) designs. They do, however, require additional supporting components to deliver optimized performance in a system."

Beyond the examples listed here, many more options—from numerous suppliers—are available via the four types of diodes for RF/microwave applications, as well as diode-based components. Such availability allows today's customers to select the device or component that is best suited for their requirements. Some diode suppliers also provide a collection of application notes on their respective websites. These documents offer a vast amount of information on the topic of RF/microwave diodes for those who wish to learn more. Skyworks has even published an "RF Diode Design Guide," which provides an overview of the company's diode products along with a great deal of practical information. www.skyworksinc.com

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Surface Mount Models				
SDRO1000-8	10	1 - 15	+8 @ 25 mA	-107
SDRO1024-8	10.24	1 - 15	+8 @ 25 mA	-111
Connectorized Models				
DRO100	10	1 - 15	+7 - 10 @ 70 mA	-111
DRO1024	10	1 - 15	+7 - 10 @ 70 mA	-109

Model	Center Frequency (GHz)	Mechanical Tuning (MHz)	Supply Voltage (VDC / Current)	Typical Phase Noise @10kHz (dBc/Hz)
Mechanical Tuning Connectorized Model				
KDRO145-15-411M	14.5	±10 MHz	15 V / 130 mA (Max.)	-88

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Small Cells, DAS Extend Wireless Coverage

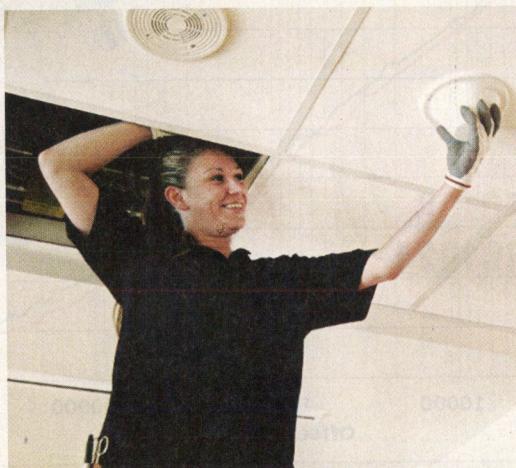
Using distributed antennas and small cells can provide continuous wireless coverage in areas that may be partially shielded from normal cellular coverage, such as within and around tall buildings.

WIRELESS-COMMUNICATIONS TECHNOLOGY keeps people and things connected—unless, of course, they're without access to a wireless network. As devices and components for wireless systems improve in terms of performance versus power consumed, antennas are improving, too, enabling wireless access in what were once deadspots, such as within buildings. By using small cells and distributed antenna systems (DASs), wireless networks continue to enhance both indoor and outdoor coverage, supporting quality voice, data, and video communications.

Internet access has become essential for most wireless networks, as users grow accustomed to mobile access in any location, whether in a car, office, or shopping center. While larger cell sites and cellular antenna towers can deliver wireless reception and transmission across healthy distances, deadspots often exist in clusters of buildings or within individual buildings if not augmented with small cells and DAS setups.

WHAT'S A DAS?

A DAS consists of multiple antennas adjusted to provide full coverage across a building or specific coverage area. In addition to delivering uninterrupted wireless coverage, a DAS can boost network capacity when a need arises, such as during a recital in a concert hall or a sporting event in a stadium, when the number of wireless users increases dramatically for a relatively small area. To augment coverage, service providers often have mobile networks, or what some have termed a "DAS on wheels"—this is a wireless system with multiple antennas and amplifiers that can



1. A DAS solution can unobtrusively provide wireless coverage for areas that are difficult to reach by a standard cellular system, such as within tall office buildings. (Photo courtesy of DAS Simplified)

be transported and operated within a truck or other vehicle.

Typically, a DAS or small cellular system comes as a complete system solution, and is relatively easy to install near a power source in an area that requires additional wireless coverage. For example, Accu-Tech (www.accu-tech.com) developed a series of small cells for increasing the coverage of in-building wireless (IBW) systems, drawing upon the components and technologies from numerous suppliers/partners.

One supplier, Commscope (www.commscope.com), crafted DAS-based solutions that offer enhanced wireless coverage while maintaining high levels of network security. The firm's DAS products employ a multi-

frequency-band approach for maximum coverage and minimal interference with existing wireless infrastructure equipment.

The DAS antennas are designed for installation in difficult-to-cover areas, such as tall office buildings, shopping malls, and parking garages. They handle various portions of the frequency range from 1,710 to 2,700 MHz. Commscope combined directional and omnidirectional antennas that can be adjusted in 2- and 5-deg. increments for optimum coverage, and linked the antennas via wireless and radio-over-fiber (RoF) technologies to take advantage of the enormous bandwidth of optical cables.

SMALL CELLS PLUS DAS

In terms of providing wireless coverage for challenging areas, DAS Simplified (www.dassimplified.com) has installed a number of small cells and DAS solutions for known locations, including the Auburn Medical Center (Auburn, Ga.) and the



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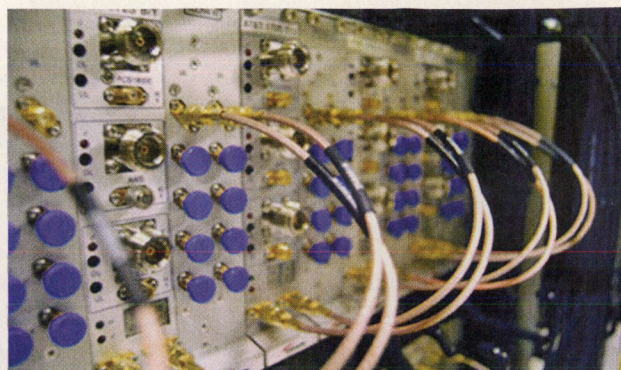
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Max Planck Florida Institute for Neuroscience (Jupiter, Fla.). The Auburn Medical Center is a campus consisting of three buildings on a total area of 350,000 square feet. Facility managers were concerned with wireless “deadspots” on the campus, especially in terms of public safety, and realized that they needed additional in-building coverage—not only for commercial cellular communications users, but also for public safety responders in case of emergencies.



2. This headend assembly is typical of the equipment that ties DAS installations to an existing cellular network. (Photo courtesy of DAS Simplified)

The small cells and DAS installed by DAS Simplified on the campus (Fig. 1) featured directional and omnidirectional antennas in unobtrusive ceiling-mount housings, and dramatically improved the school’s wireless service. The company optimizes and maintains the performance of the DAS installation per regulatory guidelines.

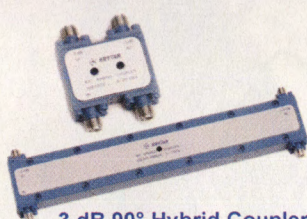
An important part of any DAS or small-cell system is the headend assembly (Fig. 2), which is the point of interface between the DAS and the existing wireless or wired network. The headend assembly must be properly connected to wireless carrier networks as well as to public safety systems, with power levels for the installed DAS and small-cell systems set according to carrier specifications. Such installations and testing have been greatly simplified by the increasing availability of high-quality portable RF/microwave test equipment from a number of leading suppliers. These include Anritsu (www.anritsu.com), Keysight Technologies (www.keysight.com), Rohde & Schwarz (www.rohde-schwarz.com), and Tektronix (www.tek.com).

System-level computer-aided-engineering (CAE) simulation software also serves as a valuable tool for many DAS system integrators. Prior to an installation, many DAS system integrators will use RF/microwave-system simulation software to model the propagation behavior of a site, to anticipate trouble areas and predict the types of antennas and performance levels that will be needed for optimum wireless coverage. **ttw**

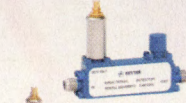
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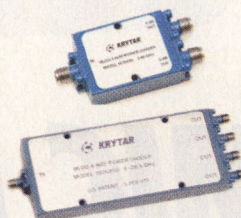
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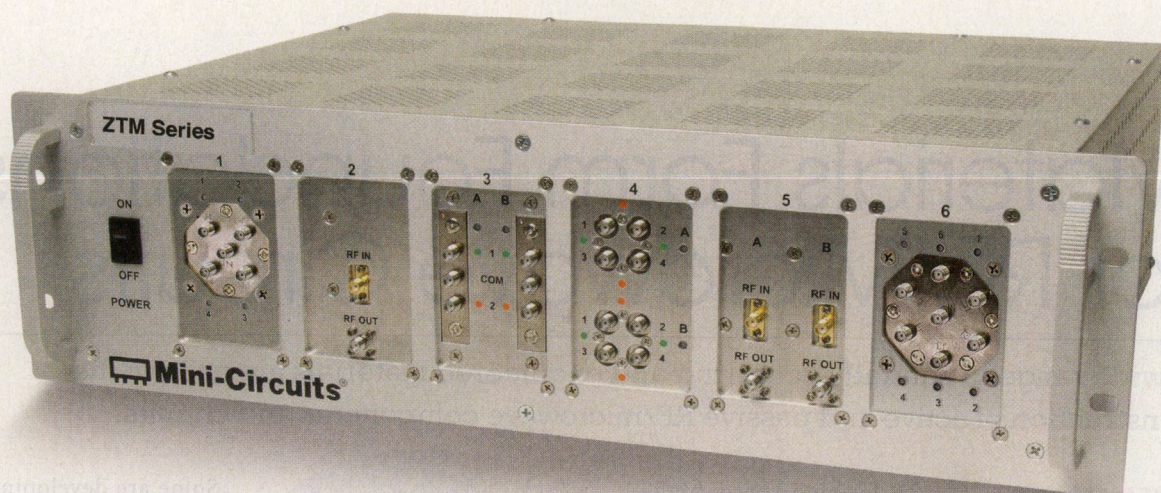
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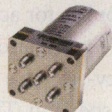
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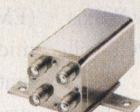
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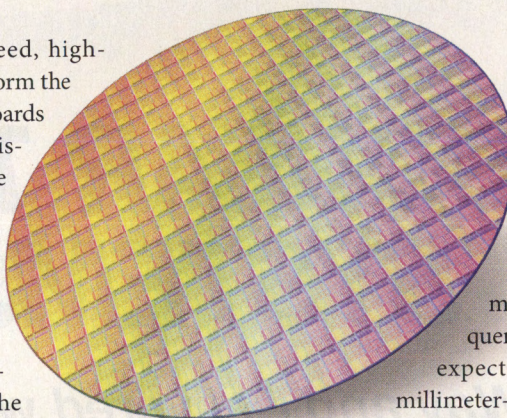
MATERIALS PAVE THE WAY for high-speed, high-frequency circuits. Whether those materials form the packages, the substrates, the printed-circuit boards (PCB), or even the thermal pathways for dissipating heat, they are essential to a wide range of electronic circuits.

PCB materials are starting points for a number of designs, and an understanding of the important characteristics of these materials can benefit almost any RF/microwave circuit design. Relative dielectric constant, for example, will determine the dimensions of transmission-line structures, such as microstrip and stripline transmission lines (*see p. 53*) at a desired impedance.

The consistency of the dielectric constant across the three axes of the PCB material, and how it changes with temperature, will also contribute a great deal to the consistency that is possible with a passive component. Examples include a filter and its passband amplitude and phase responses, along with an active component and its gain and output-power flatness.

Another critical PCB material characteristic is coefficient of thermal expansion (CTE), which is a measure of how a material expands with changing temperature. Ideally, the value should be as close as possible in the X and Y (length and width) directions of the material as the conductive layer, typically copper (16.7 ppm/°C). In doing so, the dielectric material and the copper circuit traces expand and contract with temperature at the same rate, and a minimal amount of dislocations occur in the interface between the two materials. In addition, by exhibiting low Z-axis (through the thickness) CTE, plated-through-holes in a PCB will also remain stable with temperature.

Circuit materials for RF/microwave applications are available from a wide range of quality suppliers, including Arlon (www.arlon-med.com), Isola (www.isola-group.com), Panasonic PCB materials (www.industrial.panasonic.com), Rogers Corp. (www.rogerscorp.com), and Taconic (www.taconic-add.com).



Some are developing environmentally friendly versions of PCB materials, such as RO4835HF halogen-free PCB materials from Rogers Corp. and Green Speed materials from Isola.

An area of interest for PCB materials is millimeter-wave-frequency (above 30 GHz) applications, expected to grow with greater use of millimeter-wave circuits in automotive and 5G systems. Such applications will require PCB

materials with low relative dielectric constants and low loss, and high consistency across the material to minimize frequency and phase variations for those small wavelengths at 77 GHz.

For those circuit designs that require special assistance from a substrate material, materials known as metamaterials have been engineered for specific applications. These are materials that can be refined for specific uses by engineering particular characteristics in a material or a combination of materials. For example, these electromagnetic-bandgap (EBG) materials can be used to increase the gain and bandwidth of a microstrip patch antenna while at the same time reducing its volume.

In fact, the U.S. Air Force is currently seeking research papers in pursuit of metamaterials for enhanced microwave and optical performance. The agency has invited submissions for funding of research (\$750,000 available for the first year) on various technologies related to the development of electromagnetic (EM) metamaterials. This applies for acoustic, optical, and RF/microwave use, including the fabrication of reactive electronic matching networks, frequency-selective structures, and periodic structure with engineered dispersion. The deadline for submissions for 10 possible awards is February 20, 2016.

In the semiconductor part of the RF/microwave industry, another set of materials supports miniature devices and integrated circuits (ICs), including silicon, silicon carbide (SiC), gallium



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arsenide (GaAs), and gallium nitride (GaN). GaN, with its excellent high-frequency, high-power capabilities, has become one of the more popular semiconductor materials for RF/microwave device developers (*see p. 55*).

According to a recent report from Research and Markets (www.researchandmarkets.com), "Global GaN Semiconductor Devices Market 2015-2019," the global GaN semiconductor devices market is expected to grow at a compound annual

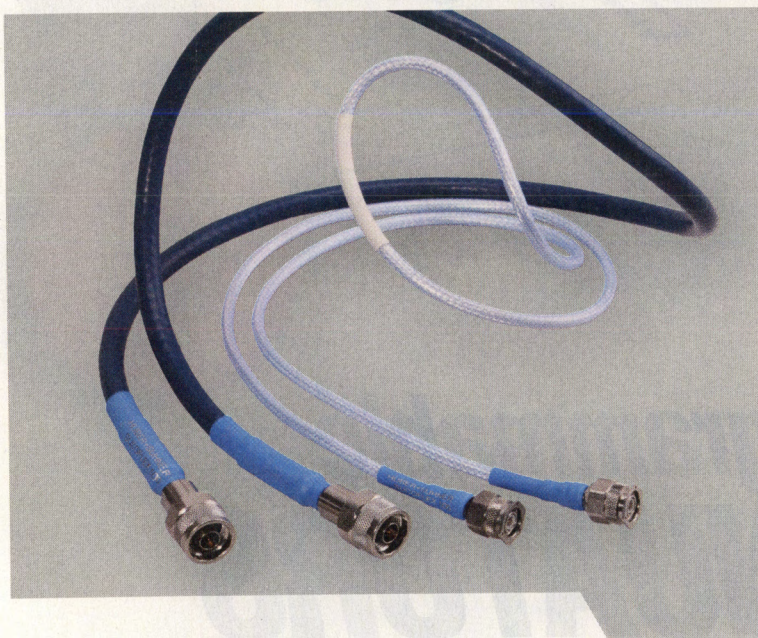
growth rate (CAGR) of 20.77% in terms of revenue during the period from 2015 to 2019. The report considers GaN semiconductor use in a wide range of markets, including automotive electronics, consumer electronics, and defense and aerospace applications. Both high-power semiconductors and light-emitting diodes (LEDs) are considered, too.

GaN is also a favorite substrate material for LEDs, with about one-half of GaN substrates currently being produced around the world for blue, green, and white LEDs.

To support the strong global demand, China-based material supplier Nanowin (www.nanowin.com) recently announced plans to produce 2-in. GaN wafers for blue and green LEDs. The firm forms high-quality GaN films on sapphire substrates using electrode-less photoelectrochemical nanostructure etching techniques and controlled growth conditions. These approaches help relieve stress within the GaN films and produce materials with low defect densities. Another GaN material supplier, Kyma Technologies (www.kymatech.com), has already moved to larger-diameter wafers to keep pace with the growing global demand for the semiconductor material.

GaAs wafers are still home to a wide range of small-signal discrete devices and ICs for RF/microwave use, and GaAs materials are very much in demand globally. If anything, the strong demand for GaN materials helps with the competitive costs of GaAs substrates. Leading suppliers such as Sumitomo Electric Industries (www.global-sei.com) offer semi-insulating GaAs wafers in 100- and 150-mm diameters, with wafers available for epitaxial or ion-implantation applications.

Finally, semiconductor device packaging also depends on advances in materials to meet the cost and performance expectations of emerging markets. For example, most power semiconductors, from audio through microwave frequencies, at one time were housed in expensive ceramic/metal packaging. With time and growing competitive cost concerns, those more-expensive package materials are being replaced by plastic and composite-material packaging that can effectively dissipate the heat produced by high-power devices at all frequencies. **mw**



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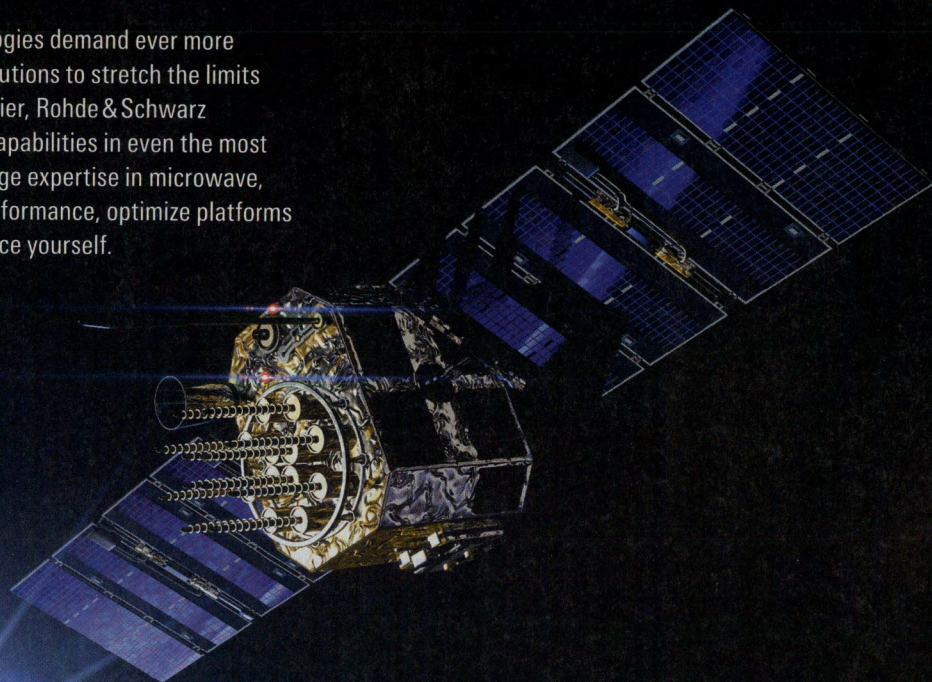
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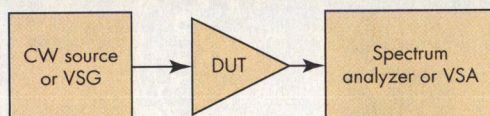
VSA Helps Simplify Harmonic Measurements

A vector signal analyzer is a powerful tool for measuring the harmonic signal levels of wireless-communications standards with complex, wideband modulation formats.

Controlling harmonic energy from communications transmitters is essential for minimizing interference in modern wireless-communications systems. As a result, the specifications for wireless standards ranging from 3GPP Long-Term Evolution (LTE) and ZigBee to Bluetooth and wireless local-area networks (WLANs) each prescribe guidelines governing how much energy a wireless device can emit into specific bands. With any wireless transmitter, one of the most significant sources of unwanted emissions is the result of nonlinear behavior from either the quadrature modulator or the final power-amplifier (PA) stage.

Such nonlinear behavior and its resulting distortion manifest itself in one of two ways: either as signal emissions into frequencies adjacent to the desired operating band, or as emissions at harmonic frequencies of the desired band. The capability to accurately measure the harmonic behavior of these components is critical for certifying a component for use in a modern wireless-communications system. Harmonic measurements can be applied to a wide range of components, ranging from modulators and PAs through digital-to-analog converters (DACs) and frequency mixers.

For PAs intended for general-purpose use, harmonic measurements involve the use of a continuous-wave (CW) stimulus. These measurements are fairly straightforward, requiring a signal generator and signal analyzer. The signal generator is set for a CW tone at a desired fundamental frequency and output-power level. The signal analyzer measures the output power from a device under test (DUT) at multiples of the input frequency. Common harmonic measurements occur at the second, third, fourth, and fifth harmonic frequencies.



1. In this basic measurement system, a signal generator provides stimulus signals to a DUT, with output signals studied on a signal analyzer.

When using an RF/microwave vector signal analyzer (VSA), several techniques are available for measuring the output power of signal harmonics. These involve either the frequency or time domain, with tradeoffs in simplicity, measurement time, and accuracy

depending on the choice of measurement approach.

One of the simplest techniques is to measure signal output power at the predicted frequency of the harmonic of interest, based on the fundamental frequency. For instruments providing the function, a peak search can be performed to determine the harmonic output power of a DUT.

For example, a DUT being fed a fundamental tone at 1 GHz will generate a third-harmonic tone at 3 GHz (Fig. 1). With this approach, several harmonics can be measured in a single test sweep, provided that the start and stop frequencies of the signal analyzer are appropriately configured. This harmonic-measurement technique is simple, but it can be quite time-consuming in automated test applications. Other harmonic measurement methods trim measurement time by focusing on measuring power only in the band of interest.

A second method for measuring harmonic power involves a VSA's zero-span measurement mode. In this mode, often called the transmit-power (TxP) measurement mode, a VSA measures power as the magnitudes of in-phase (I) and quadrature (Q) signal samples at a single frequency. In zero-span mode, the signal analyzer effectively performs a series of "channel power" measurements and displays the results as a function of time. In this mode, the bandwidth of the power measurement is configured by setting the resolution bandwidth of the signal analyzer.

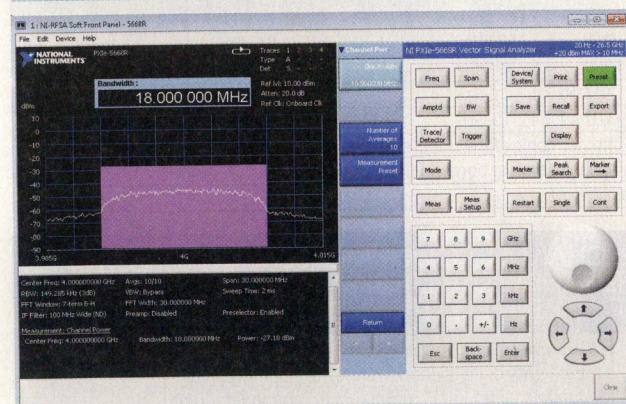
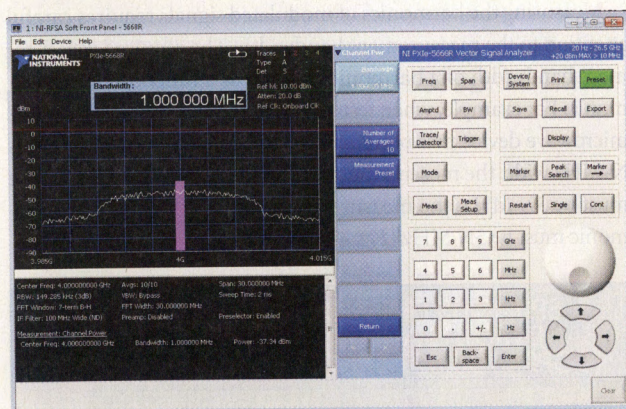
When using the TxP measurement approach, the acquisition duration operates as a built-in averaging function for the mea-

Harmonic Measurements

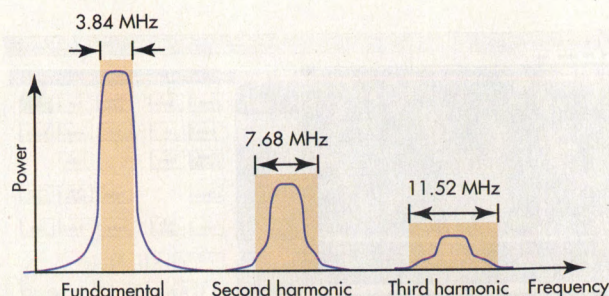
Harmonics can be measured in the time or frequency domain, depending upon the instantaneous bandwidth of a signal analyzer and whether or not bursted stimulus signals are being used. One measurement shortcut worth considering is to measure the harmonic power in a bandwidth equivalent to the system channel bandwidth.

For example, although the bandwidth of an 18-MHz LTE signal's third harmonic is 54 MHz, the majority of the power will be contained in the initial 18-MHz channel bandwidth. With the primary motivation for LTE harmonic measurements being to determine whether a PA will violate the standard's spurious-emissions requirement, the partial-bandwidth measurement method captures energy in the bandwidth most likely to influence spurious emissions.

The maximum permissible emissions of a cellular transmitter is -30 dBm in a 1-MHz bandwidth (Table 1). In example measurements of an LTE PA's second harmonics at 4 GHz (Fig. 5), the integrated power in a 1-MHz bandwidth in the center of the band is -37 dBm, or 7 dB below the LTE spurious emissions requirement. However, the integrated power in 18-MHz



5. A model PXIe-5646R vector signal generator (VSG) produces a non-bursted LTE uplink frequency-division-duplex (FDD) PUSCH 18-MHz quadrature-phase-shift-keying (QPSK) signal that serves as the input to a PA, with the PA's second-harmonic output measured by a model PXIe-5668R VSA in both 1- and 18-MHz bandwidths.



4. The bandwidth of harmonic signals increases with the order of the harmonics.

bandwidth is -27 dBm, or 3 dB higher than the LTE maximum, although the measurement bandwidth is much greater.

Furthermore, the integrated power in the full harmonic bandwidth would be slightly higher. As this case shows, it is often possible to determine the likelihood that a PA will meet a wireless standard's spurious emissions requirements by measuring harmonic power in the same bandwidth as the fundamental frequency. In many cases, the power difference between the harmonic power in the full bandwidth and the harmonic power in the partial bandwidth is quite small.

Table 2 compares the power of the harmonic in 18-MHz bandwidth and the power integrated across the full bandwidth of the harmonic. The results illustrate that the difference in power between the two measurement bandwidths increases with the order of the harmonic frequency. It is noteworthy that, for the fifth harmonic, the power in 18-MHz bandwidth is 1.5 dB lower than the power in the full harmonic bandwidth of 90 MHz.

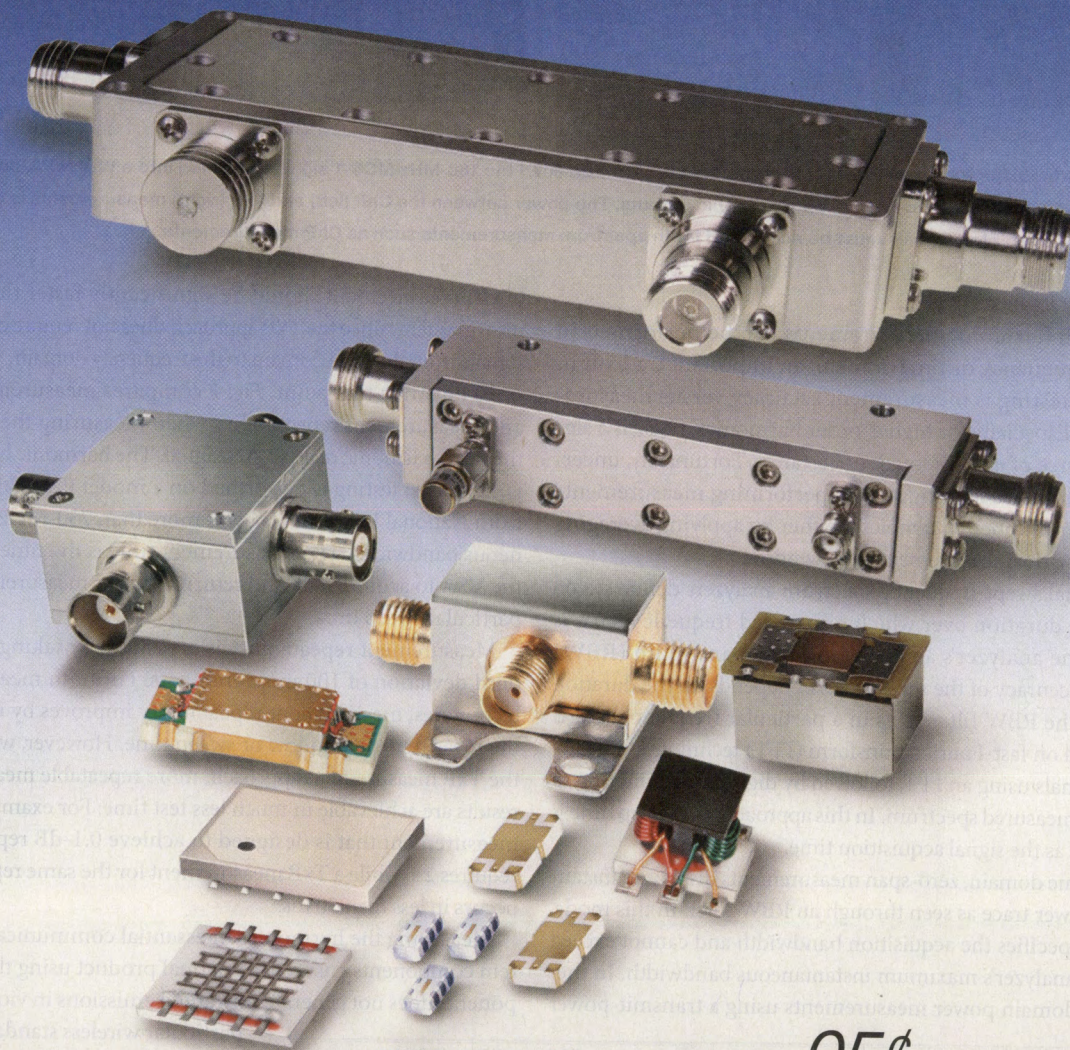
BURSTED SIGNAL CONSIDERATIONS

For harmonic measurements of bursted signals, such as for IEEE 802.11ac, time-domain measurements using zero-span mode are preferable but not always realistic. For example, accurately measuring the third harmonic of a 160-MHz IEEE 802.11ac signal requires 480-MHz instantaneous bandwidth.

In some instances, the harmonics of a bursted signal can be measured in the frequency domain, but the method requires calculations for a bursted stimulus. In such a case, a channel-power (ChP) measurement can be used to record the integrated power in the desired band, with the duty cycle of the waveform included in the calculations for an accurate assessment of the harmonic power. For example, for a signal that is on "n" percent of the time, a power offset of $20\log(n/100)$ must be calculated.

Figure 6 illustrates harmonics measurements in both the time and frequency domain of a signal with an 85% duty cycle. Given that $20\log(0.85)$ equals -1.41 dB, 1.41 dB must be added to a harmonic measurement performed in the frequency domain to account for the bursted signal's duty cycle. Accounting for duty cycle is relatively straightforward when the duty cycle is high, but is subject to error when the duty cycle is low. Because this measurement technique requires power measurements even when a signal is not present, the additive noise of a signal during its "dead" or off periods can potentially skew the final measurement result.

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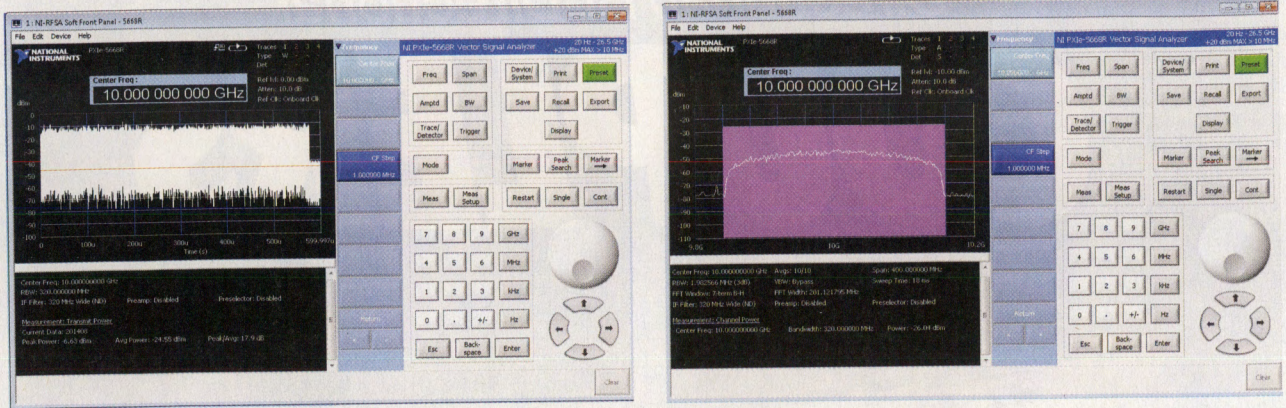
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6. A model PXIe-5646R VSG generates a 5-GHz bursted WLAN IEEE 802.11ac 160-MHz MCS-1 signal that is fed into a WLAN PA, and a model PXIe-5668R VSA measures the PA's second-harmonic outputs. The power between the ChP (left) and TxP (right) measurements is different; the duty cycle of bursted signals must be accounted for in spectrum measurements such as ChP measurements.

ACCURACY VERSUS TIME

Although harmonic measurements can be performed in either the frequency or time domain, an important tradeoff in automated testing is measurement accuracy versus measurement time. Especially for higher-order harmonics, noise is a significant source of measurement uncertainty. Fortunately, uncertainty due to noise is mitigated by performing measurements over a larger number of samples—either by applying averaging or increasing the measurement time window.

Traditional swept-frequency spectrum analyzers define sweep time as the duration over which a specified frequency span is swept by the analyzer's analog resolution-bandwidth (RBW) filter. The accuracy of the measurement depends on the duration for which the RBW filter stays in a particular frequency range. VSAs based on fast-Fourier-transform (FFT) techniques digitally process signals using an FFT, followed by digital RBW filtering to obtain the measured spectrum. In this approach, the sweep time is interpreted as the signal acquisition time.

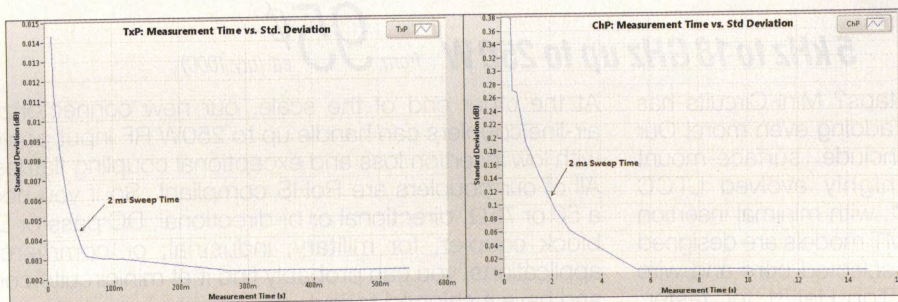
In the time domain, zero-span measurements display an instantaneous power trace as seen through an RBW filter. In this mode, the RBW specifies the acquisition bandwidth and cannot exceed the signal analyzer's maximum instantaneous bandwidth. In theory, time-domain power measurements using a transmit-power

(TxP) measurement should be significantly faster than a ChP measurement, since the TxP approach does not require converting signals from the time domain to the frequency domain.

To illustrate this point, Fig. 7 compares measurement time and measurement repeatability when measuring the power of the third harmonic of a WLAN signal. The harmonic bandwidth is 480 MHz; testing is performed on a model PXIe-5668R VSA from National Instruments, with more than 750-MHz instantaneous bandwidth. The measurement time is the time taken for the VSA to acquire data and return a power measurement for a particular sweep time.

Measurement repeatability is measured by taking the standard deviation of 100 measurements. For both measurement techniques, measurement repeatability improves by increasing the measurement window or sweep time. However, when using the TxP measurement approach, more repeatable measurement results are achievable in much less test time. For example, a ChP measurement that is designed to achieve 0.1-dB repeatability requires 2 s, while a TxP measurement for the same repeatability occurs in less than 50 ms.

Measuring the harmonics of essential communications system components ensures that a final product using those components does not generate unwanted emissions in violation of a



7. A model PXIe-5646R VSG generates a bursted WLAN IEEE 802.11ac 160-MHz MCS-1 signal that is fed into a WLAN PA, and a model PXIe-5668R VSA measures the PA's third-harmonic outputs. The ChP measurement (left) takes significantly longer than the TxP measurement (right) for similar accuracy.

particular wireless standard. When seeking an optimal approach for measuring harmonics, a number of factors should be considered, including measurement time, accuracy, repeatability, bandwidth, and a signal's behavior. By weighing the strengths and weakness of different measurement methods, a user can achieve good results with a VSA, meeting the harmonic test needs of many different wireless standards. **mtw**

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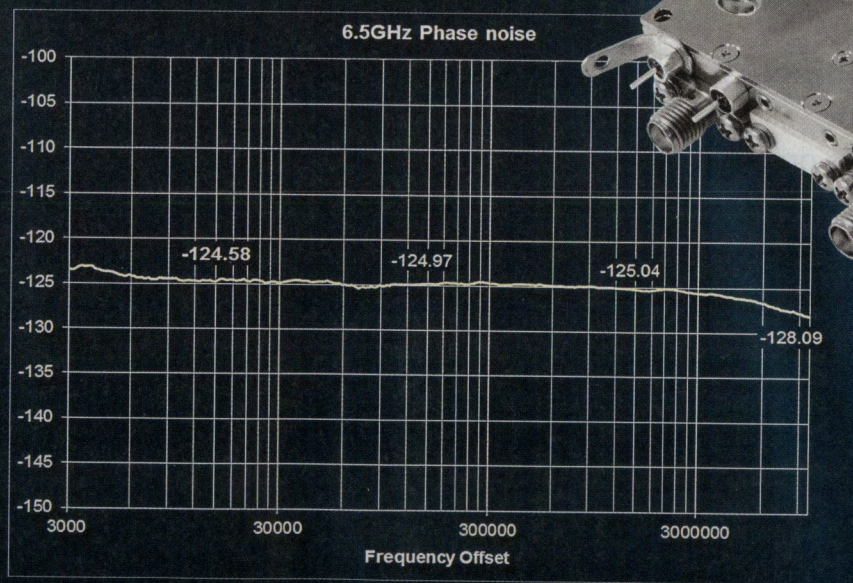
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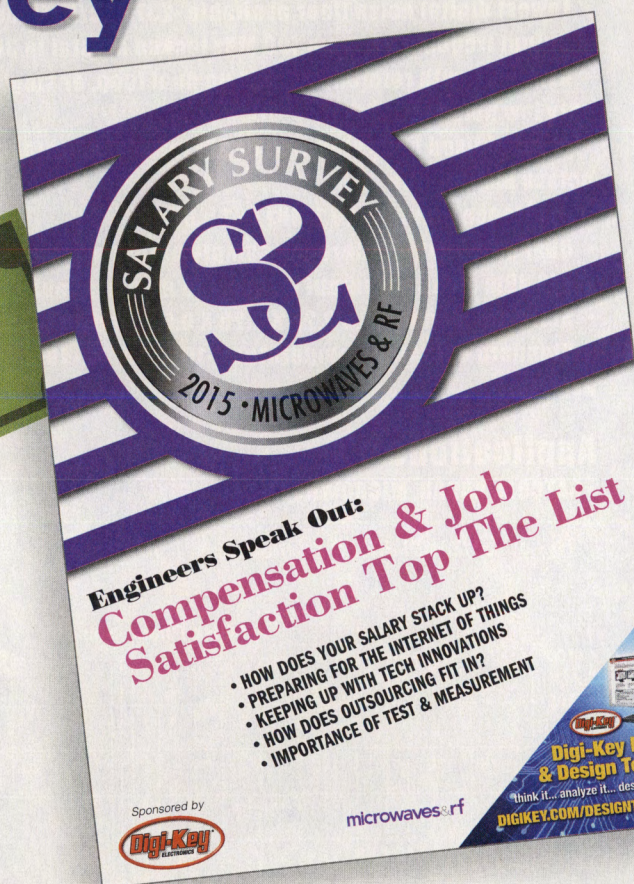
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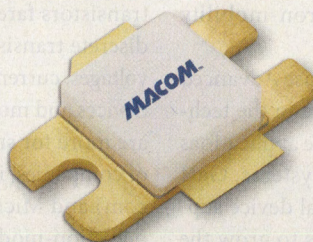
Decoding Discrete Power Transistors

GaN discrete transistors are filling many higher-frequency requirements for high output power.

Discrete power transistors for RF/microwave applications have not yet been driven into obsolescence by monolithic devices. They still have their place in applications where higher power densities are required, as in communications transmitters and pulsed radar systems. A number of technologies on different substrate materials form the building blocks for high-frequency discrete power transistors, covering a wide range of frequencies and power levels for both continuous-wave (CW) and pulsed applications.

Power transistors are built from a variety of substrate materials, with lower-frequency devices still fabricated from silicon (Si), while higher-frequency transistors are formed from gallium arsenide (GaAs) and gallium nitride (GaN) substrates. Despite their higher cost, GaN materials have grown in popularity for both discrete transistors and integrated circuits (ICs) because of their excellent high-power, high-frequency characteristics—which enable much greater power densities than GaAs at equivalent frequencies.

Whether in CW or pulsed applications, generating high power levels from a relatively small device is always a concern for the large amounts of heat that must be dissipated within a small area. As critical as the substrate materials are to discrete transistor performance, the packaging materials (see p. 44 for more on high-frequency materials) also play key roles in device performance and reliability. Many discrete power transistor suppliers offer devices in packages or as unpackaged die. Discrete transistor packages have traditionally been composed of thermally conductive materials, such as metals and ceramic materials. In recent years, device designers have developed plastic composite materials that provide effective long-term thermal dissipation of device heat at lower cost than metal/ceramic packaging.



This metal/ceramic flange-mount package is typical of the type of housing required with higher-power discrete RF/microwave transistors. (Photo courtesy of MACOM Technology Solutions)

Several device technologies are commonly used for RF/microwave applications. For high-power amplification below about 2 GHz, silicon bipolar transistors or silicon metal-oxide-semiconductor field-effect transistors (MOSFETs) are capable of high levels of CW and pulsed output power. As an example of the former transistor type, model MAPR-001214-380M00 from MACOM Technology Solutions (www.macom.com) is a negative-positive-negative (NPN) silicon bipolar power transistor capable of 380 W pulsed output power from 1200 to 1400 MHz. Operating under Class-C bias conditions with 150- μ s pulses at 10% duty cycle, the discrete bipolar transistor is typically employed in avionics radar systems. The small device achieves 8.8 dB minimum power gain across the full bandwidth with 45% collector efficiency. The typical output power for a 50-W input signal is 458 W output power at 1200 MHz and 421 W output power at 1400 MHz. The firm also produces numerous high-power silicon MOSFET discrete transistors, such as the MRF176GV which is usable to 500 MHz. It provides 200 W CW output power at 225 MHz with 17-dB typical gain and 55% typical efficiency.

PACKAGING IS CRITICAL

Packaging for such high-power devices is critical, given the high power density of the transistor. Even with its relatively high efficiency, much of the energy supplied to the transistor ends up as heat that must be dissipated. The device features gold metallization and a robust RoHS-compatible metal/ceramic flange-mount package that is hermetically sealed for environmental protection. Packaging for discrete power transistors is typically a function of output power, with the transistors at higher power levels requiring larger ceramic/metal housings while lower-power devices can often be accommodated in drop-in or even surface-mount-technology packages.

Silicon substrates also form high-power MOSFET and laterally diffused MOS (LDMOS) FET devices for high power levels often at somewhat higher frequencies than silicon bipolar transistors. The BLC8G27LS-60AV LDMOS discrete transistor from NXP Semiconductors (www.nxp.com) is designed for CW applications, with 60 W output power from 2,300 to 2,690 MHz for cellular base station amplifiers. It offers 15-dB typical gain with better than 47% efficiency and, because the amount of heat generated by the device is so much less than the larger pulsed silicon bipolar transistor for radar systems, this silicon LDMOS device can be housed in a metal/plastic SOT package for economy.

HIGHER POWER

Moving higher in frequency, more exotic substrate materials serve as the foundations for high-power discrete transistors. At one time, silicon germanium (SiGe) was a substrate material of interest, especially for transistors operating in the millimeter-wave frequency range. At the time, however, GaAs was well established as a lower-cost substrate option for high-frequency transistors. At least one decade earlier, GaAs was the basis for most microwave power transistors and is still a popular choice for fabricating low-noise FETs. But GaAs is limited in output-power capabilities compared to GaN semiconductor materials used with device structures such as high-electron-mobility transistors (HEMTs).

With a great deal of early funding from the Defense Advanced Research Projects Agency (DARPA) for its interest in the technology for higher-frequency defense and aerospace applications such as in radar and electronic-warfare (EW) systems, GaN device technology developed quickly. Commercial device suppliers sought cost-effective epitaxial approaches to grow the GaN materials and structures required for the devices. For its excellent high-power CW and pulsed capabilities, GaN con-

tinues to gain ground on applications formerly fueled by GaAs, and the number of discrete and IC GaN device suppliers for RF/microwave applications continues to grow.

The high power densities and breakdown voltages possible for discrete HEMTs fabricated on GaN substrates results in large amounts of heat that must be dissipated. For that reason, a growing number of higher-power GaN transistors employ silicon carbide (SiC) as a foundation substrate for its excellent thermal properties. SiC exhibits thermal conductivity in excess of 330 W/m-K to provide an effective heat channel to a heat sink or other heat-dissipating structure within a circuit. The goal of such thermally conductive materials is to maintain a power transistor's baseplate temperature well below the upper limit of its specified operating temperature range.

As an example, model CGHV59350 from Cree/Wolfspeed (www.cree.com) is a GaN-on-SiC HEMT device developed for pulsed C-band radar use. It is capable of 450 W output power from 5.2 to 5.9 GHz under pulsed operation, using 100- μ s pulses at 10% duty cycle. It achieves 10.5-dB gain with 55% typical drain efficiency. As with the earlier high-power silicon bipolar device, it is supplied in a ceramic/metal flange-type package for good thermal dissipation.

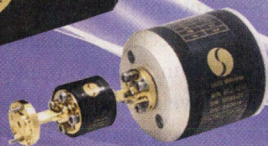
The GaAs discrete device market is shrinking as markets for GaN discrete and IC devices grow. How do GaN discrete transistors fare in terms of output power compared to GaAs discrete transistors? GaAs devices cannot withstand the high voltages, currents, or heat of GaN or even silicon-based discrete devices and most current commercial GaAs discrete transistors are more for small-signal, low-noise applications. A number of companies, including Avago Technologies (www.avagotech.com) and MicroWave Technology (www.mwtinc.com), offer depletion-mode and enhancement-mode GaAs discrete transistors, including FETs and HEMTs, although typical output power levels are a few watts or less. **mtw**

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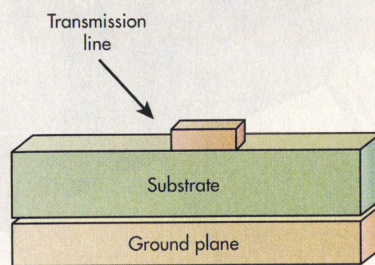
They establish the pathways for electromagnetic (EM) energy in circuits and systems, in all shapes and sizes. Whether in the form of microstrip structures, such as planar antennas for wireless handheld devices, or the larger waveguide of high-power radar systems, transmission lines of many types transfer high-frequency signals in disparate ways, with or without dielectric substrates.

Transmission lines based on printed-circuit-board (PCB) materials and semiconductor substrates exhibit a characteristic impedance—typically $50\ \Omega$ for high-frequency lines. A transmission line will also behave as a lumped-element structure, with equivalent lumped-element circuit elements: resistance (R), capacitance (C), inductance (L), and transconductance (G).

Such variable parameters make it possible to model the behavior of different transmission lines on a wide range of PCB and semiconductor substrate materials. Those materials play a major role in determining the characteristic impedance of a particular transmission line. Meanwhile material characteristics, such as dielectric constant, dielectric loss, and even the surface roughness of copper conductors, directly impact the performance of circuits fabricated on those materials.

MICROSTRIP

Microstrip is one of the more popular transmission-line types due to its high performance and relative ease of fabrication. It consists of a top conductor layer and bottom ground plane, with a dielectric layer in between (Fig. 1). The characteristic impedance will be determined by the copper weight and quality, the dimen-



1. Microstrip transmission lines consist of a top conductor layer and bottom ground plane, with a dielectric layer in between.

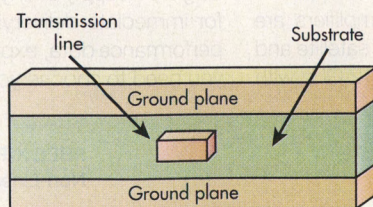
sions of the copper-formed circuit traces, and the thickness and qualities of the dielectric material.

If anything, microstrip is growing in popularity in concert with the meteoric rise in wireless applications—wireless patch antennas are commonly used in portable wireless devices. As with other microstrip circuits, microstrip patch antennas are relatively easy to fabricate and can be made with low-profile form factors.

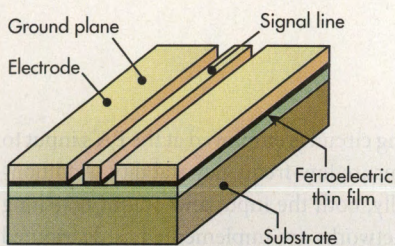
Microstrip-patch-antenna performance usually pinnacles when using thick substrate materials having low dielectric constants, since such materials support good radiation patterns with high efficiency and wide bandwidths. Using thinner PCB substrates with higher dielectric constants will lead to patch antennas with narrower bandwidths and lower efficiency. However, fabricating on higher-dielectric-constant materials will reduce circuit dimensions for a given characteristic impedance.

STRIPLINE

Stripline is also widely used for RF/microwave PCB designs. In contrast to microstrip, in which EM waves through a conductor propagate through a combination of dielectric material and free space, a conductor in stripline is surrounded on all sides by dielectric material (Fig. 2). The dielectric material in a stripline circuit sandwiches between top and bottom ground planes. Stripline is somewhat similar in electrical behavior to a coaxial cable, in which a center conductor is surrounded by a dielectric material layer that itself is surrounded by a ground-plane layer.



2. Stripline is formed with a conductive strip surrounded on all sides by dielectric material.



3. In the creation of CPW transmission lines, a conductor with ground planes on either side sits on top of dielectric material.

One type of conventional stripline circuits is offset stripline, in which the center conductor is not equidistant from the two ground planes but rather positioned closer to one of the ground planes. Another type is suspended stripline—the conductive layer is mounted on dielectric material but “floats” in a top layer of air, with the ground planes surrounding top and bottom air layers; air contributes its dielectric constant to the mix.

Suspended stripline is probably the most popular type of stripline. However, fabrication and assembly procedures for forming suspended-stripline circuits can be complex and somewhat expensive versus conventional stripline and microstrip. But suspending the circuit layer in air and surrounding it with a metal housing/ground plane can prove beneficial over conventional stripline in terms of wider bandwidth, improved radiation (less) characteristics, and low circuit losses.

Yet another form of stripline—double-conductor stripline—features two conductors of unequal widths on top of one another, surrounded by dielectric layers that are, in turn, surrounded by ground planes. Double-conductor stripline can be thought of as two microstrip circuits with unequal-width conductor strips laid on top of each other and glued together.

Stripline, suspended stripline, and double-conductor stripline can be difficult to fabricate. Components must be located between the ground planes or other structures, such as plated viaholes, and machined to make electrical connections to discrete elements and ICs that may be surface-mounted on microstrip.

OTHER TRANSMISSION-LINE TYPES

Additional types of transmission lines commonly fabricated on PCB materials for RF/microwave applications include coplanar waveguide (CPW), slotline, finline, and substrate integrated waveguide (SIW). CPW circuit structures consist of a conductor with ground planes on either side, all sitting atop a dielectric material (Fig. 3). In theory, the EM fields propagate through the conductor and the dielectric material with minimal loss. CPW can also be fabricated as grounded coplanar waveguide (GCPW), with an additional ground plane on the bottom of the substrate.

CPW is popular for high-frequency circuit design, since discrete circuit elements and active devices can be mounted on top of the circuit, in the manner of microstrip. CPW circuits can support frequencies well into the millimeter-wave frequency region with low loss and, with the dual ground-plane structure, multiple CPW circuits can be connected without discontinuities in the ground plane.

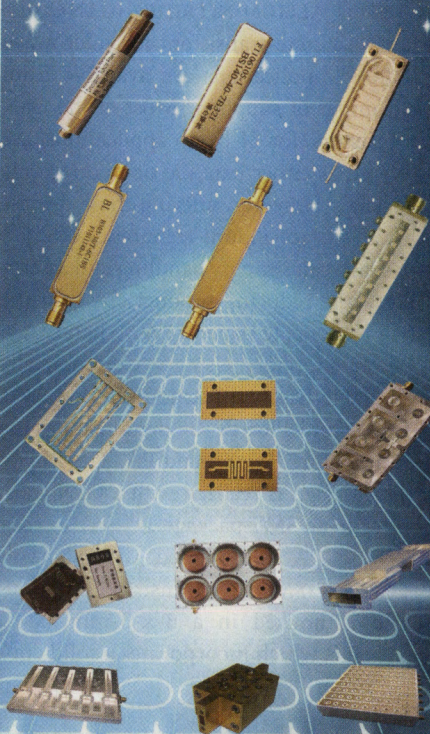
Heat dissipation of CPW circuits depends on the thickness and characteristics of the PCB material. The effective dielectric constant for a CPW substrate is the average of the dielectric material and air since, like microstrip, one-half of the electric field lines are in free space and one-half sit in the dielectric material.

Slotline consists of a slot between two conductive lines sitting on top of a dielectric substrate. As with microstrip and CPW, the exposed transmission lines make it easy to mount active and passive components.

Finline consists of two conductors and ground planes surrounded by PCB dielectric material, with a slot between the two conductors. It generates circular EM fields, and is often applied to the design of circulators and isolators. However, finline is complex and costly to fabricate. SIW transmission lines, which essentially create a rectangular waveguide within a substrate, show great promise for use at millimeter-wave frequencies to 100 GHz and beyond. **MM**

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DESIGN AN X-BAND PA USING A SURFACE-MOUNT TRANSISTOR

GALLIUM-NITRIDE (GaN) discrete transistors for microwave applications are available from a number of suppliers. Most of the GaN transistors for X-band applications are offered as either bare die or in a ceramic package. However, offering these devices in a surface-mount-technology (SMT) package can simplify handling and assembly while reducing product costs. In the five-page white paper, "5W X-Band GaN Power Amplifier Using a Commercially Available Discrete Plastic Packaged SMT Transistor," Plextek RFI demonstrates the design of a 5-W, X-band PA. The single-stage design is realized with a GaN transistor in an SMT package.

The PA is designed with Qorvo's TGF2977-SM GaN transistor. This device is housed in a 3-x-3-mm, SMT package, which incorporates a solid cop-

per base. An 8-mil-thick Rogers 4003 laminate with 1-oz. copper cladding is used to build the PA.

A plot of the transistor's maximum available gain is presented, demonstrating that the device has a maximum gain of approximately 14 dB at 9.4 GHz. Although the device demonstrates unconditional stability across the X-band frequency range, design effort is required to ensure stability below 4.8 GHz and above 12.5 GHz. In addition, the results from large-signal load-pull measurements are discussed. At 9.4 GHz, output power of +37.5 dBm at the 3-dB compression point is achieved.

The PA's biasing networks consist of radial stubs, which behave as short circuits at the midband frequency. A damp-

ing circuit is employed at the PA's input to ensure low-frequency stability. Additionally, both the input and output matching networks are implemented as distributed two-section lowpass structures.

The final PA assembly is mounted onto a heat-sink. Small-signal S-parameters were measured at package-base temperatures of -33°C, +25°C, and +85°C. These measure-

ments demonstrate a small-signal gain of approximately 11 dB across the frequency range, which varies by approximately ± 1.5 dB over temperature. The PA's output power at the 3-dB compression point was +37.1 dBm at midband while varying by only ± 0.2 dB over temperature. The document also provides the PA's efficiency performance.

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PERFORM EFFECTIVE PASSIVE-INTERMODULATION MEASUREMENTS

PASSIVE INTERMODULATION (PIM) can occur as a result of the presence of two or more high-power signals in a system. Electrical nonlinearities within a system can unintentionally act as mixers, thereby causing PIM to occur. These nonlinearities can result from loose connections, contaminated or corroded metal surfaces, ferromagnetic metals, and many other factors. It is therefore important to perform testing to verify PIM performance. In the application note, "Introduction to PIM Testing," AR RF/Microwave Instrumentation describes a test setup that can be used to measure PIM.

PIM is particularly problematic when both the receive signals and transmit signals in a system share a common transmission path, such as a coaxial cable, coupler, or antenna. Two high-power signals at different frequencies within the transmit band can mix with one another, potentially creating an intermodulation (IM) product that lies within the receive band. Satellite-to-ground communication, for example, transmits very-high-power signals while utilizing highly sensitive receivers. If preventative measures are not implemented, PIM can result from these high-power

transmission signals. This distortion can then mask the sensitive receive bands.

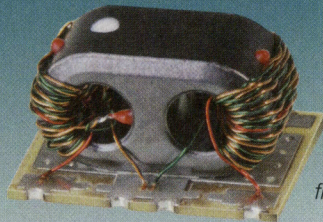
A block diagram of a PIM test setup is provided in the application note, demonstrating the components used in the configuration. The setup is suitable for the testing of a two-port component, such as a cable or filter. In addition, antenna testing can be achieved with this setup with the incorporation of an anechoic chamber.

The application note emphasizes the importance of ensuring that the test setup itself does not corrupt PIM measurements. For example, the filters, couplers, and interconnects in proximity to the device-under-test (DUT) must have superior PIM performance. Coaxial cables and connectors can be a problem, as their PIM performance can degrade with use. High-power loads can also generate PIM, so they need to be considered as well. When measuring antennas, the anechoic chamber's PIM performance is also significant. Lastly, the document concludes with a description of AR's one-box solutions, which can provide customers with a PIM test solution.

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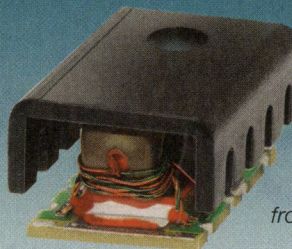


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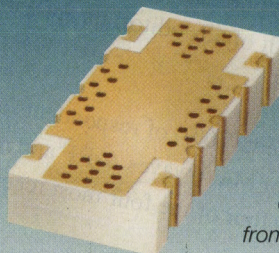


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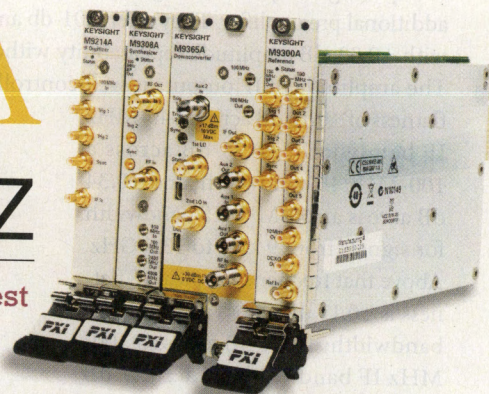
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Modular VSA Pushes to 50 GHz

A 50-GHz PXIe vector signal analyzer is just one of the latest additions to a growing lineup of modular test instruments for RF/microwave signal generation and analysis.



MODULAR RF/MICROWAVE TEST instruments are quickly becoming popular among engineers due to their flexibility and substantial measurement capability in small packages. For the M9393A modular PXIe vector signal analyzer (VSA) from Keysight Technologies, the small size also applies to its wavelengths—its new, extended frequency range to 50 GHz (and continuous frequency sweeps from 3.6 to 50.0 GHz) can handle Ka-band commercial and satellite communications (satcom) testing.

The model M9393A PXIe VSA (Fig. 1) actually comprises four separate PXIe modules: an M9214A intermediate-frequency (IF) digitizer, M9308A frequency synthesizer, M9300A frequency reference, and M9365A frequency downconverter. Together, they fit with room to spare within a PXI/PXIe chassis. When using instrument modules (e.g., AXIe or PXIe modules), performance can be modified by adding, say, an M9169E switchable attenuator to increase the M9393A's measurement dynamic range.

The VSA's frequency reference is based on an internal 10-MHz oven-controlled crystal oscillator (OCXO) and 100-MHz phase-locked loop (PLL). It provides stable outputs at 10 and 100 MHz, including directly from the OCXO (and typically at levels of +9.5 dBm or higher).

The frequency-reference module also accepts clock signals from an external frequency reference, from 1 to 110 MHz at

levels of 0 to +10 dBm with a nominal lock range of ± 1 ppm. The 100-MHz output from the frequency reference feeds the M9308A frequency synthesizer, which employs a PLL to generate RF/microwave signals from 2.85 to 9.00 GHz along with a series of dividers and multipliers to broaden the frequency range for input to the M9365A frequency downconverter.

The M9214A IF digitizer accepts IF signals from the M9365A. The digitizer is stabilized by 100-MHz signals from the frequency reference. It includes a high-performance, high-resolution analog-to-digital converter (ADC) supported by an FPGA and custom ASIC for advanced signal processing. The M9214A includes lots of dedicated random-access memory (RAM) for storing waveform data.

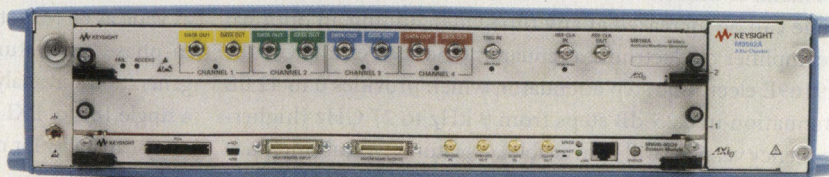
RANGE OF RANGES

Thanks to its modular configuration, the M9393A VSA is available in a number of different versions, including five frequency ranges, to meet the spectral needs of users across the board: 9 kHz to 8.4 GHz, 9 kHz to 14 GHz, 9 kHz to 18

1. The M9393A modular vector signal analyzer consists of four separate PXIe modules—the M9214A digitizer, M9308A frequency synthesizer, M9365A downconverter, and M9300A frequency reference.

GHz, 9 kHz to 27 GHz, and 3.6 to 50.0 GHz. All feature impressive 0.01-Hz frequency tuning resolution. These compact analyzers can also be specified with different maximum analysis bandwidths and final IF bandwidths available for studying different types of modulated signals. For example, analyzers with maximum available analysis bandwidths of 40 MHz have final IF bandwidth of 240 MHz. For 100-MHz max bandwidth, final IF bandwidth is 300 MHz, and 160-MHz final bandwidth has final IF bandwidth of 326 MHz.

The VSAs also come with a bypass option (WB1), which provides a wide 800-MHz nominal IF output bandwidth to be digitized by an external wideband digitizer. It analyzes signals (and interference) occupying extremely wide portions of spectrum. All instruments have 1-Hz minimum resolution bandwidth.



2. The model M8196A arbitrary waveform generator extends to 92 Gsamples/s and produces signal 3-dB bandwidths to 32 GHz in a single AXIe module.

DIGGING INTO THE SPECS

The VSAs handle RF input signals at levels to +30 dBm, with an input signal dynamic range of -170 to +30 dBm without an additional preamplifier. They offer 0.01-dB amplitude resolution with ± 0.03 -dB amplitude repeatability without a preamplifier. The amplitude of IF outputs is well controlled with typical IF flatness of ± 0.16 dB across a 40-MHz IF bandwidth; ± 0.21 dB across a 100-MHz IF bandwidth; and ± 0.34 dB across a 160-MHz IF bandwidth for signals from 9 kHz to 13.6 GHz. Above that frequency, typical IF flatness is ± 0.17 dB across a 40-MHz IF bandwidth; ± 0.31 dB across a 100-MHz IF bandwidth; and ± 0.47 dB across a 160-MHz IF bandwidth.

The VSAs also offer tightly controlled phase characteristics, with excellent IF phase linearity, for evaluating signals with phase-based modulation. For 9-kHz to 13.6-GHz signals, typical IF phase linearity is ± 0.81 deg. across a 40-MHz IF bandwidth; ± 1.34 deg. across a 100-MHz IF bandwidth; and ± 1.56 deg. across a 160-MHz IF bandwidth. For signals above 13.6 GHz, typical IF phase linearity is ± 1.69 deg. across a 40-MHz IF bandwidth; ± 2.56 deg. across a 100-MHz IF bandwidth; and ± 3.59 deg. across a 160-MHz IF bandwidth.

The displayed average noise level (DANL) remains low, even when not using the available noise correction. Without noise correction or additional preamplification, the M9393A achieves typical DANL of -129 dBm/Hz from 9 to 300 kHz; -145 dBm/Hz or better from 300 kHz to 13.6 GHz; and -122 dBm/Hz or better from 13.6 to 27.0 GHz. When using the noise correction (and no preamplification), the DANL typically drops to -135 dBm/Hz from 9 to 300 kHz; -156 dBm/Hz or better from 300 kHz to 13.6 GHz; and -133 dBm/Hz or better from 13.6 to 27.0 GHz. For higher-frequency operation through 50 GHz, achieved with the model M9169E frequency extension module (option FRX), the typical DANL is -153 dBm/Hz from 13.6 to 34.0 GHz; -151 dBm/Hz from greater than 34.0 GHz to 45 GHz; and -147 dBm/Hz from greater than 45 GHz to 50 GHz.

Thanks to the PXIe format's flexibility, dynamic measurement range can be increased at any time when adding an optional preamplifier or electronic attenuator. One such example is the M9169E electronic step attenuator, which provides 0 to 42 dB attenuation in 0.25-dB steps from 9 kHz to 27 GHz (higher-frequency versions will be available). It features typical amplitude accuracy of ± 0.71 dB from 100 kHz to 1 MHz; ± 0.49 dB from 1 to 20 MHz; and ± 0.40 dB or better across the remainder of the frequency range to 27 GHz.

The M9393A VSAs boast fast frequency-switching speeds that work with the high-speed PCIe control interface of the PXIe format to achieve fast, large-volume production testing. Its nominal frequency-switching speed is 5 ms, resulting in fast frequency sweeps for high-speed production testing. In addition, option UNZ is available for switching speeds faster than 175 μ s

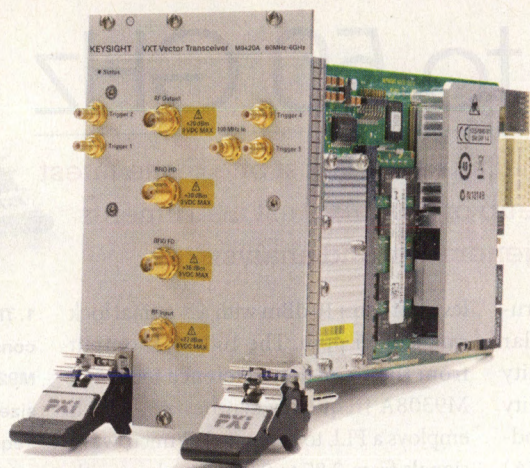
for arbitrary changes in frequency. But such switching speed does not compromise spectral purity, with the VNAs exhibiting typical phase noise of -105 dBc/Hz offset 1 kHz from a 1-GHz carrier; -110 dBc/Hz offset 10 kHz from the same carrier; and -134 dBc/Hz offset 1 MHz also from the same 1-GHz carrier.

Other high-frequency test instruments recently developed by Keysight in the AXIe or PXIe modular formats include the versatile M8196A arbitrary waveform generator (AWG) and the more recent M9420A PXIe vector transceiver. Both complement the M9393A with added signal-generation and analysis capabilities. The M8196A is housed in a one-slot-high (Fig. 2) AXIe

module with 512 ksamples of waveform memory per channel. Capable of 83 to 92 Gsamples/s, the source can generate analog signals across a typical 32-GHz, 3-dB bandwidth. The waveform generator has 8-b vertical resolution and built-in frequency and phase response calibration for well-controlled output signals.

Versions of the AWG come with one, two, and four channels, with single-ended or differential outputs (single- and dual-channel models can be upgraded to four channels via software licenses). The AXIe format supports tight synchronization of multiple output signals, with ± 7 -ps typical skew between any pair of output signals. For pulsed waveforms, the generator delivers typical rise/fall time of 9 ps. The spectral purity is quite good, with typical phase noise of -110 dBc/Hz offset 1 kHz from a 1-GHz sine wave; -118 dBc/Hz offset 100 kHz from a 1-GHz sine wave; and -138 dBc/Hz offset 1 MHz from a 1-GHz sine wave.

In terms of modular instrumentation innovation, the model M9420A vector transceiver (VXT) fits within a single three-slot-wide PXIe module (Fig. 3). With versions for frequency coverage as wide as 60 MHz to 6 GHz, it provides a maximum 160-MHz in-phase/quadrature (I/Q) bandwidth for both vector signal generation and analysis. As many as four VXT modules can fit in a single 18-slot PXI chassis, providing densely packed measurement capability for multichannel systems and components. 



3. The model M9420A vector transceiver (VXT) generates and analyzes I/Q signals with coverage as wide as 60 MHz to 6 GHz in a single three-slot-wide PXIe module.

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Manufacturing Solutions Equip Assembly Suppliers

Many current products and services meet suppliers' manufacturing demands for constructing integrated RF/microwave assemblies.

BUILDING RF/MICROWAVE ASSEMBLIES requires a variety of equipment to complete the entire process. A microwave multichip module (MCM), for example, contains an assortment of monolithic-microwave integrated circuits (MMICs) to enable the desired functionality of the complete assembly.

Depending on its complexity, a microwave MCM can have numerous MMICs incorporated into its design. Between this potentially large number of MMICs and all of the requisite interconnections, it's essential to have the proper equipment in place to succeed in creating a microwave assembly.

DIE BONDING

Several steps are required to build a complete microwave assembly. Die bonding, or die attachment, is the process of attaching a semiconductor die either to its package or to a substrate. Epoxy and eutectic bonding are two commonly used techniques for die attachment of MMIC devices.

When using epoxy to attach a MMIC die, a small amount of epoxy is typically applied to the mounting surface. The MMIC is then placed in the proper position to make the bond. Once in place, the epoxy is cured in accordance with the manufacturer's requirements.

A eutectic system involves a mixture of chemical compounds or elements that has a lower melting point than any composition made from the same ingredients. A commonly used eutectic material for die bonding of MMIC devices consists of 80% gold (Au) and 20% tin (Sn). This composition, which has a melting point of 280°C, is available as a preform. Once the preform and die are properly placed, the die-bonding machine performs the task of bonding the die onto the surface. Due to its good thermal-conductivity characteristics, the AuSn eutectic mixture is well-suited for higher-power applications.

A number of manufacturers offer die-bonding equipment. Palomar Technologies (www.palomartechnologies.com), for example, offers a selection of die bonders. In fact, the company recently unveiled its 3880 model, which provides customers with multiple options within a single machine.



1. Both epoxy and eutectic bonding are handled by this die bonder. (Courtesy of West-Bond)

One benefit of the 3880 die bonder is its z-theta, bidirectional bond-head with voice-call technology. This allows for improved force-range and reliability, tool index speed, tool-to-tool index precision and planarity, and easy setups. The 3880 will find homes in a wide range of applications, from microwave modules to RF packages and RF power amplifiers (PAs).

West-Bond (<http://westbond.com>), another manufacturer of die-bonding machines, offers a selection of manual die bonders. Its 7372E model can perform both epoxy and eutectic bonding thanks to interchangeable tool-head assemblies (Fig. 1). It uses the company's 8/1-ratio micro-manipulator to reduce the strain on the operator when making small, repeated movements.

WIRE BONDING

Once all devices have been bonded to an assembly, wire bonds must be installed to provide electrical interconnectivity. Ball bonding and wedge bonding are two techniques used to apply wire bonds to microwave assemblies. Palomar Technologies, as well as other resources, offer a more detailed description of both types of wire bonding.



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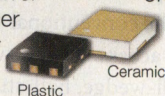
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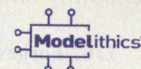
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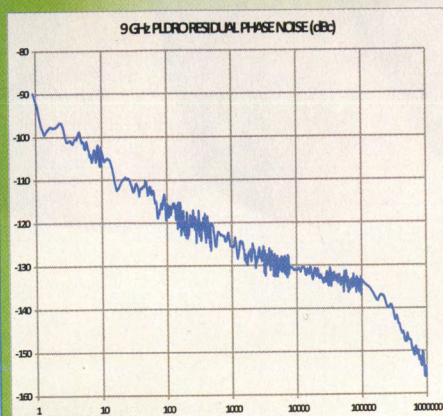
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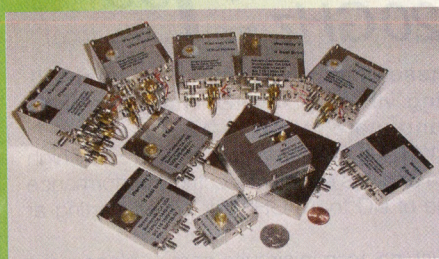
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Manufacturing Solutions

Wire bonding obviously requires wire-bonding equipment, which is available from a number of manufacturers. Hybond (www.hybond.com) offers both ball and wedge bonders. It also offers the 626 model, which is a multi-purpose-bonder

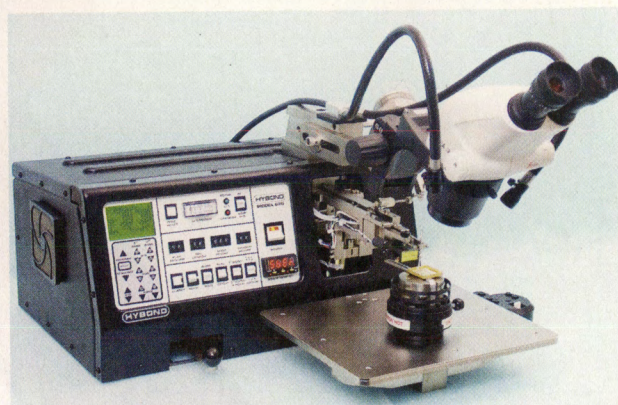
(Fig. 2). This bonder can operate as a ball, wedge, bump, or peg bonder. When used for ball-bonding applications, the 626 can bond gold wires with diameters ranging from 0.7 to 2.0 mils.

Additional wire-bonding machines from Hybond include the 676 digital thermosonic wedge bonder. It can bond wires with diameters from 0.5 to 3.0 mils, and is able to bond ribbons with dimensions extending to 1.0 x 12.0 mils. Both the 626 and 676 models are used throughout the RF/microwave industry by companies like Northrop Grumman, Raytheon, BAE Systems, K&L Microwave, and others.

In addition, the company's ball-bonding machines include the 522A model. This thermosonic ball-bonder machine is capable of bonding gold wires with diameters ranging from 0.7 to 2.0 mils.

West-Bond offers a variety of manual, semi-automatic, and automatic wire bonders. Among the company's products is the 353637F series of automatic wire bonders. These machines can automatically bond arrays of wire connections by means of a software program. A range of bonding functions is available as well, such as the conventional 45-deg. wire-feed, deep-access 90-deg. wire- or ribbon-feed, ball-wedge, ball-stud, and single-point tab/lead bonding.

Palomar Technologies also enters the fray in this space with the 8000i—a fully automatic, thermosonic, high-speed



2. This multi-purpose wire-bonder can operate as a ball-, wedge-, bump-, or peg-bonder. (Courtesy of Hybond)

wire bonder. In addition to conventional wire bonding, its capabilities include ball, stud, wafer, and chip bumping. The 8000i also offers customized looping profiles.

MANUFACTURING SERVICES

Various companies provide complete manufacturing services for RF/microwave assemblies. For example, SemiGen (www.semigen.net), a contract manufacturer, offers standard services such as die attachment, wire bonding, ribbon bonding, and much more. SemiGen also has the ability to perform testing at frequencies as high as 40 GHz.

Another player in this field is Teledyne Microelectronics (www.teledynemicro.com), which provides electronic manufacturing services. The company's process technology enables it to manufacture RF/microwave assemblies via die attachment, wire bonding, and hermetic packaging. They also can test assemblies to 65 GHz. Customers include the U.S. government and prime contractors.

To summarize, the assembly process of a microwave module is just as important as the design and testing stages. With that being case, suppliers of these products have many options to meet a customer's assembly needs, and a vast array of equipment on tap. On top of that, contract manufacturers can provide solutions to those companies that prefer to have an outside source handle the entire assembly process. **mw**

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TOP PRODUCTS of 2015

Innovations in RF/microwave product areas continue as manufacturers prepare for higher-volume applications in mobile wireless-communications products and wearable devices.

WIRELESS COMMUNICATIONS CONTINUED to steer new product innovation and development in the high-frequency industry in 2015, as products from components and devices through test equipment were developed to enable improved communications capabilities. With the coming of the Internet of Things (IoT)—and potentially billions of wireless sensors contributing data to a huge “cloud” of computer networks and memory—wireless systems developers are searching for bandwidth and ways to move large amounts of data from one location to another.

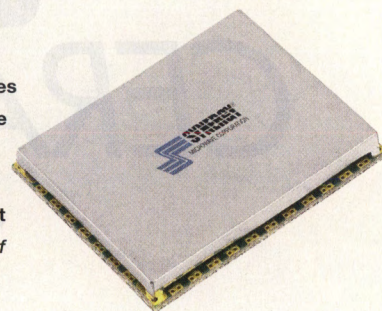
In support of an increasingly wireless future, RF/microwave product developers demonstrated innovation without extravagance, achieving new performance levels that are affordable and reliable. The dozen products detailed here represent just a small sampling of the many excellent RF/microwave products introduced in 2015.

Interest in gallium-nitride (GaN) technology continued to grow in 2015 for both commercial and military users, as this high-power-density semiconductor substrate is helping to reach high output-power levels in smaller packages. To make those packages more affordable, Qorvo (www.qorvo.com) introduced a line of plastic-packaged GaN power transistors at 2015's International Microwave Symposium (IMS), including the model TGF3015-SM with 11-W output power at 2.4 GHz. Housed in 3- × 3-mm plastic packages, the discrete transistors are usable from 30 MHz to 3 GHz (see p. 55 for more on power transistors).

Certainly deserving of a “honorable mention” for a Top Product, Freescale Semiconductor (www.freescale.com) introduced its model OM-270 plastic package at the same IMS event. It features GaN compatibility for commercial and military use.

Cree (now Wolfspeed) continued to challenge old-guard traveling-wave-tube (TWT) technology with its own GaN device introductions, including its model CMPA1D1E025 and CMPA1D-

1. A proprietary ASIC guides the low-noise performance of a line of phase-locked frequency synthesizers in coaxial and surface-mount formats. (Photo courtesy of Synergy Microwave Corp.)



1E030D Ku-band devices for satellite-communications (satcom) applications. The former is an impedance-matched GaN-on-SiC monolithic-microwave-integrated-circuit (MMIC) amplifier in a metal/ceramic package for use from 13.75 to 14.50 GHz (25-W output power), while the latter is a MMIC amplifier capable of 30-W output power from 13.5 to 14.5 GHz.

For systems in which noise is a concern, Synergy Microwave Corp. (www.synergymicrowave.com) introduced several versions of a phase-locked-oscillator (PLO) and frequency-synthesizer combination in coaxial and surface-mount-technology (SMT) packages (Fig. 1). It uses a proprietary application-specific integrated circuit (ASIC) for wideband frequency tuning from 100 MHz to 15 GHz. The architecture has been used with different tunable oscillators, including dielectric resonator oscillators (DROs) and voltage-controlled oscillators (VCOs), with excellent results. These include spurious levels of -65 dBc or better and phase noise of -118 dBc/Hz offset 1 kHz from the carrier, and -123 dBc/Hz offset 10 kHz from the carrier.

Noise was also a key parameter in the design and development of the model PMA3-83LN+ low-noise amplifier (LNA) from Mini-Circuits (www.minicircuits.com), achieving low noise figures from 500 MHz to 8 GHz. It has a noise figure of about 1.5 dB at the lower-frequency end of the frequency range and slightly more than 2 dB at the upper-frequency bandedge. The MMIC amplifier maintains flat gain of better than 21 dB across a wide operating-temperature range (-40 to +85°C).

In helping to evolve microelectromechanical-systems (MEMS) technology for use in such applications as the IoT, SiTime (www.sitime.com) developed its model SiT8021 MEMS-based clock oscillator for frequencies from 1 to 26 MHz. The source is a fraction of the size and power consumption of traditional quartz-crystal clock oscillators, and is well-suited for mobile applications and wearable devices.



2. These USB power sensors are among the smallest RF/microwave test instruments, relying on a PC for control and display functions. (Photo courtesy of Anritsu Corp.)

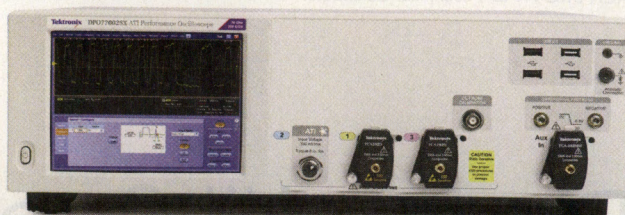
SMALLER TEST GEAR

Test and measurement solutions continued to shrink in size and grow in capability in 2015, with the MA24208A and MA24218A USB power sensors from Anritsu (www.anritsu.com) among the smallest of RF/microwave instruments—literally fitting in a pocket at 110 × 46 × 25.6 mm, excluding the Type-N connector (Fig. 2). The instruments cover 10 MHz to 8 GHz and 10 MHz to 18 GHz, respectively.

Power measurements for land-mobile radios (LMRs) are the specialty of the Channel Power Monitor introduced by Bird Technologies (www.birdrf.com) in 2015. The instrument monitors the transmission path of LMR systems from 144 to 960 MHz in real time, with versions capable of handling power levels as high as 500 W CW. Standard units feature 16 channels, but can be expanded.

In test, as in 2014, manufacturers pursued the design and development of compact modular measurement instruments, such as the 50-GHz extension of the model PXIe vector signal analyzer (VSA) by Keysight Technologies (www.keysight.com) detailed on p. 35. The frequency range of the M9393A VSA, a Top Product of 2014, was nearly doubled with the new frequency extension.

Support for a growing number of millimeter-wave applications was also provided by National Instruments (www.ni.com) with its QuickSyn Lite frequency-synthesizer modules. The product line includes units with frequency coverage of 27 to 40 GHz, 50 to 67 GHz, and



3. The model DPO70000SX 70-GHz real-time oscilloscope fits in a compact housing. (Photo courtesy of Tektronix)

TOP PRODUCTS OF 2015 (LISTED ALPHABETICALLY)
Anritsu's USB power sensors (July, p. 72)
Bird Technologies' Channel Power Monitor (July, p. 64)
Cambridge Instruments' SWaP PXIe frequency synthesizers (April <i>Defense Electronics</i> , p. S26)
Cree's GaN HEMT amplifiers (June, p. 78)
Keysight Technologies' 50-GHz PXIe vector signal analyzer (December, p. 63)
Mini-Circuits' low-noise SMT amplifier (September, p. 72)
National Instruments' 82-GHz frequency synthesizers (July, p. 70)
Qorvo's plastic-packaged GaN MMIC amplifiers (July, p. 68)
SiTime's MEMS-based clock oscillators (June, p. 72)
Synergy Microwaves' JASIC-based frequency synthesizers (March, p. 87)
Tektronix's portable spectrum analyzer (January, p. 87)
Tektronix's 70-GHz oscilloscope (April, p. 120)

76 to 82 GHz. The synthesizer modules are equipped with Serial Peripheral Interface (SPI) and Universal Serial Bus (USB) control connections.

Cambridge Instruments (www.cambridgeinstruments.com) aimed at excellent spectral purity from 6 to 12 GHz in its QuantumWave 4000 line of PXIe frequency synthesizers. These synthesizers are suitable for a variety of military and aerospace applications.

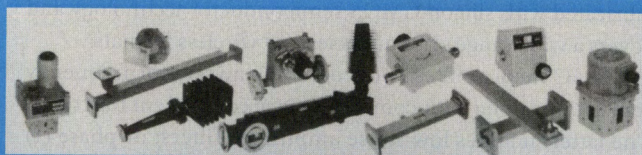
Tektronix contributed to the trend of smaller, more powerful test instruments with its model DPO70000SX 70-GHz real-time oscilloscope (Fig. 3). It packs sampling rates to 200 Gsamples/s into an instrument housing only 5.25 in. high. The versatile oscilloscope can be used for single- or dual-channel measurements, and offers one or two 70-GHz-wide channels or four 33-GHz-wide channels. Tektronix also brought the small theme to its RSA306

spectrum analyzer, a near pocket-sized instrument at 5.0 × 7.5 × 1.2 in. with a full-sized frequency range of 9 kHz to 6.2 GHz. **mw**

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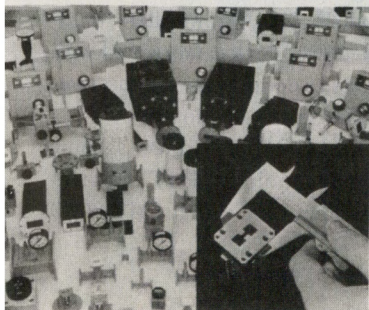
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Design Kit Speeds Wireless Development

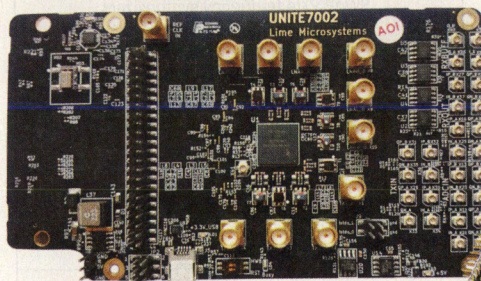
With its RF board, interconnect board, and straightforward software, this design kit helps speed the development of a wide range of wireless communications products.

MODERN WIRELESS PRODUCT design usually involves simulation with software and measurements with test gear—and with construction of a printed-circuit-board (PCB) prototype in between. To accelerate the design process, a kit developed jointly by Lime Microsystems (www.limemicro.com) and Altera (www.altera.com) provides a head start on the RF and baseband circuitry. The Universal Radio Development Platform combines two PCBs and software, and allows new designs to be developed quickly and characterized inexpensively, without costly high-end test equipment.

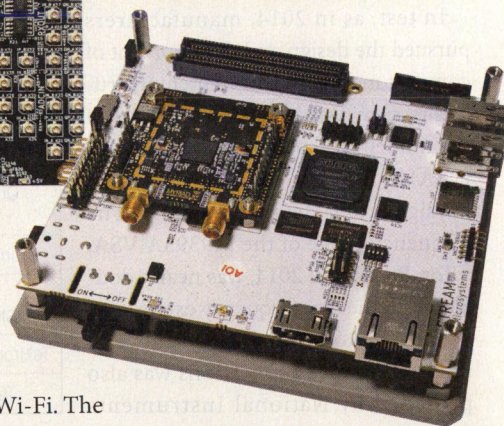
One of the two circuit boards contained in the Universal Radio Development Platform kit is an RF/baseband subsystem. This board, the model UNITE7002 (Fig. 1), is built around Lime's model LMS7002M dual-transceiver integrated circuit (IC). This field-programmable RF (FPRF) transceiver is fabricated with silicon CMOS semiconductor technology and covers a wide range of frequencies and wireless formats.

The IC incorporates two frequency mixers for frequency translation, along with complementary component functions. The latter includes low-noise amplifiers; filters; in-phase (I) and quadrature (Q) digital-to-analog converters (DACs); I and Q analog-to-digital converters (ADCs); and digital signal processors (DSPs). In spite of the number of components, the device achieves low-power operation through its CMOS technology and help from the DSPs, with the IC capable of operating on a single supply rail of +1.8 V dc.

The LMS7002M transceiver (and its board) is usable from 100 kHz to 3.8 GHz, and is software-configured for RF bandwidths to 120 MHz. It supports second-generation (2G), third-generation (3G), and fourth-generation (4G) cellular communications standards with time-division-duplex (TDD) and frequency-division-duplex (FDD) techniques, along with



1. The UNITE7002 RF circuit board is built around a second-generation FPRF device with many unique features.



2. The interconnect board includes a versatile, low-power FPGA from Altera to assist with signal-processing chores.

numerous other wireless standards like Wi-Fi. The device is programmable, with parameters such as frequency, gain, filter characteristics, and bandwidth readily adjustable. The IC features a standard serial port interface (SPI) for programming and includes provision for a full RF calibration.

With its dual-transceiver architecture, the LMS7002M can create two transmit-and-receive signal paths and will handle 2 × 2 multiple-input, multiple-output (MIMO) system architectures. The transceiver's enhanced capability features, such as an on-chip microcontroller, further simplify its calibration and installation. The LMS7002M IC is housed in a 261-pin QFN package measuring 11.5 × 11.5 mm.

The second PCB in the design kit, the Stream interconnect board (Fig. 2), includes a Cyclone IV FPGA from Altera, model EP4CE40F23C7N. This low-power device, fabricated with Altera's low-power 28-nm process, is optimized for transceiver applications requiring reliable, low-cost operation.

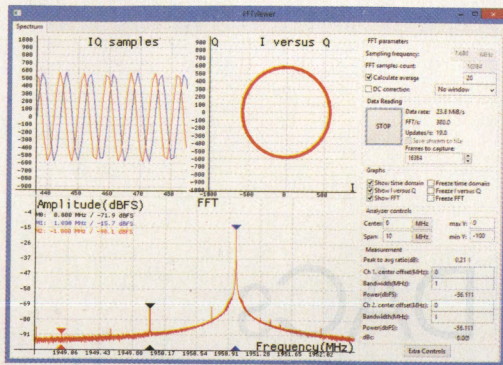
The board employs a standardized interconnect scheme with an 80-pin surface-mount-technology (SMT) connector. The connector was also used on some earlier LMS6002D boards from Lime.

The LimeSuite RF design software that accompanies the two boards runs on a personal computer (PC) with Linux (www.linux.com) or Microsoft (www.microsoft.com) Windows operating systems. It features a simple graphical user interface (GUI) to program the FPRF and provide controls for the different FPGA configurations included with the design kit (Fig. 3).

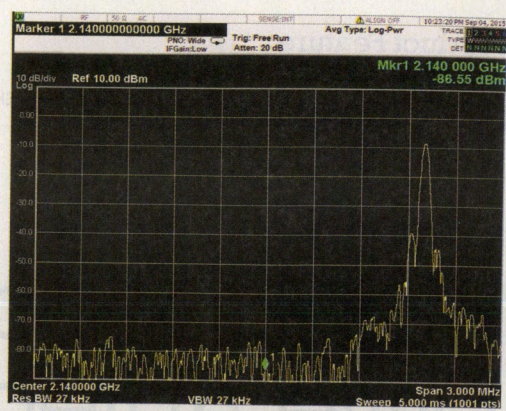
The FPRF GUI control allows users to download and test different sets of wireless communications parameters in real time. In some cases, the use of the downloaded test configurations to evaluate designs executed on the two PCBs can eliminate the need for external test equipment, with the related savings in development cost.

Setting up the development kit is straightforward, involving a basic calibration process that is designed to achieve optimum performance. To further simplify the process, an on-chip microcontroller integrated in the LMS7002M transceiver IC can calibrate numerous performance parameters.

Testing the development kit with external equipment is a simple matter, since RF signals from the UNITE7002 board can be transferred directly to external test gear such as signal analyzers (Fig. 4). An example of a test that can be performed



3. The LimeSuite RF design software supplied with the development kit provides a number of different waveform displays for analysis.



4. This plot reveals the frequency spectrum of the model UNITE7002 board's transmitter.

with an external analyzer involves the measurement of error vector magnitude (EVM), also known as receive constellation error (RCE). This is a measure of the accuracy of the constellation points on modulation schemes such as quadrature phase-shift keying (QPSK) or quadrature amplitude modulation (QAM).

The Universal Radio Development Platform kit and its two boards and software include various example system-level configurations, including MIMO architectures that can be downloaded to save engineering time. For engineers experimenting with wireless-system approaches, this kit can be a tremendous asset, and a way to truly gain a "head start" on a new system design. **mtw**

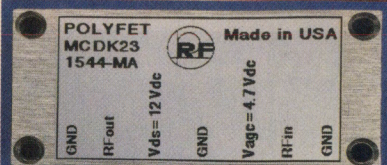
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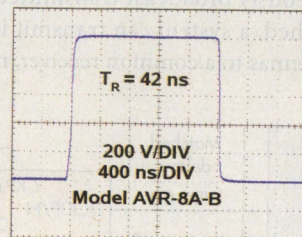


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High-Speed DACs Drive Antenna Diversity

Dramatically improve wireless signal reception by implementing antenna diversity—with the aid of multiple high-speed digital-to-analog converters.

NUMEROUS DIVERSITY TECHNIQUES are used in modern wireless systems to boost data throughput and enhance transmission reliability. Diversity techniques based on time, frequency, and codes are used to transmit signals to multiple users simultaneously and maximize the amount of transmitted data. By transmitting at different times, at different frequencies, or with different binary sequences known as Gold codes, signals can be differentiated from each other and received error-free. Such diversity techniques are well known and have been perfected over decades of use. They can also be applied to achieve antenna diversity or spatial diversity.

Antenna diversity uses multiple antennas to transmit or receive a signal. Simple antenna diversity employs the antenna combination with the best performance to decode the signal. More complex versions include multiple-input, multiple-output (MIMO) systems and beamforming applications, where multiple antennas are deployed at the transmitter and receiver to increase spatial diversity.

With multiple broadcasting antennas, it is critical to minimize timing variations (in the picosecond range) between the digital-to-analog converters (DACs) on each channel. This requires DACs that can be synchronized in order to simultaneously broadcast transmitted data. Once this is accomplished, a system can transmit identical data over multiple antennas to a common receiver, maximizing the likelihood of

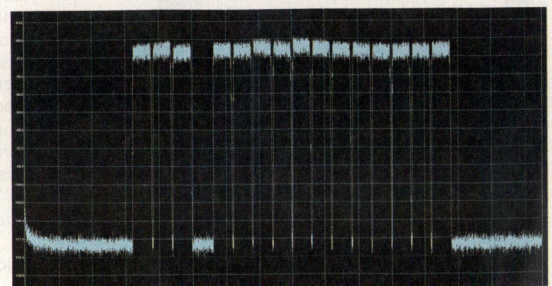
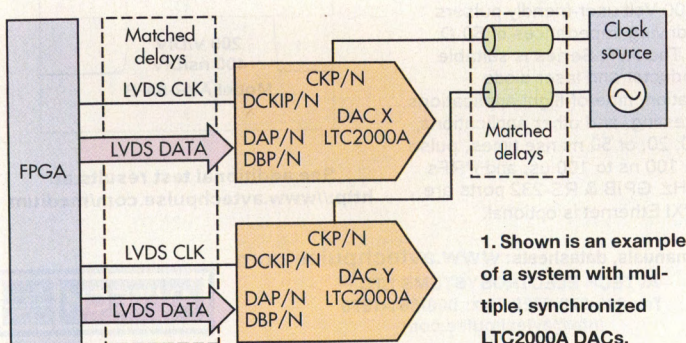
proper signal reception and minimizing the chance of dropping a signal from a transmitter.

DIVERSITY TYPES

Communication systems handle multiple users by means of diversity. The most basic version involves the use of time diversity, such as time-division multiple-access (TDMA) technology, which transmits data to multiple users at different times. A receiver then simply waits for its assigned time slot and decodes the appropriate data. Frequency-division multiple-access (FDMA) works in much the same way, but in the frequency domain using different frequencies. Data is transmitted to different users on specified frequencies and a receiver decodes only the data for its assigned frequencies.

Other modern systems incorporate code-division multiple-access (CDMA) techniques in wireless systems, where transmitted data is convolved with a specific code before transmission. This code is then used at the receiver to decode the data specifically transmitted to that user. Since these diversity techniques are implemented in different domains, they can be used together in one system for maximum diversity.

Diversity techniques have been used in several generations of wireless protocols, with each iteration experiencing improved system data throughput. Unfortunately, fading can occur when transmitting signals carrying data over any significant distance.



Fading is a loss of signal amplitude due to cancellation in the channel in which it was transmitted. From a transmit antenna, a signal can take multiple paths to a receiver, with changes in phase that can result in loss of amplitude when the different signal components recombine at the receiver.

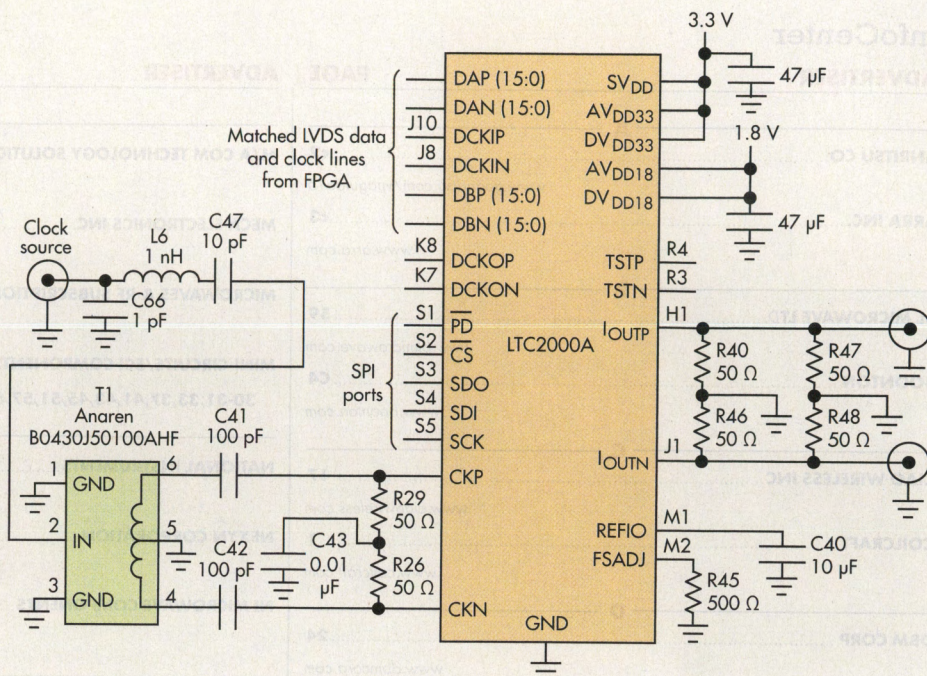
Such fading can be counteracted by utilizing multiple transmit or receive antennas. It is very unlikely that cancellation will occur in all cases when a signal is transmitted or received on multiple antennas. Use of multiple antennas is known as antenna diversity, and it can further improve data throughput in a wireless system.

IMPLEMENTATION

Antenna diversity can be implemented in a number of different ways in a wireless system. For example, spatial-division multiple-access (SDMA) techniques differentiate signals by means of spacing between antennas. There can be multiple antennas on the transmit side and a single antenna on the receive side in a multiple-input, single-output (MISO) configuration; a single transmitting antenna and multiple receiving antennas in a single-input, multiple-output (SIMO) configuration; or multiple transmitting antennas and multiple receiving antennas in a MIMO configuration.

MIMO-based systems offer the best results in terms of antenna diversity, but the complexity of the decoding requires a sophisticated transmitter and receiver. An operating environment that's constantly changing requires constant channel characterization. Also, as the distance between the transmitter and receiver increases, the complexity of the channel between the transmitting and receiving antennas becomes unstable and difficult to differentiate, making the benefits of MIMO less pronounced. Systems with multiple transmitting antennas and a single antenna for reception—quite common in wireless communications—take advantage of antenna diversity to improve performance.

In a MISO wireless system with antenna diversity, multiple DACs simultaneously transmit data on multiple antennas. Since transmitting antennas are arranged at physically different locations (e.g., on a tower), the signals will propagate to the receiver in different ways. The paths from each transmit antenna to the receive antenna will be different. The received signal will be different from each of the antennas due to the multipath effects in each of the communications signal channels.



3. Here's an example of a diversity system implementing LTC2000A DACs.

Characterization of each channel with transmitted pilot tones provides the receiver with invaluable information on each channel. This information can be used to digitally modify data before transmission, enhancing the likelihood of reception at the receiver. Since each channel requires specific modification and correction, separate DACs and a dedicated digital signal processor (DSP) are required for each transmitting antenna.

If the transmitting DACs are not perfectly aligned in time, the transmitted signals will be misaligned, resulting in poor beam-forming accuracy. The transmitter will be unable to maintain a stable channel from point to point, and the receiver will be unable to correct for these errors. To avoid this in the time domain, the DACs must be synchronized, which means that data must be transmitted from each DAC at the same time. Even the slightest variation in transmission time can degrade system performance.

When DACs output data at gigahertz (GHz) speeds, it is extremely difficult to synchronize their outputs across multiple devices. If a DAC is sampling at 2.7 Gsamples/s, the output code changes every 370 ps. The sample clock and the data clock from the FPGA need to be aligned for each transmitting DAC.

LTC'S HIGH-SPEED DAC

One example of such a DAC is the model LTC2000A, a 2.7-Gsample/s, 16-b DAC from Linear Technology Corp. (www.linear.com/LTC2000A) that simplifies synchronization by including an internal register to adjust data latency through the DAC. To use this feature, the timing mismatch of the data lines and clock lines to each of the DACs must be within 0.4 cycles of the sample clock frequency.

Figure 1 shows the ideal routing of two model LTC2000A DACs. The trace lengths of the data paths and clock paths to the individual DACs must match within negligible timing delays,

(continued on p. 80)

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Math Software Models WLANs

This versatile software-based toolkit provides customizable standards-based waveform and system models for performing quick, accurate simulations of WLAN systems.

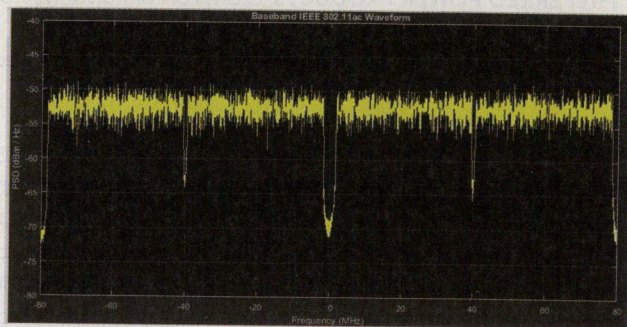
WIRELESS LOCAL-AREA NETWORKS (WLANs) HAVE become so commonplace—and so taken for granted—that most users forget how heavily they depend on them to gain quick and convenient access to the Internet. In fact, WLANs have become such a part of modern life that larger commercial businesses often provide free access to their WLANs as a convenience for customers.

Nevertheless, designing a WLAN device can be a challenge. Luckily for those tasked with designing WLANs, there's now software specifically intended to ease their way: the WLAN System Toolbox from MathWorks (www.mathworks.com). The system toolbox builds upon the firm's popular mathematics-based MATLAB software, providing models and design guidance that help engineers develop and integrate WLAN devices.

Building a WLAN transmitter or receiver requires successful coordination of hardware and software. Aside from achieving required performance levels from transmitters, receivers, and their antennas and component parts, specific waveforms must be generated and maintained to provide optimum WLAN performance—as well as minimize interference with other wireless devices and services in the vicinity.

The WLAN System Toolbox is extremely focused on WLAN design and development. It provides the necessary system functions to mathematically analyze modulation, transmission, reception, and demodulation of advanced high-frequency waveforms—notably, configurable physical-layer (PHY) waveforms for the IEEE 802.11ac and IEEE 802.11b/a/g/n WLAN standards. The WLAN System Toolbox includes reference designs to enable users to model the transmission and reception of WLAN signals, while at the same time accounting for different impairment and interference effects. This leads to a better understanding of how different conditions and operating environments can affect performance.

The WLAN System Toolbox provides MATLAB source code for the creation of different waveforms, component models, and analysis procedures. Beyond the PHY waveforms for IEEE 802.11ac and IEEE 802.11b/a/g/n WLAN standards, it offers various modeling functions for WLAN transmitters and receivers, including for single-input, single-output (SISO) and multiple-input, multiple-output (MIMO) configurations.



The WLAN System Toolbox simplifies physical-layer and standards-based signal modeling, and even over-the-air testing of WLAN systems.

The toolbox can be used to generate very-high-throughput (VHT), high-throughput (HT), and legacy, non-HT signals with channel coding and an assortment of modulation techniques. These include orthogonal-frequency-division-multiplex (OFDM) and direct-sequence-spread-spectrum (DSSS) modulation.

The design examples and standards-compliant waveforms contained within the WLAN System Toolbox can be used to assist real-world testing of WLANs, providing references for signal generation and analysis measurement equipment. Different functions and system objects can show examples of constellation diagrams for input signals; a frequency spectrum of time-domain signals; and even WLAN waveforms that can be used as starting points for an arbitrary waveform generator or other test signal generator to create stimulus signals for WLAN system testing. Among measurement examples in the WLAN System Toolbox handle are readings of error vector magnitude (EVM) and computing the bit error rate (BER) or symbol error rate (SER) of data carried on a WLAN input signal.

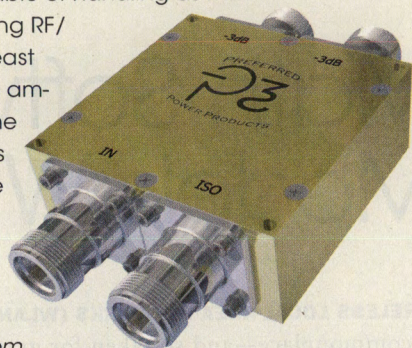
As with many of the firm's software tools, a free trial version of the WLAN System Toolbox is available for potential users to determine if this software package meets their requirements. More details are available at MathWorks' website. [mw](http://www.mathworks.com)

MATHWORKS, 3 Apple Hill Dr., Natick, MA 01760-2098; (508) 647-7000, www.mathworks.com

Hybrid Coupler Combines 1600 W

MODEL PH90-2000-4000-1R6SC is a high-power coaxial hybrid coupler capable of handling as much as 1600-W continuous-wave (CW) power when power-dividing and combining RF/microwave energy from 2,000 to 4,000 MHz. The hybrid coupler provides at least 18-dB isolation with typical insertion loss of only 0.2 dB. It achieves maximum amplitude balance of ± 0.55 dB and typical phase balance of ± 6 deg. across the full bandwidth. The coupler, which is composed of aluminum alloy, measures just $2.50 \times 2.50 \times 1.12$ in. with maximum VSWR of 1.25:1. It includes SC female coaxial connectors on all ports. It meets MIL-E-5400 and MIL-P-23971 requirements and is designed for operating temperatures from -55 to $+85^\circ\text{C}$.

PREFERRED POWER PRODUCTS, a division of Pulsar Microwave Corp., 48 Industrial W., Clifton, NJ 07012; (772) 485-9786, e-mail: sales@preferredpowerproducts.com, www.preferredpowerproducts.com



Signal Generator Tunes 9 kHz to 3 GHz

The model DSG800 is a compact, portable signal generator that provides low-noise output signals from 9 kHz to 3 GHz. It delivers output levels to $+20$ dBm with amplitude accuracy within ± 0.5 dB. The frequency tuning resolution is 0.01 Hz, while the single-sideband (SSB)

phase noise is -105 dBc/Hz. The signal generator employs an oven-controlled crystal oscillator (OCXO) frequency/time reference for better than 5 ppb temperature stability and better than 30 ppb/year aging stability. The signal generator offers various sweep functions (including step, list, logarithmic, and linear modes) and a host of analog modulation formats, including amplitude modulation (AM), frequency modulation (FM), phase modulation, and pulse modulation.

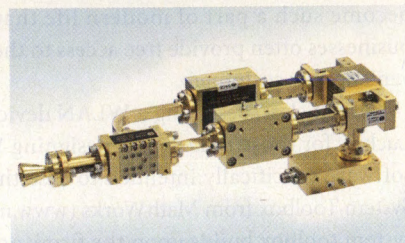
RIGOL TECHNOLOGIES, INC., 10200 SW Allen Blvd., Ste. C, Beaverton, OR 97005; (877) 4-RIGOL-1, (503) 465-4626, www.rigol.com



Amplifier Generates 2-kW CW Power at 2.5 GHz

MODEL 2180 is a high-power amplifier that provides 2-kW CW output power from 1.0 to 2.5 GHz. The air-cooled amplifier is well-suited for L- and S-band applications, including in communications, electronic-warfare (EW), and test systems. Housed in a 5U rack-mount chassis, the amplifier includes electronic VSWR protection, automatic gain control (AGC), and automatic level control (ALC). Based on high-voltage gallium-nitride (GaN) transistors, the amplifier includes numerous interfaces (such as Ethernet and RS-485), with IEEE-488 GPIB available as an option.

EMPOWER RF SYSTEMS, INC., 316 W. Florence Ave., Inglewood, CA 90301; (310) 412-8100, e-mail: sales@empowerrf.com, www.EMpowerRF.com



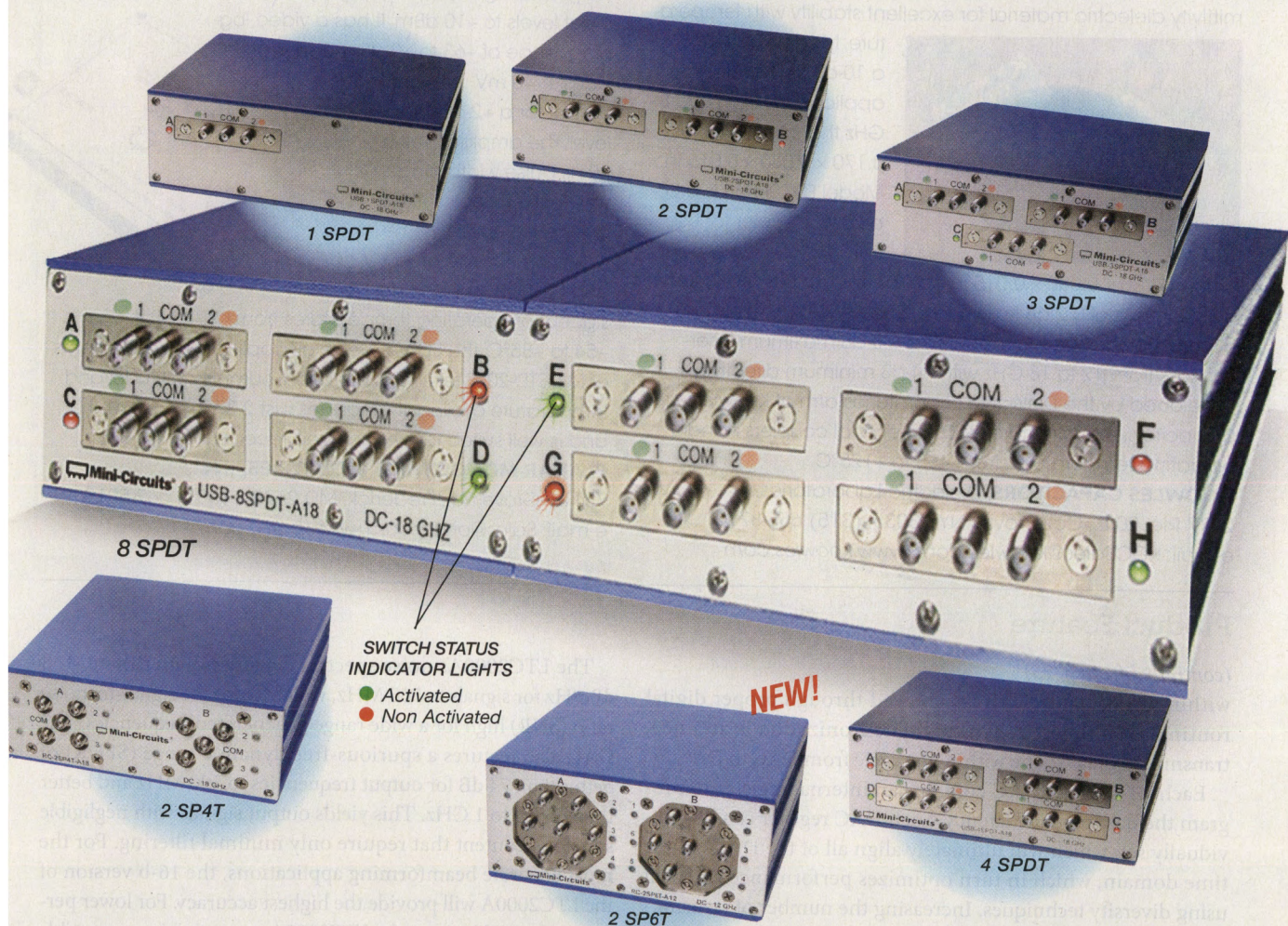
Transmitter Assembly Reaches V-Band

MODEL SSK-ST573673-15-ITS1 is a frequency upconverter that translates a 0-dBm input signal from 14.250 to 15.875 GHz through a $\times 4$ active multiplier to two orthogonally polarized signals from 57 to 67 GHz. The transmitter also produces intermediate-frequency (IF) signals from DC to 3.5 GHz. The two millimeter-wave signals are boosted by means of power amplifiers into horizontally and vertically polarized signals. These two signals are combined into circular polarized waveform through a V-band ortho-mode transducer and transmitted via a 14-dBi gain conical antenna. The polarized signals feature equivalent isotropically radiated power (EIRP) of typically $+36$ dBm. The transmitter runs on 670 mA current at $+6$ VDC and includes female SMA connectors on the LO and IF ports.

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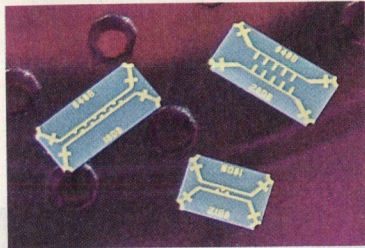
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545 Rev Orig

Miniature SMT Couplers Reach Ku-Band Frequencies

A LINE of extremely small directional couplers has been developed with coupling values of 10 and 20 dB for use through 18 GHz. Available in surface-mount-technology (SMT) packaging as well as in chip-and-wire hybrid formats, the compact thin-film couplers take advantage of high-permittivity dielectric material for excellent stability with tempera-



ture. Model FPC06073 is a 10-dB SMT coupler for applications from 4 to 8 GHz that measures just $0.170 \times 0.080 \times 0.015$ in. Model FPC06078 is a 20-dB SMT coupler for use from 12 to 18 GHz that

is only $0.100 \times 0.080 \times 0.015$ in. The former exhibits maximum insertion loss of 0.2 dB from 4 to 8 GHz with 20-dB minimum directivity, while the latter achieves 0.3-dB maximum insertion loss from 12 to 18 GHz with 14-dB minimum directivity. Developed by the Dielectric Laboratories arm of Knowles Capacitors, the miniature 50- Ω directional couplers handle operating temperatures from -55 to $+125^\circ\text{C}$.

KNOWLES CAPACITORS, Dielectric Laboratories, 2777 Rte. 20 E., Cazenovia, NY 13035; (315) 655-8710, e-mail: KCCSales@knowles.com, www.knowles.com

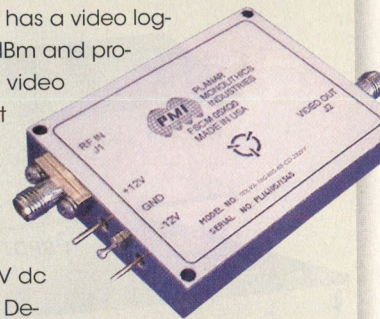
SDLVA Scans 18 to 40 GHz

MODEL SDLVA-18G40G-65-CD-292FF is a successive-detection log-video amplifier (SDLVA) for use from 18 to 40 GHz. It features a dynamic range of 65 dB with a logarithmic slope of 25 mV/dB and a nominal video bandwidth of 32 MHz. Based on GaAs technology, the SDLVA achieves tangential signal sensitivity (TSS) of -65 dBm and handles input levels to $+10$ dBm. It has a video logging range of -63 to $+2$ dBm and provides 1940 mV maximum video output for a $+2$ -dBm input level. The amplifier has a 30-ns pulse width range with 11-ns video rise time and 60-ns recovery time.

It runs on 400 mA at $+12$ V dc and 200 mA at -12 V dc. Designed for operating temperatures from -54 to $+85^\circ\text{C}$, the SDLVA meets all applicable requirements of MIL-STD-202F for shock, vibration, humidity, altitude, and temperature cycling. It measures just $2.37 \times 1.8 \times 0.42$ in. and is well suited for channelized receivers.

PLANAR MONOLITHICS INDUSTRIES, INC.,

7311-F Grove Rd., Frederick, MD 21704; (301) 662-5019, e-mail: Sales@pmi-rf.com, www.pmi-rf.com



Product Feature

(continued from p. 75)

within picoseconds. This is achieved through proper digital routing techniques. When this synchronization is attained, transmitted data will be within one cycle from DAC to DAC.

Each LTC2000A DAC contains an internal register to program the data pipeline latency. Each DAC register can be individually set, which will ultimately align all of the DACs in the time domain, which in turn optimizes performance when all using diversity techniques. Increasing the number of transmitting DACs boosts the maximum level of diversity.

The LTC2000A also provides excellent ac performance to further enhance a wireless system's capabilities. Figure 2 shows the spectrum of 16 channels of CDMA with a gap channel removed. The power in each of the carriers is -36 dBm, and the power in the gap channel is -96 dBm, demonstrating excellent spectral purity. Such spectral purity from the LTC2000A DAC allows for minimal filtering of the DAC's output prior to transmission, simplifying a transmitter's output network.

In an example application (Fig. 3), the LTC2000A DAC operates at update rates to 2.7 Gsamples/s, which extends the usable transmit bandwidth beyond 1 GHz. The high sample rate also provides enough bandwidth for demanding applications while still providing excellent spectral and noise performance.

The LTC2000A's noise spectral density is better than -158 dBc/Hz for signals to 500 MHz, which keeps the signal-to-noise ratio (SNR) high for a wide range of generated frequencies. The DAC also features a spurious-free dynamic range (SFDR) of better than 74 dB for output frequencies to 500 MHz and better than 65 dB to 1 GHz. This yields output signals with negligible spurious content that require only minimal filtering. For the most accurate beamforming applications, the 16-b version of the LTC2000A will provide the highest accuracy. For lower performance applications, the LTC2000A comes in pin-compatible 14- and 11-b versions. With or without diversity techniques, the LTC2000A DAC can improve the performance of any wireless communications system.

Synchronizing any number of LTC2000As can be performed by simply modifying a digital bit in a control register. When a large number of LTC2000A DACs are synchronized, they can be used in complex beamforming applications involving one or more antennas. They can also be used with other diversity techniques, such as those based on time, frequency, and code. For more information, go to www.linear.com/LTC2000A. **mw**

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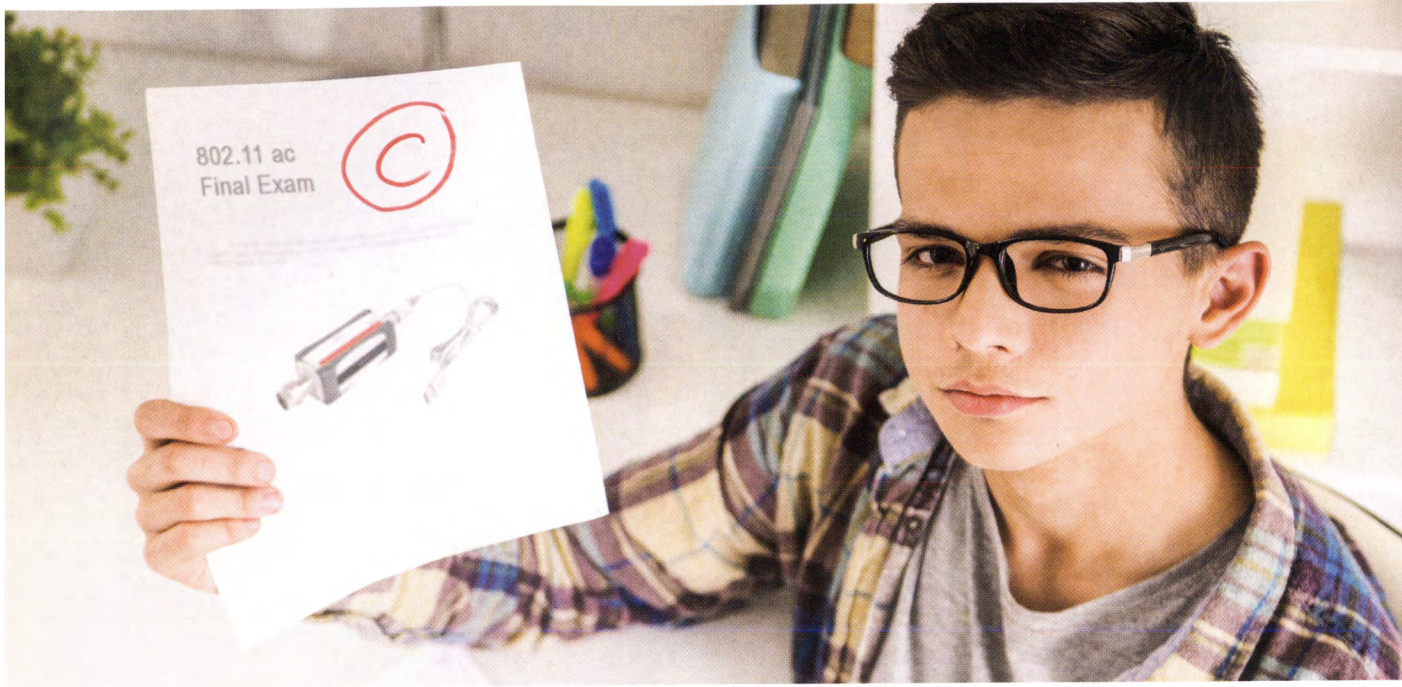
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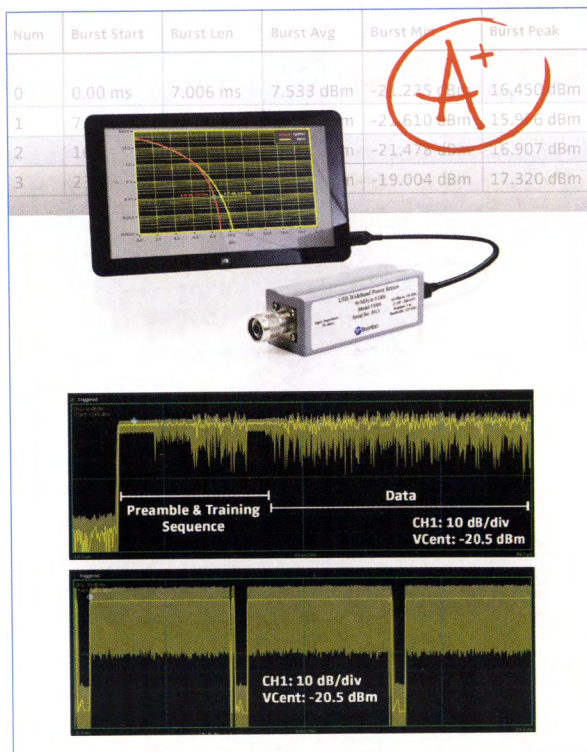
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