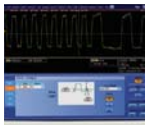
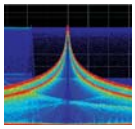
INSIDE TRACK with **Chris Kneizys,** Micro-Coax | **34**

Tektronix Scopes Scour Signals at 70 GHz | **120**



Testing Modern Radar Systems | **80**



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IMS 2015 Heats up Phoenix

p | 38

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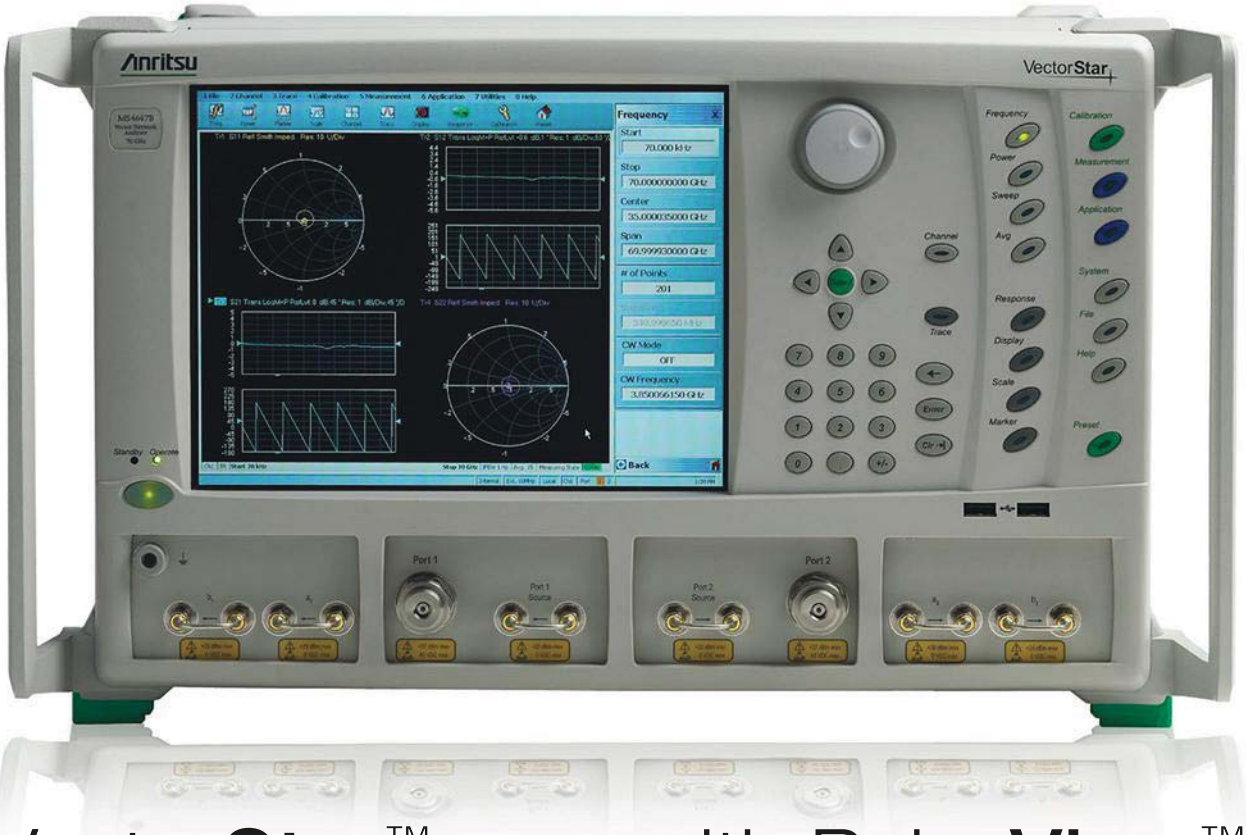

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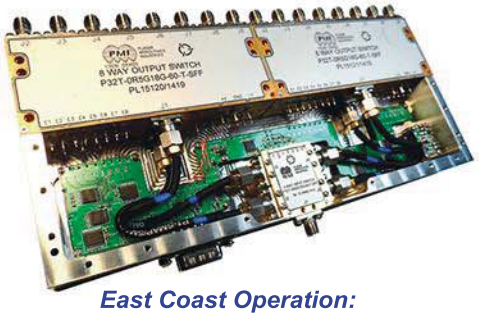

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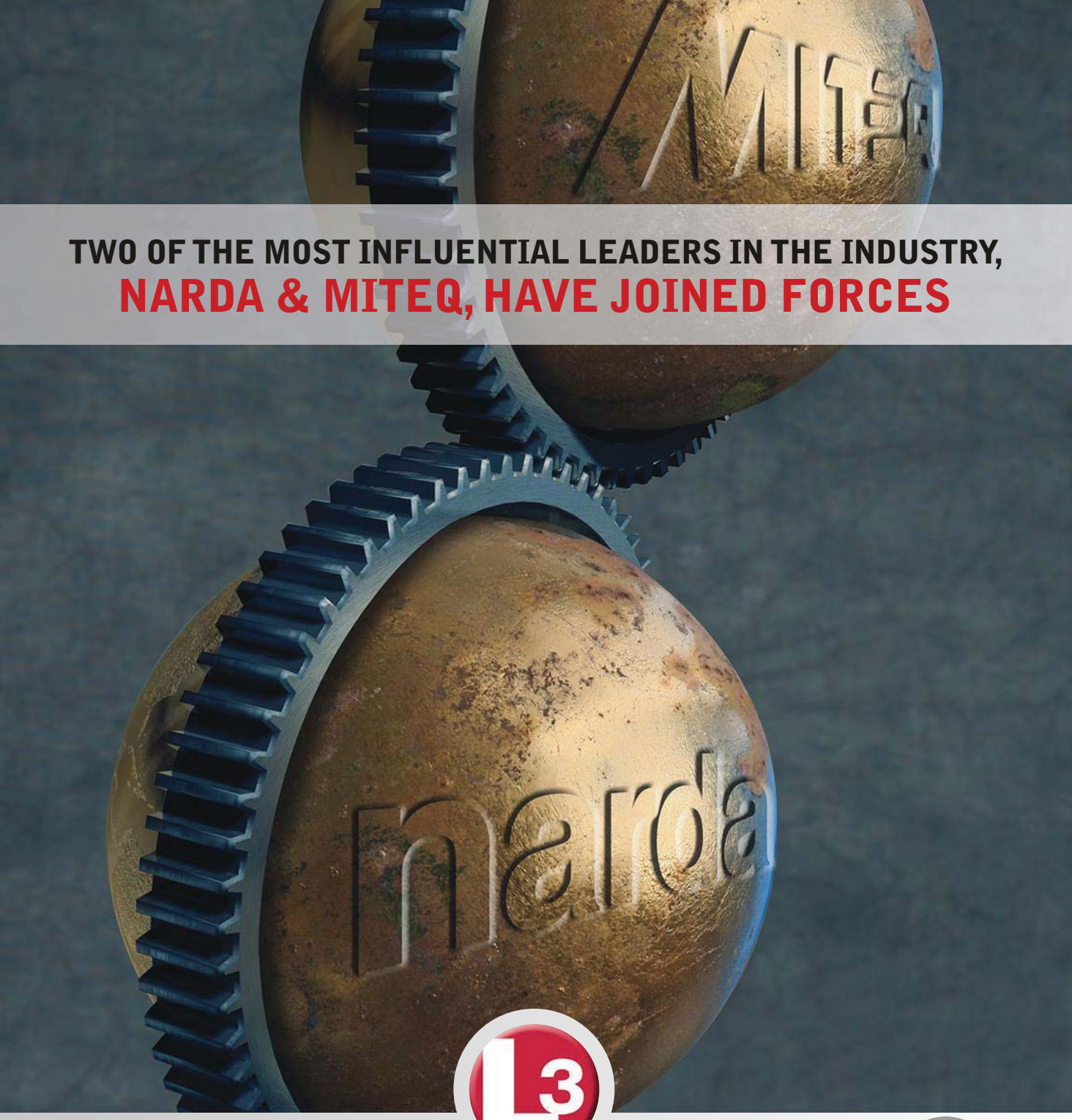

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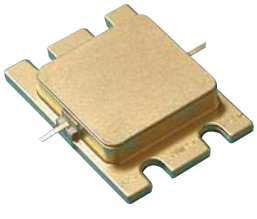
200W Discrete
9.2 to 10 GHz
120W Discrete



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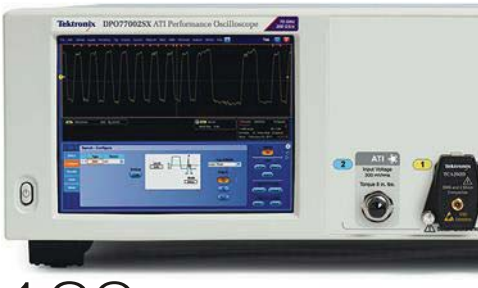
FEATURES

38



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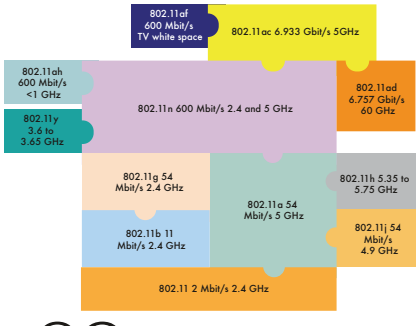

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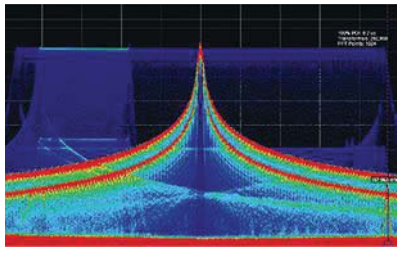

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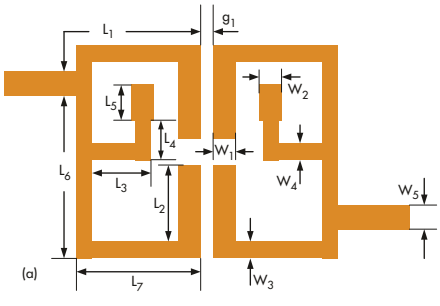

95

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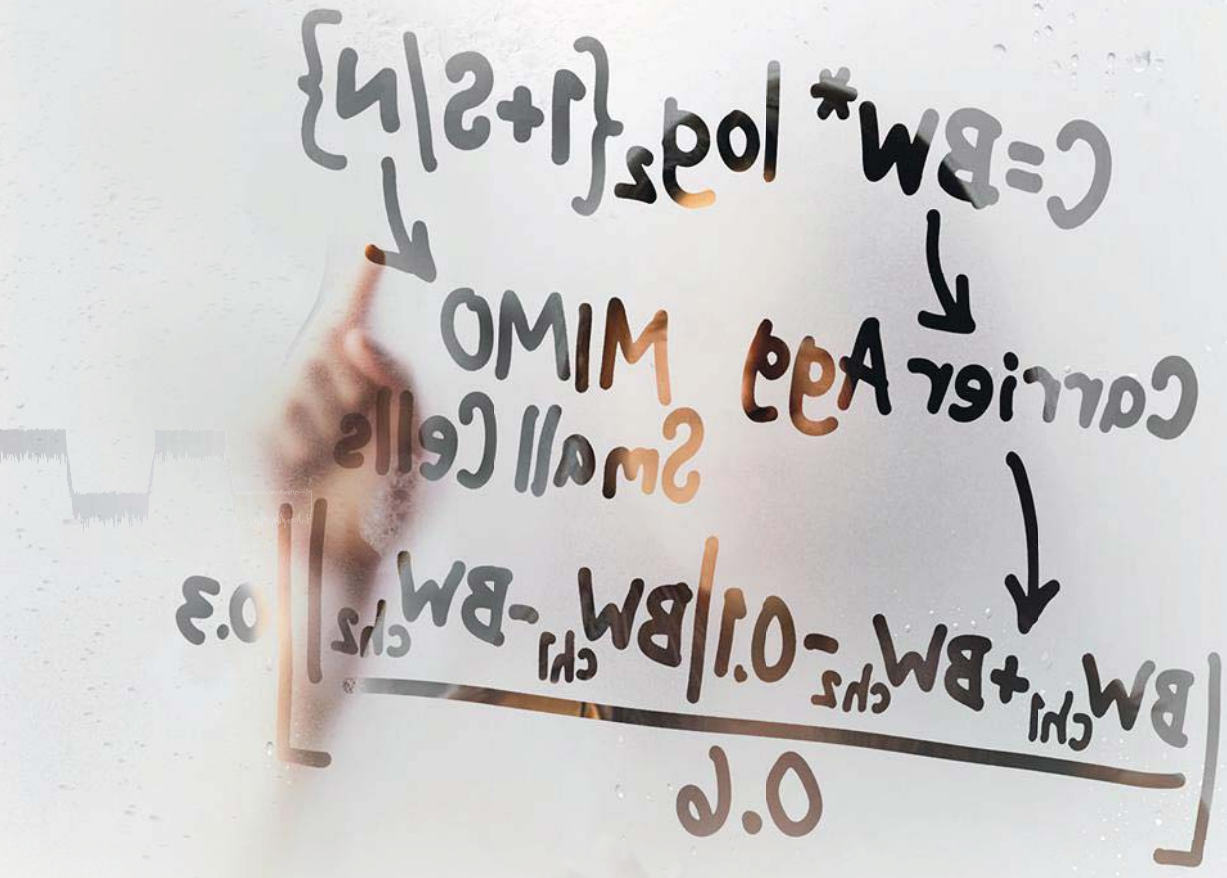

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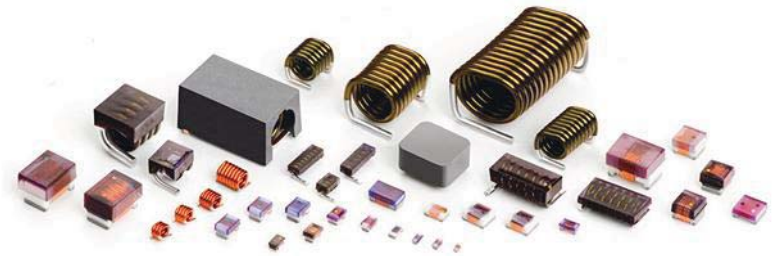

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http://mwrf.com/blog/screening-through-spectrum-analyzers
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WHATEVER HAPPENED TO WiMAX?

http://mwrf.com/blog/whatever-happened-wimax
Back in the early 2000s, the WiMAX Forum developed a new wireless technology known as WiMAX—short for Worldwide Interoperability for Microwave Access. Standardized by the IEEE as 802.16, WiMAX attracted a great of attention, and many thought it was poised to become the next Wi-Fi. But alas, it wasn't to be.

GALLERY: MULTI-FUNCTION MICROWAVE/RF INSTRUMENTS

http://mwrf.com/test-measurement-analyzers/gallery-multi-function-microwaverf-instruments
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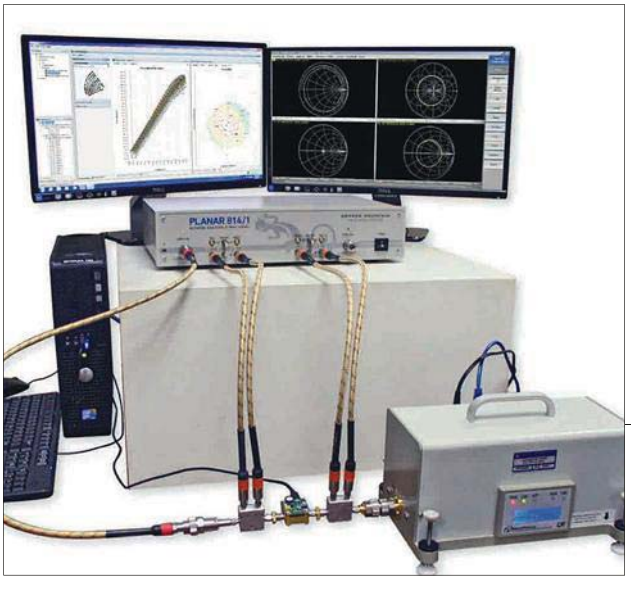

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	RCDAT-6000-30	0-30 dB	±0.4 dB	0.25 dB	✓	✓	-	$495
	RUDAT-6000-60	0-60 dB	±0.3 dB	0.25 dB	✓	-	✓	$625
	RCDAT-6000-60	0-60 dB	±0.3 dB	0.25 dB	✓	✓	-	$725
	RUDAT-6000-90	0-90 dB	±0.4 dB	0.25 dB	✓	-	✓	$695
	RCDAT-6000-90	0-90 dB	±0.4 dB	0.25 dB	✓	✓	-	$795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

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Editorial

NANCY K. FRIEDRICH
Content Director
nancy.friedrich@penton.com

The IMS 2015 Checklist

It's that time of year again. For those in the microwave and RF industry, the IEEE International Microwave Symposium (IMS)—with all of its conferences, workshops, trade show, and exhibition offerings—is something we look forward to all year long. This May, IMS (www.ims2015.org) returns to Phoenix, Ariz. Here's a basic checklist to ensure that you get the most out of your experience:

1. Who says engineers are stereotypically antisocial? For some, IMS is the one time each year to see longtime friends, partners, customers, and acquaintances. Leave time to say hello to people, catch up, and make new connections.

2. So-and-so is *where* now? Part of the fun every year is seeing someone you know, but being very surprised to find them in a different booth or wearing a different company's logo. In a specialized industry, there's a lot of career movement.

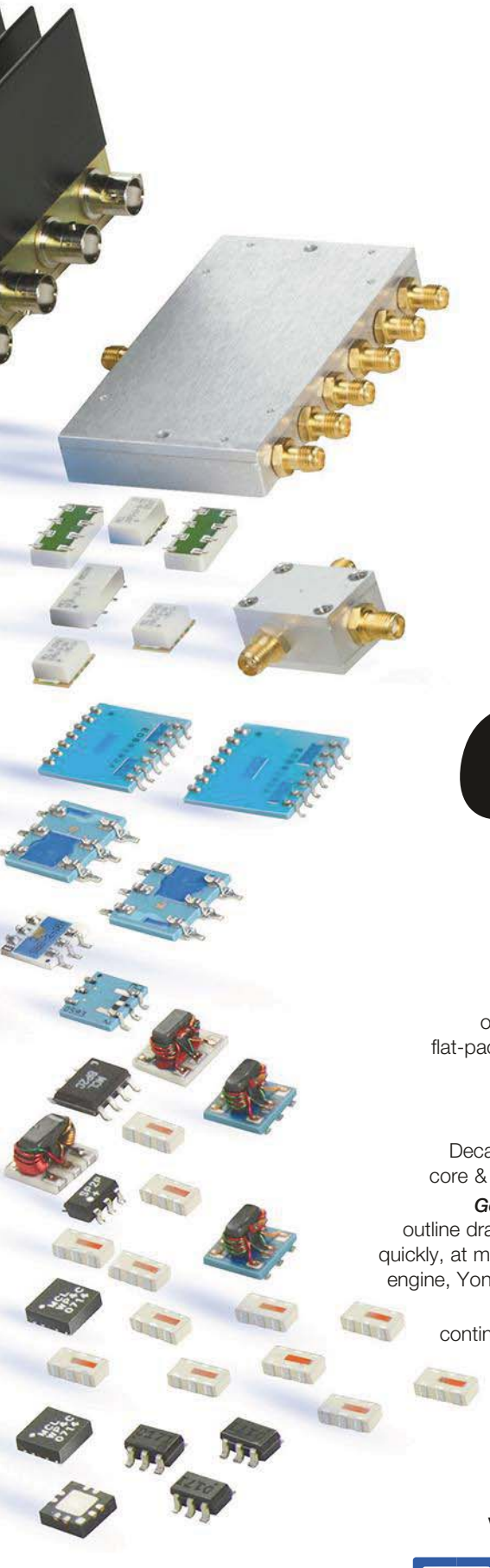
3. Did you see what they have at that booth?! IMS is an event at which many major technical advances are unveiled, from the smallest semiconductors to the largest systems. Look to test-and-measurement companies for breakthroughs in wireless communications, electronic warfare (EW), and more.

4. Did you know that Company X has done such-and-such?! Or even better: Have you heard of Company X? Don't let all your time be taken up at bigger, flashier booths. The IMS exhibition floor is teeming with smaller companies, and there are always some real game-changers among them.

5. Who knew that so many companies really are investing in these buzzword applications? Beyond the expected focus on Fifth-Generation (5G) cellular and the latest radar and EW applications, you'll hear hype about the Internet of Things (IoT), automotive and medical applications, satellite communication (satcom), and more.

6. What fruit has a particular merger or acquisition produced? Qorvo (formerly RFMD and TriQuint) should have some messaging and information about its plans and strategy at the ready. Also, keep an eye out for any hints from Analog Devices on its Hittite acquisition and any gossip surrounding NXP's pending acquisition of Freescale.

In addition to the above checklist, keep an eye out for STEM outreach efforts and a very impressive conference offering. Be prepared for high temperatures, wear comfortable shoes, and have plenty of business cards at the ready. Enjoy the show! mw



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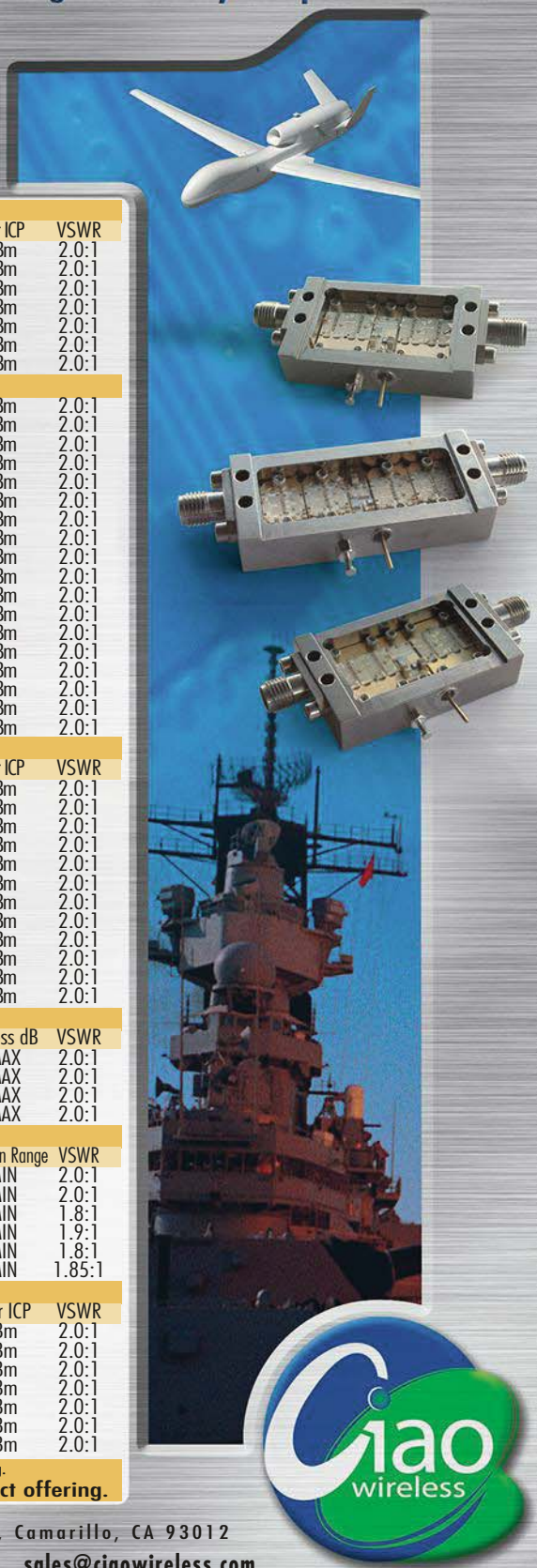

OCTAVE BAND LOW NOISE AMPLIFIERS

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

NARROW BAND LOW NOISE AND MEDIUM POWER AMPLIFIERS

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

ULTRA-BROADBAND & MULTI-OCTAVE BAND AMPLIFIERS

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

LIMITING AMPLIFIERS

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

AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

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

LOW FREQUENCY AMPLIFIERS

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

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RUNNING OUT OF GaAs FOR RF

In reading your magazine and combing through your blogs and other website items, the amount of coverage on the "latest and greatest" semiconductor technology, gallium nitride (GaN), is quite apparent. Admittedly, this semiconductor technology has a great deal to offer in terms of performance, with impressive power density and the capabilities to support healthy signal gains at microwave, and even millimeter-wave, frequencies. Military circuit designers have embraced this transistor technology wholeheartedly and it is being adopted at a rapid rate into both commercial and consumer electronics applications. This looks like a semiconductor technology that may be with us for a while.

But what about the previous "latest and greatest" semiconductor technology, gallium arsenide (GaAs)? Will your editors simply pretend that it has gone away and not cover GaAs products anymore? Or will they continue to provide genuine journalistic coverage of the latest developments in GaAs technologies and products? When it first became commercialized, GaAs devices were highly touted as the last high-frequency semiconductors you will ever need, with their capabilities to provide high gain in power amplifiers and low noise in low-noise amplifiers (LNAs). But there were problems with GaAs, such as its susceptibility to electrostatic discharge (ESD) and the way that GaAs devices could be easily damaged through poor handling.

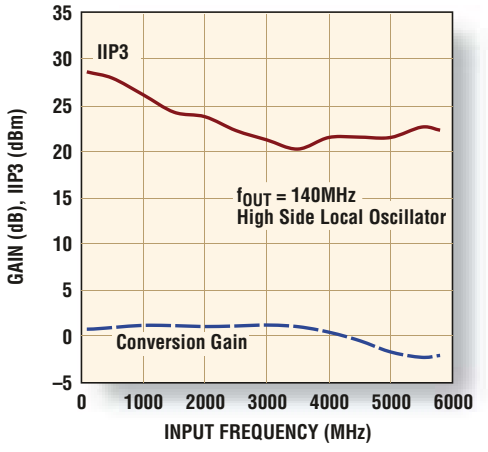
ANDREW ATHERTON

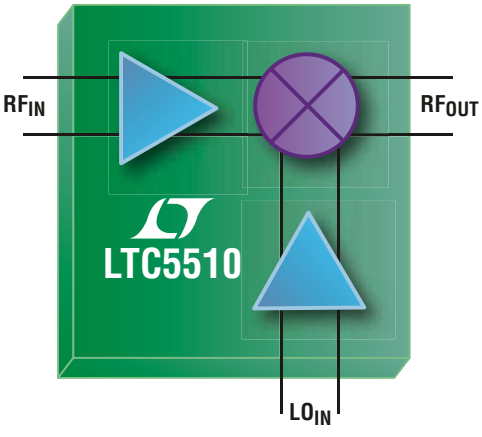
EDITOR'S NOTE

You are quite correct about the strong interest in GaN technology, and *Microwaves & RF* has assembled a number of special reports and pieces on GaN to help our readers. A quick search on our website using "GaN" as the search term will reveal the many articles that we have provided on GaN, and not just recently but for a number of years now.

But you bring up an excellent point on GaAs. The technology has not gone away. It is simply being overshadowed at the moment by all the excitement and interest in new developments in GaN technology. To help readers keep up to date, *Microwaves & RF* will be running a regular feature article which will point out "The Difference Between" two technologies, or applications, or product types. The first installment compares the differences between traveling-wave-tube amplifiers (TWTAs) and solid-state power amplifiers (see p. 116).

50Ω Matched Input 30MHz to 6GHz Mixer





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Signal Chain Components

	LTC5567	+26.9dBm IIP3, 1.9dB Gain Mixer	Detector	LTC5582	10GHz, 57dB Dynamic Range RMS Detector
	LTC5569	Dual +26.8dBm IIP3, Low Power Mixer		LTC5587	6GHz 40dB Dynamic Range RMS Detector + ADC
	LTC6430-15	+50dBm OIP3 @240MHz, 15dB Gain Differential Amplifier		LTC6412	31dB Gain Control, Analog VGA with +35dBm OIP3
	LTC6431-15	+47dBm OIP3 @240MHz, 15dB Gain Single-Ended Amplifier		LT®5554	16dB Gain Control, 0.125dB/Step Digital VGA
ADC	LTC2158-14	Dual 14-Bit, 310Msps ADC		LTC6946	Low Phase Noise Integer-N PLL + VCO
	LTC2209	16-Bit, 160Msps ADC		LTC6945	Low Phase Noise Integer-N PLL

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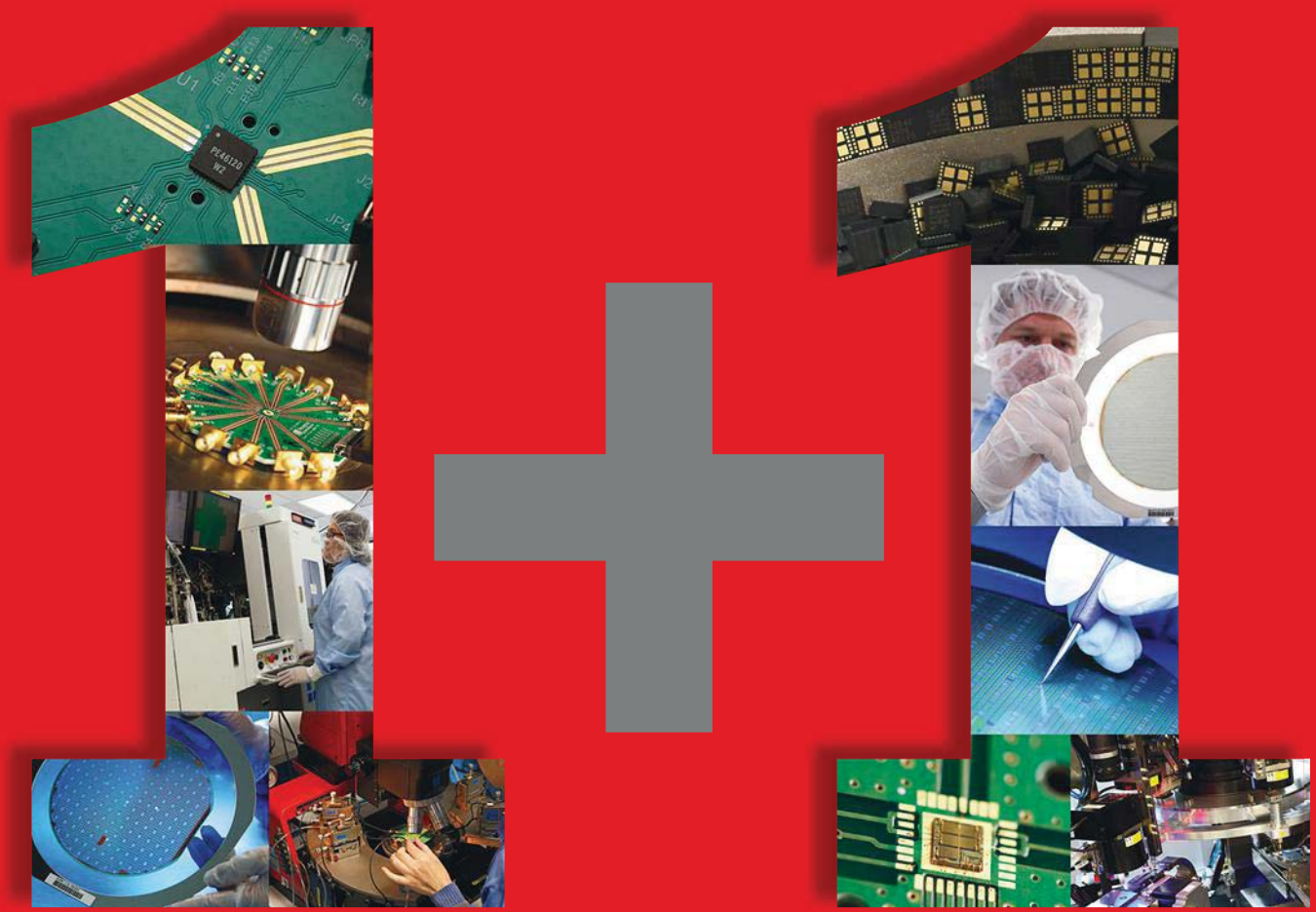

Aristotle was way ahead of his time when he said, **"The whole is greater than the sum of its parts."** So, what do you get when one global electronics giant (Murata) acquires one groundbreaking RF SOI company (Peregrine Semiconductor)? A solution that adds up to a five star RF powerhouse with almost 100 years of experience and innovation combined. Peregrine Semiconductor joining the Murata family, heralds a bold new era for the RF industry where customers can rely on:

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News

SATELLITES SHIFT,
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Bringing higher capacity and more flexibility to service providers, a jointly developed broadband system leverages the power of geostationary satellites to focus capacity on areas of need. Rather than blanket the entire globe with a thin layer of capacity, regardless of demand, the ViaSat Flexible Broadband System gives users the ability to shift or add capacity anywhere within the satellite's coverage area.

ViaSat and Boeing's new system is based on the ViaSat High-Capacity Satellite System developed for the ViaSat-2 satellite and the Boeing 702SP (small platform) satellite bus. It features compact RF satellite access nodes and an architecture that allows for auto-shifting traffic among gateways, which helps increase performance and eliminate network downtime. The Flexible Broadband System provides a roadmap to integrate existing Ku-band and Ka-band gateways into the service delivery platform.

End-user applications range from high-speed Internet web browsing, real-time video streaming/downloads, and IP-based voice and video, to Layer 2 for enterprise applications as well as multicast media and content delivery. Among the service-provider capabilities are central operation of multiple satellite access nodes and satellites, APIs to access underlying network and management capabilities, support for fixed-rate and metered service plans, and web portals for installers and virtual network operators (VNOs.) ■

The ViaSat satellites offer a flexible architecture and a variety of access nodes. *(Image courtesy of Space Systems/Loral)*

NETWORK-IN-A-BOX MEETS SOFTWARE to Extend Tactical C4

TACTICAL MILITARY RADIOS consistently face constraints for even basic voice and low-data-rate communications. Hoping to break those chains, researchers at the University Pertahanan Nasional Malaysia (UPNM) and Chemring Technology Solutions developed a new solution that combines a portable "network-in-a-box" with a defense software application. The combination bolsters C4 (command, control, communication, and coordination) capabilities for tactical operations, ultimately bringing coverage to areas where it's typically unreliable or nonexistent.

UPNM's tactical communications operations management system (TACCOMS) generates a search grid that optimizes the deployment of tactical resources within land, sea, or air scenarios. The integration of SmartLink, developed by Chemring, gives the tactical team leader complete control via a self-contained, secure communications network. SmartLink delivers high-end cellular network features, enabling the sharing of voice, image, and video to teams on the ground and in command centers.

SmartLink can be deployed in less than three minutes to deliver a wide-area cellular network. Its small form factor helps soldiers carry less weight while maintaining push-to-talk (PTT) communications and sharing real-time data. SmartLink implements UMTS 3G HSPA communications, and is AES-256-encrypted over a VPN. ■

When implemented with the SmartLink network, the TACCOMS operations system extends and enriches tactical communications. *(Image courtesy of Chemring Technology Solutions)*

DARPA THROWS SUPPORT Behind Upgradable Radar Architectures

THE ARRAYS AT COMMERCIAL TIMESCALES (ACT) program is tasked with developing technology to enable rapidly upgradable and widely deployable radar-array architectures. Furthering this initiative, the Defense Advanced Research Projects Agency (DARPA) recently awarded Raytheon $5 million in contracts for the next phase of the program.

The ACT program utilizes Raytheon's Rapid Array Performance Improvement and Deployment (RAPID) concepts, developed to shorten the timescales and costs associated with phased-array development, deployment, and upgrades. RAPID essentially creates a building block composed of a digitally-influenced common module and a reconfigurable radiating antenna element. RAPID is scalable and customizable for each individual application—without the need for a full redesign of the application space.

Other parts of the ACT program include the development of reconfigurable and tunable RF apertures spanning S- and X-band frequencies. The final objective is the implementation of precious timing and localization sufficient for networking widely separated common modules into a coherent, cooperative large array. The program was announced in 2013 and aims to push past the current ecosystem of 10-year development cycles and 20- to 30-year static life cycles. ■

MICROSEMI ACQUIRES VITESSE to Expand IoT Commitment

TO INCREASE TRACTION in the communications semiconductor industry, Microsemi Corp. announced that it entered a definitive agreement to acquire Vitesse Semiconductor. By leveraging Vitesse's portfolio of high-performance semiconductors, application software, and integrated turnkey systems, Microsemi hopes to further itself as an Industrial Internet of Things (IIoT) market leader. The total transaction value is approximated at $389 million.

The acquisition will help the company's standing in network infrastructure markets, including mobile access/IP edge, enterprise cloud access, and IIoT networking. Microsemi expects to see immediate accretion in the first full quarter of completion after the end of the second fiscal quarter of 2015. Vitesse hopes it will benefit from the increased scale, consolidated infrastructure, and cost savings enabled by Microsemi. ■

USAF NEXT-GEN RADAR
Platforms Focus of New Project

DEFINING THE OPEN ARCHITECTURES for future onboard U.S. Air Force platforms is the impetus behind a contract given to GE's Intelligent Platforms to develop new support technologies. The six-month research program will involve the optimization of synthetic aperture radar (SAR) and ground-moving-target-indicator (GMTI) radar modes on multiprocessor high-performance embedded-computing (HPEC) systems.

GE's HPEC Center of Excellence (CoE) will focus on the demand for high-technology readiness level (TRL) commercial-off-the-shelf (COTS) solutions that support rapid deployment. The study will also include the development of a lab-passed processor system for rugged deployment on USAF platforms. This will embrace the open system architecture (OSA) approach currently used in standard hardware and software.

GE's Intelligent Platforms was awarded a contract to develop new radar technologies for the U.S. Air Force. *(Image courtesy of GE)*

The GE Center also supports the development of custom systems for specific customer needs. Consulting services are available to help with architecture definition, application development, and performance optimization. Application-focused algorithms can even be created for use in a host of performance and capability demonstrations.

GE has a wide range of HPEC solutions designed for harsh military environments, including board-level solutions, complete subsystems, and an expanding software-development environment based on GE's AXIS—Advanced Multiprocessor Integrated Software. ■

COLLABORATIVE EFFORT Eyes MIMO OTA Testing Solutions

WHEN SURVEYING THE FUTURE mobile landscape, multiple-input, multiple-output (MIMO) over-the-air (OTA) testing methodologies and solutions are expected to play major roles. With that in mind, a collaboration between Anite

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	Model	Frequency (MHz)	Gain (dB)	Pout @ Comp. 1 dB (W)	Pout @ Comp. 3 dB (W)	$ Price (Qty. 1-9)
	ZVE-3W-83+	2000-8000	35	2	3	1295
	ZVE-3W-183+	5900-18000	35	2	3	1295
NEW	ZHL-4W-422+	500-4200	25	3	4	1570
NEW	ZHL-5W-422+	500-4200	25	3	5	1670
	ZHL-5W-2G+	800-2000	45	5	6	995
	ZHL-10W-2G	800-2000	43	10	13	1295
•	ZHL-16W-43+	1800-4000	45	13	16	1595
•	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	32	1495
	ZHL-30W-262+	2300-2550	50	20	32	1995
	ZHL-30W-252+	700-2500	50	25	40	2995
	LZY-2+	500-1000	47	32	38	2195
	LZY-1+	20-512	42	40	50	1995
•	ZHL-50W-52+	50-500	50	40	63	1395
•	ZHL-100W-52+	50-500	50	63	79	1995
•	ZHL-100W-GAN+	20-500	42	79	100	2395
	ZHL-100W-13+	800-1000	50	79	100	2195
	ZHL-100W-352+	3000-3500	50	100	100	3595
	ZHL-100W-43+	3500-4000	50	100	100	3595
	LZY-5+	0.4-5	52.5	100	100	1995

Listed performance data typical, see minicircuits.com for more details.

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and China Telecommunication Technology Labs (CTTL)-Terminals aims to develop MIMO OTA systems that will help foster efficient benchmarking of an array of MIMO-capable products.

The joint effort will leverage Anite's Propsim channel emulators, which comply with CTIA, CCSA, 3GPP, and major mobile operator acceptance test plans. Development goals include MIMO OTA methodologies for carrier-aggregation MIMO OTA, 3D MIMO OTA testing, virtual-drive MIMO OTA testing, MIMO OTA with multi-cell handover and interference, and device-to-device testing.

Propsim RF fading emulators serve to enable realistic propagation simulation. They emulate radio-channel characteristics, including path loss, multi-path fading, delay spread, Doppler spread, polarization, correlation, and spatial parameters necessary for MIMO testing.

The Propsim FS8 is targeted for testing in a reverberation chamber thanks to its ability to provide full control of critical parameters. *(Image courtesy of Anite)*

The Propsim F32's high RF I/O capacity suits it for OTA testing in an anechoic chamber. It can support eight or 16 dual polarized antennas to create a multi-probe environment. The Propsim FS8, on the other hand, is targeted for testing in a reverberation chamber because of its ability to provide full control of critical parameters like dynamic mobile speed, multi-path profile, range delay, and base-station antenna correlation. The devices reportedly offer more than twice the emulation capacity versus other similar products. ■

SMART BABY-BOTTLE HOLDER Helps Prevent Colic

THE ANGLE OF a baby bottle during feeding is extremely important in preventing colic and fatigue. To address that issue, Slow Control developed the "Baby Gigl" connected baby-bottle holder. The smart feeding bottle not only tracks how much the baby drinks, but provides alerts and keeps a journal to monitor wellbeing.

Through the use of an inclinometer, the bottle holder alerts the user with a sound

The Baby Gigl smart baby-bottle holder provides alerts when feeding bottles are held at incorrect angles, which helps prevent indigestion. *(Images courtesy of Slow Control)*

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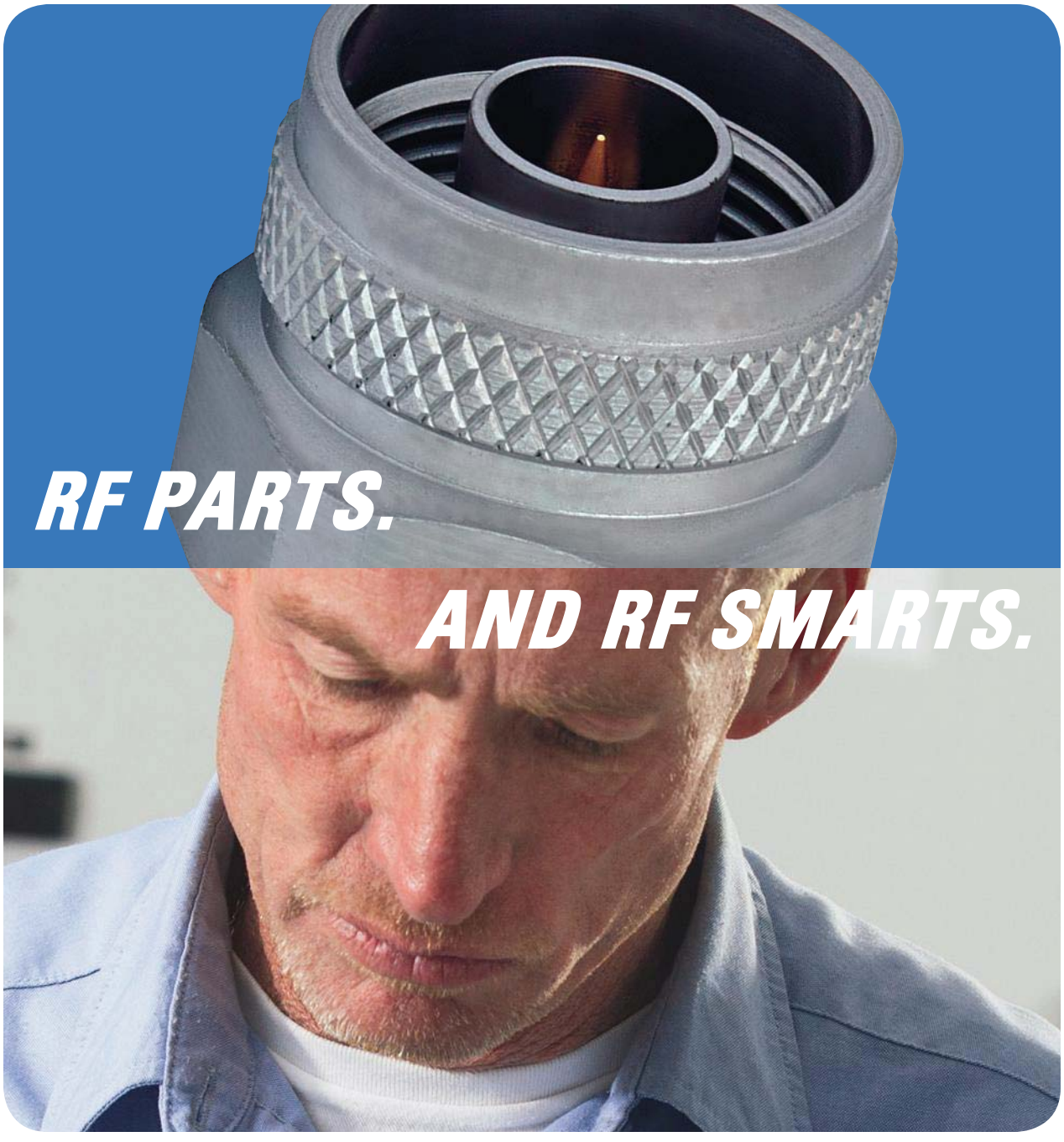

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and light signal when the angle is not correct—too sharp of an angle can cause the baby to spit up, while too low of an angle can result in the child drinking air. The Baby Gigl can also detect and issue an alert when a lump is blocking the nipple.

When another caretaker feeds the baby using the Gigl holder, parents can remotely retrieve the information generated by email or SMS at the end of every meal with its Bluetooth Shield Function. This allows the disabling of Bluetooth signals at-will when the bottle is placed in the holder and prevents signal transmission while in use. Information includes quantity at the beginning/end of feedings, feeding times, the number of lump alerts, the number of wrong angle alerts, and a graph showing all mealtimes that day.

The Baby Gigl holder also includes Baby Journal 3.0, which provides reports and data in a graphical and historical view of all meals per day, week, and month. It facilitates collaboration with other family members using color-coded status updates and can work with other connective devices to track everything from food intake to number of diapers used, number of burps, total time spent sleeping, and even photo galleries.

Slow Control's Cross-Sharing technology allows parents to organize and centralize collected information from each person involved in the baby's feeding. This works whether one Baby Gigl is used for all caretakers, or if each has their own holder (marked by a different color). Previously, Slow Control introduced the 10SFork, a connected fork that helps users eat more slowly to control the speed of food intake.

The Baby Gigl holder is currently being funded through an Indiegogo campaign. ■

STANDARDS UPDATE: MIPI Alliance Spec for RF Front-End Control Interface 2.0

VERSION 2.0 OF the MIPI RF Front-End (RFFE) Control Interface specification adds new features that enhance the controls of complex RF front-end environments with up to 20 components. The interface can be applied to a range of RFFE components to simplify design, configuration, and integration, as well as facilitate interoperability.

The updated MIPI Alliance spec brings five key features to the interface of front-end devices, such as power amplifiers, low-noise amplifiers, filters, switches, power-management modules, antenna tuners, and sensors. For example, an extended range of bus operating frequencies effectively doubles the number of command sequences that can be transferred on the bus in a given timeframe. In addition, synchronous read allows for more types of data propagation on the bus via slave devices, leading to extended bus-loading and frequency ranges.

The MIPI Alliance announced version 2.0 of the RF Front-End (RFFE) Control Interface specification, which simplifies the design and interoperability of RFFE devices. *(Image courtesy of the MIPI Alliance)*

To support carrier-aggregation system architectures and use of multiple transceivers and dual-SIM designs, the spec includes multi-master configuration. An interrupt-capable slave functionality enables quick polling of slave devices to the master controller on the bus. Finally, a new reserved register helps improve the efficiency of hardware and software developments.

Version 2.0 of the spec was worked on by the MIPI RFFE Working Group which surveyed MIPI Alliance and International Wireless Industry Consortium (IWPC) members to assess the market's needs and identify necessary features. The group is currently working on further refinements to RFFE regarding electrical and digital details, flexible bus configurations, and multiple message types.

The MIPI Alliance's charter is to develop interface specifications for the both the mobile and mobile-influenced industries. ■

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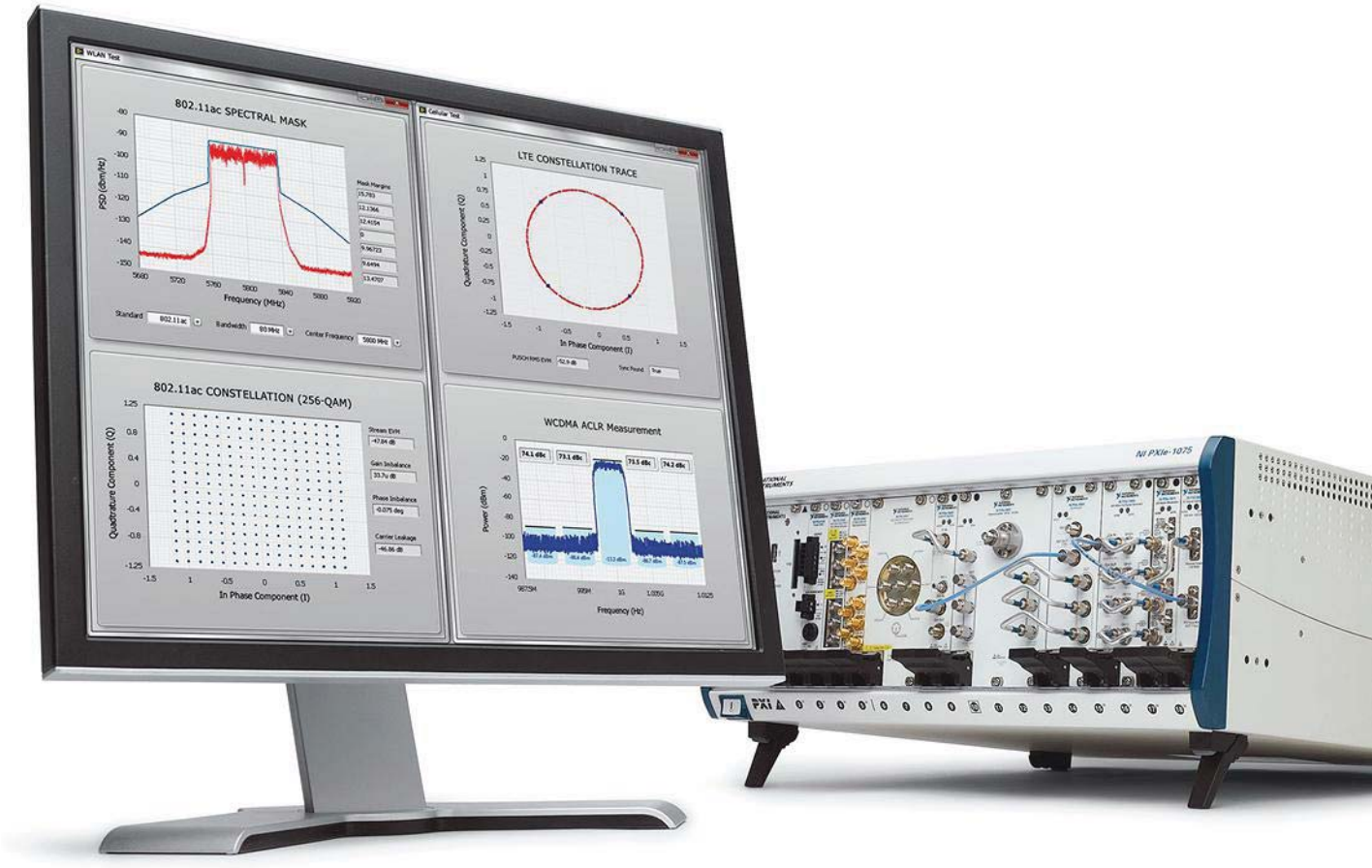

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	PWR-8GHS	CW	1 to 8000	USB	869.00
NEW!	PWR-8GHS-RC	CW	1 to 8000	USB & Ethernet	969.00
	PWR-8FS	CW	1 to 8000	USB	969.00
	PWR-4RMS	True RMS	50 to 4000	USB	1169.00

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

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

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CONTRACTS

ETL Systems—Will provide RF equipment to a large U.S. government defense contractor. This was a highly competitive bid; ETL was selected after providing a successful equipment demonstration at the agency's facility, which showed the unique form factor and performance attributes of its Vulcan matrix system. The Vulcan is a compact 16U high 128 inputs × 128 inputs distributive matrix with dual redundant power supplies and CPUs, and hot-swappable RF components.

General Atomics Aeronautical Systems Inc.—Has awarded an approximately $2.5 million contract to the Malibu Division of Communications & Power Industries LLC (CPI) for ground-based data links to support the GA-ASI Predator/MQ-9 Reaper remotely piloted aircraft (RPA) system. Under the contract, CPI Malibu Division will provide GA-ASI with C-band, advanced data link antennas for tracking and communications support.

VULCAN Wins Over Defense Firm

Conformance Tool Heads to CHINA

Keysight Technologies Inc.—Announced that China Telecom Corporation Test labs (GSTA) in Guangzhou, China, has selected the T3111S NFC Conformance System for near-field communications (NFC) device acceptance test. The T3111S is a compact and flexible tool that helps engineers gain insight into NFC performance through RF and Protocol measurements.

FRESH STARTS

Lockheed Martin—Expanded its vibration measurement capabilities for testing satellite systems, with a 450-channel PULSE vibro-acoustic data acquisition system. Supplied by Brüel & Kjær (www.bksv.com), the system is based on standard, commercial-off-the-shelf (COTS) PULSE LAN-XI Data Acquisition Hardware. The modular hardware allows individual modules to be used freely, as standalone front-ends or collectively in frame-based configurations, making it suitable for testing large structures such as satellites and spacecraft.

ElectriPlast Corp.—Completed the relocation of its North American manufacturing from Jasper, Ind., to Evansville, Ind., to prepare the foundation for expected growth. In conjunction with longtime manufacturing partner Jasper Rubber Products, the manufacturing is now taking place at the Nova Polymers facility in Evansville.

Intertek—Partnered with Rohde & Schwarz to expand its industry conformance and carrier-acceptance testing capabilities. Intertek has upgraded its testing capabilities in the areas of A-GNSS & OTDOA performance; E-911 over IMS protocol; eMBMS RF, performance, video performance and protocol; LTE carrier aggregation RF performance, data throughput performance and protocol; IMS/VoLTE protocol; video telephony (audio & video) performance; RCS protocol; ePDG/WiFi over IMS calling; and Wi-Fi offloading.

National Technical Systems Inc.—Has acquired Dunstable, UK-based National Quality Assurance, one of the largest ISO registrars in the world. Financial details of the acquisition were not disclosed.

Raytheon—Will expand its Indianapolis, Ind., facility and add approximately 250 jobs to support its work in depot and modernization services. The facility, which already employs 1,000 people, also develops leading-edge soldier-worn computers, provides weapons system sustainment, supply chain management and systems engineering, among other services, to commercial and military customers.

Digi-Key Corp.—Announced a global distribution agreement with Dialog Semiconductor 's SmartBond Basic and Pro development kits, which are now in stock for immediate delivery. The kits provide engineers with a route to developing intelligent connected devices, particularly where small size and low power consumption are critical, such as in battery-powered wearables and other IoT applications.

CiG Wireless Corp.—Announced the signing of a definitive agreement to be acquired by an affiliate of Vertical Bridge Holdings, LLC, a wireless communication towers company. Vertical Bridge is acquiring the company's tower assets, including a geographically diverse group of more than 200 tower sites, in a transaction structured as a merger. The all-cash deal is valued at approximately $143 million.

Averna—Announce that Tandem Expansion Fund, a leading Canadian growth-equity investor, has acquired a majority interest in the company. The transaction provides Averna with the financial resources to accelerate organic and strategic growth as well as to expand its international presence.

NYU WIRELESS—Announced that CableLabs has joined the university research center as it drives development of the next super-fast generation of mobile technology, 5G. CableLabs becomes the 12th industry affiliate sponsor of the research center, joining Intel, Samsung, Qualcomm, and others, as the industry starts to look beyond 4G and LTE-A, in pursuit of faster connections and greater access. Founded in 2012, NYU WIRELESS was the first university center to combine wireless, computing, and medical applications research.

PCTEST Engineering Laboratory Inc.—Has upgraded its Rohde & Schwarz R&S TS8980FTA-2 and R&S CMW500 systems to accommodate the new 4G/LTE test plans for industry conformance and carrier acceptance testing.

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Inside TRACK with Chris Kneizys,

President/CEO of Micro-Coax

Interview by JEAN-JACQUES DeLISLE

JJD: With copper and aluminum conductors prone to oxidation and corrosion, what techniques and materials can be used to enhance their performance?

CK: Probably the most common means of protecting these materials from oxidation is through the use of barrier coatings. Such coatings include the common electroplated surface layers. For example, gold, silver, and tin are often used to protect less noble metals from corrosion; preserve or enhance solderability; and provide a pleasing appearance. The coatings must be thick enough to protect the conductor during its service lifetime. Often, an intermediate layer like nickel is used to reduce porosity and inhibit the migration of the basis metal to the surface.

Other barrier methods of protection include jacket extrusions or dips, which apply a polymer film to the material and thus keep out oxygen and moisture. Coatings like benzotriazole—a transparent organic coating—temporarily exclude oxygen from the surface of the metal. Unfortunately, benzotriazole eventually evaporates and thus has a limited period of effectiveness.

Aluminum conductors can be anodized. This process actually accelerates the surface oxide growth. The resulting thick, well-formed oxide film is stable and passive.

Copper and aluminum conductors are often plated for additional corrosion protection and solderability. The most common plating materials are tin and silver, which are very soft and ductile. While silver has superior electrical conductive properties and is very resistant to corrosion from atmospheric oxygen, it is vulnerable to tarnish by atmospheric sulfides and nitrates. Silver plating is preferred anytime the material is part of the conductive path inside the cable. For semi-rigid cables, silver-plating the outer conductor is not recommended for high-humidity or saltwater environments due to susceptibility to galvanic corrosion or red plague.

Tin plating is economical, corrosion-resistant, and highly solderable. It is preferred for semi-rigid-cable outer conductors. However, tin plating can be prone to tin whiskers. These electrically conductive, crystalline structures sometimes grow from surfaces that use tin as a final finish. They can grow to lengths of several millimeters. Tin whiskers could cause short circuits by bridging closely spaced circuit elements, which are maintained at different electrical potentials. Adding a small amount of lead to the plating, referred to as electro-deposited solder (EDS), can eliminate tin-whisker risks.

JJD: What techniques help enhance the performance of polytetrafluoroethylene (PTFE) for different coaxial-cable applications? Are any other materials commonly used as a coaxial dielectric?

CK: Most semi-rigid cables utilize full-density PTFE in the solid form. However, larger semi-rigid cables are also available in a spline configuration. Spline dielectrics have a thin layer of material around the center conductor with three to five spokes projecting radially outward. The majority of a spline insulator is air, which yields an effective relative dielectric constant as low as 1.3. It should be noted that spline dielectrics, in general, are considerably more expensive than their solid PTFE counterparts.

Low-density PTFE and ultra-low-density PTFE utilize the same base material as the full-density version, but they are processed differently. The lower density reduces both the dielectric constant and dissipation factor, which leads to an overall lowering of the cable attenuation. The lower-density PTFEs are also more thermally stable when compared to solid PTFE. However, there is a tradeoff: Any time there's a drop in dielectric density, it reduces the mechanical integrity. As a result, cables employing a lower-density or spline dielectric will have larger minimum bend radii when compared to the solid full-density versions.

Sometimes, fluorinated-ethylene-propylene (FEP) and perfluroalkoxy (PFA) dielectrics are used when the need arises for very thin walls. Examples include those on low-impedance semi-rigid cables. Both FEP and PFA have properties that are similar to PTFE.

JJD: How do materials and techniques for strengthening a flexible coaxial cable impact the cable's performance?

CK: Techniques for strengthening can be applied to the cable design itself, or to complementary protection (armoring) layers. In the case of armoring, the goal is usually for the armoring layers to be invisible to the signals that are propagating in the coaxial cable. In some cases, the armor can restrict the cable from mechanical distortions, thereby improving electrical performance in the application.

Armoring typically involves a high-strength stainless-steel hose, similar to the old payphone cords, or a jacketed stainless-steel spiral. Lately, internal armoring has become more popular. This type of armoring is similar to the other armoring, except the strength member is integrated into the cable. It has the advantage of being less bulky.

JJD: Are certain coaxial materials better or worse suited for automated manufacturing? What techniques enable the efficient automated manufacturing of coaxial cables?

CK: Material and finish selection can be critical to the assembly or manufacturing methods applied. In most cases, we're able to enhance manufacturability without trading off electrical performance. For example, we can use a silver-plated copper conductor for the primary cable shield, but select a different alloy or composite for the secondary shield. The secondary shield can then be chosen to optimize the manufacturing method. For example, an alloy could be selected to manage solder wicking or enable use of compression or crimp fittings.

Equally important is the design of the connectors. Research suggests that the design phase of an assembly assumes as much as 80% of the product cost. Thus, it should not be a surprise that a coaxial connector originally designed for manual solder attachment is not optimum for automation. For high-volume applications, we always prepare ourselves for connector design enhancements.

Mostly because of cost considerations, semi-rigid cable has found the widest adoption for high-volume applications, like consumer electronics, where automation is justified. Semi-rigid cable is selected for a number of reasons, the biggest being that it is straight as opposed to coiled. This allows for precision cable location, resulting in maximum tolerance control. The finished assemblies can be put on tape and reel and used with pick-and-place robots. While semi-rigid cable is the most commonly used cable for automation, high-quality cables also lend themselves to automation. They offer very tight mechanical tolerance control on the various material diameters required to operate at microwave frequencies.

JJD: What are the benefits and drawbacks of metal-clad fibers?

CK: Metal-clad fibers (MCF) carry three key benefits: light weight, flexibility, and strength. MCF, when compared to copper, can reduce the weight of a braid by as much as 80%. MCF has a textile-like feel with no bend memory. In addition, its flex life is orders-of-magnitude longer than equivalent copper wire. Besides being a good electrical conductor, MCF is metal-plated with KEVLAR—a material stronger than steel that's used in bullet-resistant vests. So it can also be used as the primary strength member in any cable or harness. MCF is ten times stronger than copper. Compared to equivalent AWG copper wire, though, MCF will have a higher dc resistance. Known as ARACON, that braid is substantially stronger and more durable than the silver-plated copper braid wire that it replaces. Another "side benefit" of the lightweight ARACON braid, when compared to a metal braid, is that less force is delivered to the inner and outer cable component layers during integration, flexure, and handling. The reduction in force increases performance life for the cable.

JJD: How do metal-clad fibers operate for applications such as EMI shielding? What other applications can the material serve?

CK: The primary applications for MCF have been the outer shield of a coaxial cable and a braided or woven EMI shield for wires or harnesses. The large number of very fine fibers, together with the tendency of yarn bundles to flatten and spread, makes it easy to obtain high coverage levels with reduced windowing. Ease of pushback on the braid is maintained even at high coverage. Braids built with MCF can be soldered or crimped, and are a direct substitute for copper braids built to A-A-59569. Due to the textile-like properties and strength of MCF, we also find applications in wearable electronics and athletic gear. mw

THE EVOLUTION OF MICROWAVE AND MILLIMETER-WAVE CMOS ICS

SO FAR, DEMAND for millimeter-wave electronics in commercial or consumer markets isn't strong. However, if the cost structure for such devices were to become less restrictive, it could pave the way to countless applications. Millimeter-wave CMOS—with a high degree of integration at low costs—could be a potential enabler for these technologies. Postulating that different circuit approaches other than RF-CMOS are necessary to develop millimeter-wave CMOS, Asad A. Abidi of UCLA's Electrical Engineering Department presented research on the progression of millimeter-wave CMOS development since the 1970s.

Since World War II, the military has shown interest in millimeter-wave technology for electronic warfare (EW). But reliable devices that could produce millimeter waves weren't feasible until decades afterward. As part of a military grant, Texas Instruments developed silicon-based modules for phased-array radars in 1964. This spurred the development of hybrid integrated circuits (HICs), but they suffered from significant interconnect parasitics above 10 GHz. After years of further research, HICs gave way to monolithic microwave integrated circuits (MMICs).

The first real MMIC—the hybrid semiconductor—exploited gallium arsenide (GaAs), with the justification that higher-electron-mobility devices would have a higher maximum operating frequency. Techniques for developing interstage matching elements between field-effect transistors (FETs) were first performed with GaAs ICs and later implemented in CMOS MMICs.

Phased-array technologies with beam-steering capability continue to be a major application for millimeter-wave CMOS, driving the development of highly integrated millimeter-wave transistors. These applications may lead to reduced costs and the greater adoption of CMOS MMICs for radar, backhaul, 5G, and gigabit Wi-Fi. See "CMOS Microwave And Millimeter-Wave ICs: The Historical Background," *2014 IEEE International Symposium on Radio-Frequency Integration Technology (RFIT)*, Aug. 2014, pg. 1-5.

LINEAR-BEAM-BASED RF AMPLIFIERS SUFFER FROM ELECTRON EMITTANCE

CURRENT RESEARCH IN vacuum RF amplifiers focuses on attaining and reaching beyond the millimeter-wave, submillimeter-wave, and even terahertz frequencies. However, as these devices push to higher frequencies, electron-emittance effects cause RF defocusing in the high-power energy-extraction sections of amplifier circuits.

Adapting techniques used in high-energy physics research for RF amplifiers, David R. Whaley with L-3 Communications in Santa Clara, Calif., was able to devise enhancements to several formulated expressions. In doing so, a more accurate prediction of electron-beam behavior was possible for microwave to terahertz frequency signals. Increased levels of interception current and beam expansion are seen as a product of the increased radial space charge forces around the bunched sections of vacuum RF amplifiers. Using expressions to quantify the electron emittance effects for cold electron beams, Whaley developed numerical simulations that could be applied to thermionic and field-emitter cathodes.

The general formulation developed by Whaley was confirmed using numerical optics simulation techniques for a diverse number of beam properties commonly observed in vacuum RF amplifier devices. See "Practical Design of Emittance Dominated Linear Beams for RF Amplifiers," *IEEE Transactions on Electron Devices*, June 2014, pg. 1726.

MMIC QUADRUPLES FREQUENCIES INTO MILLIMETER-WAVE BANDS

THE DESIGN AND fabrication of technology for natively generating and modulating millimeter-wave signals is expensive and complex. Thus, researchers need techniques and typologies to upconvert or multiply lower-frequency signals. On that front, Catherine Algani of the ESYCOM Laboratory-CNAM, France, together with Wafae El Hamdani, Said Mazer, Moulhime El Bekkali, and Maryam Abata of the Laboratory of Information Processing and Transmission of Sidi Mohamed Ben Abdellah University, Morocco, used the UMS foundry's PH15 to design a frequency quadrupler that operates at millimeter-wave frequencies.

The research team worked with the UMS foundry to combine monolithic-microwave-integrated-circuit (MMIC) technology with the PH15 process. As a result, the researchers were able to develop a single-stage quadrupler operating with a 14- to 16-GHz local oscillator. The UMS foundry process is based on pseudomorphic-high-electron-mobility (PHEMT) field-effect transistors (FETs). Gate widths of 70.00 and 0.15 μm were used to develop the mutliplier's circuit components, a quadrupler, a high-pass filter, and a buffer amplifier.

The conclusive design stemming from the research was a quadrupler that reached 60 GHz with a conversion gain of –4.2 dB. The quadrupler demonstrated high harmonic rejection of the second, third, and fourth harmonics to 18.8 dB of the third harmonic. See "Design of a MMIC Frequency Quadrupler In Millimeter-Wave Band," *2014 International Conference on Multimedia Computing and Systems (ICMCS)*, Apr. 2014, pg. 1506.

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JEAN-JACQUES DeLISLE | Technical Editor JACK BROWNE | Technical Contributor

WELCOME TO IMS 2015: In the Valley

This year is the 85th annual ARFTG Conference, which is held along with IMS 2015 and RFIC2015.

Photos Courtesy of Phoenix Convention Center

Hot air balloons at Saguaro

Pool at Royal Palms

Photo credit: Visit Phoenix

of the Sun

Microwave Week is a time for reaffirming outstanding relationships, exploring the smorgasbord of microwave products/services, and diving into the latest and greatest technologies produced by the microwave industry.

MICROWAVES WEEK, the annual gathering of microwaves engineers, industrials, and academics, this year is set to bask in the sun of beautiful Phoenix, Ariz. From May 17-22, there will be two major symposia and a major conference covering the full range of microwave industry topics, from design, manufacturing, to test and measurement. The International Microwave Symposium (*www.ims2015.org*) is the grand feature of the week, with a battery of technical sessions, exhibits, and student programs extending throughout Microwaves Week.

The Automatic RF Techniques Group (ARFTG), a technical organization specializing in all things test and measurement, is celebrating its 85th annual ARFTG conference co-located with IMS. This year's ARFTG conference focus is on the up-and-coming 5G applications. Also co-located with IMS/ARFTG, IEEE Radio Frequency Integrated Circuits Symposium (RFIC) features technical discussion and exhibitions on the latest of RF integrated circuit technology. There are many exciting highlights in this year's IMS, ARFTG, and RFIC gatherings, and a surprising amount of focus on women in STEM, STEM education, and building up young professionals brave enough to seek a career in the microwaves industry.

THE GENERAL CHAIR'S WELCOME

The theme of this year's conference is "Microwaves Soaring Towards the Future." "New and emerging fields like wearable electronics, Internet of Things, 3D printing, 5G, and RF/MW technology in life science will be emphasized at IMS 2015," said Vijay Nair, IMS 2015 General Chair, in his IMS 2015 welcome

Copper Blues Rock Pub & Kitchen

Arizona Biltmore Event

FUTURE DATES AND LOCATIONS FOR IMS		
Future Symposia	Location	Date
IMS 2015	Phoenix, AZ	17 – 22 May
IMS 2016	San Francisco, CA	22 – 27 May
IMS 2017	Honolulu, HI	4 – 9 June
IMS 2018	Philadelphia, PA	11 – 15 June
IMS 2019	Boston, MA	3 – 7 June
IMS 2020	Los Angeles, CA	14 - 19 June
IMS 2021	Atlanta, GA	21 – 25 June
IMS 2022	Denver, CO	TBD

The IEEE MTT-S society hosts IMS annually in different cities across the United States.

PRINCIPAL JOB FUNCTIONS OF IMS ATTENDEES (2014)	
Executive/Senior Management	16
Student	15
Design Engineering	14
Professor/Research-Academic	13
Marketing/Sales	12
Engineering Management	8
R&D Industry	7
R&D Government	3
Engineering Services	2
Application Engineer	2
Consultant	2
Manufacturing/Production Engineering	1
Procurement/Purchasing	1
Editor/Publisher	1
Retiree	1
Financial Or Industry Analyst	0

message to eager IMS 2015 attendees. In the spirit of warmly welcoming the microwaves community to IMS and to make somewhat of a mission statement, Nair issued a message that includes tidbits about IMS and the surrounding city of Phoenix. A potentially exciting bit of news for those interested in making their way around the United States 5th largest city, is that there will be 'DOwntown Phoenix Ambassadors' equipped with yellow shirts scattered around the convention to help attendees make the most of city. Nair announced, "Many special programs to promote student participation from middle school to college graduates will be introduced. A panel session and focused session organized by Women in Microwave will be held at IMS 2015."

WELCOMING THE TECHNICAL PROGRAM COMMITTEE CHAIRS' WELCOME

In the theme of welcoming the microwaves community with open arms, the Technical Program Committee (TPC) Chairs also have shared a welcome message. "The IMS 2015 team is developing a world-class technical program that will bring RF/microwave researchers and practitioners from around the world to Phoenix, Arizona, in May 2015," according to Chuck Weitzel and David Ngo, the IMS 2015 Technical Program Committees Co-Chairs, in their welcome address. Also included in their welcome was a quick and convenient overview of the technical program, with brief descriptions of the major facets of the technical program. "IMS 2015 will continue to offer technical sessions, interactive forums, plenary and panel sessions, workshops, short courses, application seminars, STEM activities,

The Technical Program Committee (pictured above) bears the burden of organizing all of IMS 2015 from start to finish.

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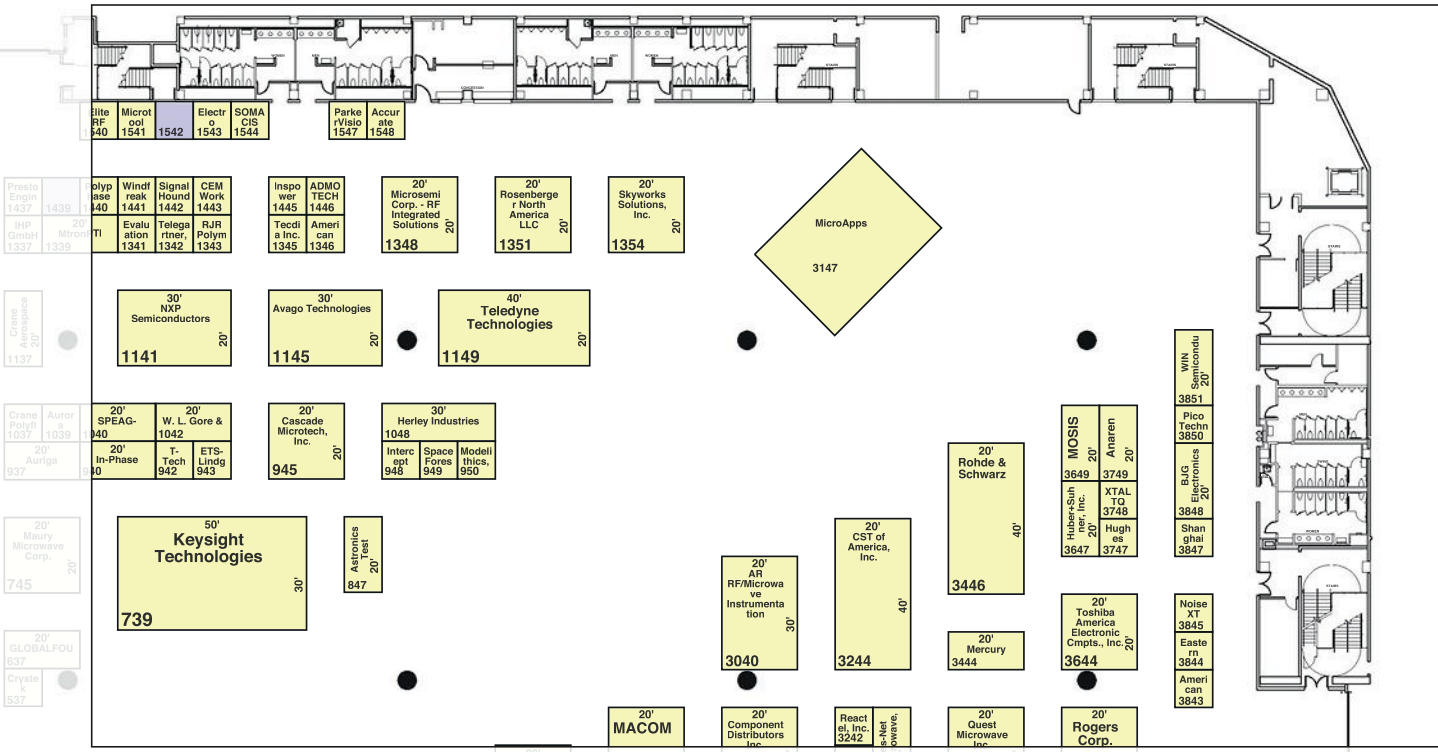


IMS 2015 features over 550 exhibits in the Phoenix Convention Center.

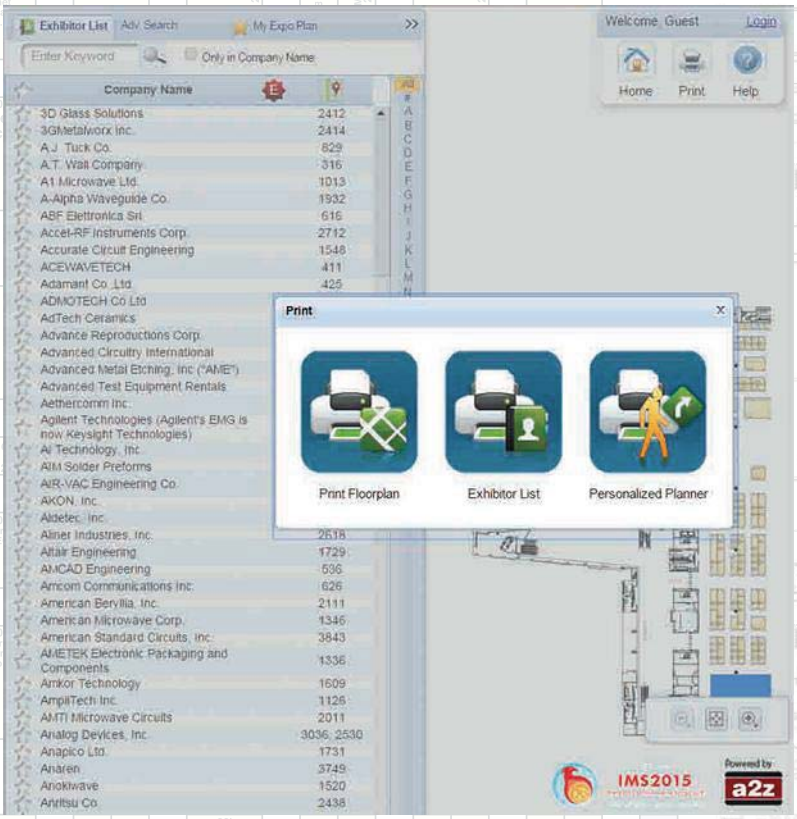
RF Boot Camp, and a wide variety of other technical and social activities."

SPONSORING SOCIETY OF IMS 2015

The IEEE Microwave Theory and Techniques Society (MTT-S) represents over 11,000 members and 150 chapters worldwide. Sponsoring IMS and aiding in the development/application of microwave technology for over 60 years, MTT-S publishes peer-reviewed papers in several journals and a magazine. On the IMS 2015 website is the following mission statement issued by MTT-S: "As we enter into an exciting future, our mission is to continue to understand and influence microwave technology, and to provide a forum for all microwave engineers. The MTT-S will continue to be the global focus for promotion of the RF and microwave engineering profession, by advancing and distributing knowledge and supporting professional development."

PLENARY SESSION

Soft radio sensor and circuit assemblies for on-skin applications will be discussed by Dr.



An interactive floor map is provided by MTT-S to aid attendees as they choose which booths to visit.

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3. **Renaissance Phoenix Downtown**
   50 E. Adams Street
4. **The Westin Phoenix Downtown**
   333 N. Central Avenue
5. **Hilton Phoenix Suites**
   10 E. Thomas Road
6. **Hampton Inn Phoenix Midtown**
   160 W. Catalina Drive
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Map of Downtown Phoenix area provided courtesy of CTT, Inc.

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With a proficiency in chemistry and physics, Dr. John Rogers will explore on-skin radio sensors and circuit assemblies in his plenary session.

John Rogers, Swanlund Chair, Professor of Materials Science and Engineering, and Professor of Chemistry University of Illinois, Urbana-Champaign. As the plenary-session speaker, Rogers will cover many of the ins and outs of medical wearables. He also will outline the challenges ahead for an audience that's eager to find solutions.

INTERACTIVE FORUM

At IMS 2015, there will be two interactive poster sessions in which authors will have an opportunity to present their work and engage with curious colleagues. The two forums will take place on Wednesday and Thursday, and the paper evaluation process will be identical to the regular session papers' process.

FOCUS SESSIONS

In order to display original works on emerging microwave technologies or topics widely relevant to the industry as a whole, at IMS 2015 there will be a series of focus sessions. The topics delve deeply into such timely topics as 100 Gbps wireless technologies, mobile communications beyond 6 GHz, adaptable microwave front ends for military applications, and more.

SPECIAL SESSIONS

With the goal of highlighting the historical moments in the microwaves community and history, and to recognize technical accomplishments, the IMS 2015 special sessions will have a mixture of history, heart, and technological growth in fields and regions of the world. Among the many topics covered are Latin American microwave research, ambient RF energy harvesting and power transfer, and small-satellite technology development.

PANEL SESSIONS

Generally conducted during lunch, the panel sessions are highly interactive discussions with lead technical experts from throughout the microwave industry. At one hour and twenty minutes, these sessions allow for a deep discussion of a wide range of critical and common questions posed every day in the industry. Topics such as wearable antennas, industry demographics, industry challenges, millimeter-wave regulation, and the latest in testing are all on the agenda with panelists from the leading companies and research universities.

WORKSHOPS

A battery of workshops to drill into a wide range of expert topics and academic research will provide details and engaging experiences with challenges, experiences, and emerging microwaves and RF engineering topics. Among the topics covered, RFICs, generating RF frequencies on CMOS technology, millimeter-wave solid state drives, and high-resolution

PRIMARY END PRODUCTS/SERVICES OF IMS ATTENDEES (2014)	
Communication Systems/Equipment	20
Semiconductors & ICs	18
Wireless (WiFi, WiMAX, UWB, other)	11
Components/Hardware	11
Defense Electronics	10
Test & Measurement	9
Government - Military	5
Government - Other	2
Consumer Electronics	2
Materials	2
Services	2
Software	2
Medical Electronics	1
Navigation/Telemetry/GPS Systems	1
Industrial Automation/Control Systems	1
Transportation (Automotive/Aviation)	1
Data Transmission	1
Retiree	1
Computers or Peripherals	0

PRODUCTS & SERVICES AREAS OF IMS ATTENDEES (2014)	
Active Components	45
Passive Components	44
Test Equipment & Instruments	35
Semiconductors/Integrated Circuits	34
Antennas	26
Software & CAD	21
Materials	19
Subsystems & Systems	18
Transmission-Line Components	17
Control Components	13
Signal Processing Components	12
Manufacturing Equipment	9
Services	8
Optoelectronics & Fiber-Optics	7
Consultant Services	7

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vital-sign detection with radar among many others will stand out throughout IMS 2015.

SHORT COURSES

Solicited from the breadth of new microwave subject areas, affiliated industries, and associated fields within the technical areas within MTT-S, the short courses at IMS 2015 feature focused courses on timely and buzzworthy topics from highly qualified instructors. The goal of the short courses is to offer a basic level of knowledge on special topics within the industry. These topics include power-supply transmitter design, near-field probes, phase locked loops, spectrum regulation, nonlinear microwave circuits, and 5G millimeter-wave device characterization.

RF BOOT CAMP

Are you ready for a rough-and-tumble, intense introduction to basics of RF and microwave theory and techniques? If so, you are in for a treat, as IMS 2015 will be hosting an RF Boot Camp with the goal of providing a solid introduction of the basics for new engineers and engineers in a shifting career role, as well as college students and industry professionals looking to be in the know. The RF Boot Camp will include short courses, technical sessions, workshops, and chances to ask questions in order to grow your knowledge on microwaves and RF fundamentals.

IMS 2015 HONORARY SESSION

Celebrating Tatsuo Itoh's dedicated service of 40 years to the MTT-S Administrative Committee (ADCOM), at IMS 2015 there will be an honorary session presented specifically for Itoh. Having received a Ph.D in electrical engineer from the University of Illinois and served a variety of universities in the United States, Itoh is also a Life Fellow of the IEEE. Among his many accolades is his induction into the National Academy of Investors as a Fellow, the National Academy of Engineering, and his holding of the Northrop Grumman Endowed Chair.

Dr. Tatsuo Itoh has served 40 years with IEEE MTT-S ADCOM.

A SPECIAL FOCUS ON WOMEN IN MICROWAVES

At IMS 2015, Women in Microwaves (WIM) is hoping to boost the num-

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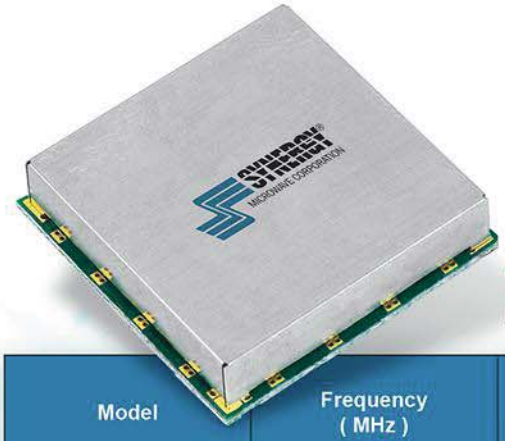

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HFSO800-5L	800	1 - 12	+5 @ 20	-142
HFSO1000-5	1000	1 - 12	+5 @ 35	-141
HFSO1000-5L	1000	1 - 12	+5 @ 35	-137
HFSO1600-5	1600	1 - 12	+5 @ 100	-137
HFSO1600-5L	1600	1 - 12	+5 @ 100	-133
HFSO2000-5 *	2000	1 - 12	+5 @ 100	-137
HFSO2000-5L *	2000	1 - 12	+5 @ 100	-133

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ber of female engineers in the microwave and RF industry. Among WIM's goals for IMS are raising awareness, highlighting prominent women in engineering working on emerging technologies, and providing a comfortable environment for women microwave engineers to socialize and share experiences. A subset of the IEEE Women in Engineering (WIE), WIM shares that organization's mission to "facilitate the global recruitment and retention of women in technical disciplines."

IMS 2015 CLOSING CEREMONY

Closing IMS 2015 will be Dr. J.S. Solomon, with a detailed talk on biology-based technology and its place in the 21st century. Discussing breakthroughs in cellular biology and our expanding knowledge of living systems, Dr. Solomon's talk will include details on molecular and biological measurement and the future of this exciting field.

IMS 2015 EXHIBITS

One of the rich and expansive traditions of IMS is the dedication of an extremely large hall to the exhibition of all things microwave. From component manufacturers, to research/design houses, the microwave industry and company representatives are able to show off their latest and greatest at the exhibition floor. This year, MTT-S is providing and interactive floor map to enhance attendees and exhibitors exploration of the exhibits.

The closing session of IMS 2015, with Dr. J.S. Solomon, embraces biological technologies and their inevitable growth in the future.

Sherry Hess and Vesna Radisic are the co-chairs of WIM at IMS 2015. Their goal is to increase the representation of professional women in the microwaves industry.

MICROAPPS

Featuring the underlying technology beneath the latest commercial products available from the exhibitors at IMS 2015, the Microwave Application (MicroApps) presentations will take place on the exhibit floor for all to experience when not exploring the exhibits. These seminar-style talks will be an information-packed series of 20-minute presentations in booth 3147 of the exhibition hall, ultra-convenient for those on the floor to attend.

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design FAQs

GaN Reaches into a Spectrum of Markets

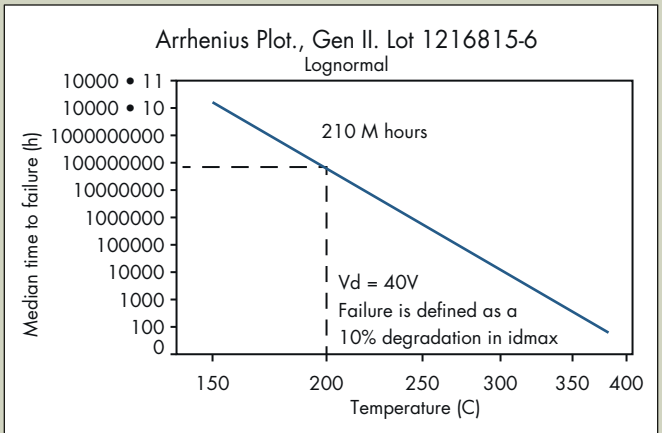
FREQUENTLY ASKED QUESTIONS

Q: What types of GaN devices are available in the RF market today?

A; When GaN is spoken of in the RF industry, typically, aluminum GaN (AlGaN) or GaN high-electron mobility transistors (GaN HEMTs) monolithic microwave integrated circuits (MMICs) are being described. Hundreds of thousands of these GaN devices have been deployed in electronic warfare (EW), commercial network infrastructure, and even space environments.

Selected semiconductor companies first began working with GaN RF power transistor technology beginning in the late-1990s driven by DARPA and other arms of the DOD. Today, the GaN market has matured into the commercial realm. As the costs of GaN devices have dropped with the adoption of larger wafer sizes, GaN technologies have expanded from higher-performance applications for defense and aerospace to 4G/LTE base stations, CATV modules, and point-to-point communications.

GaN epitaxy is grown on several different substrates, each offering a different performance, size, and thermal characteristic. The most viable substrate choices are GaN on SiC (silicon carbide), Si (silicon), sapphire, GaN, and synthetic diamond. The most popular in applications are GaN on SiC and Si. GaN on silicon carbide (GaN-SiC) is the most common substrate for high-frequency and power applications, due to its higher performance capabilities and high thermal conductivity. GaN on Si has potential as a low-cost solution where best thermal performance isn't required, such as low-power or for lower-voltage operations. GaN on Si may compete in some GaAs (gallium arsenide) applications.



At 50% confidence level, MTTF ≈ 2.1 10^3 hours at 200°C

Q: What about the frequency ranges that GaN can achieve in actual devices?

A; GaN transistors and MMICs cover a very wide range of applications, from near-DC through W-band. GaN MMICs have become common in high-power defense and aerospace applications ranging from L-band for GPS, to X and Ku-band for military communications and radar. Because of its performance capability, GAN is ideal for wide bandwidth EW applications. In commercial systems, GaN has already moved into 4G/LTE base transceiver stations (BTS) and broadband cable (CATV). For BTS, 2.5 to 3.5 GHz PAs with efficiencies peaking at 70% have been produced. There are production GaN devices well into the millimeter-waves, up to 100 GHz.

Q: With any semiconductor technology, proper thermal management is important to the overall reliability of the device. How is thermal management addressed with GaN?

A; Thermal management is a primary concern in high-power devices such as radar and new commercial markets such as BTS and point-to-point radio. GaN's high current and high voltage capability allows these devices to generate high power levels in amplifiers, while still maintaining a small device size. It is important for designers to manage heat with thermally optimized device design, substrate choice, and package design.

GaN devices are robust due to their breakdown voltage ability, allowing them to handle large voltage and current swings for both transmitted and reflected RF power--all while working in a high temperature environment. GaN HEMTs are able to survive high levels of output voltage-standing-wave-ratio (VSWR) mismatch. These properties of GaN eliminate and simplify protection circuitry while at the same time reducing field failures.

Q: How reliable are GaN devices?

A; Currently, there are several GaN suppliers who have provided active and passive devices for many markets and applications. Some such suppliers have even achieved Manufacturing Readiness Level (MRL) 9, indicating that the company's GaN devices

are ready for full production. MRL is a DOD system that benchmarks devices that have all required materials available, manufacturing and quality process, and proven procedures and low production risk. There are GaN processes that have reached mean time to failures (MTTFs) for all the half-micron, quarter micron, and 0.15 micron gate length technologies much greater than 10 million hours at 200oC. In addition, these devices were able to meeting stringent environmental qualifications, such as Highly Accelerated Stress Testing (HAST) compliance to the Joint Electron Device Engineering Council (JEDEC) requirements.

Q: GaN is available in both die and package styles. What other type package styles are currently available?

A; Many package formats developed for other technologies, ranging from LDMOS to those for millimeter wave GaAs, are applicable to GaN devices. These include traditional ceramic flange packages, and surface-mount technology (SMT) plastic packages, such as QFNs. Products have been designed with internally matched GaN transistors with 50 Ω and 75 Ω operating impedances, which can simplify customer PA application module designs. Similarly, GaN MMICs are packaged using standard formats that cover a wide range of environmental and performance requirements.

Q: What are the various products using GaN technology today?

A; Currently GaN is used for its power and efficiency on PAs, power doublers, push-pull amplifiers, and broadband amplifiers. It is also useful for LNAs due to its low noise and high power handling capacity. GaN's advantage for high-dynamic-range LNAs comes from the technology's ability to handle very high input signal levels, beyond the performance capability of GaAs FETs.

GaN is also well suited for switch and attenuator components, again due to its high voltage and low-insertion-loss qualities. Compact GaN switches can even be implemented on the same die as GaN PAs and LNAs, adding an enhanced level of integration rarely seen outside of CMOS technologies. ■

DON'T MISS THE IMS 2015 BLOG

As a fun and informative way to spark discussion about IMS 2015, MTT-S is hosting a blog on the IMS 2015 webpage. Many players in the industry are sharing their excitement about IMS 2015 on this blog. One particular quote from Christopher Marki, Director of Operations at Marki Microwave, stands out: "Some critics say that attending IMS is a waste of time for engineers and designers. The popular complaint is that conferences, in general, tend to be long on marketing sparkle and short on technical rigor. *HOWEVER*…wait for it…I contend that IMS is, by far, the most useful conference an RF engineer can ever attend. The reason is that IMS is, by analogy, a three-day Farmer's Market of RF goods and services where you can meet and share ideas with the highest-caliber people the industry has to offer. Why is IMS uniquely similar to your local Farmer's Market? Simple, the RF business is populated by a dense cluster of extremely talented 'specialist' companies that are small in stature but high in quality."

STUDENT EVENTS & STEM OUTREACH

IIMS 2015 is rolling out the carpet for high school and college students so they can experience all that the microwave industry has to offer. Using student design competitions, a high-school invitational, a STEM program, and Project Connect, MTT-S is exposing up and coming engineers to the wonder of microwaves.

GRADUATE STUDENT DESIGN AND PAPER COMPETITIONS

As detailed on the IMS 2015 website, "Through participation in the Student Design Competitions, IMS-registered student teams from around the world will have the opportunity to demonstrate the application of strong RF/microwave engineering design principles in the development of the most elegant/efficient hardware solutions to predetermined design requirements. Student Design Competitions are proposed and organized by specific Technical Committees of the MTT-S."

For more on the Graduate Student Design Competitions, visit http://www.ims2015.org/students-main/student-design-competitions.

PROJECT CONNECT

Especially exciting for high-achieving undergraduate students is a special travel grant by the National Science Foundation (NSF) and IEEE to help these students experience IMS 2015.

Roughly 30 students from underrepresented groups, chosen for their excellence in academics and career goals, will qualify.

The program, designed to attract these students to the field of microwave engineering, creates an opportunity for students to interact with practicing engineers and learn about new technologies being developed today.

At the ARFTG Conference, Dr. Hermann Eul and Prof. Peter H. Siegel will be delivering talks during the plenary session.

YOUNG PROFESSIONALS IMS

AAs mentioned previously, the microwave industry is eagerly looking to develop community and leadership while increasing the number of young industry professionals. It also hopes to awaken the entrepreneurial spirit in younger industry professionals. A special discussion forum has been developed with entrepreneurs throughout the field of engineering. Topics will range from building a successful engineering company to the obstacles and opportunities involved in starting such a company.

ARFTG'S 85TH CONFERENCE AND RFIC 2015

CCo-located with IMS 2015 are the RFIC symposium and the ARFTG Conference.

RFIC will feature two plenary sessions with Dr. Peter H. Siegel of the Jet Propulsions Laboratories (JPL) and Dr. Hermann Eul of Intel. Additionally, RFIC will offer a range of industry showcases and receptions highlighting 11 selected papers by authors spanning the industry. A new edition at this year's RFIC will be a Best Industry Paper Award to the authors of one of the specially selected papers.

The 85th ARFTG Conference will include the traditional technical presentations, interactive forum, and exhibition, offering a great platform for interactive discussions with peers in the test and measurement community. This year's conference theme is, "Measurements and Techniques for 5G Applications." A special topic forum, Nonlinear Vector Network Analyzer (NVNA) User's Forum, will gather on Thursday afternoon of Microwaves Week and all conference attendees are invited. MW

Cutting-Edge Products Invade IMS 2015

THE 2015 IMS IEEE IS, of course, an important educational event for many, featuring an excellent collection of technical presentations and focused technical meetings like the Automatic RF Techniques Group (ARFTG). But a great deal of the education takes place right on the exhibition floor with every stop—at every booth. For those working company booths on the floor, there's little more gratifying (save for a product order taken at the booth) than a visitor stopping at the booth and wanting to know more about the company and its products.

A walk through IEEE IMS Exhibition can usually bring visitors up to speed on any of the different technologies driving this industry. For example, fixed- and variable-frequency oscillator companies will have samples of their latest fare, with plots of single-sideband (SSB) phase noise to show off their performance for different carrier frequencies. Test-equipment suppliers often have the largest booths on the floor, usually with a nice assortment of different test instruments to generate and analyze signals at microwave frequencies.

However, over the last few decades, software developers have taken an increasingly prominent position on the show floor, likely because their simulation and analysis tools play an increasingly prominent role in the working lives of RF/microwave engineers. Modern computer-aided-engineering (CAE) simulation software impacts almost every device and circuit technology, and engineers across the industry use the close match between simulated and measured results as the reassurance that a circuit design is sound and reliable. Among other things, the 2015 IEEE IMS Exhibition offers an opportunity to try out the latest design software tools and perhaps grab one or two free copies of demonstration software.

1. Among the CAE software tools on display will be the CST MICROWAVE STUDIO software for 3D simulation of components such as antennas and filters. *(Photo courtesy of CST Inc., www.cst.com)*

The exhibition area is open for slightly less than three days, and visitors can easily spend all of their time just scouring the sections of the show floor and the companies devoted to CAE software or to test equipment. This article presents a sampling of what to expect from some of the companies on the show floor, but hardly covers even a significant portion of what will be on hand in the exhibition area. As always, to learn more, contact a company of interest.

SIMULATION PERMUTATIONS

Often, such product exhibitions open up possibilities to see how things work, such as simulation software and test equipment. The exhibition booths will particularly be well stocked with computer simulation software, including some of the most sophisticated electromagnetic (EM) simulation tools.

For instance, the event offers the opportunity to spend time with the likes of Dr. Jim Rautio, founder of Sonnet Software (Booth 2640; www.sonnetsoftware.com) and developer of the firm's famed Sonnet Suites of EM simulation software tools. These three-dimensional (3D) planar EM simulation programs analyze the fields around high-frequency circuits (*e.g.*, microstrip and stripline) and predict the EM fields that will occur around different structures (*e.g.*, filters and antennas) and different circuit junctions.

Though considered standalone tools, the Sonnet Suites are also integrated with many other high-frequency CAE simulation programs, including the Advanced Design System (ADS) from Keysight Technologies (Booth 739; www.keysight.com), Cadence Virtuoso from Cadence Design Systems (Booth 2832; www.cadence.com), the CST Studio Suite *(Fig. 1)* from CST of America (Booth 3244; www.cst.com), MATLAB from The MathWorks (Booth 107; www.mathworks.com), and the AWR Microwave Office design tools from Applied Wave Research (www.awrcorp.com) and parent company National Instruments (Booth 2431; www.ni.com). Each of these software tools will be available for demonstration at their respective booths.

For those who may be intimidated by the cost of electronic-design-automation (EDA) software, Sonnet Software also offers Sonnet Lite software for free download from the company's website. This is a limited version of the Sonnet Suites, which is quite useful for taking a "first look" at certain designs and

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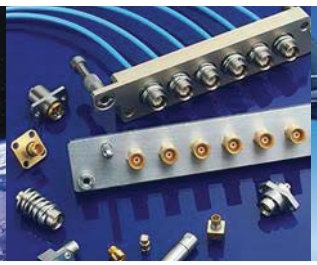

then deciding whether to make the investment in the full-scale version of the software. Across the show floor, numerous other vendors offer affordable software solutions with or without free trial versions. For example, Intercept Technology (Booth 948; www.intercept.com) provides design tools that helps create practical schematic diagrams as well as printed-circuit-board (PCB) layouts. In any case, for those exploring the 2015 IMS for high-frequency software tools, a visit to Sonnet Software makes a good first stop before delving into system-level EDA tools.

Not far from Sonnet, ANSYS (Booth 2036) will show examples of its different CAE tools, including its own 3D EM simulation software, the High-Frequency Structure Simulator (HFSS) software. This full-wave EM simulation tool has long been used to model not only RF/microwave circuits, but high-speed digital circuits as well. The software provides advanced solver approaches based on finite-element (FE) and integral-equation solutions.

2. The compact LX series of phase-locked frequency sources includes this 840-MHz unit with low phase noise. *(Photo courtesy of EM Research, www.emresearch.com)*

On the other side of the exhibition hall, at Keysight's Booth 739, visitors can learn about the latest trend in EDA software tools—products such as Keysight's Advanced Design System (ADS) and SystemVue system-level software tools. These work seamlessly with EM simulators and component-level circuit simulators to provide integrated modeling tools for high-frequency analog and high-speed digital circuit and system designers.

BUILDING BLOCKS

Visitors to the 2015 IMS Exhibition can likely fill bags with free samples and literature, and in the process gain an enormous education on the latest technologies driving the RF/microwave industry. The real problem is where to start and how long to spend at each booth. One possible way to kick things off is to simply work from the ground up and start with building-block components, such as PCB materials.

Arlon Materials For Electronics (Booth 531), which as of January became part of Rogers Corp. (Booth 3640), will show its variety of high-performance PCB materials, including PTFE-based circuit materials for high-frequency circuits. For example, its CLTE series of woven-glass/PTFE materials feature a dielectric constant of 2.94 in the z-direction at 10 GHz with excellent stability versus temperature for phase-sensitive applications (e.g., radar systems). Well suited for temperature-sensitive systems like avionics, electronic warfare (EW), and communications applications, these materials achieve outstanding coefficient of thermal expansion (CTE) performance.

The firm will also show its TC series of thermally conductive materials, available with somewhat higher dielectric-constant values such as 6.15 and 8.50 in the z-axis at 10 GHz. These materials were developed for applications plagued by heat-related issues, such as amplifiers and transmit antennas.

Not far from Arlon, at Booth 231, Taconic (www.4taconic.com) will provide samples of its different circuit materials, including woven-glass-reinforced PTFE laminates and ceramic-filled PTDE laminates. In addition, the company will unveil its new TacLam PLUS microwave laminates for low-loss circuits using single- and multiple-layer designs. These are nonwoven, ceramic-loaded PTFE-based materials with dielectric constant of 2.1 at 10 GHz and low loss tangent of only 0.004 at 10 GHz. With a metal backing, such as 1-mm-thick copper, the material maintains excellent dimensional stability.

Rogers Corp., Arlon's new parent company, will also be on hand across the show floor to update visitors on its many different circuit materials, including the popular RO4350B and RO4003C. These are proprietary woven-glass-reinforced hydrocarbon/ceramic materials with electrical performance close to PTFE/woven-glass circuit materials. They also feature the ease of manufacturability of epoxy/glass, with no special production treatments or processes required to create RF/microwave circuit boards. RO4003 exhibits a dielectric constant of 3.38 at 10 GHz and RO4350B has a dielectric constant of 3.48. Both hold those values over temperature and frequency to provide stable circuit performance under a wide range of environmental conditions.

Members of the Dielectric Laboratories Inc. (DLI) arm of Knowles Capacitors (www.knowlescapacitors.com) will be on hand at booth 129 to show its latest dielectric material, rated for high-voltage use through +50 V dc. The "UX" material, which is space-qualified to MIL-PRF-38534 Class K requirements, supports higher-valued capacitors in smaller-sized housings. The material can be specified across DLI's broad range of thin-film

3. This evaluation board was developed to support the model PE97240 PLL synthesizer for applications to 5 GHz. *(Photo courtesy of Peregrine Semiconductor Corp., www.psemi.com.)*

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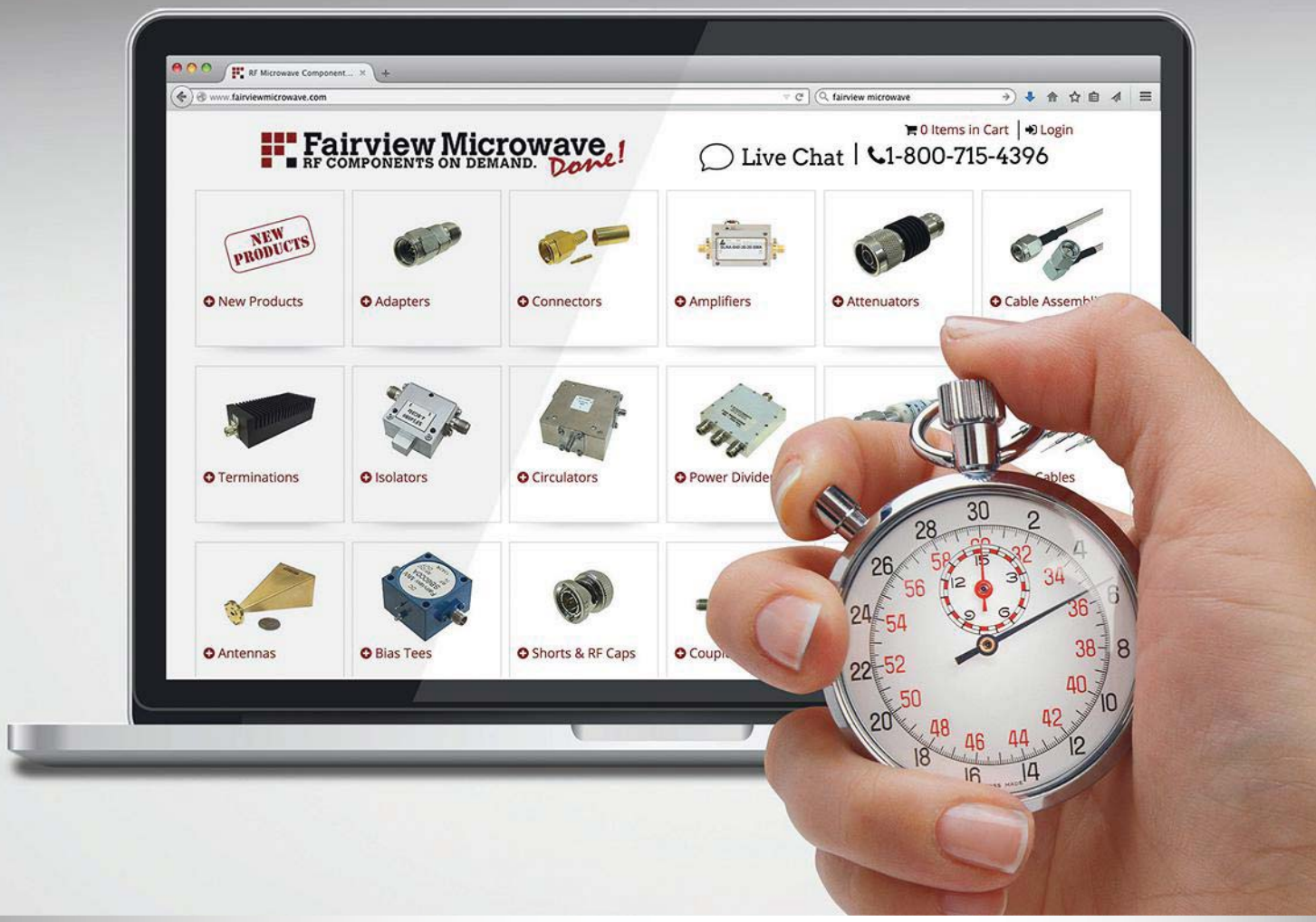

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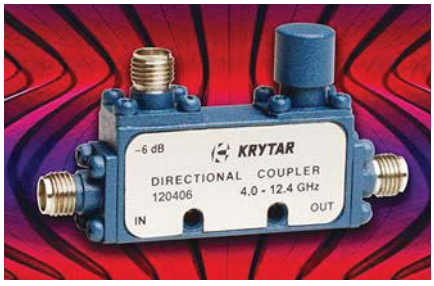
capacitors, including its Di-Caps and Border Caps. The UX material, which will be available in capacitors with a capacitance range of 51 to 10,000 pF, suits applications such as amplifier stabilization, energy storage, and dc blocking.

Coilcraft (Booth 1929, www.coilcraft.com) will be on hand to advise visitors on its many inductors and other magnetic components, as well as the latest version of the Coilcraft LC Filter Designer software for designing low-pass elliptic filters. The software enables S-parameter analysis in logarithmic or linear scales; users can work in minimum-capacitor or minimum-inductor circuit topologies for a given set of filter design goals. The software, available for free download, works with actual Coilcraft inductance values. Also on its website are a number of different tools, including the RF Inductor Finder to help quickly find inductors using operating frequency and/or inductance as search values.



4. Model 120406, which operates from 4.0 to 12.4 GHz, comes from a line of coaxial directional couplers designed for applications to 50 GHz. *(Photo courtesy of Krytar Corp., www.krytar.com)*

Among its assortment of passive components, EMC Technology (Booth 2236) will showcase its low-loss HybriX hybrid couplers. These models, optimized for applications from 0.5 to 3.5 GHz, are well suited for wireless communications applications. For example, model WH1727F exhibits insertion loss of only 0.1 dB from 1700 to 2700 MHz, with 30-dB isolation between ports in a compact housing. In addition to their low loss, the couplers feature high power-combining efficiency with excellent amplitude and phase balance. The firm will also exhibit its Thermopad temperature-variable attenuators. These devices require no bias, but can be used for attenuation purposes where different responses are needed for different temperatures.

Planar Monolithics Industries will be on hand with an assortment of its active and passive components, including amplifiers and equalizers. For instance, the EQL-17D6G21D6G-4DB-292MF passive equalizer, targeting 17.6- to 21.6-GHz applications, has a -4-dB slope with frequency and ±0.5-dB linearity. It can handle input power levels to 0.5 W CW (+27 dBm). Supplied with 2.92-mm connectors, it measures just 1.10 × 0.67 × 0.22 in.

The company will also show amplifiers, such as its model PEC-30-2R04R0-1R5-21-8V-SFF-HS low-noise amplifier (LNA) with typical noise figure of 1.5 dB or less from 2 to 4 GHz. The amplifier comes with female SMA connectors in an EMI-shielded housing. It features better than 30-dB gain across its bandwidth with +21-dBm output 1-dB compression point. The LNA draws 380-mA maximum current from a +8-V dc supply.

Armed with information on some of the latest circuit materials, visitors may be ready to audition some of the many active and passive components to be found on the 2015 IMS Exhibition show floor. Perhaps no greater assortment of components will be found than at the site for Mini-Circuits (Booth 3331). A long-time supplier of active and passive components, the company has lately grown stronger in its development of test-and-measurement equipment. Mini-Circuits will have examples of its many different product lines at the exhibition, including an array of surface-mount-technology (SMT) components. Among them are some of the most broadband surface-mount components in the industry, such as the RCAT Series of fixed attenuators (see p. 114). They provide accurate attenuation levels across a wide bandwidth of dc to 20 GHz in attenuation values from 0 to 30 dB. Though measuring just 2.25 × 2.25 × 1.1 mm, these monolithic attenuators handle power levels to 2 W.

Surface-mount components represent just one of Mini-Circuits' product lines, though. The firm is sure to show examples of its various coaxial and even waveguide components and assemblies. The HPA-272+, for example, is a much larger component than most IMS visitors will have in mind when thinking of the company's products. This rack-mount amplifier, rated for 100-W output power from 700 to 2700 MHz, suits a variety of test applications, including electromagnetic-interference (EMI) testing. Replete with a self-contained 110/220-V ac power supply, the internally cooled amplifier provides 48-dB gain across its frequency range, with gain flatness of ±1.7 dB. It comes in a standard 19-in. rack-mount enclosure.

These larger products for Mini-Circuits are perhaps best embodied by the firm's expansion into test equipment and measurement solutions through 18 GHz, including the rack-mount amplifiers, frequency counters, switch matrices, power sensors, and signal generators. Visitors to the booth will see the near-emergence of a secondary test-and-measurement company, with many practical measurement solutions.

For example, model SSG-6400HS is a USB-controlled synthesized signal generator in a compact housing. It tunes from 250 kHz to 6400 MHz with 0.01-Hz resolution and frequency tuning speed of 100 µs. It controls output-power levels from −75 to +14 dBm with power-level resolution of 0.01 dB. Despite the low cost, the signal generator provides a wide range of modulation formats and is spectrally clean.

In terms of generating signals, the IMS Exhibition will provide a wealth of sources for oscillators of every kind, from stable, fixed crystal oscillators to variable-frequency tunable varieties operating well through the microwave and millimeter-wave frequency ranges. At Booth 117, Synergy Microwave Corp. (www.synergymwave.com) will demonstrate some of the results of its latest application-specific-integrated-circuit (ASIC) technology for low-noise microwave signal generation (see "Novel ASIC Helps Sources Silence Noise," at mwrf.com). The company's latest phase-locked source designs feature low phase-noise levels

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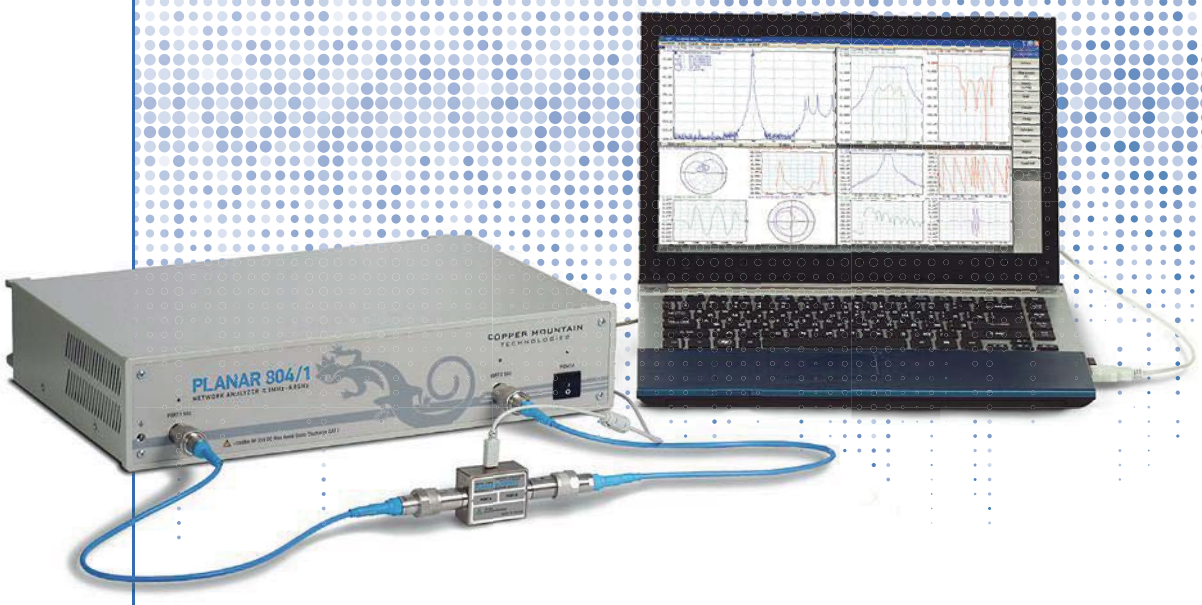

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The new ASIC works with reference frequencies, ranging from 1 MHz to 2.2 GHz, in single- and dual-loop source configurations. In addition to the low phase noise, the phase-locked sources also achieve fast frequency switching speeds, with frequency settling times of less than 100 µs.

In addition to its wide range of source products, Synergy Microwave will display examples of its different component lines, including attenuators, couplers, filters, mixers, and power dividers/combiners. Like the RF/microwave sources, these components come in a variety of package styles, including SMT and coaxial packages. As an example, model CLK-6000 is a double-balanced mixer in a package with connectors. It operates with a local oscillator (LO) and RF range to 6000 MHz, and produces intermediate-frequency (IF) signals from dc to 700 MHz.

For a stable source of RF signals, EM Research (Booth 3636, www.emresearch.com) developed the LX Series of phase-coherent, phased-locked signal sources. One model, the HFS-840-XA *(Fig. 2),* operates at 840 MHz with +13-dBm output power (flat within ±2 dB). It runs from a 10-MHz reference oscillator and controls harmonics to –25 dBc and spurious content to –80 dBc. SSB phase noise is less than –98 dBc/Hz offset 1 kHz from the carrier and less than –118 dBc/Hz offset 10 kHz from the carrier. The tiny signal source measures just 1.25 × 1.00 × 0.24 in. and draws less than 180 mA from a +5-V dc supply.

Peregrine Semiconductor Corp. (Booth 2622; www.psemi.com) plans to educate visitors on the operation of its new PE97240 phase-locked-loop (PLL) synthesizer for applications from 800 MHz to 5 GHz (see "Low-Noise Phase-Locked Loop Extends to 5 GHz," at mwrf.com). Housed in a compact 44-lead ceramic-quad-flat-pack (CQFP) package, the synthesizer includes a prescaler with selectable 5/6 or 10/11 dual-modulus operation. Visitors to the booth can learn more about this source and many others available from Peregrine, along with evaluation circuit boards that help to test the synthesizers *(Fig. 3).*

Voltronics Corp. (Booth 131; www.voltronicscorp.com) will show examples of its miniature non-magnetic trimmer capacitors for commercial, industrial, military, and medical applications. This long-time supplier of trimmer capacitors brings a great deal of expertise to an event like the 2015 IMS Exhibition, helping designers understand how to specify and add trimmer capacitors to different circuit designs requiring precision amounts of adjustable capacitance.

Krytar (Booth 3218; www.krytar.com) will unveil a number of new coaxial couplers for 300-MHz to 50-GHz frequencies, including its model 120406 for use from 4.0 to 12.4 GHz *(Fig. 4).* Ideal for space-restricted applications, the directional coupler supports measurements, monitoring, radar, and other applications. It exhibits nominal coupling of 6 dB with coupling flatness of ±0.5 dB and frequency sensitivity of ±0.3 dB. Typical directivity is better than 15 dB, while insertion loss is less than 1.8 dB.

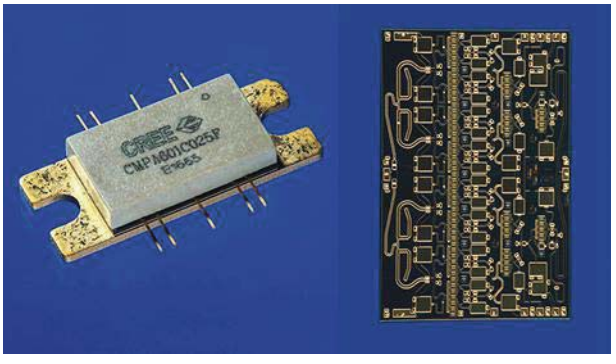
WARM UP THE TUBES

For those interested in how one of the industry's most mature technologies continues to evolve, TMD Technologies LLC (Booth 3623) will bring examples of its traveling-wave-tube (TWT) amplifiers and compact solid-state amplifiers. This is a company that does away with the usual tube-versus-solid-state stereotypes in amplifiers (see p. 116), and instead succeeds in extracting a tremendous amount of power from both compact TWTs and extremely miniature TWT amplifiers (TWTAs). In particular, TMD Technologies will showcase its new PTXM Series of microwave power modules (MPMs), which pack TWTAs and their power supplies into miniature packages. On the flip side, the firm will also display its PTS6900 series of solid-state MPMs.

The PTXM TWT-based MPMs, designed to provide output levels to 140 W from 4.5 to 18.0 GHz, are well suited for pulsed and continuous-wave (CW) broadband applications, such as communications, electronic-warfare (EW), and radar systems that need high transmit-power levels. They are a good fit for unmanned aerial vehicles used in surveillance and radar applications, where low volume and low weight are important.

In contrast to the mature TWT technology in one set of amplifiers, the firm also relies on advanced gallium-nitride (GaN) monolithic-microwave-integrated-circuit (MMIC) technology in its solid-state amplifiers to achieve similar pulsed and CW output-power levels, although across lower frequency ranges. For example, the PTS6900 GaN power amplifier delivers 150-W output power from 2 to 6 GHz, with 55-dB typical gain. The gain can be adjusted over a range from 50 to 60 dB. The amplifiers leverage the latest solid-state GaN amplification by means of low-loss power combiners. Developed to endure the most challenging airborne environments, these GaN MMIC amplifiers feature a predicted mean time before failure (MTBF) of more than 30,000 hours.

Among the solid-state amplifier companies working in GaN technology, Cree (Booth 2636, www.cree.com) will reveal a new 25-W 6- to 12-GHz MMIC amplifier that can be a potential



5. Leveraging of GaN technology has led to the creation of high-power devices like these two versions of a 6- to 12-GHz, 25-W CW MMIC amplifier. *(Photo courtesy of Cree, www.cree.com)*

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replacement for TWTAs. Based on the firm's GaN on silicon-carbide (SiC) semiconductor technology, the new amplifiers are available as a bare die (model CMPA601C025D) or in a thermally enhanced, 10-lead ceramic flange package (model CMPA601C025F). Both amplifier versions *(Fig. 5)* deliver 30% power-added efficiency (PAE) across the bandwidth.

Those looking for live demonstrations at IMS may want to check out Empower RF Systems' (www.empowerrf.com) Booth 3226, which will have compact power amplifiers on display. One of the power amplifiers expected to be in action comes in a 5U chassis measuring just 17.5 × 8.75 × 22 in., yet delivers 1-kW output power from 1 to 3 GHz *(Fig. 6)*. The design includes an internal dual-directional coupler and instrument-grade power meter for keeping track of the power levels. The crew will also show booth visitors how to work their amplifier control software.

6. This high-power amplifier is designed for 1 kW output power from 1 to 3 GHz. *{Photo courtesy of Empower RF Systems, www.empowerrf.com.}*

MACOM (Booth 2839; www.macom.com) will feature many high-power devices and amplifiers, including examples that incorporate its own GaN-on-SiC semiconductor technology. Visitors to the booth can learn more about the models MAGX-000912-650L00 and MAGX-000912-650L0S GaN-on-SiC power transistors in standard flange or earless flange packaging, respectively. Developed for pulsed L-band avionics systems, these depletion-mode power transistors provide 650-W output power from 960 to 1215 MHz. The internally matched devices achieve typical gain of 20 dB with 62% drain efficiency. The +50-V dc transistors are rated for a mean time to failure (MTTF) of more than 600 years, even when subjected to extremely mismatched conditions.

EYEING INTEGRATED CIRCUITS

Maxim Integrated Products (Booth 1915; www.maximintegrated.com) will show a wide variety of IC products, including the latest versions of its MAX2640 and MAX2641 low-noise amplifiers. Based on a silicon-germanium (SiGe) semiconductor device process, these amplifiers come in 6-pin, SOT-23 packages. Suitable for use in Global Positioning System (GPS) and Personal Communications Systems (PCS) applications, the devices boost signals from 300 to 2500 MHz and run from a single +2.7- to +5.5-V dc voltage supply while consuming only 3.5 mA.

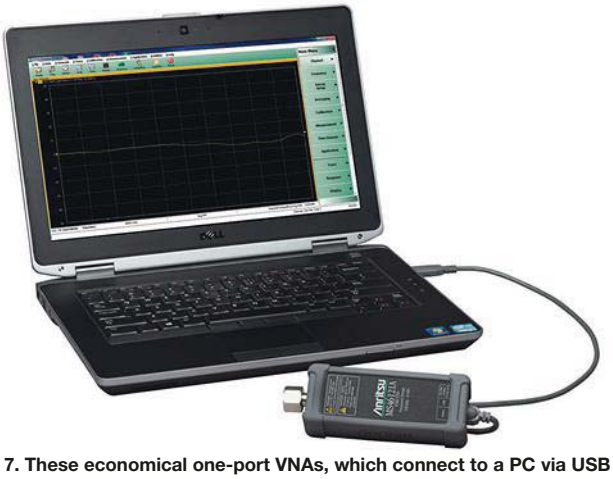
MAX2640 operates from 300 to 1500 MHz; at 900 MHz, it features a 0.9-dB noise figure and 15.1-dB typical gain. The amplifier has a input third-order intercept point of –10 dBm. Model MAX2641 operates from 1400 to 2500 MHz. It has a 1.2-dB noise figure and 15.7-dB gain at 1575 MHz, and a 1.5-dB noise figure and 13.5-dB gain at 2450 MHz. An input third-order intercept point of –4 dBm is applicable for small-signal use.

Hittite Microwave Corp. (Booths 2530 and 3036; www.hittite.com) will display its many high-performance RF/microwave components and subassemblies for commercial and military applications, including several compact amplifier lines. Now a part of Analog Devices, Hittite offers a wide range of amplifiers, such as those for CW applications.

For example, model KHPA-0811 is a miniature X-band amplifier well suited for commercial and military pulsed radar and electronic-warfare (EW) systems. A single amplifier delivers about 2000-W output power from 8 to 11 GHz with pulse widths ranging from 0.05 to 100 µs at duty cycles to 20%. Each amplifier measures just 2.3 × 2.5 in., and four of them can be stacked into a compact housing for 8000-W pulsed X-band output power.

Hittite will also provide some examples of its many switch designs, in chip and packaged form, including the HMC547LP3 and HMC547LP3E broadband single-pole, double-throw (SPDT) switches. These GaAs MESFET switches come in leadless 3 × 3-mm QFN surface-mount packages and handle applications from dc to 20 GHz. They boast better than 50-dB isolation to 5 GHz and more than 45-dB isolation through 15 GHz, with 38 dB typical isolation through 20 GHz. Insertion loss is typically 1.6 dB through 10 GHz and 2 dB or less through 20 GHz.

Among recent developments, "parent" company Analog Devices will provide guidance on the use of its new quad-channel, 2.4-Gsamples/s, 16-b digital-to-analog converter (DAC).



7. These economical one-port VNAs, which connect to a PC via USB cables, use the computer's "intelligence" to make microwave measurements to 6 GHz. *(Photo courtesy of Anritsu Co, www.anritsu.com)*

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The integrated circuit (IC) is designed for processing signals in the 100- to 300-MHz intermediate-frequency (IF) band. Incorporating a PLL circuit and eight-lane JESD204B interface, it was developed to aid designers of multiple-carrier GSM and LTE cellular transmitters for small cellular base stations and military radios. The device supports a single-carrier, 20-MHz LTE bandwidth with adjacent-channel leakage ratio (ACLR) of –76.7 dBc at an IF of 180 MHz.

TESTING IMS WATERS

Making noise (and analyzing it) once again at the 2015 IMS, Noisecom (www.noisecom.com; Booth 2932) will exhibit members from its stable of noise measurement equipment, including the UFX7000A broadband series of noise generators. These noise generators can be equipped with a wide range of frequency options, from 10-Hz to 20-kHz audio frequencies to 2- to 40-GHz millimeter-wave frequencies. Signal output-power levels and output-power flatness vary with frequency. Output-power levels can be as high as +30 dBm at lower frequencies, with as much as 127-dB attenuation control in 1-dB steps.

Looking at noise in a somewhat different way, Noise XT (Booth 3845; www.noiseXT.com) will display examples of its modular instrument lines, including the MSG series of single- and dual-channel signal generators. With models operating to 10 or 20 GHz, these signal generators achieve 0.001-Hz frequency resolution with 100-µs frequency switching speed and excellent spectral purity. Phase noise is specified as better than –132 dBc/Hz offset 1 kHz from a 1-GHz carrier, and better than –138 dBc/Hz offset 10 kHz from a 1-GHz carrier. The firm will also show its PN9000 phase-noise test set, with a standard input frequency range of 2 MHz to 1.8 GHz. It offers a phase-noise floor of –130 dBc/Hz offset 1 Hz from the carrier, –150 dBc/Hz offset 100 Hz from the carrier, and –168 dBc/Hz offset 10 kHz from the carrier.

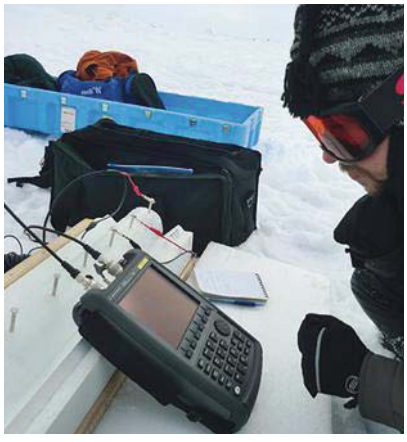
Rohde & Schwarz (Booth 3446; www.rohde-schwarz.com) will provide details on its recently released R&S SGU100A RF upconverter, an accessory that extends the range of the SGS100A vector signal generator (VSG) from a top frequency of 12.75 GHz to a top frequency of 40 GHz. The extension enables the source to provide continuous signals from 10 MHz to 40 GHz without modulation, and from 80 MHz to 40 GHz with vector modulation, packed in a half-rack instrument enclosure. In addition, the firm's R&S SMW200A high-end VSG now features frequency ranges of 100 kHz to 12.75 GHz, 100 kHz to 31.8 GHz, and 100 kHz to 40 GHz.

Huber + Suhner (Booth 3647; www.hubersuhner.com) will come armed with the cables, connectors, and cable assemblies required to reliably connect different parts of test-and-measurement systems. The firm's portfolio of interconnection solutions includes low-loss cable assemblies usable to 40 GHz, and higher frequencies and cable assemblies with low loss of just 1 dB/m at 18 GHz for critical measurement applications.

At Booth 2438, Anritsu Co. (www.anritsu.com) will show selected examples from its wide range of test equipment. These include devices that keep with the test trend of multiple functions in one package. For instance, the MS2830A and MS269xA series instruments combine spectrum analyzers and vector signal analyzers in portable housings, thus facilitating the capture of real-world signals. The analyzers, which provide spectrum analysis bandwidths as wide as 125 MHz at frequencies to 43 GHz, can capture and playback as much as a 100-MHz portion of bandwidth and easily transfer the captured information to equipment in a laboratory for further analysis. The instruments are equipped with 100 Msamples of signal-analyzer memory.

For those on tight budgets, the company will demonstrate its ShockLine MS46121A series of one-port USB VNAs in a compact package *(Fig. 7)*. Powered and controlled via a user-supplied PC, the VNAs are available for measurements from 40 MHz to 4 GHz and 150 kHz to 6 GHz. Multiple VNAs can be run by a single computer connected to a USB hub. The analyzers perform sweeps in only 100 µs/point with directivity of 42 dB for highly accurate measurements. The company's ShockLine software controls the instruments.

In addition, the firm will showcase its new MN4765B optical/electrical (O/E) calibration module for its MS4640B Series



8. The portable FieldFox analyzer, which readily makes measurements to 26.5 GHz in the field, represents just one of the many instruments on display at the upcoming 2015 IMS Exhibition in Phoenix, Ariz. *(Photo courtesy of Keysight Technologies, www.keysight.com)*

VectorStar VNAs in support of measurements through 40 GHz and 40 Gb/s. The calibration module serves as an optical receiver, allowing the VNAs to perform optoelectronic measurements on laser modulators and photoelectric receivers. The O/E calibration module, based on an InGaAs photodiode, helps reduce measurement uncertainty across the VNAs' wide 70-kHz to 70-GHz range.

Anritsu will also detail various options for its MD8475A Network Simulator platform, which supports wireless-local-area-network (WLAN) offload smartphone testing, as a way to characterize mobile telephone products. With the proper options, the test platform simulates real-world cellular communications operation, including WLANs. The system can perform WLAN offload testing with different types of Third Generation Partnership Program (3GPP) wireless products and their interactions between 3GPP and WLAN systems.

Copper Mountain Technologies (Booth 3424; www.coppermountaintech.com) will demonstrate some of its compact and full-sized vector network analyzers, including the Planar 804/1 two-port VNA designed to operate with any Microsoft Windows-based personal computer (PC). Connection to a PC is via a standard Universal Serial Bus (USB) cable. Dynamic range is 145 dB at frequencies to 8 GHz. It can perform linear and logarithmic frequency sweeps, and well as power sweeps from 100 kHz to 8 GHz; power measurements range from –60 to +10 dBm. The compact system measures S_{11}, S_{21}, S_{12}, and S_{22}, and can perform manual or automated measurements for as many as 500,001 measurement points at a speed of 100 µs/point for a 100-dB dynamic range.

The firm will also report on its work with Maury Microwave (Booth 745; www.maurymw.com); in particular, the company's MT981 and MT982 load-pull impedance tuners and IVCAD measurement and modeling software. Maury's tuners and software have been integrated into the Planar 814/1 VNA to perform practical, real-time load-pull measurements. With IVCAD software, the test setup has been used to directly measure the source and load impedances presented to a device under test (DUT), with the goal of developing impedance-matching solutions for circuits such as RF/microwave amplifiers.

Keysight Technologies can usually be expected to draw a healthy crowd to its test-equipment display (Booth 739), since it covers applications ranging from dc and audio testing through millimeter-wave frequencies. The firm will show a diversified mix of test instruments, including some of its latest network analyzers and oscilloscopes (see p. 130).

The company will also offer demonstrations of its versatile FieldFox handheld analyzers, with models capable of making spectrum and vector network measurements across bandwidths as wide as 30 kHz to 26.5 GHz. These battery-powered portable analyzers were put to the test *(Fig. 8)* in hostile environments, and proved to be effective monitors for interference and other measurements made in the great outdoors. Keysight recently offered a new series of application notes and guidance for performing indoor and outdoor cable measurements using the FieldFox analyzers, and will have samples at its show booth. mw

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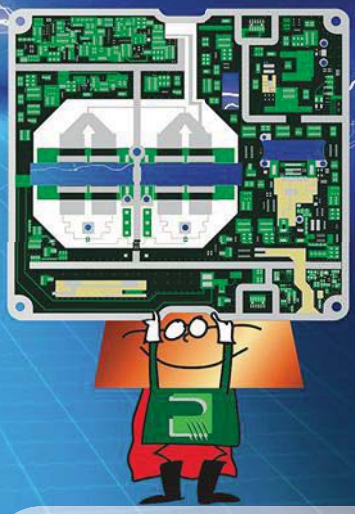

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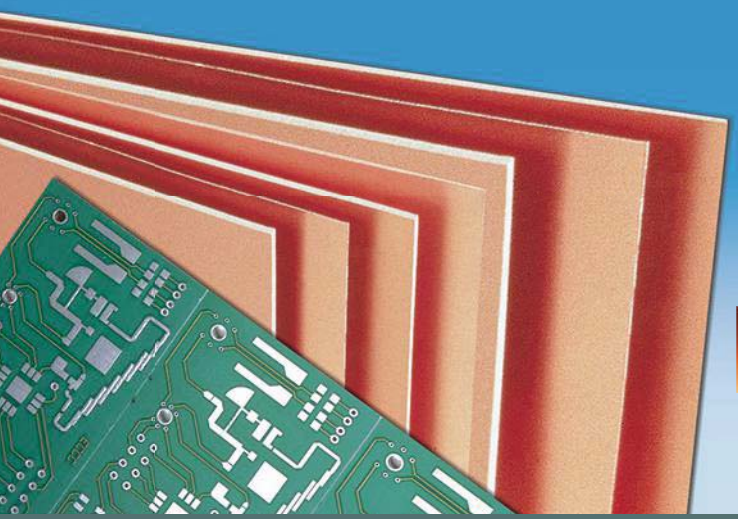

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JEAN-JACQUES DESLISE | Technical Editor

What's the Difference between IEEE 802.11af and 802.11ah?

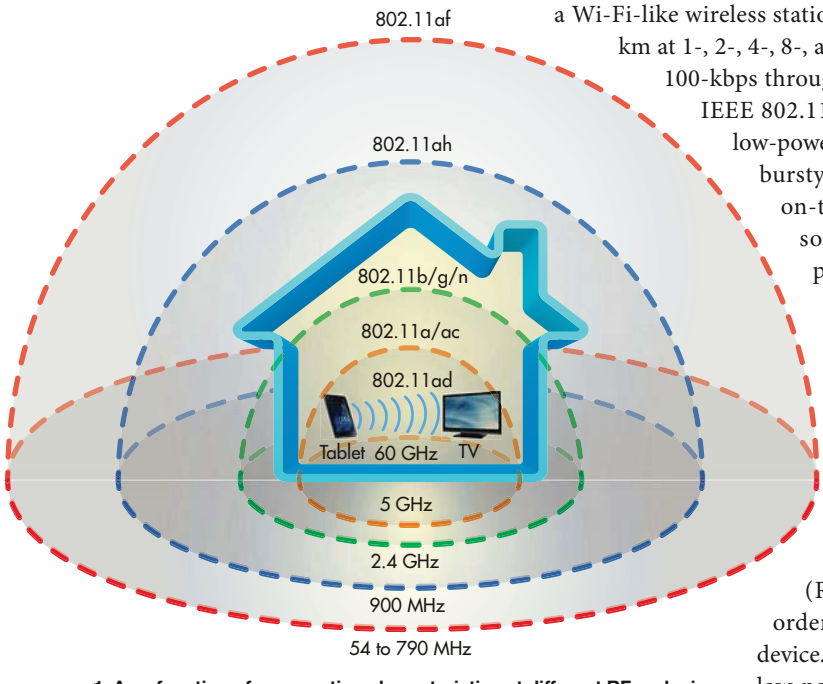
Although IEEE 802.11af and 802.11ah are both sub-1-GHz standards, they are designed to fill different niches in upcoming IoT and wireless-backhaul applications.

THE EMERGING INTERNET OF THINGS (IOT) and machine-to-machine (M2M) communication markets demand wireless networking standards that operate in the sub-1 GHz spectrum, providing long-range and low-power operation. There also is a need to offload the data demands of smartphones and portable electronics from the cellular network. The IEEE 802.11af and 802.11ah standards aim to solve these challenges by offering a Wi-Fi-like experience with reasonable data rates up to and beyond a kilometer. To do so, they occupy different parts of the 1-GHz spectrum and exhibit numerous other differences *(Fig. 1 and Table 1)*.

WHAT IS IEEE 802.11AH?

Making use of the 900-MHz licensed exempt bands could enable long-range and low-power wireless sensor networks (WSNs) and other massive, multiple-node wireless networks based on stations and relays. With IEEE 802.11ah, the concept of a Wi-Fi-like wireless station can be realized. It promises range to 1 km at 1-, 2-, 4-, 8-, and 16-MHz channels with a minimum of 100-kbps throughput *(Fig. 2)*. Maximum throughput for IEEE 802.11ah may reach as high as 40 Mbps. This low-power and low-throughput mode enables short bursty data packets, which enable a very short on-time for remote or battery-powered sensors. The medium-access-control (MAC) protocols of the upcoming standard also enable smaller-frame formats, beaconless paging modes, and sensor traffic priority for lower-power applications.

It is likely that IEEE 802.11ah will use a downsampled version of the IEEE 802.11a/g specifications to service the 26 channels around 900 MHz *(Fig. 3)*. Set to be finalized in early 2016, IEEE 802.11ah makes use of relay access points (RAPs) and network stations (STAs) in order to communicate frames from device to device. This relay function enables intelligent and low-power networking schemes that limit power use through an expansive network. In addition, the modulation and coding scheme (MCS) level



1. As a function of propagation characteristics at different RF and microwave frequencies, the various IEEE 802.11 standards exhibit different range and data-rate features.

can be adjusted based on the quantity of data that needs to be transmitted. To limit energy consumption due to the overhead of relays and hopping, bi-directional hopping will be limited to two exchanges.

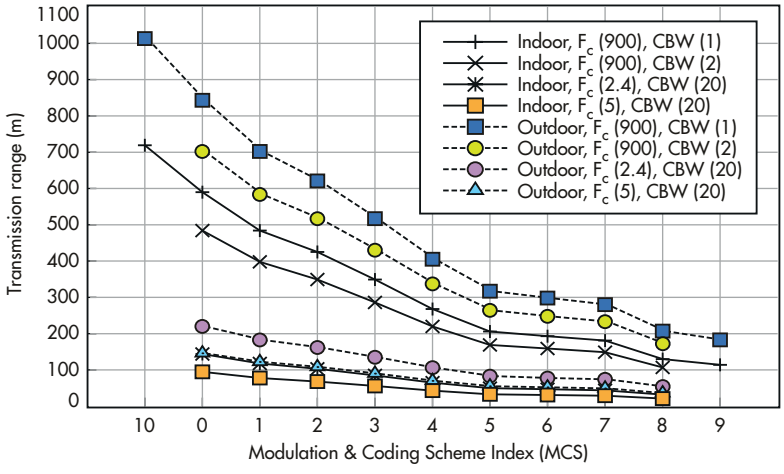
To increase energy efficiency and power savings, the target-wake-time (TWT) function in IEEE 802.11ah permits a routine and scheduled sleep time for each access point and station. The access points are grouped within a basic service set (BSS) along with restricted channel access to a designated group. The goal of this type of partitioning is to prevent multiple transmissions from networks that are unable to see each other. Sectorization can be implemented with electronically controlled antenna beams or a diversified set of antennas.

In the United States, up to 26 MHz of spectrum is available at 900 MHz, enabling up to 16 MHz of bandwidth for the standard. This increased bandwidth enables even higher-data-rate applications if necessary. Additionally, the MAC protocol is designed to account for a massive amount of nodes in an environment with the timing, paging, and sectorization protocols. Given these factors, IEEE 802.11ah can provide an IP-based Wi-Fi-like system for M2M applications with much longer range and better material penetrating frequencies over earlier versions of Wi-Fi. IEEE 802.11ah is now included as part of an amendment to the 802.11REVmc standard with working group approval planned for January 2016.

WHAT IS 802.11AF?

The IEEE 802.11 working group has already formed standards targeting the television white space (TVWS) in the very-high-frequency (VHF) band and lower end of the ultra-high-frequency (UHF) band from 54 to 790 MHz. In February 2014, the IEEE Std 802.11af -2013 amendment was approved, enabling wireless-local-area-network (WLAN) operation in TVWS *(Fig. 4)*. As a product of the legacy analog TV, digital TV, and wireless microphone, this standard requires cognitive-radio functions that limit interference for these "primary" users.

In addition, IEEE 802.11af uses many of the recent operational enhancement techniques adopted by the most recent IEEE 802.11 standards, such as multiple-input multiple-output (MIMO), orthogonal frequency division multiplexing (OFDM), and channel bonding. Specifically, IEEE 802.11af offers the ability to bond up to four of the 6-to-8-MHz-wide



2. More complex modulation and coding schemes can increase throughput while sacrificing range. The lower-frequency IEEE 802.11 standards benefit from better propagation characteristics, although they have less available bandwidth to increase data rates.

TABLE 1: IEEE 802.11 COMMON WIFI STANDARDS BREAKDOWN

Standard	Frequency Band	Bandwidth	Modulation Scheme	Channel Arch.	Maximum Data Rate	Range	Max Transmit Power
802.11	2.4 GHz	20 MHz	BPSK to 256-QAM	DSSS, FHSS	2 Mbps	20 m	100 mW
b	2.4 GHz	21 MHz	BPSK to 256-QAM	CCK, DSSS	11 Mbps	35 m	100 mW
a	5 GHz	22 MHz	BPSK to 256-QAM	OFDM	54 Mbps	35 m	100 mW
g	2.4 GHz	23 MHz	BPSK to 256-QAM	DSSS, OFDM	54 Mbps	70 m	100 mW
n	2.4 GHz, 5 GHz	24 MHz and 40 MHz	BPSK to 256-QAM	OFDM	600 Mbps	70 m	100 mW
ac	5 GHz	20, 40, 80, 80+80= 160 MHz	BPSK to 256-QAM	OFDM	6.93 Gbps	35 m	160 mW
ad	60 GHz	2.16 GHz	BPSK to 64-QAM	SC, OFDM	6.76 Gbps	10 m	10 mW
af	54-790 MHz	6, 7, and 8 MHz	BPSK to 256-QAM	SC, OFDM	26.7 Mbps	>1km ?	100 mW
ah	900 MHz	1, 2, 4, 8, and 16 MHz	BPSK to 256-QAM	SC, OFDM	40 Mbps	1 km	100 mW

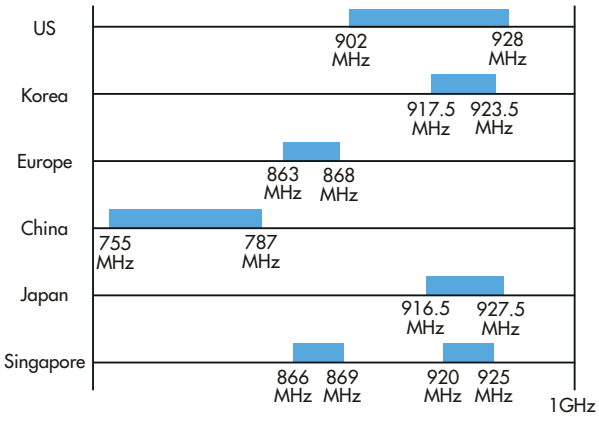
channels (the channel bandwidth depends upon the regulatory domain), which can be blocked into either one or two contiguous blocks *(Table 2)*. Up to four MIMO streams can be implemented in either multi-user (MU-MIMO) or space-time-block-code (STBC) operation.

In terms of data rates, the maximum available data rate per spatial stream for IEEE 802.11af is 35.6 Mbps at an 8-MHz channel bandwidth. The 6- and 7-MHz channel bandwidths are limited to 26.7 Mbps per spatial stream. Each additional spatial stream and bonded channel can theoretically compound-increase the data rate. The 6- and 7-MHz mode—operating with four channels and four MIMO streams—can potentially reach speeds of 426.7 Mbps. Under the same conditions, the 8-MHz mode reaches 568.9 Mbps.

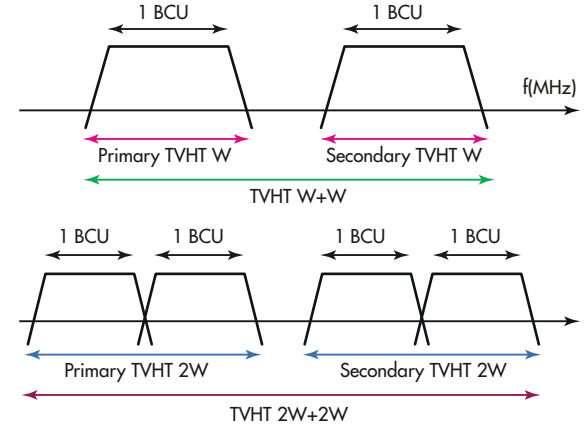
Because IEEE 802.11af channels operate over a wide frequency range, propagation characteristics differ for the various channels. IEEE 802.11af may reach up to 1 km in range at maximum power with a single stream and channel and a lower data rate. This new VHF/UHF standard may be able to offer a reasonable Wi-Fi experience in ranges reaching several hundred meters.

In the United States, only 6-MHz channel bandwidths are permitted in TV channels 2, 5, 6, 14-35, and 38-51 for a maximum of 48 hours of continuous use *(Table 3)*. The U.S. also requires a GPS geolocation query through the Internet, which will update the unit on any regional regulations that are in effect. These features enable IEEE 802.11af to operate in the licensed TVWS bands, although different countries and regions have their own specific regulations.

IEEE 802.11af is being processed for an additional standard revision in the IEEE 802.11 working group letter ballots. This move is part of a revision to IEEE Std P802.11REVmc, which is predicted to gain approval in November 2015.



3. According to the spectrum regulations of individual countries, the exact band occupied by the IEEE 802.11ah standard is adjusted.



4. IEEE 802.11af operates within the old TV white space (TVWS) bands with TV high-throughput (TVHT) physical-layer applications. They combine many TVWS channels for increased data rate over a long range.

TABLE 2: IEEE 802.11AF SINGLE SPATIAL STREAM THEORETICAL THROUGHPUT (IN MBIT/S)

			6 and 7 MHz channels		8 MHz channels	
MCS Index	Modulation	Rate	6 µs GI	3 µs GI	4.5 µs GI	2.25 µs GI
0	BPSK	2-Jan	1.8	2	2.4	2.7
1	QPSK	2-Jan	3.6	4	4.8	5.3
2	QPSK	4-Mar	5.4	6	7.2	8
3	16-QAM	2-Jan	7.2	8	9.6	10.7
4	16-QAM	4-Mar	10.8	12	14.4	16
5	64-QAM	3-Feb	14.4	16	19.2	21.3
6	64-QAM	4-Mar	16.2	18	21.6	24
7	64-QAM	6-May	18	20	24	26.7
8	256-QAM	4-Mar	21.6	24	28.8	32
9	256-QAM	6-May	24	26.7	32	35.6

IEEE 802.11AF VS. IEEE 802.1AH

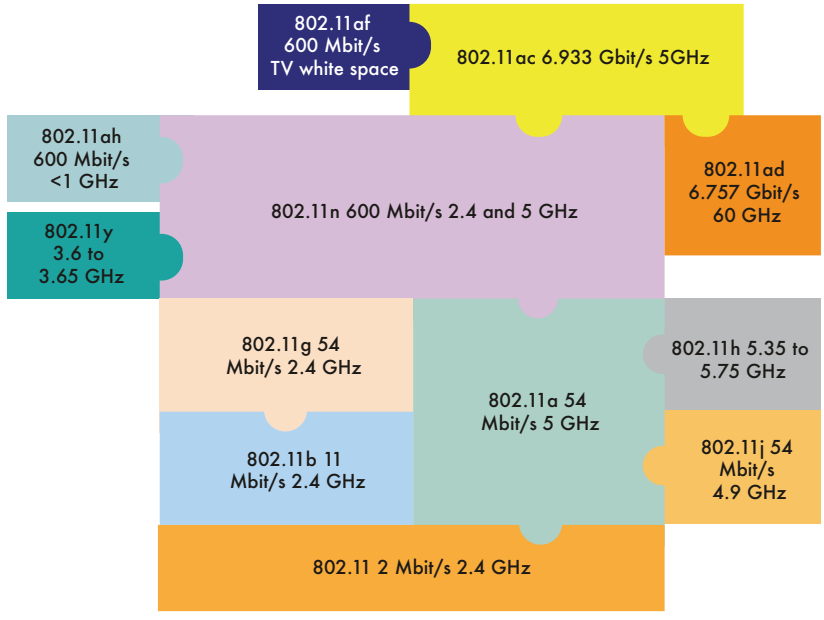
When it comes to the MAC and physical layer (PHY) for IEEE 802.11af and 802.11ah, the most significant differences are derived from a divergence in functional intent and spectrum. IEEE 802.11ah occupies a contiguous block of spectrum in the 900-MHz licensed exempt band. In contrast, IEEE 802.11af occupies many various channels of TVWS in pre-licensed bands. Its operation is limited based on potential regional interference.

IEEE 802.11af is designed to operate more like a traditional Wi-Fi network. Using many of the latest developments, it is able to increase bandwidth over a long-range wireless local-area network (WLAN). In contrast, IEEE 802.11ah is better suited for M2M and IoT applications. It is designed for low-power communication between a wireless network's APs and station nodes.

In terms of transmit power, the new standards will be limited according to the same regulation of 100mW maximum.

Generally, however, IEEE 802.11af will have a longer operating range—especially when operating in the low VHF band. In most regions, IEEE 802.11ah should demonstrate considerably higher throughput in a single stream than IEEE 802.11af. Yet this will not hold true in the United States, where IEEE 802.11af bandwidths can reach 8 MHz. Although single-stream throughput should be higher for IEEE 802.11ah, MIMO and channel-bonding aspects of IEEE 802.11af could enable it to outperform IEEE 802.11ah when multiple antenna or channels are available.

With the different MAC and PHY designs, the IEEE 802.11ah hardware should operate with higher power efficiencies than IEEE 802.11af—even at higher frequencies. In terms of power efficiency, remote and battery-operated applications may benefit more from IEEE 802.11ah than IEEE 802.11af. After all, IEEE 802.11ah can operate in bursty packet nodes and within a field of wireless nodes. Here, data sent by a node will only have to travel to the nearest node, limiting power consumption per bit. The IEEE 802.11ah standard also boasts sectorization, bi-directional transmit opportunity (TXOP), restricted access window, and target wake times, which will help to enable lower-power M2M and IoT WSN applications. Conversely, IEEE 802.11af is optimized to exchange data in a more Wi-Fi-like manner. Its access points send and receive data from remote portable devices, instead of taking IEEE 802.11ah's approach and using other APs and nodes. mw



The various IEEE 802.11 standards have evolved over time adopting techniques, technologies, and protocols from the previous standards.

IEEE 802.11AH GLOBAL FREQUENCY RANGE

Country	Frequency
US	902 to 928 MHz
Korea	917.5 to 923.5 MHz
Europe	863 to 868 MHz
China	755 to 787 MHz
Japan	916.5 to 927.5 MHz
Singapore	866-869 MHz, 920-925 MHz

TABLE 3: IEEE 802.11AF FREQUENCIES AND TV WHITE-SPACE CHANNELS

TV White Space Channel	Lower Frequency	Upper Frequency	Channel Width	Spectrum
2	54 MHz	60 MHz	6 MHz	VHF Low-Band
5	76 MHz	82 MHz	6 MHz	VHF Low-Band
6	82 MHz	88 MHz	6 MHz	VHF Low-Band
14 - 35	470 - 596 MHz	476 - 602 MHz	6 MHz	UHF
38 - 51	614 - 692 MHz	620 - 698 MHz	6 MHz	UHF

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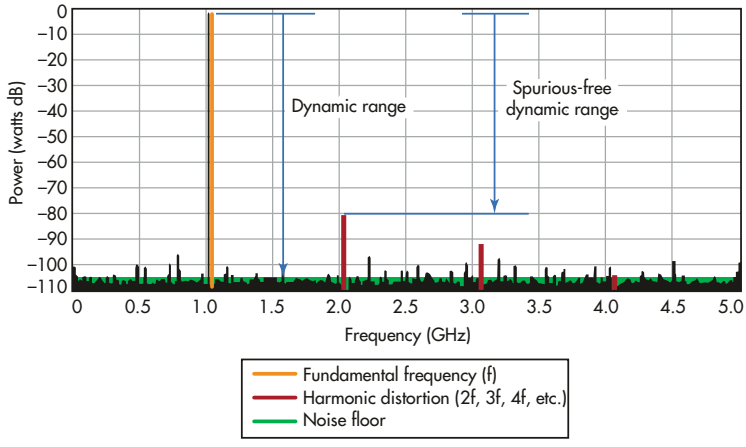
http://standards.ieee.org/getieee802/download/802.19.1-2014.pdf

JEAN-JACQUES DELISLE | Technical Editor

7 Ways to Attack Dynamic-Range Measurement Threats

MAINTAINING ADEQUATE DYNAMIC range in test-and-measurement applications can be a persistent headache. Several techniques help overcome those noise, distortion, high-power level, and ADC imbalance hurdles. By enhancing the dynamic range of a spectrum/signal or network analyzer, an instrument can discover signals well below its typical noise floor. However, every technique generally requires a tradeoff in other performance parameters.

Component and test-equipment manufacturers use various definitions for dynamic range. In essence, dynamic range represents the lowest to highest signal power that a device can operate with or receive *(Fig. 1)*. According to the simplest definition, dynamic range spans the noise floor to the peak power level that can be handled by the receiver while remaining linear.



1. Dynamic range has a fluid definition that depends on the method of noise-floor description. In contrast, spurious-free dynamic range is easily defined between the highest energy points of the signal and dominant harmonic spur.

Several different methods exist for measuring noise floor and how nonlinear—or deep into compression—the receiver can be driven. Developing a solid understanding of the challenges involved in obtaining significant dynamic range, and the methods for enhancing a test's dynamic range, helps engineers fully exploit today's test-and-measurement instruments.

It should be noted that nonlinear distortion products, such as second- and third-harmonic distortion, complicate the definition of dynamic range *(Fig. 2)*. They also limit the lower level at which signals can be received. Among other issues are memory effects, which occur when energy trapped or stored within a portion of the signal chain leads to increased noise factors from residual responses. Phase noise and mixer compression may also affect dynamic range.

For test-and-measurement instruments in particular, one limiting factor for dynamic range concerns the display range (in digital instruments, it's the range of the analog-to-digital converter, or ADC, based on auto-ranging) *(Figs. 3 and 4)*.

MEASUREMENT CHALLENGES

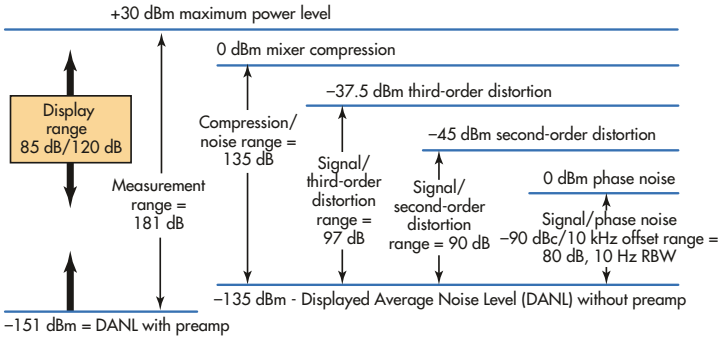
Four main challenges confront engineers when trying to achieve a high level of dynamic range:

Broadband Noise and Noise Floor

A large number of broadband and narrowband noise generators exist in a real-world system. (In this scenario, noise is typically described as anything other than the signal that you desire.) Narrowband noise generators are often deemed interference. On the other hand, broadband noise generators, such as thermal noise, are considered contributors to the noise floor. Noise floor—the power level at which an instrument cannot distinguish a desired signal from the broadband noise—can be measured using one of a handful of variables: root mean-square (RMS) values, mean value of the linear magnitude, mean value of the log magnitude, the lowest noise level, or the peak noise level of the broadband noise.

Phase Noise and Noise Distortion

Phase-noise contributions from either the instrument or the device under test (DUT) combine with the system's broadband noise to increase the effective noise floor. Phase noise also can



2. Depending on the noise generators in an environment, effects like compression, harmonics, and phase noise could be the limiting factors when measuring dynamic range.

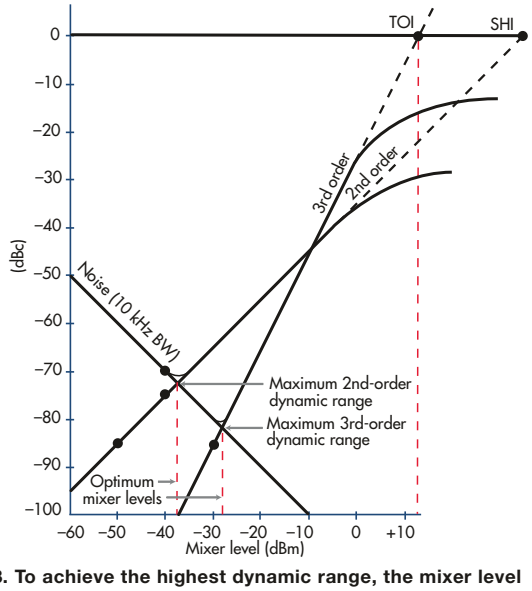
mask distortion products and increase measurement inaccuracies, as it spreads the signal's sidebands beyond the resolution bandwidth (RBW). This latter effect will ultimately limit the narrowness of the RBW setting used to reduce the noise floor.

On a dynamic-range chart, phase noise increases the displayed average noise level (DANL) and distortion relative to the mixer level *(Fig. 5)*. The broadband and phase noise affect the distortion products as they do the desired signal. Distortion noise appears on a dynamic-range chart as a web between the noise line and the second- and third-order distortion lines. Ultimately, phase noise impacts both the signal-to-noise ratio (SNR) and the spurious-free dynamic range (SFDR). It is somewhat misleadingly reported in a spectrum-analzyer display, because the displayed signal also includes the broadband noise power and phase-noise variations.

Mixer or Reference Level

For highly linear DUTs, maintaining a low mixer level will keep the mixer's distortion products under the DUT's distortion level. Although it may not impact the DUT's linearity, a lower mixer level does reduce overall dynamic range and the relative height of the noise floor at the front end of a spectrum/signal analyzer *(Fig. 6)*.

Dynamic range can be maximized by keeping the mixer level low enough to avoid compression and cause distortion. At the same time, the power input into the mixer must be optimized. Interestingly, the distortion noise shifts the optimum point of the mixer level to achieve the maximum dynamic range. Essentially, the "webbing" effect of distortion noise on a dynamic-range chart shifts the lowest DANL and distortion point relative to the mixer level. They are moved slightly away from the intersection of the noise and harmonic distortion lines.



3. To achieve the highest dynamic range, the mixer level should be set so that the noise and harmonic intercepts are at their lowest point.

Second- and Third-Harmonic Distortion

DUT or instrument nonlinearities can induce harmonic distortions that impact the signal's dynamic range. Therefore, one should consider second-order and two-tone third-order harmonics. The greater nonlinear response of a mixer, instrument, DUT, or preamplifier will no doubt increase the strength of the harmonic distortion signals.

Effectively, this scenario limits the test's dynamic range with respect to the harmonic spurs. This is commonly referred to as SFDR, after the spurious frequency content of the harmonic distortion. The system's broadband and phase noise also contribute to the power level and frequency spread of the harmonic signals, exacerbating degradation of the dynamic range. If the RBW is significantly narrow compared to the frequency spread of the spurs' sideband, it could trigger amplitude errors.

SOLUTIONS THAT MEASURE UP

Clever engineers continue to discover and design methods to minimize or knock down those dynamic-range measurement hurdles. Seven approaches particularly stand out:

Averaging or Smoothing

For many signals, the noise floor and noise contribution to the signal power vary randomly. As a result, taking the accumulated average of multiple measurements can reduce the variance in the signal response while decreasing the noise floor. The number of sweeps and sweep time scales with the amount of averaging, though. In contrast, smoothing uses an average of adjacent points of the pre-formatted data, reducing peak-to-peak noise in a way that's similar to video filtering. Smoothing cannot reduce the noise floor.

Point or trace averaging typically embraces one of two methods. Bucket, or point averaging, accumulates and averages the measured results over many sweeps at a single point or bucket. Averaging, in contrast, generally reduces the variance of the measurement, and can be coupled with other methods to increase dynamic range. In addition, averaging helps compensate for several other noise-reduction techniques that have a tendency to exacerbate

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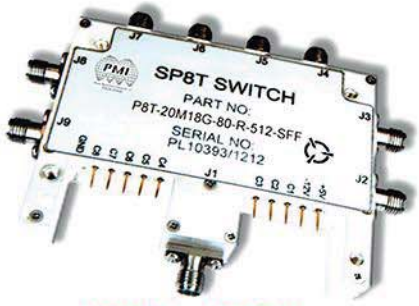
- +5V, 285mA & -5V, 45mA
- TTL Control with SMC Connectors
- 1.5" Diameter, 0.7" Height



12MHz to 18.0 GHz
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- 125nsec Switching Speed
- Independent TTL Control
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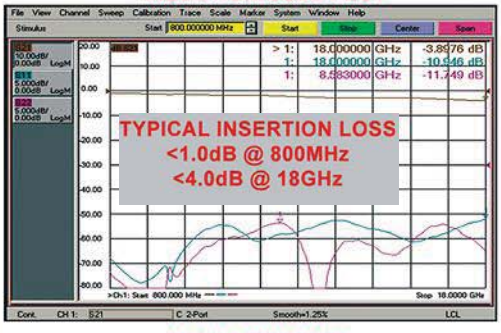
- 2.835" x 2.126" x 0.492"

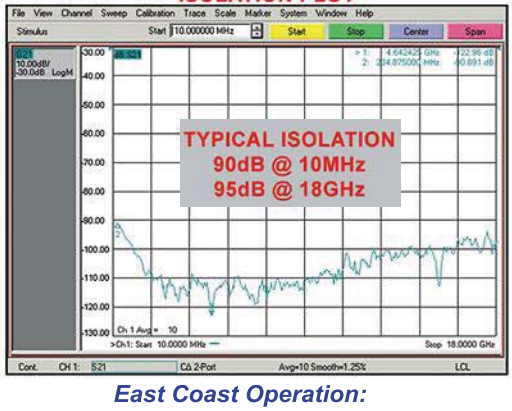
INSERTION LOSS PLOT



INSERTION LOSS PLOT

ISOLATION PLOT

ISOLATION PLOT



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the amplitude and phase, as well as frequency variance.

RBW Reduction

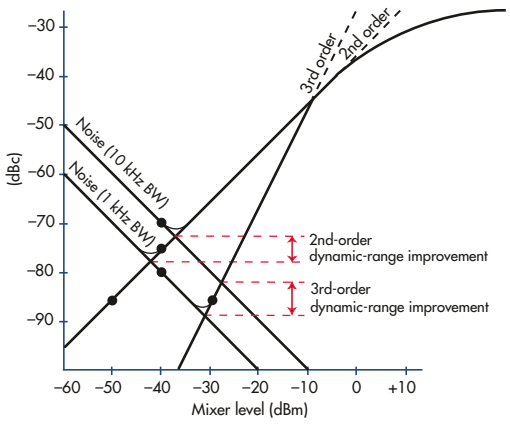
When a narrower resolution bandwidth is used with a signal analyzer, it decreases the 3- and 60-dB bandwidth. This, in turn, increases the frequency resolution and drops the average noise level. With higher-frequency resolution and a lower average noise level, one can observe lower-power signals—albeit in a limited bandwidth.

If the sidebands of modulated signals extend beyond the RBW setting, however, limiting the RBW bandwidth could degrade measurement accuracy. Reducing the signal analyzer's RBW may diminish the noise contribution that's internal to the instrument, as well as the system noise. If information on the device's noise performance is of interest, this method will also cut the apparent noise level of the signal, along with the signal analyzer's displayed average noise level (DANL). An additional drawback of decreasing the RBW is increased measurement sweep time.

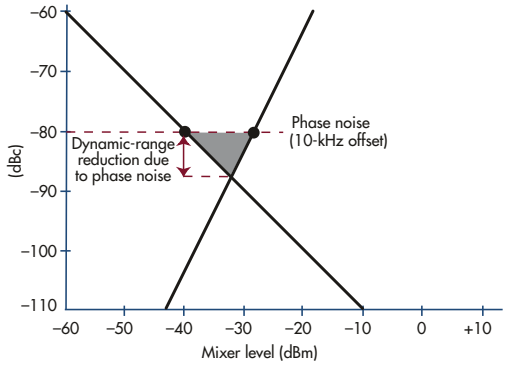
When working with continuous-wave (CW) signals, it's critical to compare the resolution bandwidth to the width of the display bucket. If the display bucket is greater than the RBW, a CW signal's peak will suffer a scalloping error. To reduce the variance, a "normal" detector can be used with a narrow video-bandwidth (VBW) setting along with trace averaging. Care must be taken to avoid averaging the residual phase noise, amplitude modulation, or frequency modulation, thus spreading the signal beyond the RBW.

Noise Correction

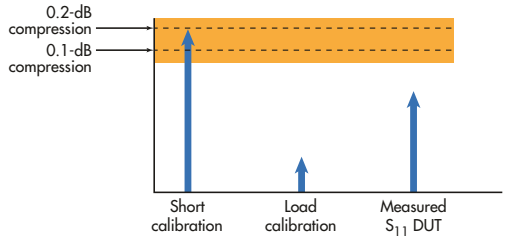
Noise correction is another feature designed to enhance a signal analyzer's noise-floor response. To lower the noise floor, one would need to measure or model the instrument's noise power and then subtract from the total measured noise power. Such an effect can significantly increase the dynamic range, depending on the noise power of the signal analyzer.



4. Averaging over a narrower bandwidth can reduce noise-level measurement in the device. This approach enhances dynamic range at the cost of slower sweep speeds.



5. Phase noise adds degradation to dynamic range—even at optimum mixer levels—for noise and harmonic content.



6. Performing VNA calibration at power levels where the receiver may reach its compression point will add nonlinear effects to the calibration reference.

Dynamic-range benefits were possible with older methods, but noise measurements had to be performed within every measurement cycle. The latest correction method exploits key noise characteristics that are measured during the manufacturer's calibration. With those measurements, it creates a noise model that can be actively subtracted from the measured noise power in real time.

The repetitive measurement-and-noise-correction approach remains the most accurate method of removing internal noise and increasing the low end of the dynamic range. Neither noise-correction method can completely remove the instrument's noise contribution—the exact contribution is not known. Unfortunately, noise correction does raise the uncertainty around the processed measurements and their variations. Fortunately, averaging can aid in mitigating some of the variance introduced by noise correction.

Segmented Sweep

Some network analyzers carry an option that subdivides a frequency sweep into several segments with its own measurement parameters. The segmented sweep's adjustable parameters include the number of sweep points, start/stop frequency, RBW, and source power level. This method is able to adjust the RBW more widely during high-power signals and lower it during low-power signals.

Overall, segmented sweeping enhances the sweep speed while maintaining a high dynamic range for DUTs that require simultaneous high-power and low-power measurements in different frequencies.

Configuring Test-Port Source Power Level

When a network analyzer is calibrated, any nonlinearity in the receiver response will introduce inaccuracies during measurement. This concept becomes especially critical when adjusting the network analyzer's power level for optimum dynamic range. Ideally, the network analyzer's signal power level should

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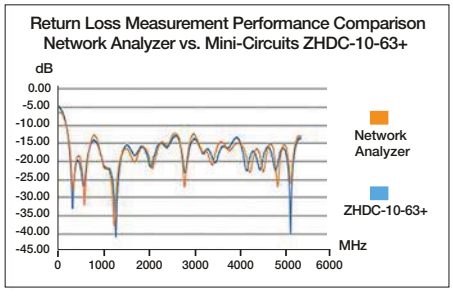

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be substantially below the 0.1-dB compression point to avoid linearity errors. A DUT's insertion loss may reduce the source power to less than the 0.1-dB compression point of the receiver. During a full calibration, however, the short calibration will induce reflections that may push the signal power beyond the 0.1-dB point, which results in linearity errors. Note that test-cable losses can also be considered when calculating the optimal source power level, as these cables are present in both calibration and testing.

Network Analyzers with Direct Receiver Input

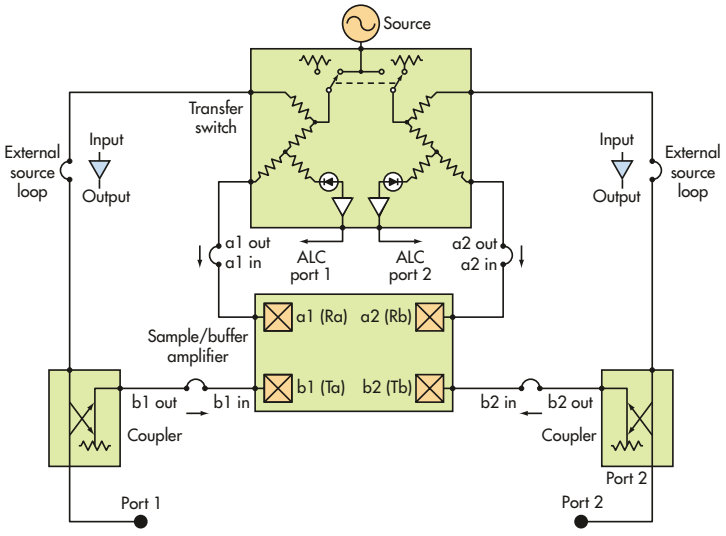
A receiver's couplers can be bypassed in specific testing applications, and in network analyzers with a direct receiver input. This approach eliminates the coupler's losses in the signal chain. The direct-access loop approach can reduce insertion loss to the receiver beyond 10 dB. In doing so, it enhances the test system's noise-floor performance. If direct access to the source power is available, it may be amplified to enhance the power observed by the DUT *(Fig. 7)*. Consequently, the signal level seen at the receiver may rise.

Care must be taken to avoid compressing the receiver with a power signal that wouldn't drive the receiver into compression under non-bypassed conditions. Port mismatch is another consideration when bypassing network-analyzer couplers. A full calibration may not be performed in some testing situations, which may lead to mismatches that ultimately increase measurement uncertainty.

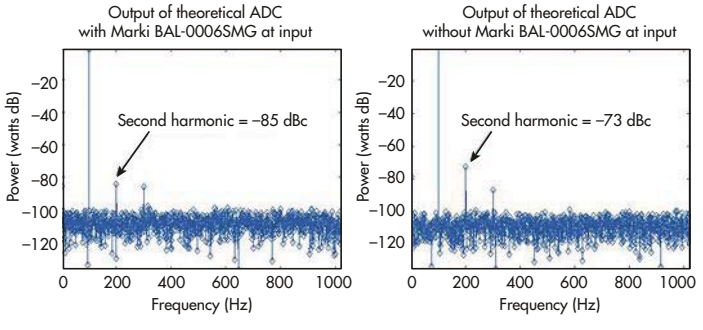
Use of Quality Baluns or Transformers

Many applications that require digitized signals used analog-to-digital converters. With high-speed ADCs, the converter's nonlinear response induces harmonic responses in its output. In this case, it's possible to enhance the dynamic range of a differential ADC and reduce the second harmonic spur's SFDR limitation *(Fig. 8)*.

Essentially, a well-balanced balun/transformer can be placed in the signal chain before the ADC. It's critical to ensure that the phase balance of the balun/transformer is as tight as possible. After all, any phase imbalance will induce distortion that's proportional to the squared amplitude of the input signal. This technique obviously limits the converter's frequency response to the bandwidth of the balun/transformer. Any insertion or return loss introduced by the balun/transformer will shrink dynamic range while increasing distortion. mw



7. The internal coupler bypass eliminates the couplers' insertion loss, effectively increasing VNA dynamic range under specific test circumstances.



8. A well-balanced balun/transformer placed in the front end of a differential analog-to-digital converter can reduce the second harmonics in the ADC output. ***(Courtesy of Marki Microwave)***

ADDITIONAL RESOURCES

Why Buy A High Quality Balun/Transformer For An Analog To Digital Converter (ADC)?
http://www.markimicrowave.com/blog/2013/07/why-buy-a-high-quality-baluntransformer-for-an-analog-to-digital-converter-adc/

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Dynamic Signal Acquisition Fundamentals
http://www.ni.com/white-paper/12349/en/

Dither Can Boost Sampled Data System Performance By At Least 10 dB
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Understanding Your Signal Analyzer's "Dynamic Range"
http://electronicdesign.com/community-home/understanding-your-signal-analyzer-s-dynamic-range

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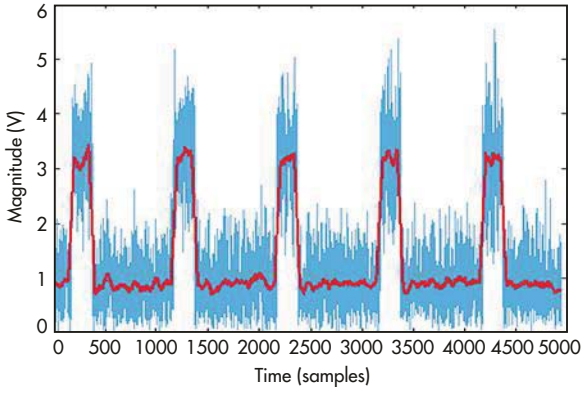
Measuring Modern Pulsed Radar

Measurements in the frequency domain and time domain with spectrum analyzers and oscilloscopes can help evaluate the pulsed signals found in modern radar systems.

Radar technology was once mainly the domain of military users, but it continues to expand into instruments for weather, automotive safety, and even astronomy. Measurements of radar systems are as important as ever, especially as these systems impact so many different applications.

Fortunately, improvements in test instruments and measurement techniques have made it possible to accurately measure, analyze, and troubleshoot radar systems with many different signal types—both in the frequency and time domains—to help achieve and maintain optimum performance levels in these radar systems.

Traditionally, radar measurements have required the use of oscilloscope and crystal detector for time domain parameters and a spectrum analyzer for frequency-domain parameters. Measurements were made on pulsed signals and depended on the type of radar system. They involved measurements of pulse width—plus pulse repetition interval (PRI) or pulse repetition frequency (PRF)—along with such parameters as signal amplitude, noise, and interference (depending upon the functions of the particular radar under test).



1. Modern pulse analysis methods speed up the process of pulse measurement by using powerful statistical algorithms such as Moving Average.

Modern radar systems continue to evolve, with improvements in range, resolution, and immunity to interference. This has made it possible for radar engineers to employ a wide variety of modulation techniques that were previously unavailable. Along with the growing complexity and sophistication of modern radar systems, the measurement systems for evaluating those systems also become more complex. Accordingly, it is important to keep track of which test systems and capabilities are needed for evaluating different radar systems, since many lives depend upon these systems.

Traditionally, the signals being evaluated during testing of a pulsed radar transmitter consisted of a steady stream of pulses. This may not be the case in modern radar systems, as pulses are generated in a number of different ways in newer systems. Modern radar designs typically strive to transmit pulses at minimum power levels while receiving return signals at greatly reduced levels.

A number of different techniques may be used in the process, including the use of modulating pulses to achieve pulse compression, varying the PRI to eliminate range-gate blind spots, and using narrow or frequency-chirped pulses. New test equipment is needed to evaluate a growing number of radar system parameters, with such capabilities as segmented acquisition memory, streamed recording, and advanced triggering techniques. Fortunately, the latest generations of spectrum analyzers and oscilloscopes have been designed to meet the measurement needs of both new and emerging radar systems.

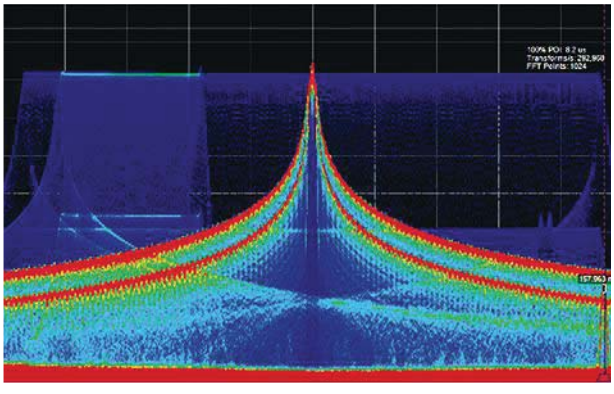
Some modern radar measurements are more appropriate in the frequency domain, while others are better made in the time domain; some may require the use of testing in both domains. Frequency-domain testing with a spectrum

Signals

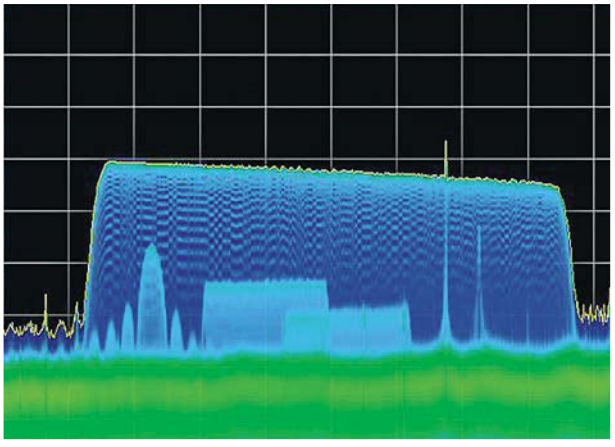
analyzer may include testing for out-of-band spurious emissions, which can be caused by many parts of a radar system [including digital-signal-processing (DSP) and control software]. Spurious signals can also be caused by hardware. Spectrum measurements of transmitted signals help detect transients and memory effects. Spectrum analyzer measurements also measure signal power levels which involve a channel of interest and adjacent channels as well as the behavior of frequency-hopped signals.

Single-pulse measurements are commonly performed in the time domain, with an oscilloscope, to evaluate the quality of individual pulses. Time-domain testing is also performed for pulse-width and PRI measurements, rise/fall-time measurements, and analysis of analog modulation.

Many modern radar transmitters may require multiple-pulse testing to reveal differences between the individual pulses that can cause false or "blurred" radar readings. This can be achieved via parametric trend analysis, whereby measurements are parameterized so that all linear measurements



2. Some modern test instruments can process and analyze up to 390,625 spectrums/s.



3. Real-time visualization tools make it possible to observe infrequently occurring defects or low power signals "hiding" within other signals.

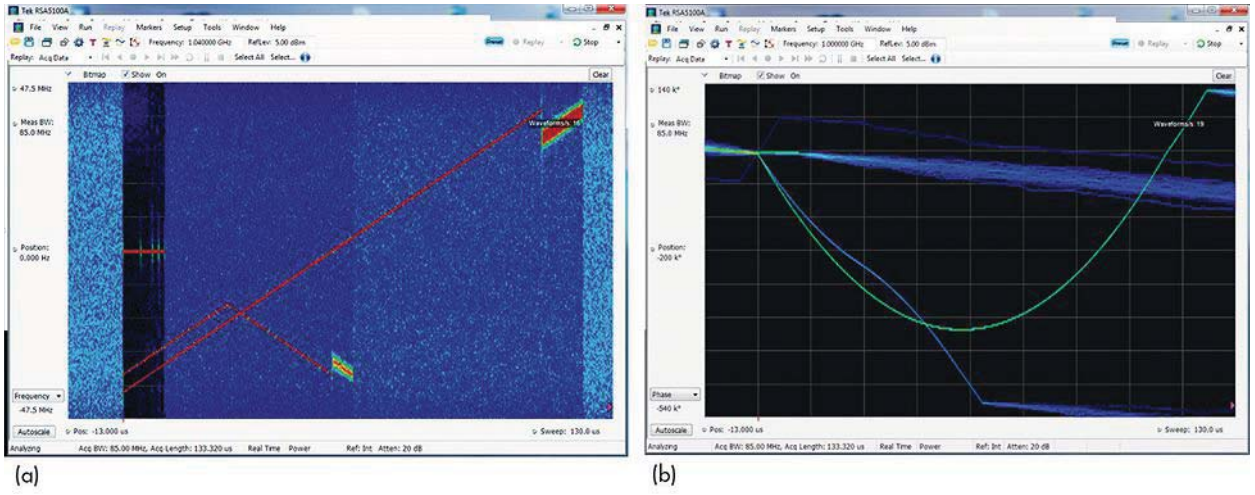
can be made on a common pulse model. Once the model has been determined, parameters for each pulse can be measured.

Linear radar pulse measurements that can be made with this model include rise and fall times, PRI, and pulse width. Statistical analysis is then applied to calculate variations in the ensemble of detected pulses. Pulse-to-pulse trends, histograms, and even frequency-domain analysis can be applied to highlight potential problems in a radar system.

Since finding a radar pulse can be an algorithm-intensive process, increased computing power is needed for modern pulse measurement solutions. This is especially true when measuring pulses over a wide range of amplitudes, since noise can make it difficult to detect and analyze pulses at lower amplitude levels.

For standard pulse-detection algorithms, a basic tradeoff exists between reliability and speed. Greater reliability means that the algorithm takes a longer time to complete—even though the pulse measurements may operate only on data already stored in memory. Modern pulse analysis methods speed up the process of characterizing transmitter designs by taking advantage of the increased computing power of modern test and instruments, with their capabilities to quickly crunch through multiple algorithms.

For example, one method applies four separate algorithms to perform pulse detection: Magnitude Histogram, Local Statistics, Moving Average (as shown in *Fig. 1*), and Least Squares Carrier Fit. Each of these algorithms is within the DSP



4. Modern instruments can display amplitude, frequency and phase versus time in real time, revealing otherwise hard-to-see system artifacts. On the left, the frequency-versus-time display of an up-chirp, up-down chirp, and modulated chirp can be seen. On the right, a phase-versus-time display for the same pulses shows a different phase view.

circuitry of the test instrument one at a time, with the simplest and fastest to perform first. If a pulse is found at any time, the process ends. This method ensures that a pulse is detected and its amplitude measured as accurately (and quickly) as possible.

Powerful test instruments are required to efficiently and quickly run such algorithms. Many of today's high-performance spectrum analyzers include advanced algorithms like these on board. Often they have built-in tools for making dozens of measurements automatically on each pulse. These include new measurements, such as impulse-response (also known as time sidelobe) and delta frequency measurements. Many modern high-performance spectrum analyzers also include new statistics capabilities, such as pulse trending and histogram analysis, to better understand variations in pulse parameters.

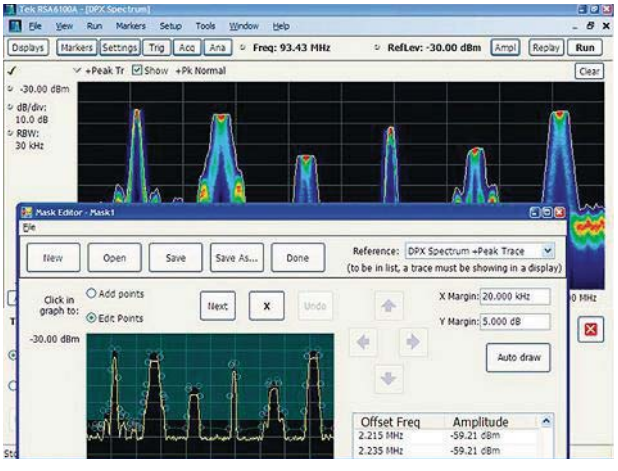
Some modern spectrum analyzers provide the rapid processing power to analyze as many as 390,625 spectrums/s *(Fig. 2)*. In addition, some time-domain visualization tools contained within modern spectrum analyzers can analyze as many as 50,000 time records/s to provide another high-speed method for analyzing radar pulses.

Real-time spectrum analyzers provide the means of measuring rapidly changing signals, such as signals that mat change in real time. This latest-generation of spectrum analyzers samples incoming RF/microwave spectrum for analysis in the time domain and converts the input signal information to the frequency domain by means of Fast Fourier Transform (FFT). Real-time spectrum analyzers can make it possible to observe signals that are difficult to detect with a standard spectrum analyzer, such as infrequently occurring signals or low-power signals that are nearby other signals within a spectrum of interest.

As an example, *Fig. 3* shows a swept DPX display spanning several gigahertz. The display reveals a large low-frequency-modulated (LFM) chirp pulse, as well as (left to right) a lower-power continuous-wave (CW) pulse, two even lower-power LFM chirps, and three other pulsed signals.

For time-domain analysis of pulsed signals, displays are available in modern instruments for showing amplitude, frequency, and phase versus time in real time *(Fig. 4)*. Such display capabilities make it possible to visualize many signal artifacts not readily apparent in a frequency-domain view.

In addition, some present-day test equipment provides the capability to correction frequency- and time-domain displays in one package, essentially combining a spectrum analyzer



5. Advanced triggering capabilities make it possible to use numerous trigger qualifiers across time, frequency, and amplitude parameters. The frequency-mask trigger shown here can act as user-defined monitor for multiple frequencies.

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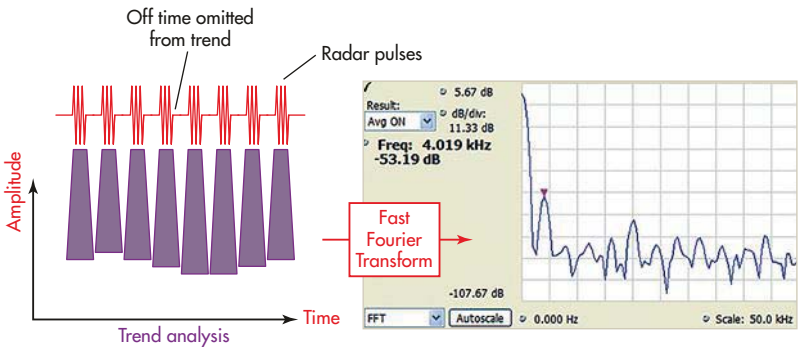

6. Amplitude trend data was converted from the time domain into the frequency domain via FFT. The spectral view shows 4-kHz modulation, so it is probably not from the incoming power.

and an oscilloscope within a single instrument enclosure. To correlate the measurements of time and frequency in real time, a measurement system is needed with appropriate sample rates, bandwidth, and memory depth that can be applied to fully characterize pulsed radar systems.

Once a signal artifact has been detected visually, triggering can be used to isolate it so that further analysis can be made. For long signal acquisitions, triggering makes use of the acquisition memory more efficiently. This is especially true for pulsed RF/microwave signals, since the "off" time is rarely used, although it almost always makes up a majority of the signal playback time. Advanced triggering capabilities in modern instruments make it possible to trigger on signals within signals, as well as to use numerous trigger qualifiers across different time, frequency, and amplitude parameters.

Having access to more trigger types can simplify the evaluation of complex signal effects. As shown in *Fig. 5*, a frequency-mask trigger (FMT) can act as user-defined monitor for multiple frequencies. Time-qualified triggering provides a way to trigger on events of specific user-defined duration. Along with hold-off features, this can help eliminate false triggering.

Frequency-edge triggers are very useful because they not only serve real-time testing by triggering real-time measurements, but enable all of the other measurements in an oscilloscope. Using different types of triggers with trigger input and output signals can make it possible to synchronize

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multiple signal instances in a radar system.

Modern real-time spectrum analyzers and software provide the means for capturing "runt" pulses, which are transient signals buried among larger signals within a bandwidth or short pulses found within a string of longer pulses. Runt pulses often overlap in time and frequency with the desired signal, making them especially hard to trap and separate.

An amplitude-qualified trigger provides the capability to capture runt signals, since an analyzer with this type of trigger can isolate pulses of specific amplitude and/or width within a pulse train. Advanced triggering capabilities make it possible to detect transient signals in many radar systems.

Modern statistical methods can be applied to explore the nature of a pulse's modulation and reveal information about its source. This is often done by converting amplitude trend data from the time domain to the frequency domain via FFT. The spectral view can show whether modulation occurs at a single frequency or is at multiple frequencies.

> "For standard pulse-detection algorithms, a basic tradeoff exists between reliability and speed. Greater reliability means that the algorithm takes a longer time to complete—even though the pulse measurements may operate only on data already stored in memory."

An FFT performed on pulse signals and the instrument's spectral view of the amplitude trend data reveal 4-kHz modulation on a pulse *(Fig. 6)*. The low modulation frequency means that it is not coming from incoming power, but more likely a switching power supply.

Modern radar systems continue to grow in complexity, and so, too, must the measurement solutions for these systems. But modern spectrum analyzers and oscilloscopes use a variety of new methods that let them accurately measure, test, analyze, and troubleshoot systems with varying signals. Such techniques employing real-time analyzers and the use of test software can greatly help to simplify these challenging measurements of pulsed signals, both in the frequency and time domains. MW

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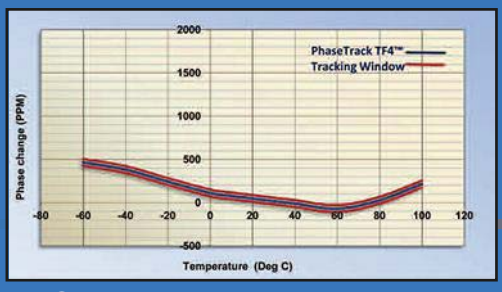

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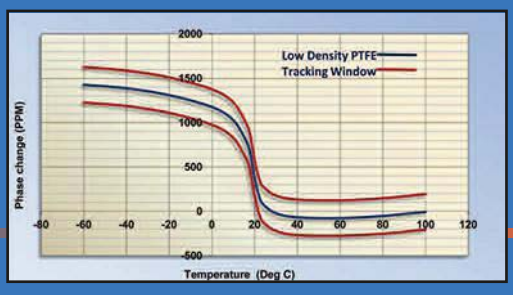

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PLL Synthesizer Provides Fast Locking

A dual charge-pump structure combined with a dynamic loop-bandwidth technique serves to improve the phase-locking performance of a 1.4- to1.6-GHz frequency synthesizer.

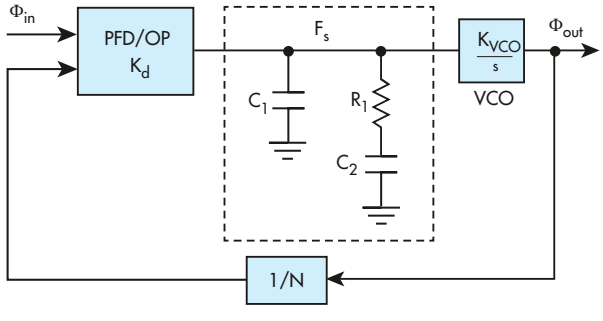
Frequency synthesizer lock time is a key parameter in many systems, especially for those in which frequency tuning speed is essential. Short lock times translate into fast tuning speeds and help make signals difficult to track—an important attribute in many military and business operations.

In pursuit of fast locking time, a simplified phase-locked-loop (PLL) frequency synthesizer was developed. It provides low phase noise and low spurious levels based on a dynamic loop-bandwidth technique which has a controllable charge-pump current and dual-charge-pump structure. Its lock time is just 4.8 µs. The phase noise ranges from −100 to −105 dBc/Hz within the loop bandwidth, with spurious suppression of better than −63 dBc for the frequency band of 1.4 to 1.6 GHz.

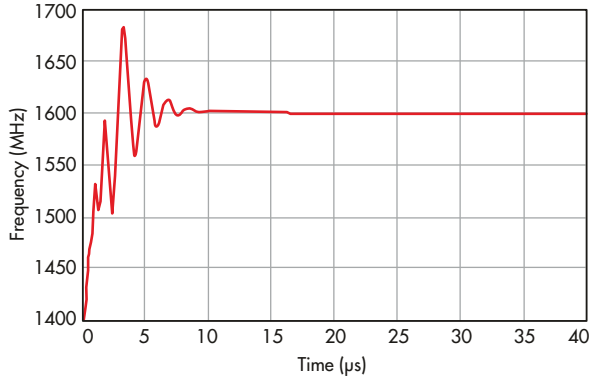
There are several ways to boost the locking speed of a PLL frequency synthesizer. The preset voltage technique can provide a preset tuning voltage for the synthesizer's voltage-controlled oscillator (VCO) to tune the oscillator's output frequency closer to the target frequency and reduce the total time needed for tuning to that target frequency. Because the speed of lookup functions and digital-to-analog-converter (DAC) circuits are in the range of nanoseconds—much faster than the typical locking time of PLLs, which is in the range of microseconds—the preset voltage technique is, in theory, the fastest method available.

However, the control module used with the PLL preset voltage technique is very complex, which can mean increased cost and larger circuit size. The dynamic loop bandwidth technique changes the loop bandwidth in different stages. It can boost the locking speed while achieving low phase noise and low spurious levels. Yet, switching the loop bandwidth can introduce frequency jitter, which may increase the locking time; the loop bandwidth is limited by the phase comparison frequency of this approach.

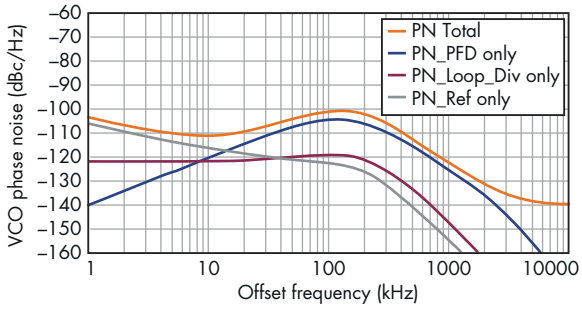
The fractional-N technique uses a higher phase comparison frequency which means a wide loop bandwidth and lower division ratio than for an integer-N frequency synthesizer.[1] This approach enables low-frequency phase noise to be suppressed to a high degree.[2,3] For optimum performance and fast locking times, the fractional-N and dynamic loop bandwidth techniques were combined. The sigma-delta technique can be applied to



1. This block diagram represents a simplified PLL system with second-order loop filter.



2. The plot is a simulation of PLL synthesizer locking time with a model ADF4154 as the phase-frequency detector (PFD).



3. The plot is a simulation of PLL synthesizer phase noise with a model ADF4154 as the PFD.

help suppress fractional spurious levels, meaning a wider loop bandwidth can be used under steady-state conditions to speed the locking time even more.[4,5]

To better understand the dynamic loop bandwidth method for speeding the tuning time of PLL frequency synthesizers, it is necessary to review the relationship between synthesizer loop bandwidth and PLL locking time. A nonlinear relationship describing the loop module is needed to accurately calculate the locking time. Based on a simplified PLL system *(Fig. 1)*, the transmission function of the loop's low-pass filter can be found from Eq. 1:

$$F(s)=\frac{1+sC_2R_2}{s(C_1+C_2)(1+s\frac{C_1C_2R_1}{C_1+C_2})}=\frac{1+sT}{sA_0(1+s\frac{A_1}{A_0})} \quad (1)$$

where

$A_0 = C_1 + C_2$;
$A_1 = C_1C_2R_1$; and
$T = R_1C_2$.

Because the high-order term has little impact, the system transmission function can be simplified to the relationship of Eq. 2:

$$H(s)\approx\frac{KTs+K}{A_0s^2+\frac{T_2K}{N}s+\frac{K}{N}}=\frac{2N\xi\omega_n s+N\omega_n^2}{s^2+2\xi\omega_n s+\omega_n^2} \quad (2)$$

with

$$(\omega_n=\sqrt{\frac{K}{A_0N}},\ \xi=\frac{T}{2}\omega_n)$$

The locking time for closing the loop[6] can be found from Eq. 3:

$$t_{lock}=\frac{2}{\omega_{BW}}\ln\frac{\Delta f}{(f_1+\Delta f)|\alpha|} \quad (3)$$

The loop bandwidth of the second-order filter is $\omega_{BW} = 2\zeta\omega_n$, so that Eq. 4 can be applied:

$$t_{lock}=\frac{1}{\zeta\omega_n}\ln(\frac{\Delta f}{(f_1+\Delta f)|\alpha|}) \quad (4)$$

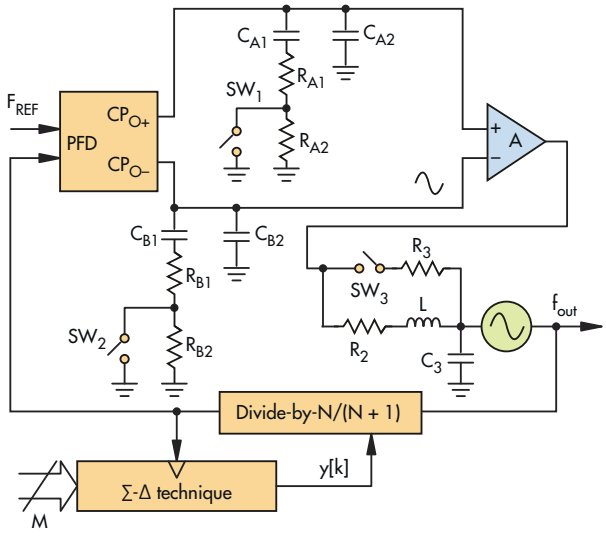
When the frequency jumps from 1.4 to 1.6 GHz, the locking time of the structure shown in *Fig. 1* with a 600-kHz loop bandwidth and frequency deviation of 10 ppb (10 Hz) can be calculated by means of Eq. 5:

$$t_{600kHz}=\frac{2}{2\pi\times600\times10^3}\ln\frac{(1.6-1.4)\times10^9}{1.6\times10^9\times|10\times10^{-9}|}=8.67\,\mu s \quad (5)$$

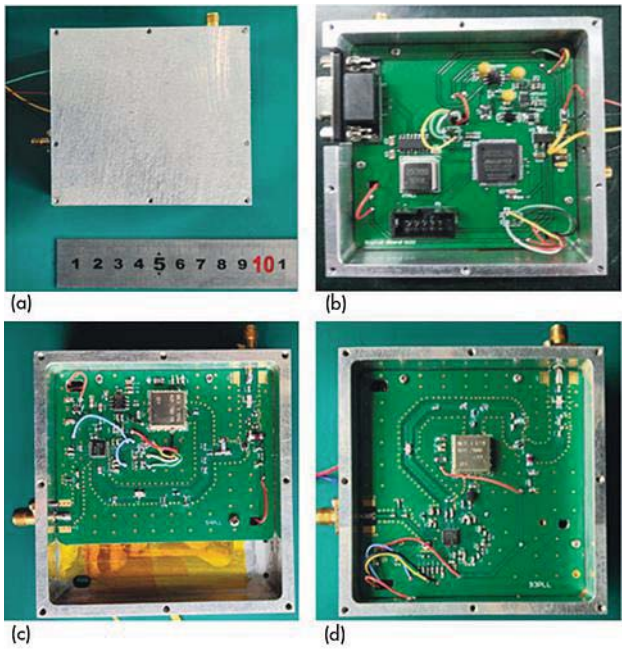
When the loop bandwidth changes to 150 kHz, the locking time can be found by means of Eq. 6:

$$t_{150kHz}=\frac{2}{2\pi\times150\times10^3}\ln\frac{(1.6-1.4)\times10^9}{1.6\times10^9\times|10\times10^{-9}|}=34.7\,\mu s \quad (6)$$

As the loop bandwidth widens, shorter lock times can be obtained. The loop bandwidth is proportional to ω_n, and ω_n is proportional to $(I_p)^{0.5}$, so it's possible to achieve a dynamic loop bandwidth by changing the charge pump current I_p. Analog Devices' (www.analog.com) ADF4154 phase-frequency detector (PFD) was chosen for the PLL due to its controllable charge pump current. Current is controllable in 12 grades with a minimum value of 313 µA and maximum value of 5 mA.



4. This block diagram is an improved approach for increasing the locking time of a PLL frequency synthesizer.



5. The photographs illustrate different aspects of the two fabricated PLL frequency synthesizers: (a) overall dimensions, (b) the control module, (c) the frequency synthesizer with a model ADF4154 as the PFD, and (d) the frequency synthesizer with a model ADF4193 as the PFD.

A value of 313 µA was selected as the standard to design the loop structure and control I_p to be 5 mA in fast-locking mode, thus quadrupling the loop bandwidth and achieving fast-locking operation. The design was simulated using the Advanced Design System (ADS) simulation software from Agilent Technologies [now Keysight Technologies (www.keysight.com)], which indicates that the locking time is close to 14 µs *(Fig. 2)* and the phase noise is –102 dBc/Hz offset 1 kHz from the carrier *(Fig. 3)*.

To further improve fast-locking PLL performance, a difference loop structure was designed with a dual-charge-pump output to increase the locking progress *(Fig. 4)*. The PFD was changed from a model ADF4154 to a model ADF4193, also from Analog Devices. Model ADF4193 is a fractional-N PFD with differential dual-output configuration. The charge pump features 64 parallel charge-pump units, each of which can provide 100-µA current. In fast-locking model, the loop bandwidth of the PLL system increases eight-fold with the full workings of the entire 64 charge-pump units, shortening the PLL lock time.

In the system shown in *Fig. 4*, when the phase error of the two input signals of a PFD increases positively, the charge pump provides the loop filter with a source current that is integrated by the loop filter structure to control the VCO. This source current makes the phase of VCO's output carrier signal approach the reference frequency phase. Conversely, when the phase error of the two input signals of the PFD increases negatively, the charge pump absorbs the sink current from the loop filter to make the phase of VCO's output signal close to the phase of the reference frequency via a negative adjustment. The final goal is for the phase error of the VCO's output and the reference frequency to become zero.

The model shown in *Fig. 4* describes the process for a PLL frequency synthesizer with a single charge pump. In a charge pump with two outputs (CP0+ and CP0–, when the phase error between two input signals to the PFD increases positively, the CP0+ delivers the source current to increase the voltage of the integral capacitance linked to the CP0+ port. At the same time, output CP0- absorbs the sink current to reduce the voltage of the integral capacitance linked to the CP0- port, quickly increasing the voltage difference between the CP0+ and CP0- outputs.

The difference charge pump largely improves the degree of mismatch between the source current and the sink current that will optimize the spurious performance. In doing so, it provides more freedom of design for the loop filter. Moreover, in the design shown in *Fig. 4*, when the loop bandwidth increases, switch SW_3 is triggered to reduce the charging resistance of the capacitance linked to the OPA's output port. This will lead to an increase in charge current. This reduces the time of reaching a certain tuning voltage even more.

However, the other parameters of the system changed with the loop width—especially the damping factor, which increases with the charge pump current and may also affect the time constant. To keep the damping factor unchanged, it is necessary to adjust R1 proportionally with the change of I_p to stabilize the loop as

6. The oscilloscope screenshots show the lock times for the PLL synthesizers, with (left) a 150-kHz static loop bandwidth, (middle) a model ADF4154 as the PFD, and (right) a model ADF4193 as the PFD.

50 MHz to 26.5 GHz

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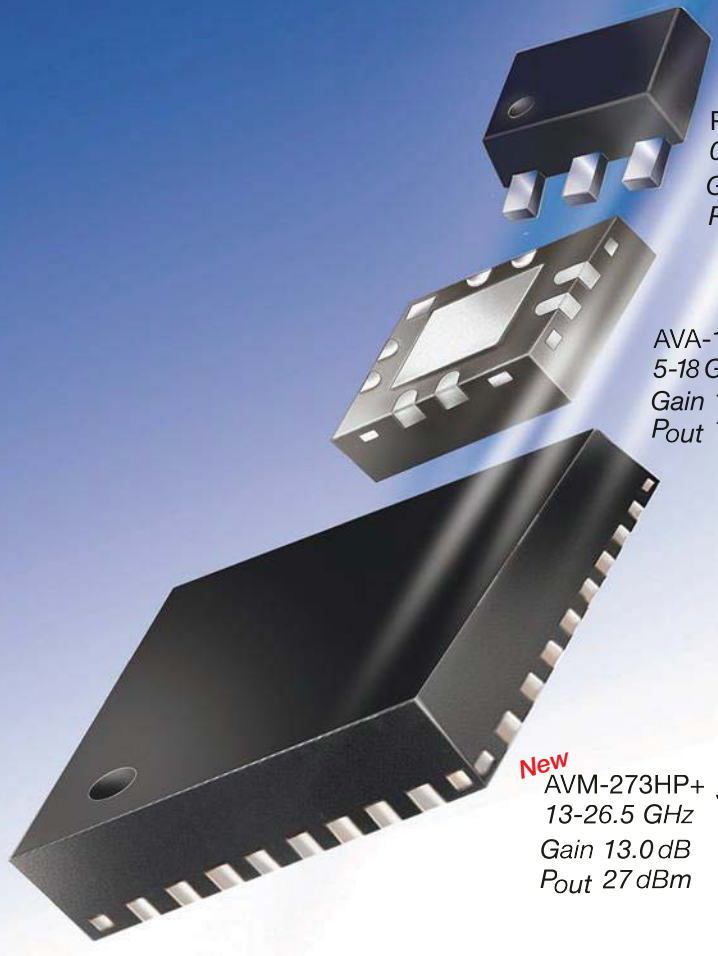

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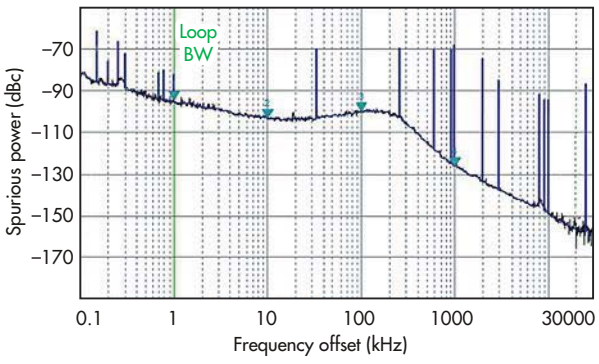


7. This plot of phase noise was measured for an output frequency of 1531 MHz.

shown in *Figure 4*. In this program, switches SW_1 and SW_2 are triggered to shorten RA2 and RB2 when the charge-pump current I_p increases multiply to keep the damping factor unchanged. To demonstrate the effectiveness of combining these methods for enhanced PLL synthesizer tuning speed, two PLL frequency synthesizers were fabricated with commercial PFDs. One used a model ADF4154 as the PFD; the other used a model ADF4193 as the PFD *(Fig. 5)*. The lock times of the two were compared.

An indirect measurement approach was used to determine the synthesizer lock times. It considers the enable signal L_E as the trigger pulse and then measures the tuning voltage.[7] *Figure 6* compares the lock times for the synthesizers with a 150-kHz static loop bandwidth, when using the model ADF4154 as the PFD, and the model ADF4193 as the PFD. For the static loop bandwidth of 150 kHz and a 200-MHz frequency step, the lock time is 30 µs. This is close to the value of 34.7 µs computed by Eq. 6. This illustrates that Eq. 3 has reference values.

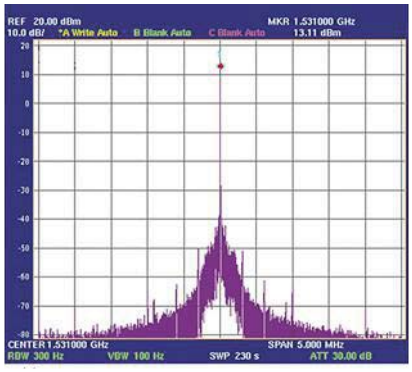
Using the improved structure and the dynamic loop bandwidth technique employed with the ADF4154 as the PFD, the PLL synthesizer lock time is 13.8 µs. This is somewhat longer than the computed result of 8.67 µs from Eq. 5, achieving a loop bandwidth of 600 kHz. This indicates that the dynamic-loop-bandwidth technique helps speed synthesizer lock time. By combining the dynamic-loop-bandwidth technique and the difference dual-charge-pump structure, it is possible to produce a frequency synthesizer with lock time of just 4.8 µs.

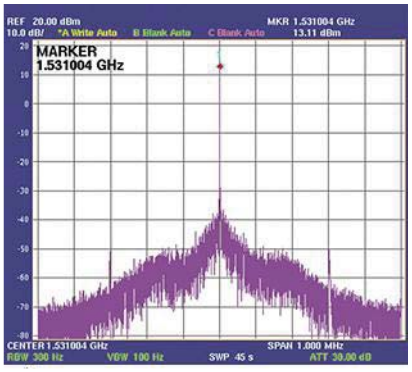
Figure 7 shows the spurious performance for an output frequency of 1531 MHz with a model ADF4193 as the PFD. When the frequency span is 1 MHz, spurious suppression is better than –63 dBc with phase-noise performance of –94.6 dBc/Hz offset 1 kHz from the carrier *(Fig. 8 and table)*. Within the loop bandwidth, the phase noise ranges from –100 to –105 dBc/Hz. The maximum spurious level of about –66 dBc occurs at a 1-MHz offset frequency. Fractional spurious signals occur at offsets of 2 and 3 MHz; the spurious suppression is better than –70 dBc.

PLOTTING PHASE NOISE AT 1531 MHz

Marker	Offset frequency	Phase noise
1	1 kHz	-94.57 dBc/Hz
2	10 kHz	-103.22 dBc/Hz
3	100 kHz	-100.13 dBc/Hz
4	1 MHz	-126.43 dBc/Hz

In short, Eq. 3 expresses the relationship between loop bandwidth and PLL synthesizer locking time. The dynamic-loop-bandwidth technique was applied to speed locking time; it allows a higher loop bandwidth during frequency tracking to achieve fast locking times. A frequency synthesizer was fabricated with the model ADF4154 PFD that achieved locking time of only 13.8 µs. To further shorten the locking time, a design structure was developed employing the difference between dual-charge-pump outputs to accelerate the speed of changing voltages. By fabricating a PLL frequency synthesizer with the model ADF4193 phase-frequency detector, a lock time of just 4.8 µs was achieved, which equates to an improvement of 9 µs. MW





8. These screenshots show two frequency spans for an output frequency of 1531 MHz: (left) a span of 5 MHz and (right) a span of 1 MHz.

ACKNOWLEDGMENT

This work was supported by the National Natural Science Foundation of China, under grant No. 61001012.

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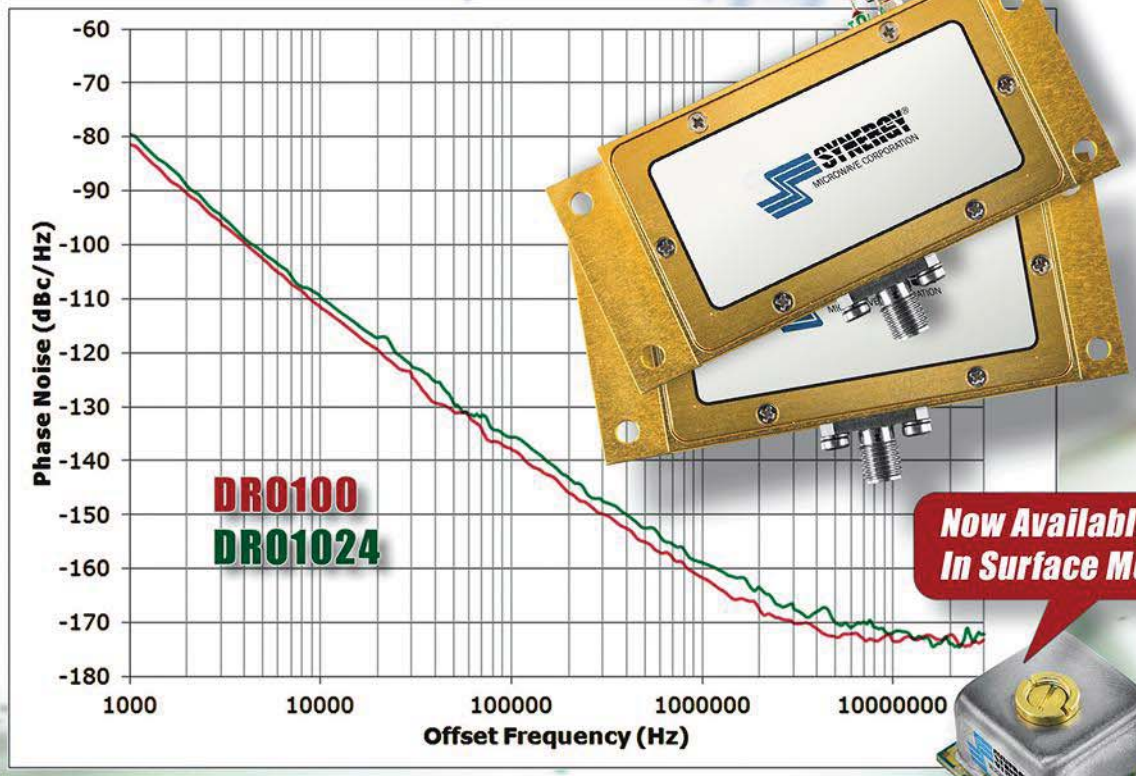

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Triband Filter Employs SIW-Loaded Resonators

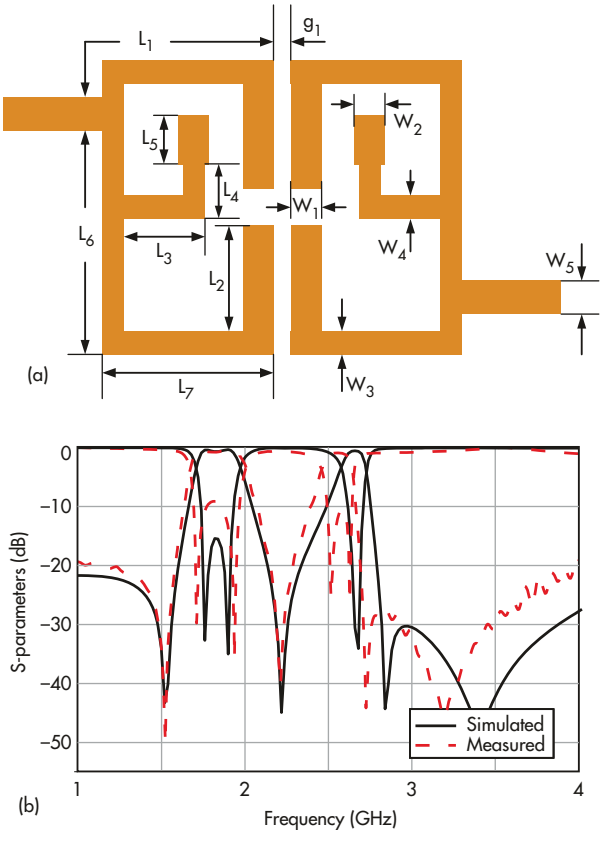
This compact filter design utilizes SIW circuit technology and several different resonator types, achieving three adjustable passbands with relatively low insertion loss.

Miniaturization is critical for many circuits and systems, and the use of substrate integrated waveguide (SIW) resonators has proven to support the design of compact filters. In particular, a novel triband filter based on SIW-loaded resonators provides passbands of 1.85, 2.575, and 3.05 GHz in a very small size.

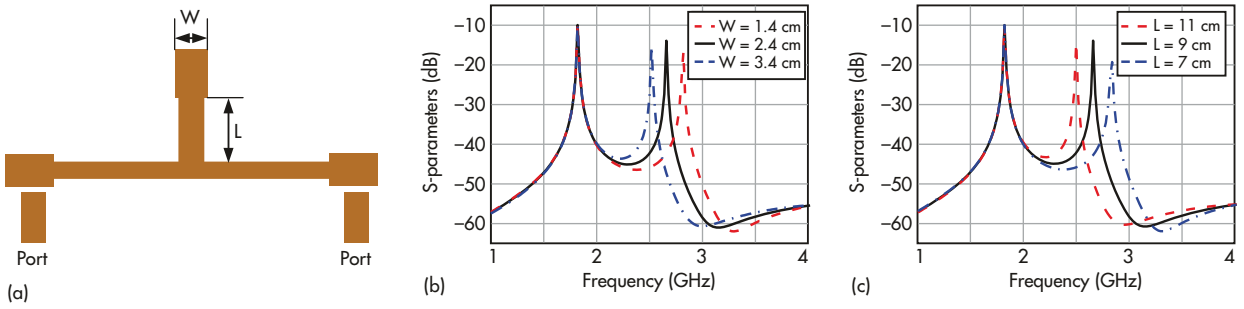
The filter incorporates quarter-wavelength resonators and a loaded SIW resonant stub. The first and second passbands are obtained using the SIW-loaded resonator, which is smaller in size than a uniform impedance resonator (UIR); the quarter-wavelength resonators help generate the third passband. To demonstrate the approach and how miniaturization is possible even with three passbands, a practical filter was fabricated. The performance yielded was quite close to the predicted simulation values.

Wireless communications applications in different frequency bands have developed rapidly. In turn, this has created demand for filters with dual frequency bands in support of different wireless applications, such as wireless code-division multiple-access (WCDMA) systems and wireless local-area networks (WLANs). Using dual-band filters rather than multiple separate filters in multiband comm systems can help reduce their volume and mass. As a result, many different approaches have been studied for the design of multiple-band filters.[1-10]

Several synthesis methods for creating multiband filters using frequency transformations have been detailed previously.[1-5] Synthesis of microwave filters involves controlling the passbands analytically. Several dual-mode, dual-band bandpass filters (BPFs) have been realized by using two nested dual-mode resonators of different sizes[6-8] or by means of multilayer circuit structures.[9,10] But most of these multiband filters have been designed without the guidance of a straight-



1. The layout (a) of the proposed triband filter is shown next to (b) simulated and measured responses for a dual-band filter



2. The layout (a) of the proposed resonator is shown next to (b) the simulated $|S_{21}|$ frequency response of a filter with different W values and (c) the simulated $|S_{21}|$ frequency response of a filter with different L values.

forward synthesis method; therefore, the design procedure isn't exact or consistent.

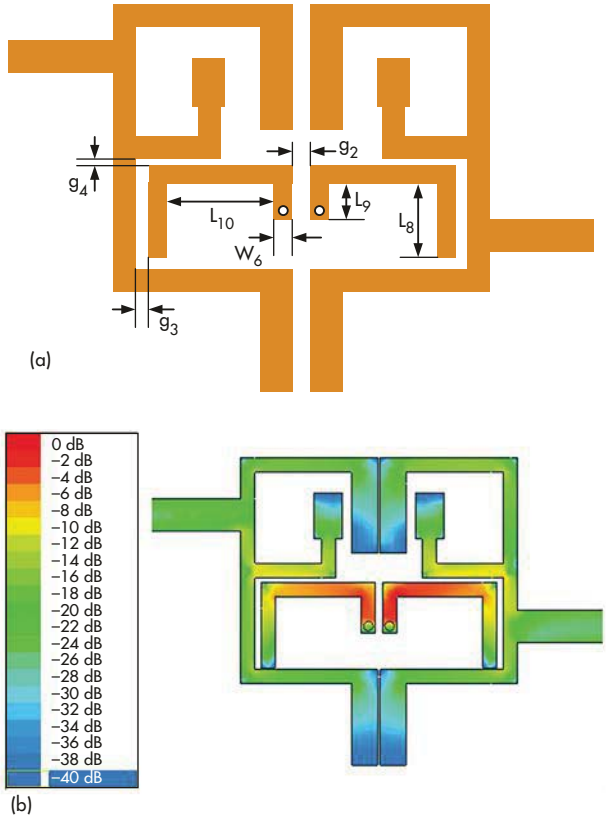
To save space even beyond what is possible with a dual-band filter, a novel triband microstrip version was developed with passbands for three different wireless communications systems. The path to the triband filter design begins with a dual-band filter with 0-deg. feed *(Fig. 1)*, which is composed of two SIW-loaded resonators. The first and second passbands can be generated by the SIW-loaded resonators. The two passbands can be adjusted to their desired values by changing the dimensions of the SIW-loaded resonators.

To create the third passband—and the triband filter—the quarter-wavelength resonators are embedded inside the microstrip printed-circuit board (PCB). This is done in such a way that the center frequency of the third passband can also be controlled and adjusted. To demonstrate the design approach, a triband filter with passbands of 1.69 to 2.02 GHz, 2.52 to 2.65 GHz, and 3.06 to 3.2 GHz was fabricated and measured, with the measured results showing good agreement with computer simulations.

In following this design approach, the initial dual-band filter design with SIW-loaded resonator is shown in *Fig. 1(a)*; the filter includes two SIW-loaded resonators to produce the first and second passbands of the triband filter. Two ports with characteristic impedance of 50 Ω are symmetrical by the center of filter, and introduce transmission zeros outside of the passbands.

The configuration of these SIW-loaded resonators is shown in *Fig. 2(a)*. It consists of a SIW structure and another SIW resonant stub loaded at the transmission-line center. To obtain a desired passband, the first center frequency (f_1) can be controlled by tuning the length of the SIW, while the second center frequency (f_2) is adjusted by tuning the length of the loaded SIW stub.

The physical parameters of the initial dual-band filter are given in the *table*. The relative dielectric constant of the PCB substrate material is 2.65 and the thickness of the substrate is 1



3. The layout (a) of the triband filter is shown next to (b) the current distribution of the filter at the third resonant frequency.

mm. Because the SIW resonant stub is loaded at the SIW center where the voltage is zero at f_1, the first center frequency will not be affected by adding the SIW stub, which can be studied by even-odd-mode analysis,[11] as shown in *Fig. 2(a)*. Overall, the size of the resonator loaded with a SIW stub is smaller than other approaches, with more parameters that can be adjusted to control the frequency response.

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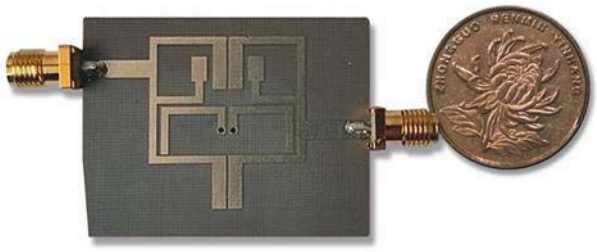
> "The use of dual-band filters rather than multiple separate filters in multiband communication systems can help reduce their volume and mass."

The stub dimensions L and W can be adjusted to control the second filter passband center frequency, f_2, without impacting the first filter passband center frequency, f_1. *Figures 2(a), (b), and (c)* show simulated results for the proposed resonators with different dimensions L and W, while the other dimensions are fixed. As these results indicate, the first passband center frequency (f_1) is unchanged while the second passband center frequency (f_2) can be adjusted by varying the dimensions L and W.

To obtain the third passband center frequency (f_3), a pair of quarter-wavelength resonators are embedded into the dual-band filter *[Fig. 3(a)]*. For the most part, the third passband frequency (f_3) is determined by the length of the quarter-wavelength resonators.

Compared with a conventional triband filter, this novel triband filter can be fabricated in a smaller footprint through its use of SIW technology. It consists of two sets of resonators: the SIW-loaded resonators and the quarter-wavelength resonators that are embedded within the PCB design. To achieve the desired bandwidths for all three passbands, separate tuning of the passbands is required.

For example, the quality factor, Q_e, depends on the position of the filter tap. The coupling coefficients at center frequencies f_1 and f_2 are determined by coupling length L_2 and coupling spacing g_1. The coupling coefficients of the third filter passband are determined by length L_9 and gap g_3 between the quarter-wavelength resonators.



4. This is the fabricated dual-mode, dual-band filter.

THE PHYSICAL PARAMETERS OF THE DUAL-BAND FILTER (DIMENSIONS IN mm)

L_1	L_2	L_3	L_4	L_5
15.2	6.9	6.9	4.5	3.9
L_6	L_7	W_1	W_2	W_3
12.97	11.7	2.2	2.4	1.2
W_4	W_5	g_1		
1.2	2.73	0.2		

The structure of the proposed triband filter is effective in controlling the coupling of the three filter passbands between the two resonators. *Figure 3* shows the current distribution of the proposed triband filter at the third resonance frequency. The current is mainly distributed at the two quarter-wavelength resonators at the third resonance frequency, in agreement with the computer simulations.

The *table* lists the physical parameters for the triband filter, while the other dimensions are the same as for the dual-band filter shown in *Fig. 1(a)*. The relative dielectric constant and the thickness of the PCB substrate measure 2.65 and 1 mm, respectively.

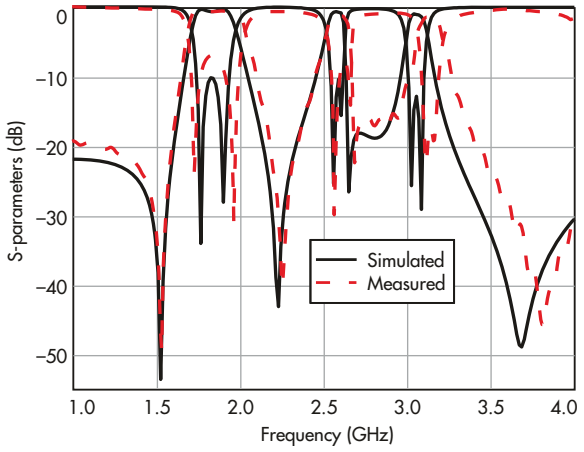
The full-wave electromagnetic (EM) simulator IE3D from Mentor Graphics Corp. (www.mentor.com) was employed in the computer simulation of the dual-band and triband filter circuits. It was also used to extract the parameters that are listed in the *table*.

To demonstrate this design approach using SIW circuitry and a combination of resonators, a filter was fabricated *(Fig. 4)* and measured with a commercial vector network analyzer (VNA), a model 8719ES from Agilent Technologies (now Keysight Technologies; www.keysight.com). The measured results were compared with simulations of the design *(Fig. 5)* using the IE3D simulation software. According to the simulations, the triband filter produced passbands at 1.69 to 2.02 GHz, 2.52 to 2.65 GHz, and 3.06 to 3.20 GHz.

Simulations showed passband insertion losses of about 0.6 dB at the center of each band. According to the measurements, the triband filter produced passband center frequencies at passbands at 1.85, 2.85, and 3.13 GHz, with measured insertion losses of 0.73, 1.20, and 1.30 dB, respectively, at the center of each passband. The transmission zeros out of the passband greatly improved the frequency selectivity.

In summary, a compact triband bandpass filter was presented and demonstrated, realized by means of SIW-loaded resonators working with additional quarter-wave resonators to achieve the three separate passbands. The first and second passbands are obtained by the SIW resonator, while the third passband results from the quarter-wave resonant structure.

The design permits control of the center frequencies and bandwidths of the three passbands. A prototype fabricated



5. These plots compare the simulated and measured frequency responses of the dual-band filter.

according to this design strategy provided measured performance quite close to the simulated values. mw

ACKNOWLEDGMENTS

This work was supported by the National Natural Science Foundation of China (NSFC) under project Nos. 61331005, 61001039, 61471292, and 61471292, and the 55th China Postdoctoral Science Foundation.

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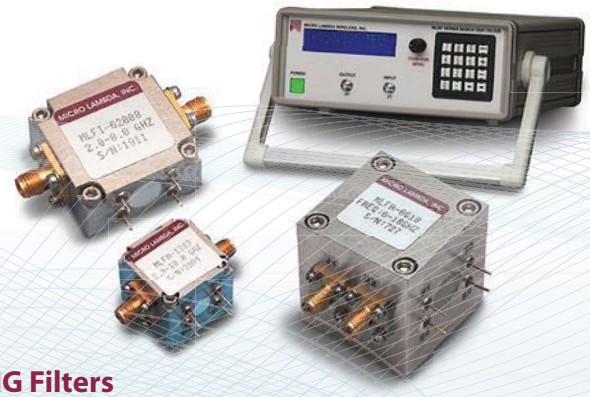

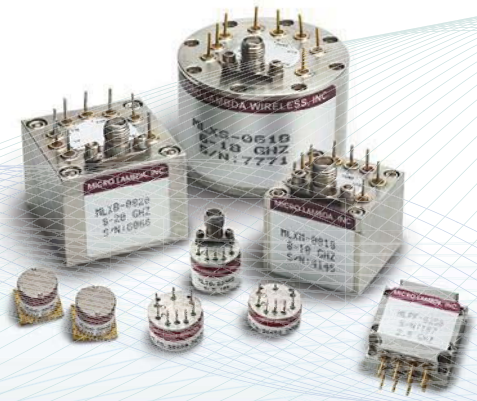

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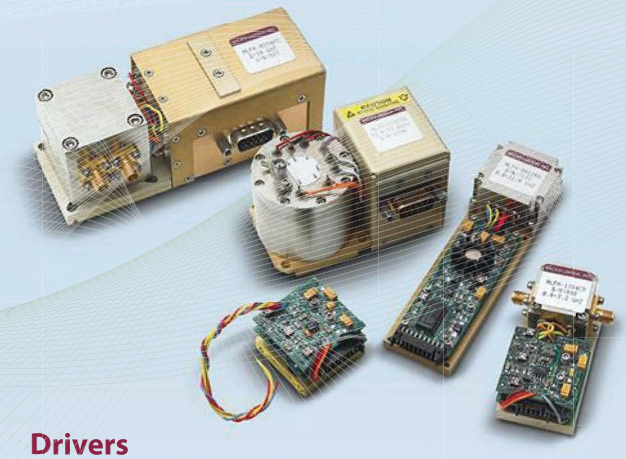

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Novel Transmission Line Impacts Antenna Design

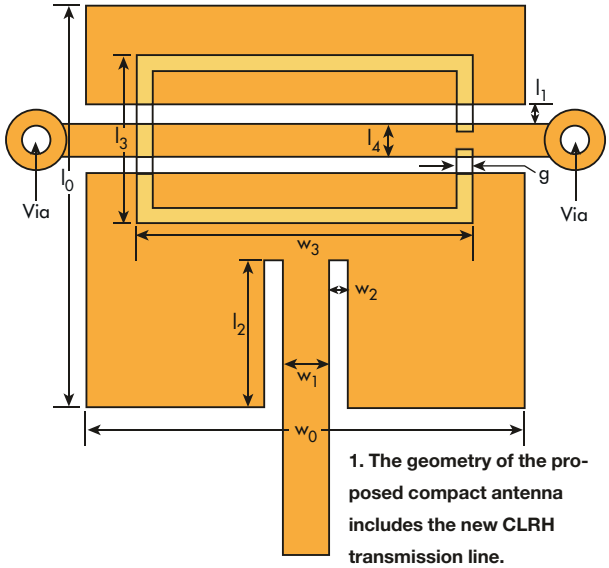
This antenna design approach takes advantage of composite-right/left-handed (CRLH) transmission lines to shrink the size of patch antennas.

Demand for electrically small antennas continues to soar, particularly among mobile electronic applications. Though the benefits are significant, these antennas aren't the easiest to achieve. Use of a novel composite-right/left-handed (CRLH) transmission line, however, facilitates the creation of these antennas. A CRLH transmission line incorporates a ground plane with an etched complementary single split-ring resonator (CSSRR) and a patch with two series gaps and two metal viaholes.

Based on a CRLH transmission-line unit cell, an antenna was designed and fabricated, and found to provide a –10-dB impedance bandwidth of 5.63% at 3 GHz. The compact antenna patch measures only $0.2\lambda_0 \times 0.17\lambda_0 \times 0.01\lambda_0$—a 69.1% reduction in size compared to a conventional patch antenna. The compact antenna design ultimately achieved peak gain of 4.29 dB.

Some of these electrically small antennas exploit the electromagnetic (EM) characteristics of CRLH transmission lines. Since the realization of resonant frequency of a zeroth-order resonator (ZOR) is independent of its dimensions, but is determined by the configuration of the unit cells, there's been a spate of ZOR-based miniaturized antennas proposed of late.[1] Unfortunately, these devices are often limited in terms of bandwidth.

By combining a TM10 transmission mode and a ZOR mode, however, some antennas increased half-power beamwidth by 53% over conventional rectangular patch antennas, with a boost in antenna bandwidth of 3.3%.[2] In one study,[3] a hybrid mode was proposed in which a wideband patch antenna with TM01 and TM10 modes was loaded with a planar CRLH unit cell to enhance its bandwidth. However, its size only shrank by 45% when compared to a conventional rectangular patch antenna.

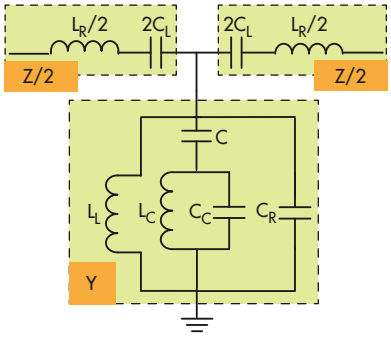


1. The geometry of the proposed compact antenna includes the new CLRH transmission line.

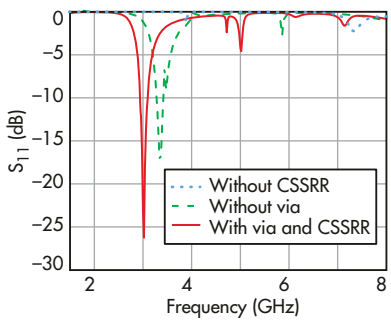
CRLH TRANSMISSION-LINE INNOVATION

To maintain antenna performance with reduced size, a new type of CRLH transmission-line structure was developed. It reduces the resonant frequency by loading with a complementary single split-ring resonator (CSSRR) for shunt inductance and a patch slot for series capacitance. Furthermore, two symmetric viaholes were incorporated to change the shunt inductance. These techniques made it possible to implement a CRLH unit cell in fully planar technology, toward the design of a compact antenna.

Figure 1 shows the geometry of the proposed antenna's geometry. A patch with two series gaps and two short stubs forms on the top side, and a CSSRR slot is etched on the ground plane on the bottom side. The two white circles denote metallic viaholes.



2. This is an equivalent-circuit model of the proposed antenna.



3. S_{11} responses are compared for three types of antennas.

According to CRLH transmission-line theory, the equivalent-circuit model of the proposed antenna can be depicted as that in *Fig. 2*. Since the patch provides series inductance and the gaps yield series capacitance, the patch with two series gaps is represented as a series LC circuit (L_R and C_L), while the CSSRR slot is represented as a shunt LC resonant tank (C_C and LC).[4] On the other hand, the capacitance between the patch and the ground plane capacitance (C) connects the shunt resonant tank to the patch, while capacitance C_R connects the ground with the patch. The two metallic viaholes connected with two short stubs are described by shunt inductance L_L, connecting the patch with ground.

$$\beta_d = \cos^{-1}\left(1 + \frac{(1-\frac{\omega^2}{\omega_{se}^2})(\frac{C}{C_L}-\frac{\omega^2}{\omega_C^2})}{2(1-\frac{\omega^2}{\omega_Z^2})} - \frac{(1-\frac{\omega^2}{\omega_{se}^2})(1-\frac{\omega^2}{\omega_{sh}^2})}{2\frac{\omega^2}{\omega_L^2}}\right)$$

and

$$\omega_{se} = \frac{1}{\sqrt{L_R C_L}} \qquad \omega_{sh} = \frac{1}{\sqrt{L_L C_R}} \qquad (2)$$

$$\omega_R = \frac{1}{\sqrt{L_R C_R}} \qquad \omega_L = \frac{1}{\sqrt{L_L C_L}}$$

$$\omega_C = \frac{1}{\sqrt{L_C C_C}} \qquad \omega_Z = \frac{1}{\sqrt{L_C (C_C + C)}}$$

Based on the analysis above, one can safely conclude that a model circuit is provided by a complex CRLH transmission-line circuit: C_L represents the left-handed capacitance; L_C and L_L represent the left-handed inductance; C and C_C represent the right-handed capacitance; and L is the right-handed inductance. From the equivalent-circuit model, the dispersion relation can be expressed as Eq. 1:

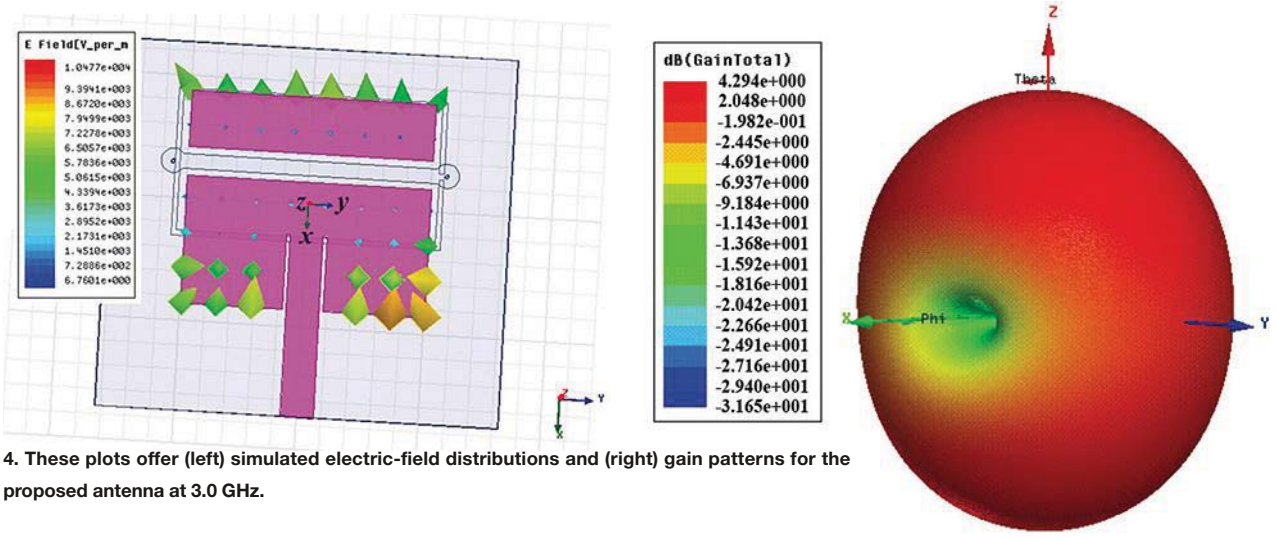
$$\beta_d = \cos^{-1}(1 + ZY/2) \quad (1)$$

where
β_d = the length of the unit cell,

and
$Z = j\omega L_R + 1/(j\omega C_L)$

and
$Y = [j\omega C/(j\omega C_C + 1/j\omega L_C + 1/j\omega L_L)] + j\omega C_R$

represent the series impedance and shunt admittance, respectively. The dispersion relation can be determined by means of Eq. 2 *(see above)*.



4. These plots offer (left) simulated electric-field distributions and (right) gain patterns for the proposed antenna at 3.0 GHz.

In another way, it's possible to obtain the resonant modes of the CRLH transmission line by applying Eq. 3:

$$\beta_d = n\pi \qquad (n = -1, 0, +1) \quad (3)$$

With these relationships, the negative first-order resonance, the ZOR, and the positive first-order resonance can be obtained according to Eqs. 5 and 6. At the ZOR, the phase constant (β_d) becomes zero and infinite wavelength propagation is theoretically possible, although the working bandwidth is narrow.

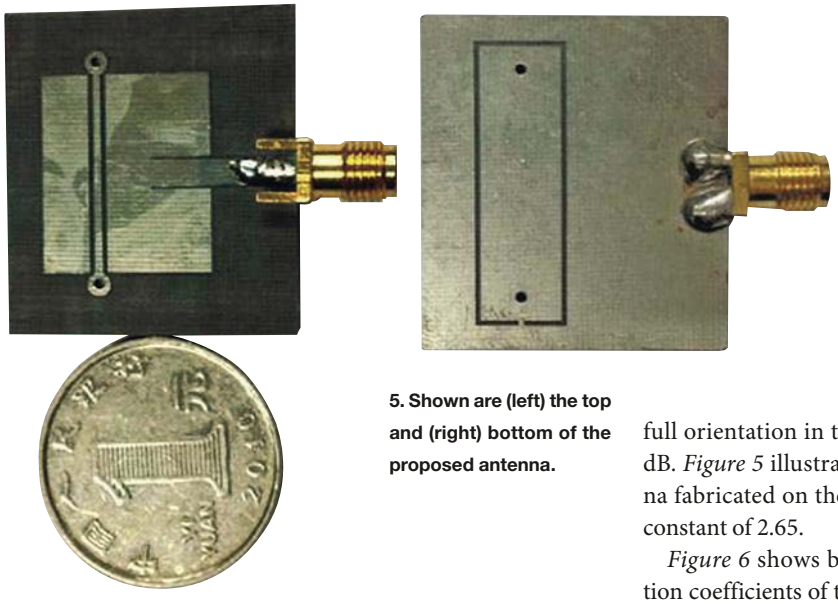
The negative first-order resonance supports backward-wave propagation with the same field distribution as the positive first-order resonance. Nonetheless, the resonance generally has such low efficiency that it cannot be used for antenna radiation purposes.[5]

ANTENNA ANALYSIS

Analyzing the antenna design can be somewhat complicated. Considering the shunt part, there are four relevant resonant frequencies relative to the shunt impedance based on this circuit model: two frequencies that null the corresponding admittance (ω_C and ω_L), a shunt resonant frequency (ω_{sh}), and a transmission-zero frequency (ω_Z). Parameters ω_C, ω_{sh}, ω_Z were previously explained in Eq. 3, and the relationship for ω_L is given in Eq. 4:[6,7]

$$\omega_L = \frac{1}{\sqrt{L_C\left(C_C + \frac{4}{\frac{1}{C_L} + \frac{4}{C}}\right)}} \quad (4)$$

The resonant efficiency is low at ω_{sh} and the right-handed



5. Shown are (left) the top and (right) bottom of the proposed antenna.

resonant efficiency (ω_R) often measures higher than is the case in practice applications.

Simulations of an antenna model were performed for a Teflon circuit substrate material with relative dielectric constant (ε_r) of 2.65, tan δ of 0.001, and thickness of 1 mm. The simulations were performed using the High-Frequency Structure Simulator (HFSS) software from Keysight Technologies (www.keysight.com), based on the finite-element method with the following dimensions: w_0 = 20 mm; w_1 = 2.72 mm; l_0 = 17.4 mm; l_1 = 0.5 mm; and g = 0.6 mm. Because the dimensions w_3 and l_3 are related to the shunt resonance, modifications to those dimensions result in changes to the resonant frequency, while modifications to dimensions w_2 and l_2 lead to impedance matching.

Figure 3 compares reflection coefficients (S_{11}) for the proposed antenna without CSSRR, without viaholes, and with CSSRR and viaholes. The antenna with viaholes and CSSRR achieves a multiple-resonant frequency response with reduced frequency compared to the other two approaches.

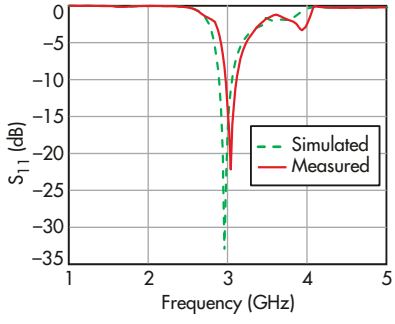
For the best radiated performance, the antenna dimensional parameters were optimized for the following values: w_0 = 20 mm; w_1 = 2.72 mm; l_0 = 17.4 mm; l_1 = 0.5 mm; g = 0.8 mm; w_2 = 0.3 mm; l_2 = 6.1 mm; w_3 = 22 mm; l_3 = 14 mm; and l_4 = 0.8 mm. The radius of the viahole was 0.15 mm.

The simulated electric-field distributions for the proposed compact antenna are depicted in *Fig. 4 (left)*. With the structure's two x-oriented edges being 180 deg. out of phase at 3 GHz, a transverse-magnetic TM10 mode is excited. The simulated gain for the antenna at 3 GHz is given in *Fig. 4 (right)*, with full orientation in the Y_0Z plane and maximum gain at 4.29 dB. *Figure 5* illustrates the prototype of the proposed antenna fabricated on the Teflon substrate with relative dielectric constant of 2.65.

Figure 6 shows both the simulated and measured reflection coefficients of the proposed antenna. The measured data were in good agreement with the simulated results, with just a few exceptions. The measured 10-dB return-loss bandwidth equaled 170 MHz (5.6%) from 2.94 to 3.11 GHz. The electrical size of the radiating patch featured dimensions of $0.2\lambda_0 \times 0.17\lambda_0 \times 0.01\lambda_0$ (20 × 17.4 × 1 mm) at a center frequency of 3.02 GHz.

Owing to the CRLH structure and use of metal viaholes to enhance the shunt inductance, antenna size was reduced 69.1%, compared to a conventional patch antenna measuring 37 × 30.4 × 1 mm. Even with this dramatic size reduction, the microstrip patch antenna provides strong performance at its 3.02-GHz center frequency. mw

6. The plots compare the simulated and measured S_{11} responses for the proposed antenna.



ACKNOWLEDGMENT

This work is supported by the National Natural Science Foundation of China under Grant No. 61372034.

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Design Feature

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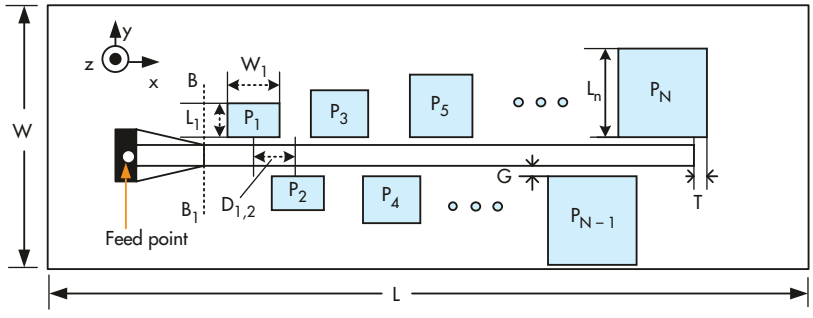
Single Microstrip Layer Holds UWB Log-Periodic Antenna

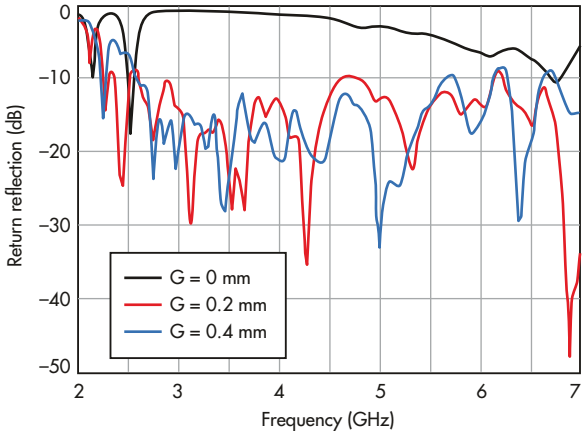
This novel antenna design employs a coplanar-coupled microstrip feed method and terminal compensation structure for high UWB efficiency and small size.

Microstrip antennas have long been used as reliable components with small profiles, large directional beams, and high gain.[1] Unfortunately, they also exhibit narrow impedance bandwidths, with single-layer dielectric-resonator-type patch antennas providing only a few percent of center frequency.[2]



1. This diagram shows the basic structure of the proposed log-periodic microstrip antenna.

Microstrip antenna impedance bandwidth can be increased by means of cross-feed logarithmic modes,[3,4] where microstrip antennas have been achieved with several octaves of coverage. In addition, through a coplanar feed approach with quarter-wavelength (λ/4) microstrip lines, an impedance bandwidth from about 1.3 to 4.0 GHz has been reached.[5]

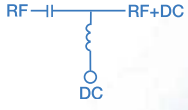


2. These are the simulated reflection coefficients of the proposed antennas with different gap G at reference plane BB1.

A number of reports[6,7] have described the use of various feed approaches—including perforated feeding, aperture coupled feeding, and embedded coplanar feed logarithmic periodic microstrip antennas—for improved impedance bandwidths, with log-period microstrip antennas showing great promise. One problem with log-period microstrip antennas, however, has been the use of a double-layer circuit medium, in which said medium must be perfectly aligned for best performance. This can be difficult to achieve at the design and production stages.

A log-periodic microstrip antenna is a form of traveling-wave antenna. Its terminal portion works with the impedance-matching load to absorb radiated energy and reduce reflected energy. The terminal section is important, since it can greatly improve the antenna's radiation pattern in the working frequency band.

But terminal matching load absorption can significantly reduce the overall efficiency of a microstrip antenna (especially across the upper frequency range), and efficiency loss can reach 10% or more.[8]



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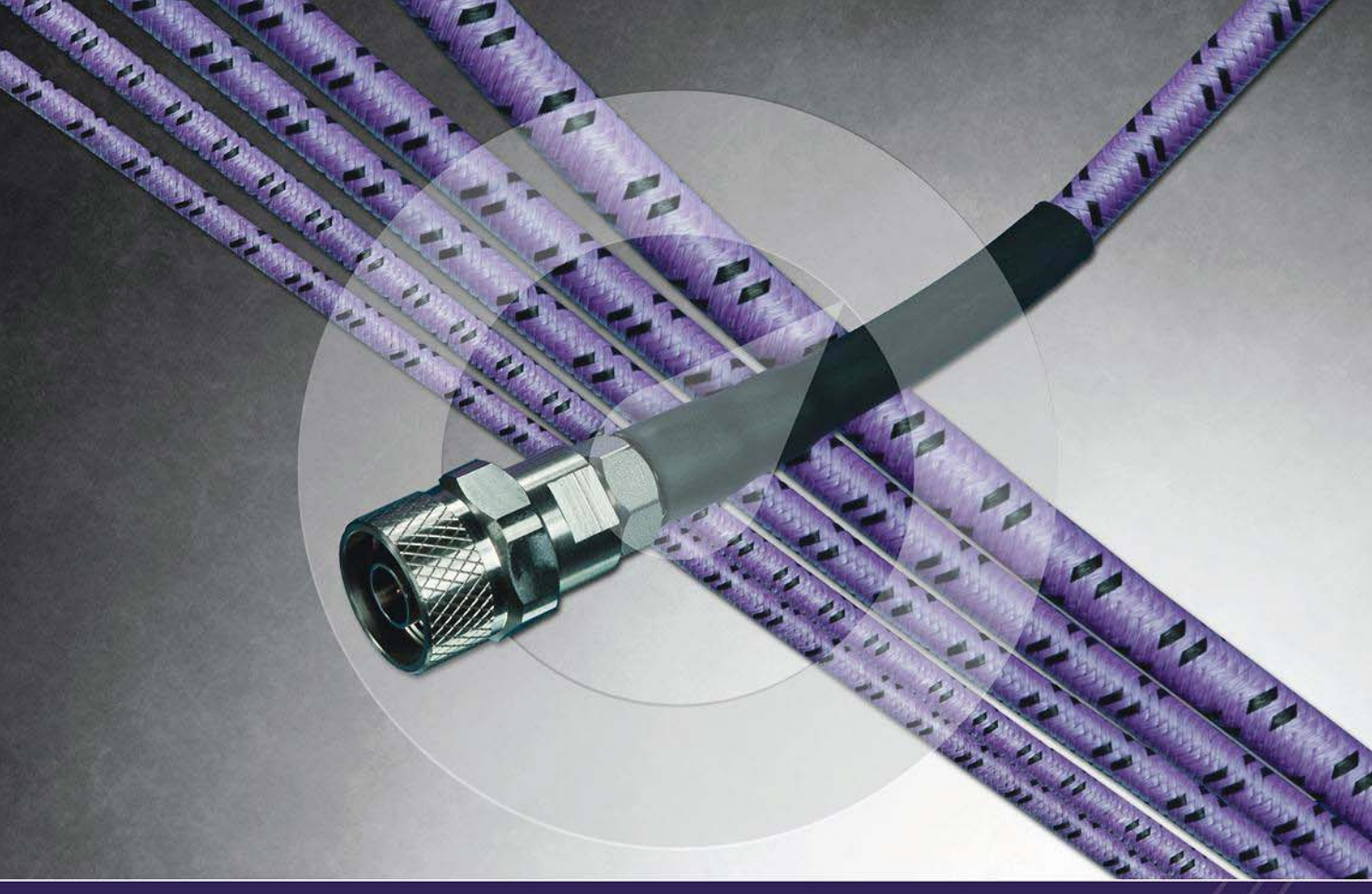

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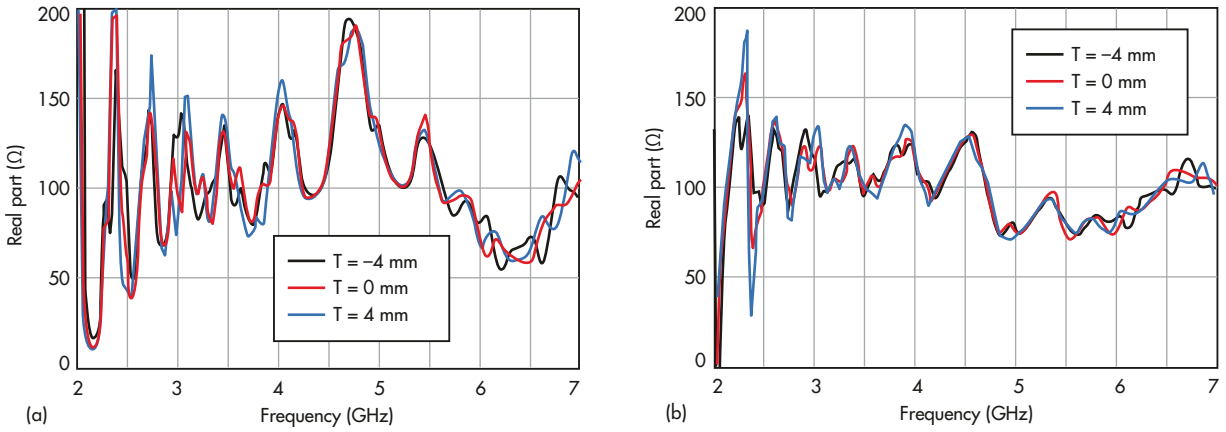


3. The plots show the simulated input impedance of the proposed antenna with different compensating T at the reference plane BB1: (a) the real part, and (b) the imaginary part of impedance.

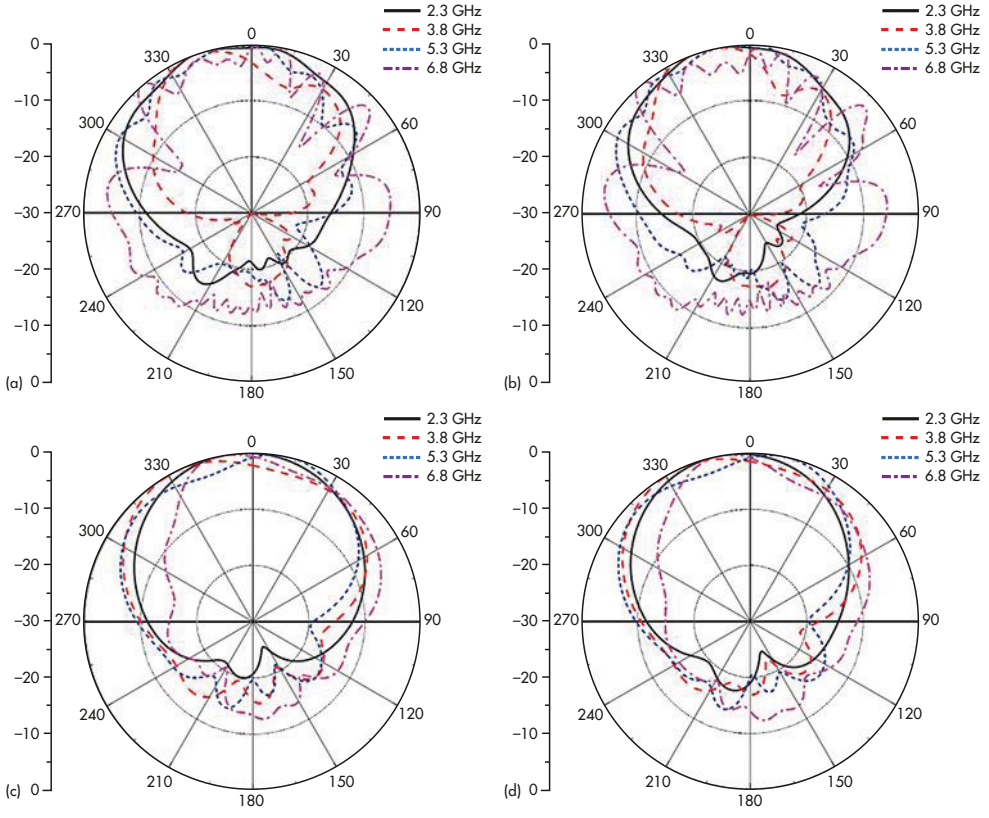
Adding a terminal matching load to a log-periodic microstrip antenna will increase complexity and cost, and eventually may cause it to fail. Periodic factor k and microstrip patch unit number n determine a log-periodic microstrip antenna's bandwidth, which is equal to k^{n-1}. If k is large, it reduces the number of required microstrip units. For example, for a scale factor of 1.05 or less, at least 21 microstrip units are required for a working bandwidth of 2.6:1. For a scale factor of 1.1, only 11 microstrip units are needed to achieve the same bandwidth.

IMPROVED DESIGN

By way of improvement, this article proposes a new type of single-layer log-periodic microstrip antenna. It uses microstrip-line capacitive coupling to feed a coplanar microstrip patch array. The single-layer design provides excellent structural strength and can be fabricated by means of standard single-layer printed-circuit-board (PCB) technology.

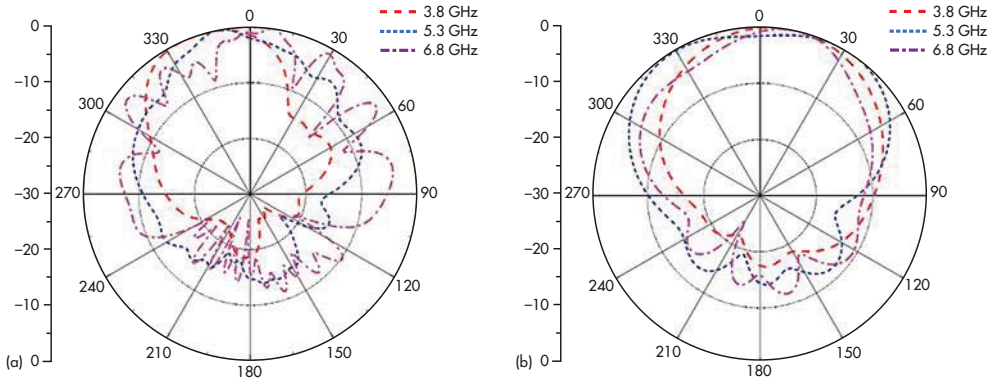
The antenna employs a new type of terminal compensation structure for improved efficiency. A large scale factor is used to reduce the number of required microstrip patch elements. A log-period microstrip antenna with 11 patch units was designed, simulated, and fabricated to demonstrate the approach. With a scaling factor of k = 1.1, the antenna obtains a 3.03:1 impedance bandwidth with stable radiation pattern.

Figure 1 shows the single-layer log-periodic microstrip antenna design. It consists



4. These are simulated radiation patterns for the proposed antennas with compensating stub and matched load (k = 1.1): (a) in the x-z plane with a compensating stub, (b) in the x-z plane with a matched load, (c) y-z plane, compensating stub and (d) in the y-z plane with a matched load.

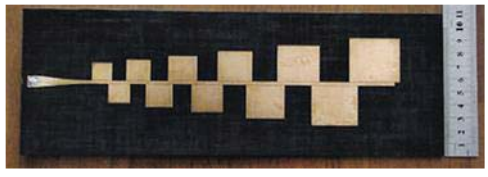
of a 50- to 100-Ω impedance-transformation line, a 100-Ω microstrip feeder, and a set of microstrip coupling feed patches. The antenna was fabricated on 3-mm-thick, glass fiber and Teflon dielectric substrate material with relative permittivity of 2.65. The size of the microstrip patch is based on the log-periodic arrangement presented in Eq. 1:



5. These are simulated radiation patterns for the proposed antenna with compensating stub (k = 1.05): (a) in the x-z plane and (b) in the y-z plane.

$$k = W_i/W_{i-1} = L_i/L_{i-1} = D_{i,i+1}/D_{i,i-1} \quad (1)$$

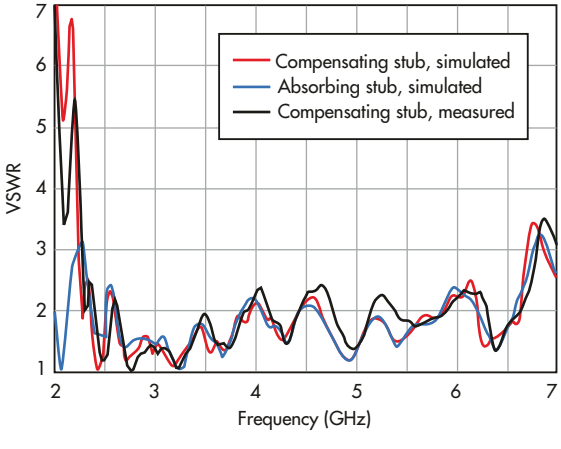
where



6. This is a photograph of one of the single-layer microstrip log-periodic antennas.

$D_{i,i+1}$ = the distance from the ith patch to the center of the ith + 1 patch;
$D_{i,i-1}$ = the distance from the ith patch to the center of the ith – 1 patch;
L_i = the height of the ith patch; and
W_i = the width of the ith patch.

The High Frequency Structure Simulator (HFSS) electromagnetic (EM) software from ANSYS (www.ansys.com) was used for the simulation and optimization of the antenna, with the optimization parameters of *Table 1* (online only). In using a coplanar coupled microstrip-line-feed approach, the couple gap, G, is an important parameter that will impact the feed's efficiency, so it must be carefully considered.



7. The plot show the simulated and measured VSWR of the proposed antenna with compensating stub and matched load (k = 1.1).

Figure 2 shows simulated reflection coefficients for different values of G; it details the results for reference plane BB1 and does not consider the influence of the impedance transformation structure or the SMA connectors used with the antenna.

The coupling gap G has a strong effect on the antenna impedance matching; when G = 0.2 mm, the antenna impedance matching is at an optimum. When G = 0.4 mm and the frequency is higher than 2.55 GHz, the impedance matching is better since part of the antenna array can absorb the high-frequency energy and radiate the higher-frequency energy. Therefore, reflections will be small in the antenna terminal.

For a frequency range of 2.25 to 2.55 GHz, the best matching is achieved with G = 0.2 mm. The distance between the feeder and microstrip patch has a strong effect on the coupling of the log-periodic microstrip antenna, while also impacting the impedance-matching characteristics.

Ideally, the feeder should supply energy to the coupled microstrip patches as efficiently as possible across a full frequency band of interest. The microstrip patches are designed to achieve effective energy radiation while reducing feeder terminal reflections. In this way, the feeder can reduce the antenna's dependence on the terminal matching load and improve antenna efficiency.

The compensation microstrip line helps improve the efficiency of the log-periodic antenna. The compensation of microstrip line length T can be divided into positive and negative modes. The microstrip line with positive compensation value can be considered as an open-circuit transmission line, equivalent to a series capacitive load without loss. The microstrip line with negative compensation value can be considered as having no inductive load.

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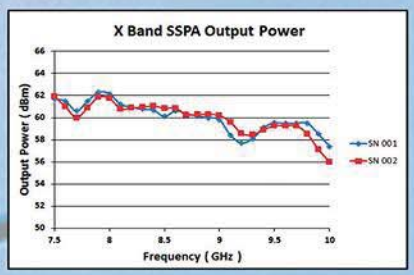

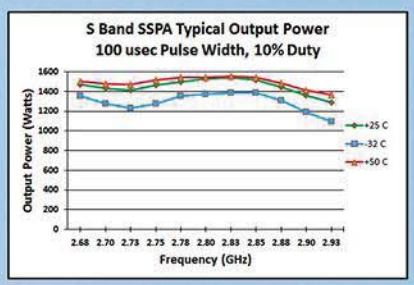

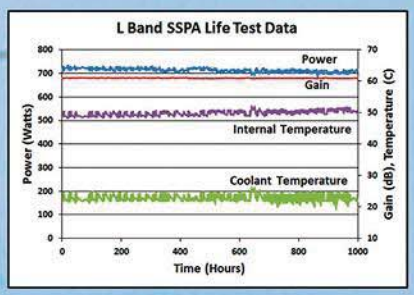

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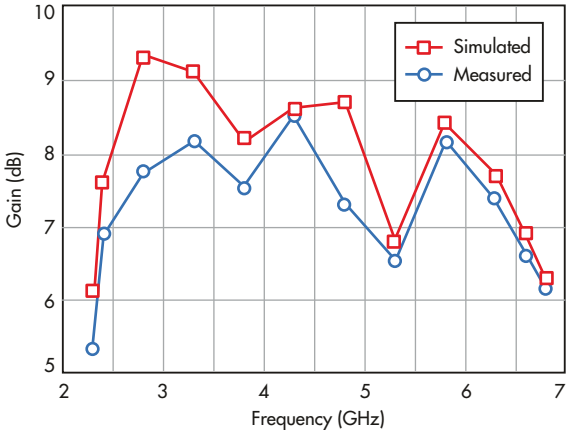
The main function of the compensation microstrip line is to provide the antenna's first resonance point, near 2.36 GHz (*Fig. 3*). The microstrip line should be chosen for optimum impedance matching. The line is relatively lossless and is used to improve the antenna's impedance matching in the low-frequency band. The antenna's terminal energy will be reflected toward the secondary radiation, so the compensation of the microstrip line may influence the directional pattern of the periodic microstrip antenna in the low-frequency band. Thus, it requires further analysis.

By using different matching load terminals and terminal compensation structures, it was possible to see their effects on the microstrip log-periodic antenna design. The terminal matching load was simulated via a "lumped resistive-inductive-capacitive (RLC) boundary" approach. Using a size of 22.4 × 3.0 mm, the resistance and characteristic impedance of the microstrip feeder were consistent, at 100 Ω.

Figure 7 offers a simulation of the antenna voltage standing wave coefficient. Between 2.4 and 6.8 GHz, the standing wave coefficients of the two antennas are similar, with good matching effects.

At less than 2.3 GHz, the terminal impedance matching characteristics of the matching load are still good, but all of the microstrip patch units cannot work effectively across this wide band. It can be deduced that the matching load will absorb a great deal of terminal energy, and the overall efficiency of the antenna will not be high at the lower frequencies. This is similar to the effects of characteristic impedance matching, and the radiation patterns of the two experimental antennas are very similar at 3.3 GHz (*Fig. 4*).

At 2.3 GHz, certain differences exist in the x-z plane of the radiation patterns of the two antennas; for the antenna adopting the matching load terminal, the beam width is narrower with a higher directivity. These differences are mainly caused by differences in the terminal impedance matching load and the terminal compensation structures. When the terminal matching load fully absorbs the EM energy, there are no reflections on the antenna terminal, so the radiation pattern remains unaffected.



8. A fabricated log-periodic antenna yielded these results for simulated and measured gain.

An effective terminal compensation structure will reflect all energy present at the terminal back to the microstrip patch array for greatly enhanced efficiency. When the matching load terminal antenna directivity is higher, the gain is less than when using a compensation structure in the antenna terminal. This is mainly due because the matching load absorbs a great deal of the terminal energy, and the total antenna efficiency suffers.

To evaluate the log-periodic microstrip antenna performance with a large periodic factor of k = 1.1, the effects of k on antenna pattern and gain must be understood. *Table 2* (online only) shows antenna parameters when choosing a smaller scale factor of k = 1.05 as a reference.[9] The VSWR of an antenna with k = 1.05 is better than for an antenna with k = 2.5; the simulation impedance bandwidth is from 3.35 to 6.95 GHz, which is consisted with the bandwidth of the antenna impedance with k = 1.1.

Figure 5 presents the radiation pattern of antenna with k = 1.05, which is similar to the pattern for the antenna with k = 1.1 (only the directivity ratio is 0.65 dB higher). This demonstrates that when adopting a larger scale factor k, it is possible to reduce the number of patch elements required in the microstrip antenna, but with some sacrifice in gain performance.[9]

Figure 6 shows a pair of antennas fabricated by means of a single-layer microstrip PCB process. The impedances of the antennas' bandwidths were tested using a commercial vector network analyzer (VNA), a model 8722ES from Agilent Technologies [now Keysight Technologies (www.keysight.com)], with the results shown in *Fig. 7*. The simulated and measured responses are quite close. The impedance bandwidth of the test standing wave ratio is less than 2.5:1 from 2.5 to 6.85 GHz, and reaches 3.03:1.

Figure 8 shows additional test and simulation comparisons, with only slight differences. This may be because the gain of the standard horn is about 20 dB higher than the average gain of the test antenna, boosting the calibration error.

The measured gain is better than 6.5 dB from the range of 2.4 to 6.6 GHz, for a gain-bandwidth product of 2.75:1. The gain fluctuation was shown to be consistent between the simulation figures of 2.4 dB and the measured gain fluctuations, within 2.0 dB. MW

Note: References and additional graphics can be found in the online version of this article at www.mwrf.com.

ACKNOWLEDGMENTS

The research is partly supported by the National Science Foundation of China (grant Nos. 61271160 and 61172045) and National Fundamental Fund of Personnel Training (grant No. J1103210).

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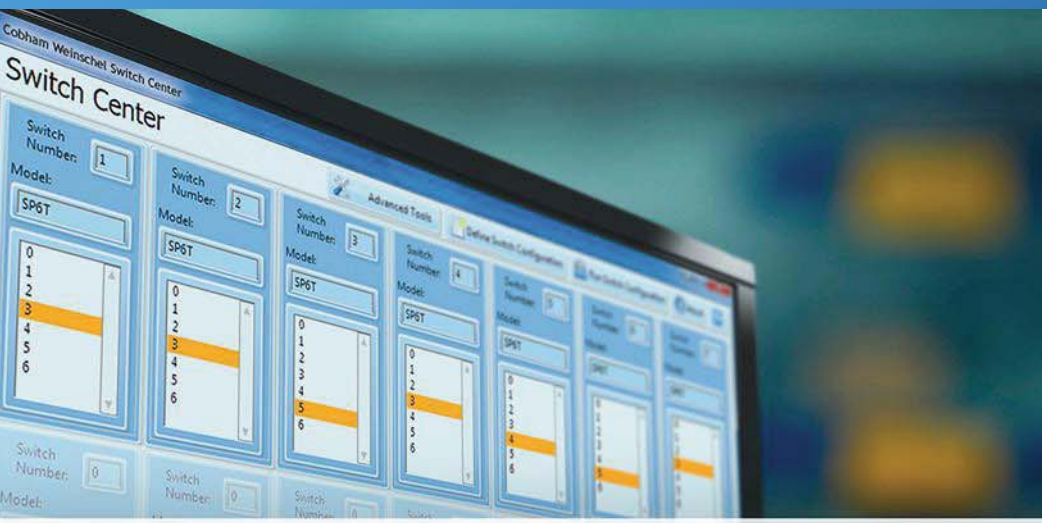

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Know When To Add ATTENUATION

Attenuation comes in many shapes, sizes, and formats, and can be integrated into a system or application as a quick fix or if there's a need for a range of attenuation.

Attenuators are found in an array of high-frequency systems, from the lowest-frequency designs through millimeter-wave communications networks. Although they perform a function—reducing signal levels—that would seem contrary to the usual design goals in an RF/microwave system, attenuators of all types serve invaluable functions in those systems. Understanding their basic parameters and options can simplify the task of selecting an attenuator for a given system.

1. ARRA's 6684 family of variable attenuators works in the 2- to 18-GHz frequency range.

When selecting an attenuator for an application, perhaps the most practical starting points are frequency and attenuation, because that component should provide the minimum bandwidth and attenuation required for a particular job. Attenuators are available for broad frequency ranges, such as 6 to 18 GHz, and other wide spans typically used in electronic-warfare (EW) and military communications systems. They also work in the more narrow frequency ranges, such as surrounding 2450 MHz, typically used for licensed commercial communications. Attenuation range for these devices spans from a mere 10 dB or less, up to 70 dB and greater.

Attenuators apply attenuation in a wide variety of ways, particularly because they can be specified as fixed, mechanically variable, voltage-variable, digitally controlled, and programmable models. On top of that, they come in multitude of shapes and sizes, from tiny surface-mount-technology (SMT) housings to larger coaxial and even waveguide packages.

Some suppliers, such as Mini-Circuits (www.minicircuits.com), supply surface-mount attenuators through a variety of different bandwidths to 7 GHz, in housings as small as 2 × 2 mm. They also offer larger attenuators for applications through 40 GHz with programmable attenuation values that can meet the needs of different circumstances, such as in test laboratories and in communications systems.

When comparing attenuators from different suppliers (for instance, fixed 10-dB attenuators), it's important to understand how the component choice may impact the amplitude behavior of the intended system or application.

DEVIATION DETAILS

First of all, one must consider the accuracy and stability of the attenuation setting, such as 10 dB. The amount of impedance mismatch, which is usually denoted by the attenuator's maximum voltage standing wave ratio (VSWR), can play a hand in the amount of attenuation variation in an application.

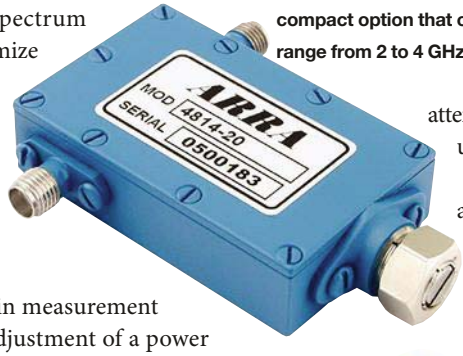
RF/microwave attenuators are specified according to the amount of attenuation deviation or flatness they will exhibit across their frequency range and across operating temperatures. The value, which in some cases can exceed ±0.5 dB, is typically a function of attenuation value and frequency, with greater attenuation variations found at higher frequencies. For a fixed attenuator, the accuracy or attenuation deviation applies to that single value, while for a variable attenuator, attenuation deviations apply to the tunable range of attenuation settings.

However, such components are also characterized in terms of insertion loss, which is the additional loss expected from using that attenuator over a given frequency range. When comparing different fixed attenuators, one should take into account both the attenuation variations and insertion loss.

Power-handling capability is another key consideration when specifying fixed or variable attenuators, since they must handle maximum power levels without any signal degradation. Many attenuators provide limits for continuous-wave (CW) and peak power levels. A drastic difference exists between the two limits

because peak power is measured for a typically short pulse at a short duty cycle, as in radar systems. Typical values for a coaxial fixed attenuator might be maximum input power of 2 to 5 W CW and maximum peak power of 1 kW for short (microsecond) pulsed signals at short duty cycles (much less than 1%).

Attenuators are normally expected to appear electrically "invisible" within a system or circuit, except for their amount of attenuation. They're often used with test equipment to bring a high-level signal under test into a suitable input range for a test receiver, such as a spectrum analyzer or an oscilloscope. To minimize impact to a measurement or other application, an attenuator will ideally exhibit low VSWR, low insertion loss, and minimal attenuation variation with frequency.



2. The 4814-20 continuously variable attenuator from ARRA is a more compact option that offers a 20-dB range from 2 to 4 GHz.

CONTINUOUSLY VARIABLE

Some applications, such as those in measurement facilities, may require continuous adjustment of a power level (e.g., test signals sent to an oscilloscope). In these cases, a continuously variable attenuator makes it possible to vary a signal's amplitude while witnessing the effects of the changes in signal power level on a system or test instrument. Of course, since the attenuation value can be varied, it's not a matter of comparing the attenuation accuracy of a unit, but rather comparing their resettability.

3. Mini-Circuits' VAT-1+ inline coaxial fixed attenuator provides 1-dB fixed attenuation from dc to 6 GHz.

For example, the 6684 model series from ARRA (www.arra.com) is a family of continuously variable attenuators for different portions of the frequency range from 2 to 18 GHz *(Fig. 1)*. They include calibrated direct-reading dials (with attenuation values calibrated in 1-dB increments) to show the value of attenuation that has been tuned, and can be specified with as much as 100-dB attenuation in some models.

These continuously variable attenuators are able to handle 10-W average input power and 5-kW peak power in their rugged aluminum housings. The firm also offers a line of motorized variable attenuators for remote applications. These units, which consist of an integrated motor head and single-turn variable attenuator in a small housing, operate from +12-, +15-, +24-, and +28-V dc supplies.

For applications that require a more compact housing, the firm's 4814-20 continuously variable attenuator, with a 20-dB range from 2 to 4 GHz, comes in a standard coaxial housing with SMA connectors measuring just 2.00 × 1.25 × 0.5 in. *(Fig. 2)*. The 4814-20 promises 0.1-dB resettability across an operating temperature range of –55 to +85°C. It's rated for 5-W average (CW) power and 5-kW peak power for short pulses, with 0.5-dB maximum insertion loss. The component, which has been qualified for military applications, achieves its attenuation in a non-contacting manner, thus ensuring wear-free performance and a long operating lifetime.

RLC Electronics (www.rlcelectronics.com), for example, offers continuously variable as well as programmable step attenuators in coaxial packages for applications through 18 GHz. The firm's PA Series of attenuators are available for frequencies from dc to 18 GHz in either 0- to 15-dB attenuation (in 1-dB steps) or 0- to 70-dB attenuation (in 10-dB steps).

Numerous companies offer RF/microwave attenuators in SMT packaging for tight spacing on printed-circuit boards (PCBs). For example, Synergy Microwave Corp. (www.synergymwave.com) offers a line of fixed-value attenuators in eight-pin miniature relay headers for handling as much as 0.5 W power from dc to 1500 MHz. These devices include values of 3, 6, 10, 15, 20, 30, and 40 dB with attenuation flatness of ±1 dB or better.

Mini-Circuits supplies fixed, variable, and programmable attenuators spanning dc to 40 GHz in surface-mount packages as small as 2 × 2 mm. The LAT-10+ is part of a line of components with fixed values from 0 to 40 dB in 0.12- × 0.10- × 0.047-in. housings. It provides 10-dB fixed attenuation from dc to 2500 MHz, with attenuation flatness of ±0.3 dB through 1000 MHz and ±0.5 dB through 2500 MHz.

The company's line of inline coaxial fixed attenuators, such as the VAT-1+ device *(Fig. 3)*, provides 1-dB fixed attenuation from dc to 6 GHz. It's rated for power levels to 1 W and is typically accurate to ±0.3 dB across the frequency range. Unibody construction with SMA connectors makes it easy to add to coaxial cables and systems requiring an impedance match or level adjustment.

In contrast, Mini-Circuits' ZX76-31-PP+ digital step attenuator in a compact RoHS-compliant housing offers extremely accurate attenuation over a 31-dB control range. The attenuation can be selected in 1-dB steps across a 31-dB range from dc to 2400 MHz by means of a 5-b parallel control interface. Typical attenuation accuracy is 0.2 dB for a 16-dB attenuation setting across the full frequency range.

While not the extremely tiny size of an SMT attenuator, this unit and other members of its product family provide simple programmability and a flexible attenuation range for testing, for level adjustments in communications systems, and even for medical systems. Able to run on a single +3-V dc supply, it's built for tough environments. mw

Design Feature

JACK BROWNE | Technical Contributor

What's the 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.

Amplifiers come in many shapes and sizes, especially as device technologies such as gallium nitride (GaN) have achieved high output levels in small packages. But in some cases, older technologies such as traveling-wave-tube amplifiers (TWTAs) are still in use and still useful solutions for many applications. There are clear differences between solid-state amplifiers and TWTAs in terms of output power, packaging, and power supplies, and understanding the differences between the two technologies helps to simplify the process of choosing the optimum amplifier for an application.

The microwave industry once relied heavily on TWTAs for amplification, although solid-state power amplifiers (SSPAs) have made great inroads over the last few decades, starting with silicon bipolar transistors, then extending at higher frequencies with gallium arsenide (GaAs) transistor devices, to a present-day expansion of applications relying on solid-state amplifiers that build upon GaN transistors and integrated circuits (ICs). Fans of solid-state amplifiers like to point out that they are not victims of the single failure point (the tube) as in TWTAs, although TWTAs typically deliver reliable operation and long operating lifetimes, even with the single failure point compared to SSPAs. TWTAs are still used in broadband applications, such as broadcasting, radar, and satellite communications (satcom) systems. Two types of tube devices are used in these amplifiers: broadband amplifiers are typically based on helix TWT devices while narrowband amplifiers may use coupled-cavity TWTs in amplifiers at higher power levels.

1. Model PTS6900 is an SSPA capable of 150 W CW output power with high gain from 2 to 6 GHz.

While debate may still rage over which technology—vacuum tube versus solid state—is better suited to RF/microwave applications, the technologies have generally settled into fitting different requirements and needs, with the generalizations often made that TWTAs can provide higher output-power levels for a given microwave frequency range than solid-state amplifiers, although their housing may be larger and heavier and have higher power-supply requirements. But at least one firm, TMD Technologies Ltd. (www.tmd.co.uk), has been pushing to overcome the size differential typical between solid-state amplifiers and TWTAs, although the tube amplifiers usually are capable of higher output-power levels, especially at higher frequencies. In fact, as solid-state devices tend to lose output power at upper microwave and millimeter-wave frequencies, tube amplifiers are still valid solutions for applications at these higher frequencies.

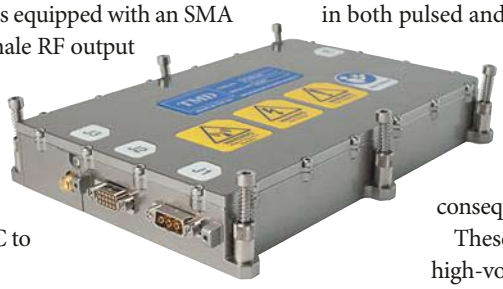
SIDE BY SIDE

Perhaps the easiest way to evaluate the difference between an SSPA and a TWTA is to compare the performance levels and characteristics of two commercial products, such as the model PTS6900 SSPA and the PTXM1000 range of mini-TWTAs, called microwave power modules (MPMs), both from TMD Technologies. Both were developed to serve the defense and aerospace markets.

The PTS6900 SSPA *(Fig. 1)* is an SSPA supplied in a compact housing measuring 325 × 200 × 50 mm and weighing 4.5 kg. For a solid-state amplifier, this is very "tube-like" in its performance, with 150 W continuous-wave (CW) output power from 2 to 6 GHz. It delivers 55 dB typical gain, which is adjustable over a range of 50 to 60 dB. The gain remains stable within a 2-dB window across the frequency range. The solid-state amplifier is intended mainly for wideband electronic-countermeasures (ECM) and electronic-warfare (EW) applications, but can be used in any application that requires a high power level over such a broad bandwidth. It is fully compliant with the conducted and radiated electromagnetic-compatibility (EMC) requirements of MIL-STD-461F.

The rugged amplifier builds upon 0.25-µm GaN MMIC power amplifier technology and the use of low-loss power combiners to preserve the output levels achieved by multiple GaN devices. The SSPA module can be supplied with a heatsink to control heat buildup, or without one and mounted onto a metal surface or other means of dissipating the heat generated by the active devices.

The SSPA amplifier is designed to operate with a +28-VDC power supply. It minimizes harmonic levels to –20 dBc or better and exhibits a noise figure of 10 dB. It is equipped with an SMA female input RF connector, a TNC female RF output connector, and an SMA female sample RF output connector, with circular military type monitor and control connectors and primary input power connector. The amplifier is designed for operating temperatures from –40° C to +70° C and altitudes of 0 to 70,000 ft.



2. The PTXM series of TWTAs includes broadband, compact models capable of more than 100 W output power across wide bandwidths to 18 GHz.

The 2-to-6-GHz SSPA is completely ITAR-free. It provides an instant startup as well as a fast mute time (only 1 µ) along with extremely high reliability of more than 30,000 hours mean time before failure (MTBF). The SSPA includes DC/DC converters and EMI filters to be fully compliant to MIL-STD-704F & MIL-STD-461F.

So how does it compare with or differ from a tube amplifier? The broadband MPMs offered by TMD Technologies compare in size and weight to their solid-state amplifiers. The PTXM series of MPMs *(Fig. 2)*, including the model PTXM1001 with 100-W CW output power from 6 to 18 GHz and as much as 140 W saturated output power from 6 to 13 GHz, take advantage of miniature TWTs and extremely efficient packaging to achieve small size even with broad frequency ranges and high output-power levels. Measuring only 205 × 120 × 36 mm and weighing no more than 1.95 kg, the PTXM1001 TWTA operates at a 100% duty cycle and delivers 100 W typical output power from 6 to 18 GHz. The nominal small-signal gain is 58 dB.

While it lacks the gain adjustment range of the 2-to-6-GHz SSPA, it is a somewhat higher-density design that includes an optimized switch-mode power supply for the tube. By integrating the power supply with the tube, rather than combining them as separate units, it is possible to eliminate interconnections between the two and reduce the overall size of the MPM housing. Because a number of different TWTs can fit into the amplifier package, the basic design can be configured for a number of different frequency ranges and output-power levels. The model PTXM1001 MPM is well suited for EW and communications applications and is one of the models that can operate in both pulsed and CW modes of operation. In conjunction with the small size of their enclosures, this series of MPMs features excellent thermal management, to ensure minimal heat buildup from the TWTs inside the housing and consequently high reliability.

These MPMs include a design in which the high-voltage section is fully encapsulated. This ensures that the tube amplifier can operate at high altitudes and high humidity and will survive high levels of vibration and shock for operation in the harshest military environments. The small size and weight of these high-power tube amplifiers has made them attractive for use in some emerging military applications.

According to TMD Product and Technology Development Manager Dr. David Cook, "The exceptionally low weight and small size of these units, but with no loss of power or reliability is a big advantage for airborne applications such as UAVs—or indeed any situation where space and weight are critical. The modular design makes it easier to manufacture and test each module separately, resulting in lower cost and greater flexibility."

In short, the difference between SSPAs and TWTAs (or MPMs) is no longer that obvious, although the tube amplifiers are still capable of higher output-power densities than solid-state amplifiers. But as designers learn to make tubes and the surrounding circuitry more compact, tube amplifiers are now rivaling the size of solid-state amplifiers for a given frequency and power level. mw

WHY DOES THE INTERNET OF THINGS NEED DIFFERENT WIRELESS STANDARDS?

THE EXPLODING GLOBAL market for wirelessly interconnected devices has RF/microwave companies working diligently to develop technologies and create solutions for an Internet of Things (IoT) world. Key to the process is choosing the right wireless protocols and wireless networking technology when implementing IoT solutions. In an application note from Texas Instruments, titled "Wireless Connectivity for the Internet of Things," the author provides an overview of the wireless technologies connecting commercial and industrial devices.

Among the critical factors cited are an IoT solution's network range and topology. In terms of network ranges, choices include personal-area networks (PANs), local-area networks (LANs), neighborhood-area networks (NANs), and wide-area networks (WANs). Different technologies better suit the key features of each network range, though. For example, Bluetooth is a common solution for PAN systems, but isn't as well equipped for LAN systems (unlike Wi-Fi).

Power and noise are the main limiting factors for throughput and range. As a result, each wireless technology leverages a variety of techniques to balance throughput and range with respect to its application. Generally, a network with a wider range will require more transmit power. Also, the maximum transmission data rate of will be lower.

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A mesh network topology can be created to increase a network's range without boosting the power and coverage area of a single node. A mesh network differs from a star network in that all of the nodes of a mesh network can exchange data to each other. They can even hop data from one node through another, and then onto the third node.

Many IoT and wireless-networking companies lack the resources or justification for producing their own proprietary wireless-networking standard. As a result, they must choose from already existing common standards. From sub-1-GHz to ZigBee/Bluetooth, the various wireless-networking standards each have strengths in different application spaces. They also operate with different network topologies in mind. The latest device concepts, for example, have configurable RF front-ends capable of multiple wireless standards, high-security systems, and ease of integration.

KNOW WHETHER TO MOUNT, REFLOW, OR BOLT DOWN RF TRANSISTORS

RF POWER TRANSISTORS channel significant amounts of RF energy. As a result, substantial considerations must be given to thermal flow, RF isolation, structural integrity, and electrical-connection reliability when inserting these components into an assembly. Over the years, various techniques have been developed to mitigate the design and manufacturing concerns over mounting and soldering RF power transistors. In an application note titled "Mounting and Soldering RF Transistors," NXP Semiconductors elaborates on good practices and manufacturing techniques for electrical, mechanical, and thermal considerations.

NXP Semiconductors,
411 E. Plumeria Drive,
San Jose, CA 95134,
www.nxp.com

When attaching air-cavity packages, a common practice is to use thermal compound as well as solder to attach the RF transistor to the printed-circuit-board (PCB) copper and substrate. Many of these methods depend on the manufacturing process used for PCBs. For example, when using a solder-mask-defined (SMD) pad process, a layer of the solder mask is left to create a ridge and a gap between the flange of the transistor and the PCB pad. In addition, the SMD pad process may not ensure adequate PCB aperture for transistor insertion, which includes providing enough curved radius at the aperture corners of the insertion rectangle. Conversely, the non-solder-mask-defined (NSMD) pad method does not exhibit the mask layer riding over the copper, leading to a more flush metallic contact.

NXP's note explains that a good contact connection is essential for effective heatsinking. Other key aspects include PCB thickness, interface thickness, solder thickness, heatsink dimensions, thermal-compound thickness, and Q dimensions. Furthermore, the surface finish of the heatsink material and transistor package affects the thermal transfer to the heatsink. Surface imperfections, such as burrs, grooves, and particulates, can degrade the thermal transfer. They also may create hot spots between the metallic, plastic, or ceramic materials.

While detailing the thermal considerations of solder joints and transistor placement, the note explains how to determine the effective lower and upper thresholds for the solder joints to form reliable connections. Because the PCB board assembly will not face equal distribution of heat across the board, hot and cold spots will form on the board. When the coldest spot sits above the lower-end threshold and the hottest spot is above the upper threshold, a reliable soldering process can be performed.

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Spotlight Feature

JACK BROWNE | Technical Contributor

Real-Time Scope "Sees"

This compact housing belies the innovative architecture that carries this new series of digital oscilloscopes to measurements across an analog bandwidth of 70 GHz.

Use of the frequency spectrum continues to climb into the higher frequencies. Once regarded as a mere curiosity, millimeter-wave frequencies are becoming commonplace, increasingly being used to transfer high-speed data across short distances. Of course, to maintain such communications functions, testing at those millimeter-wave frequencies is necessary.

On that front, the DPO70000SX 70-GHz oscilloscope developed by Tektronix (www.tek.com) is designed for the needs of today and tomorrow, with high resolution across a 70-GHz bandwidth and a lightning-fast sampling rate of 200 Gsamples/s. This instrument captures and displays the most elusive of signals at frequencies through 70 GHz, which aids developers of both microwave and optical systems.

The first impression of the DPO70000SX oscilloscope *(Fig. 1)* is its low-profile housing in a housing that stands a mere 5.25 in. tall, or about one-half the height of a standard oscilloscope. Admittedly, the low profile translates into a relatively compact display screen. But in a research-and-development (R&D) measurement application, the DPO70000SX oscilloscope can be teamed with an external display screen *(Fig. 2)* for ease of viewing. The scope's compact-size housing also makes it easier to place the instrument closer to a device under test (DUT).

1. The DPO70000SX 70-GHz ATI oscilloscope packs lots of technology into a housing about one-half the size of a conventional oscilloscope.

All models in the new series deliver better than 25-GHz edge-trigger performance, with glitch-trigger performance of better than 30 ps. They employ a new window-type trigger that can be applied on the envelope of RF/microwave signal bursts, and use time qualifications to discriminate precise widths of those envelopes. A pulse-width timer makes it possible to discriminate specific pulse widths in high-speed serial data streams, as well as identify "runt" or random pulses as part of pseudo-random pulsed signal trains. The trigger input features low-jitter edge triggering, and can be used with a number of the firm's different signal-conditioning accessories.

CHANNEL OPTIONS

The DPO70000SX oscilloscope offers a high degree of measurement flexibility, since it can be used as a single- or dual-channel scope. As a dual-channel oscilloscope, it captures signals across each of two 33-GHz-wide channels at a sample rate of 100 Gsamples/s per channel. In two-channel mode, it can handle single-ended signal levels from 62.5 to 6.00 V (full scale of reading).

When all of the measurement power is focused into a single channel, the scope operates across a 70-GHz bandwidth with better than 6-ps rise time and a sample rate of 200 Gsamples/s. In single-channel operation, it handles single-ended signal levels from 100 to

To 70 GHz

300 mV (full scale of reading). In either operating mode, the instrument provides as much as 1-Gsample/s record length.

When two channels are not enough, the UltraSync bus integrated into each oscilloscope helps achieve multiple-instrument hookups with precise timing for high-speed measurements. The bus synchronizes sample clock, trigger, and run-stop control across multiple oscilloscopes with performance matching that of a single instrument. The UltraSync bus employs a 12.5-GHz sample clock reference source and coordinated trigger bus to minimize jitter—between channels and from acquisition to acquisition—to less than 500 fs RMS.

The oscilloscope's high-speed data path makes it possible to transfer waveform data from extension instruments to a master instrument in a multiple-instrument measurement system. Since each scope in a multiple-instrument setup processes its own acquired signals, it sends processed waveforms to a master unit, helping to maintain top performance even when adding more instruments to a setup.

In addition, the oscilloscope can be controlled remotely over the Internet via a Windows Remote Desktop utility. Network cables for UltraSync connections come in 1- and 2-m lengths for different instrument setups. Any DPO70000SX oscilloscope in a multiple-instrument setup can function as the master, controlling the other units that operate in extension mode. Those roles are determined by the way the UltraSync cables are attached. At the same time, each oscilloscope includes its own display screen, and can function as a standalone unit when needed.

LEVERAGING ATI

The DPO70000SX oscilloscope incorporates patented asynchronous-time-interleaving (ATI) technology. The firm employs a unique method for digitizing a full spectrum under study by means of multiple, parallel signal paths. Each path leads to its own sampler, low-pass filter, and analog-to-digital converter (ADC), and then to a common digital-signal processor (DSP) for operating on the digitized waveforms. The approach preserves the signal-to-noise ratio (SNR) to achieve high signal fidelity within the oscilloscope.

This method deviates from legacy frequency-interleaving approaches that essentially analyze a portion of spectrum by dividing it into parts and analyzing them separately, through separate ADCs. Each ADC only sees its part of the spectrum under study; the spectrum parts are added together to create

SEEING THE LIGHT AT 1550 NM

FOR THOSE INVOLVED with next-generation optical-modulation communications systems, including in 100G and 400G systems, the OMA4245 optical-modulation analyzer (OMA)—a high-performance "accessory" for the DPO70000SX digital oscilloscope—may very well become an essential tool *(see figure)*. Developed by Tektronix (www.tek.com), the OMA4245 has a bandwidth of 45 GHz or an optical wavelength of 1550 nm. The analyzer provides support for single- and multiple-carrier optical networks, and is compatible with equivalent- and real-time oscilloscopes, such as the DPO70000SX. It can provide coherent optical analysis at rates to 80 Gbaud.

Textronix's OMA4245 optical-modulation analyzer, featuring a 45-GHz bandwidth and 1550-nm optical wavelength, delivers optical analysis rates of up to 80 Gbaud.

At first glance, the instrument enclosure for the OMA4245 is similar to that of the DPO70000SX oscilloscope, and the two instruments will fit together quite well and compactly in a workplace. The OMA4245 incorporates a narrow-linewidth local oscillator (LO) and utility lasers to measure complex modulated optical signals in both coherent and direct-detected transmission systems.

Essentially, the OMA4245 consists of a polarization- and phase-diverse receiver that's teamed with analysis software for simultaneous measurements of various modulation formats commonly used in optical communications systems. These formats include quadrature phase-shift keying (QPSK), eight-state quadrature amplitude modulation (8QAM), and 16-state QAM (16QAM).

2. Two DPO70000SXs can show results on an external monitor, and be locked to perform like multiple channels on a single instrument thanks to UltraSync cables and the UltraSync bus.

a final bandwidth, without the benefits of an improvement in SNR. In some cases, because of the summation of spectrum portions, noise levels over the fractional bandwidths could increase before they are added together.

In Tektronix's ATI approach, input signals are sampled and digitized with the aid of a special ATI application-specific IC (ASIC). Input signals for analysis are processed through parallel, symmetrical digitizing signal paths, each with a sampler, low-pass filter, and high-speed ADC. Each path digitizes the full input signal under study at a rate of 100 Gsamples/s before passing it to a common DSP. The alternating phase of the sampler in each digitizing path, in effect, inverts the signal path of one digitizing path 180 degrees out of phase compared to the other digitizing path. Once the two signal paths are reconstructed into one signal, the alignment of the signal phases results in positive reinforcement of desired signals and cancellation of noise. Overall, the approach results in a 3-dB reduction in noise for the analyzed signals.

ATI digitizes two copies of the full signal and surrounding energy for analysis, which are then processed by means of the DSP component near the output port of the ATI ASIC. The DSP uses a version of the sampling process to combine the two signals that were originally split off from the signal under test and reproduce a digitized version of the signal at the output port. Any phase inversion introduced by the sampling process results in the cancellation of intermediate-frequency (IF) mixing products and noise. The approach offers advantages over digital-bandwidth interleaving techniques often used for broadband coverage in digital oscilloscopes. With the latter, input signals are divided into different frequency bands and then reconstructed for analysis, leading to errors in amplitude and phase response but little reduction in noise.

ENHANCE WITH SOFTWARE

When aided by a personal computer with the appropriate test software, such as Tektronix's SignalVu-PC, a DPO70000SX digital oscilloscope can perform advanced measurements in the instrument's multiple domains, including in frequency, time, and phase domains. Measurements completed with the software are fully correlated with the oscilloscope's time-domain reference and triggering capabilities. Any number of items, such as particular RF/microwave signals, can be utilized for triggers in the different domains (in this case, in the frequency domain).

The software can be used to set up measurements on a wide range of different signals, including those with frequency hopping and in-phase (I) and quadrature (Q) modulation. The software simplifies performing complex measurements on modulation, pulse characteristics, changes in bandwidth, and settling time. For instance, users are able to quickly create and apply custom filtering to a measurement setup, such as a system for vector signal analysis. The measurement software, which functions in the Microsoft Windows PC operating environment, can create an almost unlimited number of analysis windows on the PC display screen, with all of the windows correlated in time.

The DPO70000SX features 53 built-in automatic measurements, organized into different categories, such as time-, amplitude-, and communications-based measurements. Each oscilloscope's built-in analysis system makes it possible for an operator to apply mathematical expressions to waveform data or create their own algebraic expressions for analysis. For ease of use, the functional editor comes in the form of a straightforward calculator.

In short, each model DPO70000SX digital oscilloscope brings with it an enormous amount of measurement power in a small package. A single unit provides one or two channels to 70 GHz; two of the instruments together provide two 70-GHz channels or four 33-GHz channels. It can go on and on, depending on measurement needs (and budget). Pricing is $315,000 and up for a 70-GHz unit. mw

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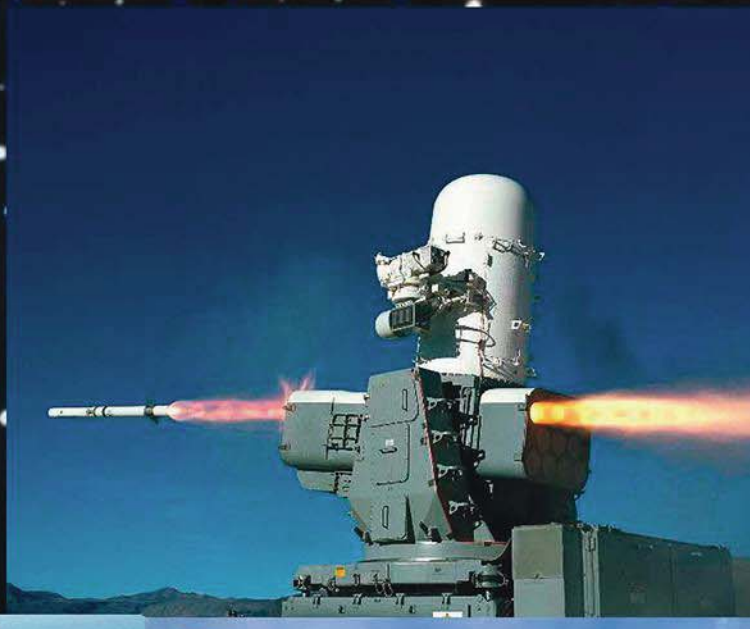

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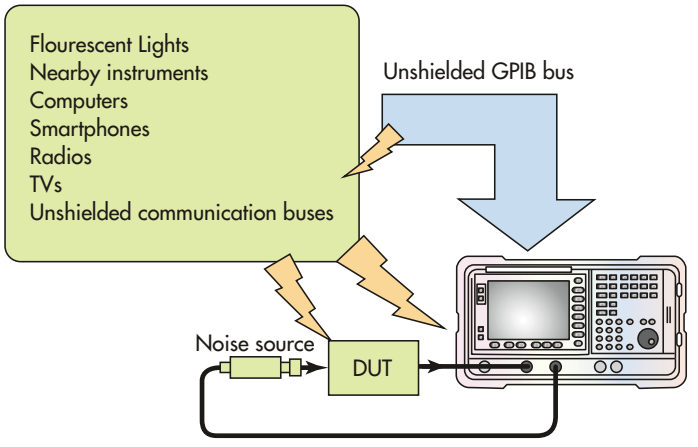
JEAN-JACQUES DELISLE | Technical Engineering Editor

6 Technologies and Techniques to Know for Measuring Noise Figure

Innovations in noise-figure and noise-parameter measurements could reduce testing time and increase accuracy to millimeter-wave frequencies.



1. In addition to the calibrated noise source used in a noise-figure measurement, many other noise generators add uncertainty to a noise measurement.

IN SMARTPHONE AND portable-device use, Internet of Things (IoT) wireless sensor networks, and military networks, wireless radio technologies are breaking barriers in terms of throughput and low-power transmission and reception. Yet the effects of noise degradation scale with such performance extremes *(Fig. 1)*. Historically, testing and characterizing the noise figure and noise parameters of the devices driving these applications has been both time-consuming and error-prone. Such challenges are now being overcome by performance enhancements in recent test and measurement instruments; optional packages designed specifically for noise testing; and automation techniques. These developments are ushering in more efficient solutions for both noise-figure and noise-parameter testing. Knowledge of these methods and their implementation can aid in greater measurement accuracy and drastically reduced testing time.

1. Y-Factor with noise source and spectrum/signal analyzer. The Y-factor method is one of the most common solutions for providing noise measurements. Essentially, this method uses a noise source connected to the device under test (DUT). The DUT, in turn, is connected at the input of an RF/microwave power-sensing device. With the noise source "on" and "off," measurements of the signal power are taken over by a set bandwidth. The ratios of noise power in the "on" and "off" states are taken to generate the Y-factor. With the excess noise ratio (ENR) specification provided by the noise-source manufacturer, the noise factor of the test system can be calculated next. Using knowledge of the DUT's gain and the noise figure of the test-system components, it is then possible to extract and calculate the noise figure of the DUT.

To shorten noise-figure measurement times while increasing accuracy and repeatability, optional packages have been made available for several recent spectrum/signal analyzers. Companies such as Keysight, Tektronix, Anritsu, and Rohde & Schwarz offer options that include a software enhancement that guides an engineer through the measurements. Doing so ensures repeatability while automatically calculating the noise figure from the noise factor measurements. Keep in mind that these measurements require calibrated noise sources with known ENR. Such sources are provided by companies like Noisewave, Keysight, Noisecom, Pasternack, and Mercury Systems.

When using spectrum/signal analyzers with very-low-power noise signals, a low-noise amplifier (LNA) will need to be added to the analyzer's signal chain. Many of the companies that provide noise-figure options include low-noise

> "To measure noise figure, the cold-source solution employs a noise source held at a reference cold temperature, a network analyzer, and several step-calibration and gain measurements."

preamplifiers for their spectrum/signal analyzers. Those preamplifiers are even built into the analyzer. With the internal preamplifier, measurement accuracy is increased while test-set component count and calibration complexity are reduced.

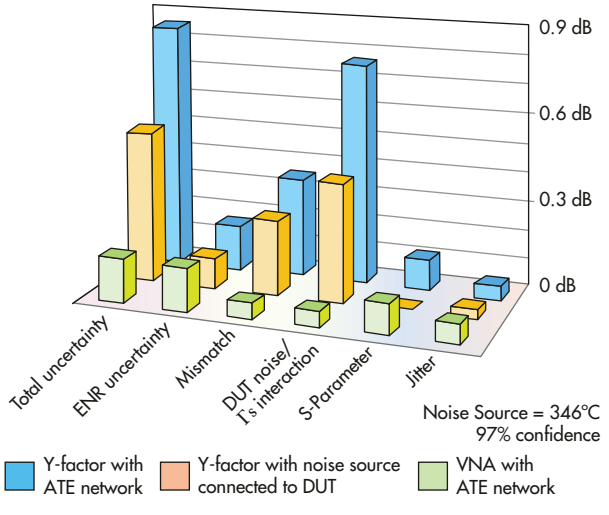
Many of the latest spectrum/signal analyzers reach 26.5 GHz and 43 GHz with a native analyzer from Rohde & Schwarz recently hitting 67 GHz. These analyzers allow noise measurements to be performed into the upper microwave and millimeter-wave bands without the need for external mixers. With external mixers, noise measurements to 110 GHz can be obtained with a spectrum/signal analyzer and the Y-factor method *(Fig. 2)*.

2. The cold-source or gain solution. To characterize and measure noise figure, the cold-source solution employs a noise source held at a reference cold temperature, a network analyzer, and several step-calibration and gain measurements. A calibrated noise source is utilized to measure the noise figure of the instrument's receiver while the network analyzer measures the DUT's gain. Once the prior measurements have been performed, the cold source can drive the DUT connected to the network analyzer. With the latest network analyzers with noise-figure packages, an additional pre-amplifier is often included inside the network analyzer. It enhances low-noise measurement capability *(Fig. 3)*.

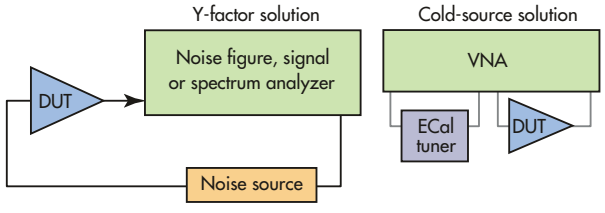
Similar to spectrum/signal analyzers with noise-figure packages, network-analyzer noise-figure packages often include software guides that aid in increasing test repeatability. With this method, the noise figure and S-parameters of a DUT can be measured in the same test setup. This aspect enhances the automation potential of the approach. An automated-test-equipment (ATE)-based setup could provide very rapid chip-and larger-device-level noise-figure testing. Obviously, automating the cold-source method could prove more repeatable and reliable than using multiple instruments and test setups.

Conveniently, software programs like MATLAB and LabView also include instrument-control and analysis toolboxes. These toolboxes enable the control and analysis of test instruments that can create complex and user-defined ATE systems. When coupled with ATE systems, software control and analysis tools enable the rapid and repeatable use of additional testing devices, such as impedance tuners, for optimizing the low-noise performance of non-50-Ω devices. An example is finding the noise figure of unmatched transistors and low-noise amplifiers (LNAs). Here, the minimum noise-matching impedance can be found with an impedance tuner in conjunction with a cold-source, network-analyzer noise-figure measurement setup. Companies like Maury Microwave and Focus Microwaves offer impedance tuners, some of which are manual or automated. They can range from 2 to 26 GHz and 8 to 50 GHz for Maury Microwave tuner systems and from 100 MHz to 67 GHz for Focus Microwaves' coaxial impedance tuners.

3. Noise-figure analyzer/meter. Noise-figure analyzers (NFAs) are one-box solutions for Y-factor-based noise-figure measurements. In contrast to a noise-figure meter, spectrum analyzer, or network analyzer, an NFA is a dedicated instrument. Its control interface and display are designed specifically for noise-figure measurements. Currently, Keysight offers a series of NFAs from 3, 6.7, and 26.5 GHz.



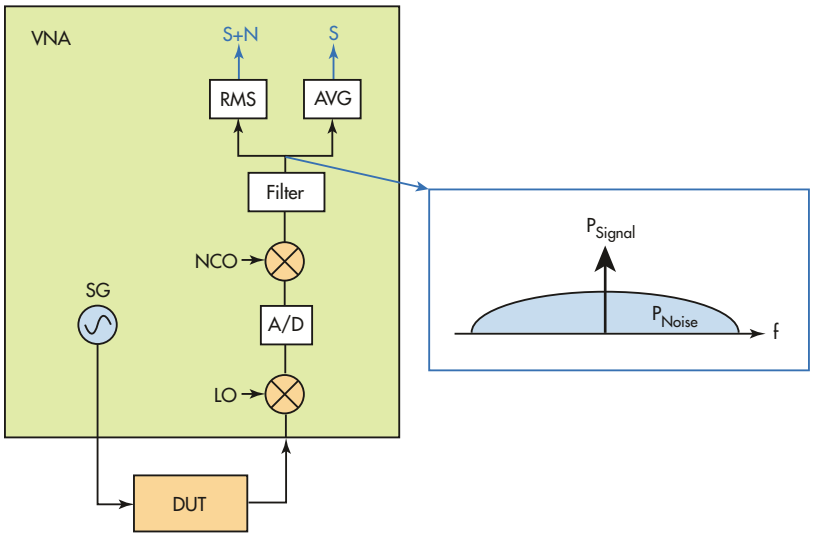
2. The Y-Factor solution requires a calibrated noise source external to the analyzer and DUT, whereas the cold-source method generally demands an electronically calibrated tuner.



3. Compared to the Y-Factor method, high-performance VNAs with automated test equipment—using the cold-source method—can significantly reduce the DUT's reflection and noise interaction during a noise test.

Using block downconverters, extensions to 110 GHz are possible. NFAs have an added benefit of being equipped with an internal preamplifier. When seeking similar frequency and quality of measurement, an NFA is often the most cost-effective option—unless a spectrum/signal and network analyzers equipped with noise-measurement options are already available.

4. VNA-only noise-figure and s-parameter measurements. A VNA with direct receiver access and internal-generator step attenuators offers a highly flexible approach to noise-figure measurements. And it does so without an external calibrated ENR noise source and impedance tuner. The VNA-only setup uses the continuous-wave output of the VNA along with the direct-receiver access port (potentially with a built-in preamplifier) and several calibration steps to perform both noise-figure and S-parameter measurements. Rohde & Schwarz provides an option to its ZVA network analyzers that enables a software walkthrough of the process, thereby eliminating errors and reducing uncertainty. Varying measurement setups are possible, depending upon the type of DUT under test *(Fig. 4)*.



4. A new noise-parameter measurement technique uses a high-performance VNA, calibrated noise source, and an automated tuner to raise noise-parameter characterization even into the millimeter-wave frequencies. *(Courtesy of Keysight)*

5. Rapid noise-parameter measurements. Noise-figure measurements may help to quantify, certify, or verify the noise response of a device under certain conditions. Yet the noise figure may not provide insight into the noise effects and contributors within a device. Deeper insight into noise generators and the way noise propagates through a device is needed to optimize a device for low noise or other performance factors. Such information may be gained by generating the noise parameters. Yet this step often requires highly specialized hardware and long test times ranging from several hours to many days. Traditionally, a VNA, calibrated noise source, noise-figure analyzer, and an external tuner are all needed to test the noise response at each frequency under a series of source impedance points. This test significantly compromises frequency and impedance resolution for testing time *(Fig. 5)*.

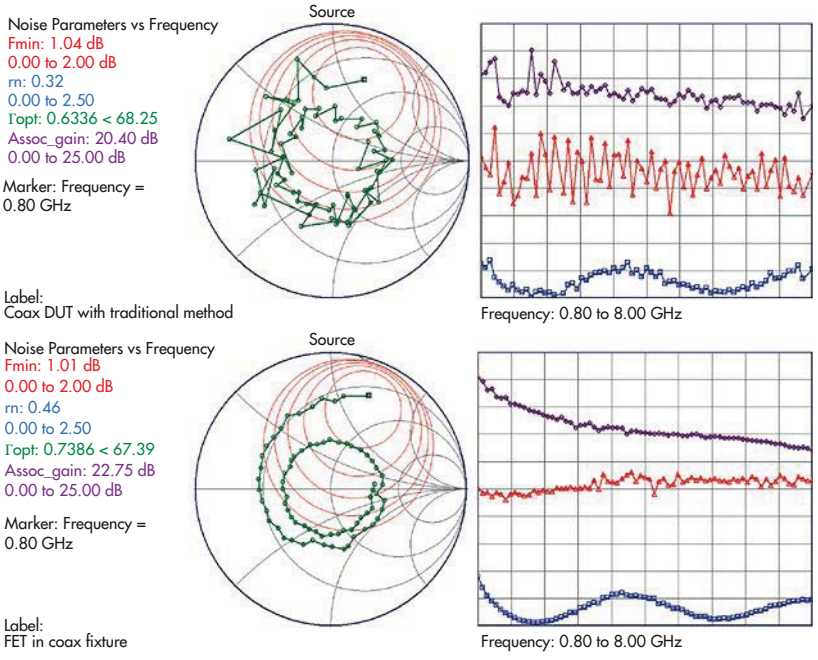
5. The noise-figure measurement method used by the ZVA and ZVT series VNAs requires no additional components. It leverages the noise variable difference from a continuous-wave signal input to the DUT. *(Courtesy of Rohde & Schwarz)*

Recently, Keysight Technologies and Maury Microwave developed a test solution that is designed to significantly automate and shorten noise-parameter measurements. The solution uses Keysight's PNA-X network analyzer with an integrated noise receiver option and a calibrated noise source together with Maury Microwaves' impedance tuner and automated tuner-system software for noise-parameter measurements. Test times for high-resolution noise-parameter measurements using this solution may reportedly be reduced by a factor of a few hundred. At the expense of additional testing time, it provides the opportunity to gain greater detailed noise-parameter responses by increasing the test resolution to a much finer degree.

6. Millimeter-wave noise-figure and noise-parameter measurements. As interest in imaging and millimeter-wave backhaul, 5G, and other wireless communications continues to grow, several companies have begun offering refined noise-figure and noise-parameter measurement systems that can reach beyond 100 GHz. Many spectrum/signal analyzers and network analyzers offer frequency operation to 26.5, 43, and 50 GHz. Block downconverters and mixer solutions raise those noise-figure measurements to 100 and 110 GHz. For example, Rohde & Schwarz has released a spectrum/signal analyzer with a receiver response to 67 GHz. It can enable Y-factor noise-figure measurements into the millimeter waves without external mixers.

Notably, the addition of Maury Microwaves' noise-receiver module to the automated noise-parameter test setup enables wideband noise-parameter measurements between 8 and 50 GHz. The noise-receiver module can reduce the second-stage noise figure caused by the internal noise receiver of the VNA by 5 to 6 dB. Without the noise-receiver module and external wideband impedance tuner, an external electronic calibration kit or the PNA-X's built-in electronic tuner can be used to test noise parameters with less sensitivity. Yet this solution only serves devices with near-50- Ω impedances *(Fig. 6)*.

Another millimeter-wave-capable example of the cold-source approach is Anritsu's VectorStar VNA with a noise-figure option. In a standard configuration, the VectorStar exhibits dynamic-range performance to 142 dB. The standard model



6. Using an automated noise-parameter measurement technique can result in measurements with less uncertainty, partially by reducing thermal variations, drift, and human calibration errors. ***(Courtesy of Keysight)***

covers 70 kHz to 70 GHz. Enhancements for the analyzer can bring the native frequency response to 145 GHz in a broadband configuration. Regarding noise-figure measurements, the VNA with the noise-figure option can measure from 70 kHz to 125 GHz with an optimized noise receiver for measurements from 30 to 125 GHz. The power output of the VNA reaches +14 dBm, which would aid in testing a wide range of DUTs with directivity, source-match, and load-match test-port performance to 50 dB. Additionally, hardware options are available to extend the VectorStar VNA to 1.1 THz. Note, however, that this configuration operates in different frequency bands as opposed to a complete broadband configuration. mw

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For noise-parameter and noise-figure measurements, tradeoffs can be made between cost, time, frequency, and quality, depending upon the test equipment available.

Product Feature

JACK BROWNE | Technical Contributor

Instruments Team for Affordable Analysis

The introductions of a cost-effective VNA and a line of powerful analog and digital oscilloscopes simplify frequency- and time-domain measurements through 33 GHz.

IN ANTICIPATION OF the upcoming IEEE International Microwave Symposium (IMS) exhibition week in Phoenix, Ariz. (see p. 38), Keysight Technologies has unveiled several new instruments that should be of interest to many show-floor visitors. Two of the instruments—the model E5080A ENA network analyzer and the Infiniium V-Series oscilloscopes—bring a great deal of high-frequency analysis power, and are aimed at "midyear budgets." In spite of their practical pricing, these new instruments bring the highest levels of accuracy and great measurement power, and will be on display at IMS booth No. 739.

The E5080A ENA vector network analyzer *(Fig. 1)* is well suited for research and production environments. It is available with two- and four-port test sets with versions for use from 9 kHz to 4.5 GHz; 9 kHz to 6.5 GHz; and 9 kHz to 9.0 GHz. Although these instruments are not designed to replace the company's metrology-standard line of PNA vector network analyzers (VNAs), they deliver a good percentage of the PNA performance at a fraction of the price.

The E5080A ENA analyzers are available with a bias T for active device measurements. Results are shown on a bright 12.1-in. thin-film-transistor (TFT), liquid-crystal-display (LCD) touchscreen display with 1280 × 800 pixel resolution *(Fig. 2)*. The analyzer is equipped with Type-N female front-panel connectors and a rear-panel BNC female connector for external triggering purposes.

In spite of the E5080A ENA analyzers having been developed as cost-effective alternatives to the PNA analyzers, they deliver outstanding performance in their own right. For example, they maintain wide dynamic measurement range across the frequency range, even though these analyzers reach down into the frequency range.

The typical dynamic range performance at the test port is 132 dB at the lowest frequencies (through about 100 kHz); typically 147 dB from 50 MHz to 6 GHz; 140 dB from 6.0 to 8.5 GHz; and typically 130 dB from 8.5 to 9.0 GHz.

For such large dynamic-range numbers, the E5080A ENA analyzers still perform quickly, with measurement speed of 3 ms for testing with 201 points and a two-port calibration. Such fast measurement speed and wide dynamic range supports the testing of a number of different component types, including broadband filters.

Using the calibration kit to perform a full two-port calibration, the corrected system performance in terms of directivity is better than 46 dB through 3 GHz; better than 40 dB through 6 GHz; and better than 38 dB through 9 GHz. Similarly, with the same type of calibration, the load match is better than 46 dB through 3 GHz; better than 40 dB through 6 GHz; and better than 36 dB through 9 GHz.

The test port frequency, which can be set with 1-Hz resolution, maintains standard continuous-wave (CW) accuracy of ±7 PPM at room temperature, with optional CW accuracy of ±0.45

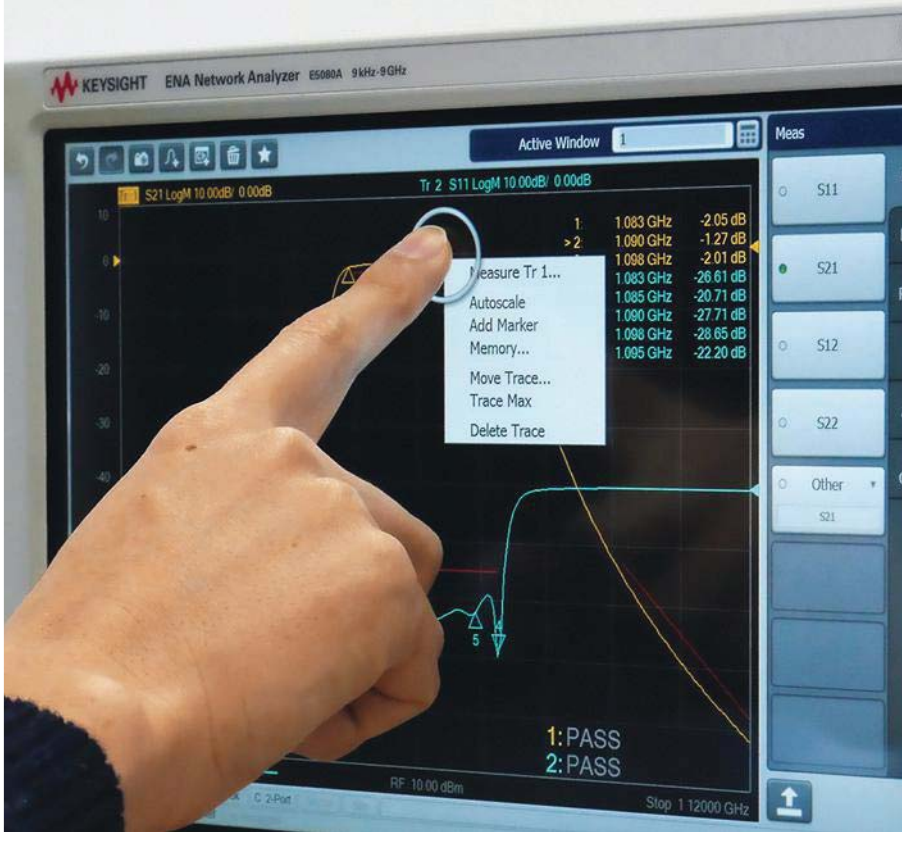
1. The E5080 ENA vector network analyzers are available in models from 9 kHz through 9 GHz.

PPM accuracy available for demanding requirements. The output power at the test port can be set with 0.01-dB resolution. It is specified as −90 to +10 dBm from 9 kHz to 50 MHz; −90 to +15 dBm from 50 MHz to 6 GHz; −90 to +12 dBm from 6.0 to 8.5 GHz; and −90 to +8 dBm from 8.5 to 9.0 GHz.

The output-power level accuracy for a stepped sweep is ±2.0 dB from 9 to 50 kHz and ±1.5 dB from 50 kHz to 9 GHz. Test port harmonics are better than −20 dBc through 9 GHz, while spurious content is better than −30 dBc through 9 GHz.

Not to be outdone, the firm introduced the Infiniium V-Series oscilloscopes, building upon an innovative front end that helps dramatically reduce noise as part of a measurement. Different models are available with test bandwidths of 8 through 33 GHz for two measurement channels and from 8 to 16 GHz for four measurement channels. The oscilloscopes *(Fig. 3)* are available as the DSO models, with four analog channels; the DSA models, with four analog channels; and the MSO models, with four analog channels and 16 digital channels. Maximum sample rates are 80 GSamples/s for two channels and 40 GSamples/s for four channels. For those who start out low in frequency and want to move higher, each model is upgradeable to a higher bandwidth.

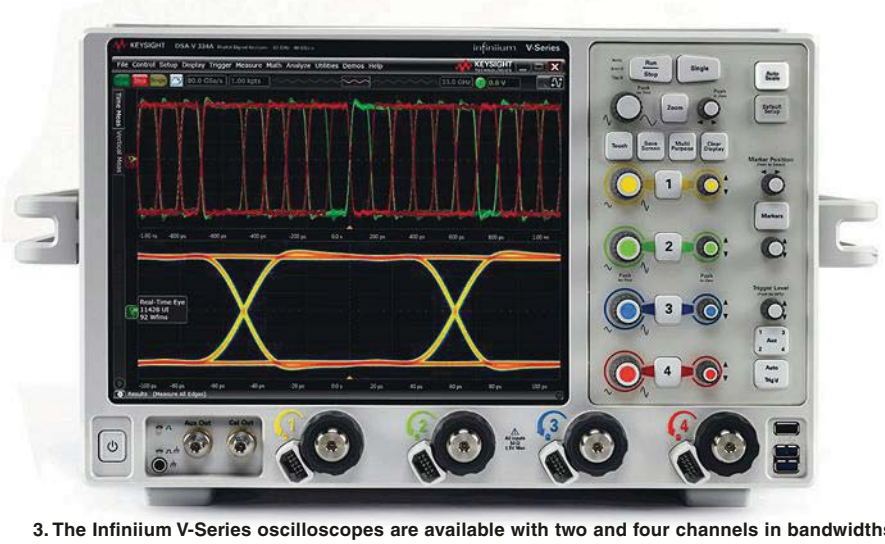
These oscilloscopes achieve remarkable 100-fs time jitter. They build on the firm's investment in indium-phosphide (InP) integrated circuits, especially for such circuits as the trigger IC, the input preamplifier, the ADC amplifier, and the probe amplifier. Together with Quick Film 3D and the use of ceramic substrate in the packaging, the InP devices are kept cool and reliable over time, and support low-loss, high-frequency operation through 33 GHz.



2. The E5080A ENA analyzers feature a 12.1-in. TFT LCD touchscreen display that allows multiple highlight zones.

Like the E5080A ENA analyzers, the Infiniium V-Series oscilloscopes show test results on a bright and flexible 12.1-in touchscreen display screen. The capacitive touchscreen supports as many as 8 waveform windows with as many as 16 separate grids in each, for as many as 128 simultaneous viewing areas, which can be extended on multiple external displays.

The oscilloscopes operate with a n optional 12.5-Gb/s serial trigger with 160-b sequence along with Spread Spectrum Clocking tracking in order to find and record even hard-to-track signal events. Data and waveforms can be stored on a standard removable 500-GB solid-state memory drive and transferred quickly by means of a USB 3.0 port. A total of five USB 3.0 ports are incorporated on each oscilloscope. MW



3. The Infiniium V-Series oscilloscopes are available with two and four channels in bandwidths of 8 through 33 GHz.

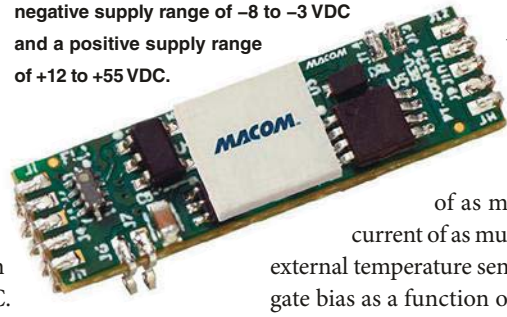
KEYSIGHT TECHNOLOGIES, INC., 1400 Fountaingrove Pkwy., Santa Rosa, CA 95403; (707) 577-2663, *www.keysight.com*

JACK BROWNE | Technical Contributor

Bias Module Keeps GaN Devices Protected

This compact bias controller and sequencer module can be used to power GaN and GaAs power devices for testing, without making the mistake of applying the wrong voltage first.

GALLIUM-NITRIDE (GAN) power transistors and integrated circuits (ICs) have caught on quickly for large-signal applications in commercial and military systems. Indeed, the technology offers impressive power levels through RF and microwave frequencies. But developing power supplies for this advanced semiconductor technology hasn't always been routine. MACOM, well-known for its GaN-based devices, has introduced a GaN bias controller and sequencer for fixed and pulsed negative gate biasing of GaN semiconductor devices. The power-supply module makes it easier to turn on (or off) a GaN semiconductor device by providing the proper gate and drain bias voltages. The module actually contains two voltage supplies, with the negative source capable of providing –8 to –3 VDC and the positive supply with an adjustable range from +12 to +55 VDC.



The model MABC-001000-DP000L GaN bias controller and sequencer module can ensure the correct voltage sequence to a GaN DUT, with a negative supply range of –8 to –3 VDC and a positive supply range of +12 to +55 VDC.

The model MABC-001000-DP000L GaN bias controller and sequencer module *(see figure)* is much more than a dual voltage supply, however. It is designed to protect GaN devices by ensuring that voltages are supplied in the proper sequence: The module will not allow a pulsed drain-source voltage to be applied to a device under test (DUT) unless the negative gate bias has already been applied. The bias controller module can be used with all of the firm's high-power transistors, including its broad line of GaN devices. It is well suited for powering depletion-mode GaN and gallium-arsenide (GaAs) power transistors and IC amplifiers.

The module is constructed of two functional elements—essentially, the drain and gate supplies for a DUT. These functional elements can be arranged vertically on a customer's test board to save space and cost. The MABC-001000-DP000L module can also be installed onto an MABC-001000-PB1PPR evaluation board as required for evaluation, test, and characterization purposes.

The first functional element is patterned and fabricated onto a customer's test board or onto the standard MACOM evaluation board. The second functional element uses the land pattern of the first functional element and interconnects vertically through the first functional element. The first functional element provides drain voltage switching while the second functional element simplifies gate switching to a GaN or other active DUT.

This bias module provides protection through proper voltage sequencing but also provides high-speed bias sequencing, with a total switch transition time of better than 500 ns. It is capable of open drain output current of as much as 200 mA and gate bias output current of as much as 50 mA. An internal thermistor or external temperature sensor voltage can be used to monitor the gate bias as a function of changing temperature under operation, and the model MABC-001000-000DPM bias module is both RoHS compliant and +260°C reflow solder compatible is designed for use in environments with heavy radio-frequency interference (RFI) and electromagnetic interference (EMI) as required, with typical EMI/RFI rejection of 30 dB at all ports.

According to Gary Lopes, MACOM's senior product director, "The MABC-001000-DP000L is ideal for a DUT such as depletion-mode GaN or GaAs power amplifiers, or HEMT devices." He added that, "in addition to these key applications, this device can be used for high power transistors including LDMOS, silicon bipolar, and more." In a standard configuration, the MABC-001000-DP000L bias module measures 6.60 × 22.48 mm and can handle operating temperatures from –40 to +85°C. mw

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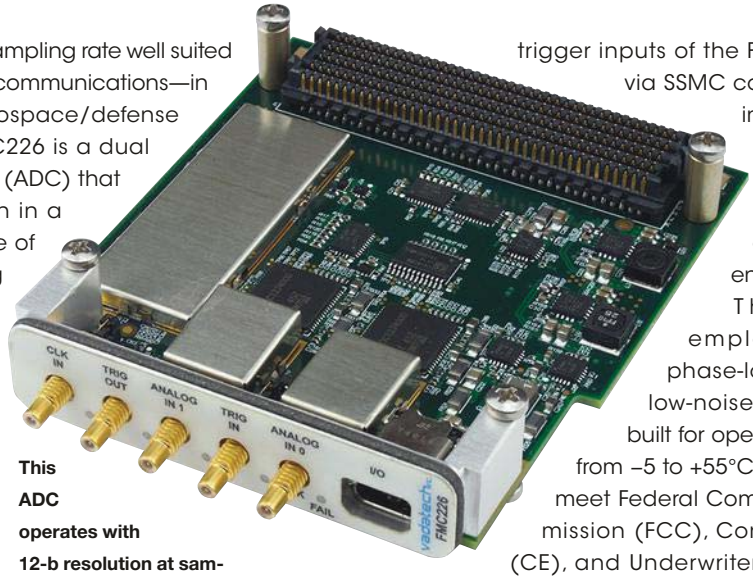
Dual ADC Tackles Radar and SIGINT

WITH A BANDWIDTH and sampling rate well suited to secure and commercial communications—in addition to numerous aerospace/defense applications—model FMC226 is a dual analog-to-digital converter (ADC) that offers high 12-b resolution in a compact module capable of a 4 GSamples/s sampling rate. It is capable of supporting an output bandwidth as wide as 800 MHz at four times the decimation rate. It includes a bypass mode to achieve the full Nyquist output bandwidth.



This ADC operates with 12-b resolution at sampling rates to 4 GSamples/s.

The compact field-programmable-gate-array (FPGA) mezzanine card (FMC) measures just 2.71 × 3.01 in. It plugs into any VITA 57 compliant circuit board. The analog input, clock input and trigger inputs of the FMC226 are routed via SSMC connectors. The ADC includes an internal clock, which is programmable, and can be locked to an external reference source as well.

This dual ADC employs a wideband phase-lock loop for stable low-noise performance. It is built for operating temperatures from –5 to +55°C and is designed to meet Federal Communications Commission (FCC), Conformite European (CE), and Underwriters' Laboratory (UL) certifications.

VADATECH, INC., 198 N. Gibson Rd., Henderson, NV 89014; (702) 896-3337, FAX: (702) 896-0332, e-mail: info@vadatech.com, www.VadaTech.com

Compact Power Module Drives 6 To 18 GHz

GAINING HIGHER POWER levels from higher-density packaging is a general trend in many broadband military/aerospace systems, and a new Class-AB linear power amplifier module from Comstock PST provides impressive power density from 6 to 18 GHz. Model BME69189-50 is a rugged power module capable of 50 W continuous-wave (CW) output power across that frequency range in an enclosure weighing less than 1.5 lb. Offering typical gain of 47 dB across the frequency range, it will overdrive its rated output-power level with +10-dBm input power.

Model BME69189-50 is a compact microwave power module (MPM) that delivers 50 W continuous-wave output power from 6 to 18 GHz.

The power module measures just 6.56 × 3.50 × 0.84 in. with field-replaceable SMA female input and output RF connectors. It achieves 14% typical DC-to-RF efficiency when running on a +28-VDC supply, consuming a mere 15 W power in standby mode. The power module minimizes noise levels, with second harmonics of typically –15 dBc and third harmonics of typically –5 dBc. Nonharmonic spurious content is typically better than –60 dBc.

For its DC/DC control interface, the power module is equipped with a 7-pin Combo D connector. It is tested to shock and vibration per MIL-STD-810F and is designed for –40 to +55°C operating temperatures. It incorporates numerous built-in test features, including notification of over-current and over-temperature conditions. The noise level at its output is measured as –105 dBm/Hz.

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

Four-Channel MMIC Powers 28-GHz Systems

HIGHER FREQUENCIES ARE being employed in everyday communications as system developers learn to make use of unlicensed millimeter-wave bands. To help with the use of higher available bands in Fifth-Generation (5G) commercial wireless communications systems, Plextek Ltd. has developed a four-channel monolithic-microwave-integrated-circuit (MMIC) amplifier with phase-adjustable channels and bandwidth of 26 to 30 GHz.

The MMIC was fabricated on a commercial 0.15-µm GaAs pseudomorphic-high-electron-mobility-transistor (pHEMT) semiconductor process, and the firm's plans include housing the device in a low-cost surface-mount-technology (SMT) package for low-volume production. Each channel in the GaAs pHEMT MMIC incorporates a power amplifier (PA) and an independently controllable 4-b phase shifter. The amplifier on each channel runs on a nominal +6-VDC supply.

The phase state of each phase shifter is controlled by a single-ended transistor-transistor-logic (TTL) compatible control line. All the logic required for controlling the phase shifters and the phase states of the four amplifier channels is included on the MMIC. With this level of phase control, the four-channel amplifier is well suited for optimum performance with phased arrays or other antenna elements in which phase must be adjusted.

The use of a 4-b phase shifter for each amplifier channel allows the insertion phase of each channel to be set with 22.5-deg. resolution. The phase error of such circuits is always a concern, and testing and simulations run on this MMIC have shown that the worst-case RMS phase error is about 2.38 deg. at around 27.5 GHz.

Each amplifier channel provides a little more than 20-dB gain from 26 to 30 GHz, with minimal gain variations with frequency. Though still in its early stages of product development, the amplifier MMIC shows great promise for filling the needs of 5G systems.

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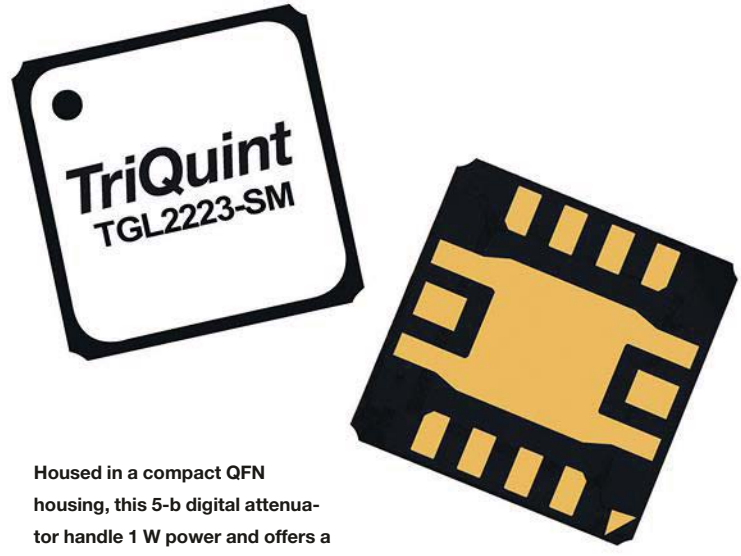
Step Attenuator Pads 0.1 To 31.0 GHz

PRECISE ATTENUATION CONTROL is now available in a small package and for a wide frequency range, courtesy of the model TGL2223-SM 5-b attenuator from TriQuint Semiconductor. With its wide bandwidth of 100 MHz to 31 GHz, the step attenuator provides a 15.5-dB attenuation range that is adjustable in 0.5-dB steps. Suitable for commercial and military applications, this 5-b digital attenuator features high accuracy and stability, with root-mean-square (RMS) attenuation error of less than 0.9 dB and RMS attenuation step error of less than 0.5 dB.



Housed in a compact QFN housing, this 5-b digital attenuator handle 1 W power and offers a frequency range of 100 MHz to 31 GHz.

The tiny attenuator measures just 3.0 × 3.0 × 1.45 mm in a QFN ceramic-air-cavity surface-mount package. It is rated for power levels to 1 W (+30 dBm) and is RoHS compliant and lead free.The attenuator suffers insertion loss of 1.8 to 4.2 dB, depending upon attenuation setting and frequency, and it operates over a control-voltage range of –3.3 to –5.0 VDC.The insertion loss is less than 2 dB from 1 to 6 GHz; less than 3 dB from 6 to 18 GHz; and less than 4.5 dB from 18 to 30 GHz.

The digital step attenuator features fast switching speed of better than 30 ns. It exhibits input return loss of better than 10 dB and output return loss of better than 7 dB. It is designed for operating temperatures from –40 to +85°C.

TRIQUINT SEMICONDUCTOR, INC., 2300 NE Brookwood Pkwy., Hillsboro, OR 97124; (503) 615-9000, FAX: (503) 615-8900, www.triquint.com

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SENIOR DESIGN ENGINEER: Required by RF Micro Devices, Inc. for a position in Greensboro, NC. Collaborate with customers/marketing engineers to architect/define/specify highly integrated solutions to wireless transceiver products for battery powered applications. On occasion, assist RF ASIC (Application Specific Integrated Circuits) development teams to develop low cost solutions to high volume, commercial RFIC's using GaAs and Silicon IC Technologies. Perform conceptual and detailed IC design of critical RF and analog elements and associated RF ASIC's. Critical RF elements include amplifiers, mixers, VCO's, high-speed dividers, power amplifiers, etc. Critical analog elements include LDO's, DCDC converters, pulse shaping bias circuitry. Interacts with all areas of the company with public interaction at conferences and in written articles/papers. PC and Workstation CAD/CAE tools used in the IC design process including Cadence, ADS, EM simulators.Knowledge of Cadence Virtuoso and Agilent ADS. Require MSEE or MS Electronics Engineering (or foreign equivalent) and two years commercial RF Power Amplifier design experience. Relocation allowances are not offered for this position. Qualified candidates please send resumes to jobs@rfmd.com and reference Job Code: **JLMEN**.

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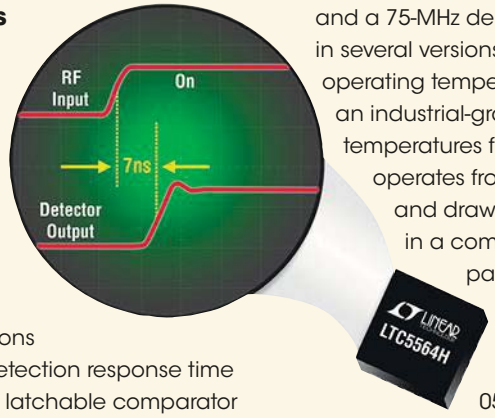


MODEL LTC5564H is a Schottky diode peak-power detector that can measure signal-power levels from –24 to +16 dBm across a frequency range of 0.6 to 15.0 GHz. Suitable for measuring fast radar pulses as well as cellular communications signals, the detector has a detection response time of 7 ns. It features an on-chip latchable comparator and a 75-MHz demodulation bandwidth. It is available in several versions, with an "H" version working over an operating temperature range of –40° C to +125° C and an industrial-grade device designed for operating temperatures from –40° C to +105° C . The detector operates from a single +3.3- or +5.0-VDC supply and draws typical current of 44 mA. It is supplied in a compact 3 mm × 3 mm 16-pin plastic QFN package. P&A: $3.44; stock.

LINEAR TECHNOLOGY CORP., 1630 McCarthy Blvd., Milpitas, CA 95035-7417; (408) 432-1900, FAX: (408) 434-0507, *www.linear.com*

GaN Amplifier Drives 600 W from 8.5 to 10.0 GHz

BASED ON gallium-nitride (GaN) power transistors, model BMC858109-600 is a rugged power-amplifier module capable of 600 W (+58-dBm) pulsed output power from 8.5 to 10.0 GHz. The Class AB linear amplifier module is designed for use with signals having pulse widths from 2 to 100 µs. Pulse rise/fall times are typically better than 60 ns. The GaN amplifier module provides 58-dB nominal gain with ±1-dB gain variation from 9.5 to 10.0 GHz and ±2-dB gain variation from 8.5 to 10.0 GHz. The amplifier is designed to handle maximum duty cycle of 10% with less than 1-dB pulse droop. The amplifier has input VSWR of less than 1.50:1 while output VSWR of less than 2.0:1, with second harmonics of better than –40 dBc. The amplifier draws 9 A from a +28-VDC supply. It measures 10.0 in. × 8.5 in. × 1.0 in. and weighs 5 lb. It is a suitable building block for phased-array radar systems, and is available with an optional digital interface for control and status monitoring.

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

Miniature Mixer Spans IF to 20 GHz

MODEL MLIQ-1845 is a compact multiple-octave microwave mixer supplied in a chip-type package measuring 0.240 in. × 0.240 in. × 0.010 in. The RoHS-compliant mixer consists of matched double-balanced mixers connected with an integrated local oscillator (LO) hybrid and RF power divider. The mixer features an RF and LO frequency range of 18 to 45 GHz and an intermediate-frequency range of DC to 20 GHz. The mixer can be used for frequency upconversion and downconversion, and nonlinear software models are available for commercial circuit simulators. The miniature mixer operates with typical conversion loss of 8 dB for IFs from DC to 6 GHz and 10 dB for IFs from 6 to 20 GHz. The mixer has a typical input 1-dB compression point of +8 dBm.

MARKI MICROWAVE, 215 Vineyard Court, Morgan Hill, CA 95037; (408) 778-4200, FAX: (408) 778-4300, e-mail: info@markimicrowave.com, *www.markimicrowave.com*

Cable Assemblies Minimize PIM

CABLE ASSEMBLIES can add unwanted passive intermodulation (PIM) to a system at various interfaces. Fortunately, a line of cable assemblies with snap-lock QMA connectors offers an alternative to traditional SMA coaxial connectors that can suffer from excessive levels of PIM. These cable assemblies are built with flexible, low-loss TFT-402-LF cables from Times Microwave. The cables are terminated with male QMA straight or right-angle connectors and meet UL910 fire requirements for in-building applications. The PIM levels are –140 dBc or better with standard QMA connectors and –155 dBc or better for premium straight QMA connectors. All of the low-PIM cable assemblies are tested, with measured results available on the firm's online PIM Tracker function.

RF INDUSTRIES, INC., 7610 Miramar Rd., San Diego, CA 92126; (800) 233-1728, e-mail: rfi@rfinstries.com, *www.rfindustries.com*

Signal Analyzer Armed with 2-GHz Bandwidth

THE ANALYSIS bandwidth of the FSW signal analyzer has been expanded to 2 GHz, via the FSW-B2000 hardware option. This combination signal and spectrum analyzer is available with frequency limit to 67 GHz. With the wide-bandwidth analysis option, it is suitable for measuring signals as found in emerging commercial wireless standards such as 5G cellular communications and IEEE 802.11ad wireless-local-area-network (WLAN) systems as well as for military applications, such as evaluating chirped radar signals. The signal analyzer works with one of the company's RTO oscilloscopes, downconverting wideband signals into the range of the oscilloscope's digitizer circuitry. Signal analyzers with the option are available with high-end frequencies of 26.5, 43.5, 50.0, and 67.0 GHz.

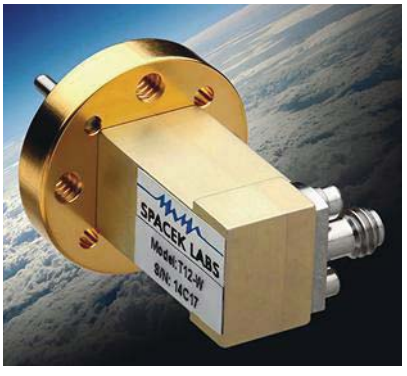
ROHDE & SCHWARZ USA INC., 6821 Benjamin Franklin Dr., Columbia, MD 21046; (410) 910-7800, FAX: (410) 910-7801, *www.rohde-schwarz.com*

LNAs Boost Bands from 700 to 2700 MHz

THE LNA1 Series of low-noise amplifiers (LNAs) covers telecommunications frequency bands from 700 to 2700 MHz. The offer 0-dBm output power at 1-dB compression with 25-dB small-signal gain and ± 3-dB gain flatness. The compact amplifiers are well suited for portable applications, drawing 100 mA from a +5-VDC supply, enabling them to be powered by a USB computer port. As an example, model LNA1-0727-25 operates from 700 to 2700 MHz with 2-dB noise figure (typically 1.5 dB) and 25-dB gain. It measures 1.5 in. × 1.0 in. × 2.5 in. (38 mm × 25 mm × 64 mm) and is supplied with Type-N input and output connectors; other connectors are available upon request. The LNAs are designed for operating temperatures from –10° C to +50° C.

AWT GLOBAL, 117 Grand Ave., Hackettstown, NJ 07840; (973) 321-3423, e-mail: sales@awt-global.com, *www.awt-global.com*

Adapter Joins E-Band Waveguide to Connectors



MODEL T12-W is a waveguide-to-coaxial adapter that is designed and machined for low-loss performance across the full E-band frequency range from 60 to 90 GHz. It achieves typical insertion loss of 1.5 dB or less across that 30-GHz millimeter-wave frequency range. The transition can be used to adapt WR-12 (UG387/U) waveguide to a 1-mm coaxial connector and/or coaxial cable assembly, or from coaxial cable and connector to waveguide.

SPACEK LABS INC., 212 East Gutierrez St., Santa Barbara, CA 93101; (805) 564-4404, FAX: (805) 966-3249, *www.spaceklabs.com*

Dual Synthesizer Tunes 23 to 6000 MHz

DUAL-FREQUENCY SYNTHESIZER model 5009 provides the performance of a laboratory signal source in a compact housing. Its two sources operate from 23 to 6000 MHz with +15-dBm output power at 3 GHz. Output power can be controlled in 0.5-dB steps by means of a 31.5-dB step attenuator. The dual synthesizer includes an internal 20-MHz frequency reference but can also work with external frequency reference sources from 10 to 200 MHz. The synthesizer incorporates one transistor-transistor-logic (TTL) port and one USB port for control by means of a PC and software. Firmware is downloadable from the company website.

VALON TECHNOLOGY LLC, 750 Hillcrest Dr., Redwood City, CA 94062; (650) 367-1059, e-mail: sales@valontechnology.com, *www.valontechnology.com*

Multiplier Doubles 12 to 18 GHz Signals

ACTIVE FREQUENCY multiplier model CMD214 accepts input signals in the range of 12 to 18 GHz) and typically +14 dBm) and produces output signals from 24 to 36 GHz at power level of +17 dBm. Fundamental-frequency and second-harmonic isolation levels are better than –32 and –25 dBc, respectively. The active multiplier, which is supplied in chip form, operates at drain voltage of +5 VDC (and 40 mA) and gate voltages of –1.8 and –0.8 VDC. The frequency doubler is suitable for a wide range of applications

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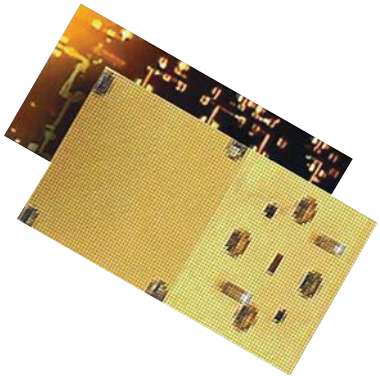
MODEL W1320302 is a four-stage GaAs pseudomorphic high-electron-mobility-transistor (pHEMT) monolithic-microwave-integrated-circuit (MMIC) amplifier with a frequency range of 98 to 102 GHz. It provides more than 20-dB stable small-signal gain across the bandwidth, with noise figure of



5 dB or less. The device can also be used as a medium-power amplifier, capable of handling more than +10-dBm input power and delivering +16-dBm saturated output power across its full frequency range.
ARRALIS LTD., Tierney Building UL, Castletroy, Limerick, Ireland; +353 (0) 61 748 264, e-mail: info@arralis.com, *www.arralis.com*

Cable Assemblies Jump DC to 6 GHz

WHEN IT is time to make a connection, several lines of UMCX, WMCX, and HMCX32 coaxial cable assemblies provide links from DC to 6 GHz. They are suitable for attaching antennas to other communications equipment, and are available in 40 different configurations, including with 0.81-, 1.13-, and 1.37-mm-diameter cables. They can be supplied with an assortment

of connectors including UMCX, WMCX, and HMCX32 snap-on connectors with mated connection heights from 1.2 to 2.5 mm. Each of the cable assemblies are 100% RF and continuity tested prior to shipment.
PASTERNACK ENTERPRISES INC., 17802 Fitch, Irvine, CA 92614; (866) PASTERNACK (727-8376), (949) 261-1920, FAX: (949) 261-7451, e-mail: sales@pasternack.com, *www.pasternack.com*

Broadband Amplifiers Boost 0.5 to 40.0 GHz

A line of broadband amplifiers has been expanded to cover a total range of 0.5 to 40.0 GHz with noise figures from 2.5 to 6.0 dB. Gain levels range from 20 to 48 dB, with gain flatness as tight as ±0.5 dB. Output power at 1-dB compression spans 20 mW to 2 W. The amplifiers run on bias current from 125 to 2500 mA from supplies of +8.5 to +15.0 VDC. Based on GaAs pseudomorphic high-electron-mobility-transistor (pHEMT) technology, the microwave-integrated-circuit (MIC) amplifiers are supplied in environ-

mentally sealed metal packages with nickel or gold plating. The amplifiers, which feature SMA or 2.92-mm coaxial connectors, are suitable for applications in wireless communications, electronic warfare, test, and radar systems.
FAIRVIEW MICROWAVE INC., 1130 Junction Dr., Ste. 100, Allen, TX 75013; (800) 715-4396, (972) 649-6678, *www.fairviewmicrowave.com*

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FOR PULSED applications in the L-band radar range from 960 to 1215 MHz, the models MAGX-000912-650L00 and MAGX-000912-650L0S are versions of a gallium-nitride-on silicon-carbide (GaN-on-SiC) high-electron mobility transistor (HEMT) capable of 650 W output power. These gold-metalized, depletion-mode HEMTs are available in standard flange and earless flange packaging. The RoHS-

compliant devices employ internal impedance matching to amplify short pulsed signals. They achieve 650 W output power with 20-dB gain when running with 128- µm pulses at a 10% duty cycle. The devices achieve 62% power-added efficiency (PAE) and boast a mean time to failure (MTTF) of 600 years. They provide stable operation from a +50-VDC supply. They are suitable for use with Mode-S, TCAS, JTIDS, DME, and TACAN systems.
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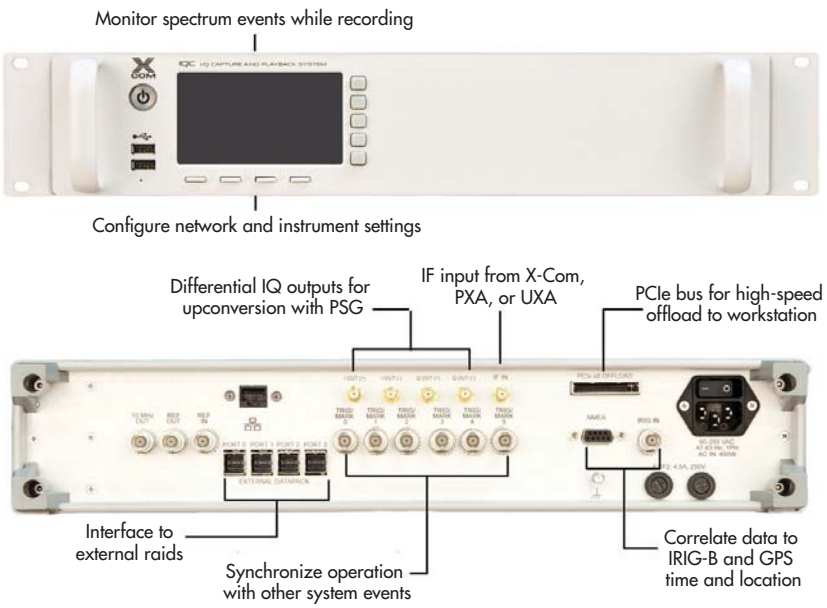

1. The front (top) and rear (bottom) panels of the IQC91000A show the signal record/playback systems straightforward setup and control.

RECORD/PLAYBACK SYSTEM Grabs 1-GHz Bandwidth to 40 GHz

JIM TABER | Director of Sales and Marketing
X-COM SYSTEMS, 12345-B Sunrise Valley Dr., Reston, VA 20191; (571) 612-5490; www.xcomsystems.com

MANIPULATING A library of complex systems is part of exercising modern defense systems. Such systems as electronic-warfare (EW) setups and military radar must be tested with signals comparable to those they will face in real-world operation. Such signals can vary a great deal, depending upon an application, with EW systems typically working with wideband signals and radars operating with more narrowband signals.

Fortunately, X-COM Systems (www.xcomsystems.com) has developed a means of capturing and storing complex signal waveforms—its model IQC91000A signal record/playback system. It can capture, digitize, store, and play back any instantaneous 1-GHz swath of spectrum from 0.5 to 40.0 GHz to help test EW, radar, and other systems under real-world signal conditions.

The IQC91000A signal record/playback system *(Fig. 1)* is well equipped to capture signals for testing and validation of radar, electronic warfare, signal intelli-

(continued on p. S24)

MICROSEMI Receives Trusted Accreditation

MICROSEMI CORP. (www.microsemi.com) has received the Category 1A Trusted Design, Test, and Broker accreditation from the Defense Microelectronics Activity organization (www.dmea.osd.mil), the program manager for the trusted-products program. This completion of Category 1A Trusted accreditation ensures that Microsemi can deliver trusted integrated-circuit (IC) solutions for critical applications as outlined in U.S. Department of Defense policy (DODI 5200.44). DODI 5200.44 policy defines protection of mission-critical components within applicable systems by requiring all custom IC-related products be procured from a trusted supplier.

According to Amr El-Ashmawi, vice president of corporate marketing for Microsemi, "This accreditation further solidifies Microsemi's position as one of a few companies committed to providing the defense and security markets with trusted products," he said. "With concerns about supply-chain assurance and the need to expand the trusted USG offerings, Microsemi is well positioned as a company to further expand the access to trusted solutions." The accreditation ensures that a U.S.-based supplier is available for mixed-signal semiconductors such as application-specific ICs and field-programmable gate arrays (FPGAs) for critical system applications. ■

(continued on p. S8)

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In This Issue

FEATURES

C1

S20

S18

Penton

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Challenges Facing Military Radio Designers

COMMUNICATIONS has long been an essential element of warfare. One set of troops needs to know their battle plans and, ideally, what their opponents are planning by intercepting their communications signals. This essentially summarizes the requirements of defense-related radio designs: to provide secure communications that cannot be deciphered by an opponent. As technology grows in complexity, defense-related communications methods must provide an increased number of operating modes while also delivering improved reliability.

Military planners have explored many different communications technologies, including commercial cellular and wireless communications networks under certain conditions. Communications security is typically a function of the modulation and encryption technique, the frequency of operation, and the use of special transmission methods, such as frequency-hopping techniques. Designers of portable HF/VHF/UHF portable radios have done impressive work in reducing the size and weight of these systems while increasing their performance and durability. But they are still limited in range by such things as hilly terrain; they also operate in frequency ranges where jammers are common.

One communications technology that provides many of the features needed by military users is satellite communications (satcom). The U.S. Army has long been a user of commercial satcom services, but is looking to strengthen its own satcom capabilities through efforts on its 2020 satcom network. Equipment design involves flexibility and portability, including smaller satcom antenna dishes that can be easily mounted on military vehicles and lighter satcom radio packs that can be managed as part of a soldier's backpack. Of course, frequency/wavelength has a bit to do with the size of the antenna, with larger satcom systems at UHF, and smaller antennas at higher X-, C-, Ku-, and Ka-band frequencies.

Of course, the key limiting factor in the spread of satcom services has been the availability of orbiting satellites. But with the help of such organizations as NASA, satellite launches can be integrated into planned space exploration efforts, and the path can be cleared for increased satcom capabilities. de

JACK BROWNE, *Technical Contributor*

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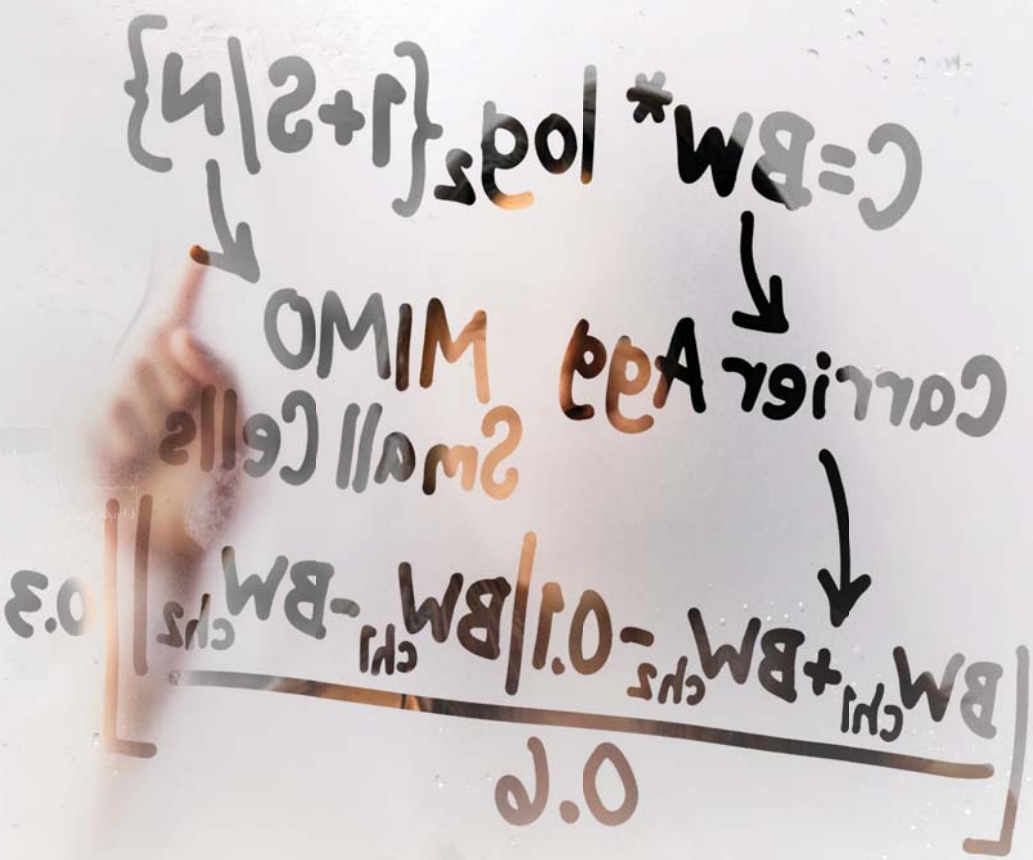

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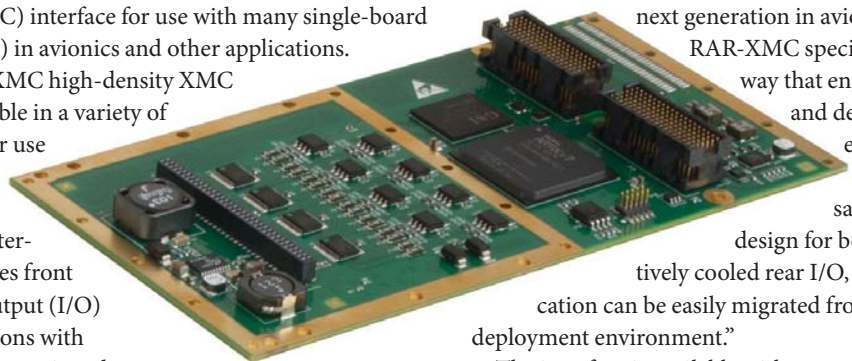
AVIONICS COMPUTING Receives Lift from GE

THE INTELLIGENT Platforms business group of General Electric (www.geembedded.com) has announced the introduction of a high-density switched-mezzanine-card (XMC) interface for use with many single-board computers (SBCs) in avionics and other applications. The firm's RAR-XMC high-density XMC interface is available in a variety of configurations for use with the ARINC 429 and related protocols. The interface, which enables front and rear input/output (I/O) avionics applications with programmable transmit and receive channels, is supported by a host of software tools to shorten time to implementation. The RAR-XMC is designed for embedded use in avionics systems as well as in laboratory and simulator applications.



According to Dwayne Cripe, product manager at GE's Intelligent Platforms business, "The RAR-XMC represents the next generation in avionics computing. The RAR-XMC specifically recognizes the way that engineers test, develop, and deploy avionics on modern computing hosts. Moreover, having the same firmware and API design for both front and conductively cooled rear I/O, the RAR-XMC application can be easily migrated from a development to a deployment environment."

The interface is available with as many as 16 transmit and 32 receive channels with software-programmable channels, so that the same interface card can be used for dynamic channel requirements. ■

Australian Army Trains with RC SIMULATOR

THE AUSTRALIAN Army is counting on the latest-generation Joint Fires Observer (JFO)/Joint Terminal Attack Controller (JTAC) simulator from Rockwell Collins (www.rockwellcollins.com) for meeting the training requirements of its soldiers for the near future. According to Nicholas Gibbs, managing director of Rockwell Collins Australia, "We look forward to working with the Australian Army to provide this vital training capability to their soldiers."

The system is part of the firm's RealFires family of JFO and JTAC simulators and is fully integrated with the Rockwell Collins FireStorm Integrated Targeting System. The system, which will be located at Australia's School of Artillery in Kabul, forms the core of the Land 17 Phase 1B Digital Terminal Control System.

The RealFire system is fully scalable and can be used for a range of training applications, from desktop to full 360-deg. training exercises. The system delivered to the School of Artillery includes training-room facilities, a 270-deg. dome, high-fidelity graphics, and full simulation of FireStorm sensors. ■

CANADIAN FOUNDRY Forges GaN Technology

HIGH-PERFORMANCE GALLIUM nitride (GaN) semiconductor technology is now available from a foundry north of the border, from the National Research Council of Canada. The foundry recently released its GaN150 Design Kit to aid with the design of circuits and devices based on 0.15-µm GaN technology. The foundry supports applications through 35 GHz and the design kit, which is available from the website (www.nrc-cnrc.gc.ca) for download, includes an operator's manual and physical design kit for the GaN technology. The foundry is available for full wafer runs and multiple-project wafer runs. ■

U.S. Navy Evaluates WEAPONS TRACKER

AN ADVANCED maintenance system developed by Lockheed Martin (www.lockheedmartin.com) could potentially save the U.S. Navy millions of dollars by automating the process of weapons tracking. The RuBee Weapon Shot Center system is capable of remotely tracking sensitive muni-

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tions equipment. In contrast to traditional tacking methods based on radio-frequency-identification (RFID) tags, which can't always be read through metals or liquids, the RuBee system operates by means of electromagnetic (EM) tags and magnetism and are not subject to the blocking and interference that impacts RFID tags.

The U.S. Navy's pilot-program evaluation of the RuBee system has found that the system could potentially save a single armory millions of dollars in labor charges annually though automation. According to Dr. Rob Smith, vice president of C4ISR for Lockheed Martin, "Most processes for tracking ammunition and scheduling maintenance for weapons are time-consuming and manually intensive. We worked with select Navy expeditionary forces to demonstrate that the RuBee system could not only increase the accuracy of their inventories, but also reduce costs, improve safety, and maximize asset security."

As part of the pilot-program evaluation, RuBee tags were embedded in select naval assets to track weapon performance and diagnostic data. The RuBee system successfully provided maintenance and diagnostic data, such as number of rounds fired, rate of weapons fire, and calculated barrel temperature. The small RuBee sensors also detected performance anomalies, such as gas port erosion and cracked bolts, before they led to potential weapon failure. The RuBee system allows weapons to be automatically located and identified within the perimeter defined by the system. It uses magnetic detection to read through and around metal and other materials, for efficient armory management. Lockheed Martin is now working to expand this effort from a pilot to a full program that generates cost savings and increases confidence in weapon safety. ■

COBHAM GRANTED Class Y from DLA

THE DEFENSE Logistics Agency (DLA) has awarded Cobham's Semiconductor Solutions Colorado Springs, Colo., facility its first MIL-PRF-38535 Class Y assembly certification. The Class Y designation was granted for the use of ceramic non-hermetic packages for space applications. The Class Y designation allows for the use of non-hermetic flip-chip packaging technology. Cobham's Colorado Spring facility has now been certified for Class Y flip-chip device assembly.

Dr. Scott Popelar, manager of the Cobham Advanced Packaging Engineering group, noted, "Attaining Class Y assembly certification is a major step toward Cobham offering its customers ASIC products in a flip chip, non-hermetic package format, and keeps Cobham at the industry forefront of Class Y technology development and productization." ■

French e2v Earns QMLV AEROSPACE CERTIFICATION

THE GRENOBLE, France, facilities of e2v Semiconductors (www.e2v.com) has earned the official MIL-PRF-30535 Class V (QMLV) certification. The QMLV certification, the highest standard of quality and reliability for aerospace-grade microelectronic circuits and ICs, defines the general requirements, quality assurance, and reliability requirements for manufacturers of microelectronic products and ICs used in military and high-reliability applications. By receiving the QMLV certification, the e2v facilities have passed all applicable requirements for space-level products.

Regarding the award, Laurent Monge, vice president of semiconductors, noted, "e2v is committed to providing high-reliability and superior-performance products for the aerospace market, and receiving our QMLV certification underpins our dedication to achieve this. We are delighted to have met and passed the criteria and performances required and plan to list our QMLV-rated products in the near future." ■

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Training System MAINTAINS ARMY READINESS

THE JOINT Pacific Multinational Readiness Capability Instrumentation System (JPMRC - IS), developed by Raytheon Co. (www.raytheon.com) and partners, is helping to train the U.S. Army to maintain readiness in a broad range of environments. The integrated JPMRC-IS includes deployable shelters, communications hardware, and software for training purposes. It is easily transported and can provide full 24-hour-per-day operation for weeks at a time, ensuring reliable training. It can extend a training battle space by linking multiple units.

As Raytheon Vice President for Global Training Solutions Bob Williams explained, "This new system gives us opportunities to maintain readiness in ways that provide great flexibility while maximizing scarce training resources. We recently completed a rehearsal with the JPMRC-IS involving more than 400 soldiers across several Hawaiian islands, and it felt and worked exactly like a full rotation at one of our Combat Training Centers." The instrumentation system is designed to collect and store specific data on different battle scenarios and aid exercise controllers in monitoring soldiers' performance levels under different conditions. Participants in an exercise receive direct feedback on how they performed a given mission, along with guidance on how to improve performance.

Raytheon leads the Warrior Training Alliance (WTA), a team of more than 150 partner companies that provides training support to the U.S. Army around the world as part of the Warfighter Field Operations Customer Support (FOCUS) contract. By way of the contract, Raytheon and the WTA have helped save the Army more than $300 million in maintaining more than 240,000 training aids, devices, and simulators for its troops.

Raytheon will test the JPMRC-IS this month during a multi-unit exercise in Hawaii called Lightning Forge. This Initial Operating Capability event will demonstrate the ability to perform distributed operations as part of a two-battalion exercise on Oahu and the island of Hawaii. ■

DoD Clears Countermeasures SYSTEM FOR EXPORT

THE SOPHISTICATED Advanced Threat Infrared Countermeasures (ATIRCM) system developed by BAE Systems (www.baesystems.com) has been approved for export by the U.S. Department of Defense. This opens the door for sales of this missile warning/stopping system to allied nations around the world. According to Bill Staib, director of Threat Management Solutions at BAE Systems, "In today's environment with the proliferation of surface-to-air missiles, a proven aircraft survivability system to counter advanced threats meets an immediate need. We are seeing tremendous international interest for this system, which has proven to be both highly effective and reliable since its fielding in 2009."

The ATIRCM system incorporates BAE's Common Missile Warning System to detect an incoming missile and communicate the missile's position relative to the system's host aircraft. The ATIRCM system then locates and tracks the incoming threat and returns a high-power laser beam to defeat the missile's infrared seeker, effectively blinding its guidance system and preventing it from targeting an aircraft. The ATIRCM system was developed in partnership with the U.S. Army and is currently deployed on military helicopters. It has proven effective in protecting both rotary and fixed-wing aircraft and has been deployed on aircraft in Iraq and Afghanistan since 2009. ■

Naval Diver System SAVES HELIUM

SCIENTISTS AT the U. S. Naval Surface Warfare Center Panama City (NSWC PC) have developed a prototype for a new life-support system for U.S. Navy divers. In addition to boosting the safety of these divers, the new system also conserves helium, a valuable natural resource.

Current Navy mobile diving and salvage units meet the requirement for manned diving operations with the Fly-Away Mixed Gas System (FMGS). In this approach, breathing air is provided to divers through an umbilical cord to a demand-regulated, open-circuit, diver-worn helmet. For each breathing cycle, all inhalation is from air supplied from the surface, with exhaust into the body of water, but large amounts of oxygen and helium are wasted. In the new system, which is part of the Initial Response Diving (IRD) project, a drastic reduction of helium is possible.

According to NSWC PC Principal Investigator Dr. John Camperman, "Where possible, we also incorporated proven technology in the system in order to speed transition to operators." Camperman adds that "testing of the new prototype system indicates that the full range of FMGS diving is supportable within Navy life support requirements, and that several life support characteristics are improved, including extended emergency come-home gas duration." ■

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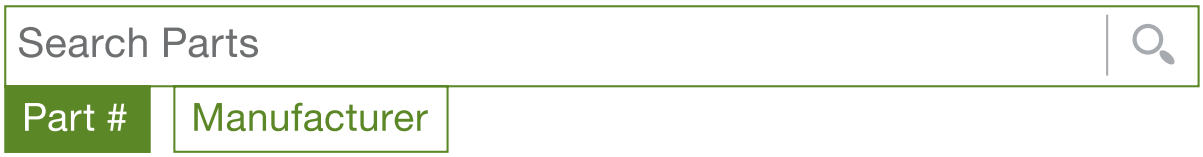

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Boeing Sheds Light on Laser Weapons

BOEING IS pursuing major improvements in high-energy-laser (HEL) weapons and will develop a beam-control system that is expected to improve the accuracy of laser weapons for U.S. Navy warships. The $29.5 million contract is part of work being performed for the U.S. Office of Naval Research's (ONR) Solid State Laser Technology Maturation (SSL-TM) program. Boeing will design a prototype High Power Beam Control Subsystem (HP BCSS) based on solid-state-laser (SSL) technology.

A performance goal of the program is to enable an HEL beam that can be focused and held on a moving target for a duration suitable to disable the target. For a naval application, the movement of the ship adds to the challenge of this goal. According to Peggy Morse, vice president of Boeing Directed Energy & Strategic Systems (DESS), "Boeing innovations in beam control and directed energy technologies are keys to understanding laser weapon system configurations that could yield a capability for the Navy in their maritime environment." Boeing's efforts build upon the company's work with the U.S. Army and the High Energy Laser Mobile Demonstrator (HEL MD) system. During recent testing, that system has succeeded in disabling mortars and unmanned aerial vehicles (UAVs). ■

Custom MMIC to Boost U.S. Navy

SEMICONDUCTOR SUPPLIER Custom MMIC (www.CustomMMIC.com) has been awarded a Phase II Small Business Innovative Research (SBIR) contract from the U.S. Navy. The contract relates to gallium-nitride (GaN) power amplifiers and low-noise amplifiers for use from 5 to 6 GHz. Work on these GaN MMIC solutions involves reducing size, cost, and power consumption for these amplifiers for Navy electronic systems. Performance goals include more than 20 W saturated output power for the power amplifiers and less than 1-dB noise figure across the full operating frequency band for the low-noise amplifiers.

As Paul Blount, president and CEO of Custom MMIC, said, "We are excited to be working with the U.S. Navy on the development of these high-performance components. The MMICs we will create as part of this program will bring cost-effective GaN solutions to the problem of periscope detection." ■

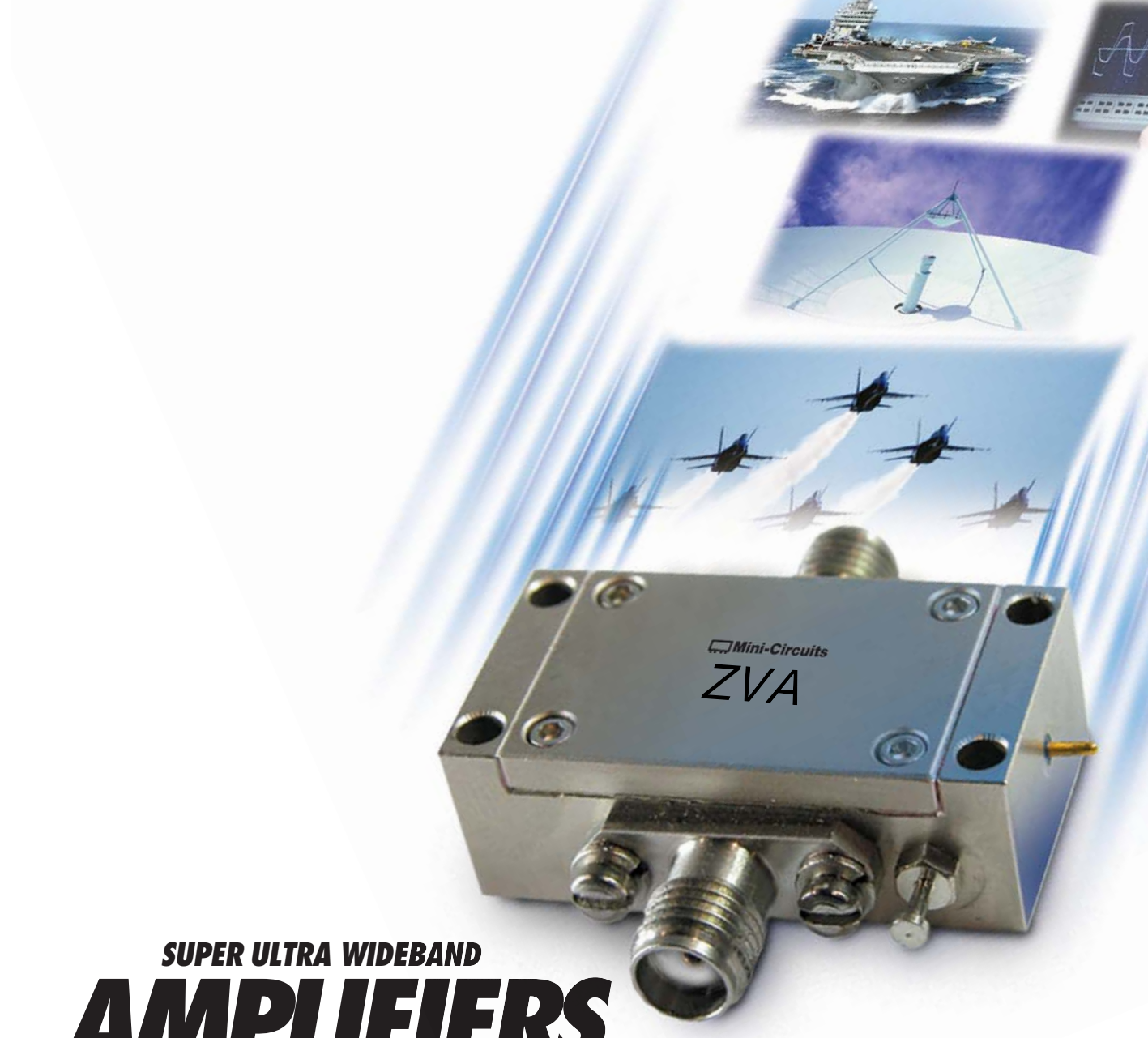
Special Forces to Ride Electric Motorcycles

LOGOS TECHNOLOGIES received a phase II SBIR award from DARPA to begin developing a prototype hybrid electric motorcycle for the U.S. Special Forces. The company received a Phase I award a month earlier during which a preliminary design was developed. The electric motorcycle will feature a quiet, all-wheel drive capability at extended range in a lightweight, rugged, single-track vehicle combining the RedShift MX electric motocross bike from Alta Motors (www.altamotors.com) with the hybrid-electric propulsion system from Logos Technologies (www.logostech.net). ■

Raytheon Adds Tomahawk Missiles for U.S. Navy

RAYTHEON CO. (www.ratheon.com) received a $122 million contract modification to a previously awarded firm-fixed-price contract (N00019-14-C-0075) for the procurement of 114 Tomahawk Block IV All Up Round missiles for the U.S. Navy. The contract addition completes the Navy's planned purchase of 214 Tomahawk Block IV missiles for fiscal year 2015 while continuing to build its warfighting equipment inventory.

As Dave Adams, Raytheon Tomahawk senior program director, noted, "Tomahawk missiles continue to be our nation's weapon of choice to defeat high-value threats. Raytheon continues an acute focus on maintaining affordability and enhancing the impressive capabilities of this sophisticated weapon system." Work on the program is expected to be completed by August 2017. ■



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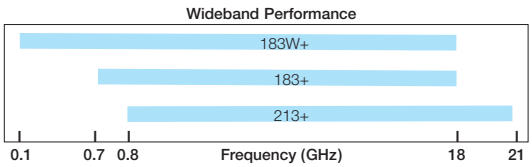

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Multiple Methods

Secure Defense Communications

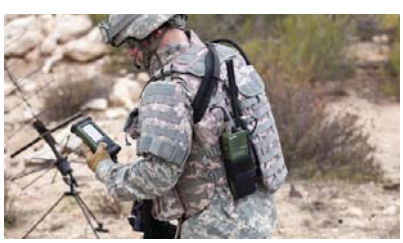
Whether for single-frequency, multiple-frequency, or frequency-hopped systems with a variety of different modulation and encryption schemes, these systems maintain privacy.

COMMUNICATIONS CAN take place in many ways, using wires, over the air, even by light beams. But at times, only certain parties are welcome to the message, and it must be made as secure and private as possible. Many defense-related communications systems, in particular, must be secure. As a result, sophisticated technologies and methods have been developed over time, from Morse code signals over telegraph lines to the latest analog and digital modulation formats. Methods for secure communications vary widely, in complexity, effectiveness, and cost, and achieving secure communications is an ongoing challenge for many involved in defense technology.

No form of communications is completely secure. Almost as soon as a new communications system or modulation approach is developed, an adversary finds a way around it. But achieving a high rate of success for secure communications is often satisfactory for many applications, and the level of security needed is generally a function of the user and the operating environment.

One company often associated with battlefield radio security is Harris (www.harris.com). The company's FALCON II AN/PRC-150(C) high-frequency (HF) manpack radio *(Fig. 1)* features a Joint Tactical Radio System (JTRS) software-defined-radio (SDR) architecture that uses embedded Type 1 encryption certified by the United States National Security Agency (NSA) for effective communications security (COMSEC). This embedded encryption allows secure ground-to-ground and ground-to-air communications in all HF modes as well as in fixed-frequency modes with single-channel ground and airborne radio system (SINCGARS) radio systems. The HF radio, which operates from 1.6 to 512.0 MHz, can be switched from Type 1 encryption to Citadel type encryption for use with coalition forces and their FALCON II radios.

1. The FALCON II AN/PRC-150(C) manpack radio system employs SDR technology to achieve excellent signal security. *[Photo courtesy of Harris Corp. (www.harris.com).]*



2. The Falcon III AN/PRC-152 single-channel multiband radio provides secure communications from 30 to 512 MHz. *[Photo courtesy of Harris Corp. (www.harris.com).]*

The AN/PRC-150(C) radio employs a serial-tone modem for high-speed data communications. The radio employs electronic-counter-countermeasures (ECCM) frequency-hopping techniques for secure communications even in the presence of jamming signals. It even includes Internet protocol capability for Internet-based communications without additional hardware.

Another model, one of the company's most widely fielded radios, is its Falcon III AN/PRC-152 single-channel multiband, multiple-mission handheld radio *(Fig. 2)*. It provides as much as 5 W adjustable transmit power over the full frequency band from 30 to 512 MHz. Like the firm's AN/PRC-150 radio, it incorporates a JTRS software-defined radio (SDR) design with a software communications architecture (SCA) operating environment. The tactical radio achieves communications security by means of programmable encryption for support of current future algorithms and waveforms. It supports SINCGARS radio waveforms and can be programmed to use new waveforms, including those within the JTRS library. The AN/PRC-152 contains a Global Positioning System (GPS) radio receiver (as an option) for precise positioning information. It even enables operation with the APCO P25 Land Mobile Radio waveform, to connect with civilian authorities, and is capable of dedicated satellite-communications (satcom) operation using demand-assigned-multiple-access (DAMA) 5- and 25-kHz channels tunable with 10-Hz resolution.

SDR technology, which is now widely used in commercial and civilian radios, has meant a great deal to the advancement of secure tactical radios. It enables JTRS designs to securely cover a wide range of applications with an admittedly limited band of frequencies. A SINCGARS radio is essentially a combat net radio (CNR) for voice and data communications on the combat network of US and allied forces. It tunes in 25-kHz channels from 30.000 to 87.975 MHz, in single-channel and frequency-hopping modes (at a rate of 111 hops/s). It has been designed into many form factors, including for airborne, backpack, handheld, and vehicle-mount configurations. For security-sensitive applications, integrated communications security (ICOM) models

3. The single-channel, vehicle-mounted VIPER system provides access to classified government networks using secret-level signals. *[Photo courtesy of Thales Defense & Security (www.thalesdsi.*

have been designed with integrated voice and data encryption.

Secure communications systems (SCS) have long been a strong requirement for military users, for a wide range of applications including in the field and within vehicles. Last year, for example, Thales Defense & Security (www.thalesdsi.com) was awarded an Indefinite Delivery/Indefinite Quantity (IDIQ) contract by the US Army for its Soldier Radio Waveform Appliqué (SRW-A) radio system, also known as the AN/VRC-121 Vehicle Integrated Power Enhanced Rifleman (VIPER) system *(Fig. 3)*. The VIPER system was developed jointly with Ultralife Corp.'s Communications Systems business (www.ultralifecorporation.com). The single-channel, vehicle-mounted radio can also be used in a stand-alone configuration and can be installed into SINCGARS Combat Net Radio (CNR) vehicular mounts. The radio system provides access to classified government networks using secret-level signals.

The VIPER radio can integrate and interact with the AN/PRC-154A Rifleman Radio co-developed by Thales and General Dynamics C4 Systems (www.generaldynamics.com). More than 19,000 Rifleman radios have been produced so that the VIPER radio provides the US Army with interoperability with currently fielded radios, with the flexibility to operate at both UHF and L-band frequencies.

In terms of advanced SDR offerings, Rohde & Schwarz (www.rohde-schwarz.com) provides a range of VHF and UHF designs with advanced modulation and security features for voice and data communications. For example, the R&S XD4410A VHF/UHF AM/FM radio covers 100 to 512 MHz for maritime and military operation. It allows interfaces for a number of different external crypto units for secure communications. The firm's R&S XD4410L/E has embedded encryption for communications from 225 to 400 MHz and, like the firm's other VHF/UHF transceivers, can be equipped with external crypto units.

For the lowest levels of command and control in the military, General Dynamics and Thales have supplied thousands of Rifleman Radios to the U.S. Army as part of the JTRS program. The Army is hoping that competition among additional firms will help reduce the cost of additional radios. Harris ITT Exelis is one of those additional firms. These lightweight radios weigh no more than 2.7 lbs. with battery and antenna and operate over bands of 225 to 400 MHz, 1250 to 1390 MHz, and 1755 to 1850 MHz. The Rifleman radios employ GPS for positioning information.

4. The Secure DTD2000 System helps increase the security of COMSEC systems. *[Photo courtesy of Secure Communications Systems (www.securecomm.com).]*

For secure radio users, Secure Communications Systems (www.securecomm.com) offers its Secure DTD2000 System (SDS). It can be used to download cryptographic key, SOI, CEOI, JCEOI, and mission-planning data to COMSEC equipment and communications systems *(Fig. 4)*. The SDS has a 640 × 240 pixel resolution enhanced visibility transflexive liquid-crystal-display (LCD) for improved readability in sunlight. It also includes a standard keyboard for ease of user data input.

Secure Communications Systems also recently introduced a compact secure terminal that embodies the latest technologies for secure voice and communications, the AIRTERM KY-100 terminal. It is designed for wideband and narrowband half-duplex communications (see sidebar) and is suitable for ground, marine, and airborne applications. In many ways, the KY-100 typifies the direction of secure communications technology, with versatility, advanced encryption algorithms, and reliability packed into smaller and smaller housings. de

SECURE TERMINAL FITS TIGHT PACKAGE

ONE CONSISTENT TREND in secure military communications equipment is increasing capability with decreasing size. As an example, the AIRTERM model KY-100 lightweight terminal from Secure Communications Systems (www.securecomm.com) supports tactical ground, sea, and air communications at operating temperatures from –46°C to +71°C and altitudes to 40,000 ft.

The AIRTERM KY-100 solution consists of a lightweight transceiver with a compact controller that epitomizes secure communications in a compact housing. It supports such military communications standards as MILSTAR and SINCGARS in a low-profile housing that measures just 5.0 × 5.7 × 4.7 in. with a controller that is just 2.6 × 5.7 × 3.2 in. With the capability to operate in either narrowband or wideband mode, it provides voice communications at 2.4 kb/s in narrowband operation and 12 or 16 kb/s voice communications in wideband mode. It meets MIL-STD-461C compliance to electromagnetic interference (EMI) requirements for U.S. Army, Navy, and Air Force users, and is built for high reliability and low power consumption.

JACK BROWNE | Technical Contributor

TECHNOLOGIES CONTINUE TO EXPAND on the Battlefield

Military communications technologies continue to make use of links through land, sea, air, and even outer space to combine security with ease of maintainability.

COMMUNICATIONS TECHNOLOGIES are vital to any military operation, whether on land, sea, or in the air, and often communications techniques rely on equipment that is found on land, at sea, and even in outer space. Many different technologies are used for military communications applications, whether for handheld battlefield reports or for space-based links using satellite-communications (satcom) equipment. Many different approaches are employed, including single frequencies, broad frequency bands, frequency hopping, and even power-line communications, and no one technology will ever dominate the armed forces in their quests for secure and reliable communications.

PROJECTS IN THE WORKS

Raytheon Co. (www.raytheon.com), for example, recently completed a number of milestones for a secure communications project for the U.S. Air Force. The system is part of a $134 million contract to provide communications between the President of the United States, senior military leaders, and the Air Force bomber fleet. The firm had received this contract to develop the Global Aircrew Strategic Network Terminal in December 2013, with expansions due by the end of 2016. The upgrade will mark the first time that the bomber fleet air bases have access to the Advanced Extremely High Frequency (AEHF) satellites, which will provide secure, protected communications. As the only provider of high-bandwidth AEHF terminals, Raytheon was able to help the Air Force drive down program costs, giving the service greater buying power and new capabilities.

Lockheed Martin (www.lockheedmartin.com) is working with the U.S. Army on the new Warfighter Information Network-Tactical (WIN-T) communications network (*Fig. 1*). It will use a layered, managed network architecture to deliver secure connectivity, automatically switching to airborne nodes as needed or to satellite-communications (satcom) links if airborne nodes are not available. With such a self-managed communications network, a war fighter will not need to be concerned about security, since the system will do the switching and maintain the security under all conditions.

1. The Warfighter Information Network-Tactical (WIN-T) communications network is being developed by the U.S. Army in conjunction with Lockheed Martin *(www.lockheedmartin.com).*

The WIN-T network is designed for flexibility and interoperability, automatically connecting airborne, naval, and ground-based networks. These networks are capable of adapting to a new device, such as a new handheld computer. To respond to threats, users will need access to intelligence from a variety of sources, with different classification levels. The new WIN-T technologies will expand the capabilities of secure intelligence sharing, keeping sensitive data safe and trusted while providing access to all authorized users.

Of course, available bandwidth is a concern with any communications network, whether for commercial or military users, and Lockheed Martin is working to ensure that bandwidth will be available for military users. The system will allow communications officers to shift bandwidth wherever the needs are the greatest, allowing military users to manage available bandwidth much more efficiently. The third increment of the WIN-T program went through modifications last year, focusing on the enhancement and simplification of Network Operations (NetOps) and looking forward to advanced communications capabilities for 2025. These efforts are meant to simplify and reduce the number of network management tools needed for the system, to make the communications systems easier to install, operate, maintain, and defend.

One of the latest Army radios for the field is the JTRS Handheld, Manpack, and Small Form Fit AN/PRC-154 Rifleman developed by General Dynamics C4 Systems (www.gdc4s.com). This lightweight, body-worn radio was tested in a variety of scenarios, including reconnaissance, counterinsurgency, and convoy operations in preparation for field use. The tactical radio is even capable of interfacing with commercial smart phones.

ENHANCING TECHNOLOGY

The Army is also enhancing communications technology within its Stryker

Brigade Combat Team (SBCT) for vehicle-based soldiers, increasing soldiers' capabilities to communicate over greater distances. Army Strykers in the 2nd Stryker Brigade Combat Team/2nd Infantry Division (2/2 SBCT) are being retrofitted with the new Capability Set 15 (CS 15) system, which provides communications capability throughout the SBCT and reduces soldiers' reliance on fixed and line-of-sight communications methods. As Captain Minou Pak, signal company commander for the 2/2 SBCT, explained, "These capabilities give commanders a huge advantage in knowing what is happening on the battlefield. It is a much more redundant system, which we can use to react quicker and maneuver through the battlefield much faster and more efficiently."

As part of these communications advances, select Strykers are being equipped with the satellite-based network communications capabilities of the WIN-T system, Increment 2. For mobile soldiers in remote terrain, the system maintains voice, video, and data communications under challenging conditions, with performance rivaling that of fixed communications posts.

In terms of space, DARPA is supporting the Airborne Launch Assist Space Access (ALASA) program to cut the costs of putting satellites in space. One goal is a threefold reduction in the costs of satellite launches compared to current U.S. military and commercial launch costs (about $30,000 per pound per satellite to launch, at present). The ALASA program is seeking to launch satellite vehicles without need of recurring maintenance or support costs, performing satellite launches from aircraft for reduced costs.

The U.S. Navy has looked to SBG Technology Solutions (www.sbgts.com) for on-orbit communications capabilities for open-ocean, littoral, and naval land operations. The multiple-year contract was issued by the Navy Program Executive Office Space Systems (PEO SS) under its PMW 146 program for communications satellites. The firm will provide services and support in the areas of operational functionality, maintenance, and management. As part of the contract, SBG will provide operational maintenance, logistics, training, development, and system testing and evaluation. SBG will also deliver production support and integration of Navy, joint military, foreign military, and commercial communications systems, encrypted secure networks, and communication links. According to Vic Blanco, SBG's director of contracts, "We are thrilled to continue our work with PEO Space Systems and PMW 146. We will use our longstanding experience with the Navy and PEO SS to execute these mission-critical communications functions for the Navy."

2. Powerline communications may be an effective means of networking for vehicular military users. *(Image courtesy of Thinkstock)*

Not all military communications are through the air, as Secure Communications Systems (www.securecomm.com) has developed a powerline communications system for vehicular users. By sending data via existing power lines on heavy equipment, buildings, ships, and other infrastructure in both commercial and defense applications, this approach can achieve data rates to 100 MB/s at distances to 1,000 ft. The system has operated successfully under high electromagnetic-interference (EMI) levels and has been used in vehicular applications running +74-VDC power lines to achieve Gigabit Ethernet capability as part of local area networks (LANs) populated by vehicular users (*Fig. 2*).

For military users, much of the future for communications involves looking to the sky. One satcom technology with great potential is the Software Reprogrammable Payload (SRP), a collaborative effort between the Office of Naval Research (ONR), the Naval Research Laboratory (NRL), and the U.S. Marine Corps Aviation. A goal of the SRP program is to transform a small radio receiver designed for space applications into a full-featured RF communications system.

Such functions as communications, RF sensing, and EW capabilities will be housed in a compact software-defined-radio-based platform. One of the initial goals for the program is to allow U.S. Marines on the ground to use NASA's Shadow network to communicate with other war fighters, no matter what types of radios or waveforms that they might be using. The SRP system employs a straightforward interface for ease of use, and is expected to find use not just in naval applications but in a wide range of military vehicles. de

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Meeting System Needs for Broadband Components

Specifying active and passive RF/microwave components for broadband systems requires tight amplitude and phase balance along with small size and high reliability.

BROADBAND RF/MICROWAVE components are typically associated with test-and-measurement applications, although they are also very much a part of different defense and aerospace systems. From active components (such as broadband amplifiers) to passive components (such as terminations), broadband RF/microwave components enable the operation of many different electronic systems for military users. These include electronic-warfare (EW), radio, radar, and surveillance systems. Successfully specifying these components for such applications relies on reviewing some of the essential specifications connected to broadband performance, both for active and passive components.

In most military and aerospace systems that are meant to operate over broad bandwidths, such as 500 MHz to 18 GHz, the amplitude and phase performance levels of active and passive components can play a hand in the system-level performance that is possible with a particular design. Even the amplitude and phase flatness of often-overlooked components in these systems, such as antennas and coaxial cable assemblies, can set limits on the ultimate performance possible from a system.

Investments by the Defense Advanced Research and Projects Agency (DARPA) and other research-minded organizations within the Department of Defense (DoD) have sought higher performance levels with greater reliability and accuracy from the active and passive components used in broadband systems. For active components, such as amplifiers, advances have often come at the device level, with such devices as gallium-nitride (GaN) high-electron-mobility transistors and other semiconductors providing new levels of performance from compact-sized components. For passive components, advances often come at the material level, by gaining improved knowledge of often-used materials, (like printed-circuit-board [PCB] laminates), and experimenting with newer materials (including superconducting circuit materials that must be maintained at cryogenic temperatures for optimum performance).

1. This mixer from Krytar (www.krytar.com) is an example of a broadband component, with a bandwidth of 10 to 40 GHz.

Specifying a broadband component, whether active or passive, usually starts with the amplitude or gain flatness with frequency, since it is normally assumed that the components used in a system should have as little impact as possible on the amplitude accuracy of the system. Typically, radar and EW systems are developed with target amplitude-with-frequency flatness of ±1 dB or better, which becomes more challenging to achieve as the bandwidth increases. Similarly, phase-with-frequency deviations must be minimized as much as possible, especially in phase-sensitive systems. Both specifications are subject to added deviations with temperature, so that specifying a broadband component also requires knowledge of the product's amplitude and phase performance across the full operating-temperature range.

Suppliers of broadband active and passive components for defense-related applications are numerous. As an example, Krytar (www.krytar.com), a long-time supplier of broadband passive components for commercial and defense applications, and a scheduled exhibitor at the upcoming IEEE IMS2015 International Microwave Symposium (IMS) in Phoenix, Ariz., has developed lines of test equipment and broadband passive components, including adapters, terminations, hybrid couplers, and power dividers. The company's model 4100400 180-deg. hybrid coupler *(Fig. 1)*, with a bandwidth of 10 to 40 GHz, is well suited for defense and test applications, providing excellent amplitude and phase matching across its 30-GHz bandwidth.

A company known for components with high performance at low cost, Mini-Circuits (www.minicircuits.com), recently announced a line of low-cost broadband mixers, the Ultra-Rel MAC mixers. Current units are available from 300 MHz to 12 GHz, with models in development through 18 GHz. What makes these mixers unusual are low prices with outstanding electrical performance, in hermetic low-temperature-cofired-ceramic (LTCC) housings that provide high reliability over an operating temperature range of –55° C to +125° C.

In spite of the low cost, these mixers are qualified to an extensive series of military testing for gross leak, fine leak, thermal shock, vibration, acceleration, and mechanical shock, including MIL-STD-202 and MIL-STD-883. Supplied in hermetic LTCC surface-mount

2. This phase shifter from ARRA is supplied in a compact aluminum housing for use from DC to 18 GHz.

housings, they measure just 0.3 in. × 0.25 in. × 0.06 in.

As an example, the firm's MAC-60 line of mixers operate at RF and local oscillator (LO) frequencies from 1.6 to 6.0 GHz and provide intermediate-frequencies (IFs) from DC to 2 GHz. The models MAC-60+, MAC-60LH+, and MAC-60MH+ operate at LO levels of +7, +10, and +13 dBm, respectively, with 6.5-dB conversion loss and 35-dB typical LO-to-RF isolation.

In terms of mixers for higher-frequency use, Marki Microwave (www.markimicrowave.com) recently introduced its highest-frequency broadband mixer, the model MM1-2567LS GaAs MMIC mixer with an RF/LO frequency range of 25 to 67 GHz. It features an IF range of DC to 30 GHz with 9-dB typical conversion loss in a compact housing. It is designed for an operating temperature range of –55° C to +100° C.

In some cases, the phase of a system must be adjusted as part of its performance, by means of a phase shifter, and commercial phase shifters are available for broad bandwidths of 18 GHz and more. As an example, the model 9426B phase shifter *(Fig. 2)* from longtime RF/microwave components supplier ARRA (www.arra.com) covers a full frequency range of DC to 18 GHz with average power-handling capability of 100 W and peak power-handling capability to 5 kW. It achieves 0.68 ns minimum insertion delay and 0.78 ns maximum insertion delay, with 30 deg. minimum phase delay at 6 GHz and 180 deg. maximum phase delay at 6 GHz. The phase shifter provides 0.5 dB insertion loss to 8 GHz, 0.75 dB insertion loss to 12 GHz, and no more than 1 dB insertion loss to 18 GHz. It is fabricated from aluminum, with stainless-steel SMA female coaxial connectors. It offers a digital readout in 0.1-deg. increments with calibration accuracy of ±0.7 deg./GHz.

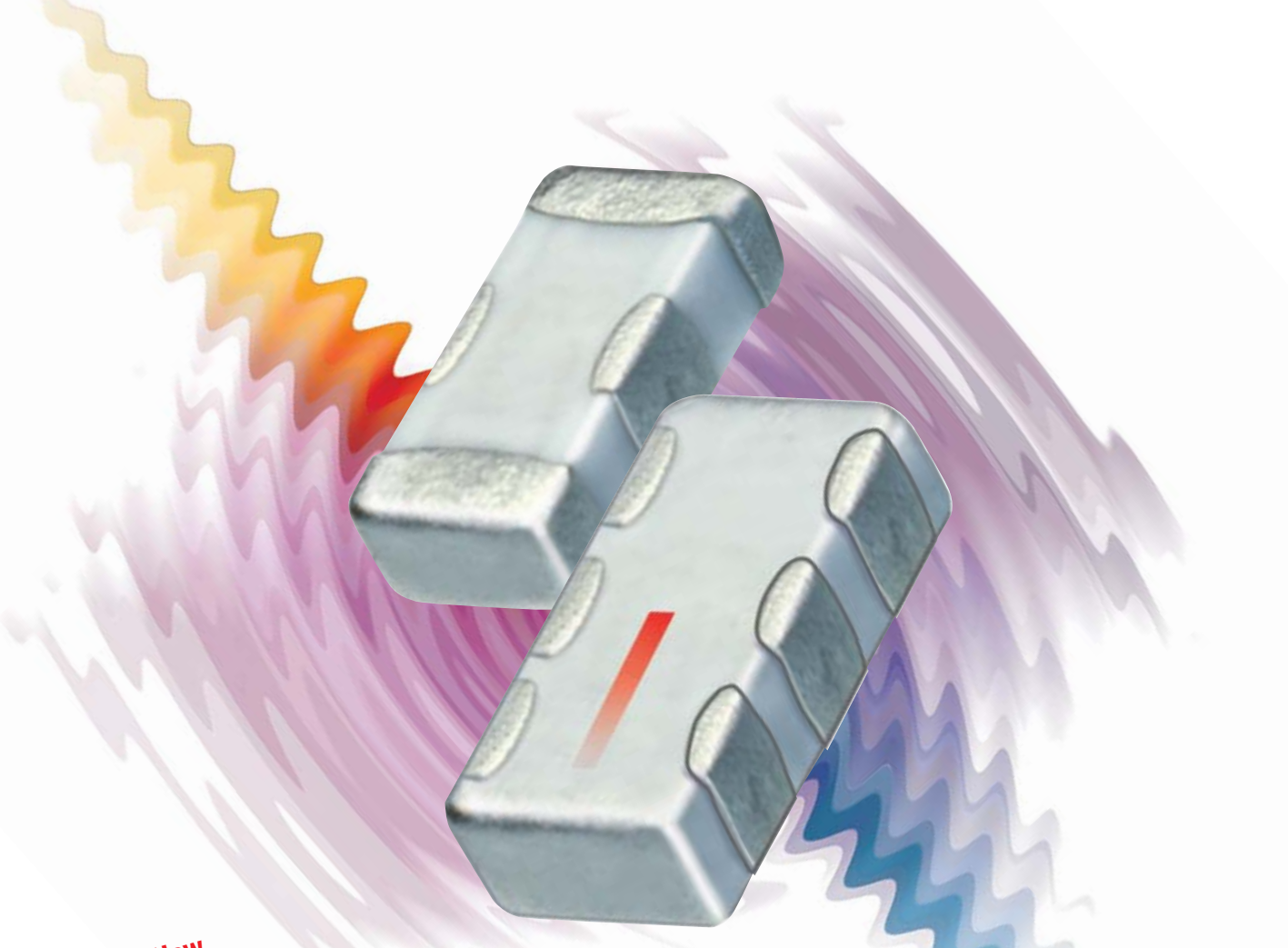
Broadband active components, such as amplifiers, usually start with transistors and achieving good amplitude and phase balance across a wide frequency range presents the challenge of achieving

an optimum impedance match between the active device and the accompanying input, output, and bias circuitry. In some cases, this task has been simplified, in the form of packaged transistors, such as the model MAGX-011086 *(Fig. 3)* from MACOM (www.macom.com). This is a gallium-nitride (GaN) high-electron-mobility transistor (HEMT) that has been optimized for use from DC to 6 GHz. It is suitable either for CW or pulsed applications and can deliver 5 W (+37 dBm) output power from a plastic, surface-mount QFN4X4-24 package ideal for the tightest spaces.

3. This transistor from MACOM (www.macom.com) is a starting point for active circuit design, with bandwidth from DC to 6 GHz and supplied in a small surface-mount package.

It should be noted that while active broadband components typically include solid-state devices, such as diodes and transistors, they are often still designed and supplied with vacuum-tube devices, such as traveling-wave tubes (TWTs), especially when high output-power levels are needed. One key in gaining high reliability from such broadband (or narrowband) tube-based components is effective thermal management, thus preventing the heat that is generated by a vacuum tube from degrading its performance.

As an example, model PTXM1002 is a microwave power module (MPM) from TMD Technologies Ltd. (www.tmd.co.uk) that integrates a high-power TWT with a high-density switch-mode power supply in a compact enclosure. It can operate with CW or pulsed signals over a broadband frequency range, with 75 W CW output power from 6 to 18 GHz and as much as 100 W CW output power from 7 to 11 GHz. It offers 58-dB nominal small-signal gain. The MPM includes a high-speed focus electrode modulator to permit operation at high pulse repetition frequencies (PRFs) and make the amplifier module ideal for pulsed applications, such as in radars and electronic-countermeasures (ECM) systems. The module measures just 190 mm × 120 mm × 30 mm and weighs only 1.7 kg, requiring just 0 dBm signal power at its input port to achieve its rated output-power levels. mw



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504 Rev F

(continued from p. C1)

gence (SIGINT) and electronic intelligence (ELINT) systems. The IQC91000A can be supplied with a downconverter that produces a narrower bandwidth at an 800-MHz intermediate frequency (IF). It can also be specified without a downconverter, for use with a commercial signal analyzer such as the PXA and UXA Series X-Series signal analyzers from Keysight Technologies (www.keysight.com), which can downconvert signals to 50 GHz.

As the first circuit in the receive chain, the receiver/downconverter must deliver wide dynamic range, low phase noise, and overall performance that provides clean IF signals following downconversion. The spurious-free dynamic range of the standard IQC91000A receiver/downconverter is greater than 50 dB, allowing it to detect both weak and strong signals within a bandwidth. The single-sideband (SSB) phase noise ranges from –90 dBc/Hz offset 1 kHz from the carrier to –130 dBc/Hz offset 1 MHz from the carrier for all supported center frequencies. From the receiver/downconverter, a 1-GHz signal bandwidth is recorded with 12-b resolution at a sample rate of 3.2 GSamples/s.

2. Captured signal data can be stored on a generous amount of removable solid-state memory.

In contrast to a swept receiver, such as a traditional analog spectrum analyzer, which measures a bandwidth by sweeping a tuned source across it, the IQC91000A operates with an instantaneous capture bandwidth of 1 GHz. That 1-GHz-wide bandwidth is always in play, with any signals within the dynamic range of the IQC91000A captured for analysis. Signals can be analyzed for further information, such as the in-phase (I) and quadrature (Q) data contained within a modulated signal.

By capturing such signal information, it is possible to perform further analysis with the aid of commercial software tools, such as MATLAB from Mathworks (www.mathworks.com), the 89600B vector signal analyzer (VSA) from Keysight, or SignalVu-PC from Tektronix (www.tektronix.com). The IQC91000A supports MATLAB class definitions so users can operate on specific data samples of interest identified by date, time, scale factor, and other parameters, without having to convert the data. Users simply read the X-COM data set and metadata into the MATLAB environment speeding their post-processing efforts.

The IQC91000A enables storage of captured signal files using two removable banks of solid-state memory configured in RAID0, each with 15 TB capacity *(Fig. 2)*. This amount of memory allows 90 minutes of recorded signal data to be stored when the ICQ91000A is operating at its full 1-GHz bandwidth. Data files or portions of files can be offloaded at greater than 500 MB via eight lanes of PCIe 2.0 to a workstation for analysis.

Although a well-equipped Windows-based PC can work with the IQC91000A, X-COM has also developed its SigAnalyst workstation to serve well with its wideband record/playback system. The workstation is based on two quad-core Intel Xeon processors, 64 GB of DDR4 random-access memory (RAM), 80 TB of hard drive memory storage in RAID6, and a 16-port serial-attached small-computer-serial-interface (SCSI) switch. The IQC91000A is also reinforced by X-COM's Spectro-X signal analysis software and RF Editor software.

Flexible triggering capabilities within the IQC91000A add to its measurement power. Triggering can allow a recording to begin and end based on different parameters, including a signal's rising or falling edges, a frequency mask, time of day, a defined gate, or even the use of Boolean AND/OR logic. Triggering based on the time of day, for example, can capture only time-related signals of interest and exclude all others.

THE IQC91000A AT A GLANCE

Carrier frequency input range	0.5 to 18.0 GHz (3.6 to 26.5 GHz or 18 to 40 GHz optional)
Maximum record bandwidth	1000 MHz
Tuning resolution	1 MHz
Record sample rate	3.2 GSamples/s
Record resolution	12 b
Spurious free dynamic range	Greater than 50 dB
SSB phase noise	100 Hz offset: –65 dBc/Hz 1 kHz offset: –90 dBc/Hz 100 kHz offset: –105 dBc/Hz 1 MHz offset: –111 dBc/Hz
Internal storage	30 TB with two 15-TB SSDs in RAID 0, removable
Data offload via PCIe 2.0, eight lanes	More than 500 MB/s, 12 and 16 b
Playback bandwidth	1000 MHz
Playback sample rate	1.6 GSamples/s each, analog I and Q, differential
Triggers	Rising edge, falling edge, both, and gated
Markers	Date, time of day, latitude, longitude, elevation, sample number. 100,000 per file.
Timing	IRIG-B122, GPS, PC
System control	Via X-COM Windows software. Laptop, desktop or X-COM SigAnalyst workstation. IQC91000A-to-computer interface: 1000Base-T Ethernet
Environmental	Compliant with IEC 60068-2; humidity, shock, vibration, altitude, power line conditions to MIL-PRF-28800F Class 3.
Dimensions, typical	19.25 × 19.00 × 23.00 in.
Weight	95 lb.

The IQC91000A includes IRIG and GPS input ports, enabling it to precisely identify recorded signals. It can place a marker on a signal sample that includes the time it was recorded to within 1 µs as well as the latitude, longitude, and elevation when it was taken. As many as 100,000 markers are available per file.

For those cases where the IQC91000A must play back a signal file for analysis or reconstruction using an external instrument such as a PSG series vector signal generator from Keysight Technologies or an R&S SMW200A signal generator from Rohde & Schwarz (www.rohde-schwarz.us), it features a playback offload rate of 1.6 GSamples/s with 12-b resolution each for the I and Q components of a captured signal. Such playback capability is useful when signal files are used to evaluate an EW or radar system, for example, in a shielded room or test laboratory and different environmental effects are being evaluated with the aid of simulation software.

In terms of software, X-COM offers Spectro-X, which allows operators to simultaneously analyze as many as four recorded RF/microwave spectrum files of any length. It can help find signals of interest by using four discrete search engines focused on carrier, wireless standard, arbitrary waveform, and pulse signals in both frequency and time domains. The desired portions of a file can then be exported for detailed analysis. The firm's RF Editor software provides the capability to edit signal data from the IQC91000A. It allows new spectra and waveforms to be added to a file, modified in the frequency domain, and moved anywhere among 10 tracks in a recording.

For secure applications, the IQC91000A incorporates a declassification procedure that allows it to be moved in and out of classified environments.

The IQC91000A base unit is a 1-GHz single-channel system with an 800-MHz IF input and digital I and Q outputs along with control software. It can be equipped with a choice of three frequency downconverters, covering 0.5 to 18.0 GHz, 3.6 to 26.5 GHz, and 18 to 40 GHz. Frequency upconverters with differential inputs are available in frequency ranges of 0.5 to 18.0 GHz and 0.5 to 40.0 GHz. A typical system (see the *table* for additional specifications) with 0.5 to 18.0 GHz receiver/downconverter, 30 TB SSD memory capacity. de

X-COM SYSTEMS, 12345-B Sunrise Valley Dr., Reston, Virginia 20191, (571) 612-5490, sales@xcomsystems.com, *www.xcomsystems.com*

JACK BROWNE | Technical Contributor

SWaP PXIe Sources Extend to 12 GHz

These compact PXIe signal generators are available in single- and dual-channel versions with frequency coverage through 6 or 12 GHz with excellent spectral purity.

LOW-NOISE SIGNALS are invaluable for many defense-related and commercial systems, especially when they can be generated by space-saving PXI Express (PXIe) modular assemblies. The QuantumWave 4000 series of single- and dual-channel synthesized signal generators from Cambridge Instruments (www.cambridgeinstruments.com) are just such compact signal sources, each occupying single-slot 3U PXIe modules while providing spectrally pure signals to 6 or 12 GHz. Designed for applications requiring low size, weight, and power (SWaP), these compact signal sources can be used as local oscillators (LOs) or test signals for a variety of applications in communications, electronic-warfare (EW), and radar systems.

The compact QuantumWave 4000 PXIe-based frequency synthesizers include the single-channel model 4061 and the dual-channel models 4062 and 4122.

The QuantumWave 4000 series of PXIe-based signal sources *(see figure)* are available in three versions: model 4061, with a single channel covering 75 MHz to 6 GHz; model 4062, with two channels, each covering 75 MHz to 6 GHz; and model 4122, with one channel spanning 75 MHz to 6 GHz and the second channel covering 6 to 12 GHz. Each source features 250-µ switching speed to settle within 0.1% of a new frequency. Each unit offers calibrated output-power levels of −10 to +10 dBm, with ±1-dB amplitude accuracy across an operating-temperature range of 0 to +55° C. Uncalibrated output levels are available from −20 to +15 dBm. Amplitude can be set with 0.1-dB resolution.

The frequency resolution of these compact sources depends upon the choice of frequency reference: these versatile PXIe signal generators can operate with internal or external reference sources. They are available with a 50-MHz internal reference with accuracy of ±1 ppm and nominal single-sideband (SSB) phase noise of −145 dBc/Hz offset 10 kHz from the carrier. Signals from the internal reference are also available from the front panel of one of the sources for use by other instruments. The QuantumWave 4000 series PXIe signal generators can also work with external reference sources providing frequencies from 50 to 200 MHz at levels from −30 to +10 dBm, via a female SMA connector.

Through 6 GHz, with an external or internal 50-MHz reference, the frequency resolution is 2.98 Hz or better. Through 12 GHz, with the same frequency reference, the frequency resolution is 11.92 Hz. Through 6 GHz, with an external 10-MHz reference, the frequency resolution is 0.6 Hz or better. Through 12 GHz, with the same frequency reference, the frequency resolution is 2.38 Hz. Using an internal reference, the phase noise is −116 dBc/Hz offset 10 kHz from a 1-GHz carrier and −96 dBc/Hz offset 10 kHz from a 9-GHz carrier. For all models, harmonically related spurious noise is better than −20 dBc (and typically better than −30 dBc) from 75 MHz to 12 GHz when measured with +10-dBm output signals. Nonharmonic spurious noise is better than −50 dBc and typically better than −65 dBc.

The PXIe frequency synthesizers run with a variety of standard software drivers, including core dll, IVI, and LabVIEW drivers from National Instruments (www.ni.com), and support all popular test application development languages for ease of integration into automated systems. In addition, for applications where manual operation may be needed, a straightforward graphical user interface is also available to control the PXIe synthesizers. The compact signal sources each measure just 210 × 22 × 130 mm and meet the following electromagnetic-compatibility (EMC) requirements: Federal Communications Commission (FCC) Class A, EMC Directive 2004/108/EC, Canadian ICES-001, and AS/NZS CISPR 11.

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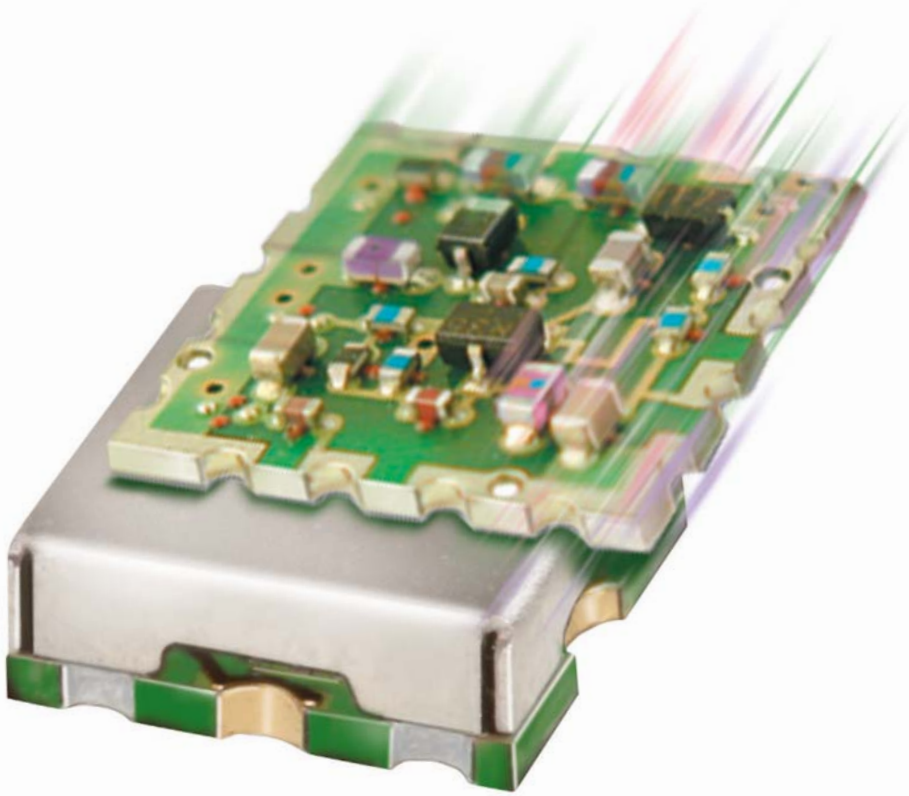

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PXI System
Speeds Satcom Measurements

This automated measurement system provides the sophisticated signal routing needed for functional testing of high-pin-count satellite communications systems.

SWITCHING THAT takes place within satellite communications (satcom) systems, whether for military or commercial applications, can be extremely complex. For that reason, Marvin Test Solutions (www.marvintest.com) recently developed and delivered a sophisticated test system to Lockheed Martin Space Systems Co. (www.lockheedmartin.com) for evaluation of its satcom systems and equipment.

To meet the ever-changing needs of complex satcom switching measurements, the flexible measurement system is based on the modular PXI format, which allows the quick and straightforward changing of modules to achieve new measurement capabilities and performance levels. The automated measurement system is backed by the firm's advanced software tools for true evaluation of end-to-end signal routing within aerospace-grade satcom systems, including the SwitchEasy software simplifies the automatic testing of complex signal switching arrangements.

The TS-323 GENASYS test system (*Fig. 1*) was developed to meet the demands of mission-critical applications requiring functional testing. The PXI test system is capable of test satcom system configurations with as many as 512 input/output (I/O) pins with multiple timing arrangements and it will be used by its customer for functional testing of satcom systems and subsystems. Much of the system features commercial-off-the-shelf (COTS) digital, analog, and switching components, along with the firm's SwitchEasy signal-switching control software.

A key part of the TS-323 GENASYS system is the 6U PXI GX7016 switching subsystem *(Fig. 2)*. The GX7016 receiver subsystem is based on a 20-slot 6U PXI chassis that can accommodate up to 19 switching or instrument cards as well as a remote PXI bus interface such as the MXI-4.

In addition to supporting all of the PXI-1 resources, the GX7016's PXI backplane provides an internal, high-performance, 16-wire analog bus via the backplane's P5 connectors. Each of the GENASYS switching cards connects to this internal 16-wire bus, providing the ability to route signals from an external instrument to any of the receiver's interface connections.

1. The TS-323 GENASYS test system employs PXI subsystems and function modules to provide flexibility when performing advanced switching in satcom and other systems.

2. An important part of the TS-323 GENASYS system is the GX7016 switching receiver subsystem, housed in a 20-slot 6U PXI chassis.

The GX7016 incorporates a modular switch matrix and multiplexer architecture with support for as many as 4,608 multiplexed hybrid I/O pins. As many as 128 external resources can be connected to any of the test system's receiver I/O pins via a high-performance, internal 16-wire matrix bus.

For digital test capability, the GX7016's switching subsystem can be connected to a digital subsystem such as Marvin Test Solutions' GX5960 digital subsystem.

The GX7016 chassis features the company's MAC Panel 6U SCOUT receiver, which provides the means to connect the test systems switch modules to an interconnection receiver, to minimize the need for cable assemblies. The modular design of the receiver allows the use of a wide range of coaxial and power connectors. The SCOUT receiver can accommodate as many as 21 connector slots and more than 8,000 connections when all slots are filled.

The GX7016 PXI receiver subsystem addresses a range of bus test requirements including IEEE-1553, IEEE-429, RS-232, and custom or parallel digital buses. It is supplied with a virtual instrument panel for monitoring and control, which includes 32-b dynamic-link-library (DLL) driver libraries and documentation. The virtual instrument panel can be used to set temperature limits and alarm conditions for the system while also monitoring power-supply voltages to the different PXI modules.

The GX7016 is supplied with an application programming interface that supports a wide range of programming tools, including tools from Microsoft Corp. (www.microsoft.com) and National Instruments (www.ni.com).

The GX7016 operates by means of a 755-W power supply and includes forced-air cooling with four fans mounted beneath the card cage for positive air flow through the PXI system. The GX7016 chassis allows monitoring of slot temperatures and power-supply voltages to keep track of operating conditions.

In addition, user setups can be stored in nonvolatile memory to support the operating requirements of different users. The GX7016 is designed for operating temperatures from 0 to +50° C. de

MARVIN TEST SOLUTIONS INC., 1770 Kettering, Irvine, CA 92614; (949) 263-2222, FAX: (949) 263-1203, *www.marvintest.com*

Compact Amplifier Gains 10 MHz to 6 GHz

BASED ON indium gallium phosphide (InGaP) heterojunction-bipolar-transistor (HBT) device technology, model CMA-62+ is a lead-free, RoHS compliant wideband amplifier that covers 10 MHz to 6 GHz with 15-dB gain and +19-dBm output power at 1-dB compression. Gain remains flat within ±0.7 dB from 50 to 4000 MHz. The low-cost amplifier draws just 65 mA current from a +5-VDC supply and achieves +33-dBm output power at 3-dB compression. The typical noise figure is 5 dB. The reliable

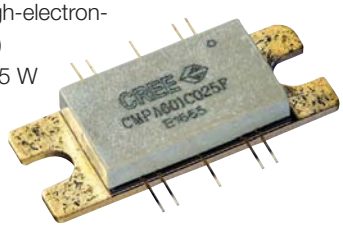
monolithic-microwave-integrated-circuit (MMIC) amplifier is bonded to a multilayer low-temperature-cofired-ceramic (LTCC) substrate and then hermetically sealed under a controlled nitrogen atmosphere with gold-plated covers and eutectic AuSn solder. It is tested to military requirements for gross leak, fine leak, thermal shock, vibration, acceleration, mechanical shock, and HTOL. The amplifier is supplied in a compact surface-mount housing measuring only 0.045 in. high and rated for operating temperatures from –55° C to +105° C

MINI-CIRCUITS

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

GaN MMIC Amp Powers 25 W to 12 GHz

A COMPACT GALLIUM-NITRIDE (GaN) monolithic-microwave-integrated-circuit (MMIC) amplifier has been developed as a medium-power replacement for much larger amplifiers, including traveling-wave-tube amplifiers (TWTAs) in a wide range of systems, including for radar and jamming applications. The GaN high-electron-mobility-transistor (HEMT) amplifier, which delivers 25 W output power from 6 to 12 GHz, is available in bare die form as model CMPA601C025D or in a thermally enhanced, 10-lead ceramic flange package as model CMPA601C025F. Both are designed for operation at +28 VDC and provide as much as 35 W continuous-wave (CW) output power across the full 6-to-12-GHz frequency range with 33-dB small-signal gain.

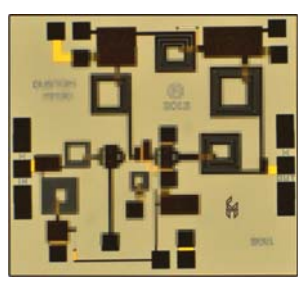


CREE, INC.

4600 Silicon Dr., Durham, NC 27703; (800) 533-2583, (919) 313-5300, FAX: (919) 313-5558, www.cree.com

Low-Noise AmpBoosts 4 to 8 GHz

MODEL CMD219 is an octave-wide low-noise amplifier (LNA) that achieves 23-dB gain and low 1.1-dB noise figure from 4 to 8 GHz. It boasts an output 1-dB compression point of +18 dBm. Typical bias conditions include a drain voltage of +10 VDC at 100 mA with a gate voltage of –2.3 VDC. The drain voltage can vary from +5 to +23 VDC. The gallium-nitride (GaN) amplifier is supplied in die form. The LNA, which can survive input power levels to 5 W without a front-end limiter, is well suited for use in receivers in commercial and military point-to-point and point-to-multipoint systems.



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Modular Computer Commands Multiple Missions

MODEL MPMC-9355-0002 is a multiple-platform mission computer housed in a five-slot 3U OpenVPX format. The modular, commercial-off-the-shelf (COTS) computer can be configured with as many as four 2.1-GHz VPX3-1257 3U OpenVPX single-board computers (SBCs), each with a quad-core Intel i7 microprocessor. The SBCs are connected by means of a Layer 2 Ethernet switch and PCIe backplane infrastructure. The integral VPX3-652 Ethernet switch supports as many as eight external Gigabit Ethernet connections.

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Attenuator/Modulator Pads 0.5 to 18 GHz

MODEL PVA-500M18G-60-SFF is a voltage-variable attenuator/modulator with a frequency range of 500 MHz to 18 GHz. It provides a wide attenuation range of typically 60 dB, with fast rise/fall time of typically 1.8 µs. It offers attenuation accuracy of better than ±2 dB across the full attenuation/modulation range.

The maximum insertion loss is 5.2 dB through 18 GHz. The component is designed for continuous-wave (CW) input levels to +20 dBm through 18 GHz and to +10 dBm below 300 MHz; it can survive levels to +30 dBm. The unit is supplied in a housing measuring 2.00 in. × 1.81 in. × 0.50 in. with SMA female input and output connectors and solder pins for bias and control. It draws 250 mA maximum current at +12 VDC and 50 mA maximum at –12 VDC.

PLANAR MONOLITHICS INDUSTRIES (PMI)

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Surface-Mount GaN Amp Powers S-Band Radars

MODEL TGA2813-CP is a high-power gallium nitride (GaN) amplifier from Qorvo (TriQuint) designed for S-band radar applications. Supplied in a flanged surface-mount package with pure copper base for excellent thermal conductivity, the amplifier can be used with long- and short-pulsed signals. It is capable of providing 100 W saturated output power from 3.1 to 3.6 GHz with better than 51% power-added efficiency. It supplies 23-dB power gain when operating with a +27-dBm (0.5-W) input signal. The surface-mount amplifier, which draws 300 mA quiescent current from a +30-VDC supply, measures 15.2 mm × 15.2 mm.

RFMW LTD.

188 Martinvale Lane, San Jose, CA 95119; (408) 4140-1450, e-mail: info@rfmw.com, www.rfmw.com

Amplifier Drives Satcom from 29 to 31 GHz

MODEL MAAP-011139 is a high-linearity power amplifier well suited for Ka-band satellite-communications (satcom) applications. It is available in die format as well as in a 5 mm × 5 mm 32-lead QFN package. The amplifier provides 24-dB linear gain with 4 W (+36.5 dBm) of saturated output power from 29 to 31 GHz. It achieves 10-dB input and output return loss with 23% power-added efficiency (PAE). It maintains third-order intermodulation (IM3) levels of –30 dBc across its 2-GHz bandwidth.

MACOM TECHNOLOGY SOLUTIONS, INC.

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

Passive Mixer Translates 60 GHz

MODEL MM1-2567LS is a passive, double-balanced mixer designed to tackle broadband frequency-conversion applications. It provides an RF and local-oscillator frequency range of 25 to 67 GHz and an intermediate-frequency range of DC to 30 GHz. The gallium-arsenide (GaAs) monolithic-microwave-integrated-circuit (MMIC) mixer is available in a compact housing with coaxial connectors in two different configurations. One is aimed at high efficiency and the other at outstanding spurious performance. Conversion loss for the first configuration is typically 9 dB, with typical input 1-dB compression point of +1 dBm. Conversion loss for the second configuration is typically 16 dB, with typical input 1-dB compression point of +5 dBm. The mixer package measures 0.560 × 0.520 × 0.39 in. (14.22 mm × 13.21 mm × 0.99 mm) and handles operating temperatures from –55° C to +100° C.

MARKI MICROWAVE INC.

215 Vineyard Ct., Morgan Hil, CA 95037; (408) 778-4200, FAX: (408) 778-4300, e-mail: info@markimicrowave.com, www.markimicrowave.com

Switch Controls DC to 8 GHz

MODEL PE42020 is a single-pole, double-throw switch developed by Peregrine Semiconductor Corp. and available from Richardson RFPD. Suitable for analog and digital functions, the switch commands DC to 8 GHz. Based on Peregrine's HaRP technology, the UltraCMOS switch makes use of the firm's patented silicon-on-insulator process. It achieves insertion loss of 1 dB and isolation of 42 dB across the frequency range. It can handle power levels to +30 dBm at DC and to +36 dBm at 8 GHz. The PE42020 can accommodate DC or AC peak voltages in the range of +10 to –10 VDC on its RF ports and DC current through RF active ports to 80 mA. The switch is supplied in a 20-lead, 4 mm × 4 mm QFN package.

RICHARDSON RFPD

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

TWTAs Drive 750 W at Ku Band

A PAIR OF traveling-wave-tube amplifiers (TWTAs) provide the power needed for various frequencies of satellite-communications (satcom) uplink applications and serve as direct replacement for klystron power amplifiers in satcom systems. The amplifiers feature the firm's SuperPower technology to achieve high power levels from helix TWT components. Model XTD-2000KHE is a Ku-band TWTA with 750 W linear output power and 2000 W peak power from 13.75 to 14.50 GHz. It draws less than 3200 W prime power in a rugged package weighing only 92 lb. Model XTD-1500DBSHE is a TWTA developed for direct-broadcast-satellite use, with 560 W linear output power and 1500 W peak output power from 17.3 to 18.1 GHz. It draws only 2500 W prime power in the same 92-lb. package. Both amplifiers incorporate pre-distortion linearizers, output protection circuitry, Ethernet monitoring and control interfaces, and built-in redundancy switch control circuitry. A number of options are available, including liquid cooling and internal frequency upconversion from L-band frequencies. Both TWTAs are available as rugged outdoor antenna-mount units designed for operating temperatures from –40° C to +60° C or as indoor rack-mount versions, with LCD touchscreen displays for ease of monitoring and control.

COMTECH XICOM TECHNOLOGY INC.

3550 Bassett St., Santa Clara, CA 95054; (408) 213-3000, FAX: (408) 213-3001, e-mail: sales@xicomtech.com, www.xicomtech.com

Coaxial Limiters Span 0.5 to 40.0 GHz

A LINE OF coaxial limiters provides coverage for different portions of the frequency range from 0.5 to 40.0 GHz. For example, model PE80L1000 operates across the full 0.5 to 18.0 GHz frequency range with insertion loss of 1.5 dB or less with limiting threshold of +10 dBm and input-power handling capability to 1 W. The limiter, which is supplied with SMA connectors and achieves recovery time of 10 ns, measures 0.5 in. × 0.5 in. × 0.22 in. For coverage from 2 to 8 GHz, model PEL1001 is a coaxial limiter with SMA connectors and frequency range of 2 to 8 GHz. It controls insertion loss to 1 dB with limiting threshold of +3 dBm and input power handling capability of 5 W. It measures 1.0 in. × 1.0 in. × 0.4 in. and achieves recovery time of 40 ns. Additional coaxial limiters in the series are available with SMA and 2.92-mm connectors for frequency ranges that include 6 to 18 GHz, 2 to 18 GHz, 18 to 40 GHz, 2 to 18 GHz, and 12 to 18 GHz.

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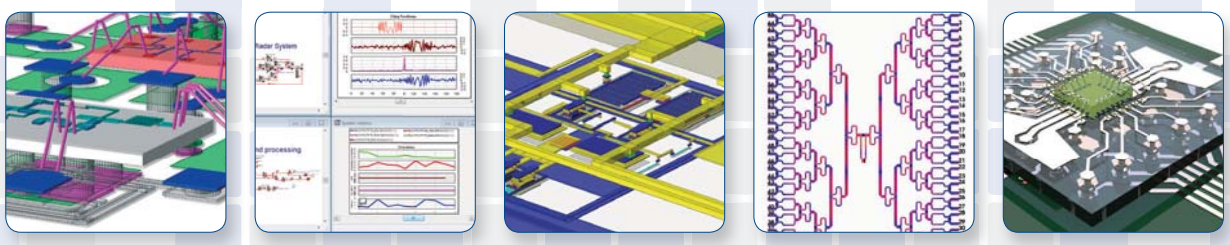

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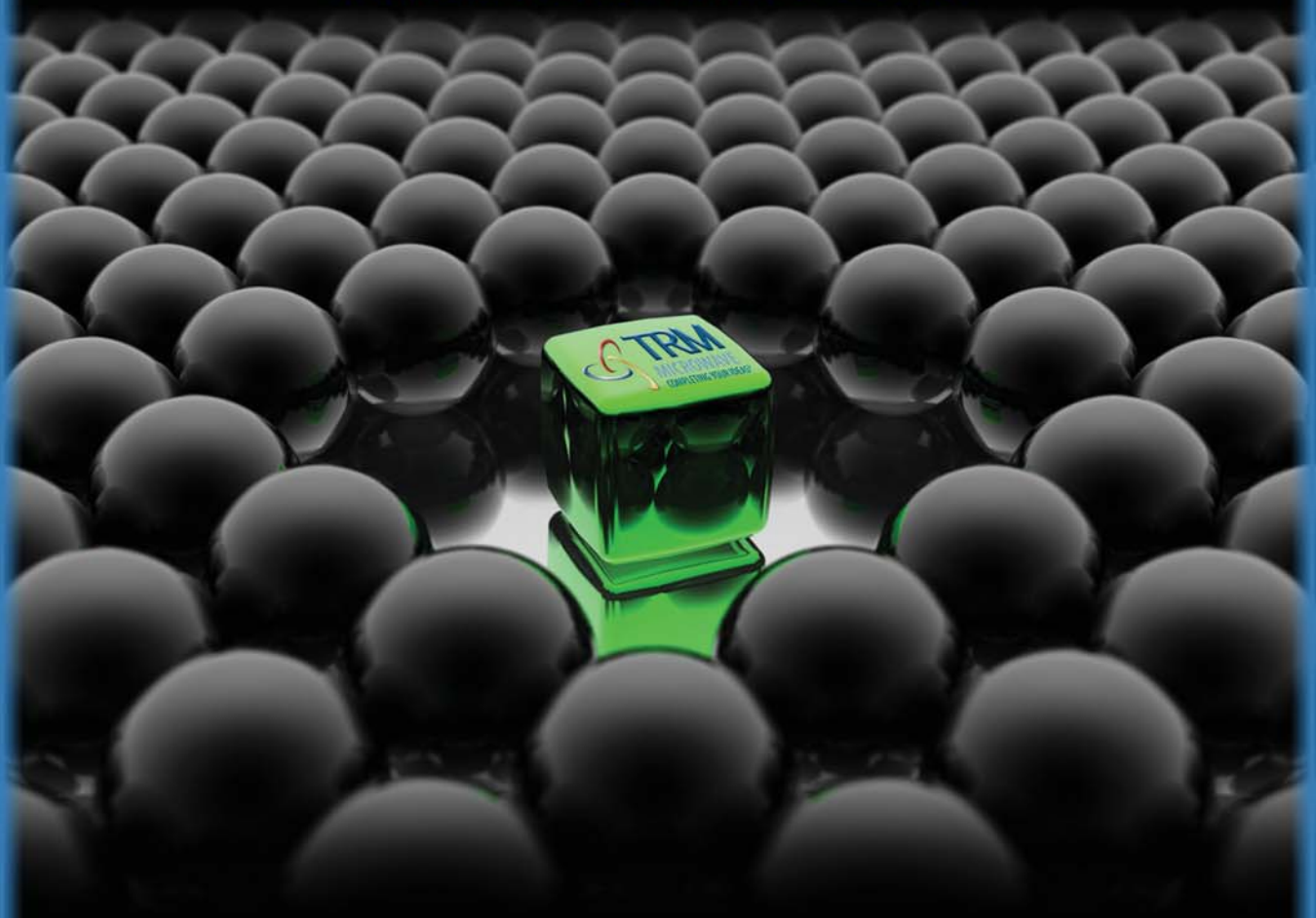

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