Managing the Coexistence of Multiple Wireless Systems Standards p 55

AWGs Generate Multiple Complex Signals to 4 GHz p 118

Five Questions Every Successful 5G Designer Needs to Ask p 132

Microwaves & RF®

YOUR TRUSTED ENGINEERING RESOURCE FOR OVER 50 YEARS

MAY 2017 mwrf.com

THE NEXT WAVE

New trends and innovators to be unleashed at IMS 2017 in Hawaii p33

$10.00
Powered by Penton

Planar Monolithics Industries, Inc.

Ultra Broadband & mmW State-Of-The-Art Digital / Programmable Attenuators

- **Amplifiers – Solid State**
- **Attenuators – Variable/ Programmable**
- **Couplers (Quadrature, 180° & Directional)**
- **Detectors – RF/Microwave**
- **DLVAs, ERDLVAs & SDLVAs**
- **DTOs, VCOs, PLO, DROs, & Frequency Synthesizers**
- **Filters & Switched Filter Banks**
- **Form, Fit, Functional Products & Services**
- **Frequency Discriminators & IFMs**
- **Integrated MIC/MMIC Assemblies (IMAs)**
- **IQ Vector Modulators**
- **Limiters – RF/Microwave**
- **Log Amplifiers**
- **Millimeter Wave Components (Up to 50 GHz)**
- **Miscellaneous Products**
- **Monopulse Comparators**
- **Multifunction Integrated Assemblies (MIAs)**
- **Phase Shifters & Bi-Phase Modulators**
- **Power Dividers/Combiners (Passive & Active)**
- **Pulse Modulators (SPST)**
- **Rack & Chassis Mount Products**
- **Receiver Front Ends & Transceivers**
- **SDLVAs, ERDLVAs & DLVAs**
- **Single Side Band Modulators**
- **SMT & QFN Products**
- **Switch Matrices**
- **Switched Filter Banks**
- **Switches – Solid State**
- **Systems – Fly Eye Radars**
- **Threshold Detectors**
- **USB Products**

PMI offers the highest quality digitally controlled programmable attenuators for industrial and military applications. Choice of attenuation ranges with resolution as low as 0.04 dB and operating frequency ranges up to 40 GHz available.

Model: DTA-100M40G-30-CD-1 & DTA-14G40G-32-CD-2

http://www.pmi-rf.com/Products/attenuators/DTA-100M40G-30-CD-1.htm
http://www.pmi-rf.com/Products/attenuators/DTA-14G40G-32-CD-2.htm

Package Size: 2.0" x 1.8' x 0.5"
DC Voltage: +15 VDC @ 38 mA
Connectors: 2.92mm (F) &
15 Pin Micro-D-Female
Switching Speed:
Measured 0.25 μs

Package Size: 2.0" x 1.8' x 0.5"
DC Voltage: +15 VDC @ 38 mA
Connectors: 2.92mm (F) &
15 Pin Micro-D-Female
Switching Speed:
Measured 0.266 μs

Specfications	DTA-100M40G-30-CD-1	DTA-14G40G-32-CD-2
Frequency	0.1 to 40.0 GHz	14.0 to 40.0 GHz
Attenuation Range	30 dB	32 dB
Insertion Loss	5.0 dB Typ. (to 20 GHz) - Measured 4.9 dB 8.0 dB Typ. (to 40 GHz) - Measured 7.1 dB	9.0 dB Typ. - Measured 8.62 dB
VSWR	2.5:1 Max. - Measured 2.49:1	2.0:1 Typ. - Measured 1.75:1
Attenuation Flatness	±1.5 dB Typ. Measured: @ 10 dB: ±0.95 dB @ 20 dB: ±1.47 dB @ 30 dB: ±2.13 dB	±1.5 dB Typ. Measured: @ 8 dB: ±0.61 dB @ 16 dB: ±1.01 dB @ 32 dB: ±1.77 dB
Attenuation Accuracy	±2.5 dB Typ. Measured: 0 to 10 dB: ±0.59 dB 10 to 20 dB: ±0.09 dB 20 to 30 dB: ±0.20 dB	±2.0 dB Typ. Measured: 0 to 8 dB: ±0.28 dB 8 to 16 dB: ±0.05 dB 16 to 32 dB: ±0.15 dB
Operating Temperature	-50 °C to +85 °C	-40 °C to +85 °C

Model: DTA-18G40G-30-CD-1 & DTA-18G40G-50-CD-1

http://www.pmi-rf.com/Products/attenuators/DTA-18G40G-30-CD-1.htm
http://www.pmi-rf.com/Products/attenuators/DTA-18G40G-50-CD-1.htm

Package Size: 2.0" x 1.8' x 0.5"
DC Voltage: +15 VDC @ 38 mA
Connectors: 2.92mm (F) &
15 Pin Micro-D-Female
Switching Speed:
Measured 0.30 μs

Package Size: 2.0" x 1.8' x 0.5"
DC Voltage: +15 VDC @ 38 mA
Connectors: 2.92mm (F) &
15 Pin Micro-D-Female
Switching Speed:
Measured 0.12 μs

Specfications	DTA-18G40G-30-CD-1	DTA-18G40G-50-CD-1
Frequency	18.0 to 40.0 GHz	18.0 to 40.0 GHz
Attenuation Range	30 dB	50 dB
Insertion Loss	6.0 dB Typ. - Measured 6.1 dB	8.5 dB Typ - Measured 10.4 dB
VSWR	2.5:1 Max. - Measured 2.11:1	2.5:1 Typ. - Measured 2.27:1
Attenuation Flatness	±1.5 dB Typ Measured: @ 10 dB: ±0.98 dB @ 20 dB: ±1.27 dB @ 30 dB: ±1.93 dB	±1.5 dB Typ Measured: @ 16 dB: ±2.10 dB @ 32 dB: ±2.10 dB @ 50 dB: ±3.88 dB
Attenuation Accuracy	±2.0 dB Typ. Measured: 0 to 10 dB: ±0.39 dB 10 to 20 dB: ±0.54 dB 20 to 30 dB: ±0.76 dB	±2.0 dB Typ. Measured: 0 to 16 dB: ±0.14 dB 16 to 32 dB: ±0.18 dB 32 to 50 dB: ±0.48 dB
Operating Temperature	-40 °C to +85 °C	-40 °C to +85 °C

IMS
Connecting Minds. Exchanging Ideas.

IEEE MTT-S International Microwave Symposium
Hawai'i Convention Center Honolulu, Hawai'i
June 4-9, 2017
Booth #701
ims2017.org

INTERNATIONAL PARIS AIR SHOW
Paris • Le Bourget

52nd International Paris Air Show
Le Bourget Parc des Expositions,
a few kilometers North of Paris
June 19 - 25, 2017
Hall 3/A38 (Maryland Pavilion)
www.siae.fr/en

West Coast Operation:
4921 Robert J. Mathews Pkwy, Suite 1
El Dorado Hills, CA 95762 USA
Tel: 916-542-1401, Fax: 916-265-2597

East Coast Operation:
7311-F Grove Road
Frederick, MD 21704 USA
Tel: 301-662-5019, Fax: 301-662-1731

sales@pmi-rf.com • www.pmi-rf.com
ISO9001-2008 REGISTERED

SKYWORKS®

Enabling Wireless Connectivity with Advanced RF Solutions

Connected Home and Wearables

For fitness/smart watches, trackers, wireless headphones, in-home appliances, smart thermostats, alarms, lighting, sensors and more.

Part Number	Description	Frequency Range (GHz)
SKY66111-11	Front-end Module for Bluetooth® Low Energy Range Extension Applications	2.400 to 2.485
SKY66112-11	Front-end Module for Bluetooth® Low Energy / Thread / ZigBee® Applications	2.400 to 2.483
SKY66113-11 SKY66114-11	Front-end Module for Bluetooth® Low Energy / 802.15.4 / ZigBee® Applications	2.400 to 2.483
SKY65623-682LF	GPS / GLONASS / Galileo / Compass Low Noise Amplifier	1.559 to 1.606

Machine-to-Machine

For low-power, wide area network (LPWAN) LTE Cat-M IoT modules and devices

Part Number	Description	Frequency Range (GHz)
SKY68000-31	LTE Dual-band Front-end Module for Cellular Bands 4 and 13 for Category M1 and NB1	0.777 to 0.787 1.710 to 1.755
SKY68001-31	LTE Universal Multiband Front-end Module for Cellular Covering >15 Bands for Category M1 and NB1	0.699 to 0.915 1.710 to 1.980
SKY68011-31	LTE Multiband Front-end Module for Cellular Covering >8 Bands for Category M1 and NB1	0.699 to 0.787 1.710 to 1.980

Mobile Devices

For Bluetooth® / WiFi-enabled handsets, tablets, and mobile / portable systems

Part Number	Description	Frequency Range (GHz)
SKY85018-11	High-Power Bluetooth® Power Amplifier	2.400 to 2.500
SKY85812-11	Dual-band 802.11ac Front-end Module	2.400 to 1.500 4.900 to 5.900

For more information about all of our wireless solutions, please visit us at www.skyworksinc.com.

sales@skyworksinc.com | USA: 781-376-3000 | Asia: 886-2-2735 0399 | Europe: 33 (0)1 43548540 | NASDAQ: SWKS |

Visit us at the IMS Show Booth #1331

IN THIS ISSUE

FEATURES

IMS 2017

33

55

86

PRODUCT TECHNOLOGY

NEWS & COLUMNS

defense electronics

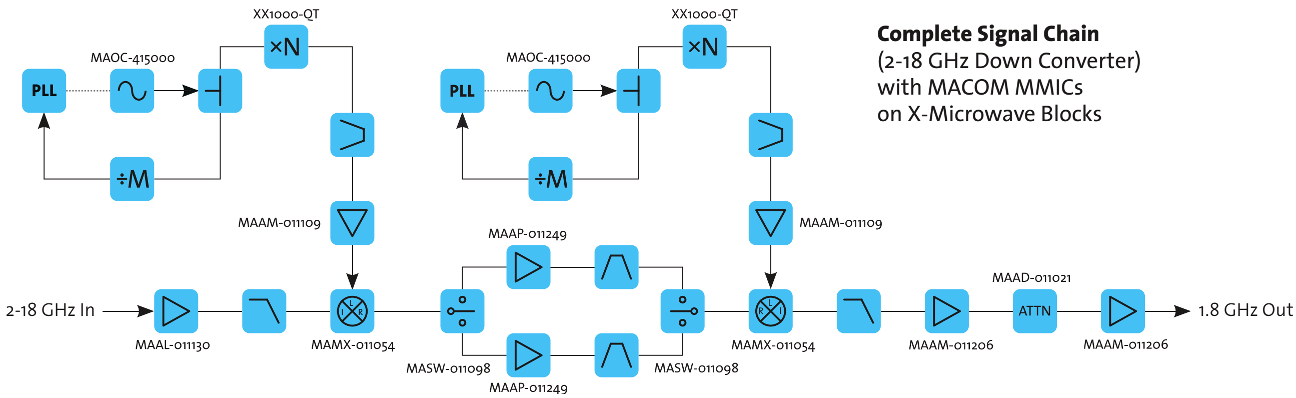
Starts on page **89**

JOIN US ONLINE

follow us @MicrowavesRF

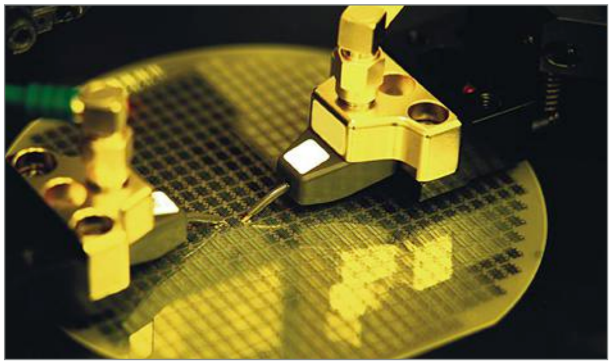
become a fan at facebook.com/microwavesRF

The Trusted Name in High



Complete Signal Chain
(2-18 GHz Down Converter)
with MACOM MMICs
on X-Microwave Blocks

ON MICROWAVES&RF.COM



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.

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

Silicon Paves Way for Photonics Expansion

Silicon has long been the building-block material of choice for analog and digital semiconductors, but it appears to be gaining favor for photonics components, as well.

http://www.mwrf.com/semiconductors/silicon-paves-way-photonics-expansion

Using Sound Waves to Analyze MIMO

Low-cost audio speakers and sound waves were used to model the effects of multipath propagation on MIMO wireless communications systems.

http://www.mwrf.com/systems/using-sound-waves-analyze-mimo

Microwave Energy Aims to Improve Health

Medical devices are now being implanted, worn, and mounted for monitoring in homes and hospitals to provide cutting-edge health benefits via modern wireless technology.

http://www.mwrf.com/systems/microwave-energy-aims-improve-health

join us online twitter.com/MicrowavesRF facebook.com/microwavesrf

Editorial

CHRIS DeMARTINO
Technical Editor
chris.demartino@penton.com

Does the RF/Microwave Industry Need an Influx of Youth?

One sentiment in the RF/microwave world concerns the need to bring more young people into the industry. Obviously, I do not know the actual percentage of industry people who have this view. However, I would say that RF/microwave engineering is generally considered a more difficult—and perhaps even less glamorous—career path than other fields.

Specifically, one could take a look at software engineering, which many would find to be an attractive career path. It would be pretty difficult to question a young person who prefers software engineering over RF/microwave engineering, especially when companies like Google offer starting salaries that are much higher than the typical starting salary in the RF/microwave industry.

With that being said, a career in RF/microwave engineering still has a whole lot to offer. Furthermore, the industry does seem to be making efforts to assist the younger generation. For example, this year's International Microwave Symposium (IMS) has plans for a number of student-based activities. These activities include the student design competition and student paper competition, among others. On top of that, the Three Minute Thesis and Hackathon competitions will debut this year. These events are fresh new ideas that should be fun to watch.

Students and young professionals were also clearly a focal point at the recent 2017 IEEE Wireless and Microwave Technology Conference (WAMICON 2017). For example, a poster session featured various student research projects. A workshop was also held for young professionals. Much of the credit goes to people like Larry Dunleavy (Modelithics and the University of South Florida) and Tom Weller (the University of South Florida), who are helping the next generation of engineers.

One could ask the question: Does the industry does need more companies to attract and then mentor young engineers? While some companies are already going this route, maybe others also need to do the same. Of course, mentoring young engineers takes time and resources—and some companies may not be in a position to fully invest themselves on that level. Nonetheless, companies should take steps to ensure that this industry becomes attractive to prospective young individuals.

On a final note, Altair *(www.altair.com)* recently announced its 2017 FEKO Student Competition, which is an international contest that is intended to support engineering education. The deadline to submit an entry is October 31. mw

JOIN US ONLINE twitter.com/MicrowavesRF
become a fan at facebook.com/MicrowavesRF


MCL B 744
ADP-2-10
MCL B 538
SCA-4-15
-75
MCL
QBA-12
071838
MCL
BPNC
MCL
BP2C
SBA-2-20
071840

Microwaves&RF — MAY 2017

EDITORIAL

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

ART DEPARTMENT

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

PRODUCTION

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

AUDIENCE MARKETING

USER MARKETING DIRECTOR: **BRENDA ROODE** brenda.roode@penton.com
USER MARKETING MANAGER: **DEBBIE BRADY** debbie.brady@penton.com
FREE SUBSCRIPTION/STATUS OF SUBSCRIPTION/ADDRESS CHANGE/MISSING BACK ISSUES
OMEDA **T** | 847.513.6022 **TOLL FREE** | 866.505.7173

SALES & MARKETING

MANAGING DIRECTOR: **TRACY SMITH** **T** | 913.967.1324 **F** | 913.514.6881 tracy.smith@penton.com

REGIONAL SALES REPRESENTATIVES
AZ, NM, TX: **GREGORY MONTGOMERY** **T** | 480.254.5540 gregory.montgomery@penton.com

AL, AK, AR, CA, CO, FL, GA, HI, IA, ID, IL, IN, KS, KY, LA, MI, MN, MO, MS, MT, NC, ND, NE, NV, OH, OK, OR, SC, SD, TN, UT, VA, WA, WI, WV, WY, W/CANADA: **JAMIE ALLEN** **T** | 415.608.1959 **F** | 913.514.3667 jamie.allen@penton.com

CT, DE, MA, MD, ME, NH, NJ, NY, PA, RI, VT, EASTERN CANADA:
SHANNON ALO-MENDOSA **T** | 978.501.7303 shannon.alo-mendosa@penton.com

INTERNATIONAL SALES
GERMANY, AUSTRIA, SWITZERLAND: **CHRISTIAN HOELSCHER** **T** | 011.49.89.95002778
christian.hoelscher@husonmedia.com

BELGIUM, NETHERLANDS, LUXEMBURG, UNITED KINGDOM, SCANDINAVIA, FRANCE, SPAIN, PORTUGAL:
JAMES RHOADES-BROWN **T** | +011 44 1932 564999 **M** | +011 44 1932 564998 james.rhoadesbrown@husonmedia.com

ITALY: **DIEGO CASIRAGHI** diego@casiraghi-adv.com
PAN-ASIA: **HELEN LAI** **T** | 886 2-2727 7799 helen@twoway-com.com

PLEASE SEND INSERTION ORDERS TO: orders@penton.com
PENTON REPRINTS: **WRIGHT'S MEDIA** **T** | 877.652.5295 penton@wrightsmedia.com

LIST RENTALS:
SMARTREACH CLIENT SERVICES MANAGER: **JAMES ADDISON** **T** | 212.204.4318 james.addison@penton.com

ONLINE

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

DESIGN ENGINEERING & SOURCING GROUP

EXECUTIVE DIRECTOR OF CONTENT AND USER ENGAGEMENT: **NANCY K. FRIEDRICH**
GROUP DIRECTOR OF OPERATIONS: **CHRISTINA CAVANO**
GROUP DIRECTOR OF MARKETING: **JANE COOPER**

PENTON

1166 AVENUE OF THE AMERICAS, 10TH FLOOR, NEW YORK, NY 10036 **T** | 212.204.4200

Penton

Electronic Design | Machine Design | Microwaves & RF | Source ESB | Hydraulics & Pneumatics | Global Purchasing | Distribution Resource | Power Electronics | Defense Electronics

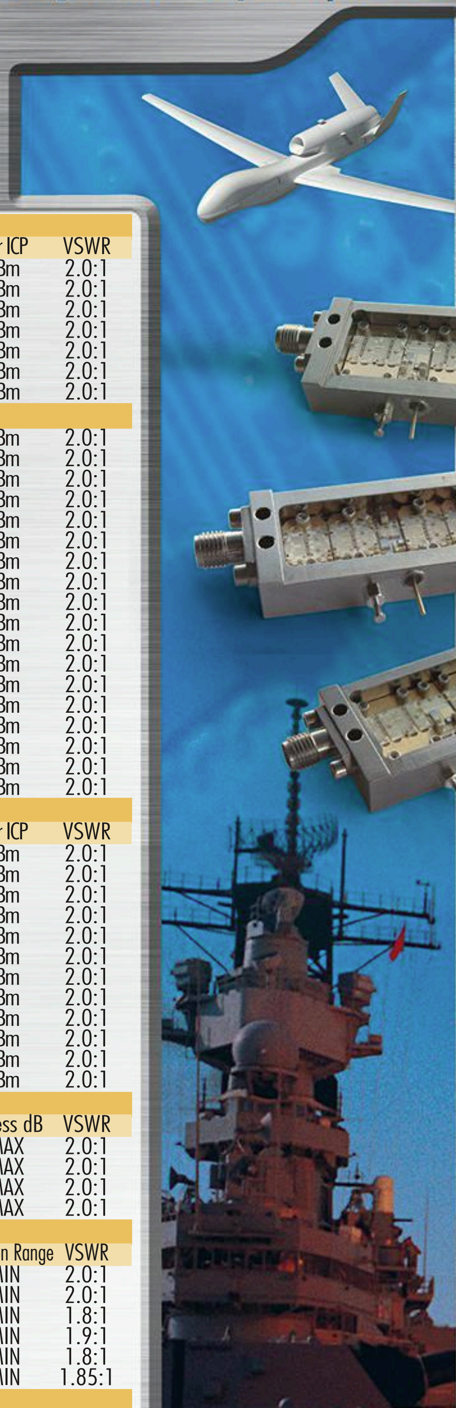
PENTON IS AN INFORMA BUSINESS

RF Amplifiers and Sub-Assemblies for Every Application

Delivery from Stock to 2 Weeks ARO from the catalog or built to your specifications!

- Competitive Pricing & Fast Delivery
- Military Reliability & Qualification
- Various Options: Temperature Compensation, Input Limiter Protection, Detectors/TTL & More
- Unconditionally Stable (100% tested)

ISO 9001:2000 and AS9100B CERTIFIED



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

CIAO Wireless can easily modify any of its standard models to meet your "exact" requirements at the Catalog Pricing.

Visit our web site at **www.ciaowireless.com** for our complete product offering.

Ciao wireless

Ciao Wireless, Inc. 4000 Via Pescador, Camarillo, CA 93012

Tel (805) 389-3224 Fax (805) 389-3629 sales@ciaowireless.com

Visit us at the IMS Show Booth #726

MAKING MILLIMETER WAVES AFFORDABLE

It is with great interest that I read Mr. Martino's piece about 5G in the April issue of *Microwaves & RF* ("5G Goes Over the Air," p. 35), as well as the promotional pieces for the upcoming IMS in Honolulu that have appeared on your website. It appears that a good portion of the IMS technical content is devoted to the different technologies that will make 5G wireless communications possible, including the use of millimeter-wave frequencies for back-haul, high-data-rate communication links. But aren't millimeter-wave components more expensive than microwave components, and mostly used for scientific and military applications? How will it be possible to produce the components needed for radio links at these higher frequencies without driving up the costs of 5G wireless telecom networks?

MARK BISSETTE

EDITOR'S NOTE

Thank you for reading and for your interest in Fifth Generation (5G) wireless communications technology. Much is being written about 5G, which is still in its formative stages and with different protocols being considered. As you have pointed out, millimeter-wave frequencies are a novel part of 5G that were not used in earlier wireless communications networks. There is a growing need for network capacity, and millimeter-wave frequencies such as 50 and 60 GHz offer wide bandwidths in support of high-data-rate transmissions, such as from a network node to a base station. In addition, some versions of 5G have proposed short-range, high-data-rate communications directly from a user to a network node using millimeter-wave frequencies.

Millimeter-wave components and circuits must handle physically smaller wavelengths than lower frequencies, with smaller circuit dimensions. At one time, the circuit machining needed to fabricate such dimensions was scarce, and the circuit materials with characteristics favorable to millimeter-wave signal propagation were short in supply. But both machining and materials have improved in recent years and millimeter-wave passive components—such as attenuators, couplers, and filters—are becoming much more affordable (see p. 130). Active components like amplifiers may still be costly, but the large volumes expected to be needed for production of 5G networks should also drive those prices down.

JACK BROWNE
TECHNICAL CONTRIBUTOR

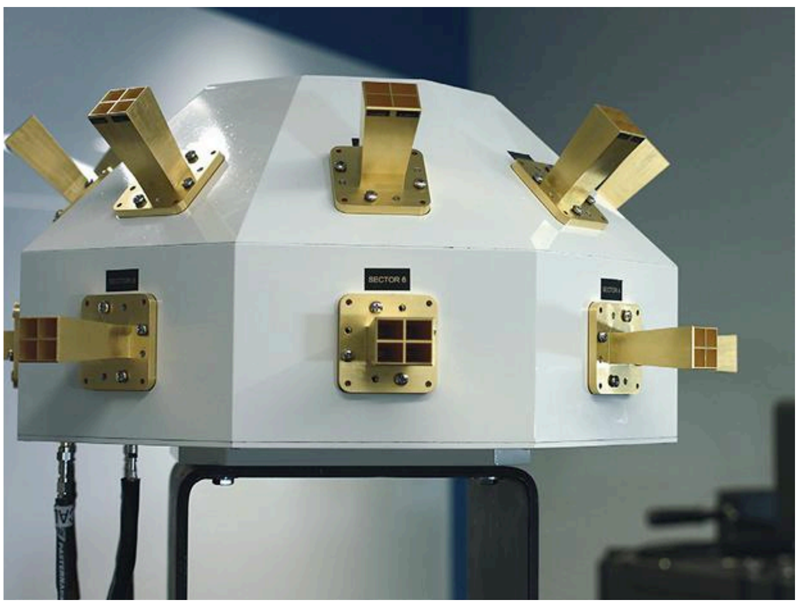
News

How AT&T Takes MILLIMETER WAVE CHANNEL MEASUREMENTS

Last January, National Instruments released a transceiver system for modeling the behavior of millimeter waves, a far-out class of high frequency bands that wireless companies have pegged for 5G communications. It came with channel coding software and could be custom programmed for testing wireless propagation.

Nokia was the first to employ the system for sounding out wireless infrastructure equipment that used 60 gigahertz signals. In April, National Instruments revealed that AT&T is also using the system in its custom tool for modeling how millimeter waves interact with trees, buildings, cars, and crowds of people.

AT&T's willingness to show the tool publicly hints at the importance of channel models in the 5G development process. The tool, called the Porcupine for its crown of horn antennas, will help the wireless carrier with tricky tests like vehicle connectivity and plan how it should space out 5G equipment in the next few years for the best coverage.



AT&T recently revealed a tool called Porcupine that models the behavior of millimeter waves, a far-out class of frequency bands that the wireless industry has pegged for 5G communications. It sits on top of a transceiver system built by National Instruments. *(Image courtesy of National Instruments)*

The tool, used internally by AT&T, can monitor millimeter wave channels in real-time. It provides angle-of-arrival measurements that take around 15 minutes with traditional tools in under 150 milliseconds, the company said. Since data is collected almost instantly, engineers can check the tool's accuracy in a short time.

That responsiveness helps cut down on time spent recalibrating tools for repeat experiments or additional tests in one location. That is significant because millimeter waves are uncharted territory for most wireless carriers, who are spreading out from lower frequencies in search of greater capacity and faster downloads.

"Utilizing mmWave spectrum for mobile 5G presents many challenges which we believe can be solved," Marachel Knight, AT&T's vice president of wireless network architecture, said in a statement. "We identified early on that designing and real-time monitoring of mmWave spectrum needs to be much more precise than today's cellular systems."

That has much to do with the tricky side effects of millimeter waves. Walls and other objects block out signals, which can also be absorbed by oxygen over long distances. These obstacles can be avoided by beaming signals into devices over short distances. But companies are still learning how millimeter waves act in large, complex networks.

The migration to higher bands is not slowing down. Last year, officials at the Federal Communications Commission voted unanimously on a rule that opened new mobile and broadband bands above 28 gigahertz. The rule also opened unlicensed spectrum between the 64 GHz and 71 GHz bands. The 95 GHz band is currently under review.

AT&T has also been maneuvering into higher bands. It recently paid $1.6 billion for Straight Path Communications, one of the largest holders of 28 GHz and 39 GHz bands that have been approved under the federal rule. It has also bought FiberTower Corporation, which owns licenses in the millimeter wave 24 GHz and 39 GHz bands.

Many others are making channel sounding tools for this spectrum. The National Institute of Standards and Technology is building an internal database of channel models with 60 GHz and 83 GHz tools. It is sharing raw measurements so that industry groups in different stages of 5G standardization can stay on the same page.

Though wireless carriers are holding their data close to the vest, other groups are sharing models more freely. New York University researchers customized NI's system to its run channel simulation software, which calculates time delays, direction, and the power received from 28 GHz and 73 GHz signals. It opened the software to the public last July and it has already been downloaded 7,000 times.

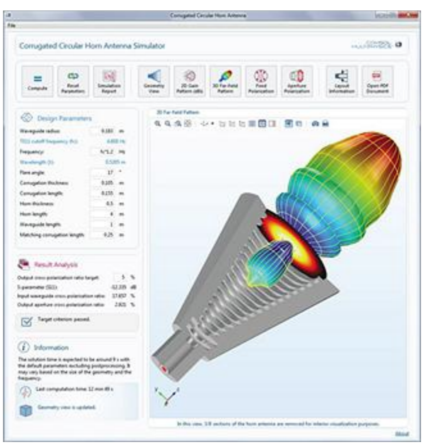
Keysight Technologies also offers a channel sounding tool using the same modular PXI approach as National Instruments' system. Testing signals up to 44 GHz, the solution makes sense of received signals to calculate their angle of arrival and other characteristics, allowing users to customize their algorithms for new 5G tests.

AT&T said that the Porcupine system is significantly faster than other setups, including ones using traditional signal generators and spectrum analyzers. Instead of spitting out one channel measurement after post-processing, the tool provides around 6,000 measurements every 15 minutes, offering more insight into channels.

"It's like capturing 15-minutes of action with a video instead of a still photo," National Instruments said in a statement. "A video tells the whole story, while a photo just shows a moment." ■

COMSOL SOFTWARE Offers Templates for Radio Frequency Parts

THE LATEST VERSION of Comsol's Multiphysics simulation software is all about increased productivity and it contains special upgrades for modeling radio frequency parts. It's not only significantly faster at loading and saving files, but it also features a library of standard RF parts that can be easily modified and shared.



The parts library, in Comsol's RF Module software, aims to assume more responsibility for modeling things like thermal effects in microwave filters, signal paths in wireless antennas, and interference in transmission lines. Determining these effects requires little more than editing the geometry, material properties, and solver settings of the standard parts.

"The benefit of using the parts library is that you don't have to create the work from scratch, which saves you a lot of time and subsequent resources," Jiyoun Munn, RF technical product manager at Comsol, said in an email. The library was introduced in Version 5.3 of Comsol's software.

The parts, Munn said, are "parameterized, which allows you to make any edits to the parts themselves so that they match what you are analyzing."

The parts library alone might not sway anyone who doesn't already own Multiphysics to buy it, but the feature provides a welcome relief to the heavy lifting required in previous versions of the RF Module. Before Version 5.3, the software came with an application library, but engineers had to modify the parts manually, which was time-consuming.

A spokeswoman for Comsol said that the parts library not only saves time in building models but also makes "RF simulations more accessible by providing new users with predefined parts to pick from." The broader updates in Version 5.3 also include tools for automating repetitive operations.

Other changes introduced last week promise to cut down on wasted time. Comsol says the software is ten times faster when loading and saving files as well as doing virtual geometry operations. It is also easier now to share models and simulations, so that engineering teams can test designs for different applications and choose the best one. ■

AN ARBITRARY WAVEFORM GENERATOR for Radar and Electronic Warfare

AN ARBITRARY WAVEFORM generator from Tektronix provides eight channels and high resolution for testing radar and electronic warfare systems. To generate its complex troubleshooting signals, the AWG5200 offers advanced capabilities that previously have been possible only with multiple generators.

The instrument provides 16-bit resolution, 10 billion samples per second, and fewer than two microseconds of latency. The channels, which support signal generation up to 4 gigahertz, contain independent paths out, individual amplification, sequencing, up-conversion, and dedicated memory. The channels can be controlled independently and support multi-unit synchronization.

"Signal generation has been a major problem for RF designers and researchers for some time now, and it is only getting worse as their needs have grown more complex," said Jim McGillivary, general manager of RF and component solutions at Tektronix, in a statement.

But generating highly detailed waveforms isn't cheap. The instrument starts at $82,000, which Tektronix says is affordable for the cumulative value of the features offered. McGillivary claims that the cost is "much lower overall" than buying "dozens of individual AWGs and attempting to get them to work together."

Test equipment from rivals like National Instruments is based on the modular PXI standard, which lets engineers choose parts for a custom test bench. Keysight, the former test division of Agilent Technologies, recently released a waveform generator for PXI systems, with three channels and 16-bit resolution, but only a single gigahertz of bandwidth. The starting cost is $22,000.

Tektronix offers tools to offset the steep cost. The AWG5200 comes with a library of plugins for generating standardized signals, pre-distorted waveforms, and automated tests. The built-in display lets engineers replay, edit, and sample signals captured with oscilloscopes and spectrum analyzers without using a personal computer." ■

FEDERAL SPECTRUM AUCTION Opens 70 Megahertz for Mobile Broadband

FEDERAL OFFICIALS ANNOUNCED that a recent auction of television spectrum had repurposed 70 megahertz for mobile and broadband applications. Wireless carriers spent $19.8 billion to license the 600 MHz spectrum, which has better range and penetration than many other bands, while 14 MHz will remain unlicensed..

The Federal Communications Commission started the auction last year, breaking it into two phases. The reverse auction set prices at which television broadcasters would voluntarily sell their spectrum rights, which wireless carriers bid on during a forward auction. The new licensed spectrum will supplement the higher frequency bands that the telecom agency has authorized for 5G.

The FCC said that the 70 MHz is the most mobile broadband spectrum ever auctioned below 1 gigahertz. The boldest bidders were T-Mobile, which paid around $8 billion for 45% of the spectrum, and Dish Network, whose $6.2 billion in bids returned a quarter of the licenses. Verizon didn't participate,while AT&T placed few bids.

The auction results only represent a fraction that the FCC has opened in the last year. Last July, agency officials voted unanimously on rules that freed up nearly 11 GHz of millimeter wave spectrum above 28 GHz. The rule also opened unlicensed spectrum between the 64 GHz and 71 GHz bands. Though the vote was unanimous, several commissioners were disappointed more bands were not included.

Wireless carriers are also using other tactics to break into higher bands. Last week, AT&T bought Straight Path Communications, one of the largest holders of 28 GHz and 39 GHz bands that have been approved under the recent federal rules. That $1.6 billion purchase built on its acquisition of FiberTower, which owns licenses in the millimeter wave 24 GHz and 39 GHz bands.

The FCC is paying out over $10 billion of the auction proceeds to the 175 broadcasters that agreed to relinquish their spectrum rights. Over the next 39 months, the agency will repackage the spectrum for mobile broadband and relocate broadcast stations to other channels, officially freeing up the bands.

If all goes according to plan, that period will end in the first half of 2020, the same year when wireless carriers expect to bring 5G communications online. These networks will likely run over a combination of millimeter wave bands, which can offer greater capacity and faster downloads, and the lower bands used by 4G networks.

"While we celebrate reaching the official close of the auction, there is still much work ahead of us," said Ajit Pai, the FCC's chairman, in a statement. "It's now imperative that we move forward with equal zeal to ensure a successful post-auction transition, including a smooth and efficient repacking process." ■

SOFTWARE TOOLS TARGET FIRST DRAFT of New Wi-Fi Stardard


(Image courtesy of National Instruments)

MANY COMPANIES, INCLUDING Qualcomm and Quantenna, are not waiting for the final draft of the new Wi-Fi standard to start manufacturing chips. That is why test equipment suppliers have started to sell software tools that not only let engineers fiddle with the unfinished standard but that can also be reprogrammed as new drafts are released.

On Tuesday, National Instruments became the latest company whose software can generate the complex waveforms of the 802.11ax standard, as well as characterize and validate products using it. The toolkit is an upgrade for a vector signal transceiver that plugs into its modular PXI test equipment.

The software follows the release of other tools from Keysight and Litepoint, which troubleshoot many of complex and advanced features of the 802.11ax standard. The technology, which is scheduled for standardization in 2019, is unique for copying the same self-organization and modulation techniques as 4G. The technology is also known as orthogonal frequency-division multiple access or OFDMA.

It coordinates multiple antennas to beam multiple streams of data into devices simultaneously, resulting in lower power consumption, higher capacity, and downloads over 10 gigabits per second. It will provide better coverage in places with lots of mobile devices and connected sensors, like apartment buildings and office buildings.

Already, Quantenna announced two antenna chips that match the first draft of the 802.11ax standard. Qualcomm also unsealed plans for two modem chips, one for routers and access points and the other for consumer gadgets like smartphones. The chips will start sampling this year.

But the standard's complexity places a burden on front-ends and wireless modules, as well as the test equipment used to validate products. National Instruments' toolkit generates and analyzes 802.11ax waveforms, including multi-user OFDMA and multi-user multiple-input multiple-output, a concept also known as MU-MIMO. The software handles systems with up to 8x8 antenna arrays.

But the initial software is just the beginning. Over time, National Instruments hopes that users will update the test software to meet new version of the Wi-Fi standard. The vector signal transceiver that runs the tools can be reworked via a field programmable gate array or FPGA chip. The transceiver can also be linked to PXI chassis, which let engineers choose parts to build custom tests.

"As the standardization and evolution of 802.11ax continues, engineers require a software-centric test approach that can keep pace with the latest standard features and challenging new test cases," said Charles Schroeder, National Instruments' vice president of RF marketing, in a press statement.

For now, the new software tools lets engineers generate trigger frames to test real-time device response and make pre-correction and relative center frequency measurements. National Instruments' transceiver also makes error-vector-magnitude measurements—a vital metric for the performance of digital radio—better than -50 dB. ■

COMSOL SOFTWARE OFFERS TEMPLATES for Radio Frequency Parts

THE LATEST VERSION of Comsol's Multiphysics simulation software contains special upgrades for modeling radio frequency parts. It is not only faster at loading and saving files, but it also features a library of standard RF parts that can be easily modified and shared.

The library in Comsol's RF Module aims to take more responsibility for modeling things like thermal effects in microwave filters, signal paths in wireless antennas, and interference in transmission lines. Measuring these effects requires little more than editing the geometry, material properties, and solver setting of the library's parts.

"The benefit of using the parts library is that you don't have to create the work from scratch, which saves you a lot of time and subsequent resources," Jiyoun Munn, RF technical product manager at Comsol, said in an email. The parts are "parameterized, which allows you to make any edits to the parts themselves so that they match what you are analyzing."

The library, introduced this month in Comsol Version 5.3, might not attract anyone who doesn't already own Multiphysics. But it provides a welcome relief to the heavy lifting required in previous versions of the RF Module. Before Version 5.3, the software came with an application library, but engineers had to modify the parts manually.

A spokeswoman for Comsol said in an email that the library not only saves time in building models but also makes "RF simulations more accessible by providing new users with predefined parts to pick from." The broader Version 5.3 updates also include tools for automating repetitive operations.

Other changes promise to cut down on wasted time. Comsol says the software is ten times faster when loading and saving files as well as doing virtual geometry operations. It is also easier now to share models and simulations, so that engineering teams can test designs for different applications. ■

INFINITE PAYS $110 MILLION for Microwave Suppliers Left at Smiths Interconnect

INFINITE ELECTRONICS, THE holding company for Pasternack and Fairview Microwave, has acquired the microwave telecom unit of Smiths Interconnect for around $110 million, giving it a wide range of parts for cellular towers and core networks.

The unit includes the Kaelus, Polyphaser, Transtector Systems, and RadioWaves brands. These companies were left out of a recent restructuring at Smiths Interconnect, which moved nine suppliers of microwave connectors and other components under a single brand. ■

MAKING INVISIBLE ANTENNAS for Satellite Solar Panels

WHEN TWO FORMS of energy must coexist, some compromises are in order. Such is the case when microstrip antennas that communicate with electromagnetic (EM) energy must be designed and fabricated for use on CubeSat satellites that rely on solar panels to generate DC power from the sun's solar radiation. To provide communications for CubeSat satellites, broadband antennas were designed at the Industrial-Scientific-Medical (ISM) frequencies of 434 MHz and 2.4 GHz by researchers working from several locations, including the University of Houston, NASA Johnson Space Center (Houston), and the Illinois Institute of Technology (Chicago). Two types of low-profile microstrip antennas were developed for the CubeSats: transparent antennas which are placed above the satellite's solar panels, and nontransparent antennas which are placed below the solar panels.

Transparent antennas have been designed in different ways, typically through the use of transparent metal conductors or by fabricating an antenna from a conductive wire mesh which is mounted on a transparent substrate material, such as glass or quartz. Transparent metals like indium tin oxide have been used for antennas, although this particular metal has a high sheet resistance and yields relatively inefficient antennas. The use of meshed antenna structures, such as a silver epoxy mesh, has provided transparent antennas with better performance than those fabricated with transparent metal conductors—with relatively high efficiency and typically 90% transparency—meaning that 90% of the incident solar radiation is reaching the solar panels beneath the antenna.

To demonstrate the feasibility of using mesh microstrip circuit designs as transparent antennas for solar cells on satellites, a number of different transparent antennas were designed and fabricated, including a linearly polarized (LP) antenna with resonant frequency of 1.644 GHz for communication with the Iridium constellation of low-earth-orbit (LEO) satellites and a broadband circularly polarized antenna for use at 2.4 GHz. Both were based on transparent quartz substrates. The CP antenna was formed of two patch antennas formed on the diagonal plane of a quartz substrate measuring 76 × 100 × 2.25 mm. Circular polarization is obtained by using two nearly square LP patch antennas that are physically rotated 90 deg. from each other and fed signals that are 90 deg. out of phase from each other. Each patch antenna has a wide bandwidth so that the combination of the two patch antennas yields about a 4% bandwidth at 2.4 GHz.

The researchers also developed microstrip patch antennas that were more conventional, fabricated on standard high-frequency circuit materials. These antennas are not transparent, intended for mounting below the solar panels (known as subsolar antennas). They faced the challenge of trying to design the antenna to cover as much as possible of the face of the CubeSat satellite, while also being resonant at a desired frequency such as 434 MHz or 2.4 GHz. Whether as supersolar or subsolar antennas, their designs show great promise for the coexistence of EM and solar energy in use on these miniature satellites.

See: "Transparent and Nontransparent Microstrip Antennas on a CubeSat," *IEEE Antennas & Propagation Magazine*, Vol. 59, No. 2, April 2017, p. 58.

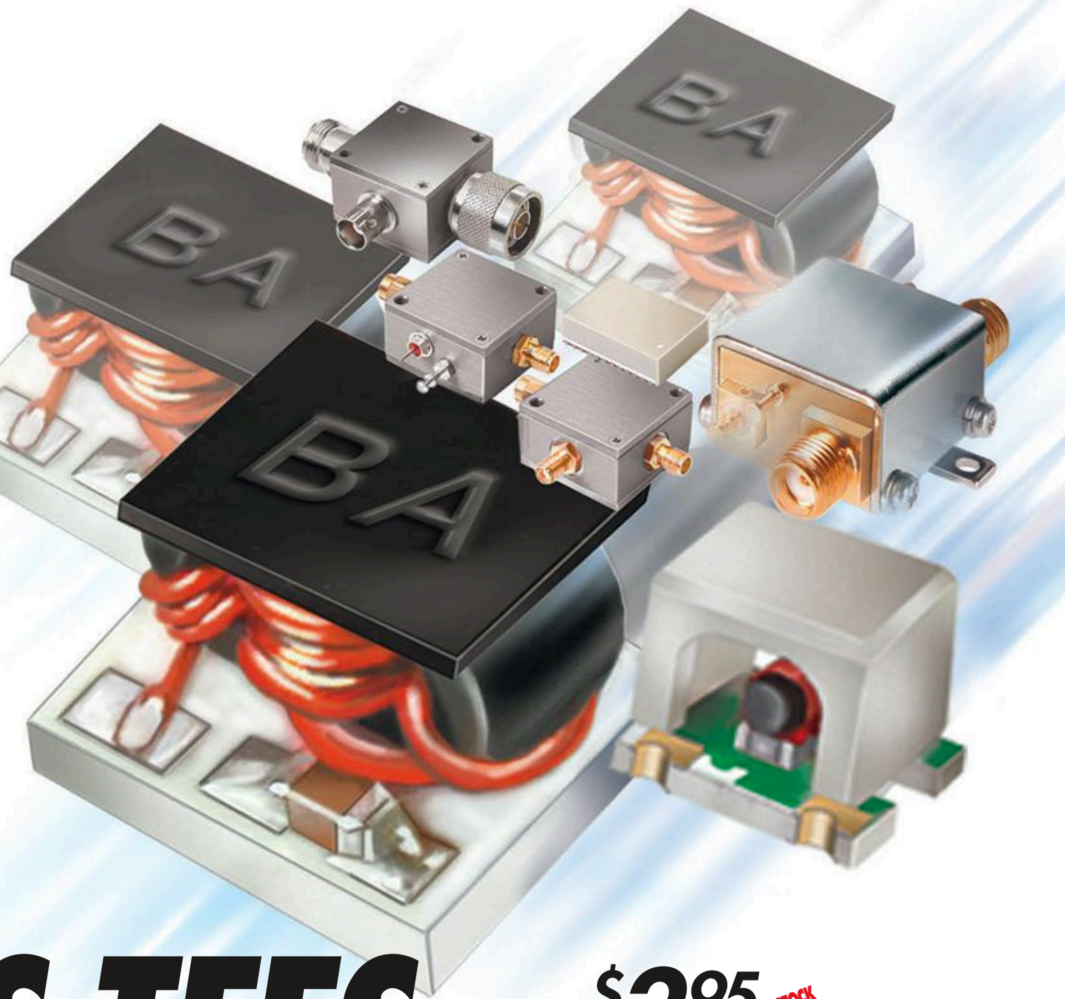
FREE ELECTRON LASER Generates 200 GHz

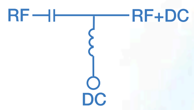
TERAHERTZ ENERGY OFFERS great promise for scientific and medical analysis, provided that signals above the millimeter-wave frequency range can be generated at sufficient power levels. Terahertz signals are typically generated by one of three different kinds of sources: optical or optoelectronic devices; solid-state oscillators; or vacuum electron devices, such as backward-wave oscillators (BWOs). So far, BWOs have shown the most capability for producing output-power levels as high as 10 W at frequencies to 300 GHz. Most of the terahertz sources produce considerably less output power and operate with extremely low efficiencies, so that the generation of usable terahertz power levels is often the starting point in the design of a research or medical terahertz system.

In pursuit of practical terahertz power, several French researchers from the Commissariat de l'Energie Atomique, Centre d'Etudes Scientifiques et Techniques d'Aquitaine, and the Centre d'Etudes Nucleaires de Bordeaux-Gradignan explored the design of a compact planar Smith-Purcell (SP) free-electron laser (FEL) with significant output power at millimeter-wave frequencies and in the low-frequency portion of the terahertz frequency range. The researchers performed simulations on an SP FEL employing a planar grating with 1-mm period.

The results of their studies revealed great potential for the planar approach versus earlier FELs using cylindrical gratings. Simulations of the planar SP FEL with beam energy of 60 keV and beam current of 2 to 5 A yielded estimated output power of about 200 W at 100 GHz for a 4-A beam, with about 0.08% efficiency. Although the planar approach tends to produce less energy at harmonic frequencies than the cylindrical designs, it is considerably simpler and can be made much smaller than cylindrical SP FELs.

See: "Radiation at 100 and 200 GHz From a Compact Planar Smith-Purcell Free Electron Laser," *IEEE Transactions on Terahertz Science and Technology*, Vol. 7, No. 2, March 2017, p. 151.





BIAS-TEES

100 kHz-12 GHz *Now up to 40W RF Power*

Whether your applications call for biasing amplifiers, laser diodes, or active antennas, DC blocking, DC return, satellite communications, test, or if you have custom requirements, just contact Mini-Circuits and let us fit your needs to a “TEE”! Mini-Circuits is your complete source for bias-tees, covering from 100 kHz to 12 GHz, handling up to 40W RF power and 4A DC current in a variety of coaxial and surface mount packages. All of our Bias-Tees provide low insertion loss and VSWR. Our patented TCBT series models are the smallest in the industry and are suitable for projects where low price, small size, and temperature stability are a must. Our ultra-wideband ZX85 bias-tees use our patented unibody construction affording small size and high repeatability.

RoHS compliant.

$3.95 *from* *ea. Qty.1000* **IN STOCK**

TYPICAL SPECIFICATIONS

Model	Freq (MHz)	Insertion Loss (dB)	Isolation (dB)	Max Current mA	Price $ ea. Qty.10
TCBT-123+	10-12000	0.3	33	200	9.95
TCBT-2R5G+**	20-2500	0.35	44	200	6.95
TCBT-6G+**	50-6000	0.7	28	200	7.95*
TCBT-14+***	10-10000	0.35	33	200	8.45
TCBT-14R+***	10-10000	0.6	33	200	8.45

TCBT: LTCC, Actual Size .15"x.15"
U.S. Patent 7,012,486**   U.S. Patent 8,644,029*

Model	Freq (MHz)	Insertion Loss (dB)	Isolation (dB)	Max Current mA	Price $ ea. Qty.1-9
JEBT-4R2G+	10-4200	0.6	40	500	39.95
JEBT-4R2GW+	0.1-4200	0.6	40	500	59.95
PBTC-1G+	10-1000	0.3	33	500	28.20
PBTC-3G+	10-3000	0.3	30	500	38.20
PBTC-1GW+	0.1-1000	0.3	33	500	38.20
PBTC-3GW+	0.1-3000	0.3	30	500	49.20
ZFBT-4R2G+	10-4200	0.6	40	500	59.95
ZFBT-6G+	10-6000	0.6	40	500	79.95
ZFBT-4R2GW+	0.1-4200	0.6	40	500	79.95
ZFBT-6GW+	0.1-6000	0.6	40	500	89.95
ZFBT-4R2G-FT+	10-4200	0.6	N/A	500	79.95
ZFBT-6G-FT+	10-6000	0.6	N/A	500	79.95
ZFBT-4R2GW-FT+	0.1-4200	0.6	N/A	500	79.95
ZFBT-6GW-FT+	0.1-6000	0.6	N/A	500	89.95
ZFBT-282-1.5A+	10-2800	0.6	45	1500	59.95
ZFBT-352-FT+	30-3500	0.4	23	4000	49.95
ZNBT-60-1W+	2.5-6000	0.6	45	500	82.95
ZX85-12G+	0.2-12000	0.6	N/A	400	99.95
ZX85-40W-63+	700-6000	0.5	33	1000	179.95

ZX85: U.S. Patent 6,790,049.

Note: Isolation dB applies to DC to (RF) and DC to (RF+DC) ports.
*Price is for quantity of 20

Mini-Circuits®

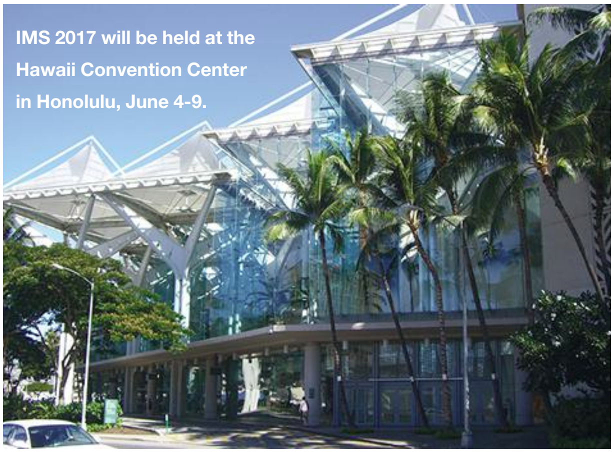
Show Preview

CHRIS DeMARTINO | Technology Editor

IMS Goes Back TO THE BEACH

This year, the RF/microwave industry's flagship event returns to Hawaii with some new tricks up its sleeve.

This year, the IEEE International Microwave Symposium (IMS) will take place June 4-9 at the Hawaii Convention Center in Honolulu. Without question, anyone affiliated with the RF/microwave industry knows that IMS is the flagship event of the year. This year's version has what one would expect to see at IMS, such as the exhibition, technical sessions, panel sessions, and more. IMS 2017 also features some new additions, such as the Exhibitor Workshops, Three Minute Thesis (3MT) competition, and the Hackathon: 30-Minute Circuits competition. In addition to all of that, the 5G Summit has much in store for attendees.


IMS 2017 will be held at the Hawaii Convention Center in Honolulu, June 4-9.

PLENARY SESSION

The plenary session will consist of an overview of the technical program, introductory remarks, a presentation of the 2017 IEEE Fellow Awards, and two keynote addresses. The first keynote, "5G: Enabled by Technology, With Public Policy Assist," will be given by Dr. Henning Schulzrinne, and will provide his insight in regard to the future of wireless data and the role of public policy.

The second keynote address, to be delivered by Dr. Wen Tong, is titled, "5G: The New Radio Technology Connecting Everything." Dr. Tong will discuss the key enabling technologies for 5G new radio technology, the associated proof-of-concept trials, and progress toward industrial standardization. He will also discuss the challenges and new directions associated with 5G radio technology, as well as the timeline for market rollout.

IMS EXHIBITION

The exhibition, which takes place June 6-8, has over 450 participating companies covering every facet of the industry. It also includes Microwave Applications Seminars (MicroApps), which are 20-minute technical presentations from various IMS exhibitors. More than 40 presentations are set to take place.

The exhibition also includes the first-ever IMS Exhibitor Workshops. These workshops are two-hour presentations from exhibitors held inmeeting rooms and are intended to provide practical, hands-on training to attendees. Participating companies include Keysight Technologies *(www.keysight.com)*, Cascade Microtech *(www.cascademicrotech.com)*, Empower RF Systems *(www.empowerrf.com)*, as well as others.

NEW ADDITIONS

Technical sessions, panel sessions, workshops, and short courses will give attendees the opportunity to take in a ton of information. Furthermore, some new additions have been made to IMS 2017. One is the Three Minute Thesis (3MT) competition, which is designed for eligible students and young professionals. Contestants will give a presentation in three minutes or less to a non-specialist audience. The competition takes place Mon., June 5.

The Hackathon competition is another new addition this year. This fast-paced competition will challenge teams to design a circuit in 30 minutes or less without using computer-aided-design (CAD) tools. The IMS 2017 Hackathon circuit will be a microstrip power divider.

To those attending, enjoy the show! mw

CHRIS DeMARTINO | Technology Editor

Q&A: Wayne Shiroma, IMS 2017 General Chair

IMS is clearly the most prominent event in the RF/microwave industry. However, several notable companies will not be exhibiting this year. Do you think this diminishes the show in any way?

Shiroma: We are confident that the attendees and exhibitors who make the trip to the Aloha State will find it more than worthwhile—with new events and initiatives launched this year. The IMS2017 Steering Committee has been working hard to make sure the show is a success and expects to have over 450 companies in the exhibition. IMS2017 had the third-highest paper submission and second-highest paper acceptance in the 60-year history of IMS. In addition, the 57 workshops, 9 short courses, new 5G Summit, and other IMS Technical Program staples ensures that IMS will draw large technical attendance.

Exhibitors also have a lot to look forward to this June. New exhibitor-focused initiatives include exhibitor workshops, a sales rep program, 5G demos, and three-and-a-half hours of dedicated exhibit time on Wednesday (no overlapping technical program activities). We are also actively pursuing new audiences for IMS, including the Hawaii-based military and high-tech communities, 5G Summit attendees from ComSoc, and Pacific Telecommunications Council members. Given these facts, I can't say that IMS2017 has been diminished in any way. To the attendees and exhibitors who are still on the fence: remember, it's not too late to "Catch the Wave!"

What can we expect to see at the 5G Summit at this year's IMS?

Shiroma: IMS2017's 5G Summit is a joint collaboration that complements IEEE MTT-S' "hardware and systems" focus with IEEE ComSoc's "networking and services" focus. The summit program features top experts from industry, academia, and government, who will share knowledge and discuss strategies and solutions with the summit attendees. Day 1 features Flavio Bonomi of Nebbiolo Technologies as the opening keynote speaker, who will give a 5G overview and show the relationship with fog computing and networking as a key enabler. Distinguished speakers following Flavio will cover topics including security, spectrum use, operator and service provider perspectives, advanced multi-carrier waveforms, channel modeling, and densification. Day 1 will end with a panel on "5G Startup Ecosystem-Network to Components."

Day 2 begins with an overview of the IEEE 5G Initiative by Ashutosh Dutta of AT&T, the initiative co-chair, and then a keynote by Arogyaswami Paulraj of Stanford University on "5G Wireless Evolution and MU-MIMO." The distinguished speakers who follow will cover topics such as massive MIMO from LTS to new radio, V2X and 5G, 5G vision and experimental trials from a service provider perspective, full-duplex wireless challenges, RFIC/CMOS techniques for 5G and beyond, and RFIC/CMOS transceivers for 5G. Day 2 will close with a panel on "5G Test and Measurement."

MULTIPLY UP TO 20 GHz

Frequency Multipliers from $5.95 qty. 10-49

For your leading-edge synthesizers, local oscillators, and satellite up/down converters, Mini-Circuits offers a large selection of ***broadband doublers, triplers, quadruplers, x5, x7 and x12 frequency multipliers.***

Now generate output frequencies from 100 kHz to 20 GHz with excellent suppression of fundamental frequency and undesired harmonics, as well as spurious signals. All models feature low conversion loss and are designed into a wide array of off-the-shelf, rugged coaxial and surface-mount packages to meet your requirements. Our new MMIC doubler, CY2-143+ generates output signals from 4 to 14 GHz in a tiny 4x4mm QFN package!

Visit our website to view comprehensive performance curves, data sheets, PCB layouts, and environmental specifications. Order direct from our web store and have a unit in your hands as early as tomorrow!

Mini-Circuits®

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

455 rev K

Following the 5G Summit is the 5G Executive Forum, a two-hour fireside chat with executive leaders in the 5G field that will be open to all conference attendees. Executives will provide their vision of the 5G market while fielding questions from both a moderator and the audience. The panelists will cover all areas within the 5G market.

More importantly, a reception including complimentary drinks and appetizers will be included! This will be a great time to network and meet the executives.

As a professor at the University of Hawaii, can you discuss some of the activity taking place there?

Shiroma: Hawaii has a unique role in the history of radio technologies. The Opana Radar Station on Oahu was the site of the first operational use of radar by the U.S. in wartime, detecting the first wave of Japanese warplanes en route toward the bombing of Pearl Harbor in 1941. Thirty years later, in 1971, the University of Hawaii demonstrated ALOHAnet—the first public demonstration of a wireless packet data network connecting computers via radio communications.

The theme for IMS2017—"Hawaii 5G: Catch the Wave"—builds on this proud heritage while looking forward to the cutting-edge technology and research presented at this year's conference, particularly those related to 5G technologies. At the University of Hawaii, we have large research thrusts spanning Big Data; the Internet of Things (IoT); cybersecurity; smart city and smart grid technologies; biomedical applications; and a wide array of device and materials research that flow into those systems, from liquid metals to microrobotic cell sorting and more.

Lastly, what are you personally looking forward to the most at IMS?

Shiroma: More than 350 volunteers comprising the IMS Steering and Technical Paper Review Committees worked very hard over the past nine years to ensure that IMS2017 will be an unforgettable experience, and we all look forward to catching the wave with everyone who attends IMS. Our desire is to have each of our technical attendees and exhibitors learn something new, meet a new friend, or generate a new idea. But most of all, we're looking forward to ensuring that every visitor experiences the Aloha Spirit—the warmth and affection that permeates our island home and makes it such a special place to conduct business while in paradise. mw

Show Preview

JACK BROWNE | Technical Contributor

2017 IEEE IMS Exhibitors PREPARE FOR "THE WAVE"

Visitors to the RF/microwave industry's largest conference and exhibition can sample some of the hardware, software, and test-equipment products that are turning 5G and IoT into reality.

Smaller recent technical conferences and exhibitions have signaled a general optimism concerning the near-term business outlook for the RF/microwave industry, an optimism reminiscent of the early 1990s and the beginnings of "the wireless revolution." Of course, those smaller shows, such as the IEEE 2017 Long Island Microwave Symposium (April 6, Hauppauge, N.Y.), are merely warmups for the one annual event that is "the granddaddy of them all": The IEEE International Microwave Symposium (IMS, *www.ims2007.org*)

Scheduled to take place in Honolulu from June 4-9, for the full conference and June 6-8 for the exhibition hall, the 2017 IMS Exhibition will boast booths for more than 500 RF/microwave companies, which will display enough items of interest to keep most high-frequency engineers away from the beach for at least a few days.

The exhibition also provides an opportunity to interact in real time with people at various booths, perhaps gaining some knowledge that could prove invaluable. It represents the community that is the RF/microwave industry. This one time during the year, members of that community can share thoughts on some of the challenges facing the industry, such as the need for lower-cost test equipment or young RF/microwave engineers to help refresh an aging engineering community.

TESTING THE WATERS

The IMS exhibition floor has traditionally served as an opportunity for test-equipment suppliers to bring current customers up to date, as well as add new customers. Since the RF/microwave industry is a relatively concentrated group of companies, a test-equipment firm's customers are often in the booth next door, since component manufacturers rely on testing to qualify their products.

As more component manufacturers attempt to support the volumes needed for high-volume IoT and higher-frequency 5G applications, their test needs will change. It becomes a no-brainer, then, for test-equipment suppliers to use events like the 2017 IEEE IMS to unveil new gear and, at the very least, query their customers on present and future measurement requirements.

For visitors interested in new test gear, **Anritsu Co.** (Booth 1116; *www.anritsu.com*) will not disappoint. The company will offer demonstrations of its affordable vector network analyzers (VNAs), including the VectorStar MS4647B four-port differential system with new Universal Fixture Extraction (UFX) software. The software speeds and simplifies the process of de-embedding user-customized test fixtures from a device under test (DUT).

Engineers working on millimeter-wave devices will be drawn to Anritsu's broadband VectorStar ME7838A system, which

1. The VectorStar ME7838A test system can perform swept-frequency VNA measurements from 70 kHz to 110 GHz. *(Courtesy of Anritsu Co.)*

can perform swept-frequency VNA measurements from 70 kHz to 110 GHz in an on-wafer environment *(Fig. 1)*. On the same probe setup will be the new 110-GHz Spectrum Master MS2760A ultra-portable spectrum analyzer directly connected to an on-wafer probe. The combined on-wafer station will display 110-GHz S-parameter measurements and 110-GHz spectral analysis for thorough device characterization.

In keeping with the need for more affordable measurements, **Copper Mountain Technologies** (Booth 1940, *www.coppermountaintech.com*) will demonstrate its line of compact, USB-driven VNAs, including the S5048 with frequency range from 20 kHz to 4.8 GHz *(Fig. 2)*. This simple but accurate two-port VNA is capable of measuring forward and reverse S-parameters for S21, S12, S11, and S22. It provides a wide output-power range from –50 to +5 dBm and an even wider measurement dynamic range of 123 dB for a 10-Hz intermediate-frequency (IF) bandwidth.

This may be one of the simplest RF/microwave instruments to connect, since the control and processing is performed by a companion PC with USB port. The front panel contains the two test ports and a power switch, while the rear panel has the USB port, power receptacle, external trigger port, and connector for an external 10-MHz reference oscillator.

2. The S5048 is a VNA with frequency range from 20 kHz to 4.8 GHz that uses a computer with USB connection for command and control. *(Courtesy of Copper Mountain Technologies)*

Use of a PC and dedicated software as the measurement controller is a growing trend for RF/microwave measurements. On that front, visitors to **Boonton Electronics** (Booth 1209; *www.boonton.com*) will have the chance to learn more about its RTP5000 real-time peak power sensors *(Fig. 3)* and Real Time Power Processing technology. In contrast to conventional serial power measurements, this technology is based on multiple, parallel measurements of power for the capture of any short-duration events.

The compact RTP5000 power sensors can perform 100,000 measurements per second with bandwidths as wide as 195 MHz and single-shot bandwidths of 35 MHz, and maintain a 100-Msample/s continuous sample rate and 10-Gsample/s effective sample rate. Power sensors are available for frequency ranges of 50 MHz to 6, 18, and 40 GHz; average dynamic range is as wide as –60 to +20 dBm through 6 GHz and pulse dynamic range extends from –50 to +20 dBm through 6 GHz.

3. The RTP5000 real-time peak power sensors include units capable of measuring a dynamic range as wide as -50 to +20 dBm at frequencies as high as 40 GHz. *(Courtesy of Boonton Electronics Corp.)*

The sensors connect to a PC running Boonton's Power Analyzer Suite of software for high-speed power measurements and comprehensive follow-up power analysis.

For high-frequency device testing through sub-terahertz (sub-THz) frequencies, **Cascade Microtech** (Booth 1626; *www.cascademicrotech.com*) will demonstrate its new PM8 manual probe system. The system allows precision probe motion to 200 mm in both the x and y axes for characterization of different types of electronic devices, including optoelectronic and microelectromechanical-systems (MEMS) devices. To enhance measurement accuracy, the PM8 features high vibration resistance and active platen cooling to boost thermal stability. The modular system is suitable for manual in-process testing and failure analysis, and is supported by probe-station control software.

MAKING A MATCH

While most high-frequency engineers will need a signal generator and analyzer of some form, not everyone will need the kind of test gear displayed by Maury Microwave Corp. and Focus Microwaves, namely impedance tuners. **Maury Microwave** (Booth 1536, *www.maurymw.com*) will provide examples of its precision machining capabilities, essential to many measurements at RF/microwave frequencies.

Maury's test systems include its MT97x and MT98x series automated impedance and load-pull tuners, respectively. These tuners employ highly detailed transmission-line structures that make it possible to match the impedance of a DUT to a terminal impedance, such as when matching a source or load impedance to a high-power transistor for optimum power or a low-noise transistor for optimum noise figure. Such impedance tuners have long been vital tools in the development of active-device software models that can simulate the performance of a transistor or IC under different conditions.

Focus Microwaves (Booth 1048; *www.focus-microwaves.com*) will show its new MPT-110200 tuner *(see "Multipurpose Tuners Control Impedances from 20 to 110 GHz" on mwrf.com)*. With three independent tuning probes, the load-pull tuner is designed to make non-50-Ω measurements from 20 to 110 GHz, in preparation for the wave of millimeter-wave components earmarked for applications from automotive radar systems to 5G backhaul links. The tuner can also be used to generate the high VSWRs needed for prematching active devices, such as transistors and ICs for optimum performance over a frequency bandwidth of interest.

Major test-equipment supplier **Keysight Technologies** (Booth 848; *www.keysight.com*) made news recently for its work with China Telecom on narrowband IoT (NB-IoT) device testing for IoT chipset and module certification testing. Specifically, it involves making measurements for power consumption to help determine the battery performance of different IoT designs.

4. The E7515A UXM Wireless Test Set incorporates a vector signal analyzer and vector signal generator in a compact package, with versions to 6 GHz. *(Courtesy of Keysight Technologies)*

The NB-IoT measurements are performed on Keysight's E7515A UXM Wireless Test Set *(Fig. 4)*, which packs a vector signal analyzer (VSA) and vector signal generator (VSG) within the same enclosure to emulate wireless receivers and transmitters, respectively. Versions are available for measurements from 300 MHz to 3.8 GHz (E7515A-504) and 300 MHz to 6.0 GHz (E7515A-506), both with 100-kHz frequency resolution. Test signal levels can be set from –60 to +30 dBm for the receivers and –53 to +30 dBm for a combination of transmitter and receiver, with level flatness of typically ±0.3 dB over a 100-MHz bandwidth.

National Instruments (Booth 740; *www.ni.com*) will demonstrate its Wireless Test System (WTS) and Wireless Test Module (WTM). Based on PXI modular instrument technology and the company's comprehensive LabView measurement software, the test system *(Fig. 5)* features a vector signal transceiver (VST) with as much as a 200-MHz instantaneous bandwidth from 65 MHz to 6 GHz. It has a "standard commands for programmable instruments" (SCPI) interface for remote automation over Ethernet and can handle testing for wireless standards ranging from GPS and Wi-Fi to Bluetooth, Bluetooth LE, and LTE-A cellular communications.

5. The WTS and WTM have been developed for wireless testing through 6 GHz using modular instrumentation and powerful measurement software. *(Courtesy of National Instruments)*

Top Dog Test (Booth 1932, *www.topdogtest.com*) will update visitors on its services related to test equipment, including repair, troubleshooting, and calibration for some leading equipment names, including Anritsu, Keysight, Rohde & Schwarz, and Tektronix. The firm provides sales, lease, and rental services for a wide range of measurement functions and instruments, and can help a company liquidate unneeded test equipment assets.

Rohde & Schwarz (Booth 1348; *www.rohde-schwarz.com*) will bring a number of its high-performance test instruments to 2017 IMS, including the R&S FPC1000 spectrum analyzer that is priced for broad appeal. The general-purpose analyzer's basic frequency range of 5 kHz to 1 GHz can be expanded to 2 or 3 GHz via software upgrades. It has a basic noise floor of typically –150 dBc, which can be extended to as low as –165 dBm with an option. The analyzer also handles input power as high as 1 W (+30 dBm) for wide-dynamic-range measurements. It shows results on a large, 10.1-in. display.

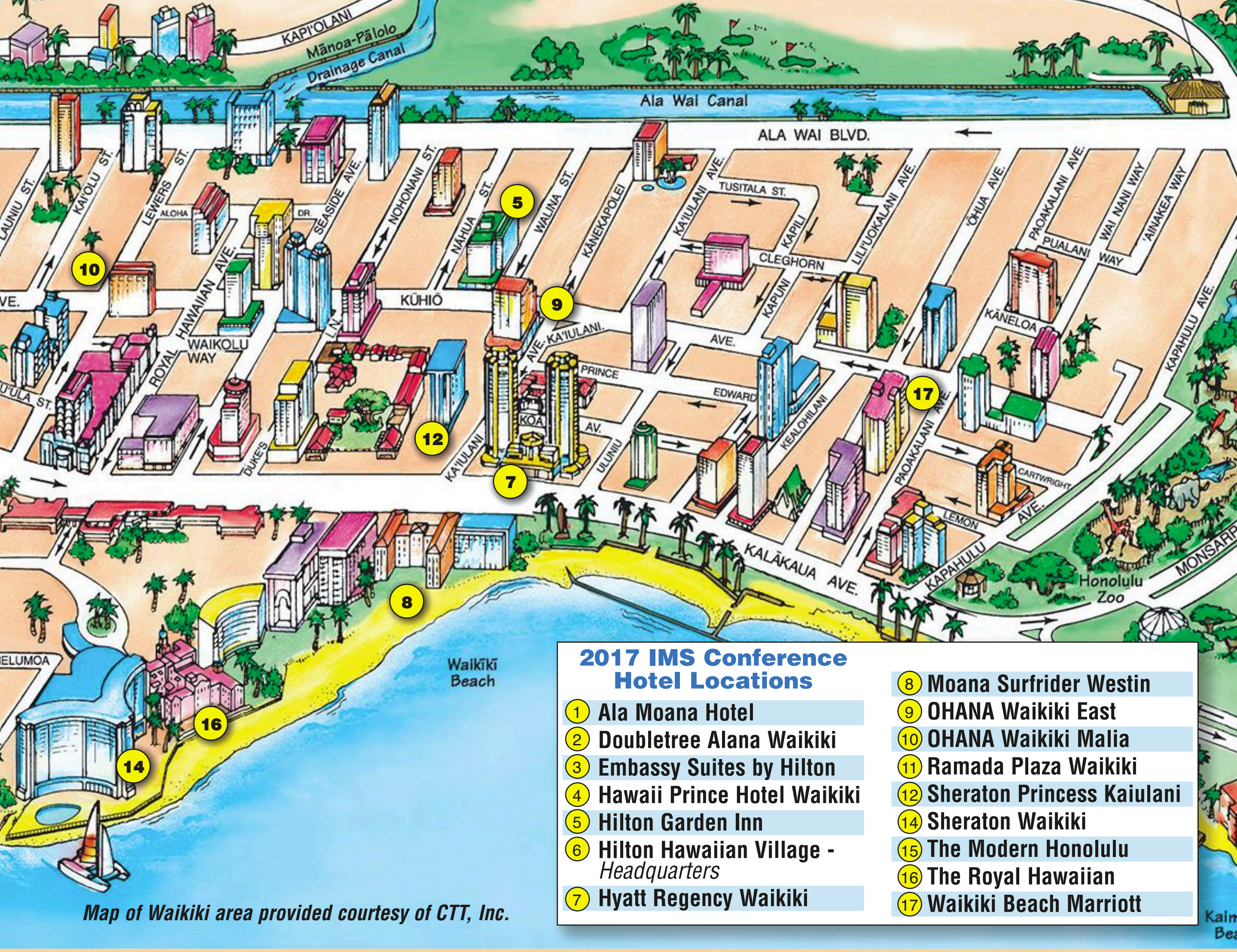
6. Companies involved in building IoT products will want to demonstrate the R&S TS 290 IoT carrier acceptance test system for wireless acceptance testing. *(Courtesy of Rohde & Schwarz)*

With the growing interest in IoT, it is likely that Rohde & Schwarz will also demonstrate its new R&S TS 290 IoT carrier acceptance test system *(Fig. 6)*. The single instrument allows manufacturers of wireless IoT devices to perform wireless acceptance testing on their integrated wireless modems.

Signal Hound (Booth 1439; *www.signalhound.com*) will unveil a sampling of its USB-powered test instruments at IMS, including its reasonably priced model USB-SA44B. Costing under $1000, the spectrum analyzer is capable of measurements from 1 Hz to 4.4 GHz. It features a wide dynamic range of –151 to +10 dBm with resolution bandwidths from 0.1 Hz to 250 kHz. Based on software-defined-radio (SDR) technology, the analyzer is effective for troubleshooting and experimentation.

The Signal Hound booth will also unleash its VSG25A vector signal generator *(Fig. 7)*, a versatile signal source with a frequency range of 100 MHz to 2.5 GHz. It features an arbitrary waveform generator (AWG) that can be clocked at


HAWAII CONVENTION CENTER
Hard Rock Cafe
To Waikiki
KAPI'OLANI BLVD.
ALA WAI BLVD.
Ala Wai Canal
ALA MOANA BLVD.
KALĀKAUA AVE.
KUHIŌ
KONA ST.
ATKINSON DR.
KAHAKAI DRIVE
HOBRON
KAIO'O DR.
LIPE'EPE'E
KALIA RD.
SARATOGA RD.
BEACH WALK
LEWERS
NIU ST.
PAU ST.
KEONIANA ST.
KUAMO'O
NAMAHANA
'OLOHANA
KALAIMOKU ST.
McCULLY ST.
'ENA RD.
HOLOMOANA
Ala Wai Yacht Harbor
U.S. Army Museum
KALAUOKALANI WAY
KANUNU
PONI ST.
RYCROFT ST.
KAHEKA
MAKALOA
1
2
3
4
6
11
15
A TGI PRODUCT COPYRIGHT © 2007 BY TRAVEL GRAPHICS INTERNATIONAL®



2017 IMS Conference Hotel Locations

1. Ala Moana Hotel
2. Doubletree Alana Waikiki
3. Embassy Suites by Hilton
4. Hawaii Prince Hotel Waikiki
5. Hilton Garden Inn
6. Hilton Hawaiian Village - *Headquarters*
7. Hyatt Regency Waikiki
8. Moana Surfrider Westin
9. OHANA Waikiki East
10. OHANA Waikiki Malia
11. Ramada Plaza Waikiki
12. Sheraton Princess Kaiulani
14. Sheraton Waikiki
15. The Modern Honolulu
16. The Royal Hawaiian
17. Waikiki Beach Marriott

Map of Waikiki area provided courtesy of CTT, Inc.

any frequency from 54 kHz to 180 MHz, and can be used to produce a wide range of modulated output waveforms and multiple tones.

7. The VSG25A vector signal generators feature a frequency range of 100 MHz to 2.5 GHz. *(Courtesy of Signal Hound)*

Holzworth Instrumentation (Booth 835; *www.holzworth.com*) will show its phase-noise measurement instruments, including the HA7062A phase noise analyzer with noise floor below −190 dBc/Hz at an offset 40 MHz from the carrier. The analyzer, with a measurement range of 10 MHz to 20 GHz, and offset range of 0.1 Hz to 40 MHz, achieves high accuracy by means of an ANSI-traceable z540 calibration. In addition to real-time measurements of phase noise and jitter, the analyzer can also measure amplitude modulation (AM) and pulse modulation. It is supplied in a 1U instrument chassis for ease of installation in ATE systems.

CRUISING FOR COMPONENTS

Component miniaturization has been a common theme of recent IMS conferences and exhibitions, and the interest will likely intensify as designers attempt to boost functionality within ever smaller packages. To that end, frequency mixers—key component building blocks for communications receivers and transmitters—of the miniature variety will be on tap at **Marki Microwave's** booth (Booth 1041; *www.markimicrowave.com*). Marki's MMIQ-0205HSM, a surface-mount in-phase/quadrature (I/Q) mixer for use from 1.75 to 5.0 GHz, comes in a 5- × 5-mm QFN package *(Fig. 8)*. Suitable for radar and radio communications systems, the mixer can be used for either frequency upconversion or downconversion.

8. This surface-mount I/Q mixer provides frequency coverage from 1.75 to 5.00 GHz in a tiny, 5- × 5-mm QFN package. *(Courtesy of Marki Microwave)*

At higher frequencies, staff at **SAGE Millimeter** (Booth 640, *www.sagemillimeter.com*) will provide guidance for visitors needing to find their way around the millimeter-wave frequency bands. Among the array of active and passive components on display will be some of the firm's latest developments, including its SBP-753-1142515-1010-E1 W-band power amplifier with +15 dBm output power and typical 25-dB gain from 75 to 110 GHz. Equipped with WR-10 waveguide and UG-387/U-M flanges, the amplifier can also be supplied with 1-mm coaxial connectors or right-angle WR-10 waveguide.

Krytar (Booth 525; *www.krytar.com*) will be among the many RF/microwave component suppliers at the 2017 IMS exhibition to show greater attention to their over-30-GHz components. The company has long been a proven supplier of directional couplers and hybrids at millimeter-wave frequencies—its coaxial models are as broadband as the model 101065013, with a frequency range of 1 to 65 GHz and 13-dB coupling that is flat within ±1.5 dB across that range. It is supplied with female 1.85-mm coaxial connectors and handles as much as 20-W input power.

Representatives from **K & L Microwave** (Booth 1401, *www.klmicrowave.com*) will be on hand to show a new line of surface-mount highpass filters with cutoff frequencies of 6 to 18 GHz. The filters *(Fig. 9)* guarantee rejection of 45 dB at one-half the 3-dB cutoff frequency and maximum insertion loss of 2.5 dB. The filters are housed in a compact surface-mount package measuring just 0.44 × 0.24 × 0.16 in.

9. Surface-mount highpass filters such as these provide cutoff frequencies from 6 to 18 GHz. *(Courtesy of K & L Microwave)*

Often it is the smallest components that have the biggest impact, and such is the case with a new line of capacitors. **AVX Corp.** (Booths 1212 and 1311, *www.avx.com*) will show its new MS Series metal-oxide-semiconductor (MOS) capacitors for applications from dc to 20 GHz. The low-profile capacitors deliver temperature-stable, high-Q performance with high breakdown voltages and low leakage. Capacitance values range from 1 to 1,000 pF, and capacitance tolerances are as tight as ±0.1 pF. They come in seven standard case sizes with four standard working voltages (25, 50, 100, and 200 V).

Smiths Interconnect's Tecom brand (Booth 1441; www.*smithsinterconnect.com*) will be displaying selected high-performance airborne antennas. Among them are space-qualified antennas, including type 401163-7, which provides S-band

hemispherical, broad beam pattern coverage for optimum telemetry control of a satellite in all orientations. The antenna is fully compliant for space environments, including outgassing, severe shock, vibration, temperature, and RF requirements. The 401163-7 antenna, with its frequency range of 1800 to 2350 MHz, was selected for installation on a NASA remote-sensing and satellite program.

When visiting **L3 Narda-MITEQ** (Booth 1201; *www.nardamiteq.com*), one can learn more about the HRT-18G fiber-optic transmitter, which turns light into a transmission line for wideband, high-data-rate communications. It is an easy-to-install module with a 3-dB bandwidth of 50 MHz to 18 GHz using a distributed-feedback (DFB) laser diode. The laser-diode transmitter, which can be used for commercial or military applications, provides a handy means of making broadband remote connections between a receiver/transmitter and a local oscillator (LO) or antenna.

BOOSTING LEVELS

The 2017 IMS exhibition floor will feature a "who's who" collection of amplifier suppliers in almost every shape and size, from tiny ICs to massive rack-mount systems for military radar and electromagnetic-compatibility (EMC) testing. The requirements are also far-ranging, since emerging applications such as IoT devices require signal amplification with almost no current and power consumption, posing real design challenges for designers of amplifiers aimed at those applications.

AmpliTech (Booth 711, *www.amplitechinc.com*) has long supplied some of the highest-performance amplifiers in the industry, whether for commercial or military use. For example, model APT4-18004000-4008-D20 is constructed to MIL-STD-883 and MIL-STD-45208 requirements for applications from 18 to 40 GHz using field-replaceable female SMA connectors. With typical noise figure of 3 dB and gain of 41 dB across that frequency range, it is well-suited for point-to-point radios and test-equipment applications in military and space environments. The gain stays flat within ±3 dB and the amplifier provides +12 dBm typical output power at 1-dB compression.

In contrast, at lower frequencies, AmpliTech'sAPTW6-07100840-50K10-WR112-D6 has WR112 waveguide input for X-band satellite-communications (satcom) applications from 7.1 to 8.4 GHz. To achieve maximum receiver sensitivity across those frequencies, this amplifier achieves a noise temperature of only 40 K (a noise figure of a mere 0.56 dB) with healthy typical gain of 63 dB across the full frequency range. The gain is flat within ±1 dB, with typical output power of +13.5 dBm at 1-dB compression.

10. This rugged amplifier module offers 25 W saturated output power with 6-dB noise figure and 58-dB gain from 2 to 6 GHz. *(Courtesy of Analog Devices)*

Analog Devices (Booth 1032; *www.analog.com*), well known for its tiny ICs, will also have larger components on display, including the model HMC7748 military-grade amplifier module *(Fig. 10)*. It provides 25 W output power from 2 to 6 GHz with 58-dB small-signal gain. It draws 0.7 A current from a regulated +12-V dc supply and can be turned on and off with an external enable pin. The rugged amplifier is well-suited for military communications and radar applications, as well as for test-and-measurement systems.

Ampleon (Booth 914, *www.ampleon.com*) will show a sampling of high-power LDMOS devices and amplifiers for commercial and military applications. Examples include an S-band amplifier capable of 400 W output power, a 900-W amplifier for UHF commercial broadcast use, and a 2-kW amplifier for ISM applications at 127 MHz. Also on display will be high-power amplifiers designed for RF heating and energy applications.

For millimeter-wave bands, **Smiths Interconnect's Millitech** brand (Booth 1441; *www.smithsinterconnect.com*) will exhibit a series of power amplifiers based on pseudomorphic high-electron-mobility-transistor (pHEMT) technology for total coverage of 18 through 110 GHz. The amplifiers achieve saturated output-power levels as high as +38 dBm at 35.5 GHz and +15.5 dBm at 110 GHz.

Empower RF Systems (Booth 1007; *www.empowerrf.com*) will bring examples of its different amplifier lines to IMS, which target radar, communications, and electromagnetic-compatibility (EMC) testing. The company supplies high-power amplifiers in several forms, including compact modules and standard 19-in.-wide rack-mount enclosures like the model 2185 for L-band radar testing. It is also a good fit for mobile EW and threat simulation applications. It produces 10 kW peak output power from 960 to 1215 MHz for duty cycles from 0.1% to 5.0%.

For 2017 IMS exhibition visitors interested in the latest online marketing techniques, **Strand Marketing** (Booth 848, *www.strandmarketing.com*) will discuss details regarding a new integrated web development, content management, and CRM software platform called Intent ICMS. The platform allows for rapid development around the unique performance parameters of any product line using a scalable database design.

Intent ICMS, which was used in the development of Custom MMIC's website *(www.custommmic.com)*, makes it easy to quickly find a product of interest based on price or performance requirements. It builds websites that include company news, educational blogs, frequently asked questions (FAQs), technical briefs, software tools, and videos.

INTEGRATED SOLUTIONS

The 2017 IMS exhibition floor contains a strong showing among the industry's integrated-circuit (IC) suppliers, with many reaching higher frequencies with their processes in anticipation of the needs of 5G applications. For example, **Peregrine Semiconductor Corp.** (Booth 1042, *www.psemi.com*) will show samples of its recently introduced 60-GHz switches, models PE42525 and PE426525, based on its UltraCMOS silicon-on-insulator (SOI) semiconductor technology.

The single-pole, double-throw (SPDT) switches, which operate over a full range of 9 kHz to 60 GHz with 8-ns switching speed, are candidates for signal switching in evolving 5G wireless communications networks, microwave backhaul applications, and test systems. The reflective switches have low current consumption of 390 nA. Port-to-port isolation is 37 dB with low insertion loss of 1.9 dB. The switches are available as flip-chip die with 500-μm bump pitch.

Skyworks Solutions (Booth 1331; *www.skyworksinc.com*) will show some of its many miniature components based on monolithic-microwave-integrated-circuit (MMIC) technology, including its recently introduced SKY65623-682LF low-noise amplifier (LNA) with a frequency range of 1559 to 1606 MHz. Useful for GPS L1, GLONASS, Galileo, and Compass navigation systems, the amplifier draws a low 1-mA current from a +1.8-V dc supply, for long battery lifetimes in portable and wearable devices, including IoT applications. The amplifier provides typical noise figure of 0.85 dB with small-signal gain of 16.5 dB. Its five-lead QFN package measures just 0.8 × 0.8 mm to fit the tightest IoT designs.

Custom MMIC (Booth 1355, *www.custommmic.com*) will unveil its model CMD230 GaAs MMIC single-pole, double-throw (SPDT) for use from dc to 26 GHz. Available in die form, the switch achieves low 1.4-dB insertion loss and high 40-dB isolation between ports at 13 GHz. It requires no bias supply and operates with 0/−5-V logic levels. The reflective switch boasts fast switching speed of 3.4 ns. The firm will also show its model CMD231 GaAs MMIC driver amplifier, with 14.5-dB gain and +13.5-dBm output power at 1-dB compression at 4 GHz. It runs on a supply from +3 to +6 V dc and has an output IP3 of +23.5 dBm at 4 GHz.

Custom MMIC's President, Paul Blount, will also offer a MicroApps presentation on "Low Phase Noise Amplifiers for LO Systems." He will explain the significance of the new amplifier line in achieving enhanced system-level performance, such as improved receiver sensitivity. The presentation is scheduled for 2:40 PM on Tuesday, June 6 in the MicroApps Theatre (Booth 1946).

On the subsystems side, among a wide range of system- and subsystem-level solutions at their booth, **Aethercomm** (Booth 831, *www.aethercomm.com*) will show its model TR 0.020-0.800-50 transmit/receive module for applications from 20 to 800 MHz *(Fig. 11)*. It is as likely to be at home in a commercial communications system or an EW system, where high power, linearity, and efficiency are important factors. The compact module can generate 40 to 50 W output power across the full frequency range when fed with a 0-dBm input signal, with about 50-dB typical full-band small-signal gain. The module includes a passive receive function with about 1- to 2-dB loss.

11. This integrated transmit/receive module serves commercial and military applications from 20 to 800 MHz. *(Courtesy of Aethercomm)*

Micro Lambda Wireless, one of the premier suppliers of YIG-based oscillators and frequency synthesizers, will talk to Booth 1101 visitors about the benefits of YIG source technology with its new MLMS series of YIG-based frequency synthesizers in a single PXI slot *(Fig. 12)*. Available in standard models covering 250 MHz to 6 GHz, 2 to 8 GHz, 6 to 13 GHz, and 8 to 16 GHz (plus other frequencies on special orders), the synthesizers are reliable in standard temperatures from 0 to +65°C and can be made for environments ranging from −40 to +85°C on special order. Suitable for a wide range of commercial and military systems and test applications, the PXI frequency synthesizers measure

2.5 × 2.5 × 0.65 in. and are supplied with 9-pin Molex and USB mini-b connectors to facilitate connectivity to system computers.

12. The MLMS series of frequency synthesizers fit a single PXI slot, but provide stable output signals covering 250 MHz to 6 GHz, 2 to 8 GHz, 6 to 13 GHz, and 8 to 16 GHz. *(Courtesy of Micro Lambda Wireless)*

BUILDING FOUNDATIONS

For many visitors to exhibition floors like that of 2017 IMS, the stroll through the rows of different booths means armloads of datasheets and product brochures that serve as reference materials for potential new suppliers. Exhibition floors are very efficient, since each stop is like making a visit to a company, with chances to compare all of the latest components, software, and even products as seemingly mundane as printed-circuit-board (PCB) materials. While the latter may not be glamorous, they are the starting points for new circuit designs and materials suppliers such as AI Technology, Isola Corp., Rogers Corp., Shengyi Technology, and Taconic.

For example, **AI Technology** (Booth 607; *www.aitechnology.com*), in addition to its many adhesives and materials for manufacturing high-frequency circuits, will show its COOL-CLAD metal-core insulated metal substrate laminates. The laminates are targeted at PCBs where thermal management is critical, such as in high-power RF amplifiers and in light-emitting-diode (LED) display circuits. The substrates provide excellent thermal conductivity, although they require no special processing requirements.

Isola Corp. (Booth 1008; *www.isola-group.com*) will present its TerraGreen and I-Tera MT40 circuit materials. Both offer low, stable dielectric constant (Dk) characteristics suitable for RF/microwave circuits, with TerraGreen a good starting point for power-amplifier circuits. It has a Dk of 3.44 that is stable through W-band frequencies, with low dissipation factor (Df) of 0.0039 and glass transition temperature (Tg) of +200°C. TerraGreen circuit materials, which are compatible with FR-4 materials and FR-4 material processing methods, are halogen-free and meet UL 94 V-0 requirements.

I-Tera MT40 materials have a slightly higher Dk of 3.45 with low Df of 0.0031 and Tg of +200°C. They are available in laminate and prepreg forms, as cost-effective alternative circuit materials to polytetrafluoroethylene (PTFE) circuit materials in commercial microwave and high-speed digital circuits.

Among its numerous market-focused circuit materials, **Shengyi Technology Co. Ltd.** (Booth 710, *www.shengyi-usa.com*) will exhibit the AeroWave 300 PPE woven-glass-reinforced ceramic UL 94 V-0 circuit materials for RF/microwave applications requiring high performance with high manufacturability. Compatible with RoHS processes, the AeroWave 300 materials are also well-suited for multilayer hybrid-circuit configurations that integrate RF, digital, and power functions. Circuits using these materials can be fabricated with standard FR-4 material methods. They feature stable dielectric constant and low dissipation factor through 20 GHz over a wide range of operating temperatures.

Rogers Corp. (Booth 1548; *www.rogerscorp.com*) will showcase many of its high-performance RF/microwave circuit materials, along with a new material that is sure to be a hit with circuit designers seeking to cut corners on price but not performance. For a circuit design that might suggest the use of low-cost FR-4 epoxy-glass circuit material, Rogers' Kappa 438 laminates offer a cost-effective alternative with better performance and stability than FR-4.

Like FR-4, Kappa 438 laminates have a design Dk of 4.38, and can be processed in the same way as standard FR-4 circuit materials. But Kappa 438 laminates offer improved performance compared to FR-4, with low loss, tight Dk tolerance, high Tg for processing flexibility, and low z-axis coefficient of thermal expansion (CTE). Kappa 438 laminates are RoHS-compliant and feature the UL 94 V-0 flame-retardant rating.

Rogers' Senior Market Development Engineer, John Coonrod, will take part in the 2017 IMS MicroApps presentations (in the MicroApps Theatre on the exhibition floor at Booth 1946). His presentation, "The Impact of Final Plated Finishes on High Frequency Performance of PCBs," explores the impact of different finishes on circuit material manufacturability, reliability, and performance.

Taconic Advanced Dielectric Div. (Booth 1309; *www.taconic-add.com*) will have samples of its new EZ-IO circuit material, a thermally stable composite material based on nanotechnology and PTFE. Due to the nanotechnology reinforcement, the material is very consistent in Dk from board to board and provides characteristics that make it a good starting point for high-speed digital circuits working to 25 Gb/s and beyond. The material essentially provides the performance of a PTFE-based circuit material but with the ease of fabrication of an FR-4-based material, with long cutting-tool lifetimes and high yields.

Once the starting materials have been selected for a PCB, forming the high-frequency transmission lines and other circuit structures is a matter of skill and precision, requir-


> Performance
> Power Density
Size <
Energy Costs <
WOLFSPEED'S NEW
KU-BAND SATCOM MMIC
• GaN MMIC for Lower Ku-Band
• 12.7-13.25 GHz Operating Frequency
• 60 W Typical Power Output
• Ideal for Satellite Power Amplifier Applications
• 3-Stage MMIC Offers 17 dB More Gain than GaAs IM FETs
IMS
LEARN MORE: GO.WOLFSPEED.COM/IMS2017
FIND US AT BOOTH 832.
Wolfspeed™
A CREE COMPANY

ing a specialized system such as a ProtoMat S103 *(Fig. 13)*. Developed by **LPFK Laser & Electronics** (Booth 1338; *www.lpkfusa.com*), this system performs the high-speed milling and drilling of single- and double-sided PCBs.

13. Using precision stepper-motor-driven material cutting tools, the ProtoMat S103 is a system capable of forming PCBs from design files. *(Courtesy of LPKF Laser & Electronics)*

14. The ProtoMat S103 PCB plotter is suitable for creating prototype circuits or supporting small production runs. *(Courtesy of LPKF Laser & Electronics)*

Featuring a spindle speed of 100,000 rpm, the ProtoMat S103 supports a maximum travel speed along a circuit board of 150 mm/s with circuit feature resolution of 0.5 µm. A pneumatic, non-contact depth (z-axis) limiter helps to fashion precise circuit features even on substrates with delicate surfaces. In addition to fabricating high-speed and high-frequency circuit boards, the system's advanced z-axis drive enables it to finish front panels and housings, and even perform depth milling of microwave PCBs.

CUING UP THE CODE

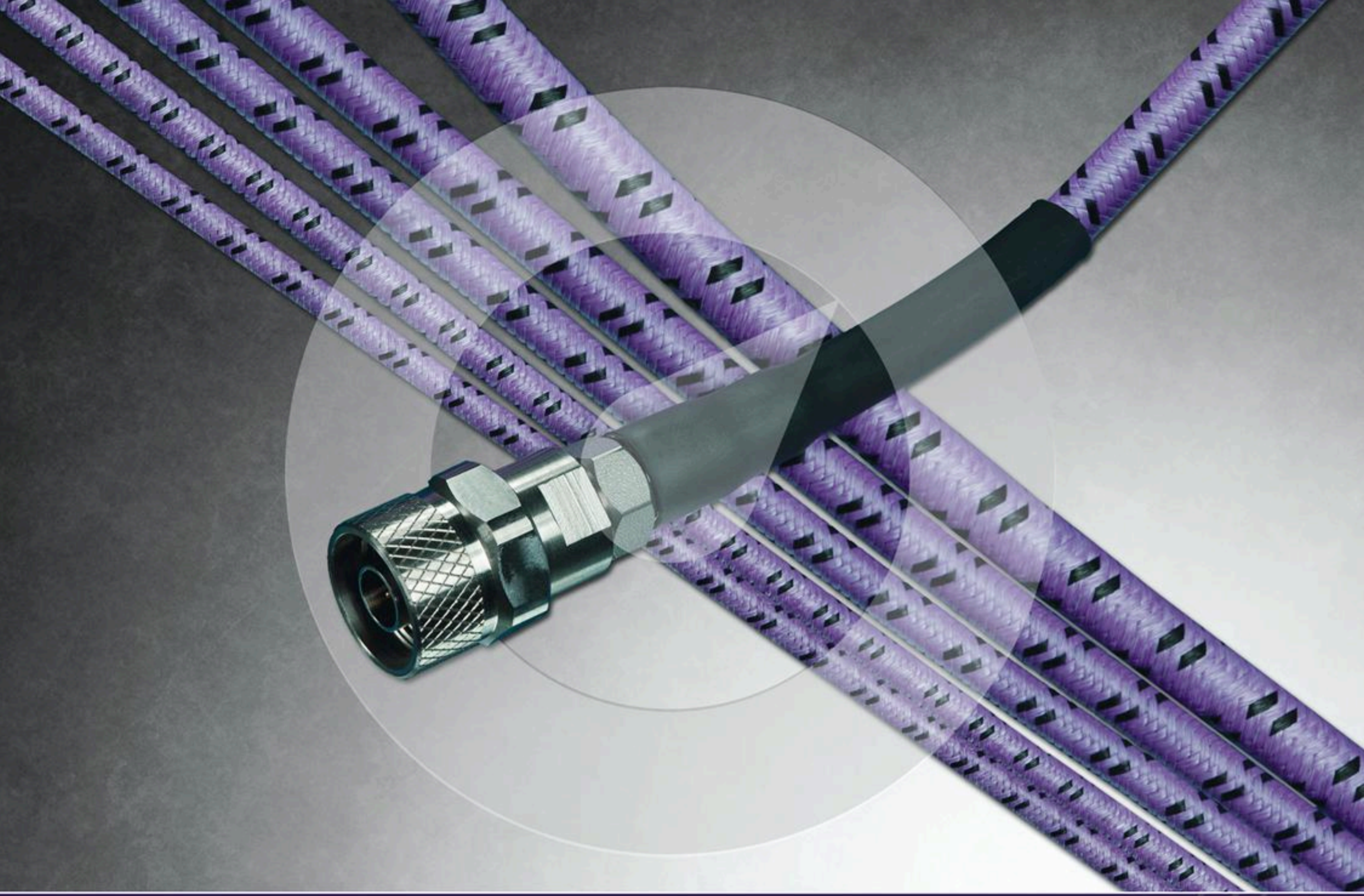
The 2017 IMS exhibition may not be the best place to sit down and try out the latest version of the industry's top computer-aided-engineering (CAE) tools. Nonetheless, many of those tools will be in full use on the show floor with large display screens to demonstrate their often-familiar graphical user interfaces (GUIs). Software is very much a part of the modern design process and, as noted earlier, it is also becoming an integral part of many measurement setups, with so many test instruments relying on computers as their control surfaces.

How long have designers been using software to create new electronic devices and circuits? One only need look at the double-digit release numbers now adorning many of the popular software tools to get a good idea. For example, **Sonnet Software** (Booth 1232, *www.sonnetsoftware.com*) will be at the 2017 IMS Exhibition to demonstrate its latest release of the Sonnet Suites of planar EM simulation programs—Version 16. The software has established a strong reputation based on its mathematical precision (to 15 decimal places) and the accuracy of its model extraction methods.

For designers who feel strongly about the use of mathematics as part of the creative process, **MathWorks** (Booth 1758, *www.mathworks.com*) will be on hand at the 2017 IMS Exhibition along with its popular MATLAB math-based simulation and analysis software. The software has been used not only for RF/microwave designs, but for health-monitoring systems, smart power grids, and even in outer-space systems. The processing power of the software combines with extensive graphic capabilities to help visualize the functionality of a design, such as a filter or coupler.

National Instruments (Booth 740, *www.ni.com/awr*) will demonstrate its well-known NI AWR Design Environment (now available in Version 13) suite of simulation software tools. Upgrades to the AWR Design Environment, with its Microwave Office design suite, revolve around the design of millimeter-wave components for 5G wireless applications. Visitors to the AWR booth can also catch demonstrations of the company's various other simulation software tools, including the Visual System SimulatorTM for Wireless Communications and Radar Systems, and AntSyn for Antenna Synthesis and Optimization.

Of course, these software tools are just a small sampling of the programs that will be on display and in use on the IMS show floor. The exhibition is scheduled for just short of three days in Honolulu, but interested parties can require one full day just to walk through the first aisle of the floor. Exhibit booths are populated by friendly and knowledgable representatives from each company, making it a pleasure to stop at each spot for an update, but also a challenge to make it from one end of the exhibition floor to the other in "only" three days. For those in attendance, the best of luck in your search for new hardware, software, and test equipment. mw



JACK BROWNE | Technical Contributor

Managing the Coexistence of Multiple Wireless Systems

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

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

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

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

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

THE ROAD TO COEXISTENCE

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

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

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

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

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

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

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

CREATING COEXISTENCE

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

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

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

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

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

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

CHRIS DeMARTINO | Technical Editor

Carry Spectrum Analysis with You

Claims are that spectrum analyzers in portable form still sustain the high performance of their benchtop brethren. Microwaves & RF got the chance to test-drive one to see if that's really the case.

A RAPIDLY GROWING trend within the RF/microwave industry is the portability of test equipment. Such is the case with the spectrum analyzer, which now can be found in various handheld sizes. Today, several different test-and-measurement suppliers offer USB-based spectrum analyzers. Let's take a look at one product that exemplifies this trend.

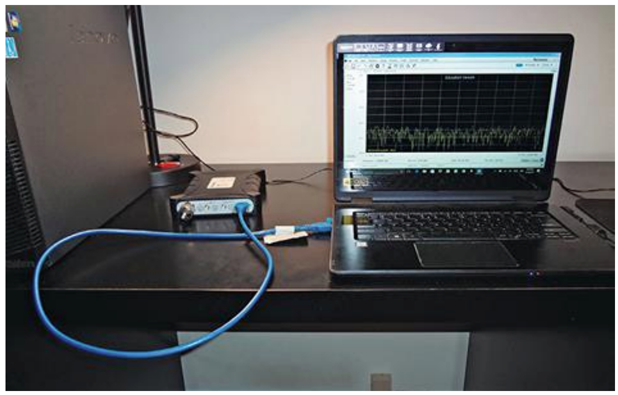
Tektronix is fully on board the portability train, providing test equipment such as the RSA306B—a portable, USB-based, real-time spectrum analyzer. The RSA306B covers a frequency range of 9 kHz to 6.2 GHz and has a measurement range of –160 to +20 dBm. It also is equipped with an acquisition bandwidth of 40 MHz. Moreover, a USB 3.0 cable comes included, so that the analyzer can connect to a laptop or desktop computer. The host computer provides all power, control, and data signals over the USB 3.0 cable.

The RSA306B operates with Tektronix's SignalVu-PC software, which allows signal analysis to be performed on a laptop or desktop computer. Of course, a traditional benchtop spectrum analyzer has a display, as well as a range of buttons, for user interfacing. When operated with the RSA306B, the SignalVu-PC software essentially equips one's computer with the display capabilities and user interfacing found on a typical spectrum analyzer.

WIDE RANGE OF OPTIONS

The RSA306B together with SignalVu-PC can perform a multitude of measurements. The free base version of SignalVu-PC offers spectrum analysis, RF power and statistics, and spectrograms. It also allows for amplitude, frequency, and phase-versus- time measurements.

Furthermore, the base version of SignalVu-PC can be enhanced by purchasing any of the advanced measurement options offered by Tektronix. The various options add different measurement capabilities, such as digital modulation analysis, pulsed RF signal analysis, wireless-local-area-network (WLAN) measurements, LTE measurements, Bluetooth measurements, and more. In essence, customers can choose the options they want to accommodate their specific needs.



1. The RSA306B spectrum analyzer connects to a computer via a USB cable.

A FIRSTHAND LOOK

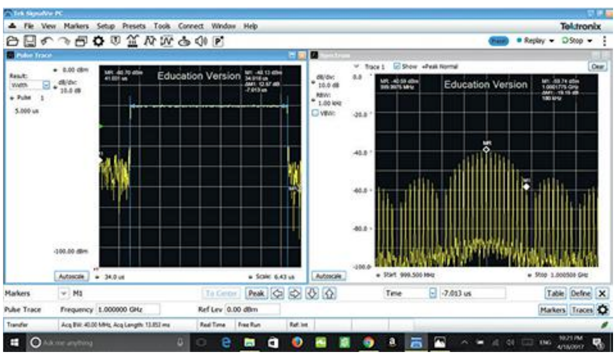
Tektronix loaned me an RSA306B, so I was able to get a better sense of what it can do *(Fig. 1)*. Of course, the first step was to install the SignalVu-PC software. Fortunately, installation was quick and painless.

Once SignalVu-PC was installed, I was able to get started with the RSA306B. Using SignalVu-PC to view a spectrum-analyzer display on a computer is obviously a new experience for anyone who had previously only worked with benchtop analyzers. However, SignalVu-PC feels very much like a typical spectrum analyzer.

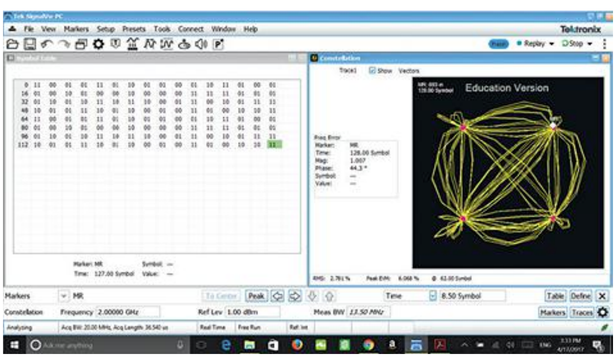
Figure 2 shows a SignalVu-PC spectrum-analyzer display of a 1.25-GHz continuous-wave (CW) signal. Here, it can be seen that the *Frequency, Span, Reference Level*, and *Resolution Bandwidth* parameters are easily accessible. In essence, those using the RSA306B with SignalVu-PC for the first time should become acclimated very quickly.

Tektronix is fully on board the portability train, providing test equipment such as the RSA306B—a portable, USB-based, real-time spectrum analyzer. The RSA306B covers a frequency range of 9 kHz to 6.2 GHz and has a measurement range of -160 to +20 dBm. It also is equipped with an acquisition bandwidth of 40 MHz.

2. Illustrated here is a SignalVu-PC spectrum-analyzer display of a 1.25-GHz signal.



3. Shown is the pulse width of a 1-GHz pulsed RF signal along with a spectrum-analyzer display.



4. SignalVu-PC can analyze digitally modulated signals, such as this 2-GHz QPSK signal.

PULSED RF SIGNAL ANALYSIS

After looking at some CW signals—which is obviously no big deal—I decided to experiment with some of the more advanced options. One in particular was the *Pulsed RF* measurement option.

It should be noted that each additional measurement option contains various display choices that users can add one-by-one to their assortment of selected displays. The *Pulsed RF* measurement option contains three display choices: *Pulse Statistics, Pulse Table,* and *Pulse Trace*. Users can analyze a number of pulse characteristics including *Average ON Power, Peak Power, Average Transmitted Power, Pulse Width, Rise Time, Fall Time,* and more. The *Pulse Table* display allows users to view whichever pulse measurements they choose in a spreadsheet format.

Figure 3 shows the *Pulse Trace* display alongside the basic *Spectrum* display. In this case, a 1-GHz pulsed RF signal is observed. The pulse width is set to 5 μs and the pulse period is set to 0.05 ms. Simply put, the *Pulsed RF* option provides users with a great deal of insight when analyzing pulsed RF signals.

DIGITAL MODULATION ANALYSIS

Next, I decided to experiment with the *General Purpose (GP) Digital Modulation* analysis option, which essentially equips the RSA306B with vector-signal-analysis (VSA) capability. The *GP Digital Modulation* option contains a number of available displays, such as *Constellation, Demod I&Q vs. Time, EVM vs. Time, Eye Diagram, Frequency Deviation vs. Time, Magnitude Error vs. Time, Phase Error vs. Time, Signal Quality, Symbol Table,* and *Trellis Diagram*.

Figure 4 shows a constellation diagram of a 2-GHz quadrature phase-shift-keying (QPSK) signal. Also illustrated in the figure is the *Symbol Table*, which displays the information in a table format.

CONCLUSION

The RSA306B packs a great deal of measurement capability into a spectrum analyzer that can be held in one hand. This article only covers a fraction of the measurement capabilities offered by the instrument. However, I can certainly attest that the RSA306B is a product that delivers serious performance, and is worth a look for those in need of spectrum analysis on-the-go.

JAMES WONG | RF PA Specialist
NAOKI WATANABE | Senior RF Engineer
ANDREI GREBENNIKOV | RF PA Specialist
Sumitomo Electric Europe Ltd, 220 Centennial Park, Elstree, Hertfordshire, WD6 3SL, United Kingdom

Efficient GaN Doherty Amplifier Peaks at 1 kW from 2.11 to 2.17 GHz

This novel asymmetric Doherty amplifier design uses multiple GaN HEMT devices to achieve 1 kW output power with 65% average efficiency for cellular transmitters from 2.11 to 2.17 GHz.

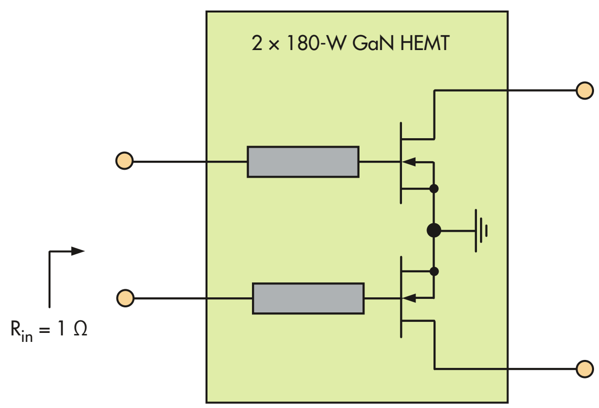
Power amplifiers are among the most important of components for modern wireless communications systems. Ideally, they can provide high output power with high linearity and high efficiency. But tradeoffs typically occur among these three key power-amplifier performance parameters, and amplifiers with the highest output power and linearity usually sacrifice linearity.

In modern telecommunications systems supporting wide bandwidths and high data rates, transmitted signals are usually characterized by high peak-to-average power ratio (PAR) due to wide and rapid variations in the instantaneous transmitting power. Therefore, it is a challenge to design a wireless base-station power amplifier having high efficiency not only at maximum output power, but at lower power levels typically ranging from 6 dB and less of the maximum power level, with minimum size and lower cost of implementation.

However, the problem is solvable by using gallium-nitride (GaN) high-electron-mobility-transistor (HEMT) device technology and innovative Doherty amplifier architectures. It's possible to achieve 60% average efficiency and reduced power consumption for average output-power levels of 100 W and higher.

GETTING ON BOARD WITH GaN HEMTS

GaN HEMTs feature high breakdown voltages, high current densities, high transition frequency (f_T), low on-state resistance, and low parasitic capacitance, resulting in a wide-bandwidth amplifier featuring high-power capabilities and high operating efficiency. The high power density enables physically compact designs, while high dc-supply-voltage operation and low parasitic output capacitance lead to higher load impedance for ease in obtaining wide impedance bandwidths. In addition, the high drain-to-source breakdown voltage in excess of 150 V enables rugged operation at 50 V dc regardless of drive level or harmonic load environment.



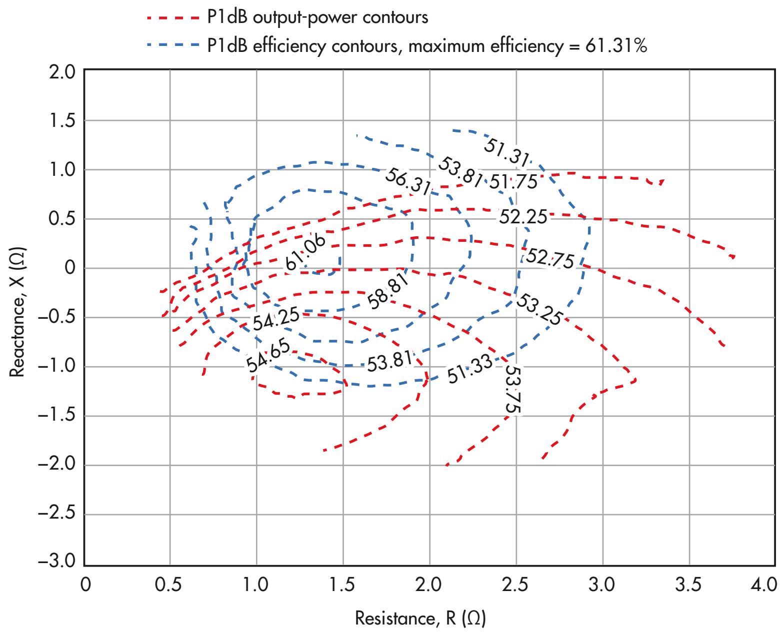
1. This simple schematic rendering represents a dual-path GaN HEMT with internal input impedance matching.

As an example, Sumitomo's GaN HEMT technology delivers high-gain packaged devices capable of peak output power levels to 300 W at frequencies to 8 GHz and higher. Applications include radar and high-reliability cellular communications transmitters. Progress in increasing power density has resulted in devices with 5-W/mm power density, and as much as 10-W/mm power density at 50 V dc. The use of high-thermal-conductivity substrates such as silicon carbide (SiC) provide excellent thermal stability even at these high power densities.

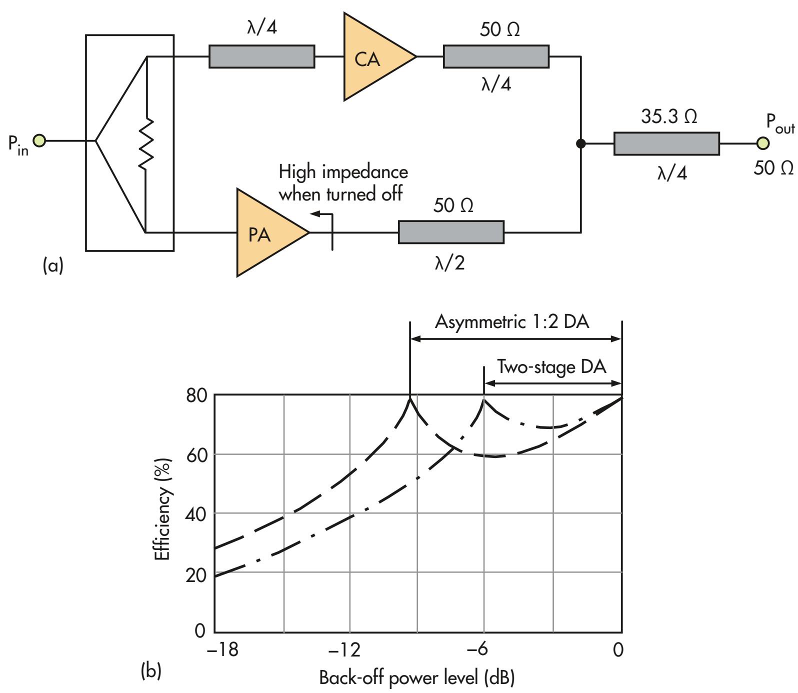
To achieve high efficiency under backed-off operating power conditions, enhancements such as envelope tracking and outphasing techniques, among others, are available. However, the use of a Doherty amplifier configuration provides a practical alternative approach. A Doherty amplifier is simple to implement and can provide high efficiency across a wide bandwidth when operating with backed-off power, depending on the number of stages. In this case, a three-way asymmetric Doherty configuration offers a suitable compromise among high gain, high output power, and high average efficiency.

GaN HEMTs can be fabricated with larger gate peripheries for higher power capabilities from a given package size. The corresponding increase in gate-source capacitance when multiple device cells are connected in parallel reduces the optimum input impedance to very low values—close to a few tenths of an ohm. As a result, a low-loss matching network is required inside the package to transform the impedance from the reference plane defined by the package leads to the reference plane of the device die.

For practical use, a packaged power device should provide reasonably high (not less than 1 Ω) input impedance with a sufficiently low quality factor (Q) to provide flat gain/amplitude performance over a required frequency bandwidth. Depending on the space within the package, as a simple matching network for narrowband operation (for example, from 2.11 to 2.17 GHz, corresponding to cellular radio band 1), a quarter-wave microstrip line on a high-permittivity substrate might be considered *(Fig. 1)* for a dual-path package. Here, two separate 180-W GaN HEMT dies are attached in parallel.

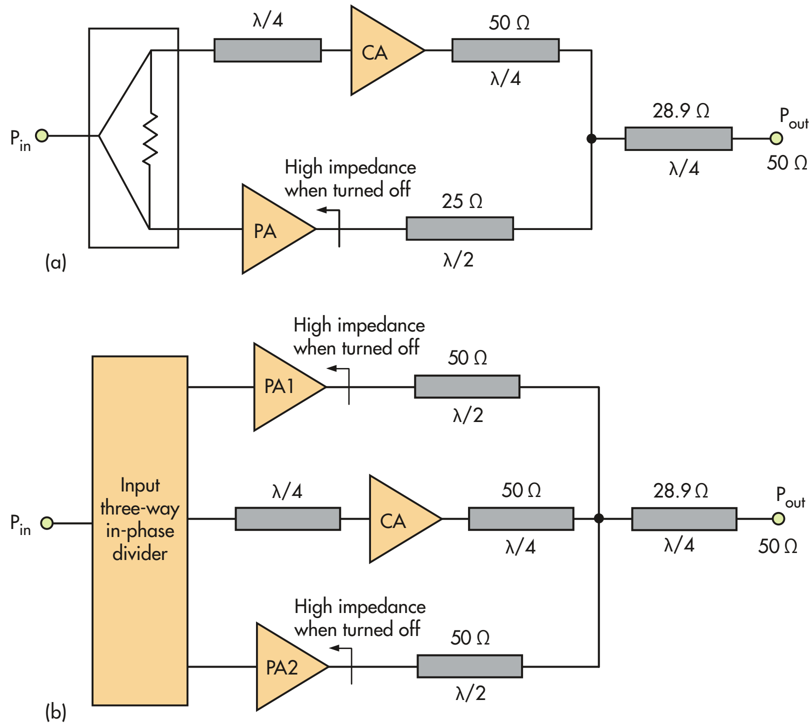


2. The load-pull contours show impedances for optimum output power and efficiency.



3. The block diagram shows a modified symmetric two-stage Doherty amplifier (a) along with its theoretical efficiency (b).

The load pulling of an amplifying path (including the packaging parameters for the transistors), where two 50-V 180W transistor die are connected in parallel and biased in a Class AB mode, resulted in the contours of *Figure 2*. It demonstrates the tradeoff in determining an optimum output impedance match, because the optimum impedance for maximum power is quite different than the optimum impedance for maximum efficiency. In this case, the output power at 1-dB gain compression reaches a maximum of about +55 dBm under low-impedance conditions of (1.2 – j1.1) Ω, whereas a maximum efficiency of greater than 61% is obtained for a purely resistive impedance of about 1.3 Ω *(Fig. 2)*.

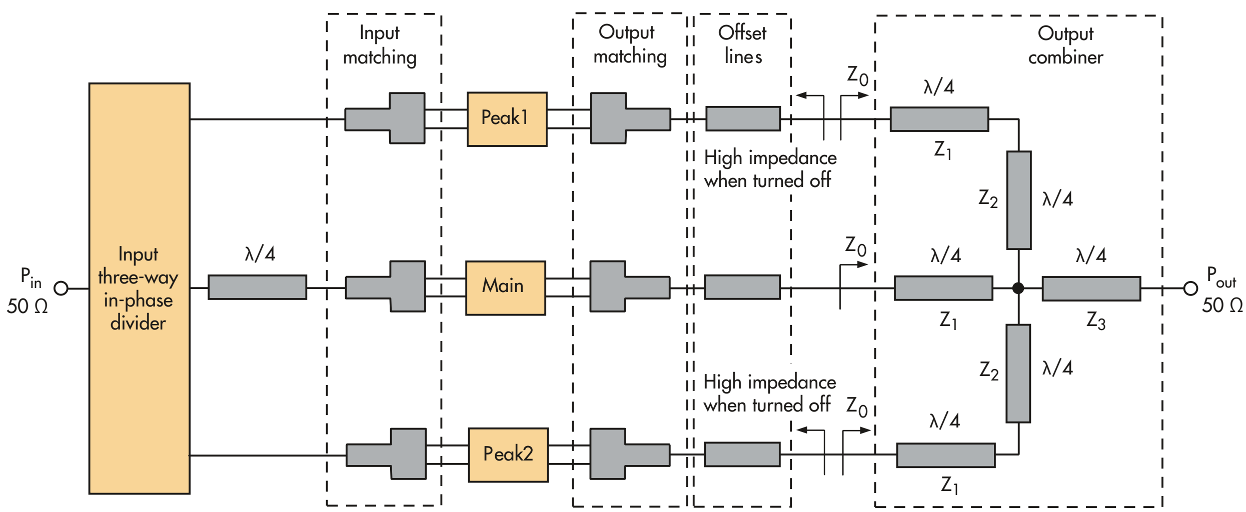


4. This block diagram illustrates a modified 1:2 asymmetric Doherty amplifier.

MODIFIED DOHERTY CONFIGURATION

For a high-power amplifier with very low output impedance, the width of the matching microstrip line is very wide compared to its length and the overall size of the matching circuit. The matching circuitry includes an offset line to create an open-circuit condition when the peaking amplifier is turned off, as well as a quarter-wavelength transforming line. As a result, it can easily become large enough whereby it becomes difficult to connect the output of the peaking amplifier directly to the main amplifier signal path.

For convenience of implementation, a classical Doherty amplifier configuration can be modified by including an additional one-half-wavelength line at the output of the peaking amplifier. *Figure 3a* shows the block diagram of a modified two-stage Doherty amplifier configuration, where a one-half-wavelength line is connected to the output of the peaking amplifier (PA) and a quarter-wave line is included at



5. Several quarter-wave microstrip lines are built into a three-way inverted Doherty amplifier.


GVA-60+
GVA-84+
GVA-62+
GVA-63+
2 New Models!
GVA-91+ 1W Power
GVA-123+ Ultra-Wideband,
0.01-12 GHz
GVA-82+
GVA-83+

the input of the carrier (or main) amplifier (CA) for phase compensation. This configuration is characterized by the same two peak efficiency points at saturation and where the power is backed off or decreased by 6 dB from its maximum level. It is similar to a classical two-stage Doherty amplifier (DA) as shown in *Figure 3b*.

It is possible to extend the region of high efficiency over a wider range of output power levels if the carrier and peaking amplifiers are designed to operate with different output power levels—smaller for the carrier amplifier and larger for the peaking amplifier. For instance, for a power-division ratio 1:2, the transition point with maximum drain efficiency corresponds to the back-off power level of 9.5 dB from peak output power, as shown in Fig. 3b. In this case, the characteristic impedance of a half-wave line is 25 Ω, which corresponds to the load impedance required for the peaking amplifier. The characteristic impedance of the combining quarter-wave line is 28.9 Ω, as shown in *Figure 4a*.

When it is difficult to choose the proper power ratio between packaged active devices, it is convenient to use identical power amplifiers in a multi-way Doherty configuration, where one carrier power amplifier is parallel with multiple peaking amplifiers. Thus, a 1:2 asymmetric two-stage Doherty structure can be transformed into a modified three-way asymmetric Doherty configuration *(Fig. 4b)*.

6. This is a photograph of an input three-way in-phase power divider with additional quarter-wave line.

The modified setup includes one carrier amplifying path and two identical peaking amplifying paths when device sizes for the carrier amplifier and both peaking amplifiers (PA1 and PA2) are equal. The half-wave line in each peaking amplifying path can be split into two quarter-wave lines. Each quarter-wave line has its own characteristic impedance for the corresponding impedance transformation when the required load impedance for the peaking device is sufficiently small.

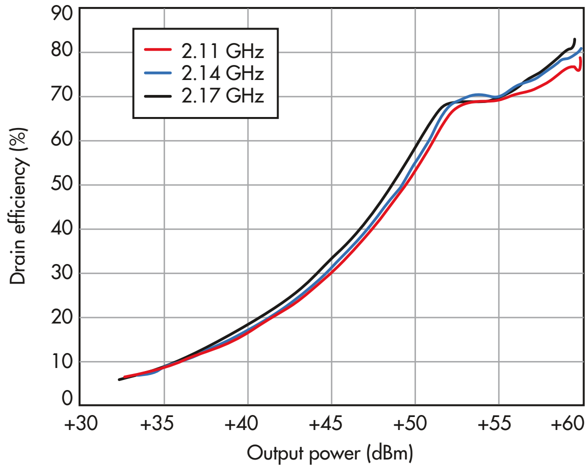
THREE-WAY DOHERTY AMPLIFIER

Figure 5 shows the block diagram of a three-way asymmetric Doherty amplifier configuration. The output combiner includes one-quarter-wavelength microstrip line in the carrier signal path, two-quarter-wavelength microstrip lines in each peaking path, and one quarter-wave microstrip combining line. Here, each amplifying path includes a packaged device with the same die size and input and output matching circuits using microstrip lines.

Offset lines are necessary to provide proper open-circuit conditions at their ends for peaking amplifiers when they are turned off. Then, two quarter-wave microstrip lines with different widths are required for the corresponding impedance transformation. They translate the open-circuit condition in each peaking path to the open circuit seen by the carrier path at output-power levels lower than 9 dBc at a common node in the output combiner.

For example, for identical amplifiers having optimum load impedance $Z_0 = 12\ \Omega$ each and $Z_2 = R_L = 50\ \Omega$, where R_L

(Continued on page 149)



7. The plots show measured drain efficiency as a function of output power.

Design Feature

LAMIN KHAN | Associate Professor
School of Optical and Electronic Information, Huazhong University of Science and Technology, Wuhan 430074, China

PEI QIU | Master's Degree Candidate
School of Optical and Electronic Information, Huazhong University of Science and Technology, Wuhan 430074, China; e-mail: peiqiu@hust.edn.cn

BAOQUAN HU | Engineer
Avic Shaanxi Aircraft Industry (Group) Corp. Ltd., Xi'an Shaanxi, China

CHANGZHONG CHEN | Engineer
Avic Shaanxi Aircraft Industry (Group) Corp. Ltd., Xi'an Shaanxi, China

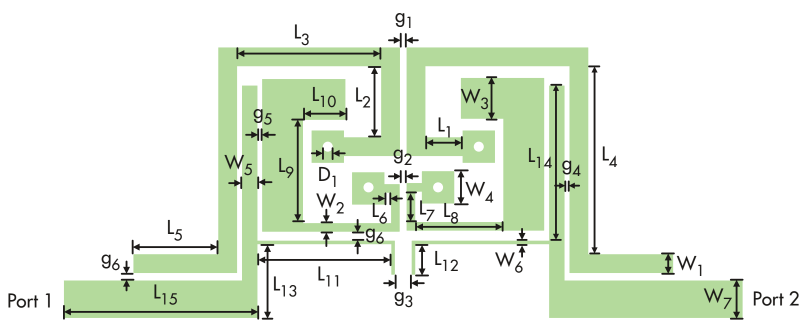
Dual-Band Bandpass Filter Has Tunable Passband Frequencies

This compact bandpass filter employs an embedded structure to achieve features independently controllable passband frequencies.

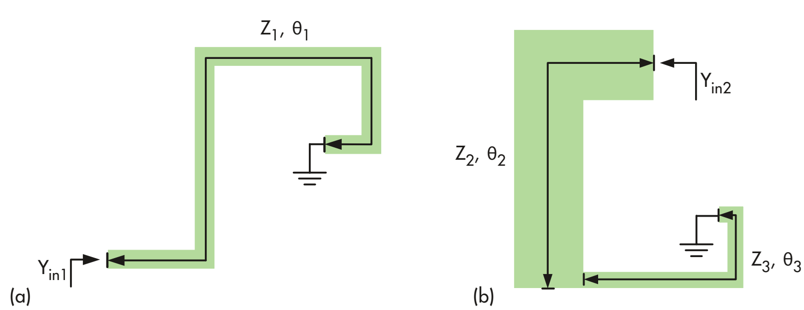
Dual-band bandpass filters (BPFs) provide the functionality of two separate filters, but in the size of a single filter. They have become an important part of many multiple-band communications systems, passing desired channels while rejecting unwanted interference and noise.

By using a pair of quarter-wave (λ/4) uniform-impedance resonators (UIRs) and a pair of λ/4 stepped-impedance resonators (SIRs), it was possible to construct a dual-band BPF with center frequencies of 1.57 and 2.07 GHz and fractional bandwidths (FBWs) of 4.46% and 4.35%, respectively. The filter, with tunable center frequencies, provides good selectivity and high out-of-band suppression, using folded resonators for extremely compact size.

A number of methods have been developed for the design of dual-band BPFs.[1-8] They can be designed by using two dissimilar BPFs in parallel or cascade with



1. This is the layout of a compact dual-band BPF with folded λ/4 UIRs and folded λ/4 SIRs.



2. These schematic diagrams represent the (a) λ/4 UIR and (b) the λ/4 SIR.

By using a pair of quarter-wave ($\lambda/4$) uniform-impedance resonators (UIRs) and a pair of $\lambda/4$ stepped-impedance resonators (SIRs), it was possible to construct a dual-band BPF with center frequencies of 1.57 and 2.07 GHz and fractional bandwidths (FBWs) of 4.46% and 4.35%, respectively. The filter, with tunable center frequencies, provides good selectivity and high out-of-band suppression, using folded resonators for extremely compact size.

common input/output (I/O) coupling structure. While this technique makes it possible to adjust the passband frequencies independently, it leads to a filter with relatively large size.[1] In ref. 1, a dual-band BPF employing a short-circuited $\lambda/4$ resonator and an improved SIR was presented, using a split-ring scheme to achieve small circuit size. In ref. 2, a dual-band filter was designed with $\lambda/4$ resonators. In this approach two separate passbands were created from one initially wide passband by forming a stopband between the two bands.

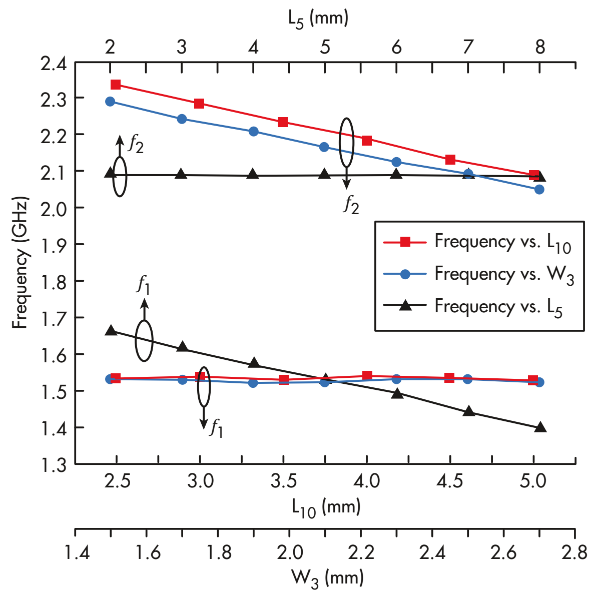
Dual-mode resonators are widely used in dual-band BPFs.[3,4] In ref. 3, two dual-mode cross-slotted patch resonators are arranged back-to-back to design a multilayer dual-band BPF. The passband frequencies can be controlled separately. Reference 4 synthesizes a dual-band BPF with two identical SIRs, obtaining good selectivity in the process. However, this filter's passband frequencies are not independent and the filter circuit is relatively large.

Another popular way to design dual-band BPFs is by employing multimode resonators.[5-7] This approach leads to a dual-band BPF with small size, but with limited independent tuning of the passband frequencies due to the internal structure of the filter.

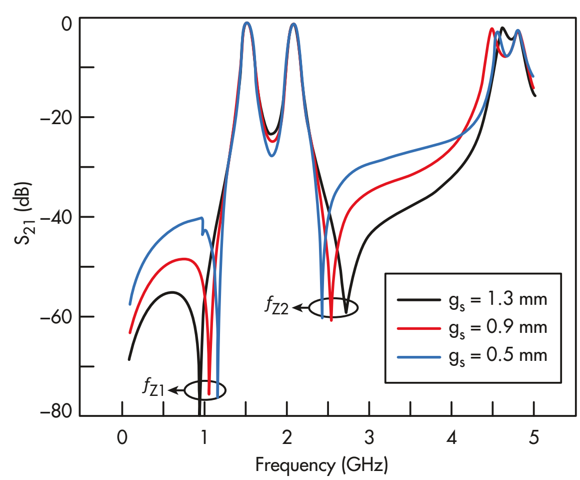
In ref. 5, a dual-band BPF was designed with a novel quad-mode resonator using coupled line sections and transmission-line section. This design offers good selectivity and small size. In refs. 6 and 7, dual-band BPFs using multiple stub-loaded ring resonators and filters based on E-shaped multimode resonators were presented, respectively. The resonant modes of these two resonators can be individually controlled. Reference 8 presents a dual-band BPF using symmetric double-spiral resonators. The filter has small circuit size, but is difficult to synthesize.

As an improved approach to implementing a dual-band BPF with independently controlled passband frequencies, a filter was developed with center frequencies of 1.57 and 2.07 GHz using two $\lambda/4$ UIRs and two $\lambda/4$ SIRs. The FBWs of the two passbands are 4.46% and 4.35%, respectively. *Figure 1* illustrates the filter's structure. Not only are the folded resonators embedded together, but the coupling lines are placed between the resonators to create a layout with small size.

The filter was analyzed by deducing the input admittance



3. The center frequencies of both filter passbands were simulated with different values of L_5, L_{10}, and W_3.



4. These are the locations of the transmission zeros with different values of g_s.

of the resonators. Both passband frequencies can be tuned independently by changing the dimensions of each resonator. Furthermore, source-load coupling is applied to generate two transmission zeros at the passband edge, leading to good selectivity and an improved stopband up to 4.74 GHz ($2.3f_2$).

Figure 1 shows the layout of a second-order dual-band BPF developed with this new approach. It consists of two folded $\lambda/4$ UIRs and two folded $\lambda/4$ SIRs. The UIRs and SIRs are embedded together and the coupling lines are placed between the resonators, which makes the filter very compact. The $\lambda/4$ UIRs generate the first passband while the $\lambda/4$ SIRs form the second passband. Two additional coupling lines realize source-load coupling.

Figures 2a and b present schematic diagrams of the $\lambda/4$ UIR and $\lambda/4$ SIR. The input admittances of the UIR and SIR are derived by Eqs. 1 and 2:

$$Y_{in1} = j\cot\theta_1/Z_1 \quad (1)$$

$$Y_{in2} = (Z_2 - Z_3\tan\theta_2\tan\theta_3)/[jZ_2(Z_2\tan\theta_2 + Z_3\tan\theta_3)] \quad (2)$$

where Z_1 and θ_1 denote the UIR's impedance and electrical length, respectively, at frequency f_1. Parameters Z_2 and Z_3 are the impedances of the SIR while θ_2 and θ_3 indicate the electrical lengths at f_2. Frequencies f_1 and f_2 are the center frequencies of the first and second passbands, respectively. The conditions of resonance can be deduced by Eqs. 3 and 4 when $Y_{in1} = 0$ and $Y_{in2} = 0$:

$$\theta_1 = \pi/2 \text{ at } f = f_1 \quad (3)$$

$$Z_2 = Z_3\tan\theta_2\tan\theta_3 = 0 \text{ at } f = f_2 \quad (4)$$

The dimensions of the resonators can be derived once the passband frequencies are defined. The electrical length θ_1 is determined by the various structural parameters, including L_1, L_2, L_3, L_4, and L_5, which determines the value of f_1. It is convenient to adjust f_1 by tuning the value of L_5 without having much influence on the coupling coefficients.

As for tuning the value of f_2, both the impedance ratio of Z_2/Z_3 and the electrical lengths θ_2 and θ_3 can be used for adjustment. W_2 and W_3 determine Z_2 and Z_3, while θ_2 and θ_3 are decided by L_6, L_7, L_8, L_9, and L_{10}. Likewise, W_3 and L_{10} are used to adjust f_2 with minimal effect on the coupling coefficients of the whole structure.

Figure 3 plots the center frequencies of both passbands with different values of L_5, L_{10}, and W_3. The variation of L_5 changes f_1 distinctly and f_2 keeps constant. On the other side, f_2 can be adjusted by tuning L_{10} and W_3, while f_1 has nearly no change. This demonstrates that f_1 and f_2 are independently controllable.

Figure 4 shows that two transmission zeros are generated. These two transmission zeros are created because of the source-load coupling introduced by the two additional coupling lines. One transmission zero is located below f_1 while the other is above f_2. Both transmission zeros are very close to the passbands, effectively improving the filter's selectivity. The filter also exhibits good high-frequency signal suppression due to the transmission zero above f_2.

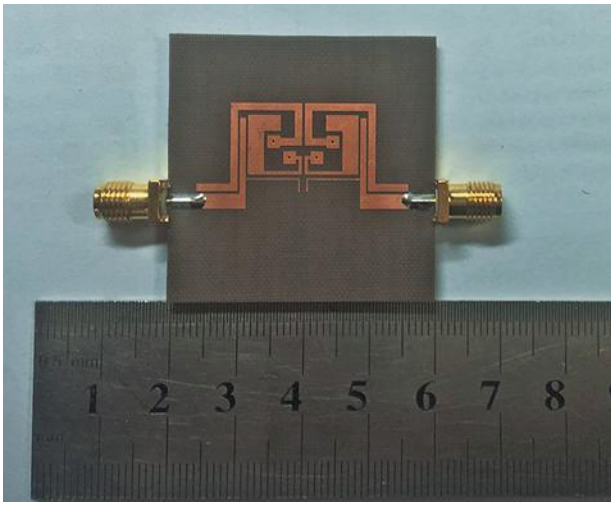
The locations of both transmission zeros can be controlled by changing g_s. As depicted in *Fig. 4*, both transmission zeros can be moved closer to the passbands by reducing g_s. The band-to-band isolation will be slightly improved in the process, although some degradation of the high-frequency signal suppression will occur as an unwanted side effect. Thus, the locations of the transmission zeros must be weighed carefully according to the specific design requirements of an application.

To demonstrate the effectiveness of this design approach, a dual-band BPF centered at 1.57 and 2.07 GHz was designed and fabricated on Arlon DiClad 880 substrate (the company is now part of Rogers Corp.) with dielectric constant of 2.2, substrate thickness of 0.762 mm, and conductor thickness of 0.035 mm. The fabricated dual-band BPF is illustrated in *Fig. 5*.

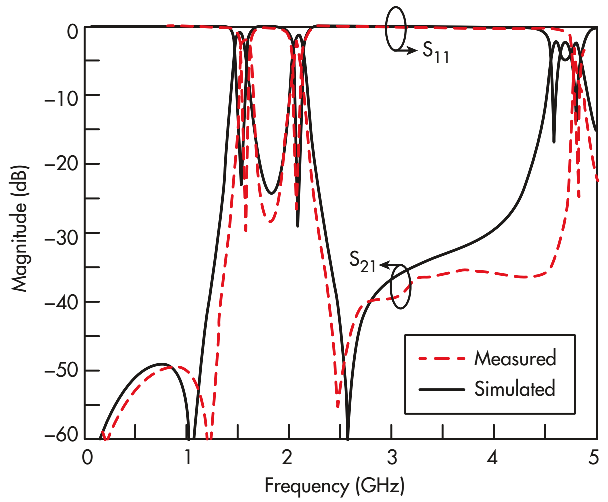
All detailed geometry dimensions of the filter are given as follows (in mm): g_1 = 0.3 mm, g_2 = 0.3 mm, g_3 = 0.9 mm, g_4 = 0.2 mm, g_5 = 0.2 mm, g_6 = 0.5 mm, L_1 = 2.1 mm, L_2 = 4.1 mm , L_3 = 8.4 mm, L_4 = 11 mm, L_5 = 5 mm, L_6 = 0.3 mm, L_7 = 1.7 mm, L_8 = 5.1 mm, L_9 = 6 mm, L_{10} = 2.5 mm, L_{11} = 7.8 mm, L_{12} = 1.8 mm, L_{13} = 4.35 mm, L_{14} = 9.15 mm, L_5 = 11.45 mm, W_1 = 1.2 mm, W_2 = 0.6 mm, W_3 = 2.5 mm, W_4 = 2 mm, W_5 = 1 mm, W_6 = 0.3 mm, W_7 = 2.3 mm, and D_1 =0.4 mm.

Not including the two feed ports, the filter circuit measures about $0.1\lambda_g \times 0.24\lambda_g$ (13.75 × 31.9 mm), where λ_g indicates the guided wavelength at f_1 = 1.57 GHz. Both UIRs and SIRs are folded and embedded together to achieve compact circuit size. Two additional microstrip lines are linked to the main coupling lines to achieve source-load coupling.

A model N5245A vector network analyzer (VNA) from Keysight Technologies (www.keysight.com) was used to measure the performance of the fabricated dual-band BPF. *Figure 6* plots the simulated and measured frequency responses, which are in close agreement. It can be seen that two passbands are centered at 1.57 and 2.07 GHz with



5. This photograph shows the dual-band BPF fabricated on Arlon DiClad 880 circuit material.



6. The simulated and measured frequency responses of the dual-band BPF are in close agreement.

FBWs of 4.46% and 4.35%, respectively.

The measured results indicate that the insertion loss (IL) is 1.54 and 1.68 dB at the first and second passbands, respectively. The return loss (RL) is better than 24 dB within the two passbands and the band-to-band isolation is greater than 20 dB from 1.68 to 1.94 GHz.

In addition, two transmission zeros were created at f_{Z1} = 1.22 GHz and f_{Z2} = 2.48 GHz, which improve the selectivity of both passbands. The filter shows good high-frequency signal suppression of greater than 20 dB to 4.74 GHz ($2.3f_2$). The *table* offers a comparison between the proposed filter with some other reported dual-band BPFs. It demonstrates that this filter realizes both compact size and independently controllable passband frequencies at the same time.

This combination of folded $\lambda/4$ UIRs and folded $\lambda/4$ SIRs and an embedded structure for small size represents an effective approach for designing a dual-band BPF with independently controllable passbands. The passband insertion loss is low and the output-of-band suppression is high, making this design a suitable candidate for many communications applications with multiple channels. mw

COMPARING DUAL-BAND FILTER PERFORMANCE LEVELS

Source	f_1/ f_2 (GHz)	FBW (%)	Insertion loss (dB)	Return loss (dB)	Area (λg^2)	Independent control
Reference 1	2.49/3.85	4.1/4.4	1.62/1.31	20/20	0.032	Yes
Reference 2	1.73/2.45	5/5	1.13/1.17	26/27.9	0.048	No
Reference 3	1.55/2.35	9.67/8.1	1.45/1.45	10/10	0.048	Yes
Reference 4	1.8/5.8	11/6	1.21/3.89	15.9/10.9	0.12	No
Present work	1.57/2.07	4.46/4.35	1.54/1.68	25/24.4	0.024	Yes

ACKNOWLEDGMENT

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

REFERENCES

1. G. Wu, L. Yang, and Q. Xu, "Miniaturized dual-band filter with high selectivity using split ring scheme," Electronics Letters, Vol. 51, No.7, April 2015, pp. 570-572.
2. S. Zhang and L. Zhu, "Compact Split-Type Dual-Band Bandpass Filter Based on λ/4 Resonators," *IEEE Microwave and Wireless Components Letters*, Vol. 23, No. 7, July 2013, pp. 344-346.
3. G. Zhang, J. Chen, J. Shi, H. Tang, H. Chu, and Z. Bao, "Design of Multilayer Balun Filter With Independently Controllable Dual Passbands," *IEEE Microwave and Wireless Components Letters*, Vol. 25, No.1, January 2015, pp. 10-12.
4. Z. Songbai and Z. Lei, "Fully canonical dual-band bandpass filter with λ/4 stepped impedance resonators," Electronics Letters, Vol. 50, No.3, January 2014, pp. 192-194.
5. Y. Peng, L. Zhang, J. Fu, Y. Wang, and Y. Leng, "Compact Dual-band Bandpass Filter Using Coupled Lines Multimode Resonator," *IEEE Microwave and Wireless Components Letters*, Vol. 25, No.4, April 2015, pp. 235-237.
6. J. Xu, W. Wu, and G. Wei, "Compact Multi-Band Bandpass Filters With Mixed Electric and Magnetic Coupling Using Multiple-Mode Resonator," *IEEE Transactions on Microwave Theory & Techniques*, Vol. 63, No.12, December 2015, pp. 3,909-3,919.
7. H.W. Liu, S. Li, and B.P. Ren, "Microstrip dual-band bandpass filter with E-shaped multimode resonator," *Electronics Letters*, Vol. 49, No.14, July 2013, pp. 887-888.
8. G. Wu, G. Wang, J.G. Liang, X. Gao, and L. Zhu, "Miniaturized microstrip dual-band bandpass filter using novel symmetric double-spiral resonators for WLAN application," *Electronics Letters*, Vol. 51, No. 15, July 2015, pp. 1177-1178.

AHMED BOUTEJDAR | Doctor-Researcher, Electrical Engineering
German Research Foundation DFG, Braunschweig-Bonn, Bonn, Germany; e-mail: boutejdar69@gmail.com

SAAD DOSSE BENNANI | Doctor-Researcher, Communication Engineering, Telecommunications, Engineering, Electronic Engineering, University Sidi Mohamed Ben Abdellah, Fès, Morocco; e-mail: saad.d.bennani@gmail.com

Design High-Frequency Filters with Cross DGS Circuit Elements

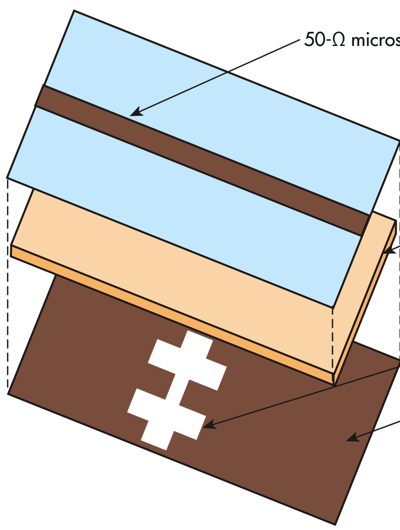
Logarithmic series and coupling-matrix methods aid in the design and optimization of cross-DGS lowpass and bandpass filters.

Lowpass filters can be designed and optimized by means of a new approach, based on the use of logarithmic series analysis and etched cross defected ground structure (DGS) topologies.[1, 2]

A simple J-inverter and coupling matrix enable the transformation of a lowpass filter (LPF) to a bandpass filter (BPF) with the same structure and conditions. In addition, Chebyshev guidelines, a suspended first-order layer technique, and logarithmic analysis are employed to design the filter's operating frequency range. Lowpass filters were designed with cutoff frequencies of 2.0, 3.0, and 4.5 GHz, suitable for use in GSM900, radar, and wireless-local-area-network (WLAN) applications. The filters feature low insertion loss and high return loss in the passband, wide stopbands, and sharp rolloff characteristics.

Research on DGSs, such as photonic bandgap (PBG) transmission lines,[3, 4] which have periodic arrays of defects, has been reported with various configurations in microwave and millimeter-wave frequency-band applications. A DGS with periodic or nonperiodic arrays provides a rejection band at some frequencies due to an increase in the effective inductance of the transmission line. The use of DGS technology has been reported for various applications, including filters,[5-27] power dividers, and amplifiers, due to its high-quality-factor (high-Q) frequency characteristics, small size, precise equivalent circuit models, and simple implementation in microstrip circuits.

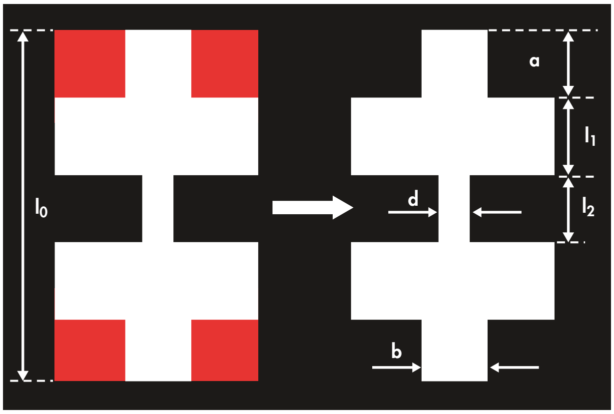
A conventional DGS consists of narrow and wide etched areas on a printed-circuit-board (PCB) material with backside



1. The cross-DGS cell can be seen in this three-dimensional (3D) view of a microstrip circuit.

metallic ground plane. The narrow and wide etched areas increase the effective capacitance and inductance, respectively, of a transmission line. A DGS is composed of two square defected areas and a narrow connecting slot, and these structures are the bases for the inductive-capacitive (LC) equivalent-circuit elements. An attenuation pole can be generated by the combination of the inductive and capacitive elements.

To explore the use of DGS circuit elements in high-frequency design, two different DGS LPFs and a DGS BPF were

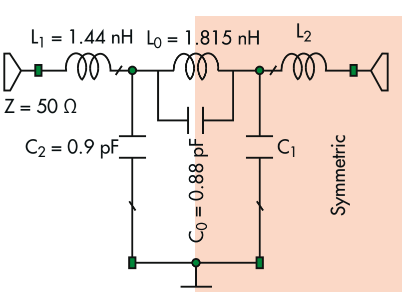


2. These are the dimensional parameters of the cross-DGS structure.

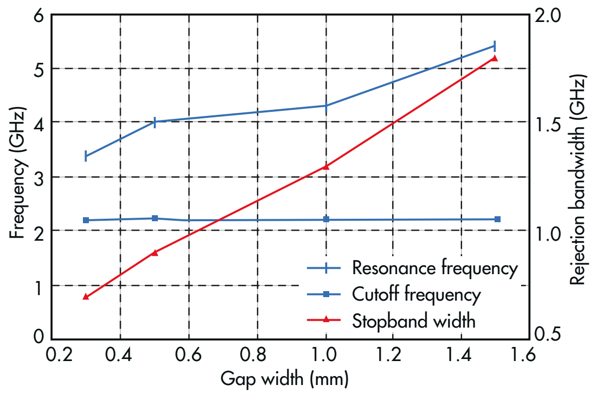
designed and fabricated. The second LPF design was extracted from the initial LPF using cascaded cross-DGS shapes and a J-inverter. Using Chebyshev's rule and two additional cross-DGS elements, the third-order LPF was shifted from L-band to S-band. A logarithmic method was applied to improve the performance of the S-band fifth-order LPF. These DGS filters feature small size, low passband loss, and wide stopbands.

When a slot is etched in the backside metallic ground plane of a microstrip line, it disturbs the current distribution in the ground, and increases the effective inductance and capacitance of the microstrip line. Therefore, a DGS is usually modeled as a parallel LC resonant circuit by using a circuit-analysis method. *Figures 1 and 2* show a DGS shape and its dimensions. *Figure 3* shows an equivalent-circuit model, where L_0 and C_0 denote the inductance and capacitance, respectively, resulting from the current disturbances in the ground plane. For enhanced DGS modelling, circuit elements C_1 and L_1 were added to the equivalent-circuit model. The additional capacitance is from the fringing field around the discontinuity.

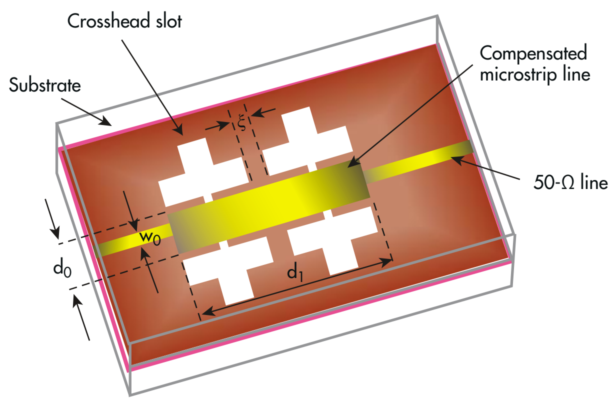
To extract equivalent-circuit-element values, the S-parameters of a DGS unit were calculating at the metallic ground plane using the Microwave Office EM simulator from AWR Corp. *(www.awrcorp.com)*. The relationship between these S-parameters and the ABCD matrix was used in designing the DGS filters. These simulations led to the following dimensions for the crosshead DGS section (Fig. 2): a = 2.8 mm; l_0 = 15 mm; l_1 = 2.7 mm; l_2 = 3.85 mm; b = 1.8 mm; and d = 0.9 mm. The corresponding equivalent-circuit values for inductors L_0, L_1, and L_2 and capacitors C_0, C_1, and C_2, after using an optimization technique, were found to be L_0 = 1.81 nH; L_1 = 1.44 nH; L_2 = 1.44 nH; C_0 = 0.88 pF; C_1 = 0.90 pF; and C_2 = 0.90 pF.



3. This is an equivalent circuit of a cross-DGS circuit element.



4. The frequency response of a cross-DGS resonator is plotted as a function of gap width.



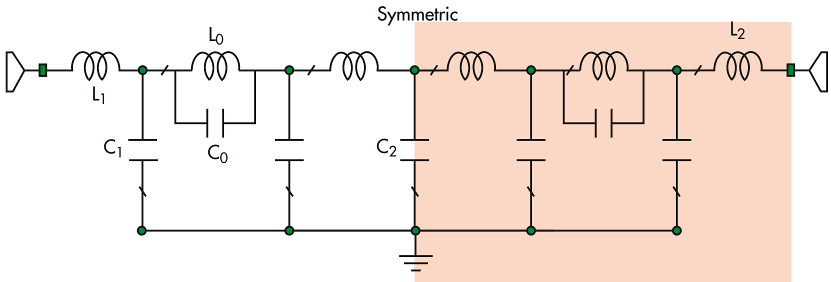
5. This 3D layout shows the second-order cross-DGS LPF.

Figure 4 provides a cross-sectional view of the proposed DGS section, located on the metal ground plane of a PCB. The crosshead slot exhibits an attenuation pole with a cutoff frequency without any periodic array of DGS circuit elements. Simulations of the cross slot with Microwave Office reveal one-pole LPF characteristics. Etching the slot in the metal ground plan increases the effective permittivity of the PCB structure, leading to an increase of the effective inductance of the microstrip line.

The dimensions of the crosshead slot determine the cutoff frequency. The etched gap, which connects both crossheads, has a significant effect on the resonance frequency, since it has inductive and capacitive characteristics. This explains the frequency characteristic of the proposed crosshead DGS. Figure 4 shows that by varying the gap width (d) of the DGS-


ARE YOU 5G-READY?
LET US BE YOUR ONE-STOP SHOP
FOR MMWAVE COMPONENTS & SUBASSEMBLIES.
60 to 90 GHz, Full E-Band Frequency Extender for Test Set Ups and Instrumentation
50 to 75 GHz, Full V-Band Low Noise Amplifier for Short Haul and Test Set Ups
50 to 75 GHz, Full V-Band Magic Tee for Test Set Ups and Instrumentation
40 to 50 GHz, Q-Band 2-Way Power Divider for Test Set Ups and Instrumentation
81 to 86 GHz, Power Amplifier for Backhaul
50 to 75 GHz, Directional Coupler for Test Set Ups and Instrumentation
26.5 to 40 GHz Full Ka-Band Orthomode Transducer for Radar and Instrumentation
60 to 90 GHz, Amplitude Detector for Communication Systems and Test Set Ups
81 to 86 GHz Waveguide Bandpass Filter for Backhaul
22 to 40 GHz, Broadband X2 Passive Multiplier for Point-to-Point and Point-to-Multipoint Radio
40 to 60 GHz, Full U-Band Faraday Isolator for Test Set Ups and Instrumentation
26.5 to 40 GHz WG to Coax Panel Mount Adapter for Test Set Ups and Instrumentation
SAGE
Millimeter, Inc.
WWW.SAGEMILLIMETER.COM
MADE IN USA
www.sagemillimeter.com | 3043 Kashiwa Street, Torrance, CA 90505
T: 424-757-0168 | F: 424-757-0188 | sales@sagemillimeter.com

resonator and keeping all other parameters constant, the resonance frequency shifts lower or higher in frequency depending of the variation. Increasing the canal width leads to a decrease in capacitance and an increase in resonance frequency, which is a shift towards the high frequency range (Fig. 4); a decrease in the canal width generates the opposite result.

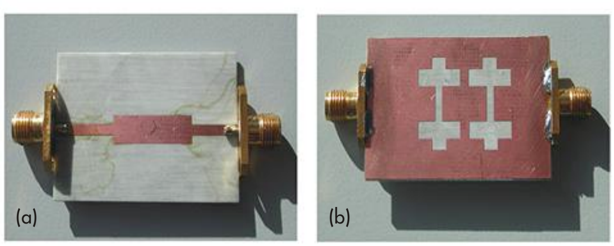


6. The equivalent circuit represents the second-order cross-DGS LPF.

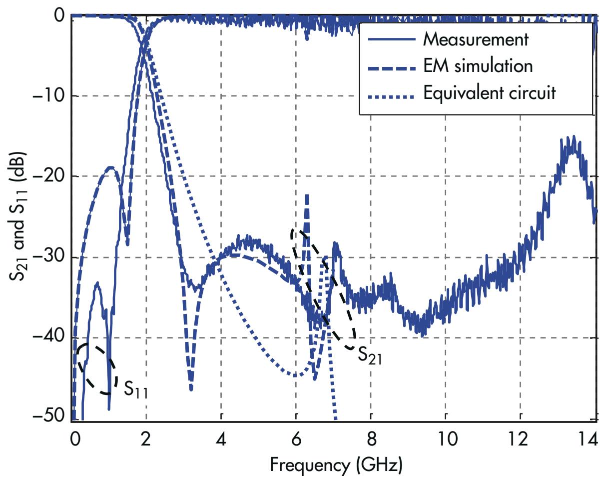
Variation of the canal width also affects the width of the stopband of the DGS resonator. There is no change in the cutoff frequency despite the variation of the gap width.[4] This means that the gap distance doesn't affect the effective series inductance of microstrip. Variation of the effective capacitance only affects the attenuation pole position. As the etched gap distance increases, the effective capacitance decreases so that the attenuation pole position moves up to a higher frequency.

Figure 5 shows a schematic view of the cross-DGS LPF, composed of two uniform crosshead slots in the metallic ground plane of a microstrip circuit board and a compensating microstrip line on the top layer. *Figure 6* provides the equivalent circuit. The three-pole LPF has dimensions of 30 × 20 mm^2. The filter was fabricated on a circuit-board material with relative dielectric constant of 3.38 and thickness of 0.813 mm. The filter dimensions are as follow: w_0 = 0.92 mm; d_1 = 16 mm; d_0 = 4.5 mm; and ξ = 2 mm. The remained dimensions are as noted earlier. The extracted capacitance and inductance values of the two DGS elements are: C_0 =0.081 pF; L_0 = 1.2521 nH; C_1 = 0.036 pF; L_1 = 1.307 nH; and C_2 = 0.166 pF. The microstrip line on the top layer corresponds to a parallel capacitance.

Photographs of the fabricated filter are shown in *Fig. 7*, while measurement results from a model HP8719D network analyzer from Hewlett-Packard Co. (now Keysight Technologies) are shown in *Fig. 8*. The measurements agree closely with EM simulations of performance. A transmission zero with about −33 dB rejection at 3.3 GHz is evident in the stopband of the LPF. These results indicate that this compact design



7. The photograph shows (a) the bottom and (b) top of the fabricated second-order cross-DGS LPF.



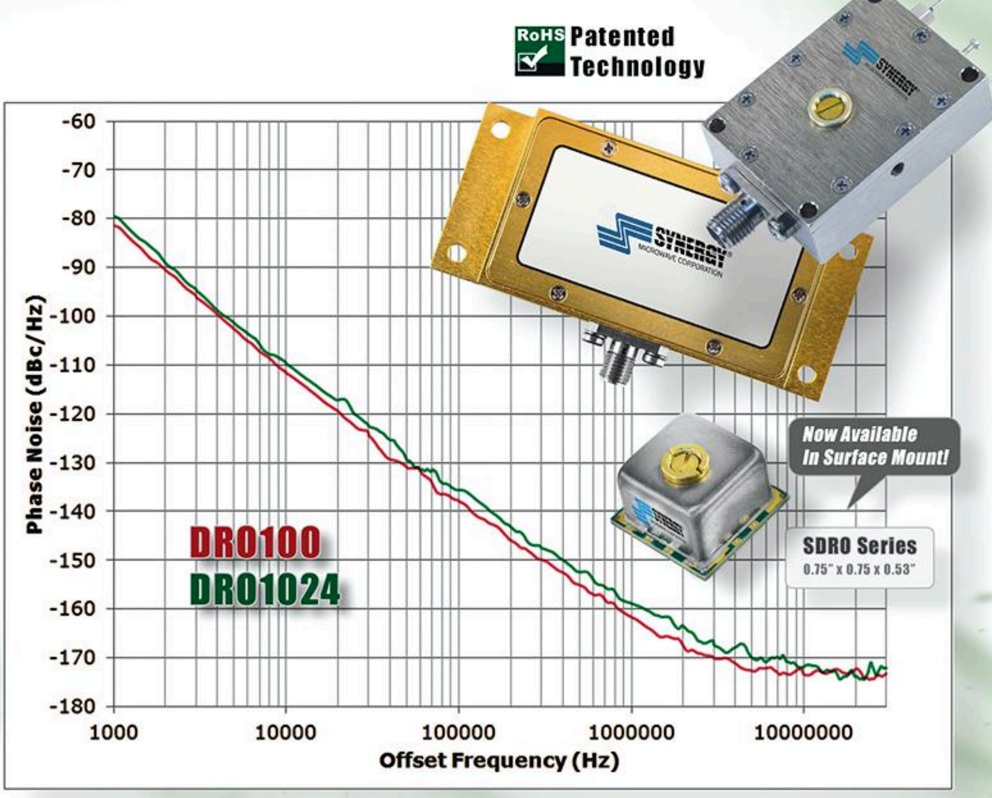
8. Simulated and measured S-parameters are plotted for the second-order cross-DGS LPF.

(30 × 20 mm^2) is advantageous compared to conventional DGS filters.[5,6] From the results, it can be seen that the LPF has better than 0.4 dB insertion loss from DC to 1.7 GHz with better than −35 dB return loss over the entire passband. Rejection is 30 dB from 2.6 to 14.0 GHz with very sharp transition from passband to stopband, from −1 dB to −35 dB within 1 GHz. As Fig. 8 reveals, this cross DGS LPF provides better performance than previous DGS LPF designs.[5]

Figure 9 presents a diagram of the second cross-DGS LPF. It is composed of two uniform crosshead slots in the metal ground plane and a compensating microstrip line on the top layer of a PCB substrate. It was simulated as a three-pole LPF with crosshead DGSs on substrate with dimensions of 35 × 20 mm^2. The substrate has relative dielectric constant of 3.38 and thickness of 0.813 mm. The new filter dimensions are d_2 = 23 mm, with all other dimensions the same as for the first LPF design.

This second cross-DGS LPF features a simple design with low passband insertion loss of 0.85 dB and wide rejection bandwidth with 20-dB rejection from 3.2 to 11.5 GHz *(Fig. 10)*.

Exceptional
Phase Noise Performance
Dielectric Resonator Oscillator

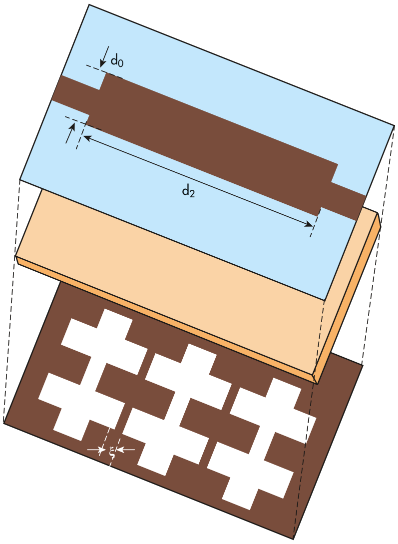


Model	Frequency (GHz)	Tuning Voltage (VDC)	DC Bias (VDC)	Typical Phase Noise @ 10 kHz (dBc/Hz)
Surface Mount Models				
SDRO1000-8	10	1 - 15	+8 @ 25 mA	**-107**
SDRO1024-8	10.24	1 - 15	+8 @ 25 mA	**-111**
SDRO1250-8	12.50	1 - 15	+8 @ 25 mA	**-105**
Connectorized Models				
DRO100	10	1 - 15	+7 - 10 @ 70 mA	**-111**
DRO1024	10.24	1 - 15	+7 - 10 @ 70 mA	**-109**

Talk To Us About Your Custom Requirements.

SYNERGY®
MICROWAVE CORPORATION

Phone: (973) 881-8800 | Fax: (973) 881-8361
E-mail: sales@synergymwave.com
Web: WWW.SYNERGYMWAVE.COM
Mail: 201 McLean Boulevard, Paterson, NJ 07504

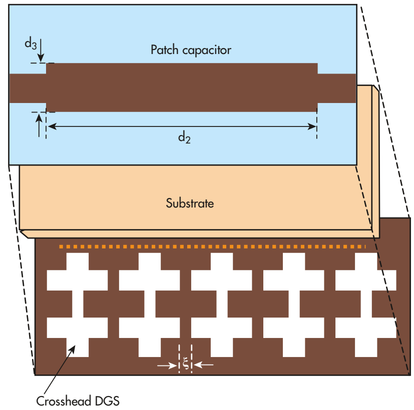


9. The topology of the third-order cross-DGS LPF is shown along with dimensions.

The compact lowpass structure occupies an area of $0.61\lambda_g \times 0.35\lambda_g$, where $\lambda_g = 57$ mm is the waveguide length at a cutoff frequency of 2.7 GHz. Such filter topologies are used in many communications systems because of their small size, low loss, and wide rejection bands.

Based on Chebyshev's theorem, an LPF using five cascaded DGS resonators etched on the ground plane was designed and simulated. Neighboring cross-DGS elements are directly electromagnetically coupled to each other and indirectly electrically coupled with the microstrip feedline. The patch capacitor plays an important role in minimizing passband loss.

The filter is designed to operate at S-band frequencies. Increasing the number of resonators leads to an improvement of passband width, as well as an increase of the sharpness factor. *Figure 11* provides a layout of the five cascaded resonators, while *Figure 12* shows that the S-band LPF measures 50 × 15 mm^2 with relatively sharp transition band and good passband performance. It features wide rejection to 15 GHz and good harmonic suppression in the stopband. It was fabricated on RO4003 circuit material from Rogers Corp. *(www.rogerscorp.com)* and optimized with Microwave Office simulation software from AWR Corp. *(www.awrcorp.com)*.



11. This is the architecture of the S-band LPF.

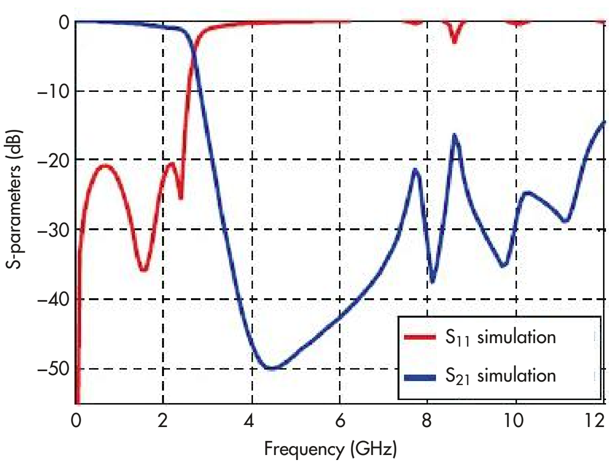
Based on the previous structure, the uniform distribution of five cross-DGS shapes was replaced by a nonuniform distribution *(Fig. 13)*. The length of the cross shape was varied in proportion to the distribution of the relative amplitudes of the logarithmic function $[\ln(10)]^{1/n}$. For this method of logarithmic distribution, the length is defined as:

$$[\ln(10)]^{1/n} \ [\ln(10)]^{1/(n-1)} \ldots [\ln(10)]^{1/2}[\ln(10)]^{1}[\ln(10)]^{1/2} \ [\ln(10)]^{1/(n-1)} \ [\ln(10)]^{1/n}$$

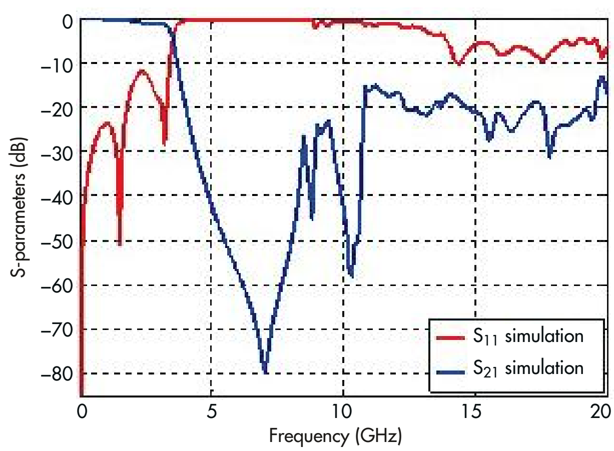
For a conventional LPF designed with five cross-DGS resonators, n is the number of resonators minus 2, or the number of resonators divided by 2 and minus ½. In the current novel approach, n is equal to 3, and the relative amplitudes are calculated as follows:

$$[\ln(10)]^{1/3} = 1.321;$$

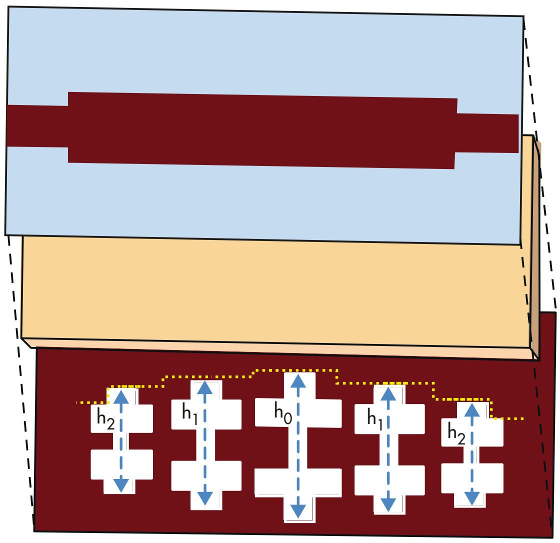
$$[\ln(10)]^{1/2} = 1.517;$$



10. These S-parameters were simulated for the third-order cross-DGS LPF.



12. These S-parameters were simulated for the fifth-order cross-DGS LPF.



13. This is a 3D view of the cross-DGS LPF developed with the logarithmic method.

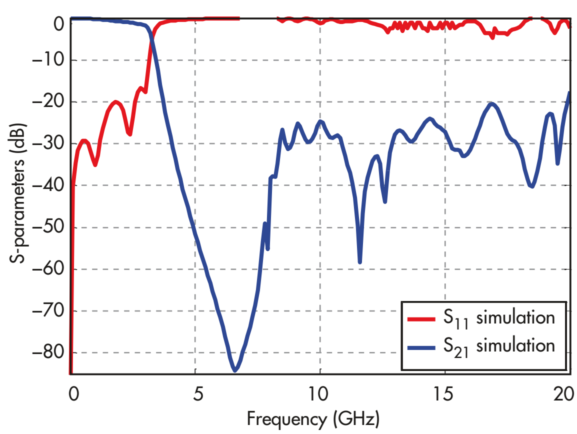
$$[\ln(10)]^1 = 2.302;$$

$$[\ln(10)]^{1/2} = 1.517; \text{ and}$$

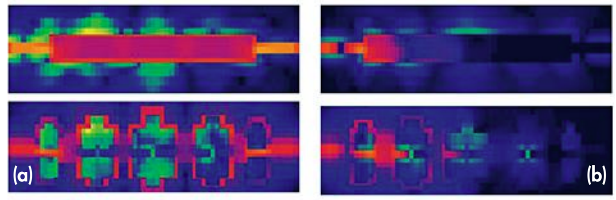
$$[\ln(10)]^{1/3} = 1.321.$$

By comparing the corresponding ratios, the optimum lengths were calculated as follows: $h_2 = 8$ mm; $h_1 = 1_0$ mm; and $h_0 = 14$ mm.

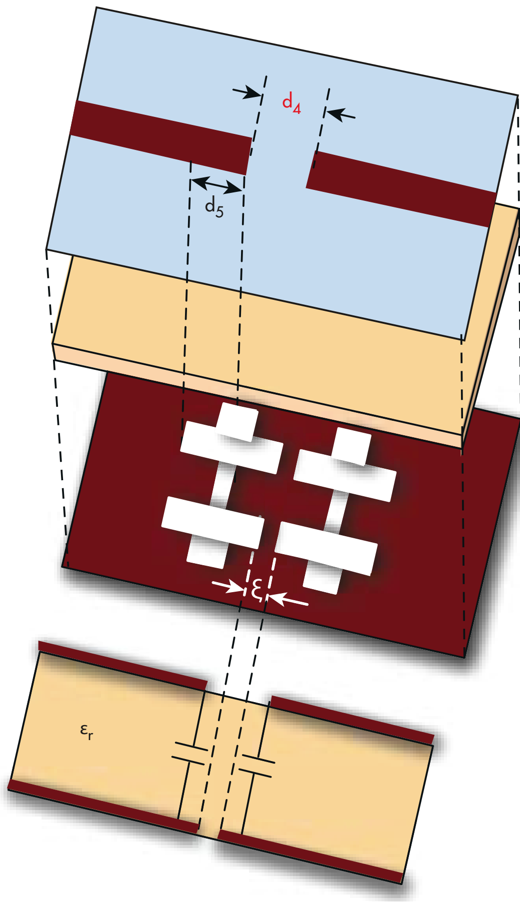
As *Fig. 14* depicts, based on a previous filter structure with cascaded identical DGS resonators, a logarithmic method was used to improve the S-band LPF characteristics without a significant change in the previous topology.



14. These S-parameters were simulated for the cross-DGS LPF developed with the logarithmic method.



15. An EM simulator was used to plot the EM field distributions at (a) 0.5 GHz and (b) 7 GHz.



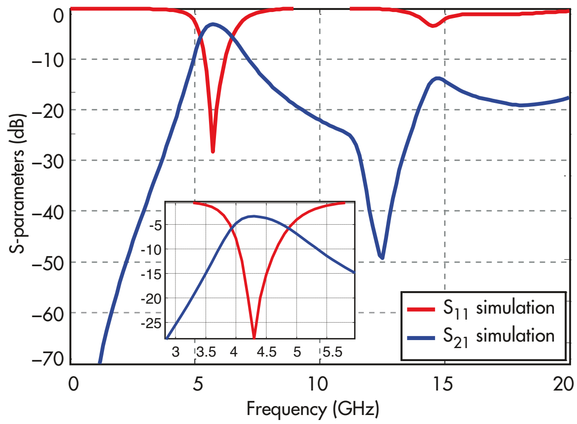
16. This is a 3D view of the cross-DGS bandpass filter extracted from the LPF using the J-inverter technique.

Compared to the previous fifth-order design, the proposed algorithmic structure has higher cutoff and resonance frequencies. As Fig. 14 shows, the proposed S-CDGS LPF topology offers low passband insertion loss and achieves a sharper cutoff and higher attenuation in the stopband compared to the previous fifth-order LPF designs. It provides a cutoff frequency and –20-dB stopband frequencies of 4 and 4.3 GHz, respectively.

The proposed filter achieves a broad –20-dB stopband from 4.3 to 20 GHz. The excellent sharpness factor and extended rejection band are due to the high characteristic impedance and slow-wave effect of a slot-back microstrip line. The cascaded DGS resonators of the lowpass structure were used to regenerate multiple transmission zeros (TZs) at 6.7, 11.5, and 13 GHz with attenuation levels of –32.81, –85, and –59 dB, respectively, and the wide stopband rejection, part of the spurious-free performance of the filter.

To understand the relationship between the scattering results and the energy flow along the proposed structure, it will be necessary to investigate the patterns of electric and magnetic energies along the cross-DGS structures. The field distribution of the S-band LPF continues until reaching the output (Fig. 13). At around 500 MHz, almost the entire magnetic energy is transferred from port 1 to port 2. The transmitted energy travels along the cross-DGS resonators and the 50-Ω microstrip lines, which serve as bridges to the output port.

The filter is in a passband state and the conductive metal area around the cross-DGS resonators exhibits inductive behavior *(Fig. 15a)*. At 7 GHz, the total energy lies between the input port and the first cross-DGS resonator, so that the full input power remains focused within the first microstrip resonator and the excited feedline at the input port. This indicates that the structure is in a stopband state, undergoing a resonant effect at that frequency *(Fig. 15b)*.



17. These S-parameters were simulated for the extracted cross-DGS bandpass filter.

DESIGN A COUPLING MATRIX

To realize a coupling matrix for an optimum filter structure, the desired specifications of the filter topology must be established. The required parameters can then be extracted using an optimization approach.[28] The coupling coefficient and quality factor (Q) curves[29, 30] will then be used to obtain the coupling coefficients. For the present case, the second-order filter has bandwidth (BW) of 1800 MHz, return loss (RL) of 20 dB, and center frequency (f_0) of 4.3 GHz. The coupling matrix obtained from the optimization scheme is that of Eq. 1:

$$m = \begin{bmatrix} 0 & 0.267 \\ 0.267 & 0 \end{bmatrix} \quad (1)$$

The external Qs are $q_1 = q_2 = 0.711$. To realize the normalized coupling matrix and Qs, a relationship of fractional bandwidth (FBW) to BW of FBW = BW/f_0 was used, so that the actual (denormalized) coupling matrix becomes as shown in Eq. 2:

$$M = \begin{bmatrix} 0 & 0.112 \\ 0.112 & 0 \end{bmatrix} \quad (2)$$

and $Q_1 = Q_2 = Q = 1.693$, where $M = FBW \times m$, and $Q = q/FBW$. The M-coupling coefficients and Q-quality factor will be inserted in the experimental curve[28-30] to discover the optimal distance between the DGS resonators (ξ) and the shifting distance (d_4) between the feed line and DGS resonator. The unknowns distances ξ and d_4 are equal to 4 and 1.5 mm, respectively (Fig. 15). The extracted bandpass filter is designed to operate at 5.1 GHz for use in WLAN applications.

The structure has the same ground structure and size as the earlier L-band LPF design. On the top layer, there are two 50-Ω feedlines which are connected to the input and output ports via coaxial SMA connectors. Both microstrip lines are connected to each other via a J-inverter *(Fig. 16)*, and thus electrically coupled via this gap (d_4). The cross-DGS resonators are directly electromagnetically coupled and indirectly electrically coupled via RO4003 circuit material.

Because they are not close to each other, feed coupling can be neglected. Consequently, the mixed coupling created from both neighboring DGS structures is the only coupling that has an effect on the BPF performance. The proposed filter was designed, optimized, and simulated on RO4003 substrate and has a center frequency of 5.2 GHz for WLAN use.

As *Fig. 17* shows, the BPF topology has low passband insertion loss with wide upper stopband characteristic. The spurious suppression is better than −20 dBc for a frequency range which is more than 20 GHz. The simulated S_{11} return loss and S_{21} transmission loss of the BPF were −14.052 dB and 3.2361 dB, respectively. The upper −15-dB rejection band extends from 6.5 to 15 GHz. The lower −20-dB rejection band extends from 1.5 to 3.5 GHz.

EM field distribution experiments

(Continued on page 131)

JACK BROWNE | Technical Contributor

AWG vs. DDS: Sources of Contention

These two types of signal sources both rely on digital architectures to generate pulsed output signals and analog sinewaves, often including complex modulation.

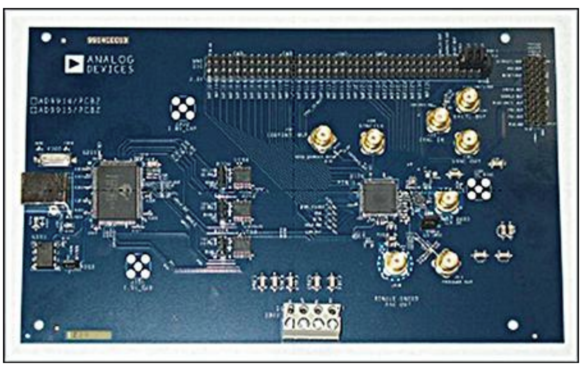
HIGH-FREQUENCY SIGNAL SOURCES based on digital techniques include arbitrary waveform generators (AWGs) and direct digital synthesizers (DDSs). Both types of signal sources have gained in frequency and bandwidth over the years, thanks to the enhanced performance of digital components such as digital-to-analog converters (DACs).

AWG- and DDS-based signal sources are both able to create complex output waveforms with high switching speeds, although DDS sources running at high clock frequencies are typically capable of higher-resolution frequency tuning than AWG sources. For that reason, DDS-based sources are often included in AWG designs to provide the benefits of both technologies within a single package.

A CLOSER LOOK AT AWGs

AWGs, also known as arbs, produce complex user-defined waveforms by converting waveform samples stored in memory to output waveforms in a continuous, point-by-point fashion, using a variable-frequency reference-clock oscillator. The output frequency of the AWG is determined by the reference clock's frequency, with a waveform sample converted to an output signal for every clock cycle. Each waveform is represented by a given number of samples, taken at different phase angles of a full 360-deg. cycle of the waveform.

Faster clock rates allow the AWG to read more quickly through the waveform samples stored in memory. As a result, for an AWG, faster clock rates generate higher output waveform frequencies. An AWG is a versatile signal source, since any kind of waveform can be stored in its internal memory for processing into output signals. The waveform shape, such as sine wave or square wave, remains constant regardless of the clock frequency.



1. The EVAL-AD9914 provides an introduction to a packaged IC DDS capable of creating output waveforms to 1750 MHz. *(Courtesy of Analog Devices)*

DIGGING INTO THE DDS

In contrast, a DDS, also known as an arbitrary function generator (AFG), reads waveform samples stored in memory using a phase accumulator at a fixed clock rate, giving users the ability to choose the samples for creating an output waveform. If a DDS reads every sample for a waveform with a fixed-frequency clock, the frequency of the output waveform would also be fixed. To change frequencies, it reads samples for the phase angles of a waveform, leaving gaps between phase samples. Thus, it uses fewer samples than an AWG to construct an output waveform.

The number of sampled phase points and size of the increments between phase angles determine the length and frequency of a desired waveform. By changing the phase increment, the frequency of a DDS will change instantly. Larger phase increments generate higher frequencies, allowing a DDS to quickly read through fewer waveform samples than an AWG to generate higher-frequency signals. This sampling/synthesis approach also allows a DDS to quickly change waveform configurations, and provide advanced output functions such as digital modulation and frequency hopping as needed.

While it lacks the high-frequency limits of a DDS, an AWG provides much greater control and precision for its generated waveforms. The precision is important for some waveforms, but not for others. For example, signals with continuous shapes, such as sinewaves, are relatively unaffected by large increments between phase angles. But signals with discontinuous shapes or anomalies or transient characteristics—e.g., fast pulse rise and fall times—can be difficult to create accurately with a DDS.

Samples representing transient events that are part of a waveform may not be triggered at a given clock rate and by a given number of samples. It results in an output waveform that is not truly representative of the original sampled waveform.

Since AWGs and DDSs are digital sources, the quality of the reference or sample clock has a great deal to do with the quality of the output waveforms. The number of frequency points available from the sample clock determines frequency precision. As a result, an AWG based on a standard 10-MHz clock oscillator and designed to generate maximum output frequency of 100 MHz will have twice the frequency resolution of an AWG designed for maximum output frequency of 200 MHz using the same clock oscillator. The clock oscillator's limited number of frequency points are spread across twice the bandwidth in the 200-MHz case, so the resolution is not as fine as for the 100-MHz case.

SELECTING EITHER SOURCE

Both types of signal sources are widely used in test and system applications, chosen for their different performance capabilities. In addition, higher-frequency DDS integrated circuits (ICs) and modular DDS circuits (with supporting components, such as memory and phase accumulators) are available for applications well through the microwave frequency range for programmable radio applications, such as software-defined radios (SDRs).

The AD9850 IC from Analog Devices (*www.analog.com*) contains a DAC and voltage comparator on the same chip as the DDS circuitry, using low-power silicon CMOS semiconductor circuitry. It operates at a clock rate of 125 MHz with 32-b tuning word to achieve spurious-free dynamic range of better than 50 dB. In contrast to instrument-grade DDS sources, the AD9850 operates with low power consumption for use in portable devices, including power consumption of 380 mW at 125 MHz and 5 V dc, and only 155 mW at 110 MHz and 3.3 V dc. It comes in a 28-lead SSOP package.

The firm also carries a number of microwave-frequency DDS ICs, including the AD9914 with an integrated 12-b DAC and 3.5-Gsample/s sampling rate. The high-resolution DAC makes possible an output frequency range of dc to 1750 MHz with tuning resolution of 190 pHz and fast frequency hopping. The source exhibits wideband spurious-free dynamic range (SFDR) of better than –50 dBc and phase noise of –128 dBc/Hz offset 1 kHz from the carrier, with characteristics that suit it for aerospace and defense applications.

The AD9914, equipped with phase-modulation capability, is supplied in an 88-lead LFCSP housing for ease of installation into circuit and system designs. To assist design efforts, the company also offers an evaluation kit for the AD9914 (the EVAL-AD9914), which includes the test board, a datasheet, and instructions on how to set up and use the evaluation board with the AD9914 mounted to it (*Fig. 1*). For many experimenters, this is a painless first step toward microwave-frequency DDS technology.

2. The AWG4000 is a single instrument that includes elements of both an AWG and a DDS, operating at up to 2.5 Gsamples/s. *(Courtesy of Tektronix Inc.)*

For those more in need of test equipment, a number of test-equipment manufacturers produce one or both types of signal sources for laboratory or production testing. For example, the 33600A Series TrueForm AWGs from Keysight Technologies (*www.keysight.com*) create sinewaves to 120 MHz and pulses to 100 MHz at sampling rates to 1 Gsample/s. These versatile, lower-frequency sources are suitable sources of modulation, with 14-b amplitude resolution and as much as 64-Msample/channel arbitrary waveform memory. Outputs are clean whether gauged in the time domain or the frequency domain, with 1-ps jitter and –125-dBc/Hz phase noise, respectively.

For those with a bent toward modular instruments, National Instruments' (*www.ni.com*) 5411 is a 100-Msample/s, 16-b AWG in PXI format. It can create output sinewaves to 43 MHz and output square waves to 25 MHz. It also allows operators to select output impedance by means of software, either 50 Ω for RF testing or 75 Ω for CATV environments. Users can also set output attenuation from 0 to 51 dB.

For those who can't decide between an AWG or DDS, the AWG4000 from Tektronix (*www.tektronix.com*) functions as both an AWG and a DDS (*Fig. 2*). In basic DDS mode, the instrument operates at 2.5 Gsamples/s with 14-b resolution and 16 kpoints of arbitrary waveform memory. It can has two channels, each capable of output sinewaves to 600 MHz.

In AWG mode, the AWG4000 has two analog channels and two 16/32-b digital channels with bandwidths to 750 MHz and single-ended or differential outputs. It achieves SFDR of –60 dBc and can operate as a continuous signal source, triggered source, sequenced source, and gated source. Its sampling clock can be varied from 100 samples/s to 2.5 Gsamples/s with 14-b vertical resolution. As an AWG, it offers sinewaves to 600 MHz, square waves and pulses to 330 MHz, and arbitrary waveforms to 400 MHz. mw

defense electronics

Learning Lessons in Power and Portability p|90

Mercury Systems Supplies Jammer DRFMs to Navy p|92

DRFMs Serve as Waveform Recorders p|96

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

JACK BROWNE | Technical Contributor

EASR System Passes Preliminary Design Review

A modular design approach is being used to fit variations of the AN/SPY-6 radar system to different naval ship classes, such as the DDG 51 Flight III destroyers. *(Courtesy of Raytheon Co.)*

EARLY REPORTS on the new Enterprise Air Surveillance Radar (EASR) are favorable, according to a recent preliminary design review (PDR) of the system conducted by the U.S. Navy and developer Raytheon Co. *(www.raytheon.com)*.

The EASR has passed several milestones that confirm that its developmental schedule is on track for on-time delivery to designated ship classes. The EASR is an advanced radar system for aircraft carriers and amphibious warfare ships, providing simultaneous anti-air warfare, anti-surface warfare, and air traffic control mission capabilities. The EASR is designed to replace the Volume Search Radar for the CVN 78 class ships, and the AN/SPS-48 and AN/SPS-49 radar systems for a number of other ship classes.

The EASR system will provide enhanced detection capabilities compared to the current radar systems. According to U.S. Navy Captain Seiko Okano, major program manager for Above Water Sensors, Program Executive Office Integrated Warfare Systems, "Each EASR development milestone brings us closer to providing this needed mission capability to our sailors and Marines deployed on aircraft carriers and amphibious ships." As Captain Okano noted, there were no surprises in the PDR: "As the PDR confirmed, the technical and design maturity of this advanced radar is right where it should be."

By adopting a modular design approach *(see accompanying story)*, Raytheon has been able to leverage the AN/SPY-6(V) Air and Missile Defense Radar system to rotating antenna and fixed-face versions for the different missions of the multiple ship classes. The EASR is based on Radar Modular Assembly (RMA) technology and has already been demonstrated on the success in adopting the basic AN/SPY-6 system architecture for the DDG 51 Flight III destroyers. The RMA approach basically creates a full-sized radar antenna array by combining RMA modules measuring 2 × 2 × 2 ft. RMA modules of different sizes and configurations can be combined with modular software to modify radar systems as needed for the different ship classes. de

Building Scalable Radars with Radar Modular Assemblies

THE NOVEL Radar Modular Assembly (RMA) is a building block for a number of different advanced radar systems. While it may appear as nothing more than a 2-ft.^{3} box, each RMA is actually a self-contained radar that contributes its performance to a full system to provide increased sensitivity and detection range.

The AN/SPY-6 radar antennas have been built in different configurations by combining RMAs for different performance levels. *(Courtesy of Raytheon Co.)*

The RMA approach has been used for both the Air and Missile Defense Radar (AMDR) and the Enterprise Air Surveillance Radar (EASR). The AMDR is constructed from 37 RMAs, to achieve a

(Continued on page 92)

Learning Lessons in Power and Portability

POWER AND portability often go together for an electronic device, especially when it comes equipped with a fully charged battery. But when the power runs out, it doesn't matter how small or otherwise portable an electronic device might be. Batteries and power cells can be made to last longer, with increased capacities for greater portability *(see page 109)*. But this usually means larger batteries with an increase in size and weight.

As in civilian life, the battlefield has been experiencing a growing reliance on electronic devices. Many of the portable electronic devices are tools meant to support a soldier, such as a two-way radio or a backpack computer. However, in a growing number of cases, portable electronic technology is needed for "things," such as the portable radars or surveillance systems that are installed in unmanned ground vehicles (UGVs). In the commercial world, device and circuit designers faced with the growing number of Internet of Things (IoT) applications are learning how to develop more efficient electronic solutions that can operate with less current draw and at lower voltages.

In many portable tactical applications involving transmission and reception of RF/microwave signals, the power amplifier is one of the main culprits when it comes to power consumption. Amplifier designers have seen something of a parade of different semiconductor devices over the last few decades. Some applications must balance signal linearity with efficiency, so that saving power becomes a challenge. A number of different amplifier architectures enable high efficiency, but amplifier efficiency also starts at the device stage.

The growing amount of digital content in battlefield electronics also requires taking an approach of designing for efficiency. The use of nanostructures and small-dimensioned digital circuits can help achieve some of the data conversion and signal processing functions needed from digital circuits. Ultimately, designing for efficiency will help set the threshold for the amount of power needed for a device, and for how long it can be truly portable. de

Jack Browne, Technical Contributor

Mercury Systems Supplies Jammer DRFMs to Navy

MERCURY SYSTEMS *(www.mrcy.com)* has received a follow-on, five-year sole-source basic ordering agreement (BOA) from the U.S. Navy for digital RF memory (DRFM) subsystems. The DRFM subsystems provide the means of recording and reproducing waveforms that are received from threat sources and then used as jammer signals in a multiple-threat environment. The BOA has a value of as much as $153 million and was received by Mercury in the company's fiscal third quarter for 2017. It provides for research and development, production, engineering services, and ongoing support for the DRFMs. Work will be performed at Mercury's Cypress, Calif. facility with a period of performance from March 2017 through February 2022.

"This award showcases Mercury's ability to deliver open standards-based, leading-edge DRFM subsystems that bring real value to our customer and ultimately, the warfighter," said Brian Perry, president of Mercury Defense Systems. "Our DRFM solutions have been used for over three decades for training and radar environment simulation, vulnerability assessment and self-protection. We take our role in safeguarding our airborne warfighters seriously, especially in today's environment where advanced threats can come from a wide variety of sources." ■

Expertise in DRFM technology has earned Mercury Defense Systems a follow-on BOA from the U.S. Navy for DRFM subsystems.

Mercury Acquires Delta Microwave

MERCURY SYSTEMS recently added to its capabilities in RF/microwave engineering with the acquisition of Delta Microwave *(www.deltamicrowave.com)*, a stalwart designer and manufacturer of high-frequency active and passive components. Delta is well known for active components, such as power amplifiers, and passive components, like power dividers and filters.

The addition of Delta Microwave strengthens Mercury's engineering capabilities at RF, microwave, and millimeter-wave frequencies and deepens its market penetration into key markets—including guided munitions, electronic warfare (EW), and radar. The acquisition also opens new opportunities in areas such as space and satellite communications (satcom) systems.

Based in Oxnard, Calif., Delta Microwave is a long-time developer of components and multi-function integrated subassemblies for military and space applications. The company has enjoyed success in these markets for its capabilities to combine complementary functions, such as filters and amplifiers, into compact housings that are also built for high reliability. It has been a leader in providing competitive size, weight, and power (SWAP) combinations that result in enhanced and more efficient performance at the system level. ■

Building Scalable Radars

(Continued from page 89)

15-dB increase in sensitivity of a current AN/SPY-1D(V) radar system. The large increase in sensitivity means that an AMDR can detect smaller targets at a much greater range than an AN/SPY-1D(V) system.

The EASR is built with nine RMAs. This number of radar system modules gives it the equivalent sensitivity of the AN/SPY-1D(V) radar system found on many destroyers, at a fraction of the size of a legacy SPS-48 system. For EASR-designated ship classes, the use of the RMA approach provides significant performance improvements. The modular approach has enabled the development of two variants of the EASR. One uses a single rotating face formed of the nine RMAs, and the other uses three fixed faces, each made with nine RMAs. The first type is suitable for replacing air search radars and the second for ship self-defense, air-traffic control (ATC), and situational awareness functions.

The RMAs are based on gallium nitride (GaN) power semiconductors and promise much higher reliability and longer lifetimes than previously used gallium arsenide (GaAs) semiconductor devices in the radar systems. The GaN devices are capable of higher power densities and higher output power at higher operating temperatures, and have become the active device technology of choice for microwave amplification. The RMAs also feature digital receiver exciter (DREX) technology to achieve RF/microwave signal processing (including frequency synthesis) in a compact modular format. ■

DARPA Seeks Protection from Cyber Attacks

The Rockwell Collins cyber protection team uses mathematical analysis to thwart cyber attacks on military platforms, including UAVs.

AS PART of a contract that runs through 2018, the Defense Advanced Research Projects Agency (DARPA) has selected Rockwell Collins *(www.rockwellcollins.com)* to protect new land, sea, and air platforms from cyberattacks. Mathematics-based methods developed by Rockwell Collins and its partners in DARPA's High Assurance Cyber Military Systems (HACMS) program will be employed to eliminate vulnerabilities in these platforms in the war against cyber criminals.

"In today's highly connected world, land, air, and sea platforms can fall victim to cyber attack," explained John Borghese, vice president of Rockwell Collins' Advanced Technology Center, "HACMS provides peace of mind and high assurance that these systems are resistant to a cyberattack." The HACMS methods involve architectural modeling and analysis, a secure microkernel, and automatic generation of application code. Each uses mathematical reasoning to ensure the absence of vulnerabilities that can be exploited in a cyberattack, improving the safety and security of critical electronic systems in military and commercial platforms.

The Rockwell Collins HACMS team, which includes Galois, Data 61, HRL, and the University of Minnesota, recently demonstrated the effectiveness of the approach during a demonstration in Sterling, Va. Among the platforms that received the cyber protection were an unmanned helicopter, a small unmanned aerial vehicle (UAV), and an enhanced soldier vision helmet. ■

Startup Recruits AI for Battlefield Protection

ARTIFICIAL INTELLIGENCE (AI) is the key to developing products to protect service members and civilians on the battlefield, and it is the technology driving Shield AI. The San Diego-based startup company raised $10.5 million in investment capital as part of Series A round funding led by Andreesen Horowitz. The funding will be used to speed the development of the company's AI products.

Peter Levine, general partner at Andreesen Horowitz, has been appointed to Shield's board of directors. Other major venture investors include Homebrew, Bloomberg Beta, and Founder Collective. One of the AI-based projects in development by Shield is an unmanned aerial aircraft (UAV). The drone is capable of finding people and detecting threats inside buildings without a remote pilot.

Shield's co-founder, Brandon Tseng, gained knowledge about battlefield needs during combat experiences in Afghanistan, founding the company in July 2015 with his brother, CEO Ryan Tseng, and CTO Andrew Reiter. "When Brandon shared his stories of loss, and inspiring vision of artificially intelligent machines that would save lives, Andrew and I left our jobs to join Brandon and start Shield," said Ryan Tseng.

The Shield drone is being developed as a virtual combat partner with its own decision-making capabilities. "When deployed," explained Brandon Tseng, "Shield AI drones will be the first example of service members using artificial intelligence on the battlefield to gather real-time information that saves lives, and will provide immediate protection to U.S. ground forces and innocent civilians caught in conflict." ■

This battlefield drone is being developed by startup company Shield AI to provide protection to ground forces.

JACK BROWNE | Technical Contributor

DRFMs Serve as Waveform Recorders

These highly integrated subsystems combine the best of analog and digital signal processing to accurately record signal waveforms in the field, such as from radars.

RADAR TECHNOLOGY is an effective means of locating distant targets. But radar systems can also be fooled. That is one of the purposes of a digital RF memory (DRFM): to digitize signals that a receiver has captured from an adversary's radar transmitter so that those signals can be modified and transmitted back the way they came to change the apparent characteristics of the target represented by those signals.

Changes in phase, amplitude, and delay can change the speed, size, and location of a target as an adversary's radar perceives it. By duplicating return signals, even the number of apparent targets can be increased. The DRFM is a very specialized component but, in the world of electronic countermeasures (ECM), there are few components more important.

A DRFM is a key component in an ECM system or in an electronic-warfare (EW) jammer for its ability to digitize received signals and make precise changes to those signals for retransmission. As an example, changes can be made to a received radar signal's Doppler characteristics, thus providing an adversary with a false reading on a troop's location. As with many components for the battlefield, a growing demand is for smaller, lighter DRFMs that can be used not only on aircraft and terrain vehicles, but for remote use in unmanned aerial vehicles (UAVs).

DRFMs are also useful for performing different types of signal jamming, sending back replicas of signals to degrade the performance of their radar receivers. A high-performance DRFM allows accurate, high-resolution control of an input signal, so that adjustments in phase, amplitude, and delay can be made on radar returns, altering such parameters as the location and radar cross section (RCS) as detected by an adversary.

To perform such tasks, a DRFM must be capable of digitizing a received signal with adequate accuracy and bit resolution and store a coherent copy of the received signal in digital memory. The bit resolution of a DRFM's digitizing components, such as an analog-to-digital converter (ADC), must be high enough to represent the different characteristics of a pulsed radar signal, including leading and trailing edges.

1. This rugged DRFM is actually a full subsystem with power supply and cooling fan. It is capable of digitizing signals present in a 1200-MHz instantaneous bandwidth at S- and X-band frequencies. *(Courtesy of Mercury Systems)*

The amount of digital memory must be sufficient to replicate the signal as needed for retransmission as a jammer or false radar return. By having additional control over pulse Doppler shift and delay time, a DRFM can alter the effective location being detected by an adversary's radar system. The same capabilities make it possible for a DRFM to serve as part of the development platform for a new radar system, such as a hardware-in-the-loop simulator.

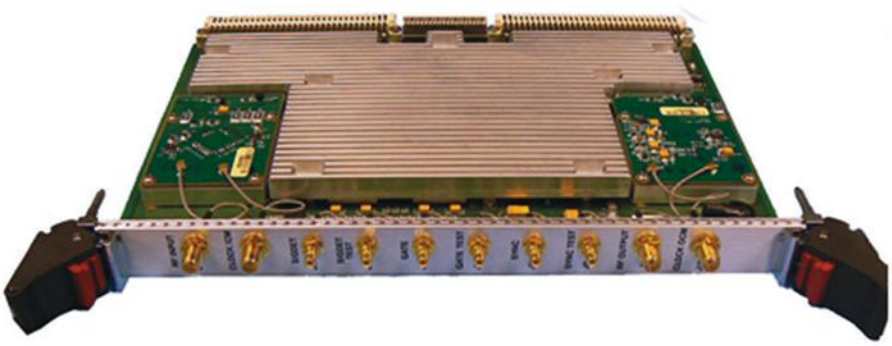
To generate the false radar returns that will be transmitted to jam or disrupt an adversary's radar system, a DRRF typically employs a digital-to-analog converter (DAC) as baseband signal source and then some means of upconverting those baseband signals to the frequency range of interest—notably, the frequency range of the input signals. An upconverting frequency mixer and local oscillator are often used for the frequency translation in order to maintain any artifacts that may have been received with the incoming signals.

Of course, a frequency mixer and other frequency translation components will typically add signal artifacts of their own, but efforts are made to minimize these artifacts in order to prevent detection by an adversary's radar system. Still, many DRFMs are moving to a more-or-less all-digital architecture, with frequency translation performed in terms of DSP methods and radar returns generated by a high-speed DAC.

Due to the complexity and number of electronic functions required, DRFMs have traditional been relatively large subsystems, typically contained within a large printed-circuit board (PCB) or an enclosed module. In some cases, they can be larger when they must handle environments with severe shock and vibration, such as in avionics applications.

One example is the ruggedized systems developed by Mercury Systems (*www.mrcy.com*). These robust DRFMs (*Fig. 1*) are actually full-featured subsystems with multiple circuit boards, dedicated power supplies, and functionality to support long operating lifetimes, such as forced-air cooling. Weighing in at less than 13 lb., these modules measure just 4.75 × 6.25 × 12 in., but that size buys a tremendous amount of capability.

These DRFMs are available to cover 1200-MHz instantaneous bandwidths at S- and X-band frequencies. They cover an input power range of −55 to +10 dBm with as much as 12 b quantization while operating with low noise floor, typically −60 dBc. These DRFM subsystems can process pulse widths from 20 ns to C with range resolution of better than 4.4 ns, and feature a Doppler range of ±300 kHz with better than 20 kHz Doppler resolution. For its functionality, this is actually a compact system, and one example of Mercury Systems' large lineup of DRFMs. The company offers DRFMs with quantization from 1 to 12 b and in a variety of package sizes, from single-board units small enough for operation in UAVs to full-sized, rack-mount systems for test laboratories.



2. This board-level DRFM operates at sampling rates to 2.2 GSamples/s. *(Courtesy of the Electronic Products Div. of Kratos/CTI)*

DECIDING ON A DRFM

This variety of mechanical designs is common among DRFM suppliers and is an indication of the wide range of applications for DRFMs in defense and even commercial electronic systems. Comparing and evaluating the performance levels of different DRFMs is a matter of understanding how the key specifications contribute to system-level performance. Three of the main DRFM performance parameters are instantaneous bandwidth, input power range, and quantization resolution. The mechanical size of a DRFM design will determine whether it is suitable for avionics applications or better left on the ground, such as in the test laboratory. The three main performance parameters will determine the types of radar returns that can be processed. Another important specification is the sampling rate, since this will determine the frequency range of signals that can be regenerated with a DRFM.

In addition, waveform memory is a critical DRFM performance parameter, since the amount of memory determines the length of waveform that can be digitized for analysis. Some DRFM suppliers may specify memory in terms of standard memory size, such as gigaBytes, while others may provide details about the memory in terms of the amount of waveform time that can be recorded.

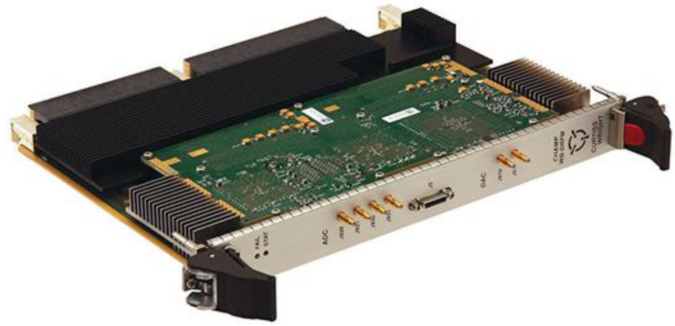
How do these different specifications translate into DRFM performance? The requirements for a particular application will depend on the type of waveform to be quantized, the amount of detail that must be known about the waveform, and the required accuracy and resolution of a modified waveform to be generated based on the captured waveform. DRFMs designed for simple waveform recognition tasks can be implemented with 1 or 2 b resolution, while greater detail requires higher bit resolution. The tradeoff is in power consumption. A portable application such as signal identification and recognition in a UAV may require only low bit resolution, but will also benefit from the low power requirements.

As an example of a higher-resolution unit, the Electronic Products Div. of Kratos/CTI (*www.kratosdefense.com*) offers a board-level DRFM with instantaneous bandwidth of 900 MHz (*Fig. 2*). It digitizes input signals across a better than 47-dB spurious-free dynamic range at sampling rates to 2.2 GHz. It also digitizes input signals with a 10-b analog-to-digital converter (ADC) and recreates analog radar returns with a 12-b digital-to-analog converter (DAC).

A high-performance DRFM allows accurate, high-resolution control of an input signal, so that adjustments in phase, amplitude, and delay can be made on radar returns, altering such parameters as the location and radar cross section (RCS) as detected by an adversary.

This DRFM allows multiple returns per Doppler channel to accurately simulate another Doppler radar's returns and provides better than 0.5-ns delay resolution for fine control of pulse returns. It can be equipped with as much as 200 ms of waveform memory, and is supplied in a VME module format for ease of integration into larger systems, such as ECM, EW, and signal-intelligence (SIGINT) systems.

A modular approach was also used in the design of the CHAMP-WB-DRFM DRFM from Curtiss-Wright (*www.curtisswright.com*). Based on the modular VPX format (*Fig. 3*), it features a 6-GHz bandwidth and sampling rates to 12 GSamples/s, employed for an 8-b ADC and a 10-b DAC, supported by 8 GB of DDR3L SDRAM waveform memory. The wide bandwidth, high sampling rate, and large waveform memory make this a powerful candidate for DRFM functionality in a variety of systems, including EW, electronic intelligence (ELINT), and SIGINT systems. Additional models are available with higher sampling rates as needed.



3. This DRFM is based on the modular VPX format and includes ADCs and DACs operating at 12 GSamples/s. *(Courtesy of Curtiss-Wright)*

CREATING CUSTOM SOLUTIONS

Due to the specialized nature of DRFM applications, a growing number of DRFM suppliers are developing flexible, adaptable architectures that allow a user to select the amount of functionality and performance needed from a DRFM. For example, the latest member of the Jade family of data converter XMC modules from Pentek (*www.pentek.com*) is based on the Kintex Ultrascale field-programmable gate array (FPGA) from Xilinx (*www.xilinx.com*) and is generously equipped with high-speed data converters for flexibility.

It includes two 500-MHz-bandwidth analog-to-digital converters (ADCs) with multiband digital downconverters (DDCs), one digital upconverter (DUC), and two 800-MHz-bandwidth 16-b digital-to-analog converters (DACs).

This programmable data converter system supports capture and generation of a 200-MHz bandwidth. While it has performance limits like any DRFM, it also provides a great deal of programming flexibility to allow a user to define their performance requirements for a particular application and the conserve power consumption in the process.

In addition, Mercury Systems has developed its CRFM series of test systems geared to the development of DRFMs. As an example, the CRFM 9041 test system samples at 2.2 Gb/s to capture, store, and replay RF/microwave signals for the development of communications, EW, and radar systems. It allows CW signals to be delayed by as much as 7.5 ms and pulsed signals to be delayed by as much as 15 ms to explore different propagation possibilities.

The CRFM 9041 test system provides an instantaneous bandwidth as wide as 1 GHz across a baseband frequency range of 55 to 1050 MHz (which can be defined as required by a customer), with worst-case spurious level of −45 dBc. The system is highly configurable as a receiver and/or exciter, to capture and generate, respectively, a wide range of signal waveforms for experimentation. The modular test system fits a five-slot, 6U space in a VME chassis. It is supplied with a single-board computer (SBC), power supply, and either a desk-top or rack-mount enclosure.

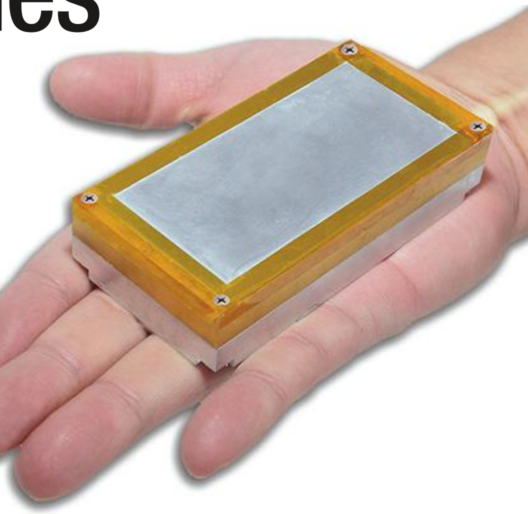
As with many electronic subsystems, the trend in DRFMs is to provide more capability in smaller packages. Because of the large amount of data conversion, memory, and digital processing required, power consumption is always a concern, along with thermal management as DRFMs are designed into smaller footprints.

With the growing number of more complex signal threats from portable sources, such as UAVs, the need for reliable DRFMs has never been greater. Still, the volumes represented by these applications and the custom natures of DRFMs may never be quite enough to motivate the development of a DRFM on a chip for truly low-power, portable applications.

JACK BROWNE | Technical Contributor

Cognitive EW Provides Computer-Powered Protection

Combining signal detection with sophisticated signal-analysis algorithms provides the means to quickly determine whether an unknown signal is friend or foe—and how to react to it.



The Disruptor SRx is a small-form-factor cognitive EW system capable of detecting and identifying signal threats across a number of different frequency bands. *(Courtesy of Harris Corp.)*

COMPUTERS AND ARTIFICIAL intelligence (AI) make many lives more comfortable, but they can also make lives safer through the defense-electronics technology known as cognitive electronic warfare (EW). In many cases, adversaries rely on the ability to recognize threat signals—for example, from an enemy radar—and respond as quickly as possible by some means of electronic countermeasures (ECM), such as sending a false return signal to the transmitting radar.

Cognitive EW systems literally "cut out the middleman" by eliminating the need for human intervention and decision-making. They allow a computer and machine intelligence to decide when a threat signal has been detected and requires a response.

Radar jammers have traditionally transmitted false return signals in response to received signals that matched waveforms in a database. But as radar systems have become more programmable, using techniques similar to software defined radios (SDRs), it has become more difficult to "fool" an adversary's radar system by sending waveforms meant to represent a particular amplitude, phase, and Doppler shift.

Sensitive modern receivers and software signal-analysis programs can scrutinize returns in a number of ways to determine which are true and which are false. The goal of cognitive EW systems is to provide the capability to respond instantly to waveforms not contained in a database, through thorough analysis of the received waveforms and application of signal analysis algorithms that are part of a computer-based decision-making process.

The development of cognitive EW was motivated by a 2013 Defense Science Board study that expressed concerns about the U.S. military and the capabilities of its EW systems to respond to adaptive radar systems and their digitally programmable waveforms. Around the same time, DARPA created the Adaptive Radar Countermeasures (ARC) program to encourage the development of effective means of countering the threats represented by digitally programmable radar systems.

Cognitive EW technology was actually implemented in 2014 in a line of subsystem products introduced by then Exelis (now part of Harris Corp.; *www.harris.com*) known as the Disruptor SRx line. The subsystems were designed to respond in real time to previously unrecorded and unknown signal waveforms, and were developed for such applications as manned aircraft and unmanned aerial vehicles (UAVs) as a way to counter digitally programmable radar systems.

The compact Disruptor SRx modules (*Fig. 1*) are self-contained signal detection and response units now available from Harris Corp. Each highly integrated Disruptor SRx module contains a digital receiver, digital radio-frequency memory (DRFM), and digital signal processor (DSP).

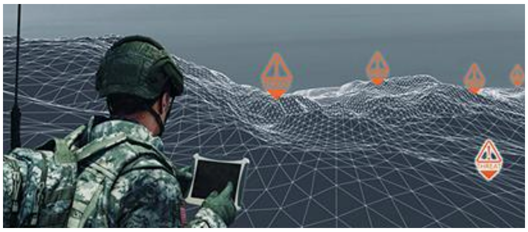
They are capable of identifying signals from a database of recorded waveforms and classifying unknown signals and generating jamming or response signals accordingly by using the machine learning capabilities of an integral microprocessor. The Disruptor SRx modules are designed for different frequency bands, depending on application, from RF through millimeter-wave frequencies.

A number of major defense contractors are involved in developing cognitive EW technology, including BAE Systems (*www.baesystems.com*), which is providing the cognitive EW system for the F-35 Joint Strike Fighter (JSF). The firm recently announced a handheld tactical sensor that employs cognitive processing algorithms to identify RF/microwave

signals in the field, even in the presence of interference (*Fig. 2*).

Developed under several DARPA contracts, the device and its technology can be integrated into various communications, EW, and signal-intelligence (SIGINT) systems for improved tactical situational awareness.

Additional defense contractors involved in developing cognitive EW technology include Boeing Co. (*www.boeing.com*), Lockheed Martin (*www.lockheedmartin.com*), and Raytheon Co. (*www.raytheon.com*) with their Silencer EW technology. For example, Lockheed Martin is performing upgrades on the EW suites on the U.S. Navy's MH-60 helicopters as part of the Navy's Surface Electronic Warfare Improvement Program (SEWIP). The upgrades include reinforcing the EW systems against the threat of anti-ship missiles.



2. This handheld tactical sensor employs cognitive processing to identify RF/microwave signals even in the presence of interference. *(Courtesy of BAE Systems)*

Lockheed Martin's Advanced Technology Laboratories (ATL) has worked closely with DARPA to develop and demonstrate the capabilities of a cognitive EW system that can dynamically counter adaptive threats to communications. One demonstration involved the use of DARPA's Behavioral Learning for Adaptive Electronic Warfare (BLADE) program for almost instantaneously detecting, characterizing, and countering jamming signals meant to block or interfere with wireless communications systems.

Cognitive EW is in its early stages of development and will require the coordinated development of powerful, low-power microprocessors and software tools capable of guiding those computer engines in signal analysis and recognition and in "thinking" according to well-developed signal-processing algorithms. With the growing number of electronic devices (and signal sources) on the battlefield, the use of cognitive EW represents a tactical edge when properly implemented. Steady improvements in semiconductor and AI software technologies will help that edge grow over time. de

JACK BROWNE | Technical Contributor

Surveying SDLVAs for ELINT and EW

SDLVAs provide the means to amplify and analyze short pulses over wide bandwidths at the front ends of RWRs, as well as ELINT and ECM receivers.

SIGNALS CAN BE exclusively short-lived and signal analysis difficult in tactical applications. Many electronic defense systems rely on a component that is a combination of a detector and an amplifier, such as a detector log video amplifier (DLVA) or a successive detection log video amplifier (SDLVA), to sort low-level signals from such a crowed signal environment. A SDLVA essentially adds gain stages to a DLVA to increase its amplitude dynamic range.

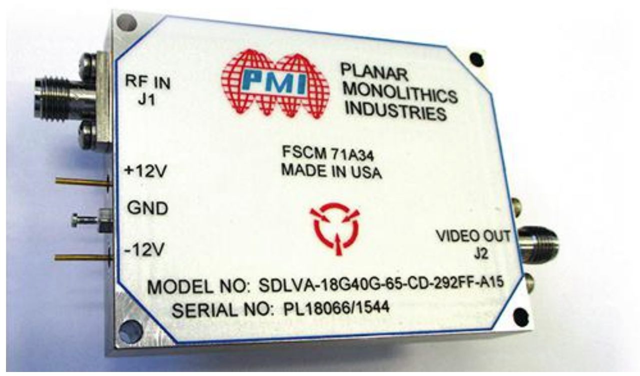
Cognitive EW systems literally "cut out the middleman" by eliminating the need for human intervention and decision-making. They allow a computer and machine intelligence to decide when a threat signal has been detected and requires a response.

SDLVAs are key components in a number of different receiver types where it is desirable to perform signal processing on received/captured signals without frequency translation, so that information can be known about those signals. This is a useful function for radar warning receivers (RWRs), EW receivers, and electronic-countermeasures (ECM) receivers.

When processing short pulses over a wide range of amplitude levels, SDLVAs and DLVAs must convert short-duration signals to proportional DC voltages that can be analyzed for information about the input signals. For that reason, it is important that a SDLVA or DLVA preserves the amplitude information of the original input signals, even when they may occupy a wide dynamic range and wide frequency range.

A DLVA can be as simple as a single-diode detector followed by one or more stages of amplification in order to detect and amplify low-level signals within a frequency range of interest. When a greater dynamic range is needed for low-level signals buried amidst higher-level signals in the same frequency range, a SDLVA is a more complex, multiple-stage version of a DLVA—with much greater dynamic range, as might be needed in particular applications, such as in a direct-finding (DF) receiver trying to pinpoint the location of a distant radar emitter.

When dynamic range is not critical, a DLVA with a 30- or 40-dB dynamic range may provide sufficient performance to help capture and process all signals present. However, modern signal environments, with their ever-increasing blend of pulsed and modulated signals, typically require more processing gain than a DLVA, in addition to the wide dynamic range provided by the multiple detection/logging stages of a SDLVA to effectively capture and decipher low-level signals amidst the surrounding signal clutter.



1. This coaxial-packaged SDLVA (model SDLVA-18G40G-65-CD-292FF-A15) has a frequency range of 18 to 40 GHz and a dynamic range of -63 to +2 dBm. *(Courtesy of Planar Monolithics Industries.)*

A SDLVA may employ six or seven detection stages to provide typically 10-dB detection capability per stage to capture and process signals from the surrounding signals and noise. In contrast to a DLVA, which involves signal detection and then amplification, a SDLVA employs multiple stages of RF gain and compression to provide an exponential transfer function from input to output ports. By combining enough gain stages, a SDLVA can handle a large, 60- or 70-dB dynamic range, with the contributions of each gain stage summed in a video amplifier for processing.

A third option exists between the simplicity (but limited dynamic range) of the DLVA and the greater dynamic range (but complexity) of the SDLVA: the hybrid or sequential DLVA, with multiple detector stages to increase dynamic range. Each detector is typically sensitive to different portions of the dynamic range, making it possible for a hybrid DLVA to respond to a wider dynamic range for a given frequency range than a standard DLVA.

How do the performance parameters of a typical SDLVA relate to its effectiveness in a typical system application, such as in a RWR or DF receiver? Assuming, first of all, that a SDLVA can cover a frequency range of interest, it should also provide the signal sensitivity and dynamic range to handle the different levels of signals expected to be received within that frequency range.

SDLVAs are typically specified in terms of sensitivity by a

ULTRA•REL™

CERAMIC MMIC AMPLIFIERS

10 MHz to 7 GHz

Low NF from 0.5 dB *High IP3 up to +42 dBm* *Low DC current 65 mA* from $7.45 ea. (qty 20)

When failure is not an option! Our CMA family of ceramic MMIC amplifiers is expanding to meet your needs for more critical applications. Designed into a nitrogen-filled, hermetic LTCC package just 0.045" high, these rugged models have been qualified and are capable of meeting MIL standards for a whole battery of harsh environmental conditions:

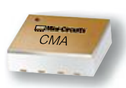
Qualified for: *(see website for complete list and details)*

Gross and Fine Leak	*HTOL (1700 hours @ +105°C)*
Mechanical Shock	*Steam Aging*
Vibration	*Solder Heat Resistance*
Acceleration	*Autoclave*
PIND	*And More!*

**Gross leak only*

Robust performance across wide bandwidths makes them ideal for military and defense applications, hi-rel instrumentation, and anywhere long-term reliability adds bottom-line value. Go to minicircuits.com for all the details today, and have them in your hands as soon as tomorrow!

Electrical Specifications *(-55 to +105°C)*



3 x 3 x 1.14 mm

Model	Freq. (GHz)	Gain (dB)	P_{OUT} (dBm)	IP3 (dBm)	NF (dB)	DC (V)	Price $ ea. (qty 20)
CMA-81+	DC-6	10	19.5	38	7.5	5	8.95
CMA-82+	DC-7	15	20	42	6.8	5	8.95
CMA-84+	DC-7	24	21	38	5.5	5	8.95
CMA-62+	0.01-6	15	19	33	5	5	7.45
CMA-63+	0.01-6	20	18	32	4	5	7.45
CMA-545+	0.05-6	15	20	37	1	3	7.45
CMA-5043+	0.05-4	18	20	33	0.8	5	7.45
CMA-545G1+	0.4-2.2	32	23	36	0.9	5	7.95
CMA-162LN+	0.7-1.6	23	19	30	0.5	4	7.45
CMA-252LN+	1.5-2.5	17	18	30	1	4	7.45

RoHS compliant

Mini-Circuits®

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

parameter known as tangential signal sensitivity (TSS), which is essentially the lowest-level signal within a frequency range that a SDLVA can repeatedly and accurately detect without additional front-end preamplification.

Speed is an important characteristic of a SDLVA since the amplifier must be capable of responding quickly to a constantly changing signal environment—typically processing short-duration pulses. A SDLVA is characterized by the duration of signals that it can process, from nanosecond pulses to continuous-wave (CW) signals.

The amplifier stages of some SDLVAs can be saturated by CW signals at sufficiently high levels, and many SDLVAs are characterized for their CW immunity and for how long and at how high levels of CW signals they can function without reaching a state of saturation and essentially becoming useless while saturated for detecting low-level pulsed signals.

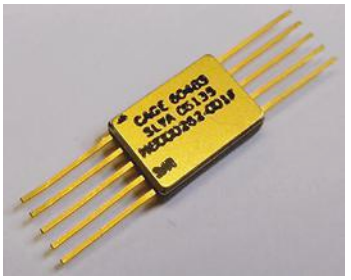
In addition, even for short pulses, a SDLVA requires time to process a continuous flow of pulsed input signals. It must be capable of delivering output voltages in proportion to very fast pulsed signals. A SDLVA's rise time establishes that it is capable of detecting and amplifying pulsed signals at least as short as that rise time. The SDLVA's recovery time identifies how long the amplifier requires to change from a condition of full output power to a state where it is capable of detecting a low-level signal at the threshold of its dynamic range.

Modern DLVAs and SDLVAs come in many shapes and sizes, from packaged components to integrated-circuit (IC) die, affording system designers the flexibility to add functionality to a system as needed. For example, one of the industry's long-running SDLVA suppliers, Planar Monolithics Industries (www.pmi-rf.com), offers a variety of packaged components in different form factors and performance levels, to allow system designers to add detection capability as required.

As an example, the SDLVA-18G40G-65-CD-292FF-A15 is a coaxial SDLVA with microwave/millimeter-wave frequency range of 18 to 40 GHz (*Fig. 1*). Based on GaAs IC technology, it sports a 2.92-mm female "K" connector at the input port and an SMA female connector at the output port. With a logging range of -63 to +2 dBm and nominal TSS of -67 dBm, this SDLVA is designed to detect extremely low-level pulses at high frequencies, maintaining log linearity within ±3 dB over its operating temperature range. It is also built for speed, with typical rise time of 8 ns and typical recovery time of 40 ns.

When lower-frequency coverage is needed, the firm's SDLVA-50M18G-70 is an SDLVA with broad frequency range of 50 MHz to 18 GHz and outstanding TSS of -70 dBm (dynamic range of -70 to 0 dBm). In spite of including a voltage-variable detector circuit that maintains video output voltage within 5%, this broadband SDLVA measures just 2.3 × 2.2 × 0.4 in. with SMA female connectors.

When an even smaller SDLVA footprint is required, PMI also offers DLVAs and SDLVAs from DC through 40 GHz in surface-mount, multipin (*Fig. 2*), and even custom packaging. Amplifiers such as the SLVAC-06135M-MA08 cover typical dynamic range of 65 dB with typical logging accuracy of ±1.5 dB across the frequency range and dynamic range. The standard package measures only 0.75 × 0.75 in.



2. This SDLVA (model SLVAC-06135M-MA08) is supplied in a multipin package measuring only 0.75 × 0.75 in. but usable to 40 GHz. *(Courtesy of Planar Monolithics Industries.)*

Monolithic semiconductor technology has also contributed to smaller SDLVAs. One of the most broadband SDLVAs in the industry is also one of the smallest, the HMC613LC4B from Analog Devices (*www.analog.com*). Based on GaAs integrated-circuit (IC) technology acquired with Hittite Microwave Corp., the SDLVA is supplied in a 24-lead, 4 × 4 mm surface-mount-technology (SMT) package (*Fig. 3*), for ease of mounting in most circuits.

In spite of the small size, it performs well, with a 59-dB logging range, from -54 to +5 dBm, from 100 MHz to 20 GHz. It also delivers log linearity of ±1 dB and output frequency flatness of ±1.5 dB across the wide frequency range, with rise time of 4 ns, fall time of 18 ns, and recovery time of 26 ns. It operates from a single +3.3-V dc supply. When even smaller size and more broadband coverage is needed, the same company's HMC813 SDLVA is supplied in chip form. With a 55-dB logging range from 1 to 26 GHz, it also operates on a single +3.3-V dc supply.

3. By leveraging semiconductor technology, this SDLVA (model HMC613LC4B) fits into a 24-lead, 4 × 4 mm SMT housing. It has a 59-dB logging range from 100 MHz to 20 GHz. *(Courtesy of Analog Devices.)*

Of course, these are just a few samples of SDLVAs currently available as standard products from a number of manufacturers. Additional suppliers of DLVAs and SDLVAs include L3 Narda-MITEQ (*www.nardamiteq.com*), Microphase Corp. (*www.microphase.com*), Paciwave, Inc. (*www.paciwave.com*), and Teledyne Defence & Space (*www.teledynemicrowave.com*).

Although DLVAs and SDLVAs are most often associated with defense electronics applications, such as RWRs, EW receivers, and DF receivers, they are widely used in commercial settings like test equipment that must detect and analyze signals over a wide dynamic range. They remain a trusted and reliable solution for achieving a wide dynamic range over a wide frequency range.

JACK BROWNE | Technical Contributor

Photodetectors Shed Light on Optical Sensing

These high-responsivity photodetectors cover wide wavelength ranges for a variety of commercial, industrial, and military applications, including for munitions guidance.

LIGHT IS A FORM tof electromagnetic (EM) energy that plays an important role in battlefield activities. It is being used, for example, for directed-energy weapons using high-power lasers, and is the basis for a number of different detection methods used both for tracking lasers and munitions guidance. In support of such applications is the YAG series of silicon PIN quadrant photodetector diodes from Excelitas (www.excelitas.com). They provide excellent sensitivity and responsivity over the infrared (IR) range of 400 to 1,100 nm, making them strong candidates for optical detection applications at 1,064 nm. The IR detectors employ a circular active area with four pie-shaped quadrants; to minimize noise, a guard ring collects current outside the circular active area.

The YAG series (*Fig. 1*) includes silicon P- and N-type devices with a breakdown voltage of 180 V dc, and is designed for use at voltages from 0 to 180 V dc. Individual models include the P-type model YAG-444-4AH and N-type model YAG-444N-4AH, both with an active diameter of 11.3 mm. The P-type model YAG-555-44H, in contrast, has an active diameter of 14.1 mm. All three models are supplied in hermetic TO-36 packages for ease of handing and mounting. They can also be provided with additional window anti-reflection coating and built-in heaters.

1. The YAG Series of photodetectors includes silicon P- and N-type devices for optical detection applications from 400 to 1100 nm.

All three photodiodes are characterized by low noise equivalent power and wide detection ranges, as well as excellent responsivity. All provide typical responsivity of 0.60 A/W at 900 nm and 0.44 A/W at 1064 nm, with noise equivalent power of 0.30 pW/(Hz)$^{0.5}$ measured in a 1-MHz bandwidth at 1064 nm for both P-type devices. For the YAG-444N-4AH, the typical noise equivalent power is 0.25 pW/(Hz)$^{0.5}$ measured in a 1-MHz bandwidth at 1,064 nm.

The three detectors feature wide fields of view, determined by an angle, α, where the surface of the device is totally illuminated, and angle α′ where the surface is only partly illuminated. For the YAG-444-4AH and YAG-444N-4AH detectors, α is nominally 110 deg. and α′ is nominally 160 deg. The larger active area of the YAG-555-4AH reduces α to around 85 deg.

For a 50-Ω load, the photodetectors exhibit 60-MHz bandwidth with 12-ns typical rise time. They operate with good linearity and without dead zones across the dynamic range, with an operating temperature range of –55 to +125°C.

In support of automotive LIDAR, laser range finding and designation, and high-speed optical communications, the company has also introduced its C30659 Series of Si or InGaAs avalanche photodiodes (APDs), supplied in hermetic TO-8 packages with low-noise GaAs preamplifiers (*Fig. 2*). These APD-based detectors offer effective detection of wavelengths from UV to 1,550 nm with fast rise and fall times at all wavelengths and system bandwidths of typically 50 to 200 MHz. They are designed to handle high optical power levels without damage.

2. The C30659 Series of Si or InGaAs avalanche photodiodes (APDs) includes low-noise GaAs preamplifiers housed in hermetic TO-8 packages for wavelengths from 830 to 1,550 nm.

The outputs of these detectors should be capacitively or AC-coupled to a 50-Ω termination. The amplifier features an inverting amplifier design with an emitter follower used as an output buffer stage, enabling good low-noise performance and optimized responsivity. The nominal field of view for these APDs is between 136 and 153 deg., depending upon model.

These optical detectors can function effectively in a number of different applications, including for temperature sensing, vehicle safety systems, high-speed free-air communications, and munitions guidance. Both types of detectors are securely packaged and constructed to survive the types of harsh environments associated with some of these applications.

EXCELITAS TECHNOLOGIES, 22991 Dumberry Rd., Vaudreuil-Dorion, Quebec, Canada J7V 8P7; (450) 424-3300, (800) 775-6786, e-mail: detection.na@excelitas.com, www.excelitas.com

JACK BROWNE | Technical Contributor

Wearable Batteries Take to the Field

These two flavors of chargeable and non-rechargeable battery packs are light in weight and conform to a soldier's body for ease of transport with plenty of power to spare.

TACTICAL COMMUNICATIONS can make the difference between a successful mission and empty time spent in the field. The radio technology certainly supports in-field tactical communications, with man-pack radios that are almost as rugged as weapons. But for extended missions, powering these radios can be a challenge.

For that reason, Inventus Power (*www.inventuspower.com*) developed the CWB 150 FlexPack, a wearable battery pack that was designed to be carried into the field. It provides a large degree of flexure in both its horizontal and vertical axes. The conformal wearable battery (CWB) is completely safe for the battlefield. It can even be worn under water without fear of discharge or damage to the wearer.

This conformable primary battery pack features a removable command module and large capacity for long missions.

For the infantry, bringing enough power to energize the modern military electronics pack can be a daunting task—one even more challenging than the mission at hand. In most cases, it can be likened to strapping a car battery on the back and heading out with a pack full of equipment. The CWB 150 FlexPack brings the equivalent or more energy than a car battery, in a flexible pack weighing only 2.6 lb. (1179 g). It has a nominal voltage of 14.8 V, with a full voltage range of 10.0 to 16.6 V dc.

The flexible battery pack is based on lithium-ion (Li-ion) chemistry with nominal capacity of 10 Ah and total energy of 148 Wh. It can be go through 500 charging cycles with no memory effect, to achieve within 80% of its original charged capacity. It is rated for maximum continuous discharge of 5 A.

The flexible battery pack can recharge at temperatures as low as −20°C (from −20 to +55°C) and it provides three levels of charge/discharge safety protection. It meets electromagnetic-interference (EMI) standards for MIL-STD-461 and the battery pack can be safely immersed under 1 m of water for two hours according to MIL-STD-819G/Method 512.4. The battery pack employs an SMBus v1.1 communications bus for sharing data and communications with other electronic devices and systems, and is designed for operating temperatures from −30 to +60°C.

"Our CWB products provide soldiers with a safer, ergonomic, centralized power solution that reduces weight and the overall number of batteries needed for a mission," said Jeff Helm, Inventus Power's business development manager. "Soldiers can rely on power for up to 72 hours without having to recharge or replace battery packs."

> "Our CWB products provide soldiers with a safer, ergonomic, centralized power solution that reduces weight and the overall number of batteries needed for a mission. Soldiers can rely on power for up to 72 hours without having to recharge or replace battery packs."
>
> —Jeff Helm, Business Development Manager, Inventus Power

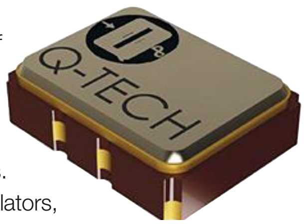
The P-CWB battery pack is based on lithium manganese dioxide (LiMnO2) chemistry and provides an output voltage of nominally 15 V. It has power capacity of greater than 195 Wh, and meets all the safety requirements of MIL-PRF-32271 in a much more ergonomic form factor compared to traditional battery packs. The command module monitors and controls battery discharging, voltage output, and current output.

The CWB 150 FlexPack is one example of the technology developed by Inventus Power for the battlefield. The firm was recently awarded Patent No. 9,564,761-B2 by the U.S. Patent Office for complementary non-chargeable battery technology to the CWB 150 FlexPack: a Primary Conformable Wearable Battery (P-CWB) with removable command module (*see photo*). The power pack was developed in partnership with the U.S. Army.

As the modern soldier takes to the field, the assortment of electronic devices for surveillance, positioning, and communications increases, along with it the need for primary and secondary power. These innovative, flexible power packs literally become part of a soldier's armor, eliminating the need to carry additional, heavy battery packs.

INVENTUS POWER, 1200 International Pkwy., Woodridge, IL 60517; (630) 410-7900, (877) 423-4242, www.inventupower.com

Surface-Mount Crystal Oscillators Generate 625 kHz to 133 MHz



THE QTCC230 SERIES of surface-mount crystal oscillators is suitable for application in navigation, avionics, and smart munitions systems. The miniature hermetic oscillators, which are available with square-wave output frequencies from 625 kHz to 133 MHz, operate on supplies of +1.8, +2.5, and +3.3 V dc and with HCMOS logic. The lead-free, RoHS-compliant oscillators can handle operating temperatures from –55 to +125°C and can be screened to MIL-PRF-55310 requirements. Maximum start-up time is 5 ms and rise/fall times are 5 ns or less. Typical RMS jitter is 2.4 ps

Q-TECH CORP.

10150 W. Jefferson Blvd., Culver City, CA 90232; (310) 836-7900, www.q-tech.com

GaN-on-SiC Transistor Fires 10 W to 4 GHz

MODEL QPD1010 IS a GaN-on-SiC discrete transistor capable of 10 W output power from DC to 4 GHz. It is RoHS compliant and supplied in a 3 × 3 mm surface-mount, low-thermal-resistance QFN package for ease of installation. The discrete transistor is a good fit for amplifiers in military and civilian radar systems, jammers, and test and measurement applications. It provides 24.7-dB linear gain across the full 4-GHz bandwidth, with typical power-added efficiency (PAE) of 70% at 3-dB compression. The transistor, which is designed for use with pulsed and continuous-wave (CW) signals, is powered by a +50-V dc supply.

RFMW, LTD., STOCKING DISTRIBUTOR FOR QORVO

188 Martinvale Ln., San Jose, CA 95119; (408) 414-1450, e-mail: info@rfmw.com, www.rfmw.com

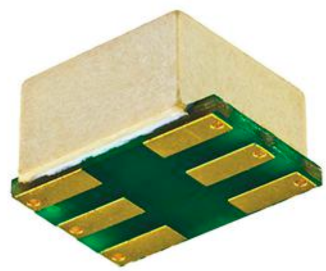
GaN Amplifier Powers X-Band Radars

MODEL BMPC9X89X8-8000 IS a solid-state Class AB GaN power amplifier for X-band radar applications from 9.0 to 9.9 GHz. It provides as much as 8 kW peak output power across instantaneous bandwidths as wide as 600 MHz with 60-dB nominal power gain. It is designed for pulse widths from 0.25 to 100.00 µs and maximum duty cycles of 10%. The input and output VSWR are less than 1.50:1. Harmonics are –60 dBc while phase noise is –100 dBc/Hz offset 100 Hz from the carrier. Typical rise/fall times are less than 50 ns. The rugged GaN amplifier measures 19.0 × 12.25 × 24 in. and weighs 90 lb.

COMTECH PST

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

Surface-Mount Hybrid Spans 40 to 120 MHz



MODEL SLQ-305 IS ta surface-mount 90-deg. hybrid designed to save space in tight circuit layouts. It is designed for applications from 40 to 120 MHz and offers low insertion loss of typically 0.3 dB and high isolation between ports of typically 23 dB across the full frequency range. The miniature hybrid can handle as much as 1 W input power and achieves amplitude unbalance of typically 0.6 dB and phase unbalance of typically 2 deg. The 50-Ω hybrid has typical VSWR of 1.25:1. It is reliable over a wide range of operating temperatures, from –40 to +85ºC.

SYNERGY MICROWAVE CORP.

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

GaN Amplifiers Boost 2 to 40 GHz

SEVERAL LINES OF GaN power amplifiers can be used in pulsed and continuous-wave (CW) signal applications in frequency bands from 2 to 40 GHz. The amplifiers are designed to provide high power densities at high temperatures, making them good candidates for tactical communications and radar systems. The amplifiers are designed for operating temperatures from –55 to +85ºC. As an example, model AGX/0218-3946 provides 46-dB small-signal gain and +39 dBm saturated output power from 2 to 18 GHz. It has ±3 dB gain flatness and operates from a +32 V dc supply with 1.35 A current draw. It has a noise figure of 8 dB.

CTT, INC.

5870 Hellyer Ave., Ste. 70, San Jose, CA 95138; (408) 541-0794, www.cttinc.com

Hi-Rel 90-deg. Coupler Spans 8.2 to 8.4 GHz

THE X6111 3-DB 90-deg. coupler is a high-reliability, space-qualified component based on stripline transmission-line technology. It has maximum insertion loss of 3.5 dB from 8.2 to 8.4 GHz with 20-dB minimum isolation between ports. The peak-to-peak amplitude balance is within 0.5 dB and the phase balance is within ±5 deg. The 90-deg. coupler has maximum VSWR of 1.20:1 and handles as much as +45 dBm power in a vacuum. It measures 0.47 × 1.00 × 2.90 in. and weighs 1.62 oz. and is supplied with SMA female coaxial connectors.

DELTA MICROWAVE

300 Del Norte Blvd., Oxnard, CA 93030; (805) 751-1100, www.deltamicrowave.com

MPMs Power Ground and Airborne Systems to 40 GHz

A FAMILY OF MICROWAVE power modules (MPMs) leverages solid-state and traveling-wave-tube (TWT technologies to provide optimum solutions for high-power amplification from 2 to 40 GHz. The MPMs can be specified for pulsed and CW output-power levels. They are available with output power levels of 20 to 400 W CW signals and 100 W to 20 kW for pulsed signals. The MPMs are excellent signal boosters for airborne data links, ground and airborne radar systems, and ground and airborne electronic counter measures (ECM) systems.

DB CONTROL

120 Auburn St., Fremont, CA 94538-7328; (510) 656-2325, www.dB Control.com

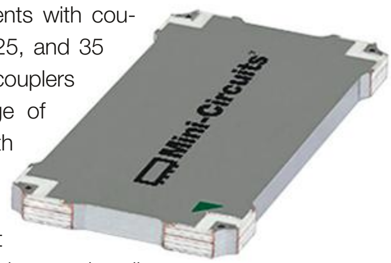
Frequency Synthesizers Fit into Single-Slot PXI Chassis

THE MLMS SERIES of YIG-oscillator-based frequency synthesizers is designed to fit into a single-slot PXI chassis. The product line includes models covering 250 MHz to 6 GHz, 2 to 8 GHz, 6 to 13 GHz, and 8 to 16 GHz, although custom frequency ranges are also available. Ideal as signal sources in UAVs, communications receivers, and in test equipment, the stable signal sources measure just 2.5 × 2.5 × 0.65 in are supplied with a 9-pin Molex connector and a standard USB mini-b connector. Models can be supplied for operating temperatures from 0 to +65ºC as well as for –40 to +85ºC.

MICRO LAMBDA WIRELESS

46515 Landing Pkwy., Fremont, CA 94538; (510) 770-9221, www.microlambdawireless.com

Bidirectional Couplers Channel High Power to 2700 MHz

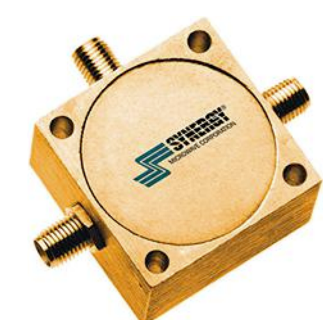


THE BDCH SERIES of high-power bidirectional couplers includes the BDCH-15-272, BDCH-20-272, BDCH-25-272, BDCH-35-272 components with coupling values of 15, 20, 25, and 35 dB, respectively. All four couplers cover a frequency range of 700 to 2,700 MHz with low insertion loss of typically 0.2 dB and typical return loss of 25 dB at all ports. The robust couplers can handle input power levels as high as 150 W and can also pass DC current as high as 2.5 A. The typical coupling flatness of ±1.25 dB and typical directivity of 18 dB. The couplers are designed into an open PCB laminate measuring just 0.5 × 1.0 in. with wraparound terminations for ease of installation onto circuit boards.

MINI-CIRCUITS

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

Triple-Balanced Mixer Translates 1 to 3500 MHz



MODEL CMK-3500 IS a triple-balanced mixer with coaxial connectors for applications from 1 MHz to 3.5 GHz. Suitable for broadband or narrowband frequency upconversion and frequency downconversion, the rugged mixer is designed for nominal local oscillator (LO) power of +17 dBm and exhibits typical conversion loss of 8.7 dB or better across the full frequency range. The typical input intercept point is +28 dBm and the typical 1-dB compression point is +14 dBm. The mixer achieves better than 20 dB isolation among all sets of ports.

SYNERGY MICROWAVE CORP.

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

K-Band Filters Help Screen UAVs

A LINE OF K-BAND stripline bandpass filters has been designed with a center frequency of 23 GHz. Developed with light weight for use in communications unmanned aerial vehicles (UAVs), the bandpass filters are supplied in a gold-plated housing weighing only 0.0163 oz. (0.46 g) and measuring only 0.5 × 0.2 × 0.115 in. The small size and low weight make them suitable for airborne applications, with or without pilots. As an example of the performance possible from these miniature filters, model CMIBPF-23G-2G has ±0.4 dB passband ripple from 22 to 23 GHz with better than 60-dB rejection from 7 to 10 GHz, better than 50 dB rejection from 10 to 15.5 GHz, better than 30 dB rejection from 27 to 30 GHz, and better than 55 dB rejection from 30 to 33.7 GHz. Maximum passband insertion loss is 2 dB.

CORRY MICRONICS, INC.

761 Commonwealth Dr., Ste. 2011, Warrendale, PA 15086; (724) 940-7556, www.cormic.com

Transistor Supplies 100 W from DC to 3.5 GHz

THE HERMETIC TGF2929-HMS power transistor provides 100 W output power from DC to 3.5 GHz and as much as 132 W saturated output power at 2 GHz. It achieves 72% power-added efficiency (PAE) from a +28-V dc supply with as much as 17.4-dB small-signal gain. The transistor is prematched for S-band applications in satellite-communications (satcom) amplifiers and space-based radar systems.

RFMW, LTD., STOCKING DISTRIBUTOR FOR QORVO

188 Martinvale Ln., San Jose, CA 95119; (408) 414-1450, e-mail: info@rfmw.com, www.rfmw.com

GaN TECHNOLOGY STRETCHES MIXER PERFORMANCE

GALLIUM-NITRIDE (GaN) TECHNOLOGY is generally associated with power amplifiers (PAs). However, GaN technology may now be a viable option to realize high-linearity passive mixers. In the tech brief, "Reach New Levels of Linearity in Passive Mixers with GaN Technology," Custom MMIC explains why GaN technology possesses the capability to usher in a new breed of mixers. Three different GaN-based mixers are then presented.

The tech brief begins by explaining how many of today's mixers are based on various gallium-arsenide (GaAs) processes, such as MESFET, pseudomorphic-high-electron-mobility-transistor (pHEMT), and heterojunction-bipolar-transistor (HBT) technologies. Moreover, third-order intercept point (IP3) is a parameter commonly used to classify mixers. Local-oscillator (LO) drive level is a key factor in terms of IP3 performance.

A new metric, linear efficiency, is defined as the difference between the IP3 and LO drive level of a mixer. The tech brief notes that many of today's mixers have linear efficiencies ranging from 3 to 8 dB. System linearity requirements have increased over time, requiring mixers with greater IP3 levels. However, GaAs-based mixers would require extremely large LO drive levels to achieve the high IP3 levels that are being sought after, according to the document.

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

The desire for mixers with higher linearity prompted the investigation of GaN-based mixers. GaN processes can support two types of mixing elements: a two-terminal Schottky diode and a three-terminal field-effect transistor (FET). A typical GaN diode has a higher turn-on voltage than a typical GaAs pHEMT diode. Thus, mixers based on GaN diodes can achieve a higher IP3—at the expense of requiring a greater LO drive level. However, the document states that such mixers can achieve a higher linear efficiency than mixers based on GaAs pHEMT diodes.

The tech brief concludes by describing the individual design and performance of three different GaN-based mixers. The first one is an S-band three-terminal FET mixer, while the second is an X-band double-balanced diode-based mixer. The third is a Ku-band single-ended, cold FET mixer.

HANDLE GaAs AND GaN MMICs WITH CARE

PROPER PROCEDURES MUST be used when building integrated assemblies that incorporate gallium-arsenide (GaAs) or gallium-nitride (GaN) monolithic microwave integrated circuits (MMICs). Hence, this topic is the subject of Qorvo's white paper titled, "GaAs and GaN Die Assembly and Handling Procedures." In it, Qorvo discusses component placement, attachment, and interconnect techniques that can be utilized to successfully build assemblies containing GaAs or GaN MMICs.

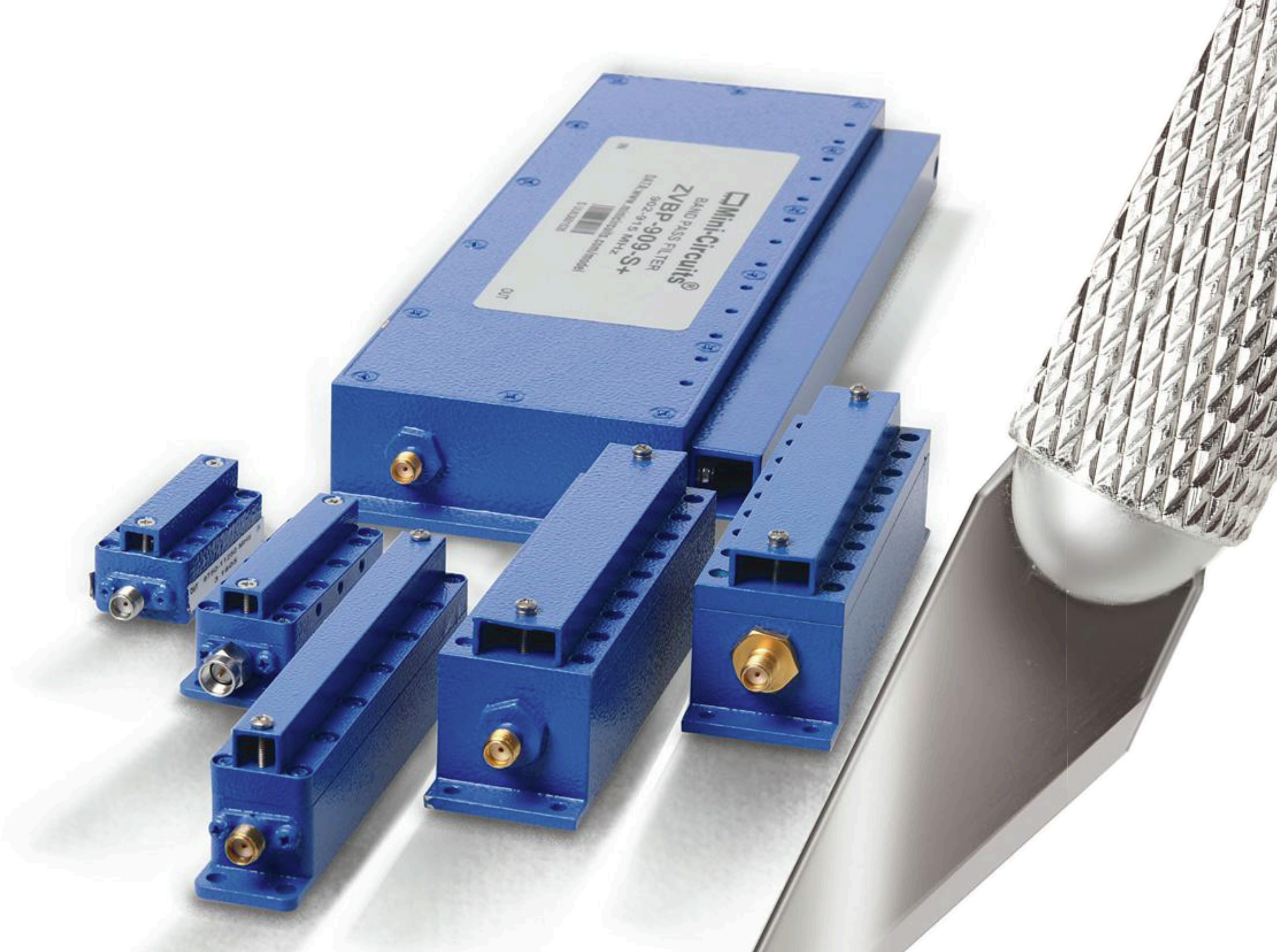
The white paper begins by discussing component placement, which involves picking up and then placing MMICs into microwave circuits or modules. It explains that both GaAs and GaN MMICs should be picked up by using either an automatic or semi-automated pick system along with an appropriate pick tool (e.g, a vacuum pencil or collet).

Qorvo Inc.,
7628 Thorndike Road,
Greensboro, NC 27409
(336) 664-1233
www.qorvo.com

Solder attachment is the next topic presented. The white paper recommends that solvent cleaning of solder preforms and substrates/packages be performed to remove any existing surface contaminants. Moreover, gold-tin (AuSn 80/20) is the alloy that is most commonly used when soldering GaAs and GaN MMICs. AuSn solder is usually available as a preform, with common thickness values ranging from 0.5 to 2 mils. One additional point of emphasis involves choosing a substrate or base-plate material with a suitable coefficient of thermal expansion (CTE).

Epoxy attachment is another technique that can be used to attach GaAs and GaN MMICs to a surface. In the past, this technique was recommended only for low-power applications. However, advancements in technology have made expoy attachment a viable option for high-power MMICs—as long as proper measures are taken. Furthermore, the document notes that epoxies cure at temperatures ranging from +100°C to +200°C. Curing should take place in a convection oven with proper exhaust.

Lastly, interconnection techniques are discussed. Thermosonic ball bonding is the preferred interconnect technique, according to the white paper. Critical factors when using bonding equipment are force, time, and ultrasonic power. Acceptable wire diameters with respect to the bond-pad size on a device are discussed as well.



SHARP REJECTION

CAVITY FILTERS

Passbands from 900 to 11400 MHz from $199.95 ea.

Need to separate signal from scramble? Mini-Circuits' new ZVBP-series cavity filters are designed to give you razor sharp selectivity and high stopband rejection for bandwidths as narrow as 1% to keep your signal clean. These filters feature rugged construction and robust design with protection from accidental detuning, so you can put them to work with confidence in almost any environment, in the lab or in the field.

FEATURES

- *Outstanding selectivity*
- *High rejection*
- *Rated for operation from -55 to +100°C*
- *Power handling up to 15W*
- *Rugged construction*

They're available off the shelf for immediate shipment, so place your order today for delivery as soon as tomorrow! Need a custom filter? We've got you covered. Just send your requirements to apps@minicircuits.com for a fast response.

Mini-Circuits®

www.minicircuits.com P.O. Box 350166, Brooklyn, NY 11235-0003 (718) 934-4500 sales@minicircuits.com 559 RevOrig

JACK BROWNE | Technical Contributor

AWGs Generate Multiple Complex Signals to 4 GHz

These AWGs pack enough digital processing power to generate as many as eight independent RF/microwave signal channels per instrument for emulating complex signal environments.

ARBITRARY WAVEFORM GENERATORS (AWGs) provide the means to precisely replicate complex waveforms when they are armed with sufficient bit resolution, sampling rate, and sample memory. The AWG5200 Series of AWGs is equipped with a generous measure of all three commodities, with standard sampling rate to 5 GSamples/s (and as high as 10 GSamples/s with 2× interpolation), 16-b vertical resolution, and enormous 2 GSamples waveform memory per channel. It amounts to modular AWGs in 2-, 4-, and 8-channel configurations with the capabilities to directly generate complex modulated signals with carriers to 4 GHz without frequency translation. The high-bit resolution also means that the generated signals will benefit from a -70 dBc spurious-free dynamic range.

Signal generation for RF/microwave test grows more complex according to a number of factors, including the growing number of devices operating within a frequency range of interest and the various modulation schemes that are used to maintain coexistence of different devices within a common frequency range. Realistic test signals must recreate the modulation used by a device under test (DUT) but may also require the reproduction of noise and interference to mimic a DUT's actual operating environment. Measurements meant to emulate occupied spectrum, whether for military or commercial purposes, can never have enough test sources because the environments they are simulating are filled with literally thousands of RF/microwave signals from such sources as radars, portable radios, and smartphones.

The AWG5200 Series test sources (*Fig. 1*) allow a user to specify (and pay for) the number of signal channels needed for a test. While eight is the maximum number of channels per instrument, as many as four AWG5200s can be synchronized (as many as 32 channels) when eight channels are not enough. This can be the case when testing phased-array antenna systems or multiple-input, multiple-output (MIMO) antenna arrays.

The AWG5200 Series of AWGs currently consists of the two-channel AWG5202, the four-channel AWG5204, and the

1. AWG5200 Series arbitrary waveform generators (AWGs) can be equipped with as many as eight independent waveform generation channels at sampling rates to 5 GSamples/s.

eight-channel AWG5208. Instruments are available with sampling rates as high as 10 GSamples/s, although the base performance level is 2.5 GSamples/s. The AWGs can be supplied with different levels of performance as needed, with a base price of $11,000 per channel for standard levels.

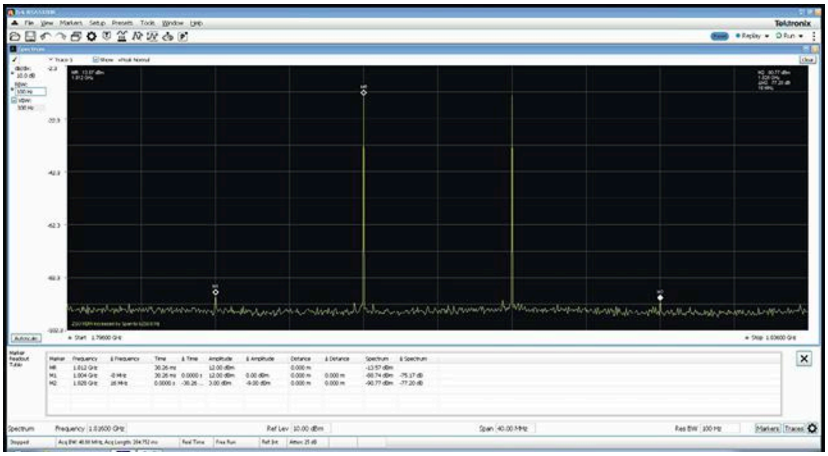
RETHINKING SIGNAL GENERATION

For RF/microwave engineers accustomed to traditional analog signal generation— i.e., starting with an oscillator— an AWG requires a different way of thinking. In an analog source or even a digitally controlled phase-locked-loop (PLL) frequency synthesizer, output signals are defined by the performance limits of an oscillator. In an AWG (even one as elegant as one of the AWG5200 Series sources with its high-speed digital-to-analog converters DACs), multiple numerically controlled oscillators (NCOs), and digital architecture, output signals are essentially defined by an operator's imagination— within the limits of the digital circuitry.

An AWG can create waveforms according to mathematical relationships (such as sine and cosine) or by deriving those relationships from measurements made on actual signals and then stored as waveform files. Because of the digital, computer-like architecture for generating signals, memory is a valuable resource in an AWG: more memory means longer running times for generated waveforms, especially those with broad bandwidths. For example, when creating a signal waveform at a sampling rate of 5 GSamples/s, 2 GSamples of waveform memory will provide as much as 400 ms waveform time.

Sample rates can be set from 1.5 kSamples/s to 5 GSamples/s (and interpolated to 10 GSamples/s), resulting in a 3-dB sin x/x bandwidth of 2.22 GHz at 5 GSamples/s (and 4.44 GHz when interpolated at 10 GSamples/s). This yields a maximum sinewave output frequency (F_{max}) of 2 GHz, which can be raised to 4 GHz with interpolated sampling. Output waveforms to 7 GHz and beyond can be generated, but at reduced output-power levels. The amplitude levels of the output waveforms can be set with 0.1-dB resolution at power levels from -85 to +10 dBm with ±2% accuracy for waveforms from 10 MHz to 2 GHz.

The AWG5200 Series generators have several DAC modes, allowing an operator to choose which mode provides the most suitable output waveforms for an application. A built-in in-phase/quadrature (I/Q) modulator equips the AWGs with fundamental vector-signal generator (VSG) capability and the capability to generate differential output signals for complex modulation signal formats.



2. The AWGs provide as many as eight synchronized output channels of spectrally pure waveforms, with typical SFDR performance of better than -70 dBc.

Signals can be generated as dc or ac outputs, with dc outputs available in single-ended and differential forms, ac direct outputs in single-ended form. As expected for an AWG with its digital architecture, output performance is defined by mathematical relationships. For example, the single-ended dc amplitude range is 100 mV to 0.75 V peak to peak for single-ended outputs and twice that for differential outputs. An available option raises the top single-ended level to 1.5 V peak to peak. AC direct output levels range from -17 to -5 dBm, with available dc bias of ±5 V at 150 mA. An amplified ac output range is also available, covering -85 to +10 dBm with the same bias power. For ac and dc outputs, the amplitude flatness is ±1 dB at 1 GHz and ±2 dB at 2 GHz. Because waveforms can be defined mathematically, the amplitude flatness can be improved to ±0.1 dB for all frequencies by using predistortion as part of the waveform definition.

For defining waveform transition points or anomalies in an AWG5200 Series instrument's output signals, as many as 32 markers (four markers per channel) can be placed across the eight channels. The markers greatly simplify operation and measurements, but also require processing power. Each marker uses 1 b of vertical resolution from an output waveform. For example, with no markers active, a waveform's vertical resolution is 16 b. With one marker active, the vertical resolution drops to 15 b. With two markers active, the vertical resolution is 14 b, dropping to 12 b when as many as four markers are placed on a generated waveform.

Even when compared to single-channel RF/microwave signal sources, the spectral purity of the signals created by the AWG5200 Series AWGs is impressive, with low spurious content and harmonics (*Fig. 2*). However, with the capability to produce multiple signals precisely aligned in time, an AWG5200 is a veritable signal-generation system in a box, replacing one or more racks of signal sources for test applications and simulations where the timing among multiple test tones must be tightly controlled. Each AWG5200 has up to eight separate signal sources, with shielded, independent circuitry per channel for such functions as sequencing and upconversion, resulting in a signal-generation architecture with little or no crosstalk between channels. The only commonality among the channels is the reference clock, used for synchronization.

The multiple channels share a common clock for synchronization, and this can be the internal 10-MHz reference source or an external reference oscillator. The standard 10-MHz reference oscillator is more than stable enough for most applications, with typical random jitter of 700 fs (RMS) and typical total peak-to-peak jitter of 10 ps. The stable reference oscillator contributes to low channel-to-channel skew of typically 10 ps or less. In terms of time-domain performance, such as generating short pulses for testing various types of radar systems, the AWG5200 sources can generate pulses with 20% to 80% rise times as fast as 150 ps for minimum pulse widths of 400 ps.

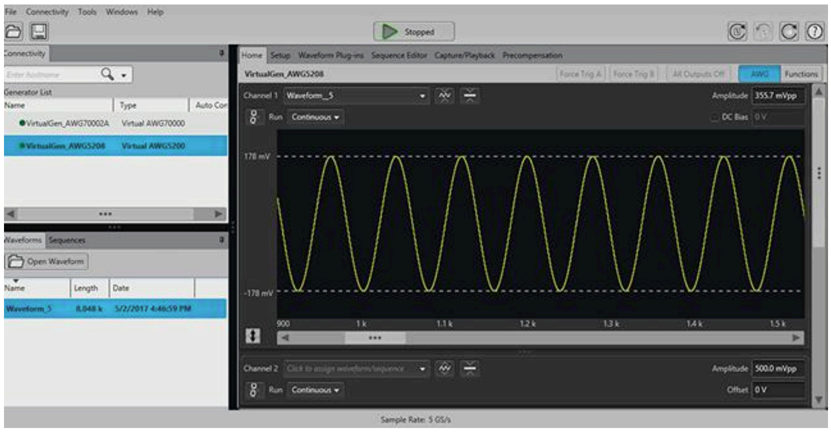
The signal synthesis capability of a single AWG5200 previously required a rack full of signal generators, with synchronization tied to a common stable reference source. In addition to the size and complexity of maintaining individual signal generators, a rack of signal generators can represent a significant investment, not to mention signal analysis instruments also needed with such an instrument installation. The AWG5200 AWGs are code compatible with previous-generation AWGs from Tektronix. Matlab and custom waveforms work across AWG platforms such as the AWG4000 (see page 86), so that legacy software is just as effective.

SETTING SIGNALS STRAIGHT

Many users will choose to control an AWG5200 from a PC running Tektronix SourceXpress software for remote control and waveform creation. The connection is as simple as inserting an Ethernet or USB cable between the PC and the AWG. The SourceXpress software (*Fig. 3*) runs on a PC with Microsoft Windows 7 or newer operating system, and it is powered by a growing library of waveform creation plug-in software modules. These plug-in modules allow for fast design of specific waveform types, including modulated communications signals and radar pulses. In addition, the RF Generic plug-in module allows operators to digitally synthesize modulated signals to generate custom modulated waveforms.

An AWG5200 can also be controlled from its own 6.5-in. touchscreen display. The responsive display offers menu choices and presents images of generated waveforms. Combined with the company's familiar front-panel rotary control and keypad for data entry, the touchscreen display simplifies the selection of existing waveforms from stored files and the generation of new waveforms based on measured data or on waveform design criteria.

Given the complexity of modern signal waveform environments, many users will rely on waveforms defined by various software programs, such as Excel or Matlab. The AWG5200 series AWGs can work with Matlab .mat files as well as Excel .xls spreadsheets, not to mention even simple .txt text files used to define waveform characteristics. The digital signal sources can also generate waveforms from various .awg and .awgx files created by Tektronix AWG5000 and AWG7000 series AWGs. The AWG5200 AWGs can be programmed for automatic testing using imported waveform files, to create complex sequences of different signal types as needed.



3. The AWG5200 Series AWGs can be used as stand-alone instruments or remotely controlled with a PC running SourceXpress or other waveform-generation software and waveform files.

The AWG5200 generators have a removable hard disk drive for ease of changing test setups and for ensuring data security. Trigger inputs on the rear panel enable triggering waveforms with minimum pulse widths of 20 ns and with negligible latency of 2 μs. Rear-panel input ports also accept an external 10-MHz reference oscillator with amplitude of -5 to +5 dBm. An additional 50-Ω input connector accommodates a variable-frequency reference source of 35 to 250 MHz. A rear-panel SMA connector also provides access to the AWG5200's internal 10-MHz reference oscillator, at a nominal level of +4 dBm. The AWG5200 signal sources are not for everybody. But for testing that attempts to emulate extremely complex signal environments, one (or more) of these instruments may just provide the solution. P&A: $82,000 and up; stock to 4 wks. mw

TEKTRONIX INC., P.O. Box 500, 14150 SW Karl Braun Dr., Beaverton, OR 97077; (503) (800) 833-9200, www.tek.com.

STUART GLYNN AND LIAM DEVLIN | Plextek RFI, www.plextekrfi.com

Design of a Dual-Band PA for Millimeter-Wave 5G Applications

With several millimeter-wave frequency bands currently under investigation for 5G, an innovative dual-band power amplifier has been designed that addresses two of the proposed bands using a single component.

CONSIDERABLE TIME AND money are currently being invested in developing millimeter-wave technology for 5G, and there is much debate and lobbying in regard to the most suitable frequency bands for this application. In the U.S., the FCC has allocated licensed spectrum at 28 GHz, 37 GHz, and 39 GHz. In Europe, the Radio Spectrum Policy Group (RSPG) has recommended the 26-GHz band (24.25 to 27.5 GHz) as the pioneer band for 5G, with all the EU member states making a portion of this band available for 5G. It also recognized that the 32-GHz band (31.8 to 33.4 GHz) could be made available by many European administrations and effort should be made to keep it as an option for 5G in the future.

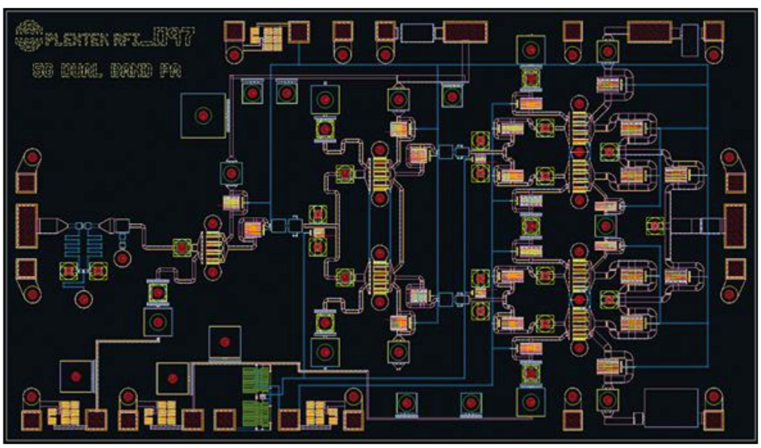
Development work is currently underway in all of these bands, and it is looking increasingly unlikely that a single band will be designated on a worldwide basis for millimeter-wave 5G in the immediate future. This means that the availability of dual-band or multi-band millimeter-wave components will become increasingly attractive.

This article describes the design, layout, and performance of a dual-band power amplifier (PA) monolithic microwave integrated circuit (MMIC), capable of electronically switching its operating band between the 26-GHz and 32-GHz bands. The starting point was to undertake the preliminary design of two standalone PAs, each addressing one of the target bands. The targeted output power was 1 W at 1-dB gain compression (P1dB)—a commercially available 0.15-µm gate length pHEMT process was selected to achieve this. A three-stage design was implemented to achieve a small signal gain of around 20 dB.

PA DESIGN PROCESS

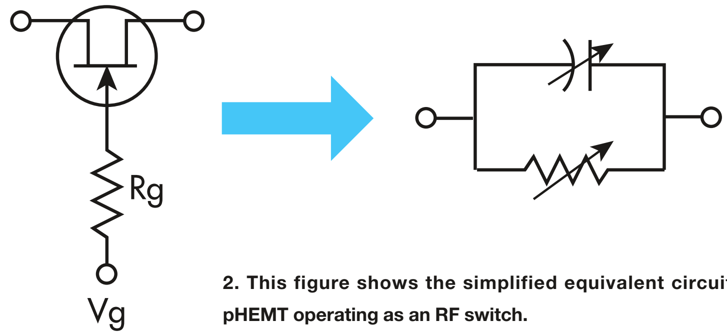
The design of each PA commenced with the selection of the output transistor size and bias. Increasing the total gate width of the selected transistor also increases the available RF output power. However, the higher parasitics of the physically larger transistor result in a reduction in available gain. The proven design approach to address this is to use multiple power-combined transistors. To achieve the target output power, a total of four eight-finger transistors were power-combined in the output stage. This output stage was driven by a pair of devices, and this in turn was driven by an input stage realized using a single transistor. The topology adopted is evident from the layout plot of the dual-band PA *(Fig. 1)*.

It was necessary to adopt certain commonalities in the initial design of the two PAs. The transistor sizes in each stage needed to be identical, and the basic power-combining



1. Shown is the layout of the dual-band millimeter-wave 5G PA

topology needed to be similar. It was also necessary to have some degree of commonality in the matching structures used in the two PAs. However, some differences in the structures could be accommodated as part of the dual-band implementation—this versatility allows freedom to optimize the performance in both bands.



2. This figure shows the simplified equivalent circuit of a pHEMT operating as an RF switch.

BAND SWITCHING APPROACH

Converting the two individual PA designs into a single switched design commenced at a relatively early stage in the design process. The basic approach was to switch certain RF elements in and out of the circuit. pHEMT transistors can be used to realize good RF switches by biasing the drain-source voltage (Vds) at 0V and controlling the gate bias voltage.[1]

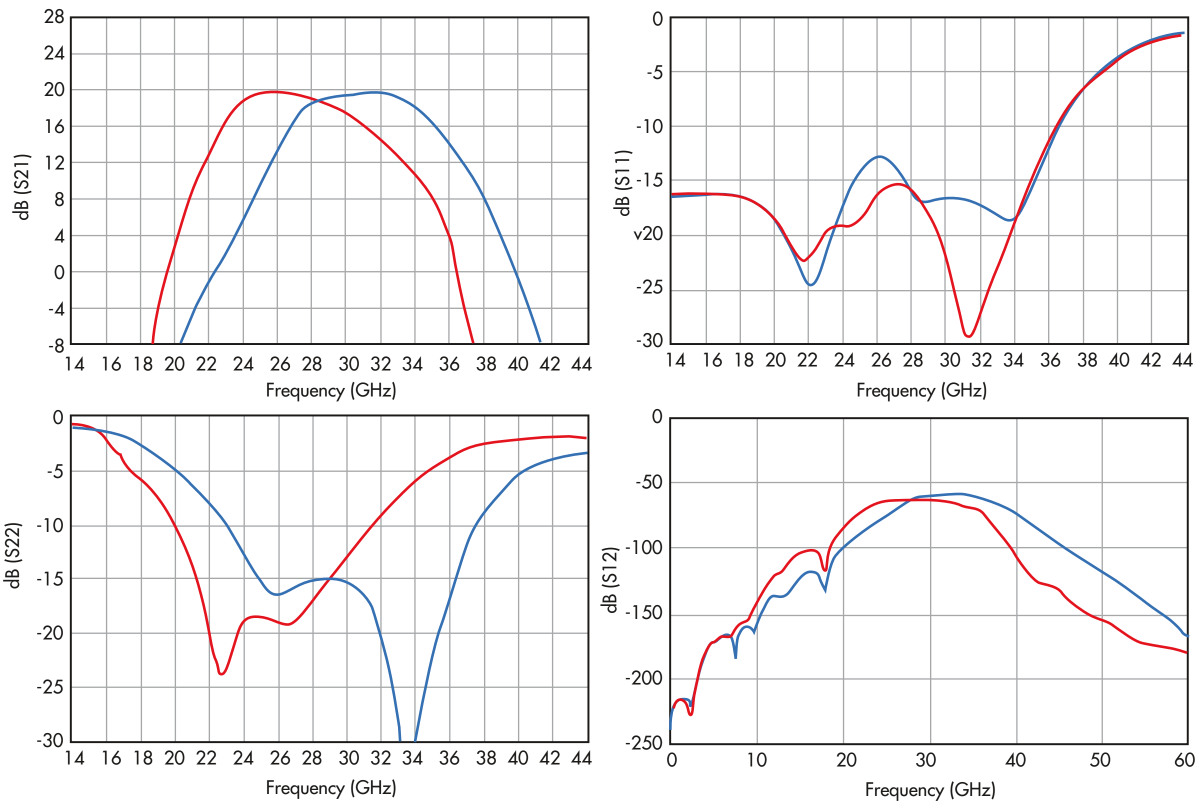
Figure 2 depicts a simple equivalent circuit for a pHEMT operating as a switch. The resistance varies from a low value with the gate at 0 V to a high value when the transistor is pinched off. This provides a simple but effective switching function, which is the basic means of realizing RF switches.

The problem with using pHEMTs as millimeter-wave switches is the parasitic capacitance. This capacitance can be lowered by reducing the total gate width of the switching transistor, but that in turn increases the insertion loss. The basic structure of the pHEMT—with its parallel drain and source fingers—means that pushing the parasitic capacitance to very low levels results in small transistors that have very high insertion loss and poor linearity. Even a capacitance of just 0.1 pF has an isolation of just 1 dB at 31 GHz.

The key to implementing the RF switches in the dual-band PA was to consider them not as ideal switching elements but as varying reactance elements. The reactance was absorbed into the PA matching structures such that the switch parasitics became an integral and required part of the matching networks. The matching networks of the two PAs were reviewed individually from output to input.

It was necessary to adopt common positions for certain key matching elements such as the drain bias feeds, which were configured with switching elements to shorten the effective electrical length in the higher band implementation. It was possible to retain some matching elements as common for both bands, but others were switched in or out as appropriate. The key in all cases was to adopt a topology that could accommodate the switch parasitics in both bands.

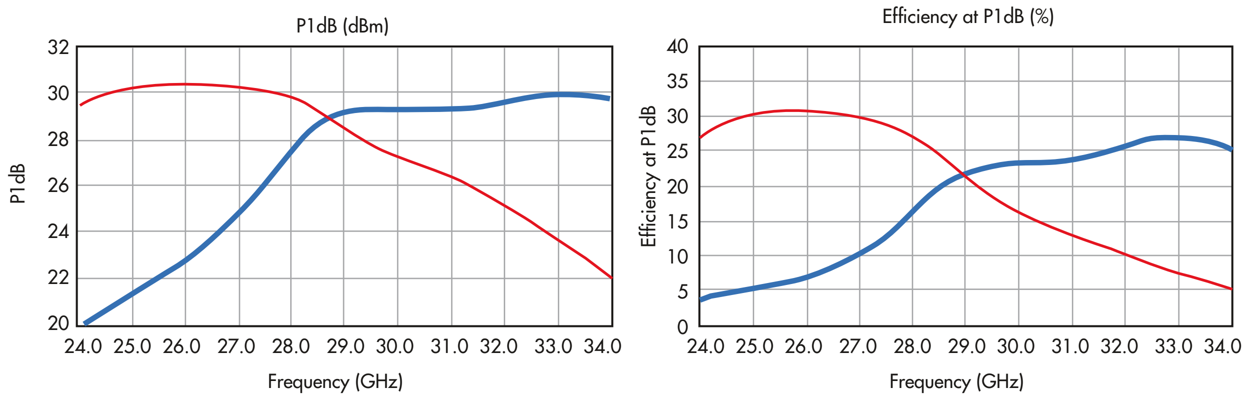
The process of implementing switchable matching structures throughout the entire amplifier required great care and attention to detail. Much effort was expended on



3. Shown are the simulated S-parameter plots of the dual-band PA in both states.

keeping the number of switching elements down to an acceptable level. If the number of required switching elements becomes excessive, the size and cost benefits of having a dual-band PA start to diminish. The resulting design was ultimately of comparable size to a single band PA, as can be observed from the layout of Fig. 1. An inspection of the layout verifies that the switching elements are integral to the matching networks.

As the PA is switched from low-band to high-band operation, the effective length of some key transmission lines need to become shorter and certain key capacitance values must be reduced. In order to achieve this, some switching elements will need to be "ON" in order to bypass portions of key transmission lines and some switching elements will need to be "OFF" in order to switch out, or significantly reduce, certain key capacitances.



4. Simulated results for P1dB and efficiency of the dual-band PA in both states are shown here.

To control the switching pHEMTs that produce the ON/OFF states, complementary control signals are required. However, the requirement for complementary control is inconvenient in terms of the increase in the number of control lines. Hence, a novel on-chip inverter circuit has been included to generate the complementary switching signals from a single-ended control input. The implementation of such an inverting function on a depletion mode-only process is not straightforward, and careful design of the control interface is essential.

SIMULATION RESULTS

Figure 3 shows the simulated S-parameters plots of the dual-band PA. The dual-band responses are clearly evident (26-GHz band in red and 32-GHz band in blue). The amplifier shows good input and output return loss in each band and has a small signal gain of 20 dB.

The simulated large-signal performance is plotted in *Fig. 4*. As with the small-signal case, the performance of the amplifier operating in the 26-GHz band is plotted in red, while the 32-GHz band is shown in blue. P1dB is around 1 W (+30 dBm) for both bands, being slightly higher in the 26-GHz band and slightly lower in the 32-GHz band. The efficiency at P1dB is around 30% in the 26-GHz band, dropping to around 26% at 32 GHz.

One alternative to the dual-band approach would be to design a broadband amplifier capable of covering both bands. However, the gain, output power, and efficiency would all be lower with a broadband design. The compact layout and excellent dual-band performance demonstrated here shows the potential benefits that this approach can bring to dual-band millimeter-wave PAs. It is likely that dual-band operation will be highly desirable for 5G Ka-band systems, and this approach could bring huge benefits in terms of size and cost. mw

REFERENCES

Devlin, Liam, "The Design of Integrated Switches and Phase Shifters," Proceedings of the IEE Tutorial Colloquium on "Design of RFICs and MMICs," Wednesday, November 24th, 1999, pp 2/1-14.

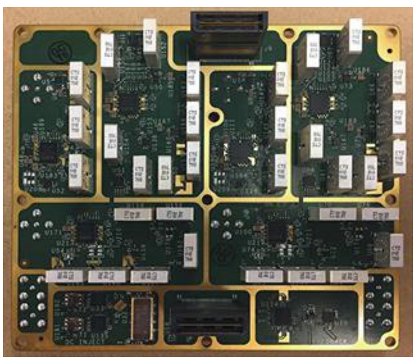
JACK BROWNE | Technical Contributor

Facility Takes on the Most Challenging Circuits

Drawing on the expertise and experience of its operators, this company provides fabrication and assembly services for single-layer and multilayer PCBs.

DESIGNING A CIRCUIT is often only part of the adventure—the rest of the journey involves waiting to see how well that circuit will perform when fabricated from real-world components and printed-circuit-board (PCB) materials. Fortunately, this industry has its hotbeds of experience in constructing practical PCBs, such as San Francisco Circuits *(www.SFcircuits.com)*. That experience not only helps in the assembly of reliable, repeatable high-frequency PCBs, but it provides invaluable guidance for the type of circuit material and assembly services that will work best in assembling a particular circuit design.

The company offers single- or double-sided FR-4 circuit materials for lower-cost designs and higher-quality circuit materials, such as the RO3000 and RO4000 series from Rogers Corp. *(www.rogerscorp.com)*, for higher-performance prototype services. Lower-volume prototype circuits can usually be turned around from a layout file in 12 to 24 hours, even with detailed circuit structures such as blind and buried vias.



Here's an example of San Francisco Circuits' circuit-fabrication capabilities when working with flexible, high-frequency circuit materials (and with precision housing). The firm can provide circuits on a wide range of flexible and rigid-flex commercial circuit materials.

For higher-volume, production quantities, the firm offers less-expensive circuit materials like Kapton as well as FR-4. Standard production processes support circuits with 1 to 12 circuit layers on Kapton or FR-4 with copper thicknesses ranging from 0.5 to 3.0 oz. Two-layer boards can be produced with minimum thickness of 0.010 in., four-layer boards with minimum thickness of 0.020 in., and 12-layer boards with minimum thickness of 0.062 in. The maximum two-layer board thickness for FR-4 or Kapton is 0.125 in.

For higher-performance circuits, more advanced circuit-manufacturing processes based on materials such as RO3000 and RO4000 can be fabricated with as many as 40 layers, with copper-layer thicknesses ranging from 4 to 6 oz. Two-layer circuit boards have minimum thickness of 0.005 in.; four-layer boards, a minimum thickness of 0.010 in.; and eight-layer boards, a minimum thickness of 0.040 in. Maximum board thickness for these high-performance materials is 0.250 in.

HANDLING MICRO SIZES, TOO

In addition to fast-turnaround fabrication services, San Francisco Circuits provides microcircuit capabilities with micron-sized circuit features as well as numerous services essential to those working with PCBs. These accessory services include: two-dimensional (2D) and three-dimensional (3D) x-ray testing; BGA x-ray testing; automated optical inspection (AOI); in-circuit testing (ICT); functional testing at board and system levels; and even access to a flying probe for making measurements on fine-featured circuits.

Automated assembly equipment can assemble through-hole devices (THDs) and surface-mount-technology (SMT) components to PCBs; perform mixed assembly of SMTs and THDs; and assemble circuits with flip-chip underfilled CCGA housings, tiny 0201 and 1005 passive components, and PoP packages. Standard circuit dimensions on flexible circuits include 3 mil spaces and circuit traces.

San Francisco Circuits works with a network of partners to provide quick-turnaround PCB production services as well as layout design and prototyping. They can also perform assembly of military-grade circuit boards according to certification standards such as MIL-PRF-55110, MIL-PRF-50884, and MIL-PRF-31032. The facility itself is ISO 9001-2008 certified, and the company opened a second office in San Diego last year. mw

SAN FRANCISCO Circuits Inc., 1660 S. Amphlett Blvd., No. 200, San Mateo, CA 94402; (800) SFC-5143, e-mail: info@SFcircuits.com.

JACK BROWNE | Technical Contributor

Low-Power OCXOs Take Flight in LEOS Systems

These oven-controlled crystal oscillators provide stable output signals with low phase noise and power consumption and high radiation tolerance for satellite applications.

RUNNING OUT OF power in a satellite can be costly, since changing batteries is no simple matter. Fortunately, advances made by Bliley Technologies on its Iris line of oven-controlled crystal oscillators (OCXOs) have instilled the traditional stability of OCXOs without the traditionally high power consumption.

Available with sinewave or HCMOS-level outputs, the product family includes high radiation tolerance, low phase noise, and excellent acceleration sensitivity with output frequencies reaching 100 MHz. The Iris OCXOs are designed for long running times in low-Earth-orbit satellites (LEOS) or any application where power consumption is a concern, including unmanned aerial vehicles (UAVs).

One example of a LEOS master reference oscillator available in the Iris line is model NV45AY *(see figure)*, a 100-MHz sinewave Iris OCXO designed to handle the radiation exposure typical of LEOS, both total ionizing dosage (TID) and linear energy transfer (LET). It is radiation-tolerant to 40 krad TID and 40 MeV LET. For space use, it also boasts 0.3 ppb/g acceleration sensitivity. Model NV45AY provides +10 dBm typical output power at 100 MHz with 1.5-W typical steady-state power consumption from a +5-V dc supply. Power consumption at startup is only 2.5 W, with a maximum warmup time of about 3 min.

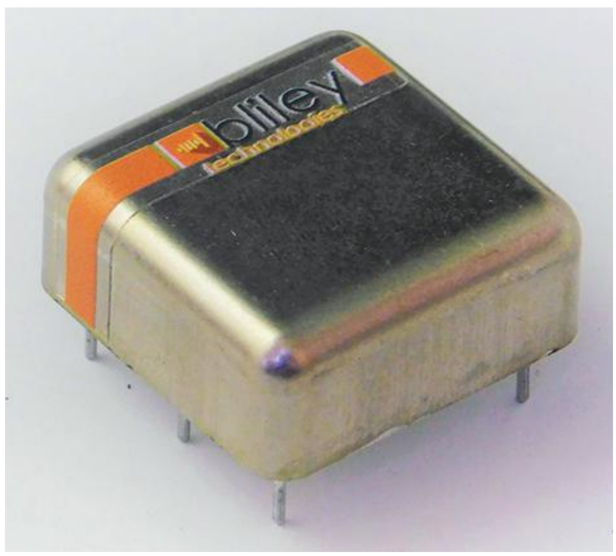
The NV45AY OCXO is well-suited for battery-powered electronic devices, such as commercial and military portable radios, and even in guidance/navigation devices that require accurate timing but Global Positioning System (GPS) coverage may not be available. Maximum harmonic and spurious levels into a 50-Ω load are –30 and –80 dBc, respectively. Room-temperature (+25°C) phase noise for the model NV45AY is quite impressive, with worst-case values at –95 dBc/Hz offset 10 Hz from the carrier, –125 dBc/Hz offset 100 Hz, –155 dBc/Hz offset 1 kHz, –168 dBc/Hz offset 10 kHz from the carrier, and –168 dBc/Hz offset 100 kHz from the carrier.

All members of the Iris line come in surface-mount-technology (SMT) housings measuring 0.5 × 0.5 in. They can be designed for supply voltages of +3.3 V dc ±5% or +5.0 V dc ±5%.

The oscillators are available with various grades of frequency-versus-temperature performance: ±25, 50, 75, or 100 ppb from –20 to +70°C, or ±75 or 100 ppb from –40 to +85°C. The aging rate is ±100 ppb within one minute for the first year and ±500 ppb within one minute for the first 15 years, both per MIL-PRF-55310. The Allan deviation for frequency versus load is ±5 ppb; for frequency versus voltage, it is also ±5 ppb. They are equipped with electronic frequency control from typically 0 to +4 V dc for a frequency tuning range of ±2 ppm.

Whether with HCMOS or sinewave outputs, the Iris OCXOs provide clean, stable output signals for a fraction of the power consumption of traditional OCXOs. They also add little in weight and size to a circuit design, and help keep satellites stay on time. mw

BLILEY TECHNOLOGIES Inc., 2545 Grandview Blvd., Erie, PA 16506; (814) 838-3571, e-mail: connect@bliley.com, www.bliley.com.



The Iris line of OCXOs, which comes in compact surface-mount housings with low power consumption, includes the 100-MHz model NV45AY with high radiation tolerance for LEOS applications.

JACK BROWNE | Technical Contributor

Coaxial Attenuators Control Levels to 50 GHz

The BW-VX-1W54+ series of fixed attenuators includes models with attenuation values of 3, 6, 10, and 20 dB across a broad bandwidth of dc to 50 GHz.

These coaxial attenuators cover a broad frequency range of dc to 50 GHz and provide tightly controlled, fixed attenuation values of 3, 6, 10, or 20 dB with low VSWR.

WIRELESS DATA REQUIRES frequency bandwidth, and the promise of emerging Fifth Generation (5G) wireless communications networks is that bandwidth will be available to transfer data within local area networks via millimeter-wave frequencies. Frequency bands above the microwave range are also being used for automotive radar systems. Such frequencies above 30 GHz now represent the part of the spectrum that can provide the bandwidth for these applications.

In support of millimeter-wave applications, Mini-Circuits *(www.minicircuits.com)* has been cultivating a variety of affordable component families for frequency coverage to 40 GHz and beyond, including coaxial cable assemblies, power dividers/combiners, terminations, and adapters. In addition, for those faced with regulating signal power levels at these higher frequencies, the firm offers the BW-VX-1W54+ series of fixed attenuators, with available attenuation values of 3, 6, 10, and 20 dB for a broad bandwidth of dc to 50 GHz.

The precision coaxial attenuators *(see figure)* are well-suited for impedance-matching and level-setting applications in measurement systems. Each attenuator is equipped with a 2.4-mm male connector and a 2.4-mm female connector, with passivated stainless-steel connectors used for low loss and long-term durability. All of the attenuators typically handle maximum input power of 1 W (+30 dBm) at room temperature (+25°C), with the power-handling capability derated linearly with temperature to 0.1 W at +100°C. All are designed for an operating temperature range of −55 to +100°C.

PAY ATTENTION TO ATTENUATOR SPECS

Regardless of the attenuation value selected, the performance levels are remarkably consistent across the broad frequency range, with minimal power reflected back to the source (low VSWR) and very little variation in attenuation. In terms of variation of attenuation with frequency, variations are typically less for units with higher attenuation values and less for all attenuations at higher frequencies.

For example, model BW-V3-1W54+ is a 3-dB fixed attenuator that exhibits 3.0-dB typical attenuation from dc to 26.5 GHz, 3.4 dB typical attenuation from 26.5 to 40.0 GHz, and 3.8 dB typical attenuation from 40 to 50 GHz. It has VSWR of 1.10:1 from dc to 26.5 GHz, rising to 1.20:1 from 26.5 to 40.0 GHz, and then dropping to 1.10:1 from 40 to 50 GHz.

At twice the attenuation, model BW-V6-1W54+ is rated for 6-dB attenuation from dc to 50 GHz. It shows the greatest percentage attenuation variation for the four attenuation values, with typical attenuation of 5.8 dB from dc to 26.5 GHz, 6.1 dB from 26.5 to 40.0 GHz, and 6.6 dB from 40 to 50 GHz. Its typical VSWR is quite consistent, at 1.10:1 from dc to 26.5 GHz, remaining at typically 1.20:1 from 26.5 to 50.0 GHz.

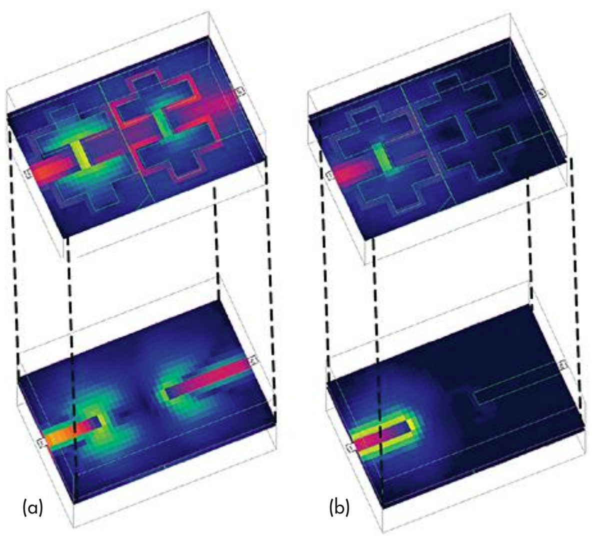
Model BW-V10-1W54+ is a 10-dB fixed attenuator that features remarkably flat attenuation with frequency, typically 10.0 dB from dc to 26.5 GHz, 10.1 dB from 26.5 to 40.0 GHz, and 10.2 dB from 40 to 50 GHz. The VSWR is also consistent, typically a low 1.20:1 from dc to 26.5 GHz and then gradually rising to 1.50:1 from 26.5 to 50.0 GHz.

Model BW-V20-1W54+ is a 20-dB fixed attenuator that remains within 0.3 dB of its nominal attenuation value across the full 50-GHz bandwidth. The attenuation is typically 19.8 dB from dc to 26.5 GHz, 19.8 dB from 26.5 to 40 GHz, and 19.7 dB from 40 to 50 GHz. The VSWR for this model actually improves at higher frequencies, with typical VSWR of 1.20:1 from dc to 40 GHz, decreasing to a mere 1.10:1 from 40 to 50 GHz.

The attenuators measure 0.871 in. (22.12 mm) lengthwise with 0.360-in. (9.14 mm) diameter. Thanks to their broadband frequency coverage, they are well-suited for a number of different applications aimed at testing emerging 5G wireless communications networks as well as satellite-communications (satcom) networks. They represent the growing number of components being developed at Mini-Circuits for use through millimeter-wave frequencies, including coaxial cable assemblies, adapters, and power combiners/dividers. mw

MINI-CIRCUITS, P. O. Box 350166, Brooklyn, NY 11235-003; (718) 934-4500, FAX: (718) 332-4661, www.minicircuits.com

(Continued from page 85)



18. An EM simulator was used to show the EM field distributions of the extracted bandpass filter at (a) 4.3 GHz and (b) 1 GHz.

were conducted on the bandpass filter at 1 and 4.3 GHz to better understand the effect of the C-DGS resonators on filter performance. Experimental results show that at around 7 GHz, a maximum amount of RF electrical energy is transferred from input to output using the J-inverter gap between both feed lines on the upper layer and both DGS resonators etched on the ground plane. The energy wave travels between the neighboring feed lines due to direct electrical coupling, while the transition between the feedlines and the DGS elements is due to indirect electromagnetic coupling. This indicates that the filter structure is in a passband state *(Fig. 18a)*.

At 0.5 GHz, full RF input power is blocked between the input and the first cross-DGS resonator. Due to coupling via the printed-circuit structure, energy is transferred from the feed line to the nearest cross-DGS resonator. The energy oscillates between port 1, the microstrip feed, and the closest DGS-resonator but energy does not reach port 2, indicating that the filter structure is in a stopband state. As *Fig. 18b* shows, the filter structure undergoes a resonance effect. mw

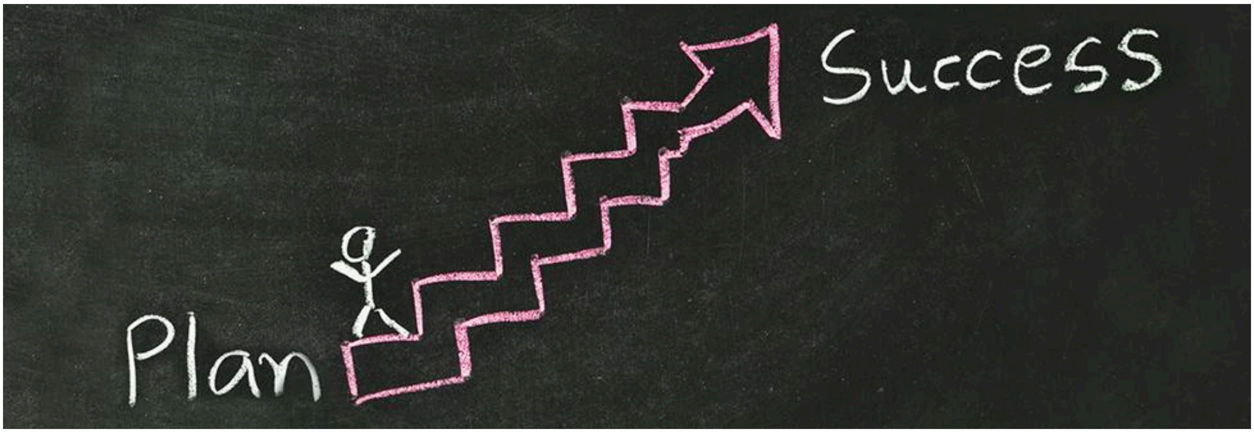
REFERENCES

1. S. Oh and Y. Kim, "A Compact Bandpass Filter Using Microstrip Slow-Wave Open-Loop Resonators with High Impedance Line," *Microwave and Optical Technology Letters*, Vol. 38, No. 3, August 2003, pp. 185-187.
2. L. Liu, Y. Wei, X. Xu, F. Shen, G. Zhao, M. Huang, T. Tang, W.X. Wang, and Y. Gong, "A novel helical slow-wave structure for millimeter wave traveling wave tube," proceedings of the 5th Global Symposium on Millimeter Waves Conference, 2012, pp. 312-315.
3. M. A. G. Laso, T. Lopetegi, M. J. Erro, D. Benito, M. J. Garde, and M. Sorolla, "Multiple-frequency-tuned photonic bandgap microstrip structures," *IEEE Microwave and Guided Wave Letters*, October 2000, pp. 220-222.
4. Q. Xue, K.M. Shum, and C.H. Chan, "Novel 1-D microstrip PBG cells," *IEEE Microwave and Wireless Component Letters*, Vol. 10, No. 10, October 2000, pp. 403-405.
5. "DGS Resonators Form Compact Filters," Microwaves & RF, Vol. 5, May 2015, pp. 12-27.
6. "DGS and Multilayer Methods Make LPF," Microwaves & RF, Vol. 3, March 2011, pp. 18-22.
7. A. Boutejdar, et al., "Compensating For DGS Filter Loss," *Microwaves & RF*, February 2012, pp. 38-43.
8. A. Boutejdar, et al. "LPF Builds On Quasi-Yagi DGS," *Microwaves & RF*, September 2013.
9. D. Ahn, J. Park, C. Kim, J. Kim, J. Park, Y. Qian, and T. Itoh, "A design of the low-pass filter using the novel microstrip defected ground structure," *IEEE Transactions on Microwave Theory & Techniques*, Vol. 49, January 2001, pp. 86-93.
10. L. Chiu, T. Yum, Q. Xue, and C. Chan, "A wideband compact parallel-strip 180° Wilkinson power divider for push-pull circuitries," *IEEE Microwave and Wireless Components Letters*, Vol. 16, No. 1, January 2006, pp. 49-51.
11. David M. Pozar, *Microwave Engineering*, 4th ed., Wiley, New York, 2011.
12. A. Boutejdar, A. Elsherbini, and A.S. Omar, "A Compact Microstrip Multi-Layer Lowpass Filter Using Triangle Slots Etched in the Ground Plane," Proceedings of the 36th European Microwave Conference 2006 (EuMC), Manchester, UK, September 2006.
13. A. Boutejdar, "Design of Compact Reconfigurable Broadband Band-Stop Filter Based on a Low-Pass Filter Using Half Circle DGS Resonator and Multi-Layer Technique," *Progress In Electromagnetics Research C*, 2017, pp. 91-100.
14. J.-S. Lim, C.-S. Kim, Y.-T. Lee, D. Ahn, and Nam, "Design of lowpass filters using defected ground structure and compensated microstrip line," *Electronics Letters*, Vol. 38, No. 22, October 2002, pp. 1,357- 1,358.
15. A. Boutejdar, N.M. Eltabit, A.A. Ibrahim, and E.P. Burte, "Design of Wide Stop Band L-Band LPF Based on DMS-DGS-Technique for Radar Applications," Hindawi Publishing Corp. International Journal of Microwave Science and Technology, Article ID 101602, 2015, pp. 7-10.
16. A. Boutejdar, "Design of Compact Reconfigurable Broadband Band-Stop Filter Based on a Low-Pass Filter Using Half Circle DGS Resonator and Multi-Layer Technique," *Progress In Electromagnetics Research C*, 2017, pp. 91-100.
17. Lin-Chuan Tsai and Ming-Lu Lee, "Design of Low-pass Filters Using Three-and Two-section Stubs," *Electron Devices and Solid-State Circuits*, 2007 EDSSC IEEE Conference, December 20-22, 2007, conference proceedings, pp. 729-732.
18. C.S. Kim, J.S. Park, A. Dal, and J. Kim, "A novel 1-D periodic defected ground structure for planar circuits," *IEEE Microwave Guided Wave Letters*, Vol. 10, April 2000.
19. A Boutejdar, "Design of a very compact HI-LO lowpass filter using meander technique and quasi horn inductors for L-band and C-band applications," *Microwave and Optical Technology Letters*, Vol. 58, No 12, 2016, pp. 2,897-2,901.
20. L.-Y. Ren, "Quad-band bandpass filter based on dual-plane microstrip/DGS slot structure," *Electron Letters*, Vol. 46, 2010, pp. 691-692.
21. A. Boutejdar, N.M. Eltabit, A.A. Ibrahim, E.P. Burte, and M.A. Abdalla, "New Compact Dual Bandpass Filter Using Coupled Double-Ring Resonators and DGS-Technique," *ACES Journal - The Applied Computational Electromagnetics*, Vol. 31, 2016, pp. 132-137.
22. A. Boutejdar, A. Elsherbini, S. Amari, M. Awida, and A. Omar, "Design of a novel microstrip bandstop filter using one compact C-open-loop resonator," in proceedings of the Asia-Pacific Microwave Conference, Yokohama, Japan, December 2006.
23. L. Liu, R. Jin, X. Bai, Y. Li, X. Liang, J. Geng, and C. He, "A tri-band bandstop filter with sharp rejection and controllable bandstop frequencies," 2015 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting, 2015, pp. 2543-2544.
24. A. Boutejdar, "A New approach to Design Compact Tunable BPF Starting from Simple LPF Topology Using a Single T-DGS-Resonator and Ceramic Capacitors," *Microwave and Optical Technology Letters*, Vol. 58, 2016, pp. 1142-1148.
25. A. Boutejdar, "Entwurf, Entwicklung und Optimierung von kompakten HF-Mikrostreifen-Filtern mittels Defected Ground Structure-Technik (DGS)," Ph.D thesis, Otto-von-Guericke University, Magdeburg, Germany, November 2010.
26. M. Awida, A. Boutejdar, A. Safwat, H. El-Hannawy, and A. Omar, "Multi-Bandpass Filters Using Multi-Armed Split Ring Resonators with Direct Feed," presented at the IEEE MTT-S International Microwave Symposium (IMS), Honolulu, HI, June 2007.
27. M.K. Khandelwal, B.K. Kanaujia, and S. Kumar, "Defected Ground Structure: Fundamentals, Analysis, and Applications in Modern Wireless Trends," *International Journal of Antennas and Propagation*, Volume 2017, Article ID 2018527, 22 pp.
28. A. Boutejdar, A. Elsherbini, A. Balalem, J. Machac, and A. Omar, "Design of New DGS Hairpin Microstrip Bandpass Filter Using Coupling Matrix Method," *Progress In Electromagnetics Research Symposium*, Prague, Czech Republic, August 2007, pp. 261-265.
29. M. Mokhtaari, J. Bornemann, and S. Amari, "Coupling-matrix design of dual/triple-band uni-planar filters," in *IEEE MTT-S International Microwave Symposium (IMS) Digest*, San Francisco, CA, June 2006, pp. 515-518.
30. A. Boutejdar, "Design of 5 GHz-compact reconfigurable DGS-bandpass filter using varactor-diode device and coupling matrix technique," *Microwave and Optical Technology Letters*, Vol. 58, 2016, pp. 304-309.

ROGER NICHOLS | Director of 5G Programs, *Keysight Technologies*

Five Must-Ask Questions for Successful 5G Design

Design teams involved with 5G technology must bear much in mind in order to obtain a winning formula.



YOU ARE LEADING a team to go after this 5G business. Your organization's strategic imperatives include leadership in 5G and you are an essential part of making that real. Your management, your team, your C-suite, and your board of directors are counting on you. No pressure. You embark on this initiative, you have your team intact, it is time to draw battle plans and start the assault. But is your team ready? Do they have Tom Wolfe's "Right Stuff" to realize that vision of 5G dominance?

After 32 years in the high-tech world, most of which I spent in engineering management roles, I have found that the team I am managing often has more insight into the success factors, enablers, roadblocks, and landmines on the road ahead. I suggest you check in with them and see where their heads are. If you are two years into your effort, it's not too late—have a chat with your team and find out:

1. Do you have the right background and expertise?

I recall once having to make the unpopular decision for my team to standardize on a single programming language. Once I made that call I realized that everyone not only had to learn the language, but also had to become proficient object-oriented programmers—a rarity at that time. It was still the right decision, but the implementation time was greater than originally expected.

5G means new technologies for many of us. This might mean designing for carrier frequencies and bandwidths that are not familiar ground to your engineers. It might mean antenna technologies with which nobody is familiar. Have you considered all the things that your team must learn or acquire? Have you considered how much will need to be acquired the hard way—by making mistakes and discovering their severity too late for anything other than a dreadful impact to your schedule or costs?

5G may mean new business models for you. This might mean your first foray into open-source software. This might mean selling services or upgrades rather than making net-30 sales. How will your design team's skills have to be adjusted in this new environment?

2. Do you have the right tools?

Some of those new technical areas will require new tools for your team. In many cases, they will know a lot about what will make the difference. Is there new hardware? Do you need RF chambers of a different size? Do you need a new computer system focused on handling much more data quickly? Do you need EDA tools to reduce hardware turns? Which ones? And, with a nod to the expertise bullet above, does your team know how to use them efficiently and effectively?

3. Are you properly connected to your key customers?

I am a fan of the agile software manifesto, especially in its commentary about putting your designers close to customers and providing rapid and frequent updates to functionality, while embracing regular and rapid changes in requirements. In an industry that is driven by consumer fad, these elements are critical not just to software development, but also hardware and business development. And without intimacy with your most

(Continued on page 143)

CHRIS DeMARTINO | Technical Editor

Q&A: Charles Trantanella,

Chief Scientist at Custom MMIC

You gave a presentation at EDI CON 2016 titled, "Reaching New Heights in Mixer Linearity with GaN MMIC Technology." For those who may not have seen it, what prompted you to investigate developing mixers based on GaN technology?

Trantanella: Essentially, it was engineering curiosity! I have been designing passive MMIC mixers for nearly 20 years, and during that time I've always jumped at the chance to create mixers on new technologies. The impetus for this curiosity began in the early 2000s when the GaAs industry pivoted towards pHEMT technology, which was touted as being vastly superior to the current MESFET technology in all regards. And in many circuits, such as amplifiers and switches, pHEMT certainly was better. But surprisingly enough, for passive mixers, I found that pHEMT was inferior to MESFET from a linearity perspective.

For example, the IP3 of a diode mixer fabricated on pHEMT was typically 2 to 3 dB lower than a similar MESFET-based design. I refused to accept this as the norm, so I began looking for ways to increase mixer linearity, since our customers generally do not ask for less linearity—they always want more. One of the paths I've chosen to accomplish this goal is to design at least one passive mixer on each process for which we have access.

A few years ago, we at Custom MMIC expanded into GaN development, and I was excited to use this technology since GaN offered so many benefits on paper: higher breakdown voltage, higher diode turn-on voltage, better efficiencies, etc. However, I also knew that when it came to passive mixers, the proof was in the fabricated design. Over the past few years, I've had the privilege of designing mixers on a number of different processes and foundries, and not all have performed as advertised. However, one GaN process in particular exceeded all of my expectations, and designs from this process were the ones I discussed at EDI CON 2016.

Do you really believe that GaN technology will play a significant role in the mixer arena in the future?

Trantanella: Absolutely. GaN has demonstrated the ability to combine high linearity in mixers with low conversion loss, high port-to-port isolations, and good harmonic/spur suppression—properties that are desired by almost all microwave system designers. The only downside to GaN is the need for higher LO drive as compared to MESFET or pHEMT mixers. However, GaN is also very good for highly efficient power amplifiers, so the drive problem is an easy one to solve. Additionally, GaN mixers tend to achieve a much higher IP3-to-LO power ratio than pHEMT or MESFET-based mixers—a term called "linear efficiency." In other words, with GaN we're generating high linearity more efficiently than we could with other technologies.

At EDI CON last September, you explained that GaN-based mixers can now achieve input IP3 levels ranging from +35 to +40 dBm. What has the company done in this area since then, and what is planned for the future?

Trantanella: Over the past few months, we've been working to release a few of our current GaN mixers as standard products, a task which should be accomplished in the next two quarters. Additionally, we are exploring a variety of mixer topologies, including balanced diode, balanced FET, and cold FET designs at numerous frequency bands, since each topology offers unique benefits depending on the operating frequency and application. Finally, we are starting to integrate LO driver amplifiers with our GaN mixers, in order to reduce the high LO drive requirement. This is a very exciting area of research, for it also allows us to use techniques such as wave shaping to further enhance the linearity of the mixer. mw

JACK BROWNE | Technical Contributor

VNAs Deliver S-Parameters Without Breaking the Bank

By leveraging the computing power of a PC, these easy-to-use VNAs make it possible to bring S-parameter measurement capability to every engineering workstation— to 3 or 6 GHz.

VECTOR NETWORK ANALYZERS (VNAs) are test instruments considered almost synonymous with the RF/microwave industry. They are vital to the 50-Ω impedance matching of components through their scattering-parameter (S-parameter) measurements, and are rarely used outside of companies and laboratories working with RF/microwave equipment. Nonetheless, they have traditionally been "high-end" instruments, in terms of both performance and cost.

Many high-frequency designers can probably volunteer a story or two about waiting for their company's VNA to be available for testing. Well, the wait is over, with the introduction of the quite affordable, yet precise, TTR500 two-port VNAs from Tektronix *(www.tek.com)*.

Priced at $12,000 USD for a 6-GHz VNA and $9,000 for a 3-GHz instrument, these VNAs literally bring S-parameters to the RF/microwave engineering masses—at least wherever there is a PC with a Universal Serial Bus (USB) 2.0 port to run the test software and control the TTR500. The measurement capability at these prices paves the way for affordable wireless products, such as for Internet of Things (IoT) and Fifth Generation (5G) wireless communications networks.

The TTR500 USB VNAs *(Fig. 1)* are available for two-port measurements from 100 kHz to 3 GHz or 100 kHz to 6 GHz, in both cases with better than 122-dB dynamic range. The two ports provide for forward- and return-loss measurements in the form of S21, S12, S11, and S22 parameters.

Although unimpressive in appearance, especially compared to their full-sized, rack-mount (and much more expensive) counterparts, they don't skimp on performance with 0.008 dB root-mean-square (RMS) or less trace noise to enable that huge dynamic range. At the other end of the dynamic range, the VNAs provide as much as +7 dBm clean test source power (harmonics are –30 dBc or better), with test source power that can be adjusted over a broad range from –50 to +7 dBm. They even have a built-in bias tee for applying test signals and bias energy to active devices, such as transistors and amplifiers.

A BIRD'S-EYE VECTOR-VU

For a host of applications, two test ports provide sufficient measurement capabilities for many high-frequency component measurements, such as gain/loss, phase, group delay, and impedance matching. The analyzers are controlled by means of a USB connection to a PC running Tektronix's VectorVu-PC software; the software is compatible with Microsoft Windows 7 and newer operating system (OS) software.

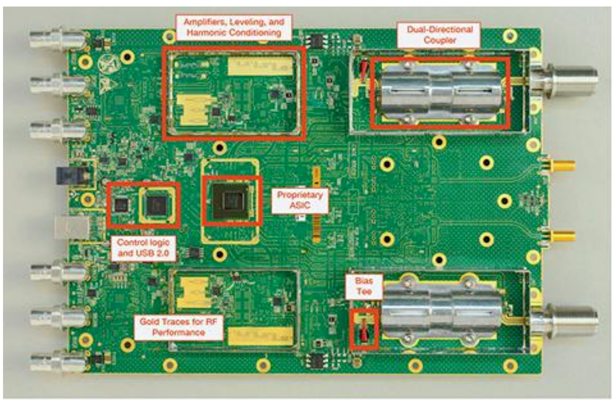
Such reliance on a PC translates into the humble appearance of the TTR500 VNAs—they lack the display and wealth of control knobs of a traditional VNA—but it also accounts for their stunningly low price tags. The TTR500 VNAs actually have more control knobs and interconnections on their

1. This unobtrusive little package houses a two-port, vector network analyzer capable of making S-parameter measurements from 100 kHz to 6 GHz.

2. The rear panel of each TTR500 two-port USB VNA includes connectors for access to the internal 10-MHz reference oscillator and an input port to connect an external 10-MHz reference oscillator. Connecting to the latter will deliver better stability/phase-noise performance—when needed—than is possible with the internal reference oscillator.

rear panels *(Fig. 2)*, including access to the internal 10-MHz reference oscillator and a port for feeding an external 10-MHz reference oscillator to the TTR500, as well as bias connection points for the built-in bias tees.

The "guts" of the TTR500 measurement system are contained in the unobtrusive housings and its internal test board, which contains a specially designed application-specific integrated circuit (ASIC) with multiple receivers. The ASIC *(Fig. 3)* contains two channels of incident, reflected, and RF reference functions to provide the high-frequency signal processing to transmit and receive test signals through forward and reverse signal paths of a device under test (DUT).



3. This ASIC is one of the keys to achieving full two-port S-parameter measurements in a package as small as the TTR500.

The "smarts" can be found in the controlling computer and the VectorVu-PC software, which provides a straightforward graphical user interface (GUI) for intuitive control of two-port VNA measurements. The firm also provides a number of instructional videos on its website, to help users get started with measurements such as broadband gain as a function of frequency.

The VectorVu-PC software provides all of the analysis capabilities of a full-sized VNA, including Smith chart displays of S-parameter amplitude and phase as a function of impedance *(Fig. 4)*. For circuit designers, the VectorVu-PC software can generate .sNp Touchstone-compatible files for use in a commercial computer-aided-engineering (CAE)

TEST CABLES *up to 40 GHz!*

Reliability You Can Trust... from $68.95 ea. (qty.1-9)

Why do 10,000 customers trust Mini-Circuits test cables? Because they simply don't fail! Our test cables have been performance qualified to 20,000 flexures* and come backed by our 6-month product guarantee**, so you can be confident you're getting rugged construction, reliability, and repeatable performance you can depend on. Whether you're performing production test, burn-in, over-temperature testing, hi-rel testing – you name it – chances are there's a Mini-Circuits test cable for your application in stock, ready for immediate shipment. Order some for your test setup at minicircuits.com today, and you'll quickly find that consistent long-term performance, less retesting and fewer false rejects really add up to bottom-line savings, test after test!

Model Family	Capabilities	Freq. (GHz)	Connectors†
KBL	Precision measurement, including phase, through 40 GHz	DC-40	2.92mm
CBL-75+	Precision 75Ω measurement for CATV and DOCSIS® 3.1	DC-18	N, F
CBL	All-purpose workhorse cables for highly-reliable, precision 50Ω measurement through 18 GHz	DC-18	SMA, N
APC	Crush resistant armored cable construction for production floors where heavy machinery is used	DC-18	N
ULC	Ultra-flexible construction, highly popular for lab and production test where tight bends are needed	DC-18	SMA
FLC	Flexible construction and wideband coverage for point to point radios, SatCom Systems through K-Band, and more!	DC-26	SMA
NEW! SLC	Super-flexible spaghetti cables with 0.047" diameter and 0.25" bend radius, ideal for enviromental test chambers.	DC-18	SMA/SMP
VNAC	Precision VNA cables for test and measurement equipment through 40 GHz	DC-40	2.92mm

* All models except VNAC-2R1-K+

** Mini-Circuits will repair or replace your test cable at its option if the connector attachment fails within six months of shipment. This guarantee excludes cable or connector interface damage from misuse or abuse.

† Various connector options available upon request.

Contact apps@minicircuits.com to discuss your special requirements.

Mini-Circuits®

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

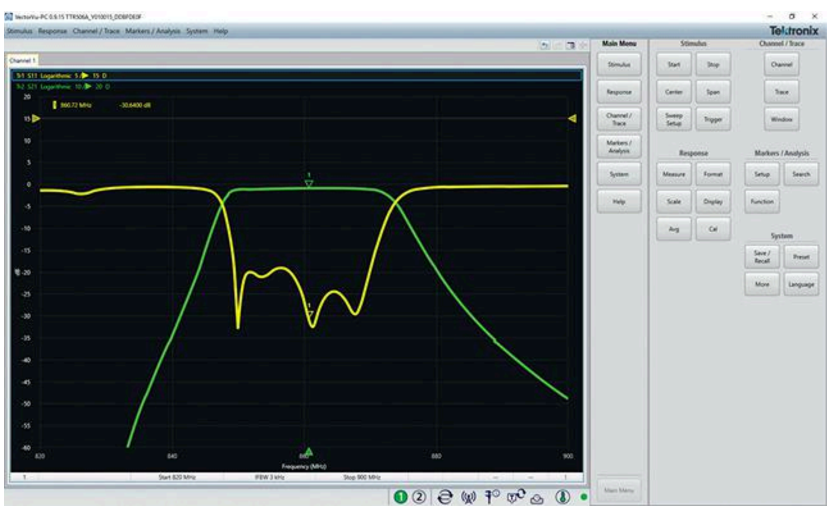
These USB VNAs and the VectorVu-PC software make S-parameters affordable and, in so doing, should make measurements like gain, phase, and VSWR with frequency accessible for a growing number of RF/microwave engineers and their applications.

simulation program. The software should run on a fairly robust PC, with a Core i7 microprocessor from Intel with 8-GB memory—the recommended computing engine—and minimum of a Core i3 microprocessor with at least 8-GB memory.

These USB VNAs and the VectorVu-PC software make S-parameters affordable and, in so doing, should make measurements like gain, phase, and VSWR with frequency accessible for a growing number of RF/microwave engineers and their applications. The VNAs enable students and industry professionals to perform two-port S-parameter measurements without waiting for access to the single VNA system at a particular location.

The TTR500 VNAs are backed by a complement of accessories, including calibration kits, coaxial adapters, phase-stable measurement cables, rack-mount kits—even a carrying case to make it easier to transport the VNA. Each of the TTR500 VNAs measures just 8.125 × 11.25 × 1.75 in. (206.4 × 285.8 × 44.5 mm) and weighs only 3.5 lbs. (1.59 kg). They are small enough to fit almost anywhere, yet still possess the performance needed for troubleshooting, design support, and even classroom instruction. The minuscule price tags all but ensure that those working on the growing number of "commodity" wireless applications, such as impedance matching of antennas for IoT wireless sensors, will find a two-port VNA in their price range. mw

TEKTRONIX INC., P. O. Box 500, 14150 SW Karl Braun Dr., Beaverton, OR 97077; (800) 833-9200, www.tek.com.



4. The TTR500 USB VNAs are controlled by a USB-equipped PC running VectorVu-PC measurement software. The combination is capable of a 122-dB dynamic range to 6 GHz with performance comparable to full-sized, rack-mount VNA systems.

KEN KARNOFSKY | Senior Strategist, Signal Processing Applications, MathWorks
www.mathworks.com

What You Need to Become a Multi-Functional Engineer

A software platform with multi-domain capabilities can be highly beneficial for next-generation wireless system development that incorporates various technologies.

WITH THE CURRENT pace of innovation in wireless technology, the days of domain experts working in silos are numbered. Wireless engineering teams know that in order to keep up with the demands of next-generation systems, they need a more integrated approach. It starts with enabling team members to become multi-functional engineers who can comfortably work in the digital, RF, and system domains.

Domain specialists productively use tools that are tailored to their task, such as modeling RF architectures, designing digital hardware, and developing algorithms. But those tools don't help specialists understand how their individual work fits into the rest of the system. Because the performance of digital, RF, and antenna designs are so tightly coupled, using tools that bridge those domains has become essential.

THE EXPERTISE EXPLOSION

The tools capable of supporting the work of the multi-functional wireless engineer are already on the market. They are particularly useful for advanced research and design problems, such as modeling multi-antenna (MIMO) systems found in LTE and WLAN systems and 5G proposals, including antenna arrays, propagation patterns, and beamforming.

When working on these or other advanced technologies, wireless engineers have to focus on accelerating research and innovation, while minimizing the time and resources spent on programming, debugging software, or building FPGA hardware realization of their design ideas. For a typical team that consists of engineers with strong signal processing and algorithm development backgrounds—but relatively little experience with RF design or hardware implementation—it is often difficult to simulate or prototype complete radio designs without outside assistance. They are similarly challenged by problems such as developing massive multi-antenna systems that depend on understanding the behavior of highly coupled digital, RF, and antenna elements.

The expertise needed to develop wireless technology is exploding. This is a major challenge for R&D teams as they race to deliver the next breakthrough. The days of domain experts working separately, using separate tools, are numbered. Fortunately, there is a better way.

Many of these teams recognize the need for a software environment that can encompass algorithm design, system simulation, over-the-air testing, prototyping, and implementation. Compared with groups still designing in silos, successful wireless teams are turning to MATLAB and Simulink as platforms that can help teams integrate multiple engineering disciplines into a coherent workflow.

Wireless engineers are leveraging MATLAB algorithms all the way to full system simulation and implementation of LTE, WLAN, 5G, and other wireless systems. These engineers use MATLAB and Simulink to integrate RF, mixed-signal, and digital technologies into multi-domain system models; connect to hardware for over-the-air testing with live signals; and prototype and implement their designs on a range of hardware.

By developing fixed-point algorithms in MATLAB and Simulink, then verifying them in system-level simulations, R&D engineers can rapidly iterate on new design concepts. Once the algorithm runs correctly in simulation, they can automatically generate synthesizable Verilog or VHDL code for deployment to an FPGA-based testbed with the click of a button.

THE FUTURE OF THE MULTI-FUNCTIONAL ENGINEER

Traditionally, digital communications, RF, and antenna engineers have worked in different environments, with integration occurring when the first hardware prototype was developed. The advent of highly integrated RF transceivers has put a strain on this workflow. Now wireless engineers can use MATLAB and Simulink to model, simulate, and analyze complex RF front ends that include RF, analog, digital, and control logic components.

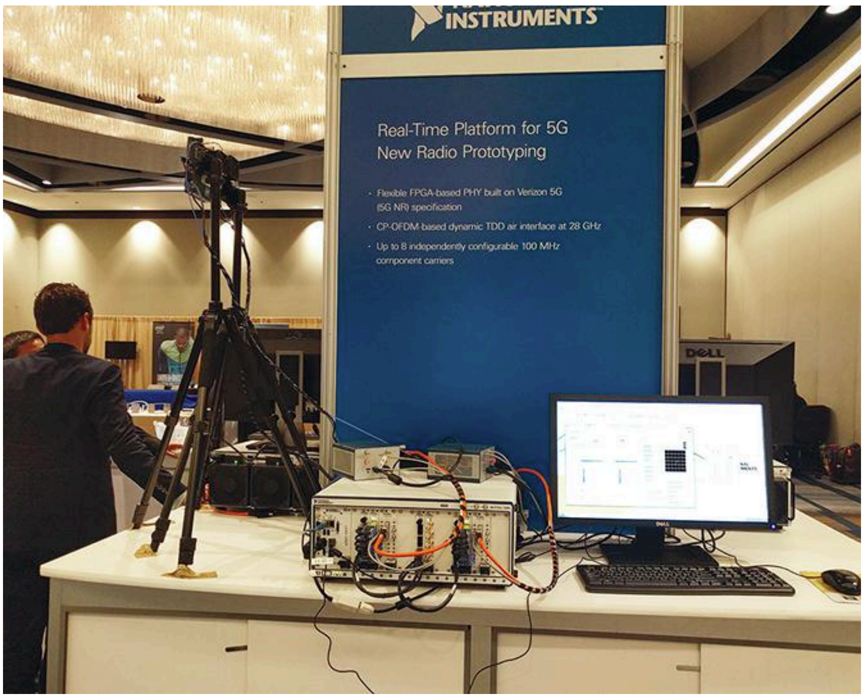
Together, this enables an integrated workflow that unifies design of algorithms and RF components, system simulation, prototyping, testing, and implementation. As a result, engineers can eliminate steps and correct design problems before moving to implementation, accelerating delivery of error-free prototypes and products for the next generation of wireless communications systems.

As long as the pace of wireless technology continues, the need for the multi-functional engineer will only increase. Will you be ready? mw

CHRIS DeMARTINO | Technical Editor

Partnership Propels 5G Development

NYU WIRELESS and National Instruments (NI) are teaming up to develop the advanced solutions needed to bring 5G to fruition.



On display at the Brooklyn 5G Summit was National Instruments' 5G OTA test solution.

RECENTLY, I HAD the opportunity to attend the fourth Brooklyn 5G Summit, which took place April 19-21 at the New York University (NYU) Tandon School of Engineering in Brooklyn, N.Y. A wide range of 5G topics were discussed at the event, such as massive multiple-input, multiple-output (MIMO), 5G network architecture, and much more. In addition, the exhibition featured a number of demonstrations.

One company that had a notable presence at the Brooklyn 5G Summit is National Instruments (NI; *www.ni.com*). NI made headlines in the days prior by announcing a generous donation to the NYU WIRELESS academic research center. The donation is intended to assist research efforts at NYU WIRELESS regarding 5G communications and beyond. Thanks to that donation, NYU WIRELESS labs will be able to take advantage of hardware and software from NI's flexible software-defined-radio (SDR) solutions.

OVER-THE-AIR DEMONSTRATION

Visitors to the exhibition were able to take in several demonstrations from NI. One of them was the same 5G over-the-air (OTA) test solution that was first shown at the IEEE Wireless Communications and Networking Conference (WCNC) in March.

James Kimery, director of marketing for RF, communications, and software-defined radio (SDR) initiatives at NI, led a walk-through of the demo. "This is one of the first OTA demos based on Verizon's 5G specification," said Kimery. "What's interesting is that it's actually a MIMO setup at 28 GHz—and it's the full spec. You can actually test the full bit rate."

Kimery continued, "We announced the baseband portion of the system last year. And we recently announced our 28-GHz heads, which have both transmit and receive capability. Another key technology is the phased-array antennas. This technology allows for real-time control of the beams in the array, which is really important. What's good about this is that researchers can experiment with the beams to

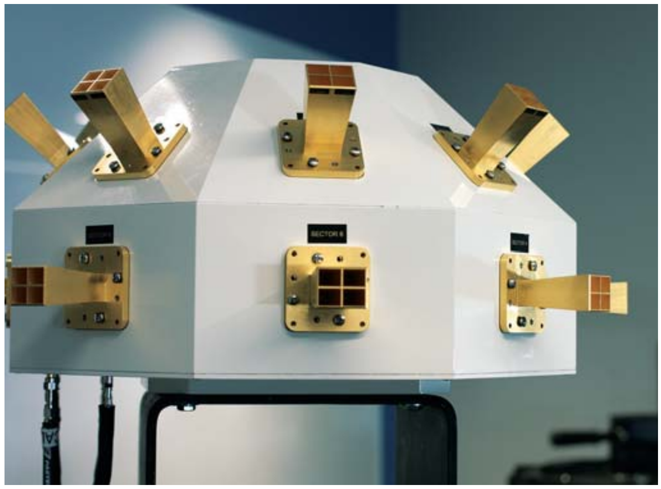
understand how the beams are shaped and then optimize performance that way."

THE PORCUPINE-CHANNEL SOUNDER

Also demonstrated was AT&T's channel sounder, which was created in collaboration with NI. The channel-sounding system, referred to by AT&T as the "Porcupine," uses the same aforementioned 28-GHz heads. However, the difference is that it connects to the Porcupine on the receive side.

"We're using some advanced techniques," noted Kimery. "A typical channel sounder will have two horn antennas—one for transmitting and one for receiving. Those horn antennas are rotated using a servo motor to cover 360 degrees. This system does everything automatically. There are switches inside to go through each of the horns in less than 150 ms."

According to Kimery, the fast measurement speed of the Porcupine is highly beneficial. He explained, "The speed allows you to take measurements faster. You can capture 2 GHz of bandwidth from four streams and have all the measurements done in 150 ms. The normal way is to take a snapshot, move the antenna, take another snapshot, etc. But that process only acquires the data. You then have to take that data and post-process it. This new system takes 4X or more data than a typical channel sounder and processes it an order of magnitude faster."



The "Porcupine" channel sounder can deliver 360-deg. channel measurements in real time.

Kimery added, "The other benefit of this channel sounder is that it allows you to know how a channel really behaves. If you're taking snapshots and moving a servo, there is a time gap between snapshots. This system can quickly take 360-degree measurements, allowing you to get a good picture of what the channel looks like in real-time."

CHANNEL EMULATION

The NI donation is also spurring channel-emulation development at NYU WIRELESS. Kimery said, "With channel sounding, you get an accurate picture of the channel. But now you want to try some different things without having to go over the air." In essence, channel emulation allows one to test real hardware without even needing to transmit signals over the air.

Aditya Dhananjay, a postdoctoral research fellow at NYU, is driving channel-emulation development efforts. He stated, "If you have to test wireless systems, you need to do testing in various scenarios. This over-the-air testing is very expensive and time-consuming.

"We can connect the transmitter and receiver to a box, known as an emulator, instead of transmitting a signal over the air," added Dhananjay. "The emulator will take the signal from the transmitter and modify it as if it has gone over the programmed wireless channel. The resulting signal is then given to the receiver. So you can test the transmitter and receiver while sitting in the comfort of your lab without having to go outdoors and do measurements."

This article only covers some of the activity taking place at NYU WIRELESS. But it is clear that NYU WIRELESS and NI together are helping to pave the way for 5G communications. While much work still needs to be done before 5G becomes a reality, the partnership of NYU WIRELESS and NI will surely drive the technology to make it finally happen. mw

(Continued from page 132)

important customers (the ones with, or who can influence, the most money—not the loudest ones) your ability to address needs, anticipate changes, and respond to both will be too slow for your market success.

Are you talking to the right people in your key accounts? I once watched a major project fail even though the team was working quite well with a critical customer. However, the team was getting its guidance from the wrong individuals. After significant investment, the people who were in charge stepped in and unceremoniously cancelled the entire program.

4. Is your timing consistent with theirs?

The recipe for the most fabulously successful projects I have witnessed are probably familiar to you: your project is timed to supply your lead 2-3 customers in perfect alignment with their project timing and the overall market demand is simultaneously growing. This magical combination is, to some extent, the result of luck, but my very first boss in this high-tech world always told me that you make your own luck. What this means to me is to start with a well-prepared team, with the right tools tightly connected to their most important customers, and then make sure your schedule matches theirs.

You may argue that your strategic process needs to be honed to ensure alignment with the "market growth" ingredient in my recipe. But I also recall our CEO at Agilent, Bill Sullivan, saying more than once that "execution eats strategy for lunch." So make sure your timing is right!

5. Do you have the support you need from your organization?

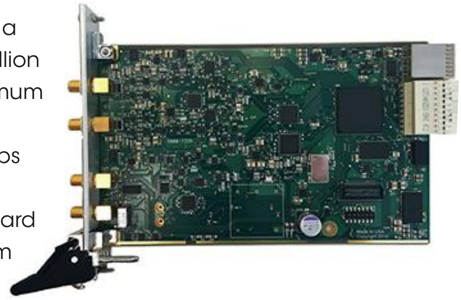
This is hardly unique to 5G, but we all need this reminder. I have never personally witnessed a manager leading a "strategic imperative" who was satisfied with the support coming from the rest of the organization. I have also never witnessed true innovation in a relaxed atmosphere. Therefore, we leaders are asked to embrace these challenges.

Your team is probably keenly aware of some organizational support that will make a huge difference in their chances for success. Sometimes, getting this support is not difficult. I have been frustrated by subordinate managers in the past who, after inadequate results, have said to me, "If only we would have had A or B…" My response to them was, "Why didn't you ask?" I am, however, embarrassed to admit having made the same mistake myself.

CONCLUSION

Talk to your team and find out what they think would make the difference. They and you will not get everything you ask for, but this process will likely clear a few roadblocks. And the innovation associated with a well-prepared, customer-connected, and motivated team will help you overcome the other challenges. mw

Counter/Timer Measures 30-ps Rise Times



DESIGNED FOR PRECISE ltime and frequency measurements, model NK732 is a modular PXIe counter/time-interval analyzer (TIA) that can make up to 20 million measurements/s. It is capable of measuring frequency to 500 MHz and minimum pulse widths of 100 ps. The instrument can capture pulse rise times as fast as 30 ps. Based on a patent-pending architecture, the counter/timer features 2-ps single-shot resolution. With its modular format and four-lane PXIe interface, as many as 32 measurement channels can fit in a single PXIe chassis. The standard time base is a temperature-compensated crystal oscillator (TCXO) with 1-ppm stability, although an oven-controlled crystal oscillator (OCXO) time base with 0.005 ppm stability and low phase noise is available as an option. P&A: $4950; stock.
CARMEL INSTRUMENTS, LLC, 1622 W. Campbell Ave., Ste. 107, Campbell, CA 95008; (408) 866-0846, *www.carmelinst.com*

WLAN Tester Characterizes Chipsets

THE WIRELESS CONNECTIVITY Test Set MT8862A, which has been designed for testing wireless local area network (WLAN) protocol standards such as IEEE 802.11ac/n/a/g/b while a device under test (DUT) is actually operating within the standard, now includes a network mode. In this new mode, the test set can be used to verify the performance of WLAN chipsets for electronic products such as smartphones and IoT devices. It can evaluate a wide range of performance parameters, including transmit power and receive sensitivity, eliminating the need for dedicated test modes for each chipset. For ease of use, the test set can be operated remotely via web browser from a control personal computer (PC) connected by Ethernet.
ANRITSU CO., 490 Jarvis Dr., Morgan Hill, CA 95037-2809; (408) 778-2000, *www.anritsu.com*

Amp Drives 900-W Pulses from 3.1 to 3.5 GHz

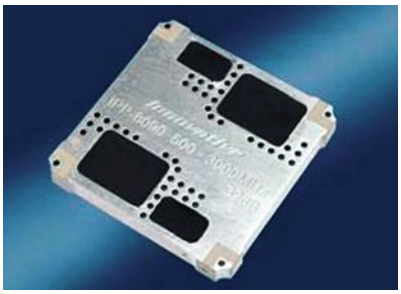
MODEL BMPC318358-900 is a Class AB linear power amplifier module based on GaN solid-state device technology. It provides as much as 900 W peak output power for S-band radar systems from 3.1 to 3.5 GHz when operating with pulse widths from 2 to 200 µs. The power gain is nominally 37 dB at 900 W output power. The pulse droop is less than 1 dB. The input VSWR is less than 1.50:1 and the output VSWR is less than 2.0:1. Second harmonics are –40 dBc and third harmonics are –50 dBc. The GaN amplifier module measures 10.1 × 6.33 × 1.60 in. and weighs 5 lb. It is equipped with SMA input RF ports and Type N RF output ports. It draws 6 A at +50 V dc.
COMTECH PST, 105 Baylis Rd., Melville, NY 11747; (631) 777-8900, *www.comtechpst.com*

Lowpass Filters Fit Compact 0805 Housings

A LINE OF thin-film surface-mount lowpass filters are supplied in 0-805 housings in support of dense circuit applications. Available with cutoff frequencies of 1,800, 1,900, 2,400, 2,900, 3,500, and 4,000 MHz, the filters are suitable for a wide range of wireless applications including in satellite television receivers and GPS receivers. The 50-Ω filters handle as much as 8 W continuous input power across operating temperatures from –40 to +85°C. The RoHS-compliant lowpass filters measure 2.03 × 1.55 × 1.02 mm. They are supplied in tape-and-reel format for automated manufacturing processes.
AVX CORP., One AVX Blvd., Fountain Inn, SC 29644; (864) 967-2150, *www.avx.com*

Programmable Pad Ranges 26.5 to 40.0 GHz

MODEL DTA-26R5G40G-30-CD-1 IS a 10-b TTL programmable PIN diode attenuator that provides 30-dB attenuation in 0.03-dB steps from 26.5 to 40.0 GHz. It is rated for maximum CW power of +24 dBm and has an input 1-dB compression point of +10 dBm. The programmable attenuator has 6-dB typical insertion loss and is capable of fast switching speeds of 300 ns. The attenuation accuracy is typically ±2 dB. The attenuator operates on a single +15 VDC supply and draws only 50 mA of current. It measures just 2.0 × 1.8 × 0.5 in.
PLANAR MONOLITHICS INDUSTRIES, INC., 7311-F Grove Rd., Frederick, MD 21704; (301) 662-5019, e-mail: sales@pmi-rf.com, www.pmi-rf.com



Surface-Mount Coupler Handles 200 W Power

THE IPP-8090 dual-directional coupler provides 32-dB coupling within ±1.5 dB from 500 to 3,000 MHz. The coupling flatness is within ±1 dB with better than 17-dB directivity across the frequency range. Insertion loss is 0.3 dB or less while mainline VSWR is less than 1.30:1. The surface-mount coupler measures just 1.00 × 1.00 in. but handles as much as 200 W power. The dual directional coupler is designed for operating temperatures from –55 to +85°C.
INNOVATIVE POWER PRODUCTS, INC., 1170 Lincoln Ave., Unite 7, Holbrook, NY 11741; (631) 563-0088, e-mail: info@innovativepp.com, www.innovativepp.com

Directional Couplers Handle High Power

THE 780 SERIES of miniature directional couplers includes more than models covering portions of the frequency range from 500 MHz to 18 GHz with nominal coupling values of 10, 20, and 30 dB. As an example, the broadband 780-dB-9.500-M01 operates from 1 to 18 GHz with nominal values of coupling specified with ±1 dB coupling flatness. The coaxial couplers can handle 50 W forward power and 2 kW peak power. The mainline VSWR is 1.40:1 and the secondary line VSWR is 1.50:1. These couplers offer directivity of 15 dB to 12.4 GHz and 12 dB at frequencies greater than 12.4 GHz. Insertion loss is controlled to 0.85 dB.
MECA ELECTRONICS, INC., 459 East Main St., Denville, NJ 07834; (866) 444-6322, (973) 625-0661, e-mail: sales@e-MECA.com, *www.e-MECA.com*

Vector Phase Shifter Spans 2 to 18 GHz

MODEL PS-2G18G-360-8D is an 8-b vector phase shifter suited for frequency translation applications where continuous monotonic phase shifting is requiring. It operates from 2 to 18 GHz with 360-deg. phase-shift range and ±15-deg. phase accuracy and better than 410-ns phase switching speed. Maximum insertion loss is 18 dB and harmonic distortion is typically less than –60 dBc. The vector phase shifter is supplied in a package measuring 4.25 × 3.50 × 1.00 in. with female SMA connectors and subminiature D control connector. It draws 100 mA from a power supply of ±12 to ±15 V dc.
PLANAR MONOLITHICS INDUSTRIES, INC., 7311-F Grove Rd., Frederick, MD 21704; (301) 662-5019, e-mail: sales@pmi-rf.com, www.pmi-rf.com

Low-Noise Amp Bypasses Large Signals to 5 GHz

Mini-Circuits' model ZX60-53LNB+ is a low-noise amplifier with wideband frequency range of 500 MHz to 5 GHz. It contains internal switching to extend its dynamic range by bypassing high-level signals. Well suited for wireless base stations and test applications, the amplifier has typical noise figure of 1.12 dB at 500 MHz, 1.40 dB at 3 GHz, and 1.63 dB at 5 GHz. It provides typical gain of 22 dB at 500 MHz, 20.2 dB at 3 GHz, and 17.9 dB at 5 GHz, with outstanding gain flatness of ±0.6 dB from 700 to 2000 MHz. The RoHS-compliant amplifier is supplied in a compact housing measuring 1.88 × 1.18 in. with SMA connectors.

Surface-Mount Filter Passes DC to 264 MHz

Mini-Circuits' model ULP-264+is a miniature, surface-mount lowpass filter with passband of DC to 264 MHz and high rejection beyond that frequency range. The passband insertion loss is typically 1.5 dB and no worse than 2 dB, with typical passband VSWR of 1.55:1. The stopband rejection is typically 27 dB from 365 to 600 MHz and typically 47 dB from 600 to 1600 MHz. Measuring only 0.25 × 0.25 in., the tiny filter is rated for maximum input power of 1 W. It provides removal of spurious signals from transformers and wireless communications receivers, and can be used at operating temperatures from -40 to +85°C.

SPDT Switch Controls 5 MHz to 6 GHz

Mini-Circuits' model JSW2-63VHDRG+ is a high-power, single-pole, double-throw (SPDT) reflective switch for applications from 5 MHz to 6 GHz. It is supplied in a tiny, 12-lead 2 × 2 mm MCLP package complete with internal CMOS driver. Designed for a single supply voltage of +2.3 to +5.5 V dc, the component has typical switching time of 2 μs from 50% control signal to 90%/10% RF level. The switch handles 2.5 W power at 2 GHz with only 0.4-dB typical on-state insertion loss at 3 GHz and only 0.9 dB typical on-state insertion loss at 6 GHz. Isolation between ports is 69 dB at 100 MHz and still 20 dB at 5 GHz. The switch offers high linearity, with IIP3 of typically 75 dBm through 6 GHz.

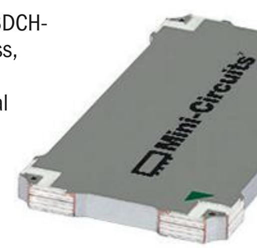
Flexible Test Cables Connect DC to 18 GHz

Mini-Circuits' SLC-2FT-SMSM+ Series super-flexible test cables provide phase-stable interconnections from DC to 18 GHz for test and research applications. The 0.064-in.-diameter, double-shielded cables achieve a minimum bend radius of 0.25 in. with negligible change in loss and phase with flexure. Available in a variety of standard lengths, the cables are terminated with straight SMA to straight SMA stainless-steel connectors. For a 2-ft. length, the typical insertion loss is 1 dB from 1 to 2 GHz and 2.9 dB from 10 to 18 GHz. The typical return loss is better than 33 dB from DC to 6 GHz and 28.5 dB from 6 to 18 GHz. The cables are performance qualified to 100,000 flexures.

SP8T Switch DC to 12 GHz

Mini-Circuits' model MSP8TA-12-12D+ is a single-pole, eight-throw (SP8T) absorptive switch rated for 5 million switching cycles from DC to 12 GHz. The rugged absorptive failsafe switch is designed in a make-before-break configuration and provides reliable sleep-mode switching in ATE systems and redundancy switching in microwave radio systems. It provides 90-dB typical isolation from DC to 12 GHz and 100 dB typical isolation from DC to 8 GHz. The typical insertion loss is 0.4 dB through 12 GHz. The patented +12-V switch handles as much as 20 W cold-switching power with typical switching speed of 20 ms. The RoHS-compliant SP8T switch is supplied with SMA coaxial connectors.

Bidirectional Coupler Handles 150 W from 700 to 2700 MHz



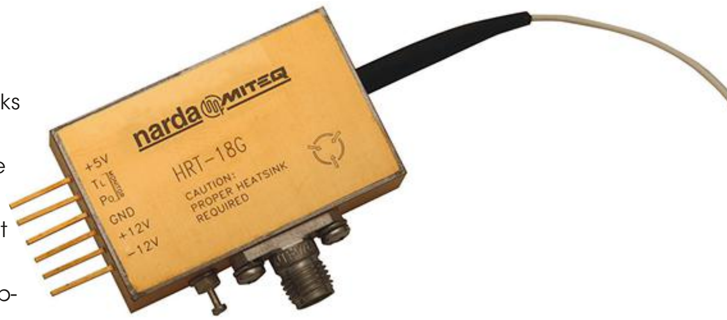
Mini-Circuits' model BDCH-15-272 is a DC-pass, high-power bidirectional coupler suitable for signal monitoring from 700 to 2700 MHz. It provides coupling of 15 ± 0.5 dB across the full range, with typical coupling flatness of ±1.25 dB and typical directivity of 18 dB. The compact 50-Ω coupler handles RF/microwave power to 150 W and passes DC current to 2.5 A. It is designed into an open PCB laminate measuring just 0.5 × 1.0 in. with wrap-around terminations. The coupler has low insertion loss of typically 0.2 dB across the full frequency range, with typical return loss of 25 dB at all ports.

BAW Bandpass Filter Spans 1920 to 1980 MHz

THE TQQ7301 BULK-ACOUSTIC-WAVE (BAW) bandpass filter from Qorvo is now available from stocking distributor RFMW, Ltd. Designed for Band 1 uplink cellular communications applications, the filter has a passband of 1,920 to 1,980 MHz with typical insertion loss of 2 dB at room temperature and 3 dB across the full operating temperature range of –40 to +95°C. The input and output return loss is typically 10.4 dB or better. Stopband attenuation is typically 34 dB or better from 900 kHz to 1,870 MHz and typically better than 36 dB from 2,030 to 6,000 MHz. The filter is supplied in a six-pin leadless SMT housing measuring 3 × 3 mm.

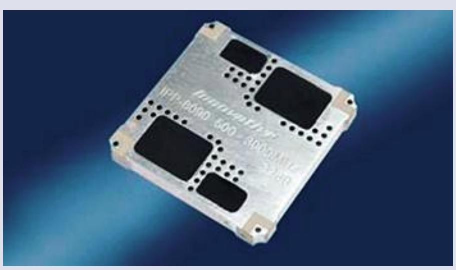
RFMW, LTD. (QORVO STOCKING DISTRIBUTOR), 188 Martinvale Ave., San Jose, CA 95119; (408) 414-1450, e-mail: info@rfmw.com, *www.rfmw.com*

Optical Transmitters Offer Bandwidths to 18 GHz



A RANGE OF fiber-optic transmitters enables fiber-optic links with bandwidths from 50 MHz to 18 GHz across operating temperatures from –40 to +85°C. Suitable for a wide range of commercial and military applications, including for antenna remoting, these plug-and-play links are compact and include field-removable optical attenuators for high-loss installations. They provide 14-dB typical electrical-to-optical gain and can handle signals at maximum input power levels as high as +10 dBm. The optical links include 50-Ω SMA female connectors. The peak-to-peak group delay is typically only 0.12 ns. The typical input VSWR is 1.70:1.

L3 NARDA-MITEQ, 435 Moreland Rd., Hauppauge, NY 11788; (631) 231-1700, e-mail: nardaMITEQ@L3T.com



Amp Drives 900-W Pulses from 3.1 to 3.5 GHz

THE IPP-8090 dual-directional coupler provides 32-dB coupling within ±1.5 dB from 500 to 3,000 MHz. The coupling flatness is within ±1 dB with better than 17-dB directivity across the frequency range. Insertion loss is 0.3 dB or less while mainline VSWR is less than 1.30:1. The surface-mount coupler measures just 1.00 × 1.00 in. but handles as much as 200 W power. The dual directional coupler is designed for operating temperatures from –55 to +85°C.

INNOVATIVE POWER PRODUCTS, INC., 1170 Lincoln Ave., Unite 7, Holbrook, NY 11741; (631) 563-0088, e-mail: info@innovativepp.com, *www.innovativepp.com*

Amp Drives 900-W Pulses from 3.1 to 3.5 GHz

THE ID SERIES is of industrial dipole antennas include a bracket molded into the assembly (IP-67 rated) for ease and reliability of installation and operation. Designed for indoor or outdoor use at 2.4 GHz, the ID series antennas handle a wide operating-temperature range of –40 to +85°C. The antenna features UV resistance that meets UL 2556 section 4.2.8.5 requirements.

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

(Continued from page 69)

is the standard 50-Ω load impedance, $Z_1 = (Z_0Z_2)^{0.5} = 24.5$ Ω and $Z_3 = (Z_2R_L)^{0.5}/(3)^{0.5} = 28.9$ Ω. There may be different combinations of the characteristic impedances between quarter-wave microstrip lines in the output combiner. The quarter-wave microstrip line in the input path of the carrier amplifier is used to compensate for the delay provided by the output combiner.

The input three-way in-phase power divider *(Fig. 6)* was implemented on 20-mil-thick RO4350 circuit material from Rogers Corp. (www.rogerscorp.com), which was also used to implement the entire Doherty amplifier circuit. It includes a transforming quarter-wave line, and an asymmetric 1:2 two-way Wilkinson divider to split power between the two signal paths, one with the carrier and first peaking amplifiers and the other with the second peaking amplifier. Also incorporated is a symmetric two-way Wilkinson divider to equally split power between the carrier and first peaking amplifiers; an additional 50-Ω quarter-wave microstrip line in the carrier path; and three equal-length 50-Ω connecting microstrip lines in the carrier and two peaking paths.

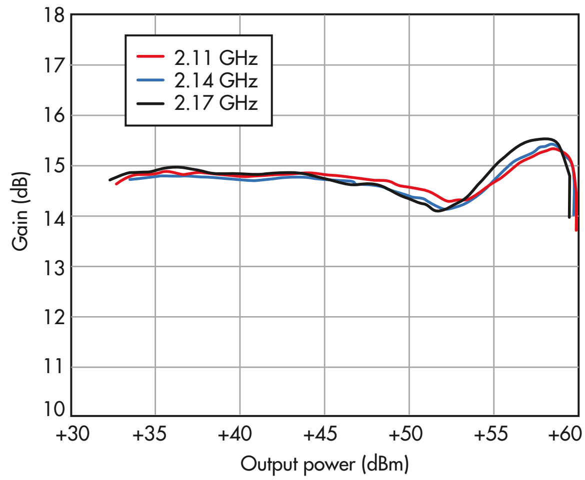
TEST RESULTS

The test board of a modified three-way Doherty amplifier based on three dual-path GaN HEMT devices in metal-ceramic flange packages, each including a pair of 180-W GaN HEMT dies with internal input matching, was fabricated on 20-mil-thick RO4350 circuit material. The input three-way divider, input and output matching circuits, offset lines, output combiner, and gate and drain bias circuits (having bypass capacitors on their ends) are fully based on microstrip lines of different electrical lengths and characteristic impedances. Special care was taken for the device implementation process to minimize the output lead inductances of the packaged GaN HEMT devices.

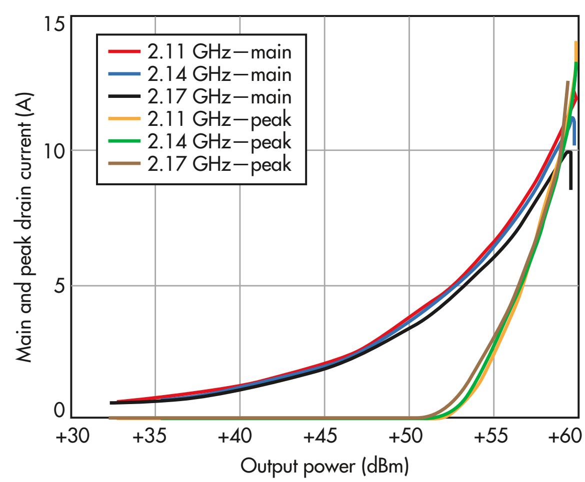
The output power at 1-dB gain compression point P_{1dB} was measured at 60 dBm, while peak efficiency of 80% and power gain of about 15 dB were achieved at a supply voltage of 55 V dc within a frequency range of 2.11 to 2.17 GHz. *Figure 7* shows the plots of the drain efficiency versus output power, revealing a drain efficiency of about 70% at around 8.5-dB power back-off.

For a 20-MHz Long Term Evolution (LTE) signal with 8-dB PAR, an average power of 52 dBm was obtained with a drain efficiency of about 65%. In this case, a power gain of about 15 dB was achieved in a linear operating region having 2-dB flatness over the entire output power range to 60 dBm when its value is reduced by just 1 dB compared to its value in the linear region *(Fig. 8)*.

Figure 9 shows the measured dc drain current of the main and peaking amplifiers versus output power. The cutoff point of the peaking amplifiers, when turned off, is about 50 dBm across the operating frequency range of 2.11 to 2.17 GHz.



8. Here, the plots reveal measured gain as a function of output power.



9. The drain currents for the carrier and peaking amplifiers are plotted as a function of output power.

This is the first implementation of a 1-kW three-way asymmetric Doherty amplifier configuration based on innovative Sumitomo GaN HEMT device technology. It features 65% average drain efficiency for cellular communications transmitters operating from 2.11 to 2.17 GHz.

It was shown that high average efficiency of 65% and high power gain of about 15 dB can be achieved at exceptionally high output power of 1 kW corresponding to 1-dB gain compression point. At the same time, the modified asymmetric Doherty amplifier has the ability to be digitally predistorted to meet stringent spectral mask requirements. This is the highest performance for peak power and drain efficiency ever recorded in a high-power Doherty amplifier development for cellular base-station applications. mw

IMS

IEEE 5G SUMMIT AGENDA

5-6 June 2017

13:00-13:10 | Welcome Address and 5G Summit Overview

Debabani Choudhury, *Intel Labs*

13:10-13:40 | Keynote Topic on 5G Core and Fog Networking

Keynote Speaker: Flavio Bonomi, *Nebbiolotech*

13:40 -14:00 | 5G: New Spectrum, More Security and Opportunities for New Ideas

Henning Schulzrinne, *FCC CTO*

14:00-14:20 | 5G Operators and Service Providers

Chih-Lin I, *China Mobile*

14:20-14:40 | Advanced Multicarrier Waveforms for 5G and Beyond

Hanna Bogucka, *Poznan University of Technology*

14:40-14:50 | Coffee Break

14:50-15:10 | 5G Views from NTT-DOCOMO and Experimental Trials

S. Suyama, *NTT-DOCOMO*

15:10-15:30 | 5G Channel Modeling for mmW Systems

Andrew Molisch, *USC*

15:30-15:50 | Enabling 5G Densification Utilizing mmW Capable Access and Backhaul

Ali Sadri, *Intel*

15:50-16:30 | Panel Session: 5G Start Up Ecosystem – Network to Components

Moderator: Joy Laskar, *Maja Systems*

Panelists: Nitin Jain, *Anokiwave*; Khurram Sheikh, *Kwikbit*; Farooq Khan, *PHAZR*

16:30 (Adjourn) | REMEMBER TO ATTEND THE IMS2017 PLENARY SESSION

HAWAI`I 5G Catch the Wave! IEEE ComSoc IEEE Communications Society MTT-S

HAWAI‘I CONVENTION CENTER • HONOLULU, HAWAI‘I, USA

Exhibition Dates: 6-8 June 2017 • Symposium Dates: 4-9 June 2017

TITLE SPONSOR: KEYSIGHT TECHNOLOGIES

PATRON: IEEE 5G

CATCH THE WAVE AT THE 5G SUMMIT!

REGISTER TODAY!

13:00-13:05 | Welcome and Overview on Day 2
Doug Zuckerman, *IEEE COMSOC*

13:05-13:10 | 5G Initiative Overview
Ashutosh Dutta, *AT&T*

13:10-13:40 | Keynote: Emerging Research Tracks in Massive MIMO
Keynote Speaker: Arogyaswami Paulraj, *Stanford University*

13:40-14:00 | Massive MIMO in 3GPP: from LTE to New Radio
Fred Vook, *Nokia NSN*

14:00-14:20 | V2X and 5G
Robert Heath, *UT Austin*

14:20-14:40 | Living on the Edge – How 5G is Going to Enable the Medical Internet of Things Big Time
Christoph Thuemmler, *Edinburgh Napier Univ., UK*

14:40-14:50 | Coffee Break

14:50-15:10 | Full Duplex Wireless: From Fundamental Physics and Integrated Circuits to Complex Systems and Networking
Harish Krishnaswamy, *Columbia University*

15:10-15:30 | RFIC/CMOS Technologies for 5G, mmW and Beyond
Ali Niknejad, *UC Berkeley*

15:30-15:50 | 5G Radio Design for Mobile Products
Kamal Sahota, *Qualcomm*

15:50-16:30 | Panel Session: 5G Test and Measurements
Moderator: Kate Remley, *NIST*
Panelists: Malcolm Robertson, *Keysight*; Jin Bains, *NI*; Chris Scholz, *Rohde Schwartz*; Jon Martens, *Anritsu*

16:30 (Adjourn) | REMEMBER TO ATTEND THE 5G EXECUTIVE FORUM AND RECEPTION FOLLOWING DAY 2 OF THE 5G SUMMIT!

FOR MORE INFORMATION, VISIT WWW.IMS2017.ORG

Follow us on: #IMS2017

This index is provided as an additional service by the publisher, who assumes no responsibility for errors or omissions.

Subscription Assistance and Information:
(ISSN 0745-2993)
Microwaves & RF is published monthly. Microwaves & RF is sent free to individuals actively engaged in high-frequency electronics engineering. In addition, paid subscriptions are available. Subscription rates for U.S. are $95 for 1 year ($120 in Canada, $150 for International). Published by Penton Media, Inc., 9800 Metcalf Ave., Overland Park, KS 66212-2216. Periodicals Postage Paid at Kansas City, MO and additional mailing offices. POSTMASTER: Send change of address to Microwaves & RF PO Box 2100, Skokie, IL 60076-7800. For paid subscription information, please contact Microwaves & RF at PO Box 2100, Skokie IL 60076-7800. Canada Post Publications Mail agreement No. 40612608. Canada return address: IMEX Global Solutions PO Box 25542, London ON N6C 6B2.

Help bring wireless communications all around the globe.

What will your RF applications do?

Help carriers unleash faster data speeds and greater bandwidth.

Help physicians save lives.

Help situational awareness on the modern networked battlefield.

The Trusted Name in High Performance RF Applications

For over 60 years, MACOM engineers have spearheaded innovation in the RF, Microwave and Millimeterwave domain, and remain committed to revolutionizing and powering how the world connects and protects. We're continuing this leadership with a growing portfolio of wide band RF devices for your most demanding applications.

We help enable a better-connected and safer world by achieving breakthrough RF performance in bandwidth, power, packaging, and reliability.

GaN

Diodes

MMICs

GaN

The Trusted Name in High Performance GaN Devices

Only MACOM delivers GaN performance at silicon cost structures to drive adoption in an array of commercial, ISM and wireless applications.

Our unique GaN on Silicon technology delivers the requisite high power and efficiency at Silicon cost structures. MACOM GaN is signaling the future of RF power—today.

Featured MACOM GaN Devices

Application	Function	Part Number	Frequency
Basestation	Power Transistor	MAGB-101822-360A0P MAGB-100710-550S0S	1.8 – 2.2 GHz 0.7 – 1 GHz
RF Energy Cooking & Lighting	Power Transistor Power Transistor	MAGe-102425-300 MAGe-100809-500	2.45 GHz 915 MHz
Avionics	Power Transistor	MAGX-100914-250	1.2 – 1.4 GHz

MMICs

The Trusted Name in High Performance RF MMICs

Covering DC to 100 GHz, MACOM partners with today's leaders from Test & Measurement to SATCOM, to deliver industry leading High Performance MMICs that cover the entire signal chain.

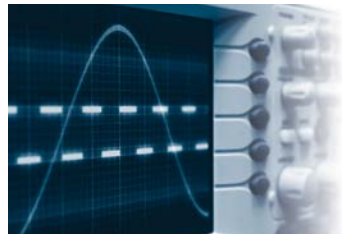
MACOM delivers the leading design and applications expertise with proven technical support to enable the most demanding wideband applications.

Featured MACOM DC-100 GHz MMIC Devices

Application	Function	Part Number	Frequency
Test & Measurement	Wideband Power Amplifier Voltage Variable Attenuator Wideband Mixer Wideband Low Noise Amplifier	MAAP-011249 MAAV-011013 MAMX-011036 MAAL-011141	DC - 22 GHz 5 - 45 GHz 8 - 43 GHz DC - 26.5 GHz
Aerospace & Defense	Octave Voltage Controlled Oscillator	MAOC-415000	10 - 20 GHz

Diodes

The Trusted Name in High Performance RF Diodes



MACOM is committed to offering unrivaled diode development and design expertise to tackle any RF challenge. We'll partner with you to create a specific diode solution for your most critical RF applications, strengthening signals in markets from A&D and ISM to wired broadband.

Services	Expansive Portfolio	Patented Technologies
> Lot Approval – secured inventory location at our factory > Product Extensions / Variants > Custom design & development > Hi-Rel Screening capabilities – Space & JAN, JANTX, JANTXV, and JANS qualified RF & DC devices > Applications support – Industry leading world class experienced team available to support your critical requirements	> PINs, Schottkies, Varactors, Zeners, Rectifiers, Current Regulators > Chip Capacitors, Attenuator Pads, Thin Film Resistors, Spiral Inductors > RF / Mw /mMW and DC General purpose solutions • Integrated Diode Products • Switch Modules • Limiter Modules • Comb Generators • Driver Modules	> AlGaAs – Industry leading high frequency switch portfolio (Products up to 94 GHz) > HMIC – Industry leading high power diode & switch portfolio (0.1-20 GHz , 6.5W CW Incident Power)

Featured MACOM Diodes

Application	Function	Product Family	Description	Part Examples
Medical - MRI	RF Switching	MELF PIN Diodes	Non-Magnetic SMT PIN Diodes	MA4P7464F-1072T MA4P7446F-1091T
Test & Measurement	RF Switching	AlGaAs Switches	AlGaAs PIN Switch IC's (to 50GHz)	MA4AGSW2 MA4AGSW4
		Beamlead PIN Diodes	Fast Switching Mesa & Planar Beamlead Diodes	MA4PBL027 MPND4005-B15
Aerospace & Defense	Double Balanced Mixers	Silicon Schottky Quads	Low, Medium & High Drive Quads (Beamleads & Packaged)	MSS30 / MSS40 / MSS50
	Passive Limiter Circuits	Limiter Diodes	Silicon Limiter Diodes	MA4L021 MADL-011023-14150T

MACOM™

Partners from RF to Light

www.macom.com