The Wheatstone Bridge Effect on VNA Measurements p34

Metamaterial-Based Transmission Lines Help Form Triple-Band Resonator p40

Radio Transceiver Takes on Wireless, Military, and Test Applications p54

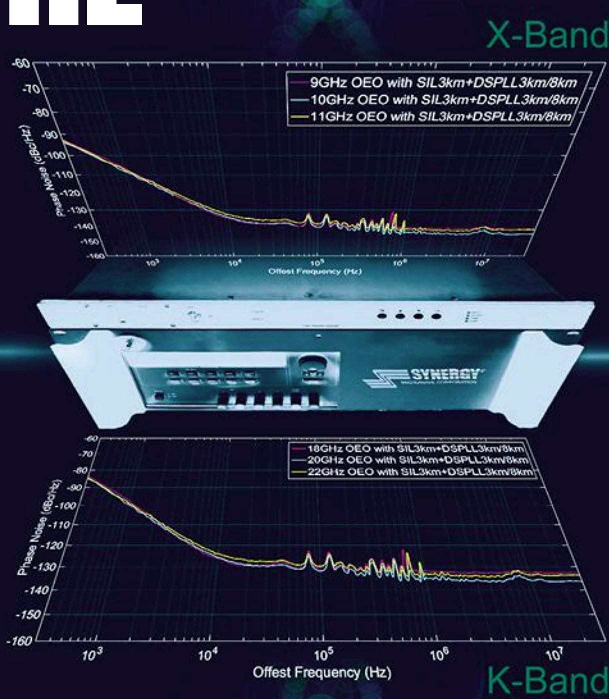

# Microwaves & RF®

YOUR TRUSTED ENGINEERING RESOURCE FOR OVER 50 YEARS

AUGUST 2018 mwrf.com


# REDUCING THE NOISE

## Optoelectronics Drive High-Frequency Synthesizers p52




$10.00

# *Ultra high bandwidth Payload & RF Multipath Link Emulator*

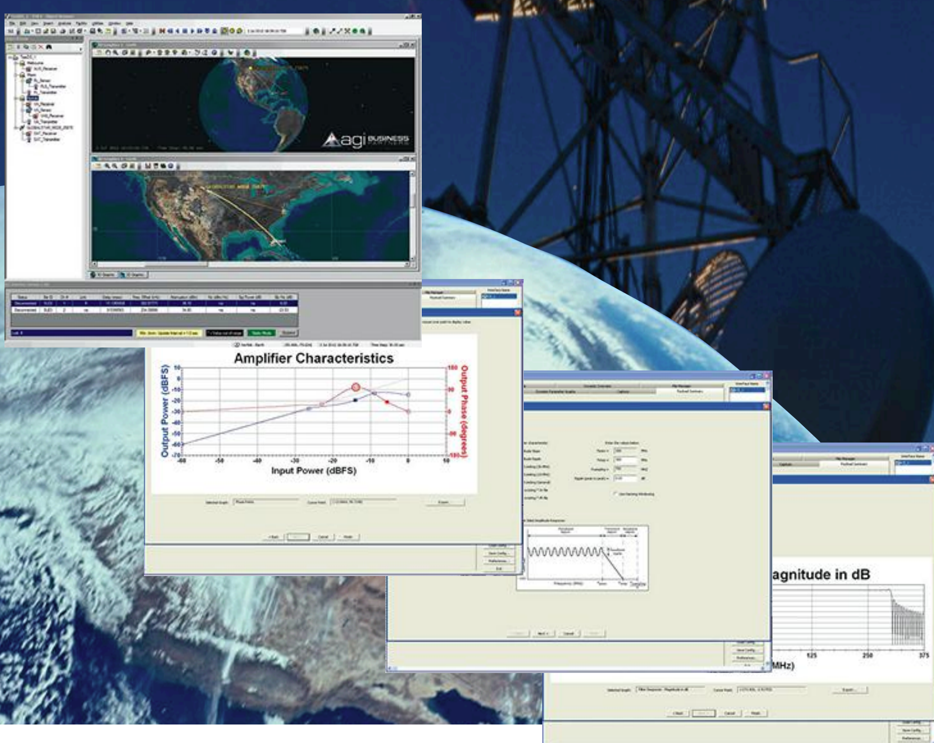
Just released ...

Sophisticated high bandwidth (up to 600MHz) emulation of physical layer RF link effects channel modeling (delay, Doppler, AWGN, Multipath) and hardware in the loop impairments modeling (programmable Group delay, Phase noise, gain/compression distortion and non-linearity AM/AM, AM/PM simulation etc.

Comprehensive range of instruments from 72 MHz to 600 MHz bandwidth with a wide RF frequency tuning range.

Contact dBm for specifications, pricing information and demonstration/evaluation units.

- **RF physical layer Link emulation**
- **Point to Point UHF/VHF radio testing**
- **Real time control for Arial Vehicle (UAV) testing**
- **Payload and ground station emulation**
- **Multipath, 12 paths @ 600MHz BW**




**dBm**

*RF Test Equipment for Wireless Communications*

**email: info@dbmcorp.com**

**dBm Corp, Inc**

**32A Spruce Street ◆ Oakland, NJ 07436**
**Tel (201) 677-0008 ◆ Fax (201) 677-9444**

**www.dbmcorp.com**

# RF/Microwave Switches


Patent Pending

**14 GHz SPDT SMT Relay:** Three models covering DC to 14 GHz, each packaged in a 0.61” sq. plastic casing that is mountable manually or by wave soldering. Small size enables dense population for increased testing capabilities. Ideal for applications requiring high RF performance in a small footprint.

- 0.03 dB IL repeatability / 2M cycles / 3ms / Latching
- 2W hot switching / individual units or tape & reel
- Evaluation boards and Gerber files are available


**DC to 40 GHz:** A family of high performance and ultra-broadband switches with excellent insertion loss repeatability.

- 80 dB isolation, 0.3 dB insertion loss and 5M cycle life
- SPDT, TRAN and SPMT models w/2.92mm connectors
- Failsafe, Latching or Normally-Open operations
- 12, 24 & 28 VDC, TTL, indicators, 50Ω terminations
- 2W hot switching / 30W cold switching


**Switch Matrices:** Compact “plug & play” benchtop testing solutions for RF/microwave signal switching from DC to 18, 26.5 or 40 GHz.

- Multiple SPDT and SPMT combinations
- USB, Ethernet or manual control from the front panel
- LED indicators, cycle counter
- Optional 50Ω internal terminations
- AC/DC adapter, WIN® 32/64 drivers and intuitive GUI

*Other Products and Services:*

- *100,000+ standard models*
- *High Power (2kW)*
- *LoPIM -170dbc*
- *SP8T and SP12T*
- *Form, Fit & Function to other switch suppliers*
- *High quality with fast delivery*

*Prices starting @* ***$85.00***

*(SPDT, sma, failsafe, dc-18 GHz, 24vdc, solder pins, qty 10pcs)*

*Santa Clara, CA / www.e360microwave.com*

*ISO9001 - RoHS - REACH*

e360 microwave®

## Fast Pulse Test Systems from Avtech

Avtech offers over 500 standard models of high-speed pulsers, drivers, and amplifiers ideal for both R&D and automated factory-floor testing. Some of our standard models include:

**AVR-E3-B:** 500 ps rise time, 100 Volt pulser

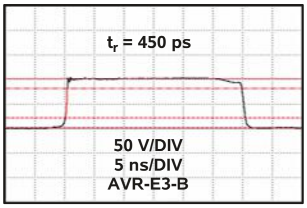
**AVRQ-5-B**: Optocoupler CMTI tests, >120 kV/us

**AVO-8D3-B:** 500 Amp, 50 Volt pulser

**AV-1010-B:** General purpose 100V, 1 MHz pulser

**AVO-9A-B**: 200 ps $t_r$, 200 mA laser diode driver

**AV-156F-B**: 10 Amp current pulser for airbag initiator tests

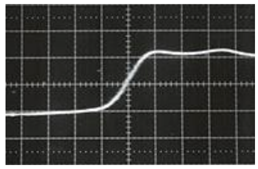



Nanosecond Electronics
Since 1975

**Pricing, manuals, datasheets and test results at:**
www.avtechpulse.com

AVTECH ELECTROSYSTEMS LTD.
Tel: +1-613-686-6675 Fax: +1-613-686-6679
info@avtechpulse.com

## High Output - Low Risetime Pulsers from Avtech



Sub-nanosecond rise time pulsers for every amplitude range!

Model AVP-3SA-C provides up to 10V with < 50 ps rise times.
← Typical waveform, 50 ps/div, 5V/div.

At the other extreme, Model AVI-V-HV2A-B provides up to 100V with < 300 ps rise times.

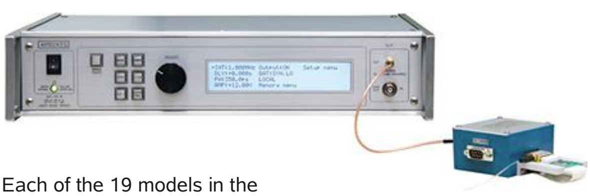
| Ampl | tRISE | Max. PRF | Model |
|---|---|---|---|
| 100 V | 500 ps | 0.1 MHz | AVR-E3-B |
| 100 V | 300 ps | 0.02 MHz | AVI-V-HV2A-B |
| 50 V | 500 ps | 1 MHz | AVR-E5-B |
| 20 V | 200 ps | 10 MHz | AVMR-2D-B |
| 15 V | 100 ps | 25 MHz | AVM-2-C |
| 15 V | 150 ps | 200 MHz | AVN-3-C |
| 10 V | 100 ps | 1 MHz | AVP-AV-1-B |
| 10 V | 50 ps | 1 MHz | AVP-3SA-C |
| 5 V | 40 ps | 1 MHz | AVP-2SA-C |

Nanosecond Electronics
Since 1975

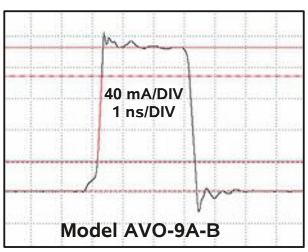
**Pricing, manuals, datasheets and test results at:**
www.avtechpulse.com/

AVTECH ELECTROSYSTEMS LTD.
Tel: +1-613-686-6675 Fax: +1-613-686-6679
info@avtechpulse.com

## Pulsed Laser Diode Drivers from Avtech



Each of the 19 models in the Avtech **AVO-9 Series** of pulsed laser diode drivers includes a replaceable output module with an ultra-high-speed socket, suitable for use with sub-nanosecond pulses.




Models with maximum pulse currents of 0.1A to 10A are available, with pulse widths from 400 ps to 1 us.

GPIB, RS-232, and Ethernet control available.

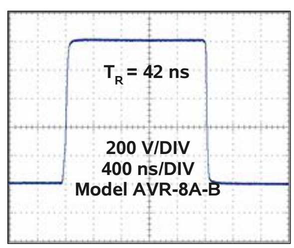
Nanosecond Electronics
Since 1975

**Pricing, manuals, datasheets and test results at:**
www.avtechpulse.com/laser

AVTECH ELECTROSYSTEMS LTD.
Tel: +1-613-686-6675 Fax: +1-613-686-6679
info@avtechpulse.com

## 100 to 1000 Volt Lab Pulsers

Avtech offers a full line of 100, 200, 500, 700 and 1000 Volt user-friendly pulsers capable of driving impedances of 50 Ω and higher. The **AVR Series** is suitable for semiconductor and laser diode characterization, time-of-flight applications, attenuator testing, and other applications requiring 10, 20, or 50 ns rise times, pulse widths from 100 ns to 100 us, and PRFs up to 100 kHz. GPIB & RS-232 ports are standard, VXI Ethernet is optional.




**See additional test results at:**
**http://www.avtechpulse.com/medium**

Nanosecond Electronics
Since 1975

**Pricing, manuals, datasheets and test results at:**
www.avtechpulse.com/medium

AVTECH ELECTROSYSTEMS LTD.
Tel: +1-613-686-6675 Fax: +1-613-686-6679
info@avtechpulse.com

August 2018 VOLUME 57, ISSUE 8 Microwaves&RF

# IN THIS ISSUE

## FEATURES



23


38

52

## PRODUCTS & TECHNOLOGY



## NEWS & COLUMNS




54

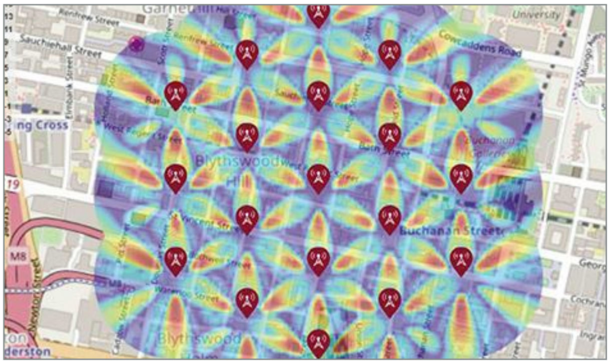
JOIN US ONLINE

follow us @MicrowavesRF

become a fan at
facebook.com/microwavesRF

61

# ON MICROWAVES&RF.COM




## Visualize Antenna-Array and SINR Patterns on a Map

Visualizing antenna patterns on a map can be helpful in design. This latest "Algorithms to Antenna" blog post from Rick Gentile discusses several methods on how to do that via MATLAB.

*https://www.mwrf.com/software/algorithms-antenna-visualize-antenna-array-and-sinr-patterns-map*

## Brushing Up on Network Analyzer Fundamentals

Whether measuring production components or engineering prototypes, today's versatile network analyzers have become essential tools in the designer's toolbox. This article explains what functions these instruments perform, and how they perform them.

*https://www.mwrf.com/test-measurement/brushing-network-analyzer-fundamentals*

## Robust RFID Tags Track Firearms

New laws are calling for the dependable tracking of firearms, and modern RFID tags now can be integrated with the metal components of firearms to monitor the use of guns.

*https://www.mwrf.com/components/robust-rfid-tags-track-firearms*


## Passives Cram More Power into Ever-Smaller Packages

The trend throughout the high-frequency industry is to design passive components that can handle higher power levels with effective thermal management in tighter spaces.

*https://www.mwrf.com/components/passives-cram-more-power-ever-smaller-packages*

twitter.com/MicrowavesRF facebook.com/microwavesrf

# PRECISION ATTENUATORS

## 2 W to 100 W


*50 W & 100 W models*

**NEW**
*BW-E Series 65 GHz models*

# DC-65 GHz *from* $31.95 ea. (1-49)

Customers trust Mini-Circuits' BW-family precision fixed attenuators for accuracy, reliability, and repeatability. Now, we've expanded your choices by adding the BW-E series, covering even more applications from DC up to 65 GHz! With fixed attenuation values from 3 to 20 dB, these new, ultra-wideband models feature 1.8mm connectors and provide outstanding attenuation accuracy, excellent VSWR, and RF power handling up to 1W. Our full "BW" family of fixed precision attenuators now includes over 70 models with attenuation values ranging from 1 to 50 dB and power handling from 1 to 100W to meet your requirements with performance you can count on.

Visit minincircuits.com for free data, curves, quantity pricing, designer kits, and everything you need to find the right BW attenuator for your needs. All models are available off the shelf for delivery as soon as tomorrow!

*RoHS compliant*

**Mini-Circuits®**

Editorial

LOU FRENZEL | Contributing Editor
lou.frenzel@informa.com

# What Are Your Favorite Microwave Books?

You do still use books, don't you? Even with the vast resources on the internet, most of us still go to books for in-depth material on subjects of interest. Or do you? I know I still do. As a writer, I am in constant need of background material, fundamentals, theory, explanations, and so on. Though I get a great deal from the internet, books are still useful. But there seems to be some books that I consult more often than others. Here's a short list of the books I like, have learned from, and have found useful over the years.

My all-time favorite microwave books are the 28 volumes of the *MIT Radiation Lab* series. The Rad Lab existed during World War II to develop microwaves and especially radar. These in-depth books are fantastic. I was lucky enough to work in a company early in my career that had a full set of these. I now have the entire series on a CD. Great references even today.

A more recent favorite is *Planar Microwave Engineering* by Thomas Lee of Stanford. This is a Cambridge University Press book. It offers very broad coverage on all microwave-related topics. The writing style is such that it's easy to read for a technical book. It's a great engineering reference if you need a refresher or just an intro to a topic you never learned.

Another good general RF book is *The ARRL Handbook for Radio Communications.* The American Radio Relay League is an organization for hams (licensed radio amateurs) that's been around since 1914. The Handbook, updated and published every year, covers radio and electronic theory and all aspects of communications. Very practical and loaded with projects you can build. They also have a great antenna handbook.

Two books that I essentially learned RF and microwave from are oldies. Used book stores were the source. One of them you may have heard of if you're old enough: Frederick Terman's *Electronic and Radio Engineering*. My copy has a date of 1955 on it. Still a useful reference. Another oldie but goodie I learned from is *Generation and Transmission of Microwave Energy,* TM 11-673, Department of the Army, 1953. The Navy also had some good microwave and radar books.

*RF Circuit Design*, 2nd edition by Chris Bowick, is another favorite. Good coverage of filters, impedance matching, the Smith chart, and amplifiers. It's still available from Newnes/Elsevier.

One book I go back to again and again is Volakis' *Antenna Engineering Handbook* by McGraw-Hill. A real tome but a good reference. And if you want a good source of electronic warfare books, try Artech House.

Finally, I always have copies of the latest Code of Federal Regulations (CFR) 47 Parts 0 through the End. Three volumes available from the Government Printing Office. I prefer the hard copies, but it's all available on the FCC website. Practically all wireless engineering requires that you know these rules and regulations, so they're not only useful, but necessary as well.

What are your favorite books? Old or new? What did you learn from and what do you use for reference today? We would love to hear. mw

**Microwaves&RF** AUGUST 2018

## EDITORIAL

EXECUTIVE DIRECTOR, CONTENT: **KAREN FIELD** karen.field@informa.com
TECHNICAL CONTRIBUTOR: **JACK BROWNE** jack.browne@informa.com
TECHNICAL ENGINEERING EDITOR: **CHRIS DeMARTINO** chris.demartino@informa.com
ASSOCIATE EDITOR/COMMUNITY MANAGER: **ROGER ENGELKE** roger.engelke@informa.com
ASSOCIATE EDITOR/COMMUNITY MANAGER: **JEREMY COHEN** jeremy.cohen@informa.com
ASSOCIATE CONTENT PRODUCER: **JAMES MORRA** james.morra@informa.com

## ART DEPARTMENT

GROUP DESIGN DIRECTOR: **ANTHONY VITOLO** tony.vitolo@informa.com
CONTENT DESIGN SPECIALIST: **JOCELYN HARTZOG** jocelyn.hartzog@informa.com
CONTENT & DESIGN PRODUCTION MANAGER: **JULIE JANTZER-WARD** julie.jantzer-ward@informa.com

## PRODUCTION

GROUP PRODUCTION MANAGER: **GREG ARAUJO** greg.araujo@informa.com
PRODUCTION MANAGER: **VICKI McCARTY** vicki.mccarty@informa.com

## AUDIENCE MARKETING

USER MARKETING MANAGER: **DEBBIE BRADY** debbie.brady@informa.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@informa.com

REGIONAL SALES REPRESENTATIVES:

AZ, NM, TX: **GREGORY MONTGOMERY** **T** | 480.254.5540 gregory.montgomery@informa.com

AK, NORTHERN CA, OR, WA, WESTERN CANADA: **STUART BOWEN** **T** | 425.681.4395 stuart.bowen@informa.com

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

CT, DE, MA, MD, ME, NH, NJ, NY, PA, RI, VT, EASTERN CANADA:
**SHANNON ALO-MENDOSA** **T** | 978.501.9116 shannon.alo-mendosa@informa.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

PAN-ASIA: **CHARLES LIU** **T** | 886 2-2727 7799 liu@twoway-com.com

PLEASE SEND INSERTION ORDERS TO: orders@informa.com
INFORMA REPRINTS: **WRIGHT'S MEDIA** **T** | 877.652.5295
LIST RENTALS/ SMARTREACH CLIENT SERVICES MANAGER: **MARY RALICKI** **T** | 212.204.4284
mary.ralicki@informa.com

## DIGITAL

GROUP DIGITAL DIRECTOR: **RYAN MALEC** ryan.malec@informa.com

## DESIGN ENGINEERING & SOURCING GROUP

EXECUTIVE DIRECTOR, CONTENT: **KAREN FIELD** karen.field@informa.com
VP OF MARKETING: **JACQUIE NIEMIEC** jacquie.niemiec@informa.com

## INFORMA MEDIA INC.

605 THIRD AVENUE
NEW YORK, NY 10158 USA **T** | 212.204.4200

informa

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

# 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 |

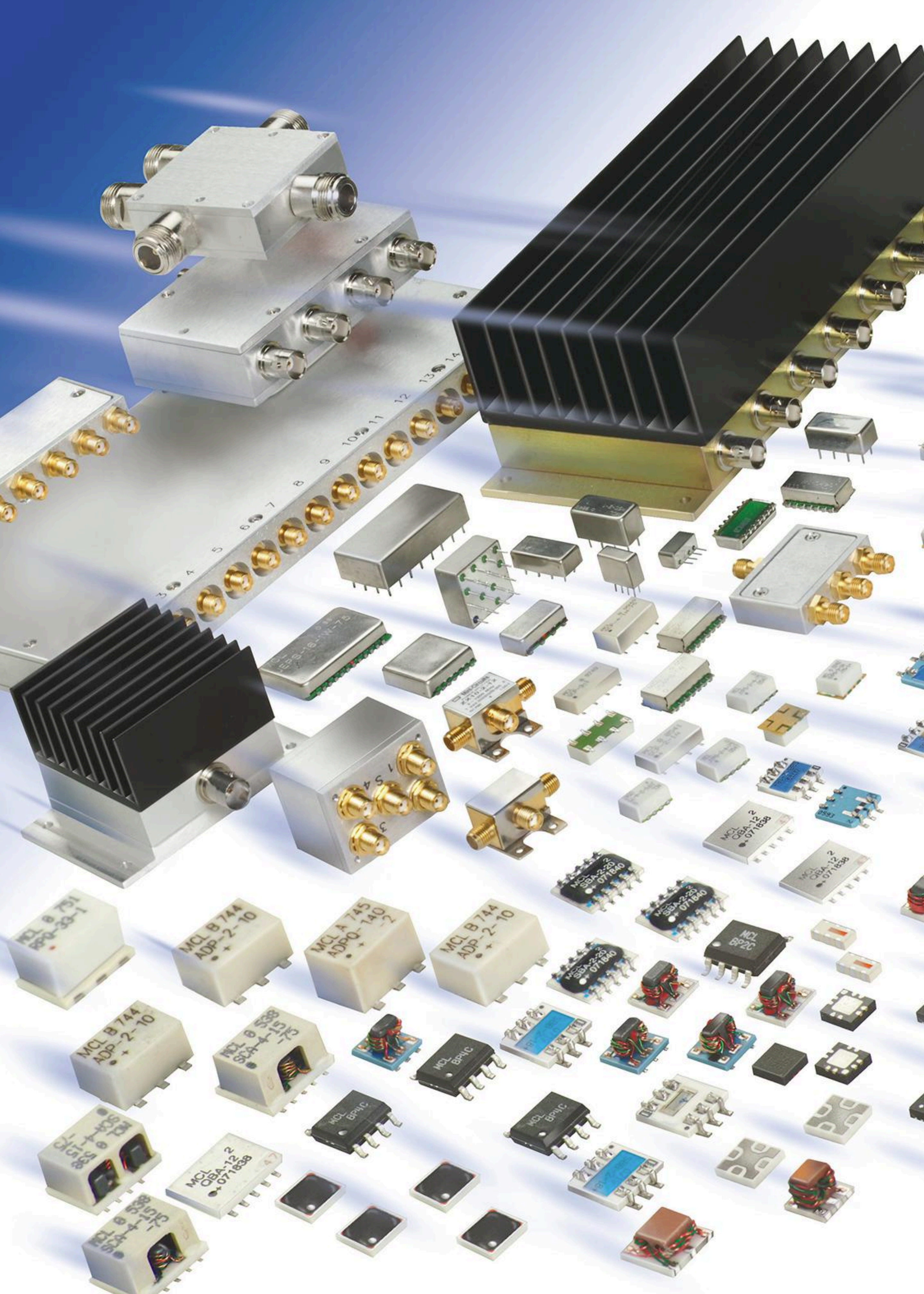
CIAO Wireless can easily modify any of its standard models to meet your "exact" requirements at the Catalog Pricing.

**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

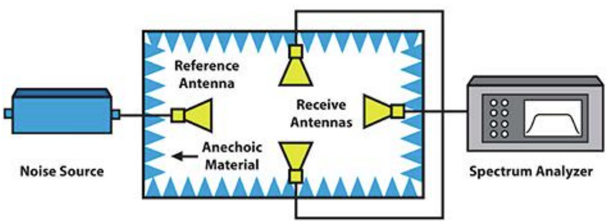

MCL B 744
ADP-2-10
MCL A 745
MCL B 538
SCA-4-15
-75
MCL
QBA-12
2
071838
MCL
SBA-2-20
071840
MCL
BP4C
MCL
BP2C

# News

# NOISE SOURCES, POWER SENSORS
## Move into OTA Test Systems

With 5G communication on its way, over-the-air (OTA) testing has become a focus of many companies throughout the industry. That's because 5G test methods will almost certainly extend beyond traditional cable-based methods. One firm that has entered into the OTA test fray is Wireless Telecom Group (www.wirelesstelecomgroup.com), which demonstrated its own OTA test system at IMS 2018. Wireless Telecom Group is comprised of Boonton Electronics *(www.boonton.com)*, CommAgility *(www.commagility.com)*, Microlab *(www.microlabtech.com)*, and Noisecom *(www.noisecom.com)*.

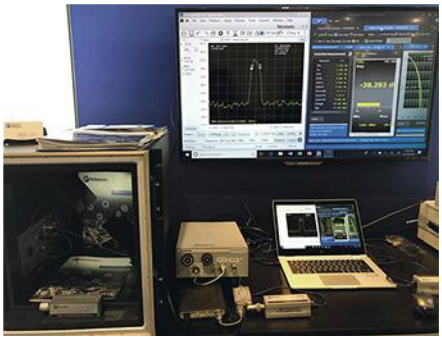
*Figure 1* shows a block diagram of an OTA test system. This test system consists of a noise source, a test chamber, antennas, and a spectrum analyzer. In terms of configuration, the noise source located outside the chamber is connected to a transmit antenna within the chamber. The receive antennas inside the chamber are connected to a spectrum analyzer on the outside.




**1. This OTA test system utilizes a calibrated noise source.**

Noisecom is emphasizing the suitability of noise sources for OTA testing. The company notes that "making reliable and repeatable measurements inside any chamber requires the chamber—and test system as whole—to be calibrated and quantified."

Furthermore, Noisecom points out that "noise sources are ideal for this type of calibration process, as they provide a known source with calibrated data points that can be used to determine cable loss, air path loss, antenna efficiency, and total chamber response. After the system is calibrated and quantified, the same noise sources with known characteristics can be used as a reference source for the device under test (DUT) to receive signals."



**2. During Wireless Telecom Group's OTA test demonstration, which took place at IMS 2018, measurements were made with both a power sensor and spectrum analyzer.**

Noise sources for OTA testing are also more cost-effective in comparison to more expensive signal generators. Noisecom offers calibrated noise sources that cover all frequencies required for 5G testing in OTA chambers.

*Figure 2* shows the OTA test system that Wireless Telecom Group demonstrated at IMS 2018. In this demo, a modified Noisecom NC3200 noise source is driving a 14-dB gain amplifier. The output of the amplifier is connected to the transmitting Vivaldi antenna located inside the test chamber.

Another Vivaldi antenna inside the chamber functions as the receiving antenna. That antenna is connected to a power divider located outside the chamber. One of the power-divider outputs is connected to a Boonton RTP5006 real-time peak power sensor, while the other is connected to a spectrum analyzer. This test setup therefore allows for simultaneous power-sensor and spectrum-analyzer measurements.

Both the spectrum-analyzer and RTP5006 power-sensor measurements are displayed on the monitor in *Fig. 2*. The power-sensor display reveals the average power along with a complementary cumulative distribution function (CCDF) curve.

When driving the amplifier into compression, the average power measurements obtained from the spectrum analyzer and power sensor correspond with one other. However, the peak power decreases, which can be determined by the CCDF analysis.

"The point we are making is that power sensors are great at seeing the reduction of crest factor and complement spectrum analyzers and vector network analyzers," says Matt Diessner, regional sales director at Wireless Telecom Group. ■

## NEXT-GENERATION RADAR SYSTEMS Stock up on GaN

**ONE OF THE MOST** significant developments in the RF/microwave industry has been the rise of gallium-nitride (GaN) technology. Lockheed Martin *(www.lockheedmartin.com)*, which has been involved with GaN development since 2000, is currently utilizing GaN to develop cutting-edge radar systems. The company has experience developing GaN-based solutions through millimeter-wave (mmWave) frequencies.

GaN technology is generally associated with high-power amplifiers (HPAs). While Lockheed Martin is active in this area, its engineers are also utilizing GaN to design other RF components, such as low-noise amplifiers (LNAs), switches, and mixers. Lockheed Martin does not actually have its own GaN foundry, but rather works with commercial foundry partners to allow for strategic growth.

One significant GaN-based radar system from Lockheed Martin is the TPS-77 multi-role radar (MRR) system *(Fig. 1)*. The TPS-77 MRR is the latest entry to Lockheed Martin's product line of surveillance radars. Leveraging GaN technology, the TPS-77 MRR is designed for ultra-low power consumption.

The TPS-77 MRR, which operates from 1,215 to 1,400 MHz, can be configured for medium- or long-range. It's mountable on vehicles and easily transportable via a C-130, truck, rail, or helicopter. Example missions for the TPS-77 MRR include unmanned-aerial-vehicle (UAV) detection, low-level flight surveillance, ground-based air defense, etc.

The radar system's multi-role single-scan technology allows operators to select multiple missions for the radar at a single time, such as medium- or long-range low-level flight surveillance. It automatically adjusts to the selected mission as the radar rotates through each 360-degree scan. Changes can be made if the system is moved or if the mission is changed.

Lockheed Martin recently completed a successful site-acceptance test of its TPS-77 MRR *(Fig. 2)*. The company made an on-time delivery of the first of three radars to the Ministry of Defense of the Republic of Latvia. Lockheed Martin noted that this was a "major step forward in strengthening Latvia's national defense."

According to the company, "TPS-77 MRR plays a vital role in improving the Latvian Air Force's airspace defense by increasing its identification capabilities, leading to enhanced early warning and situation awareness that allows its armed forces to make more informed and efficient decisions in response to modern day threats."

Also powered by GaN technology is Lockheed Martin's Space Fence system *(Fig. 3)*. Space Fence is a ground-based system of GaN-based S-band radars that's designed to enhance the Air Force space-surveillance network. Lockheed Martin has partnered with Wolfspeed *(www.wolfspeed.com)* to provide GaN-based HPAs for the Space Fence system.

The main purpose of the Space Fence is to detect, track, and catalog the innumerable number of objects in space. According to Lockheed Martin, Space Fence technology will allow for a 10-fold increase in the amount of space-junk tracked in comparison with the current system. The Space Fence system not only tracks objects, but also precisely determines their projected orbit. This allows operators to reconstruct recent events, such as collisions and satellite breakups, as well as accurately predict future ones. ■

**1. Here, the TPS-77 MRR is mounted in a truck in the deployable mobility configuration.** *(Courtesy of Lockheed Martin)*

**2. This is the TPS-77 MRR in Latvia during a site-acceptance test earlier this year.** *(Courtesy of 22nd Mobile Public Affairs Detachment)*

**3. Shown is an aerial view of the Space Fence facility, Kwajalein Atoll.** *(Courtesy of Lockheed Martin)*

## QUALCOMM WAVES WHITE FLAG in NXP Semiconductors Deal

**QUALCOMM HAS WALKED AWAY** from buying NXP Semiconductors after almost two years, interrupting its plans to expand into new markets like cars and factories. The San Diego, California-based company ended the $44 billion deal after running into regulatory roadblocks in China, which never gave Qualcomm the green light amid growing trade tensions with the United States.

The company has plans for the leftover cash. While it will have to pay NXP $2 billion for terminating the deal, Qualcomm will follow through on $30 billion in stock repurchases to boost its share price, which will take place before the end of next year. Now that the deal has been scrapped, Qualcomm is planning to return more cash to shareholders and cut costs.

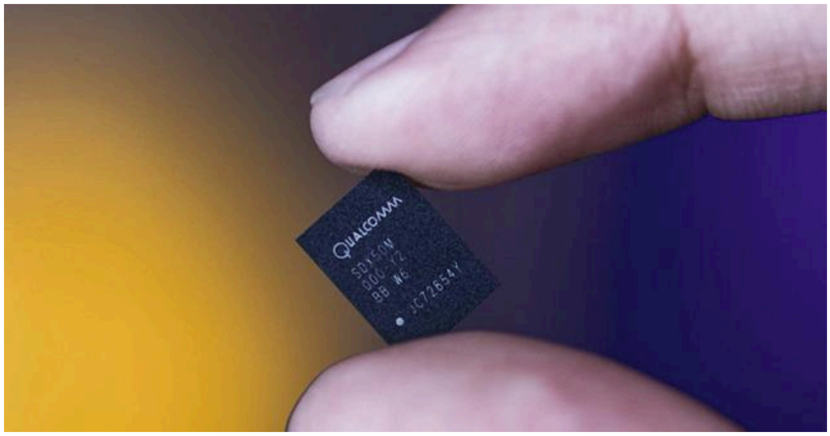
Qualcomm started waving the white flag in July while broadcasting third quarter revenue that beat Wall Street estimates. Sales climbed 4.2 percent to $5.6 billion, while profits jumped to $1.22 billion, up from $866 million a year ago. Barring any last-minute announcements from Chinese regulators, Qualcomm said that it would terminate the deal, moving ahead as an independent company.

"The decision for us to move forward without NXP was a difficult one," said Steve Mollenkopf, Qualcomm's chief executive, on a conference call with analysts. The company was trying to dispel the uncertainty hanging over the deal. "We weighed that risk against the likelihood of a change in the current geopolitical environment, which we didn't believe was a high-probability outcome in the near future."

The deal had long odds during the escalating trade dispute between the Chinese and the Trump administration, which has threatened tariffs to curtail the trade imbalance between the two countries. It raised an array of other complications, including how to combine the sprawling workforces at NXP, the world's largest maker of car chips, and Qualcomm, the world's largest smartphone chip supplier.

"Most of the Qualcomm future unknowns were cleared up at the company's earnings disclosure today," said Patrick Moorhead, founder of technology research firm Moor Insights and Strategy. "Many investors over the past 18 months have been concerned with unknowns over NXP, future growth opportunities, and its licensing business."

The deal was terminated more than 20 months after Chinese regulators began to review the deal, which would have reshaped the chip industry. China was the last country suppressing the deal, which



Qualcomm had vowed to get approved before the end of last year. In April, the Chinese had still not consented to the deal, driving Qualcomm to impose the deadline in July.

Ditching the $44 billion deal is the latest setback for Qualcomm. The San Diego, California-based chipmaker has been badly bruised in multibillion-dollar legal battles with Apple, which has refused to pay Qualcomm patent royalties for wireless chips used in its smartphones. Qualcomm said Wednesday that Apple would not use its modems in the next-generation iPhone.

Qualcomm's woes worsened with Broadcom's hostile takeover attempt, which was averted after the Trump administration blocked the $117 billion deal on national security grounds. While it was being hounded by Broadcom, the company pointed to the NXP Semiconductors deal to convince shareholders that its current executive team could reap bigger profits in the long run than Broadcom.

The breakdown also deals a blow to the Eindhoven, Netherlands-based NXP. Even though it sells hundreds of millions of microcontrollers and other chips for the growing Internet of Things market, the company faces questions about operating on its own. The company is slowly entering the machine learning space and it has struggled to compete with Nvidia in supplying the robotic brains of cars.

The deal would have given Qualcomm access to chips embedded in everything from cars and factory equipment to thermostats and traffic lights. That the company was willing to pay $44 billion—around $7 billion higher than at first—shows how serious the Internet of Things is to Qualcomm. It also suggests the challenge facing Qualcomm to muscle into the market without NXP.

But under Mollenkopf, who was hired as an electrical engineer more than two decades ago, Qualcomm has won over new customers. Last year, the company sold $3 billion worth of chips used in non-mobile applications, including car dashboards, wearables and security cameras. The company's backlog of sales to the automotive industry is currently around $5 billion, up $2 billion from January.

Qualcomm is also under pressure to take the lead in 5G technology, which could be installed in smartphones by the first half of next year. The company scarfs down profits by charging manufacturers to use technology based on its wireless patents, taking a percentage of the wholesale price of smartphones or other products. But how that business operates has been under threat by antitrust regulators on three continents.

The company has been fined billions of dollars by regulators and ordered to renegotiate contracts with customers in some countries, including China. But analysts say that the business is holding steady. Last month, Qualcomm said that a major customer disputing its license made a $500 million royalty payment. It also signed licensing deals for 5G technology with Xiaomi and Sharp, among others. ■

# UWB TECHNOLOGY Makes RF the Doctor

RF/microwave technology is quickly becoming viewed as a possible way to treat illnesses. For example, by using in-body sensors, many health parameters, such as blood pressure and heart rate, can be measured automatically by any doctor with access to the internet.

For that to take place, though, a better understanding is needed of how such sensors will work within the human body, using a body as a propagation medium. To learn more, researchers from the Institute of Telecommunications and Multimedia Applications of the Universitat Politecnica de Valencia, Valencia, Spain, analyzed the human body as an RF/microwave propagation medium, especially for UWB signals.

Today's medical-analysis methods depend more on wireless sensors to provide insights into a patient's health. IEEE Standard 802.15.6-2012 has been established to allocate different portions of the electromagnetic (EM) spectrum for the operation of wearable or implantable sensors for medical use.

The Industrial, Scientific, and Medical (ISM) frequency band from 2.400 to 2.483 GHz is well-established as available spectrum for medical devices, but interest has been growing in the possible use of ultrawideband (UWB) frequencies in the range from 3.1 to 10.7 GHz for medical applications as well. In support of that goal, the researchers set out through computer simulations and measurements to characterize the human body as a propagation medium for wireless medical devices.

The human body represents a complex propagation medium for in-body sensor networks, and details on the effects of living tissues on UWB radio waves aren't easily found. To better understand how living tissues will serve as a radio channel for UWB signals, the permittivity, conductivity, and permeability characteristics of the tissues must be known in the way they are known for substrate materials, such as PCB materials, that serve as the basis for high-frequency circuits.

The researchers point to a healthy background of measurement data on these electrical parameters from previous experiments on different living animals. Measurements were performed with the aid of on-body and in-body patch antennas and microwave vector network analyzers.

Using EM simulation software, the experimenters developed several human-body models for analyzing UWB radio-channel performance and the relative losses that can be expected through different parts of the body. Multiple antenna setups are recommended for the most efficient use of UWB signals in medical in-body propagation applications, due to the diversity in reception throughout the human body.

See "Ultrawideband Technology for Medical In-Body Sensor Networks," *IEEE Antennas & Propagation Magazine,* Vol. 60, No. 3, June 2018, p. 19.

# COMPOSITE DRA TACKLES UWB Frequency Range

**GROWING REQUIREMENTS FOR** short-range communications involving high data rates has sparked tremendous interest in the development of ultrawideband (UWB) technology. Since 2002, when the U.S. FCC identified the frequency spectrum from 3.1 to 10.7 GHz for UWB systems, work has continued in designing various components needed for such systems, including antennas.

Basically, three types of antennas have been employed for UWB systems: microstrip, slot, and dielectric resonator antennas (DRAs). Microstrip and slot antennas provide the small sizes that are attractive for many UWB systems, but they exhibit extremely low gain. DRAs offer much higher gain, but they are also much larger than microstrip and slot antennas.

To overcome that limitation of DRAs, researchers from the Indian Institute of Technology (IIT) in Dhanbad, India, explored the miniaturization of a high-gain DRA capable of operating from 3.23 to 10.98 GHz. During their efforts, they used composite design techniques and adopted unique shapes for their antennas.

The researchers investigated the creation of antenna structures without unnecessary nonradiating field modes, planning to build their designs on low-cost circuit substrate materials, such as FR-4. They also relied on commercial EM simulation software, such as the HFSS from ANSYS, to perform analysis of composite radiator structures.

For example, they performed studies of return loss for different annular-shaped transmission-line structures to better understand the surface current densities through various shapes of circuit structures at different frequencies within the UWB frequency range. By finding structures with multiple resonances that could be enhanced in terms of bandwidth via impedance transformers, they developed 3D antenna structures that could cover the UWB frequency range by means of multiple resonances from a single structure.

One of the more effective printed-circuit antenna structures was a dumb-bell-shaped cylindrical DRA (CDRA). Using a novel feed structure, additional resonances in the DRA are excited, notably within the mid-UWB range at 5.2 GHz. The enhancement of these additional transverse-electromagnetic (TE) modes to higher frequencies enables this dumb-bell-shaped DRA to provide relatively consistent return loss across the full UWB frequency range.

A prototype of the CDRA was fabricated and analyzed with the aid of ANSYS HFSS software as well as CST Microwave Studio simulation software. In addition, a commercial handheld vector network analyzer (VNA model N9916A) from Keysight Technologies was recruited for measurements from 30 kHz to 14 GHz.

The two software simulators agreed quite closely in their predictions, giving average values of gain and radiation efficiency of 3.1 dBi and 0.88, respectively, for the dumb-bell-shaped CDRA.

See "Composite Antenna for Ultrawide Bandwidth Applications, *IEEE Antennas & Propagation Magazine*, Vol. 60, No. 3, June 2018, p. 57.


## *Up to 50 GHz!*

# TEST CABLES

## *Reliability You Can Trust...*

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. 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!

*Varies by model. See individual model data sheets for details.

**Mini-Circuits®**

**www.minicircuits.com** P.O. Box 350166, Brooklyn, NY 11235-0003 (718) 934-4500 sales@minicircuits.com 507 Rev K

JACK BROWNE | Technical Contributor

# 2018 IMS Prologue: Prepping for the mmWave Era

**The RF/microwave industry was generally optimistic at the exhibition in anticipation of real opportunities for mmWave products in automotive and 5G markets.**

1. **The BW-E Series fixed attenuators are available with attenuation values of 3, 6, 10, and 20 dB from dc to 65 GHz.** *(Courtesy of Mini-Circuits)*

Heightened interest in millimeter-wave (mmWave) frequencies was in evidence throughout the exhibit floor of the recent 2018 IEEE International Microwave Symposium (IMS). Thousands of visitors came to the Pennsylvania Convention Center (Philadelphia, Pa.) to visit display booths and representatives from hundreds of RF/microwave companies, with more companies than ever before showing products at frequencies of 28 GHz and beyond.

The companies worked under the shadows of large signs showing the now familiar "5G," in anticipation of the fifth generation of wireless-network communications technology. 5G wireless networks will work at frequencies below 6 GHz, but will also use mmWave frequency bands at 28 GHz, 39 GHz, and higher for short-haul, high-speed data links. In addition, almost all commercial (and many military) autonomous "self-driving" vehicles will be loaded with mmWave components, devices, and circuits in the form of front- and rear-looking radar systems as part of advanced driver assistance systems (ADAS).

The 2018 IMS Conference and Exhibition was relatively upbeat, despite the industry's earlier loss of one of its great leaders and innovators, Harvey Kaylie, the founder of Mini-Circuits *(see Microwaves & RF, June, p. 13)*. The RF/microwave industry is very much a close-knit community, and its members honored the life and many accomplishments of Harvey Kaylie by remembering him in their thoughts and pushing ahead in pursuit of advances and progress as he would have wished. The strong foundation established at Mini-Circuits was apparent by the large number of visitors to the company's exhibition booth in search of good-quality products at low prices.

As with many companies at the 2018 IMS exhibition, Mini-Circuits has been seeking to push the upper-frequency limits of some of its components into the millimeter-wave range. Examples of these higher-frequency components were available at the booth, such as coaxial fixed attenuators and terminations operating well into the mmWave range. For example, precision fixed coaxial attenuators in the BW-E Series *(Fig. 1)* are available with attenuation values of 3, 6, 10, and 20 dB and attenuation accuracy of ±1.5 dB or better over a continuous frequency range of dc to 65 GHz. The RoHS-compliant attenuators are equipped with 1.85-mm connectors.

2. **The UVNA-63 is a kit for creating a practical VNA for 500 to 600 MHz.** *(Courtesy of Mini-Circuits)*

Visitors to Mini-Circuits' booth may have also been surprised by the demo of a new product, the UVNA-63 *(Fig. 2)*. It's the first in a series of University Kits that provide students with a chance to build their own systems. This model is for a microwave transceiver that can be used as part of a vector network analyzer

Visitors to the Flann Microwave booth were intrigued by the firm's direct-reading Series 100 rotary attenuators, which also worked well into the mmWave range. Using waveguide connectors, models were available to 500 GHz with attenuation levels from 0 to 60 dB and attenuation accuracy of 1% or better.

(VNA) with a frequency range from 500 to 6000 MHz and support for different software environments. Users have access to all components and interconnections to simplify adjustments and calibrations.

One of the truly stalwart suppliers of mmWave components, Sage Millimeter, was visible on the exhibition floor with both coaxial and waveguide components and test equipment in support of mmWave applications. One of the industry's longest-running developers and suppliers of such products, the firm drew visitors to its booth with products such as direct-reading variable attenuators reaching as high as 220 GHz. Sage's array of microwave through mmWave antennas is truly impressive, available in almost every configuration, from microstrip patches to sector antennas, lens antennas, and rectangular horns.

In addition to presenting an impressive array of components at RF through millimeter-wave frequencies, Pasternack explained its growing role in fulfilling needs for high-reliability hardware for commercial, industrial, and military applications. Visitors also had a chance to learn more about the company's connection to software, in particular, its Pasternack Cable Creator, available on the firm's website. It allows users to customize their cable and connector orders and even receive same-day shipping service for specialized, high-reliability cables and connectors, choosing from thousands of different connectors and hundreds of different cable types.

Antenna suppliers followed the industry trend of making higher-frequency products for mmWave applications. Flann Microwave showed its Series 240 standard gain horns, with waveguide models available for coverage at microwave frequencies from 1.14 to 1.75 GHz and extending to frequencies as high as 217 to 330 GHz. Visitors to the Flann Microwave booth were intrigued by the firm's direct-reading Series 100 rotary attenuators, which also worked well into the mmWave range. Using waveguide connectors, models were available to 500 GHz with attenuation levels from 0 to 60 dB and attenuation accuracy of 1% or better.

San-tron showed its wide range of military-grade cable assemblies, including its SRX low-PIM cable assemblies and coaxial adapters for test and other critical applications. With intermodulation levels as low as −168 dBc (depending on cable and connector types), these cable assemblies are essential components for in-building wireless communications systems and distributed antenna systems (DAS).

## MAKE IT SMALLER

As part of the continuing trend of designing and manufacturing smaller and ligher microwave components, Quest Microwave showed how smaller components could also handle relatively large amounts of input power without overheating.

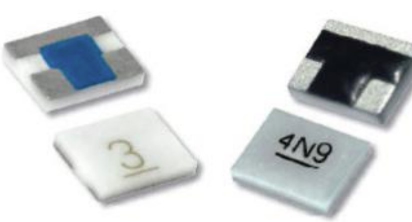
As an example, Quest's D38-M1720C01 four-port isolator/circulator is a drop-in component measuring just 1.50 × 0.75 × 0.25 in., but capable of handling as much as 10 W CW power from 1.7 to 2.0 GHz. With maximum VSWR of 1.25:1 and maximum insertion loss of 0.4 dB, the device is designed for operating temperatures from −30 to +70°C. Yet, the company also makes larger, standard and custom coaxial and waveguide isolators/circulators for commercial and military applications through 40 GHz.

In terms of miniaturized antennas, few companies can match Anokiwave and its wide range of IC antennas for commercial and military applications. The firm showed its active antenna phased-array antenna ICs for microwave and mmWave applications, including for satellite communications (satcom) and 24/26-, 28-, and 37/39-GHz antenna ICs aimed at 5G applications. In terms of commercializing antenna ICs at mmWave frequencies, the company's founder and CEO, Dr. Nitin Jain, explained, "Anokiwave has over a decade of experience designing silicon mmWave active antenna ICs and is enabling the commercialization of mmWave active antennas with silicon ICs."

Boeing exhibited at the IMS, but perhaps not in the way that most people would have expected: On display were analog, digital, and mixed-signal ICs and custom ASIC design assistance in a wide range of semiconductor technologies. Boeing's Solid-State Electronics Development (SSED) organization performs work for commercial, military, and aerospace customers, with experience in technologies that include CMOS, GaAs, GaN, and SiGe processes. The firm's ASIC engineers specialize in the design of semiconductors for harsh environments, including power supplies for temperatures from −55 to +225°C and a wide range of RF/microwave active and passive components through 44 GHz.

Atlanta Micro displayed its chip-sized RF/microwave components, including miniature passive components such as analog-tuned filters and filter banks to 26 GHz in surface-mountable QFN packages. As examples, model AM3060 is a digitally tunable filter for 400 to 6000 MHz in a 12.5- ×12.5-mm QFN package, while model AM3025A is a fixed-band filter bank for 400 to 6000 MHz in a 9- × 9-mm QFN. The firm also showed miniature heterodyne tuners for receive and transmit functions from 2 MHz to 12 GHz with 80-MHz bandwidths and receive functions from 100 MHz to 18 GHz and 500-MHz bandwidths.

Smiths Interconnect had several new product announcements at the 2018 IMS, including the release of its SpaceNXT HC Series high-reliability chip attenuators for commercial space applications *(Fig. 3)*. With component failure not a realistic option for space-based systems, these cost-effective attenuators are fully tested for full mission assurance. Available in both fixed and temperature-variable versions for use from dc to 18 GHz, the surface-mountable components are totally passive for ease of installation. In fact, the temperature-variable attenuators can combine attenuation and level setting with temperature compensation to further shrink a PCB design.




**3. The SpaceNXT HC Series high-reliability chip attenuators have been developed for commercial space applications from dc to 18 GHz.** *(Courtesy of Smiths Interconnect)*

Smiths Interconnect also introduced its SpaceNXT Q series of flexible coaxial-cable assemblies at the exhibition. The cable assemblies are tested and qualified for space orbit applications. The cost-effective cable assemblies *(Fig. 4)* can be cut to customer-specified lengths for use from dc to 40 GHz (depending on connectors). They can meet NASA/ESA outgassing requirements when tested to ASTM E595 standards.

**4. The SpaceNXT Q series of flexible coaxial cable assemblies are qualified for space applications from dc to 40 GHz.** *(Courtesy of Smiths Interconnect)*

Even power-amplifier suppliers, such as Empower RF, have worked to shrink the size of its products, and its designers have been facing the challenges of higher output power levels from smaller volumes by boosting efficiency and enhancing thermal management. Using both LDMOS and GaN active devices, the company developed more compact power amplifiers for a variety of applications, including communications, radar, electronic warfare (EW), and testing.

A company long-synonymous with high-frequency switching, Dow-Key Microwave, displayed a sampling of its wide range of coaxial, waveguide, and space-qualified switches in many different configurations, from tiny drop-in components to rugged rack-mount matrices for testing. Part of the Dover companies (including K & L Microwave and Pole Zero) exhibiting at the 2018 IMS, Dow-Key offered advice on the use of its many different switches for RF through mmWave frequencies. Many visitors showed interest in lines of low passive-intermodulation (PIM) switches. These are growing in importance due to the greater number of carriers in communications systems, which increases the potential for intermodulation distortion.

Similarly, Krytar, a name very much connected to RF/microwave couplers, was on hand at the 2018 IMS exhibition with examples of its now extensive line of directional couplers, detectors, and hybrids, including its latest space-qualified coupler, model 101040010SQ. This broadband, 1- to 40-GHz directional coupler with 10-dB coupling remains flat within ±1 dB across the frequency range. The stripline coupler has less than 1.3-dB insertion loss to 20 GHz and less than 1.7-dB insertion loss through 40 GHz. Given the space-based need for small-sized, lightweight components, the coupler measures just 2.00 × 0.40 × 0.65 in. and weighs just 1.3 oz.

SemiGen impressed visitors not familiar with the company with the diversity and quality of its services, ranging from RF/microwave circuit design and PCB assembly to extensive high-frequency testing at component through system levels. With experience in many different board-assembly methods, including wire and ribbon bonding and die-attach techniques for circuits through millimeter-wave frequencies, the firm can produce RF, microwave, mmWave, digital, and mixed-signal PCBs from single- to multiple-layer configurations, and perform full electrical and environmental testing on all manufactured parts.

## MODULARITY

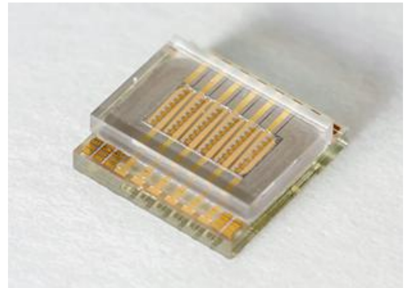
Many modular solutions were in evidence at the 2018 IMS exhibition. For example, Ancortek demonstrated the benefits of software-defined-radio (SDR) technology with various low-power, lightweight radio systems for S-, C-, X-, and K-band frequencies targeting applications like medical diagnosis and public safety.

The firm also showed examples of kits based on its SDR modules, such as a kit with its 240B SDR module and SDR-PM 402 processor module *(Fig. 5)*. The S-band (2.45 GHz) kit makes it easy to get started in SDR technology. It includes both modules, a power supply/adapter, USB and RF cables, a copy of the firm's SDR graphical user interface (GUI) software, and a pair of transmit and receive antennas.

Colorado Engineering brought its expertise in compact module design to

**5. This 2.45-GHz kit makes it easy to get started with SDR technology.** *(Courtesy of Ancortek)*

**6. The iScan Radar Series modules are miniature radar system modules with options for 24, 60, and 70 GHz.** *(Courtesy of Colorado Engineering)*



**7. By teaming with glass-maker Corning, Menlo Micro fabricated this tiny six-channel SPST MEMS switch on a glass substrate.** *(Courtesy of Menlo Micro)*

the exhibition, demonstrating its iScan Radar Series modules *(Fig. 6)* for land, sea, and air environments. Available with 24-, 60-, and 77-GHz options, the modules can measure range, speed, and radar cross section (RCS) with their steerable beams and digital-beamforming capabilities.

Polyphase Microwave demonstrated a PXIe block frequency up/downconverter system with models for C-band (4 to 8 GHz) and X-band (8 to 12 GHz) frequencies. Well-suited for use in vector signal transceivers and Doppler weather radar systems, the modular system features automatic local-oscillator (LO) feedthrough calibration and as much as 30-dB signal attenuation in 1-dB steps. The miniature frequency converter includes an internal phase-locked-loop (PLL) LO frequency synthesizer and is capable of 1-GHz in-phase/quadrature (I/Q) bandwidth. It operates with a standalone control panel and software.

**MORE ABOUT MATERIALS**

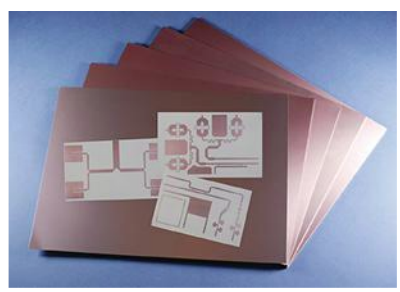
Materials of many kinds caught the attention of 2018 IMS visitors, especially at the Menlo Micro booth, where many different microelectromechanical-systems (MEMS) switches could be found, including the latest miniature six-channel switch fabricated on pristine dielectric glass wafers from Corning *(see " MEMS Switches Shrink with Glass Substrates," p. **58**)*.The outstanding dielectric properties of the glass substrates made possible a miniature MEMS switch with high power-handling capabilities (25 W CW) from dc to 3 GHz despite its semiconductor-chip size *(Fig. 7)*.

In addition to showing what it could do on glass, representatives from Menlo Micro also demonstrated the performance of some more-established MEMS components—essentially semiconductor-sized mechanical devices activated by applied voltages. For example, the MM7100 high-power MEMS switch handles 100 W CW input power from dc to 750 MHz with 8-µs switching time in a compact low-temperature-cofired-ceramic (LTCC) package. For higher frequencies, model MM5120 is a SP4T switch that handles more than 25 W CW input power from dc to 12 GHz and comes in a surface-mount package.

RO4835T laminates on display by Rogers Corp. are circuit materials reinforced by spread glass. These thin (3-, 4-, or 5-mil-thick) thin layers are well suited for the inner layers of multiple-layer circuit assemblies, where they can provide high-frequency circuit functionality without adding to the overall height of the circuit assembly. Newly launched RO4450T thin bonding materials were also exhibited at the Roger's IMS booth, as a complement to RO4835 and RO4835T laminates for creating multilayer circuit assemblies.

Rogers showed many of its high-frequency circuit materials, including some formulated especially to meet the demands of mmWave antennas needed for ADAS vehicular applications.

The firm's low-loss circuit laminates, such as RO3000 and RO4000 materials, are already well-established in automotive collision-avoidance radar systems at 28 and 77 GHz. Its RT/duroid 6035HTC laminates *(Fig. 8)* caught the eyes of many circuit designers in need of materials with excellent thermal conductivity to control the heat generated by high-power amplifiers.



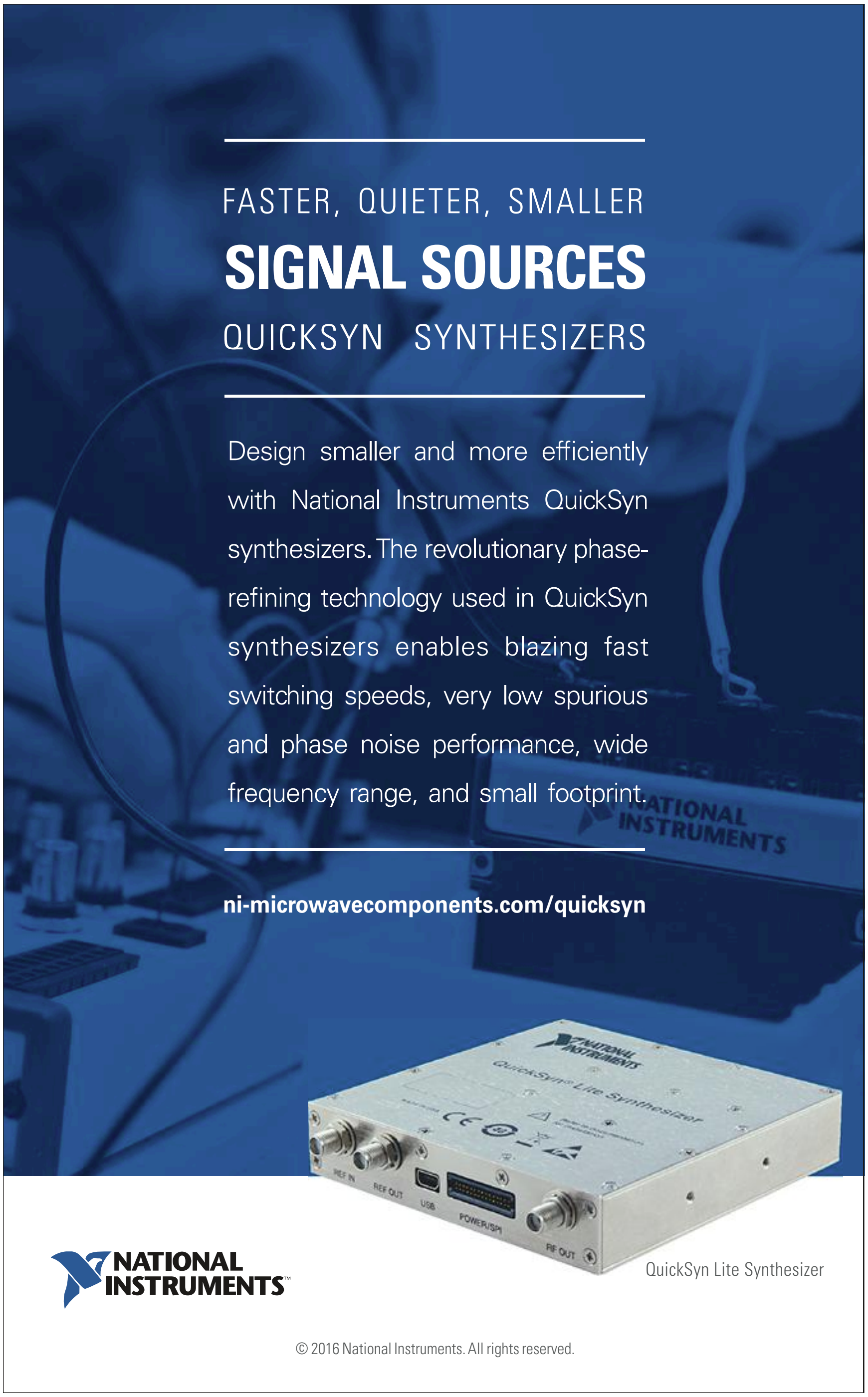
**8. Due to its excellent thermal conductivity, RT/duroid 6035HTC laminates are popular circuit materials for high-power RF/microwave amplifiers.** *(Courtesy of Rogers Corp.)*

Rogers also showed its Kappa 438 materials, which are the thin-but-durable circuit materials needed for more reliable alternatives to FR-4 laminates. These new materials piqued the interest of circuit designers working on carrier-



grade Wi-Fi circuits, small cells, and vehicle communications.

With its I-Tera MT40 low-loss circuit material, representatives from Isola Group advised circuit designers on both high-speed digital and RF/microwave circuits. The material, with low dissipation factor of 0.0031, exhibits a dielectric constant of 3.45 that remains stable with operating temperatures from −55 to +125°C. Available in laminate and prepreg forms, the RoHS-compliant circuit material supports circuit designs to W-band (75 to 110 GHz) frequencies as a foundation for 5G and ADAS automotive radar circuits.




## GET READY FOR 5G

This was an IMS exhibition dominated by designs and solutions intended for 5G applications. LitePoint, for example, showed its iQgig-5G fully integrated 5G millimeter-wave test system for 5G measurements at 28 and 39 GHz. The system provides three bidirectional source and measurement ports each with 2.92-mm coaxial connectors. The configuration enables both horizontal and vertical antenna polarization testing with a single coaxial interface. The test set *(Fig. 9)* features error-vector-magnitude (EVM) performance to 40 dB and a 1-GHz bandwidth to cover pre-5G and 3GPP cellular/wireless standards. It can be equipped with a 3GPP NR 5G software license as well as a Verizon 5G Technical Forum (5gTF) license.

**9. Model iQgig-5G is a mmWave test system for 5G measurements at 28 and 39 GHz.** *(Courtesy of LitePoint)*

In addition to showing its trusted benchtop test equipment, Anritsu's representatives spent a great deal of time with a pocket-sized solution: the model MS2760A Spectrum Master spectrum analyzer. Available with a frequency range as wide as 9 kHz to 110 GHz, this portable measurement marvel can be brought to the device under test (DUT), rather than the other way around. It's ideal for on-site 5G measurements of channel power and occupied bandwidth. And the analyzer has the frequency range to detect and measure other RF sources in the area, such as wireless local-area networks (WLANs) and Bluetooth devices, as well as possible interference signals from mmWave automotive radar systems.

The MS2760A Spectrum Master *(Fig. 10)* has a displayed average noise level (DANL) as low as –136 dBm and a dynamic range of better than 103 dB, to capture low-level signals in many different environments. But as visitors to the Anritsu booth learned, don't let the small size fool you. With its low phase noise and resolution bandwidths of 1 Hz through 1 MHz, this instrument is a match for any rack-mount spectrum analyzer on the market, especially when it comes time to track down rogue mmWave signals.

In preparation for 5G, pSemi Corp. (formerly Peregrine Semiconductor) displayed several miniature mmWave components, including a pair of switches for 40 and 50 GHz and a 50-GHz digital step attenuator (DSA). The 6-b model PE43508 DSA operates from 9 kHz to 50 GHz with as much as 31.5-dB attenuation in 0.5- and 1-dB steps. The DSA, with impressive switching speed of typically 350 ns, is available as a flip-chip monolithic die. The company also announced an evaluation kit for the DSA to speed designers in the use of the tiny attenuator.


**10. The MS2760A Spectrum Master is a full-featured spectrum analyzer that operates from 9 kHz to 110 GHz and fits in the palm of the hand.** *(Courtesy of Anritsu)*

**SEEKING SOFTWARE**

Software users found much to like at the 2018 IMS, with all of the leading suppliers of high-frequency software design and simulation tools in attendance on the exhibition floor. Visitors to the Sonnet Software exhibition booth learned more about Version 16 of the company's popular Sonnet Suites software design and analysis tools, including Sonnet Professional electromagnetic (EM) simulation software. This latest version includes a high-resolution (64-b) interface to another popular suite of RF/microwave software design tools, Microwave Office from NI AWR.

**Antenna designers passing the Remcom booth saw demonstrations of the Wireless InSite MIMO software, which will no doubt see plenty of action during the erection of 5G wireless networks. The software helps in the design of MIMO antenna arrays by simulating many MIMO channels and their interactions.**

The enhancement of existing functions such as adaptive band synthesis (ABS) in Version 16 enables the software to simulate the presence of circuit resonances and other performance characteristics.

Antenna designers passing the Remcom booth saw demonstrations of the Wireless InSite MIMO software, which will no doubt see plenty of action during the erection of 5G wireless networks. The software helps in the design of MIMO antenna arrays by simulating many MIMO channels and their interactions. It can model beamforming scenarios and spatial multiplexing effects, as well as perform three-dimensional (3D) ray tracing to 100 GHz to predict antenna patterns and signal-path characteristics between transmitters and receivers in 5G networks.

For amplifier designers and others interested in achieving effective impedance matches between active devices and surrounding circuitry, Focus Microwaves showed examples of its electromechanical source and load-pull tuners, including its Omega tuner for 5G applications. The tuner features a small footprint for on-wafer testing, and is light weight for ease of transport. It operates through mmWave frequencies (67 GHz) with 1.85-mm connectors and can handle power levels to 14 W. The firm also showed its M-67100 DELTA tuners for harmonic on-wafer load-pull measurements through 67 GHz.

In general, visitors to the 2018 IMS were enthusiastic about business prospects for the future, based on healthy markets expected for 5G and autonomous vehicles, especially at mmWave frequencies. In addition, defense spending is still strong, and exhibitors and visitors alike acknowledged the continuing needs for product and technology improvements aimed at aerospace and defense applications. mw

BRIAN WALKER | Senior RF Design Engineer, Copper Mountain Technologies
www.coppermountaintech.com

# THE WHEATSTONE BRIDGE: How Does It Impact VNA Measurements?

**One fundamental electrical engineering topic is the Wheatstone bridge, which plays an important role in terms of vector-network-analyzer incident and reflected measurements.**

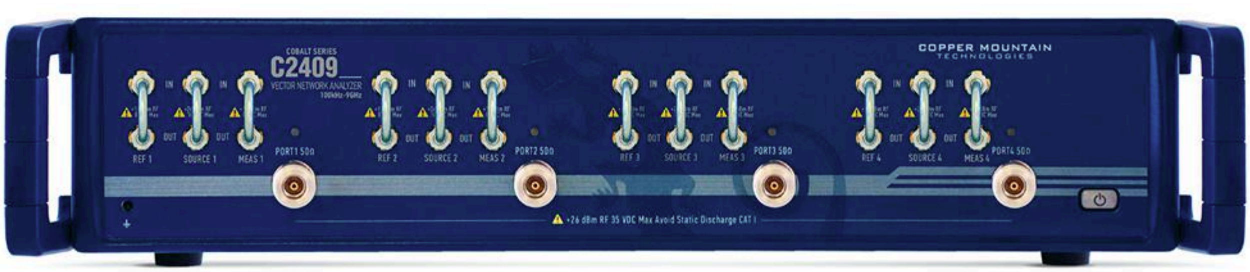
A very wise engineer once told me, "If you want to make an accurate measurement of something, use a bridge." I have found this advice to be true on more than one occasion. A bridge can be made in many different ways, as long as two paths are conjured up to make a comparison: a reference path and a measurement path.

Here, I'll only consider the Wheatstone bridge with resistive elements. How might it be used to measure an unknown resistance or complex impedance, or to measure the forward and reverse components of a "traveling wave" over a broad range of frequencies? This last capability is an essential part of a vector network analyzer (VNA), a tool used to determine the S-parameters of a device under test (DUT) by measuring the reflected and transmitted components of incident RF waves in a 50-Ω system.

*Figure 1* shows a Wheatstone bridge driven by a 1-V DC battery. Resistors R1, R2, and R3 are each 1,000 Ω. R4 takes on the values of 800, 900, 1,000, 1,100, and 1,200 Ω. The plot to the right of the schematic shows the voltage difference between the two arms of the bridge going from −55 to +45 mV, with a 0-V balance occurring when R4 is 1,000 Ω. This makes sense of course. When R4 is 1,000 Ω, the voltage between the resistors of each arm is half of the supply voltage and the difference between them is zero.

It's important to note that at the balance point, small changes and noise from the power supply are canceled out. This is a very important feature. Modern resistance-measurement gear relies on precision voltage references to accomplish this task. However, it's not required for a bridge.

Circuits like this were used at one time to make precision resistance measurements, primarily in the case of telephone cables. R3 was replaced with a decade box, which could "dial in" a known and precise resistance. The unknown resistance was attached to the R4 position and a sensitive microammeter was placed across the bridge. R3 was then dialed in until the meter



read zero volts; the value of R4 must then equal R3.

### DIRECTIONAL BRIDGE, INCIDENT WAVES

The method described was how resistance was measured with great precision in the past. Now, let's look at a bridge used to monitor the output of an RF source in a directional manner. We may have a source with a 50-Ω impedance that requires an output-level control. If we have no control over the loading of that source, we will probably want our output-level detector to only look at the incident signal. While a directional coupler will do this over a narrow frequency range, a resistive bridge will operate over a large range—and will probably be less expensive. *Figure 2* shows a bridge designed for a directional measurement.

The bridge in *Figure 2* is balanced due to the resistor values having the same ratio. The ratio of R2 to R1 is 9:1, as is the ratio of the nominal 50-Ω load to R3. This results in a 20-dB coupling ratio and less loss through the RF output path (about 1 dB).

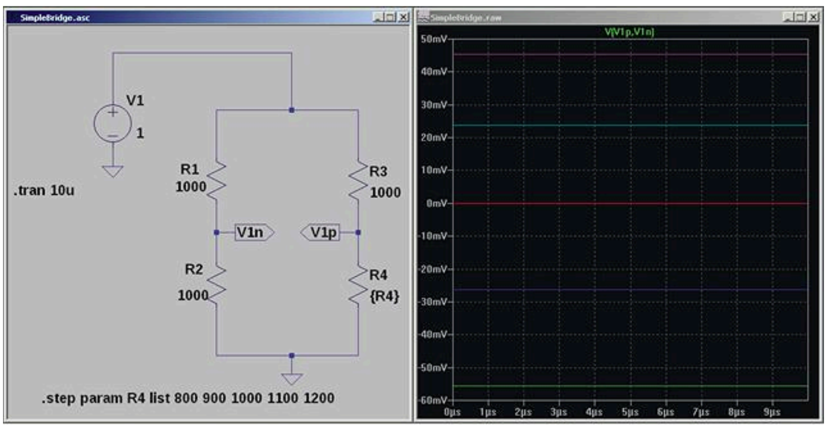
The top chart in *Figure 2* shows the current through R1, which would result in a 100-mV peak sine wave across it (2 mA * 50 Ω). The bottom chart shows how the voltage, Vin, varies with the combination of the 50-Ω, 1-V incident wave and reflections caused by loads ranging from 30 to 70 Ω. With a 50-Ω load, there's no reflection and the red trace shows the 1-V wave with no interference from either constructive or destructive interference.

When setting the load impedance to other values, Vin is either bigger or smaller. This simulation shows how a monitor across R1 would provide a good measurement of the incident wave from the source regardless of loading. Because of the distribution of grounds in this diagram, a balun would be needed across R1, or in place of R1, to "couple off" the signal to a detector, mixer, or other circuit. As long as the "arm" where R1 resides looks like 50 Ω, the bridge will function properly.

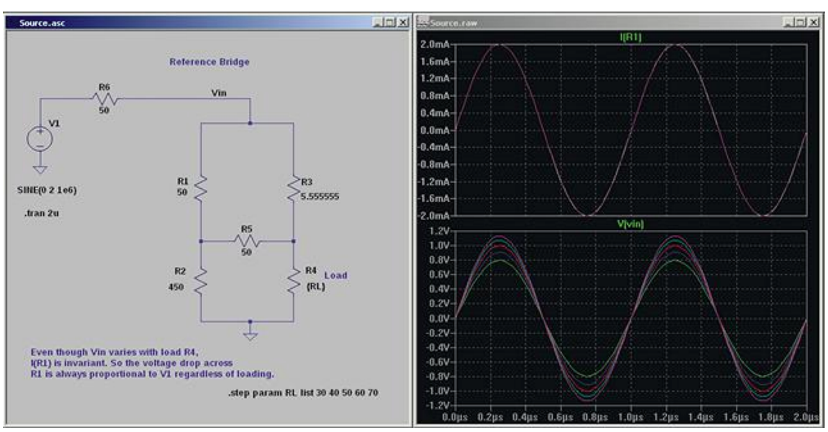
Mathematically, if a 10-to-1 or 20-dB sampling of the incident wave is desired, then R1 is set to the source resistance (R6 in *Figure 2*). The ratio of R2 to R1 and nominal RL to R3 would be 9 to 1, as one would calculate for any other 10-to-1 resistive voltage divider (shown in *Figure 2*). This example is for a 50-Ω system with a 50-Ω source. For a 75-Ω system, one would simply scale up the resistors accordingly.

How does this work? *Figure 3* shows the open-circuit condition of the load resistor. A 1-V battery functions as the source. The bridge is 50 Ω in each position to make it easier to see what is happening. In the open-circuit case, the source is seeing 133.333 Ω and the total current is 7.5 mA. That current splits, leaving two-thirds, or 5 mA, across the sense resistor, R1.

*Figure 4* shows the short-circuit case in which the source sees 80 Ω and the total current increases to 12.5 mA. The current splits between R1 and R3, resulting in 5 mA across R1 once again.




**1. This figure depicts a Wheatstone bridge circuit. The plot reveals the voltage difference between the two bridge arms.**




**2. Shown is a resistive bridge intended for directional measurements.**

Therefore, the total impedance seen by the source changes as the load varies from open to short. However, the balancing of the bridge keeps the current through R1 constant in all cases.

### REFLECTED WAVES

Reflected waves can be measured with a bridge as well. In *Figure 5*, the load varies from 30 to 80 Ω. The current through R5 is proportional to the reflection from this load. The green and blue curves in the plot represent 30 and 40 Ω. The reflections are anti-phase to the driving waveform. The red trace shows zero reflection at 50 Ω, while the cyan, violet, and gray traces are in-phase reflections with load-resistance values of 60, 70, and 80 Ω.

But how does this work? First, let's substitute source resistor (Rs) values along with K * Rs and Rs/K for a general case. If Rs = 50 and K = 9, we would have the configurations previously shown for a 50-Ω, 20-dB sampling bridge *(Figure 6)*. Taking V1, Rs, and K to be constants, we set up the three equations:

$$V1 = (i1 * Rs) + (i2 * Rs) + ((i1 - i3) * Rs * K) \quad (1)$$

$$V1 = (i1 * Rs) + (i2 * Rs) + (i3 * Rs) + ((i1 - i2 + i3) * RL) \quad (2)$$

$$V1 = (i1 * Rs) + ((i1 - i2) * Rs/K) + ((i1 - i2 + i3) * RL) \quad (3)$$

One can solve for i3 as a function of RL, which turns out to be:

$$i3 = -V1/2 * (K/(K + 1)^2) * 1/Rs * ((RL - Rs)/(RL + Rs)) \quad (4)$$

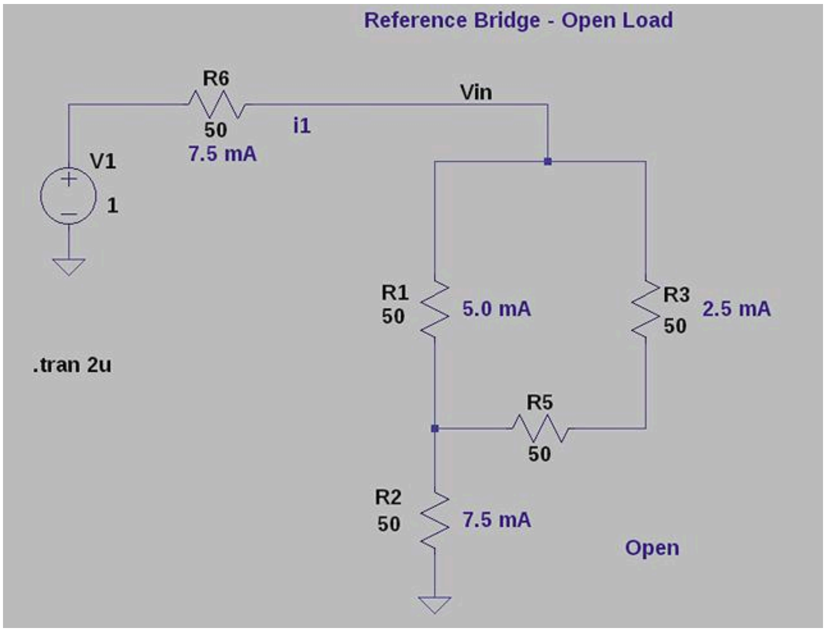
Multiplying i3 by the resistor it passes through will give the sampled voltage (V3). The 1/Rs term vanishes:

$$V3 = -V1/2 * (K/(K + 1)^2) * ((RL - Rs)/(RL + Rs)) \quad (5)$$

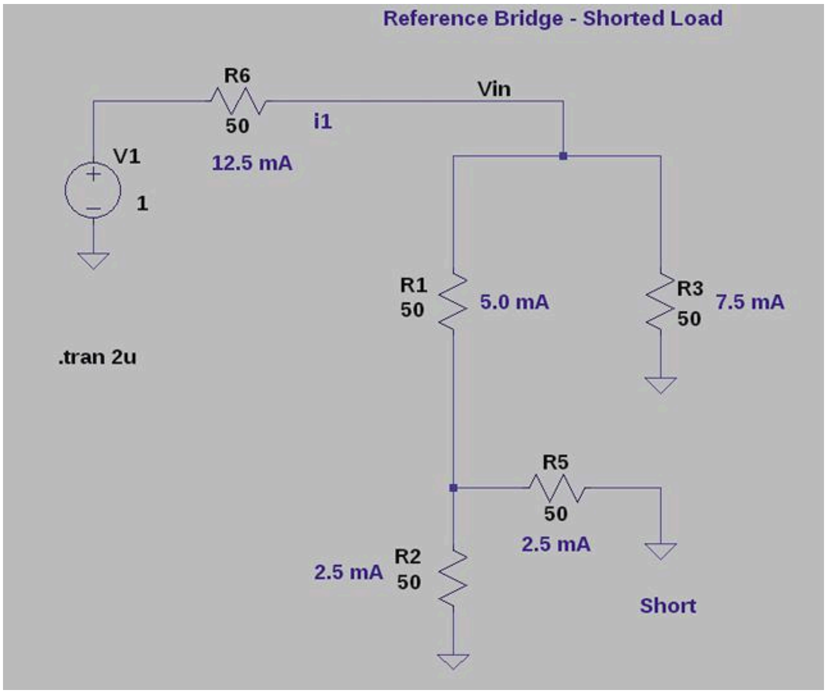
$$V3 = -V1/2 * (K/(K + 1)^2) * \Gamma \quad (6)$$

Immediately recognizable is the last term in Eq. 5, which is the reflection coefficient of RL with respect to Rs, usually designated by a capital gamma (Γ). We see the not-so-surprising result that the voltage across the middle arm of the bridge provides a simple way to measure the reflection coefficient of any load RL.

In practical terms, it would be necessary to use an instrumentation amplifier or a balun to process this voltage. Many mixers and detectors require a differential input anyway, so this isn't terribly burdensome.




3. In this circuit, the load is replaced with an open circuit.




4. Here, a short circuit takes the place of the load resistor.

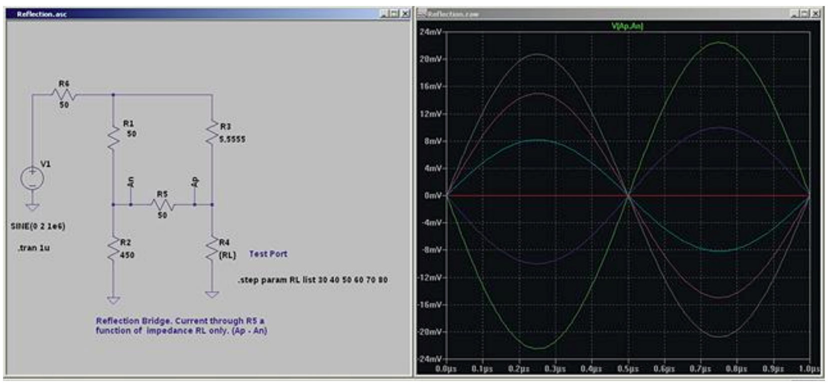
A VNA might use a combination of source-monitoring and reflection-measuring bridges to provide a very wideband solution. These resistive bridges will essentially operate down to DC and as high as spurious effects allow, which can be very high for a carefully designed bridge with 0201-sized resistors.

In contrast, directional couplers have been used to separate the forward and reverse components of a signal, but they will have a lower cutoff frequency and may operate only over an octave or two of bandwidth. The Wheatstone bridge is a tool that should be in every RF engineer's toolbox, and in many cases, it might be the ideal solution for a measurement circuit.

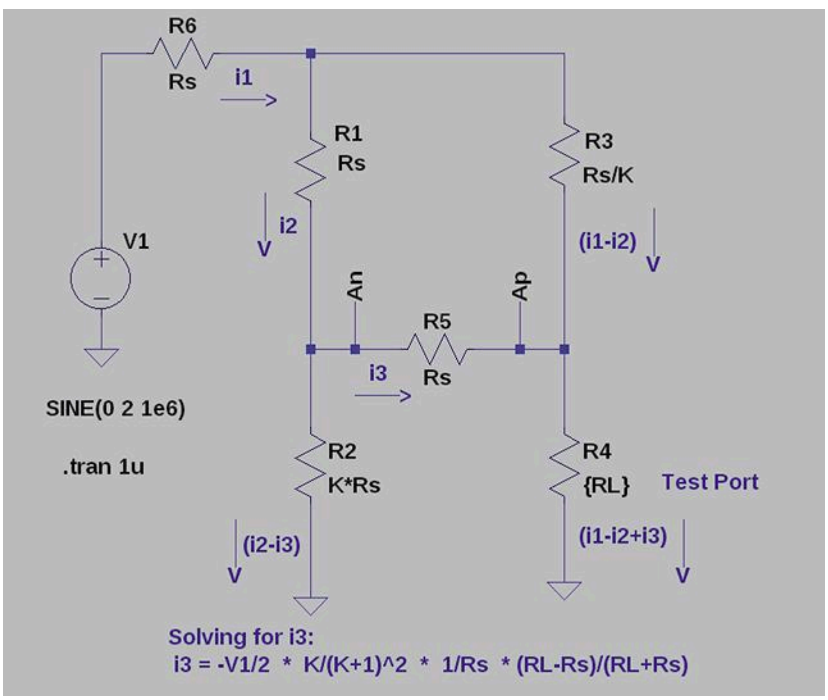
The figures and charts for this article were created using LTSpice, a free program available from Analog Devices (ADI). Many thanks to ADI for this great tool. mw


REFERENCE

Dunsmore, Joel. "Simple SMT Bridge Circuit Mimics Ultra-Broadband Coupler," *RF Design*, November 1991: 105-108.

5. In this analysis, reflected waves are measured with different load-resistance values.




6. The last term in the equation shown represents the reflection coefficient.

CHRIS DeMARTINO | Technical Engineering Editor

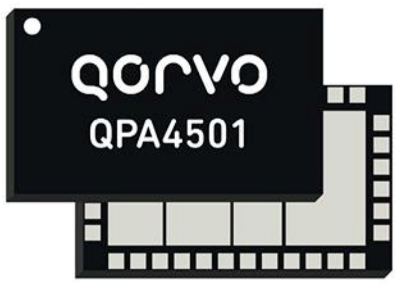
# 5G Runs on Different Fuel

**From gallium nitride and gallium arsenide to sub-6-GHz and millimeter-wave frequencies, this company is addressing 5G requirements on multiple fronts.**

As 5G communications reality draws closer, one major point of interest involves the actual semiconductor technologies that will enable it. Technologies like gallium nitride (GaN), gallium arsenide (GaAs), and more all figure to somehow play a role. One firm at the forefront of semiconductor technology—and heavily invested in 5G—is Qorvo *(www.qorvo.com)*. Qorvo had a significant presence at IMS 2018, showcasing its various technology solutions and making some notable announcements that centered around 5G and GaN technology.

5G can be divided into two categories based on frequency: sub-6-GHz and millimeter waves (mmWave). Scott Vasquez, senior market strategy manager for infrastructure and defense products at Qorvo, attended IMS and weighed in on the company's efforts along these lines. "Several frequencies are involved in the sub-6-GHz market, whether it's 2.5, 3.5, or 4.5 GHz," he said. "We have many different products that support those frequencies, such as GaN Doherty-based products that integrate driver, carrier, and peaking amplifiers with power outputs to 5 W—and potentially moving up to 10 W."

One recently introduced Doherty-based product is the QPA4501—an integrated two-stage GaN power-amplifier (PA) module *(Fig. 1)*. The QPA4501, which operates from 4.4 to 5.0 GHz, consists of a driver amplifier and a Doherty final stage. It's rated for 3 W of average output power. At 4.6 GHz, the QPA4501 achieves 32 dB of gain when delivering 1.25 W of average output power. In addition, at 4.6 GHz, power-added efficiency (PAE) is 38% when delivering 3 W of average output power. The QPA4501 is intended for 5G massive multiple-input, multiple-output (MIMO) applications.




**1. The QPA4501 is a GaN PA module that covers a frequency range of 4.4 to 5.0 GHz.**

Another new Doherty-based product, the QPA3506, is a 5-W GaN PA module. Covering a frequency range of 3.4 to 3.6 GHz, the QPA3506 can achieve 30 dB of gain and 40% PAE. Qorvo also plans to release a next-generation version of this device that will have significantly better performance in terms of efficiency and other key specifications.

Vasquez also explained some of Qorvo's other strengths, noting the company's achievements in the areas of filters, switches, and low-noise amplifiers (LNAs). "We have a 4-W bulk-acoustic-wave (BAW) filter at 2.5 GHz. We also have switch/LNA modules that can handle as much as 5 or 8 W of maximum input power with even higher power levels in development. And we have several gain blocks and driver amplifiers. So, we're one of the companies that can really fill out the front-end block diagram of sub-6-GHz applications."


**2. The QPB9329 dual-channel switch/LNA module operates from 3.8 to 5.0 GHz.**

Regarding the switch/LNA modules that Vasquez mentioned, two recently announced products are the QPB9329 and QPB9319 *(Fig. 2)*. The QPB9329 switch/LNA module integrates a two-stage LNA and a high-power switch in a dual-channel configuration. Covering 3.8 to 5.0 GHz, the QPB9329 provides 31.5 dB of gain in the receive (Rx) mode, high-gain state and 16.5 dB of gain in the Rx mode, low-gain state. Noise figure in Rx mode is 1.8 dB. Furthermore, the QPB9329 can withstand as much as 5 W of average input power in transmit (Tx) mode.

The QPB9319 switch/LNA module also integrates a two-stage LNA and a high-power switch in a dual-channel configuration. The QPB9319, which covers a frequency range of 1.8 to 4.2 GHz, delivers 37 dB of gain in the Rx mode, high-gain state and 19 dB of gain in the Rx mode, low-gain state. The QPB9319 achieves a noise figure of 1.45 dB in Rx mode. On top of that, it can withstand as much as 8 W of average input power in transmit (Tx) mode.

As for the driver amplifiers noted by Vasquez, Qorvo announced the QPA9120 wideband driver amplifier. The QPA9120 covers a frequency range of 1.8 to 5.0 GHz. It offers 29 dB of gain and achieves an output third-order intercept point (IP3) of +35 dBm. Furthermore, it operates from a single +5-V supply and consumes less than 100 mA.

**TARGETING mmWAVE**

Qorvo's dive into the mmWave side is demonstrated by solutions like the QPF4005 and QPF4006 GaN front-end modules (FEMs), which operate from 37 to 40.5 GHz. Vasquez noted some advantages that GaN technology offers at mmWave frequencies.

"At mmWave frequencies, size is critical from an integration perspective for a few reasons. There are lattice-spacing requirements for mmWave phased-array systems," said Vasquez. "Using GaN helps us to achieve really small lattice-spacing sizes to support phased-array applications. GaN is advantageous from a power-density perspective, too. If you design a 2-W GaN FEM at 28 GHz, it can be significantly smaller than a 2-W GaAs front-end module or a silicon-germanium (SiGe) or CMOS solution."

While GaN technology is clearly a focal point of Qorvo, the company hasn't forgotten about GaAs. "5G will potentially be a very large market," explained Vasquez. "There will be many different applications for 5G. Because there will be all these different use cases, each of them can potentially have different radiated output power requirements. For low-power applications—which will represent a very large part of the market as well—GaAs can bring some benefits. With that, we're looking at GaAs to address use cases that do not require such high effective-isotropic-radiated-power (EIRP) levels—and it's a great way for us to internally benchmark performance of GaN and GaAs."

Vasquez noted that Qorvo is developing a 28-GHz GaAs FEM that should be released later this year. mw

AHMED F. DAW | Assistant Professor, Electrical Systems Engineering Department, MSA University, Cairo, Egypt; E-mail: afali@msa.eun.eg
MARIAN N. ADLY | Researcher, Electrical Systems Engineering Department, MSA University, Cairo, Egypt; E-mail: marian.nashaat@msa.edu.eg
MAHMOUD A. ABDALLA | Associate Professor (IEEE Senior Member), Electronic Engineering Department, Military Technical College (MTC), Cairo, Egypt; E-mail: maaabdalla@ieee.org

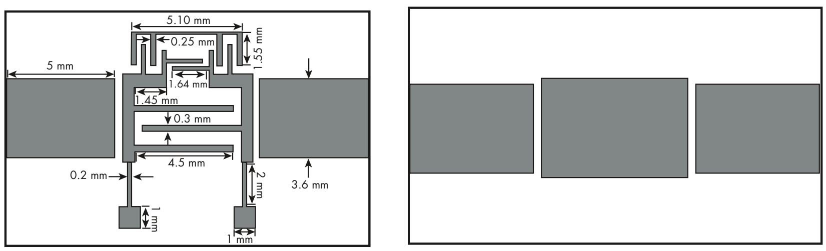
# Metamaterials Mold Multiband Resonator

**A new configuration of composite right/left-handed metamaterial-based transmission lines were the building blocks for this novel triple-band compact resonator.**

Advances in materials have been the springboard to enhancements in higher-frequency circuits and higher-efficiency, more compact circuits. As an example, the use of composite right/left-handed (CRLH) metamaterial transmission lines has made possible a miniature multiple-band resonator with frequencies extending from 2.8 to 10.4 GHz and high selectivity between the resonant circuit structures. In addition, the resonant structures have closely matched return losses.

The multiple-band resonator is fabricated on standard commercial circuit material with dielectric constant of 3.55 and thickness of 1.52 mm. It consists of a CRLH unit cell plus an additional series-connected resonant circuit that tunes the overall structure and provides the third frequency band. The resonator measures just 16.5 × 18.9 mm$^2$ and delivers the multiple frequencies and compact size required for many modern communications circuit designs.

The steady expansion of wireless functions creates the need for denser high-frequency circuitry in smaller circuit sizes. CRLH circuitry has been shown as an effective means of shrinking the size of planar microwave components,[1] with even greater circuit density and miniaturization possible using dual (D-CRLH) circuit structures.[2] The two types of circuit configurations have been employed as filters, duplexers, diplexers, couplers, and power dividers in much smaller sizers than possible with conventional microstrip and stripline high-frequency transmission-line circuitry.[3-5]




(a) (b)

**1. The configuration for the novel three-frequency resonator based on CRLH metamaterial transmission lines (a) is compared with a traditional multiple-band resonator (b).**

For multiple-frequency-band applications in communications systems, CRLH transmission-line (CRLH-TL) resonators offer numerous advantages over traditional TL resonators because they have three branches in a half-periodicity configuration.[2] To enhance the bandwidth of the compact resonators, U-folded resonators[3] and multimode resonators[4-6] were developed, too.

Multiple-band resonators had been built previously, serving as a starting point for the current design,[7] while stepped-impedance resonators were also developed to produce multiple frequency bands.[8,9] Unfortunately, the performance of these multiple-band stepped-impedance resonators was limited and, to improve the spectral purity of these multiple-band resonators, the small size of the initial design was sacrificed for an improvement in performance.[10,11]

The researchers' current work consists of a new resonator structure in which a gap-coupled microstrip resonator optimizes the use of tuning an additional tuner with a CRLH cell. This achieved three resonant frequencies/bands with simple control of the center frequencies and bandwidths. By using the CRLH transmission line, resonator length can be decreased to less than one-quarter wavelength at each frequency of interest, while maintaining good spectral performance.

*Fig. 1a* shows the layout of the CRLH triple-band line resonator in comparison to a traditional coupled-gap resonator in *Fig. 1b*. The triple-band resonator consists of a CRLH unit cell with additional tuner circuitry in series.

The CRLH cell is designed to operate at two low-frequency bands of 2.8 and 4.0 GHz, as shown by the S-parameters in *Fig. 2a*. The additional series circuitry tunes the operating bands of the CRLH resonator as well as the third frequency band at 10.4 GHz *(Fig. 2b)*. The input and output ports are coupled by means of the small gap capacitor connected to the CRLH circuitry.

The novel three-frequency design features low losses, with insertion loss equivalent to 3 dB at the first resonator band of 2.8 GHz, 1.5 dB at the second resonator band of 4 GHz, and 1.7 dB at the third resonator band of 10.4 GHz. The three-frequency resonator's measured ($S_{21}$) performance is compared to simulated ($S_{21}$ and $S_{11}$) responses in *Fig. 3*.

One step in designing the CRLH unit cell involves determining the value of n in Eq. 1 related to resonator phase:

$$\text{Phase} = -\beta L = n\pi \qquad (1)$$

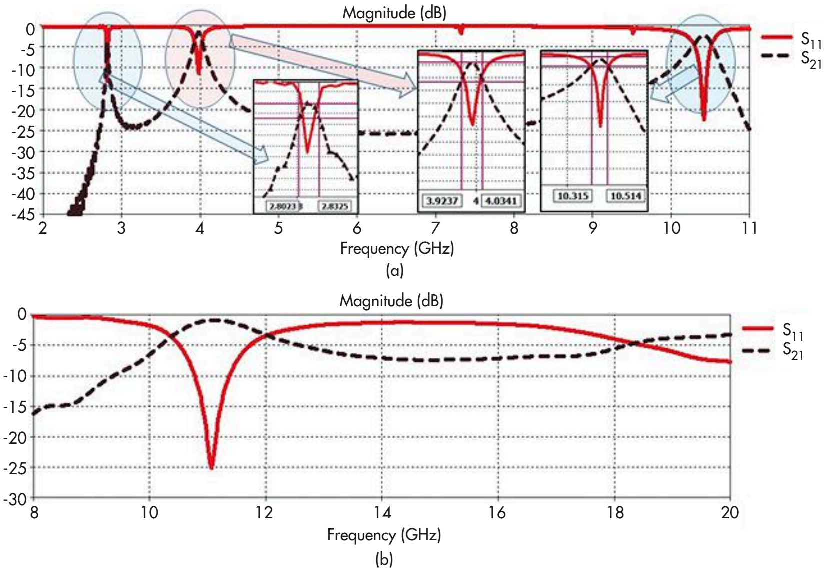
where:

L = the total physical length of the resonant transmission lines

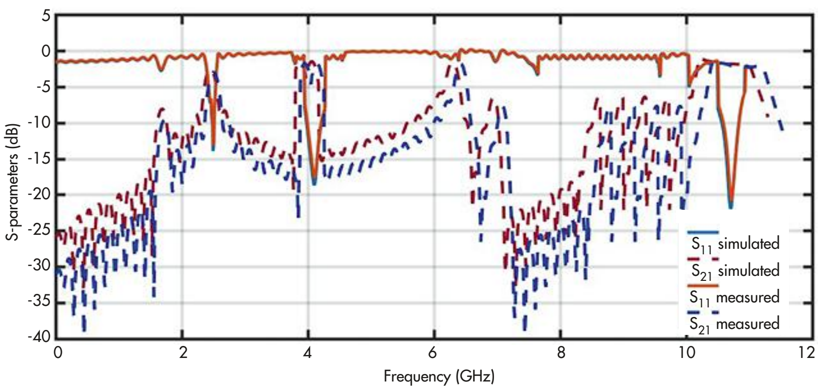
n = a constant

β = a propagation constant

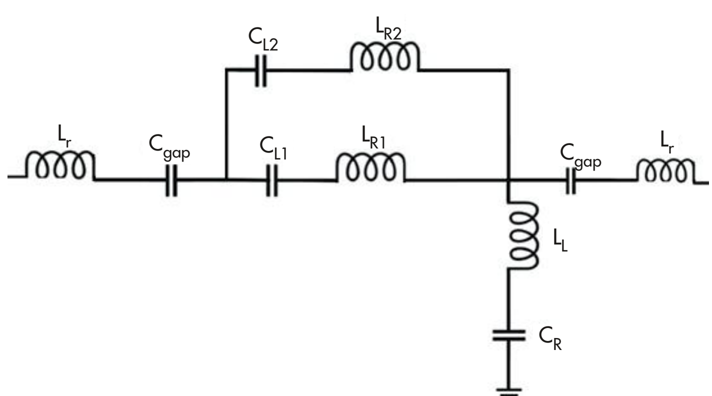
*Fig. 4* shows an equivalent circuit for the three-frequency CRLH resonator deduced from its physical behavior. The LR section is equivalent to a microstrip feed line, while the gap is equivalent to the gap capacitor, $C_{gap}$. Parameters $C_{L1}$, $L_{R1}$, $L_L$, and $C_R$ are equivalent to the capacitances and inductances of the CRLH circuit cell. Capacitance $C_{L2}$ and inductance $L_{R2}$ represent the additional series tuning branch.



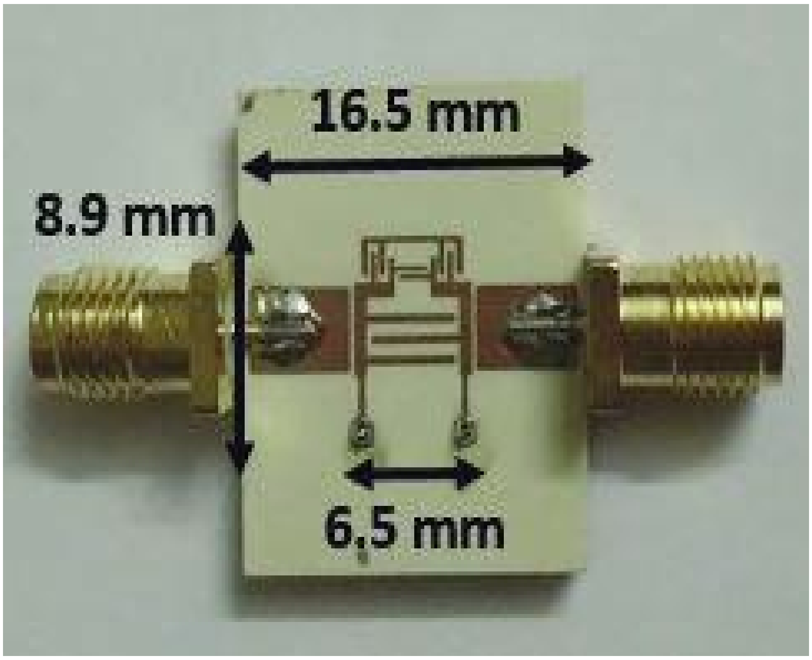

**2. The plots show the simulated ($S_{21}$ and $S_{11}$) and measured ($S_{21}$) S-parameters for the three-frequency resonator (a) and a traditional coupled-gap resonator (b).**




**3. These plots reveal how closely the simulations compare to measurements for $S_{21}$ and $S_{11}$ parameters for the three-frequency resonator.**




**4. This equivalent circuit shows the basic circuit elements required for the three-frequency CRLH resonator.**




5. This version of the three-frequency CRLH resonator is fabricated on commercial PCB material with dielectric constant of 3.55 in the z-axis (thickness) at 10 GHz.

In the three-frequency CRLH resonator, the first and second resonances are produced by the CRLH cell, with key circuit values for the two lower-frequency resonances, $f_1$ and $f_2$, calculated by Eqs. 2 and 3, respectively:

$$f_1 = 4\pi(C_{L1}L_{R1})^{0.5} \quad (2)$$
$$f_2 = 1/\pi(C_R L_L)^{0.5} \quad (3)$$

**TUNING HIGHER**

The third resonance frequency in the circuit, $f_3$, is achieved by tuning the interdigital capacitor, where low values of capacitance and inductance are used to obtain the third frequency band with a higher frequency. Equation 4 is used to determine the key circuit parameters:

$$f_3 = 1/2\pi(C_{L2}L_{R2})^{0.5} \quad (4)$$

The loaded quality factor of the three-frequency resonator, $Q_L$, can be found by applying Eq. 5:

$$Q_L = f_0/f_{3dB} \quad (5)$$

where:

$f_0$ = the resonant frequency
$f_{3dB}$ = the 3-dB bandwidth surrounding the resonant frequency

The 3-dB bandwidth of the resonator insertion loss for the first band is 0.0302 GHz, 0.1104 GHz for the second band, and 0.199 GHz for the third band. The quality factors (Q) for the three bands are 92.7, 36.2, and 52.26, respectively. In comparison to the traditional gap-line resonator of Fig. 1b, the three-band resonator achieves much improved Q, since the Q of a traditional coupled-gap resonator *(Fig. 2b)* is relatively low, at 6.93.

**COMPACT RESONATOR**

*Fig. 5* shows a three-frequency CRLH resonator constructed with a CRLH transmission line and a conventional microstrip transmission line. The resonator is fabricated on commercial printed-circuit-board (PCB) material

**For multiple-frequency-band applications in communications systems, CRLH transmission-line (CRLH-TL) resonators offer numerous advantages over traditional TL resonators because they have three branches in a half-periodicity configuration. To enhance the bandwidth of the compact resonators, U-folded resonators and multimode resonators were developed, too.**

from Rogers Corp. *(www.rogerscorp.com)* with dielectric constant of 3.55 and thickness of 1 mm. The circuit material is laminated with 0.035-mm-thick copper foils on both sides of the dielectric material. The distance between the CRLH and microstrip transmission lines is 0.3 mm.

This miniature triple-frequency resonator represents an example of how this transmission-line technology can be applied to produce multiple signal frequencies while also miniaturizing the circuitry. The novel CRLH structure used in the three-frequency resonator is designed with one cell consisting of two patch capacitors for the two lower-frequency bands and an additional series-connected circuit branch to produce the third, higher-frequency resonance. The frequencies in this resonator are easily controlled and tuned, with low insertion loss and reasonable values of return loss, suggesting that the design approach has promise for use across a wide range of resonator frequencies. mw

### REFERENCES


1. C. Caloz and T. Itoh, *Electromagnetic Metamaterials: Transmission Line Theory and Microwave Applications,* Wiley, New York, 2006.

2. C. Caloz, "Dual Composite Right/Left-Handed (D-CRLH) Transmission Line Metamaterial," *IEEE Microwave and Wireless Components Letters*, Vol. 16, No. 11, November 2006, pp. 585-587.

3. S. Zhang and L. Zhu, "Compact Tri-band Bandpass Filter Based on λ/4 Resonators with U-Folded Coupled Line," *IEEE Microwave and Wireless Components Letters*, Vol. 23, No. 5, May 2013, pp. 258–260.

4. L. Gao, X. Y. Zhang, and Q. Xue, "Compact Tri-band Bandpass Filter Using Novel Eight-Mode Resonator for 5G WiFi Application," *IEEE Microwave and Wireless Components Letters,* Vol. 25, No. 10, October 2015, pp. 660–662.

5. Ahmed F. Daw, Mahmoud A. Abdalla, and Hadya M. Elhennawy, "Dual Band High Selective Compact Transmission Line Gap Resonator," 2014 Loughborough Antennas & Propagation Conference, United Kingdom, pp. 91-94.

6. Ahmed F. Daw, Mahmoud A. Abdalla, and Hadia M. EL-Hennawy, "Multiband Sharp-Skirt Compact Gap Resonator Based D-CRLH," 2015 32th National Radio Science Conference (NRSC), Egypt, pp. 43-50.

7. R. Zhang and L. Zhu, "Analysis of Dual-Wideband Bandpass Filters with Source-Load Coupling Network," *IEEE Transactions on Microwave Theory & Techniques,* Vol. 62, No. 3, March 2014, pp. 441–449.

8. A. F. Daw, M. A. Abdalla, and H. M. Elhennawy "New configuration for multiband ultra-compact gap resonator-based D-CRLH," IEEE, Middle East Conference on Antenna and Propagation (MECAP) conference proceedings, 2016, pp. 1-4.

9. C. F. Chen, "A Compact Reconfigurable Microstrip Dual-Band Filter Using Varactor-Tuned Stub-Loaded Stepped-Impedance Resonators," *IEEE Microwave and Wireless Components Letters,* Vol. 23, No. 1, January 2013, pp. 16–18.

10. B. Wu, C. H. Liang, P. Y. Qin, and Q. Li, "Compact dual-band filter using defected stepped impedance resonator," *IEEE Microwave and Wireless Components Letters,* Vol. 18, No. 10, October 2008, pp. 674–676.

11. H. Lobato-Morales, A. Corona-Chavez, T. Itoh, and J. L. Olvera-Cervantes, "Dual-band multi-pole directional filter for microwave multiplexing applications," *IEEE Microwave and Wireless Components Letters,* Vol. 21, No. 12, December 2011, pp. 643–645.

Design Feature

MAHMOUD A. ABDALLA | Assistant Professor, Electronic Engineering Department, MTC College, Cairo, Egypt,
E-mail: maaabdalla@ieee.org

ASHRAF Y. HASSAN | Ph. D. Student, Electronics and Communications Department, MSA University, Giza, Egypt,
E-mail: ashrafyoussef92@hotmail.com

AHMED A. IBRAHIM | Assistant Professor, Communications and Electronics Department, Faculty of Engineering,
Minia University, Minia, Egypt and University Oierre and Marie Curie, Sorbonne University, Paris VI, France;
E-mail: ahmedabdel_monem@mu.edu.eg

# Building a Zero-Order BPF with CRLH Transmission Lines

**Metamaterials and unconventional CRLH transmission lines combine to create RF/microwave bandpass filters with miniature dimensions for wireless applications such as WiMAX.**

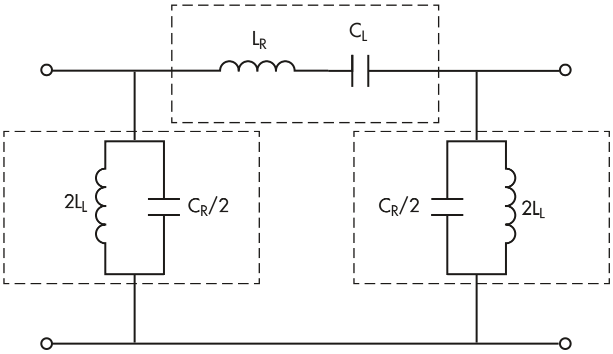
Miniaturization of RF/microwave filters helps pave the way to developing smaller wireless devices for internet access. Using metamaterials and circuit structures such as composite-right-left-handed (CRLH) resonators has proven effective in shrinking RF/microwave filter circuits and was demonstrated in the design of a compact bandpass filter (BPF) well-suited for WiMAX wireless applications.

Leveraging third-order coupled CRLH resonators, the filter achieves a center frequency of 5.9 GHz with transmission zero at 6.4 GHz. Measuring just $16 \times 24$ mm$^2$, or about 40% the size of BPFs based on conventional resonators, the filter has a passband insertion loss of just 1.5 dB.

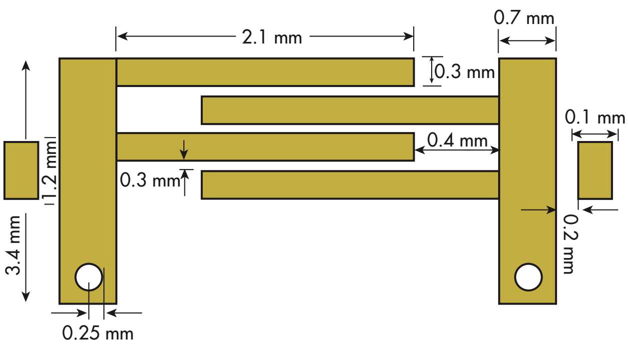
Metamaterials have shown great promise for the fabrication of compact, high-frequency RF/microwave circuits.[1-4] First proposed in 2002, CRLH transmission lines (CRLH-TLs) are forms of high-frequency transmission lines that exhibit backward-wave transmission behavior capable of unusual electromagnetic (EM) wave propagation. Metamaterial approaches to microwave circuit design are typically based on CRLH or negative-refractive-index transmission lines in planar structures by loading a host transmission line with series capacitor and shunt inductive load.

Use of metamaterials and CRLH-TLs enables the design of RF/microwave BPFs with small size, low passband loss, and even low cost. The small sizes supported by metamaterials make possible multiple-band filters that are a fraction of the size of BPFs formed with conventional transmission lines.[5-10] Coupled metamaterial resonators have formed compact BPFs.[8,10] In addition, compact microwave CRLH gap resonators with high quality factors (Qs) show great promise for forming miniature BPFs.[11,12]

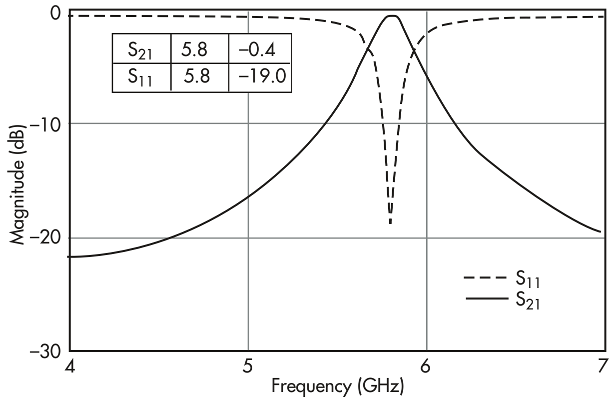
To demonstrate, by combining high-Q CRLH gap resonators with third-order zeroth-order-resonator (ZOR) coupled resonators, a microwave BPF with extremely compact dimensions was designed and fabricated for WiMAX applications with standard, low-cost circuit materials. The filter was constructed on RT/duroid 6010 circuit material from Rogers Corp. *(www.rogerscorp.com)*. The 1.27-mm-thick circuit material has dielectric constant of 10.8 at 10 GHz in the z-axis (thickness). Commercial electromagnetic (EM) simulation software helped optimize the design, which was



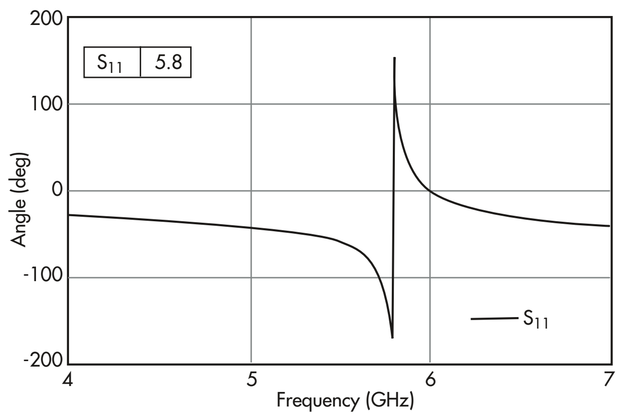

**1. Shown is an equivalent-circuit representation of a composite-right-left-handed (CRLH) unit cell resonator.**




**2. This layout was used in the fabrication of a CRLH unit cell on commercial PCB material.**




**3. These simulated scattering parameters depict the insertion loss ($S_{21}$) and return loss ($S_{11}$) of the CRLH unit cell.**




**4. The plot shows the simulated $S_{21}$ phase angle (in deg.) of the CRLH unit cell.**

characterized using a 50-Ω microstrip feed line and commercial test equipment, notably an RF/microwave vector network analyzer (VNA).

*Figure 1* shows an equivalent-circuit model of the CRLH-TL that consists of right-handed inductance ($L_R$), right-handed capacitance ($C_R$), left-handed inductance ($L_L$), and left-handed capacitance ($C_L$). In a practical circuit design, $C_L$ is fabricated as a four-finger interdigital capacitor, $L_L$ is a viahole in the printed-circuit-board (PCB) material, and capacitance $C_R$ and inductance $L_R$ are parasitic circuit elements essentially invisible in size.

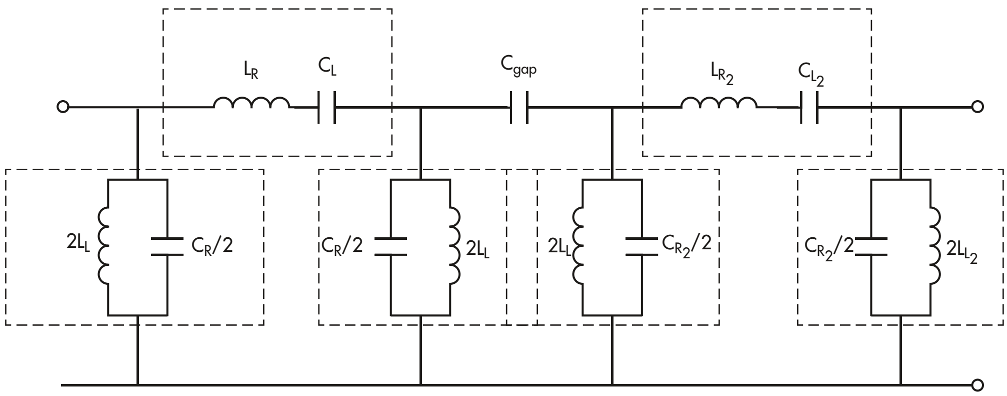
Mathematical analysis of the CRLH structure can be performed by applying transmission-line theory to the equivalent circuit of a CRLH cell. In this case, the CRLH cell is coupled to a short 50-Ω ($Z_0$) feed line for impedance matching to 50-Ω environments and measurements with an RF/microwave VNA.

The frequency of a ZOR is independent of the order of the unit cell. This property can be parlayed into the design of a novel filter in which the center frequency is independent of the physical length of the transmission lines. In turn, the filter's size can be dramatically reduced, since the resonator frequency does not rely on the half-wavelength size of the transmission lines.[5-8]

The phase of the transmission lines can be found by applying Eq. 1, as a super-position of right- and left-banded phases from the CRLH transmission lines. By controlling the circuit loading elements ($C_L$ and $L_L$), a zero-phase condition ($\varphi_{CRLH} = 0$) is achievable:

$$\varphi_{CRLH} = -\beta l = [1/\omega(C_L L_L)^{0.5} - \omega(C_R L_R)^{0.5}] \quad (1)$$

*Figure 2* provides a layout of the CRLH unit cell used in the design of the compact BPF. *Figure 3* shows the computer-simulated full-wave scattering (S) parameters of the CRLH cell. The curves indicate a sharp resonance at 5.9 GHz, where the value of $S_{21}$ (insertion loss) is almost –1 dB and the value of S11 (return loss) is less than –20 dB. *Figure 4* shows the computer-simulated phase of the CRLH resonator cell, where



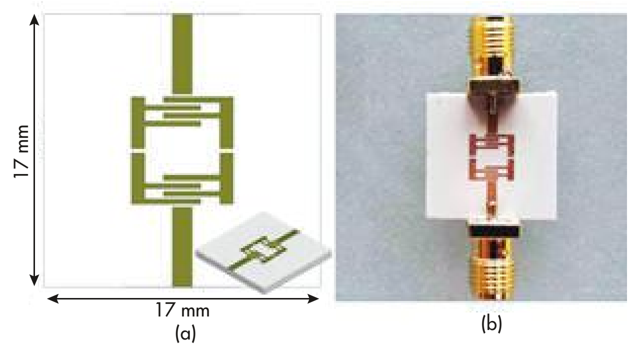

5. This CRLH resonator equivalent-circuit diagram was used to construct a two-pole CRLH filter.

the phase at 5.9 GHz is almost equal to 0. This is the justification for claiming that a zeroth-order coupled resonator has been created.

**CRLH CONSTRUCTION**

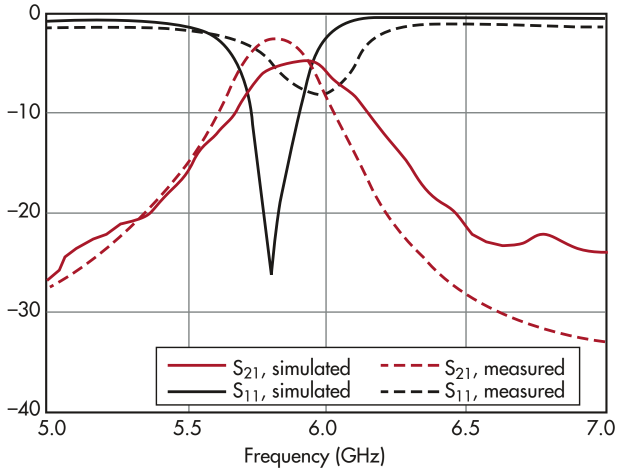
A microstrip configuration was used to fabricate a two-pole filter using equivalent circuits of the CRLH unit cell resonators *(Fig. 5)* as building blocks along with a capacitive gap, with the design aided by full-wave EM simulations in the ANSYS HFSS software to find computer-simulated S-parameters. The filter was constructed on commercial PCB material (including low-loss viaholes). The circuit material was Rogers Corp.'s RT/duroid 6010.2, with dielectric constant of 10.8 and dissipation factor of 0.0023, both at 10 GHz. Substrate thickness was 1.27 mm, with 0.35-µm-thick copper cladding for forming the circuit traces.

These parameters were duplicated in the HFSS EM simulation software from ANSYS *(www.ansys.com)*. The lumped-element circuit parameters for the equivalent-circuit model of a two-pole filter, which were also developed with the aid of the Advanced Design System (ADS) simulation software from Keysight Technologies, include $C_R$ of 0.2 pF, $L_R$ of 0.21 nH, $C_L$ of 5.0 pF, $L_L$ of 5.2 nH, center frequency ($f_0$) of 5.9 GHz, and feed-line impedance ($Z_0$) of 50 Ω.




6. The layout of a two-pole CRLH-based bandpass filter (a) is shown next to a fabricated prototype of the filter (b).

*Figure 6a* shows the layout of the two-pole symmetrical BPF using coupled CRLH transmission-line resonators, where the overall size of the filter is 17 × 17 mm$^2$. And *Figure 6b* shows a prototype of the fabricated CRLH filter. *Figure 7* contains the simulated S-parameter magnitudes, where it should be clear that the passband surrounds a center frequency of 5.9 GHz with magnitude values of $S_{21}$ = −2 dB and $S_{11}$ = −25 dB. By comparing full-wave HFSS EM simulations with S-parameters measured with a VNA on the fabricated prototype, values of $S_{21}$ = −2.5 dB and $S_{11}$ approaching −10 dB were found for the experimental CRLH BPF design.

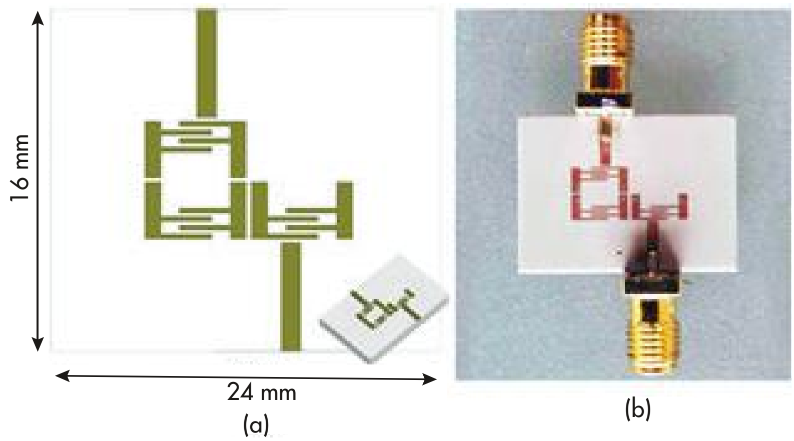



**7. Two-pole filter scattering parameters and fabrication measurements are provided in this plot.**

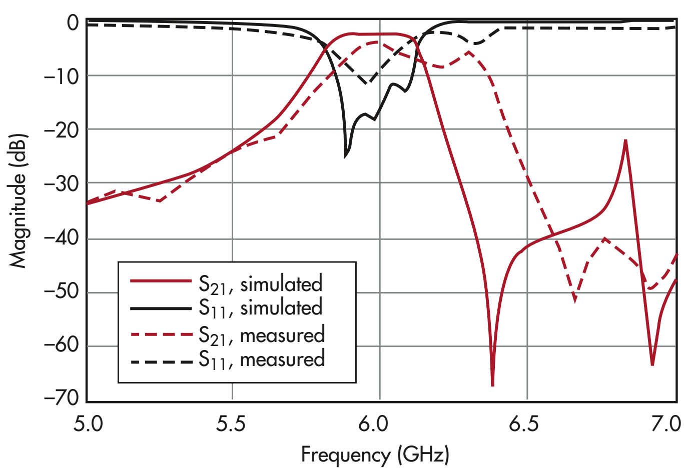
### THIRD-ORDER RESULTS

*Figure 8a* shows the layout of the BPF designed with third-order coupled CRLH-TL resonators, where the overall size of the BPF formed with these resonators is 16 × 24 $mm^2$. The simulated (HFSS) scattering parameters for the filter *(Fig. 9)* indicate that it provides excellent performance through the passband surrounding its center frequency at 5.9 GHz, with passband insertion loss, $S_{21}$, of just 1.5 dB, and passband return loss, $S_{11}$, close to 30 dB. The filter has a transmission zero at 6.3 GHz, which equips it with an advantage in smaller dimensions compared to a conventional two-pole filter design.

The single transmission zero also yields much improvement in skirt selectivity; the order number of the transmission zero is equal to N – 2, with N the number of resonators in the design. *Fig. 9* shows good agreement between design theory and the EM simulation results, indicating that a lower trans-




**8. The layout of the ZOR BPF formed with third-order CRLH resonators (a) is shown next to the fabricated prototype (b).**




**9. These measured results reveal the performance of the BPF fabricated with third-order CRLH resonators.**

mission zero can be added to the design by increasing the filter order.

In fact, the compact filter has a frequency and passband characteristics that make it well-suited for WiMAX applications. It takes full advantage of the zeroth-order resonance of third-order coupled CRLH resonators to achieve good passband loss characteristics in a small size. The zeroth-order resonance at 6.3 GHz improves the passband skirt selectivity in a filter size of only 16 × 24 mm$^2$. By following a design procedure that achieved good agreement among theory, computer simulations, and measurements, a 5.9-GHz BPF was created with CRLH resonators that's about 40% smaller than BPFs designed with conventional microstrip transmission-line resonators. mw

**By following a design procedure that achieved good agreement among theory, computer simulations, and measurements, a 5.9-GHz BPF was created with CRLH resonators that's about 40% smaller than BPFs designed with conventional microstrip transmission-line resonators.**


REFERENCES

1. C. Caloz, "Metamaterial Dispersion Engineering Concepts and Applications," *Proceedings of the IEEE*, Vol. 99, No. 10, 2011, pp. 1711-1719.
2. Yuandan Dong and T. Itoh, "Promising Future of Metamaterials," *IEEE Microwave Magazine*, Vol. 13, No. 2, 2012, pp. 39-56.
3. G. V. Eleftheriades, "Enabling RF/microwave devices using negative refractive-index transmission-line (NRI-TL) metamaterials," *IEEE Antennas and Propagation Magazine*, Vol. 49, No. 2, 2007, pp. 34-51
4. M. A. Abdalla and Z. Hu, "Design and analysis of tunable left handed zeroth-order resonator on ferrite substrate," *IEEE Transactions on Magnetics,* Vol. 11, 2008, pp. 3095-3098.
5. C. L. Holloway, Edward F. Kuester, J. A. Gordon, J. O'Hara, J. Booth, and D. R. Smith, "An Overview of the Theory and Applications of Metasurfaces: The 2-Dimensional Equivalents of Metamaterials," *IEEE Antennas and Propagation Magazine*, Vol. 54, No. 2, 2012, pp. 10-35.
6. Qingshan Yang and Yunhua Zhang, "Negative-order ridge substrate integrated waveguide coupled-resonator filter," *Electronics Letters*, Vol. 50, No. 4, 2014, pp. 290-291.
7. M. A. Abdalla, M. A. Fouad, and A. A. Mitkees, "Wideband Negative Permittivity Metamaterial for Size Reduction of Stopband Filter in Antenna Applications," *Progress in Electromagnetics Research C*, Vol. 25, 2012, pp. 55-66.
8. J. Sorocki, I. Piekarz, K. Wincza, and S. Gruszczynski, "Right/Left-Handed Transmission Lines Based on Coupled Transmission-Line Sections and Their Application Towards Bandpass Filters," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 63, No. 2, Part: 1, 2015, pp. 384-396.
9. Mohammed. A. Fouad, and Mahmoud A. Abdalla, "A New π-T Generalized Metamaterial NRI Transmission Line for a Compact CPW Triple BPF Applications," *IET Microwave, Antenna, and Propagation,* Vol. 8, No. 9, 2014, pp. 1097-1104.
10. Ahmed A. Ibrahim, Mahmoud A. Abdalla, and Diuradi Budimir, "Coupled CRLH Transmission Lines for Compact and High Selectivity Bandpass Filters," *Microwave and Optical Technlogy Letters*, Vol. 59, No. 6, 2017.
11. Ahmed Ibrahim, Adel Abdel-Rahman, and Mahmoud Abdalla, "Design of Third-Order Band Pass Filter Using Coupled Meta-Material Resonators," 2014 IEEE AP-S, Memphis, USA, pp. 1702-1703.
12. Ahmed F. Daw, Mahmoud A. Abdalla, and Hadya M. Elhennawy, "Dual Band High Selective Compact Transmission Line Gap Resonator," 2014 Loughborough Antennas & Propagation Conference, 2014, Loughborough, UK, pp. 91-94.
13. Ahmed Fawzy Daw, Mahmoud Abd El Rahman Abdalla, Hadia Mohamed El Hennawy, "Multiband Sharp-Skirt Compact Gap Resonator Based D-CRLH," 32nd National Radio Science Conference (NRSC2015), March 24-26, 2015, MSA University Egypt, pp. 43-50.
14. S. Karimian, M. Abdalla, and Z. Hu, "Left-Handed Stepped Impedance Resonator for WLAN Applications," 3rd International Congress on Advanced Electromagnetic Materials in Microwaves and Optics, August 30-September 4, 2009, London, UK, pp. 105-107.
15. M. A. Abdalla, A. Y. Hassan, and A. M. Galal Eldin, "A Compact High Selective Gap Bandpass Filter Based CRLH TL," 2015 9th International Congress on Advanced Electromagnetic Materials in Microwaves and Optics – Metamaterials, 2015, Oxford, UK.

# HOW TO SOLVE the Coexistence Conundrum

As Internet of Things (IoT) devices utilize different protocols on crowded bands, one major issue that emerges is communication failure attributed to coexistence. Coexistence can be defined as the capability of wireless equipment to operate when other equipment using dissimilar operating protocols is present.

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

In the white paper, "Overcoming Interference is Critical to Success in a Wireless IoT World," Keysight Technologies dives into the topic of coexistence. It discusses techniques for improving coexistence of devices and networks, along with steps that can be taken to implement an effective coexistence test plan.

The white paper states that concerns surrounding coexistence are driven by three key factors. First is the increased use of wireless technology for critical equipment connectivity. The second factor is the intensive use of unlicensed or shared spectrum. Finally, there's the higher deployment rates of sensitive equipment like intravenous infusion pumps, pacemakers, and defibrillators. These factors directly impact the reliability of medical-device communications.

Three techniques are commonly used to improve coexistence of devices and networks. One technique is physical separation. By placing two networks in different locations, each network encounters a weaker signal from the other. However, physical separation is not always practical, as is the case with healthcare environments that utilize the 2.4-GHz industrial-scientific-medical (ISM) band. In this scenario, a vast amount of wireless IoT devices throughout the facility may be operating on this band.

The second technique involves frequency separation. Essentially, interference between two networks is reduced when one network operates on a different frequency than the other—whether they are located close to one another or not. However, frequency separation is not always effective in the case of the 2.4-GHz ISM band, as Bluetooth, Zigbee, and IEEE 802.11 channels all make use of this band.

The third technique is time separation, whereby transmissions are sent and received at different times to avoid collisions. Furthermore, the white paper presents four steps that should be implemented to create a good coexistence test plan.

# LEARN THE INS AND OUTS of Pulsed Noise-Figure Measurements

**COMPONENTS USED IN** mobile-communication applications and radar systems often operate under pulsed or bursted conditions. Such components must be characterized under pulsed conditions to obtain valid measurement data. However, noise figure is one parameter that can only be determined under continuous-wave (CW) operating conditions when using conventional test equipment. In the application note, "Pulsed Noise Figure Measurements," Rohde & Schwarz explains how to measure noise figure under pulsed conditions with spectrum analyzers and noise sources.

The technique described utilizes a signal and spectrum analyzer along with a broadband noise source that contains two temperature states. A function generator is also used to stimulate the device under test (DUT) with a pulsed signal. The noise source is connected to the input of the DUT, and the noise power at the DUT's output is measured for each of the two input noise states.

Rohde & Schwarz,
Mühldorfstrasse 15, 81671
Munich, Germany;
(410) 910-7800;
www.rohde-schwarz.com

The application note lists the three primary steps involved in making the measurement. The first step is doing the calibration, which leads to the second step of measuring the DUT cascaded with the test equipment. The last step is to calculate the DUT's parameters with the cascaded noise-figure equation.

To determine the noise figure of an amplifier in pulsed operation, hot and cold power measurements must only be performed during the active part of the periodic pulse. Because the sampling process should only happen during the "on" phase of the pulse, a trigger signal is needed to synchronize the data acquisition of the spectrum analyzer with the "on" period of the pulse. A gated-sweep mode is used, meaning that data sampling only occurs during the active period of the RF burst.

A complete block diagram of the test setup for measuring pulsed noise figure is presented, followed by a detailed description of the entire procedure. Real pulsed measurement results are provided. In this test, the DUT is an amplifier used in a radar transmit/receive (T/R) module. The results demonstrate an agreement with the DUT's performance when operating in CW mode.

DR. ULRICH L. ROHDE | Chief Executive Officer, Synergy Microwave Corp., Paterson, NJ
DR. AJAY PODDAR | Chief Scientist, Synergy Microwave Corp., Paterson, NJ
PROFESSOR AFSHIN DARYOUSH | Drexel University, Philadelphia, PA

# Optoelectronic Oscillators Charge mmWave Synthesizers

**These X- and K-band synthesizers apply optoelectronic technology to achieve high levels of frequency stability with reduced phase noise.**

Reducing noise in higher-frequency oscillators is one way to achieve reliable, high-data-rate communications, although noise tends to rise with increasing frequency. All sorts of oscillators and frequency-synthesis techniques have been applied in recent years in attempts to trim phase-noise levels at microwave frequencies. Many of these approaches have been electrical in nature.

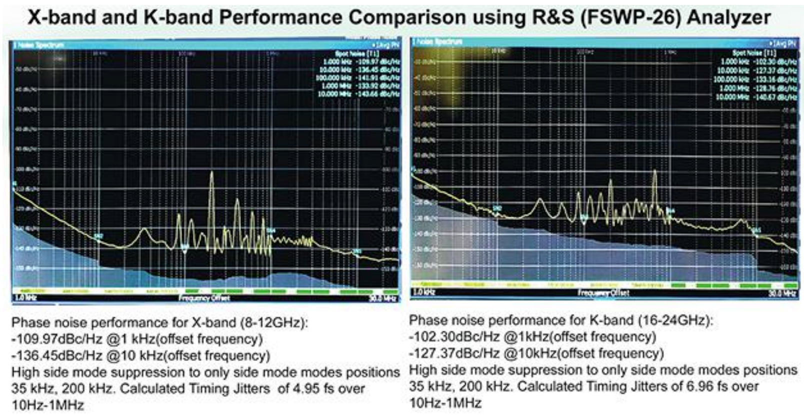
Taking a different tack, Synergy Microwave Corp. and Drexel University jointly developed a line of frequency synthesizers that leverage optical circuit techniques to help achieve lower-noise microwave signals at X- and K-band frequencies. In these low-noise frequency synthesizers, optoelectronic transmission lines and optoelectronic oscillators (OEOs) are part of the solution for reducing both close-in and far-from-the-carrier phase noise in microwave signal sources.

The latest line of low-noise frequency synthesizers from Synergy Microwave Corp. *(Fig. 1)* builds upon OEOs to produce tunable, low-noise output signals at X- and K-band frequencies. They use long fiber-optic delay lines to reduce phase noise close to the carrier. The synthesizers also employ self-phase-locked-loop (SPLL) and self-injection-locking (SIL) techniques to reduce phase noise otherwise located close-in and far-from the carrier, respectively.

The X- and K-band frequency synthesizers are truly subsystem designs, incorporating several different technologies to provide variable-frequency output signals with low phase noise. The frequency synthesizers are suitable for applications in test systems, wireless-communications systems, radar systems, and remote-sensing systems, or wherever microwave receivers require high sensitivity not limited by phase noise.

The frequency synthesizers orchestrate SIL and double-sideband PLL techniques simultaneously, with multiple signal paths within the synthesizers in support of enhanced signal stability as well as application of modulation as needed. Signals are

**1. Shown in two views, this line of rack-mountable frequency synthesizers employs different techniques and technologies to trim phase noise at X- and K-band frequencies.**




**2. The low phase noise at X-band frequencies is evident both close to and far from the carrier.**

combined within the synthesizer with the aid of a custom-designed, double-balanced frequency mixer and lowpass-filter-amplifier (LPFA) assembly. The synthesizer design also incorporates operational-amplifier (op-amp) circuits that work as the phase detector and lowpass portion of the PLL.

**VERY MUCH IN TUNE**

The high resolution and wavelength-sensitive tuning is due to the fine tuning made possible by an optical transversal filter. The optical filter uses a chirped fiber Bragg grating (CFBG) as a dispersive component to achieve narrowband filtering. A current-tuned YIG filter is used in cascade along with the optical filter and CFBG to provide coarse frequency tuning across wide tuning ranges of X- and K-band frequencies.

At X-band frequencies from 9 to 11 GHz, for example, the YIG filter tunes with a response of about 25 MHz/mA. Since the resolution of the current supply feeding the YIG filter is about 1 mA, the effective frequency-tuning resolution of the YIG filter is 25 MHz. This combination of optical and electronic technologies results in relatively wide frequency-tuning ranges with outstanding phase noise, both close in and far from the carrier.

Case in point: at X-band, the single-sideband phase noise is −109.97 dBc/Hz offset 1 kHz from the carrier and −136.45 dBc/Hz offset 10 kHz from the carrier for carrier frequencies from 9 to 11 GHz *(Fig. 2)*. In the time domain, this translates to 4.395 fs measured at sidemode markers of 35 and 200 kHz from the carrier. At higher K-band frequencies, the SSB phase noise is −102.30 dBc/Hz offset 1 kHz from the carrier and −127.37 dBc/Hz offset 10 kHz from the carrier, or time-domain response of 6.961 fs measured at sidemode markers of 35 and 200 kHz from the carrier.

In terms of size and power, the YIG filter is the dominant component in these optoelectronically driven frequency synthesizers. The synthesized signal source can be contained in a 19-in. rack-mount enclosure for portability.

The main current consumption in the frequency synthesizer assembly takes place due to the YIG filter, which draws 150 mA at +10 V dc and about 1.5 W power. The amplifier, with two channels, draws 80 to 160 mA currents at +10 V dc and as much as 1.6 W power. The mixer LPFA, which uses a combination of frequency translation and filtering to extract the RF/microwave signals from higher-frequency optical signals, draws about 60 + 5 + 45 mA, or 110 mA current, from respective supplies of +15, +5, and −5 V dc.

In stark contrast, the photodetector used in the frequency synthesizer operates at very low current and power, with its three cells each drawing about 10 mA current or 30 mA current at +5 V dc and about 0.15 W power as part of the frequency synthesizer dominated in terms of size and power by the YIG filter. The broadband dual-channel amplifier draws roughly 80 mA current per channel or 160 mA current from a +10-V dc supply, or about 1.6 W total power as part of the frequency synthesizer. mw

SYNERGY MICROWAVE Corp., 201 McLean Blvd., Paterson, NJ 07504; (973) 881-8800, FAX: (973) 881-8361, e-mail: sales@synergymwave.com, www.synergymwave.com.

BIBLIOGRAPHY

U. L. Rohde, A. Poddar, and A. Daryoush, "Self-injection locked phase locked loop optoelectronic oscillator," U.S. Patent No. US9088369B2, 2012.
U. L. Rohde, A. Poddar, and A. Daryoush, "Integrated production of self-injection locked self-phase locked opto-electronic oscillators," U.S. Patent No. US9094133B2, 2013.
T. Sun, L. Zhang, A. K. Poddar, U. L. Rohde, and A. S. Daryoush, "Frequency synthesis of forced opto-electronic oscillators at the X-band," *Chinese Optical Letters*, Vol. 15, 010009 (2017).
L. Zhang, A. K. Poddar, U. L. Rohde and A. S. Daryoush, "Self-ILPLL Using Optical Feedback for Phase Noise Reduction in Microwave Oscillators," *IEEE Photonics Technology Letters,* Vol. 27, No. 6, March 15, 2015, pp. 624-627.
L. Zhang, A. Poddar, U. Rohde, and A. S. Daryoush, "Phase noise reduction and spurious suppression in oscillators utilizing self-injection loops," 2014 IEEE Radio and Wireless Symposium (RWS), Newport Beach, CA, 2014, pp. 187-189.
L. Zhang, A. K. Poddar, U. L. Rohde, and A. S. Daryoush, "Comparison of Optical Self-Phase Locked Loop Techniques for Frequency Stabilization of Oscillators," *IEEE Photonics Journal*, Vol. 6, No. 5, October 2014, pp. 1-15.
T. Sun, L. Zhang, A. K. Poddar, U. L. Rohde, and A. S. Daryoush, "Forced SILPLL oscillation of X- and K-band frequency synthesized opto-electronic oscillators," 2016 IEEE International Topical Meeting on Microwave Photonics (MWP), Long Beach, CA, 2016, pp. 91-94.
L. Zhang, A. Poddar, U. Rohde, and A. Daryoush, "Analytical and Experimental Evaluation of SSB Phase Noise Reduction in Self-Injection Locked Oscillators Using Optical Delay Loops," *IEEE Photonics Journal*, Vol. 5, No. 6, December 2013, pp. 6602217-6602217.

CHRIS DeMARTINO | Technical Engineering Editor

# Integrated Radio Transceiver Confronts Challenges from Every Corner

This integrated radio solution is equipped for current and emerging wireless applications, as well as the military and test-and-measurement realms.


1. The ADRV9009 transceiver, which has a tunable frequency range of 75 MHz to 6 GHz, is equipped to support current, new, and legacy wireless standards and more.

5G communications is associated with higher levels of complexity, such as an expanded frequency spectrum, wider bandwidths, and higher channel counts. The technology will also require products with reduced size, weight, and power (SWaP), as well as lower costs. Moreover, while original equipment manufacturers (OEMs) will obviously need to support 5G networks, they still must support previous-generation 2G, 3G, and 4G communications, too. Thus, demand will ramp up for solutions that can wrestle with current, new, and legacy wireless standards.

One company, Analog Devices (ADI; *www.analog.com*), developed what it describes as a "single radio platform that can handle emerging wideband applications, while delivering the high-performance required for existing applications." Those "single radio platforms" are the ADRV9008/9 solutions, which are the latest entries to ADI's RadioVerse RF transceiver product line *(Fig. 1)*. The ADRV9008/9 products are not only intended for cellular applications, but also for aerospace and defense applications and test-and-measurement equipment.

High integration is a key trait of the ADRV9008/9 family—the ADRV9009 transceiver itself takes the place of more than 20 discrete components. The ADRV9009 also achieves a bandwidth of 200 MHz, which is twice the bandwidth of the previous-generation AD9371. And the integrated common radio platform reduces product-development cycles and product design variations while slashing power consumption by 50% and size by 60%, according to ADI.

Additional features include local-oscillator (LO) synchronization. This simplifies digital beamforming, reducing system complexity and cost for massive multiple-input, multiple-output (M-MIMO) and phased-array radar systems. Furthermore, fast frequency hopping reduces system downtime and improves spectral efficiency and link security.

## A CLOSER LOOK AT THE ADRV9009 AND ADRV9008-1/-2

ADI offers the ADRV9009 integrated transceiver along with the ADRV9008-1 integrated receiver and ADRV9008-2 integrated transmitter. Each has a tunable frequency range of 75 MHz to 6 GHz. All three come in a 196-ball ball-grid-array (BGA) chip-scale package (CSP) that measures 12 × 12 mm.

The ADRV9009 transceiver can be described as a single-chip time-division-duplex (TDD) solution. As seen in its block diagram *(Fig. 2)*, the ADRV9009 contains two transmitters and two receivers along with two observation receivers.

Fractional-N phased-locked-loop (PLL) frequency synthesizers are incorporated into the ADRV9009, too, as is a clock synthesizer that generates the clocks needed for the converters, digital circuits, and serial interface. And with the previously mentioned LO synchronization feature, the LOs on multiple ADRV9009 chips can be phase-synchronized to support beamforming applications.

The ADRV9009's maximum receiver bandwidth is 200 MHz, and its maximum transmitter synthesis bandwidth is 450 MHz. Maximum observation receiver bandwidth is 450 MHz. Furthermore, the ADRV9009 utilizes a 12-Gb/s JESD204B interface.

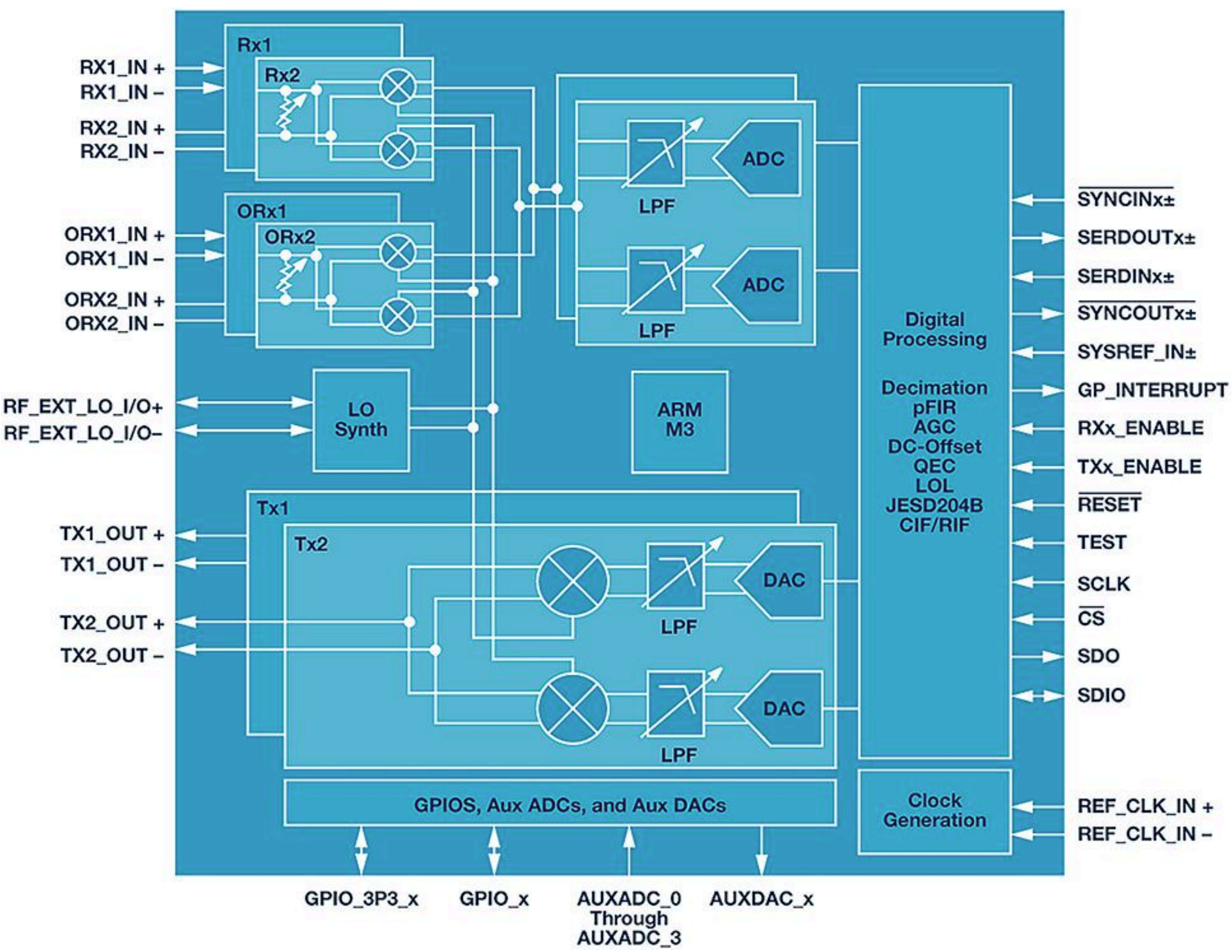
For frequency-division-duplex (FDD) applications, ADI offers the ADRV9008-1 and ADRV9008-2. The ADRV9008-1 is an integrated dual receiver, while the ADRV9008-2 is an integrated dual transmitter and observation receiver. Together, these two devices form what ADI describes as a two-chip FDD solution.

The ADRV9008-1 has a maximum receiver bandwidth of 200 MHz. The ADRV9008-2 has a maximum transmitter synthesis bandwidth of 450 MHz and a maximum observation receiver bandwidth of 450 MHz. Both are also equipped with the LO synchronization feature, and utilize a 12-Gb/s JESD204B interface. mw

---

ADI OFFERS various resources for its RadioVerse line, such as evaluation kits and software tools. For more information, visit www.analog.com/radioverse.

**2. Two transmitters, two receivers, and two observation receivers populate the ADRV9009 transceiver.**



CHRIS DeMARTINO | Technical Engineering Editor

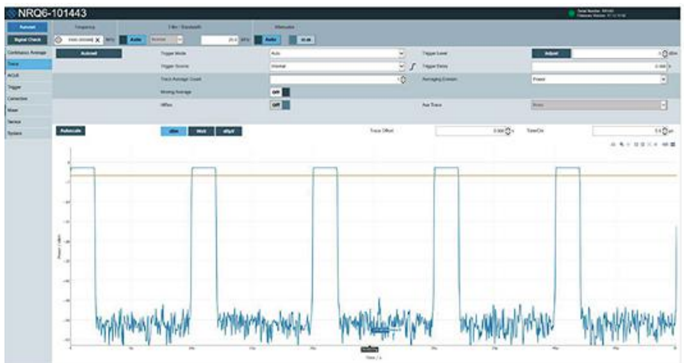
# Frequency-Selective Power Sensor Combines Best of Both Worlds

**Based on a receiver architecture, this new sensor can measure signals at power levels as low as –130 dBm.**

Power meters and spectrum analyzers are fundamental instruments in any RF/microwave test lab. But what do you get when you combine the accuracy of a power meter with the dynamic range of a spectrum analyzer? Those intrigued by that question may want to consider the NRQ6 frequency-selective power sensor developed by Rohde & Schwarz *(www.rohde-schwarz.com) (Fig. 1)*.

**1. The NRQ6 frequency-selective power sensor covers a frequency range of 50 MHz to 6 GHz.**

The NRQ6, based on receiver technology, can perform band-limited power measurements, i.e., power measurements on a selected transmission channel. What's impressive about the NRQ6 is its measurement range—it's able to measure signals ranging from –130 to +20 dBm. In terms of frequencies, the NRQ6 has a measurement frequency range of 50 MHz to 6 GHz. It offers a measurement bandwidth of 100 MHz.




**2. Pulsed-signal analysis is one of the capabilities offered by the NRQ6 power sensor.**

A LAN web interface controls the NRQ6. Connection to the LAN is achieved with a Power-over-Ethernet (PoE+) switch. In addition, the power sensor's integrated web server makes it possible to operate the graphical user interface (GUI) without any extra software—all that's needed is a PC with a web browser.

The NRQ6 power sensor allows for more than just conventional continuous average-power measurements. For one, the trace-display functionality enables users to analyze pulsed signals *(Fig. 2)*. The NRQ6 is also well-suited for adjacent-channel leakage ratio (ACLR) measurements. The ACLR measurement function, which is accessible from the web GUI, can automatically be set to predefined filters in accordance with Third Generation Partnership Project (3GPP) specifications.

In addition, the optional NRQ6-K1 in-phase/quadrature (I/Q) data interface makes it possible to capture vector-modulated I/Q signals. With the NRQ6-K1 option, captured I/Q data can be downloaded to a PC and further analyzed.

Targeted applications for the NRQ6 include transmitter power calibration, as the sensor allows users to perform calibrations at extremely low power levels. In fact, Rohde & Schwarz describes the NRQ6 as a "compact, single-device solution for calibrating transmit power," as no additional instruments or components—such as spectrum analyzers and power splitters—are needed. And since the sensor can directly connect to a DUT, no cable is required.

Measuring band-limited power of multi-standard radios (MSRs) is another use case for the NRQ6. Hence, those involved with MSR base stations may want to take advantage of the NRQ6.

The NRQ6 frequency-selective power sensor is available now. mw

ROHDE & SCHWARZ GMBH & CO. KG, P. O. Box 80 14 69 81671, Munich, Germany; 888-TEST-RSA (1-888-837-8772); www.rohde-schwarz.com


Mini-Circuits
USB/LAN PEAK POWER SENSOR
MODEL PWR-SEN-8P-RC
10 MHz – 8 GHz
-60 dBm ... +20 dBm
Power Indicator
Trigger In
USB
LAN
RF IN 50Ω

JACK BROWNE | Technical Contributor

# MEMS Switches Shrink with Glass Substrates

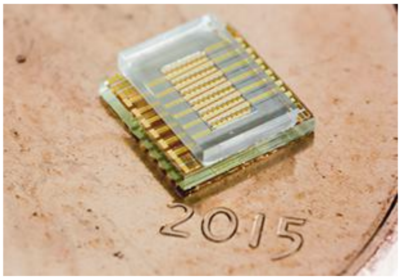
**MEMS technology is impressive, but fabricating the components on glass substrates provides high performance in a fraction of the size of conventional RF components.**

Glass is a filler for many circuit-board materials. It's also an excellent substrate material, as Menlo Micro has shown by fabricating miniature, high-performance microelectromechanical-systems (MEMS) switches on glass wafers.

By teaming with glass-master Corning and applying its own through-glass-via (TGV) technology and patented digital-micro-switch (DMS) technology, Menlo Micro is on a clear path to making RF/microwave switches even smaller—without compromising key performance parameters like power-handling capability. The recently announced model MM3100 MEMS switch is one example of what can be done with MEMS technology built on a glass foundation.

The MM3100 is a six-channel, single-pole, single-throw (SPST) MEMS switch for applications from dc to 3 GHz *(see figure)*. As Corning continues to refine its glass-wafer production processes, to enable glass substrates as large as 8 in. diameter with impeccably smooth surfaces, it's the quality of those surfaces and dielectric consistency of that glass material that enables thousands of MEMS devices (e.g., the MM3100) to be produced from a single wafer. The high quality of the metal-on-glass interfaces results in consistently low-loss transmission lines on the substrates and highly repeatable performance from the devices fabricated on the glass wafers.

The high-performance levels possible from glass-substrate-fabricated components is evident with the model MM3100 switch. Operating from dc to 3 GHz, it features low insertion loss of 0.3 dB at 3 GHz (and less at lower frequencies) when the switch is in the "on" position. It also achieves good isolation between inputs and the output port with isolation of typically 25 dB (and more at lower frequencies) when the switch is in the "off" position.




**Model MM3100 is a six-channel, single-pole, single-throw (SPST) MEMS switch capable of handling 25-W CW power and 200-W peak (pulsed) power per channel from dc to 3 GHz. It's shown here without the BGA package, in die form.**

The six-channel switch is housed in a hermetic BGA package measuring just 6.0 × 6.0 × 1.3 mm. Despite the small size, over the full frequency range it can handle 25-W CW input power per channel and as much as 200-W peak (pulsed) input power per channel. Operating temperature range is –40 to +85°C.

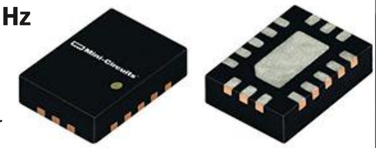
Lest circuit and system integrators think of glass as being in any way frail, they need only look at the long-term reliability of these glass-based MEMS switches. They are rated for 3 billion switching cycles without failure or performance degradation even when used in harsh military environments. Switches like the MM3100 are well-suited for multiple-signal control in radar and communications applications such as for signal beamforming in multiple-input, multiple-output (MIMO) antenna arrays. The MM3100 is controlled by means of a Serial Peripheral Interface (SPI) and includes an integrated switch driver; SPI control is via an external +5-V dc logic supply and +77-V dc bias source.

The MM3100 exhibits many characteristics favorable to both analog and digital circuit designs because of the high-quality glass dielectric substrates and Menlo's proprietary high-conductivity metal alloy transmission lines. For example, in addition to its excellent EM signal conductivity and low insertion loss in the "on" state, the switch is virtually invisible to a circuit when in the "off" state, with its high isolation and low off-state (parasitic) capacitance of less than 200 fF. It's quite rugged and can withstand voltages as high as 200 V dc when in the "off" state. The switch also exhibits very low "on" state resistance of typically less than 0.5 Ω, enabling it to maintain low loss even under high-current conditions.

Of course, the MM3100 is just the start of what can be done with this combination of MEMS technology and semiconductor-quality glass wafers. However, its combination of small size, performance, and reliability are sure to reach higher frequencies in the future to serve many other commercial and military specifiers. mw

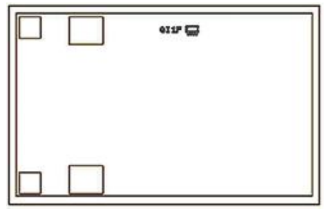
MENLO MICROSYSTEMS Inc., 49 Discovery, Ste. 150, Irvine, CA 92618; 1-(949) 771-0277, www.menlomicro.com

## Dual-Matched Amp Boosts DC to 5.2 GHz



Mini-Circuits' model MGVA-82+ is a broadband MMIC amplifier with high gain from DC to 5.2 GHz. Fabricated with GaAs InGaP HBT technology, the RoHS-compliant device features two matched amplifiers in a 16-lead surface-mount MCLP housing measuring just 3.5 ×2.5 mm. The 50-Ω amplifier offers generous gain, typically 15.3 dB at 50 MHz, 14.1 dB at 2 GHz, and 12.1 dB at 4 GHz, with typical gain flatness of ±0.6 dB from 50 to 2000 MHz. It has wide dynamic range well suited for many communications applications, with output power at 1-dB compression of typically +20.3 dBm at 1 GHz, +20.2 dBm at 2 GHz, +19.8 at 3 GHz, and +19.5 at 4 GHz, and output third-order intercept of typically +38 dBm at 1 GHz, +36 dBm at 2 GHz, +35 dBm at 3 GHz, and +33 dBm at 4 GHz.

## Gain Equalizer Die Extends DC to 6 GHz



Mini-Circuits' model EQY-1-63-D+ is a broadband absorptive gain equalizer die with nominal well suited for leveling the gain response in communications and radar systems. It exhibits a nominal attenuation slope of 1.2 dB from DC to 6 GHz with excellent input-power handling capability of typically +31 dBm. The typical insertion loss is 1.5 dB at 1 GHz, 0.9 dB at 3 GHz, and 0.4 dB at 6 GHz, with typical VSWR of 1.09:1 from 1 to 2 GHz, 1.06:1 from 3 to 4 GHz, and 1.24:1 from 5 to 6 GHz. The GaAs MMIC gain equalizer die is designed for operating temperatures from -40 to +85°C.

## High-Dynamic-Range Amp Drives 1 MHz to 1 GHz

Mini-Circuits' model LHA-13LHN+ is a wideband 50-Ω MMIC amplifier with high dynamic range from 1 MHz to 1 GHz. Supplied in a 12-lead MCLP surface-mount package measuring just 3 × 3 mm, the RoHS-compliant amplifier combines a low noise figure with high gain and output power. The gain is typically 24.9 dB at 1 MHz, 23.0 dB at 250 MHz, 22.7 dB at 500 MHz, and 20.3 dB at 1000 MHz. As impressive, the noise figure is typically 3.0 dB at 1 MHz, 1.1 dB at 250 MHz, 1.2 dB at 500 MHz, and 1.4 dB at 1000 MHz. The output power at 1-dB compression is typically +25.4 dBm at 1 MHz, +28.1 dBm at 250 MHz, +28.0 dBm at 500 MHz, and +26.1 dBm at 1 GHz.

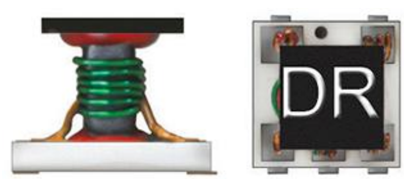
## Directional Coupler Channels 1 to 200 MHz


Mini-Circuits' model ZADC20-22-7550+ is a coaxial directional coupler with low loss for HF, VHF, and CATV applications from 1 to 200 MHz. It includes 75-Ω SMC connectors at the input and output ports and 50-Ω SMA connector at the coupled port. Coupling is typically 20.5 dB from 1 to 100 MHz and 21 dB from 100 to 200 MHz. The RoHS compliant directional coupler achieves mainline insertion loss of 0.2 dB or less across the full frequency range and handles as much as 2 W power. Typical directivity is 25 dB at 100 MHz and 18 dB at 200 MHz. The directional coupler is designed for operating temperatures from -55 to +100°C.

## Precision Fixed Pads Attenuate DC to 65 GHz

Mini-Circuits' BW-EX-1W653+ Series precision fixed attenuators provide attenuation values of 3, 6, 10, and 20 dB across a frequency range extending well into the millimeter-wave range, from DC to 65 GHz. The 50-Ω, RoHS-compliant coaxial attenuators, which transition 1.85-mm female connectors to 1.85-mm male connectors, are well suited for system and test applications. They handle power levels to 1 W with typical VSWR of 1.20:1 at 26.5 GHz and 1.30:1 at 65 GHz and maintain ±1.5 dB accuracy across the full frequency range. They are designed for operating temperatures from -55 to +100°C.

## Surface-Mount Coupler Spans 5 to 2850 MHz

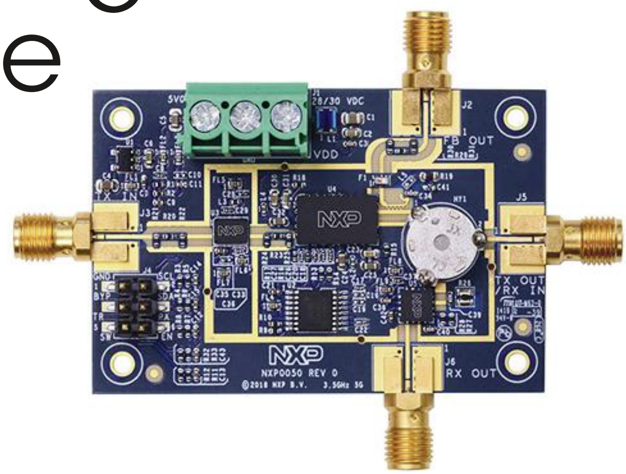



Mini-Circuits' model DBTC16-282LX+ is a 50-Ω, surface-mount directional coupler for applications from 5 to 2850 MHz, including in GPS, cellular communications, and wireless communications systems. The RoHS-compliant coupler features nominal coupling of 16.8 dB with coupling flatness of typically ±0.3 dB from 5 to 1000 MHz and typically ±0.6 dB from 1000 to 2850 MHz. It handles input power of as much as 0.5 W from 5 to 100 MHz and as much as 1 W from 100 to 2850 MHz. The compact directional coupler, which is designed for operating temperatures from -40 to +85°C, features all-welded construction and a temperature-stable, low-temperature-cofired-ceramic (LTCC) base.

CHRIS DeMARTINO | Technical Editor

# 5G Front-End Reference Design Meets Multiple Needs

**Integrating a power amplifier, a pre-driver amplifier, and a receiver switch/low-noise amplifier, this flexible front-end solution is equipped for next-generation 5G communications.**




**This new RF front-end reference design for 5G massive-MIMO systems supports frequencies from 2.3 to 5.0 GHz.**

Without question, 5G communications was a central theme at IMS 2018. One standout 5G-based product at the show was NXP Semiconductors' *(www.nxp.com)* new RF front-end reference design for 5G massive multiple-input, multiple-output (MIMO) systems *(see figure)*. This front-end solution supports frequencies ranging from 2.3 to 5.0 GHz. Furthermore, it integrates a combination of silicon-germanium (SiGe), gallium-arsenide (GaAs), and laterally diffused metal-oxide semiconductor (LDMOS) technologies.

The functionality of the front-end solution is the product of three main components. One is an LDMOS Doherty power amplifier module (PAM). NXP offers different PAM variants that are all footprint-/pin-compatible, meaning any PAM version can be mounted onto the reference design board.

The second component is a low-power Doherty pre-driver amplifier module. Like the PAMs, NXP offers different footprint-/pin-compatible pre-driver amplifier versions, so that each one be incorporated into the reference design. The third component is a receiver front-end module, which is comprised of a transmit/receive (T/R) switch and low-noise amplifier (LNA).

With the footprint-/pin-compatible PAMs and pre-driver amplifiers, customers can essentially "plug-and-play" among different frequencies and power levels, as the same board design can accommodate different component versions. The PAM versions each cover various frequencies and power levels, while the pre-driver amplifier versions handle different frequency bands. Moreover, the front-end solution requires fewer components on a printed-circuit board (PCB), which reduces total system costs. NXP also notes that a significant benefit of the design is its small size—the front-end assembly measures about 21 × 35 mm.

The PAMs, which are based on LDMOS technology, come in packages that measure 6 × 10 mm. Their output power level ranges from 2.5 to 5 W. In addition, the input and output of the components are both matched to 50 Ω.

The pre-driver amplifiers, offering 32 dB of gain, are housed in a 3- × 4-mm package. The amplifiers achieve a 1-dB compression (P1dB) of either +25 or +29 dBm, depending on the supply voltage (the amplifiers require either +3.3 or +5 V; $I_d$ is 50 mA). Like the PAMs, the input and output of the pre-driver amplifiers are matched to 50 Ω.

Lastly, as mentioned, the receiver front-end module comprises a T/R switch and LNA. It comes in a 4- × 4-mm package. Covering the full frequency range of 2.3 to 5.0 GHz, the receiver front-end module provides about 33 dB of gain while achieving a noise figure of less than 1.2 dB. Its switching speed is 0.8 µs. Operating from a 5-V supply, the component's current consumption is 100 mA. Like the PAMs and pre-driver amplifiers, the input and output of the receiver front-end module are both matched to 50 Ω. mw

### Educational Kit Has Build-Your-Own VNA

**MODEL UVNA-63 IS** a microwave transceiver kit that contains all of the ingredients needed to construct a fully functioning vector network analyzer (VNA). Developed in partnership with Vayyar Imaging (www.vayyar.com), the kit enables users to develop S-parameter algorithms and perform real-time measurements of two-port RF/microwave devices across a frequency range of 500 MHz to 6 GHz. It features a six-port Vayyar transceiver chip and PCB combined with an assortment of RF/microwave components from Mini-Circuits, including interconnecting cables and SMA calibration standards. The VNA kit, which functions as an excellent, affordable educational tool, is compatible with multiple software environments, including Python and MATLAB, for the development of real-time S-parameter measurement software programs.

**MINI-CIRCUITS,** P.O. Box 350166, Brooklyn, NY 11235-0003; (718) 934-4500, www.mini-circuits.com

### Coaxial 2.4-mm Adapters Reach 50 GHz for 5G

**THE JOHNSON 2.4-MM** series of 50-GHz high-frequency adapters includes same-series and between-series adapters with low loss through 50 GHz. The adapters, with VSWR of better than 1.25:1, include a right-angle jack (male) to jack (male) adapter, while the between-series adapters feature 2.4- to 2.92-mm and 2.4-mm to SMP adapters. The coaxial adapters aid design and development as well as test applications for 5G and other high-frequency systems.

**CINCH CONNECTIVITY SOLUTIONS, A BEL GROUP,** 1700 Finley Rd., Lombard, IL 60148; (630) 705-6000, www.bel.com/cinch

### DVI Cable Assemblies Include Assorted Connectors

**A NEW SERIES** of DVI cable assemblies is available with straight, 45-deg., and 90-deg. (right-angle) connectors, creating an assortment of digital video interconnection options for military and avionics systems. The variety of connectors enables secure and reliable interconnections in tight enclosures and cabinets where standard DVI connectors will not fit. Cable assemblies come with DVI-D Dual Link, DVI-D Single Link and DVI-I Dual Link connector options to address a myriad of digital video applications. The high-quality cable assemblies are well-suited for high-resolution display applications in confined spaces.

**MILESTEK CORP., AN INFINITE ELECTRONICS CO.,** 301 Leora Lane, Ste. 100, Lewisville, TN 75056; (866) 524-1553, (940) 484-9400, FAX: (972) 394-7913, www.MilesTek.com

### Real-Time Analyzers Scan 4.5-GHz Spans

**THE RSA3000 REAL-TIME** Spectrum Analyzer is available in 3.0- and 4.5-GHz models. Both models can be equipped with tracking generators and real-time bandwidths of 10 MHz, which is upgradable to 40 MHz at any time. When outfitted with a 40-MHz bandwidth, the analyzer provides 7.5-μs probability of intercept (POI) to capture transient signals. It can function as a traditional swept spectrum analyzer with standard resolution bandwidth of 10 Hz and an option for 1 Hz. The noise floor is as low as −161 dBm for tracking low-level signals. The instrument boasts full-span sweep speed as fast as 1 ms with phase noise of −102 dBc/Hz.

**RIGOL TECHNOLOGIES,** 8140 SW Nimbus Ave., Beaverton, OR 97008; (503) 465-4626, www.rigol.com

### Triple-Balanced Mixer Covers X, Ku, and K Bands

**MODEL MM2-0530HSM IS** a triple-balanced, passive MMIC mixer capable of covering all three X-, Ku-, and K-band frequency ranges in a single QFN surface-mount package. The high-linearity mixer has a local oscillator (LO) range of 5 to 30 GHz, an RF range of 5 to 30 GHz, and an intermediate-frequency (IF) range of 2 to 20 GHz. Typical conversion loss is 8 dB when operating with +20-dBm LO drive level. The mixer features a typical third-order intercept point (IP3) of +28 dBm and 35-dB port-to-port isolation. It can be supplied in die form, in the QFN package, or as part of a coaxial module.


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

## SMT Module Packs Switch, Two-Stage LNA

**MODEL QPB9319 IS** a surface-mount-technology (SMT) module that combines a dual-channel switch based on silicon-on-insulator (SOI) technology with two stages of low-noise amplifier (LNA). Designed for small time-division-duplex (TDD) base stations from 1.8 to 4.2 GHz, the module can achieve 1.45-dB noise figure in receive mode and 0.7-dB insertion loss in transmit mode at 2.7 GHz. The module, which requires only a single +5-V dc supply for the switch and the LNAs, is housed in a RoHS-compliant, 7- × 7-mm SMT package and is compatible with 1.8-V TTL logic.
**QORVO CORP. HEADQUARTERS,** 7628 Thorndike Rd., Greensboro, NC 27406; (336) 664-1233, (844) 890-8163, e-mail: customer.support@qorvo.com, www.qorvo.com

## VNA Calibration Kit Tunes Analyzers to 110 GHz

**MODEL STQ-TO-10-U3-CKIT1 IS** a calibration kit for W-band waveguide-equipped vector network analyzers (VNAs) operating from 75 to 110 GHz. The calibration kit features two straight waveguide sections, one fixed short, one fixed matchng load, one sliding load, one quarter-wavelength shim, and two waveguide quick connects. It also includes 10 3/32-in. hex-head waveguide screws, a 3/32-in. hex waveguide screwdriver, and one USB memory drive with calibration data. The metrology-grade calibration kit is protected within a wooden case.
**SAGE MILLIMETER INC.,** 3043 Kashiwa St., Torrance, CA 90505; (424) 757-0168, FAX: (424) 757-0188, E-mail: sales@sagemllimeter.com, www.sagemillimeter.com

## SSB Modulator Covers 77 to 82 GHz

**MODEL SFM-77382312-1212SF-N1IS** a single-sideband (SSB) modulator designed for E-band applications from 77 to 82 GHz. The modulator features typical conversion loss of 25 dB with the quadrature intermediate-frequency (IF) port driving signals of 6 V peak-to-peak and 3 mA for both in-phase (I) and quadrature (Q) ports. The typical input/output isolation is 20 dB and the typical image rejection is also 20 dB. The SSB modulator can readily be used as an I/Q mixer by using one of the RF ports as a local-oscillator (LO) port and adding an IF hybrid coupler.


**SAGE MILLIMETER INC.,** 3043 Kashiwa St., Torrance, CA 90505; (424) 757-0168, FAX: (424) 757-0188, E-mail: sales@sagemllimeter.com, www.sagemillimeter.com

## Cassegrain Antenna Scans 43 to 50 GHz

**MODEL SAY-4335035104-188-S1 IS** a Cassegrain antenna with nominal gain of 51 dBi and half-power beamwidth of 0.4 deg. from 43 to 50 GHz. The lightweight but rugged design is fabricated from fiberglass, with a corrugated horn for high feed efficiency and uniform illumination. The corrugated horn is covered with an all-weather radome. The RF port employs a 0.188-in.-diameter circular waveguide with UG-383/U-M grooved flange to keep the antenna watertight in outdoor applications. It can be used for both linear and circularly polarized waveforms across the 7-GHz bandwidth.
**SAGE MILLIMETER INC.,** 3043 Kashiwa St., Torrance, CA 90505; (424) 757-0168, FAX: (424) 757-0188, E-mail: sales@sagemillimeter.com, www.sagemillimeter.com

## High-Power Filters Handle 25 kW

**A LINE OF** high-power filters comes in a variety of design configurations across RF and microwave frequencies with power-handling capabilities to 25 kW. The filters can be supplied with lowpass, highpass, and bandpass responses across a frequency range of 5 MHz to 5 GHz. Typically, these units are intended to be used with convection cooling, forced-air cooling, or heat-sink plates; however, the low-loss characteristics combine with effective heat-transfer design to efficiently handle high power levels. As an example, model 7R6-269-X17S11 is a narrowband high-power notch filter capable of handling 100 W CW power. The center of the notch is 269 MHz with a nominal 3-dB bandwidth of 16 MHz. Passband insertion loss is less than 0.3 dB. The notch depth is 85 dB. The rugged filter is supplied in a compact housing measuring just 1.5 × 1.15 × 3.5 in.
**REACTEL INC.,** 8031 Cessna Ave., Gaithersburg, MD 20879; (301) 519-3660, FAX: (301) 519-2447, E-mail: reactel@reactel.com, www.reactel.comqorvo.com, www.qorvo.com

## High-Definition Scopes Scan to 8 GHz

**THE WAVEPRO HD** high-definition oscilloscopes leverage HD4096 technology with 12-b analog-to-digital converters (ADCs) for capturing and displaying high-speed waveforms from dc to 8 GHz in various models. WavePro oscilloscope models are available with vertical analog channels of 2.5, 4.0, 6.0, and 8.0 GHz, and respective risetimes of 117, 73, 50, and 40.5 ps. All of the oscilloscopes feature sampling rates to 20 Gsamples/s, as much as 5-Gpoint signal acquisition memory, and 1900- × 1080-pixel capacitive touchscreens. Sensitivity levels are fully variable from 1 to 10 V/div. The channel-to-channel isolation is as high as 70 dB to 200 MHz, 40 dB to 2.5 GHz, and 30 dB to 6 and 8 GHz. A powerful, deep toolbox of measurement functions is included with each scope.

**TELEDYNE LECROY,** 700 Chestnut Ridge Rd., Chestnut Ridge, NY 10977; (845) 425-2000, www.teledynelecroy.com, support@qorvo.com, www.qorvo.com

## 4-in-1 Cal Kits Feature 26.5-GHz Capability

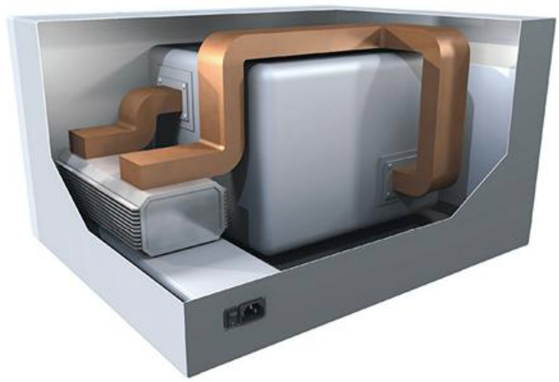
**A LINE OF** portable 4-in-1 calibration kits support short-open-load-through (SOLT) measurement calibrations of vector-network-analyzer (VNA) systems through 26.5 GHz. These coaxial calibration kits include gold-plated 3.5-mm coaxial connectors and a handy lanyard. The kits have nominal impedance of 50 Ω with maximum phase deviation of ±2 deg. and minimum return loss of 30 dB from dc through 26.5 GHz. They are ideal for applications in military, medical, aerospace, automotive, and consumer testing.

**PASTERNACK ENTERPRISES INC.,** 11792 Fitch, Irvine, CA 92614; (949) 261-1920, www.pasternack.com


## Peak Power Meter Has 80-dB Range to 40 GHz

**THE MODEL 4500C RF** peak power meter and the appropriate power sensor is capable of measuring signal levels from −60 to +20 dBm across a frequency range of 30 MHz to 40 GHz with accuracy of ±0.2 dB. It provides time resolution of 100 ps with the measurement capability of reading minimum pulse widths (rise time) of 6 ns. The power meter includes two RF measurement and two trigger channels, and a video measurement bandwidth as wide as 125 MHz. The peak power meter includes USB ports for digital connectivity and ease of memory storage. An 8.4-in. full-color thin-film-transistor (TFT) front-panel display shows fine details of captured waveforms.

**WIRELESS TELECOM GROUP INC.,** 25 Eastmans Rd., Parsippany, NJ 07054; (973) 386-9696, FAX: (973) 386-9191, www.boonton.com



## Connector Helps Power RF Energy Applications

**THE RFEX CONNECTOR** is an RF energy connector designed for cost-effective, high-power-handling capabilities in large-volume applications. It provides a configuration for simple assembly and can be directly integrated into component housings to reduce the size of a final design. The connector is suitable for attachment to rectangular waveguides, dielectric-filled waveguides, and cooking cavities.

**HUBER+SUHNER AG,** Herisau, Switzerland; +41 71 353 4220, www.hubersuhner.com

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 Informa 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.

A ♦

The best deal in town
. . . from ARRA, of course!

# FIXED ATTENUATORS DC-18 GHz

- Models to 55 dB
- SMA or Type N conn.
- 50 W average models

| Freq. Range (GHz) | Average Power (W) | Model No. | |
|---|---|---|---|
| | | N Conn. | SMA Conn. |
| DC-18.0 | 1 | N9412-* | 9412-* |
| DC- 5.0 | 1 | N4402-* | 4401-* |
| DC- 4.0 | 5 | N4405-* | 4405-* |
| DC- 4.0 | 10 | N4410-* | 4410-* |
| DC- 4.0 | 25 | N4425-* | 4425-* |
| DC- 4.0 | 50 | N4450-* | 4450-* |

*Value of attenuation

4425 Types

9412 & 4401 Types (1.14")


N9412 Types (2.42")

Call (631) 231-8400 or
Fax (631) 434-1116

*. . . the last word in variable attenuators*

**ARRA** INC.
15 Harold Court • Bay Shore, N.Y. 11706

A ♣

The best deal in town
. . . from ARRA, of course!

# BROADBAND COAXIAL TERMINATIONS

- DC-18 GHz model
- 50 W model
- SMA or Type N conn.

| Freq. Range (GHz) | Average Power (W) | Model No. | |
|---|---|---|---|
| | | N Conn. | SMA Conn. |
| DC-18.0 | 1 | | 9512 |
| DC-12.4 | 2 | N9512 | |
| DC-12.4 | 5 | N9505 | 9505 |
| DC-12.4 | 10 | N9510 | 9510 |
| DC- 8.0 | 25 | N9525 | 9525 |
| DC- 8.0 | 50 | N9550 | |

Call (631) 231-8400 or
Fax (631) 434-1116

*. . . the last word in variable attenuators*

**ARRA** INC.
15 Harold Court • Bay Shore, N.Y. 11706

A ♠

The best deal in town
. . . from ARRA, of course!

# WAVEGUIDE LOADS

- Low VSWR
- Fast delivery!
- WR284 thru WR62

| Freq. Range (GHz) | Medium Power | | High Power | |
|---|---|---|---|---|
| | Average (W) | Model No. | Average (W) | Model No. |
| 2.60- 3.95 | 1200 | 284-925 | 4500 | 284-920 |
| 3.30- 4.90 | 1000 | 229-925 | 3000 | 229-920 |
| 3.95- 5.85 | 750 | 187-925 | 2000 | 187-920 |
| 4.90- 7.05 | 625 | 159-925 | 1500 | 159-920 |
| 5.85- 8.20 | 500 | 137-925 | 1000 | 137-920 |
| 7.05-10.0 | 425 | 112-925 | 600 | 112-920 |
| 7.00-11.0 | 325 | 102-925 | 500 | 102-920 |
| 8.20-12.4 | 225 | 90-925 | 500 | 90-920 |
| 12.4 -18.0 | 200 | 62-925 | 250 | 62-920 |

Call (631) 231-8400 or
Fax (631) 434-1116

*. . . the last word in variable attenuators*

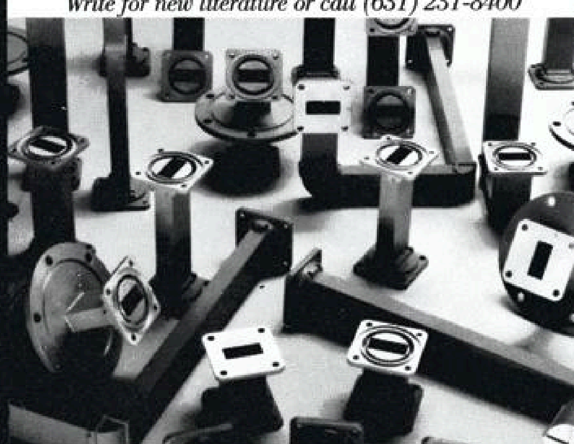
**ARRA** INC.
15 Harold Court • Bay Shore, N.Y. 11706

A ♥

The best deal in town
. . . from ARRA, of course!

# WAVEGUIDE COMPONENTS & SPECIAL ASSEMBLIES

*Write for new literature or call (631) 231-8400*



Call (631) 231-8400 or Fax (631)434-1116

*. . . the last word in variable attenuators*

**ARRA** INC.
15 Harold Court • Bay Shore, N.Y. 11706

Visit our website at www.arra.com

# 5G


# Synthesizers Designed Specifically for Your Next 5G Application

## Superior Integrated Phase Noise Performance Over 6 to 22 GHz In-Bands

Micro Lambda Wireless, Inc has developed a product line of frequency synthesizers for the next 5G generation of systems and test equipment applications. With a focus on industry leading integrated phase noise performance over the 1Hz to 100 MHz offset frequencies which yields superior EVM performance. This family of frequency synthesizers are perfect for multiplication thru 80 GHz. Give us a call or your local representative and check out what we have available today.

**For more information contact Micro Lambda Wireless.**

**www.microlambdawireless.com**

***Micro Lambda is a ISO 9001:2015 Registered Company***

MICRO LAMBDA WIRELESS, INC.

*"Look to the leader in YIG-Technology"*

46515 Landing Parkway, Fremont CA 94538 • (510) 770-9221 • sales@microlambdawireless.com