

Vol. 62 • No. 11

November 2019

# Microwave Journal



## KEEPING IT COOL



Founded in 1958

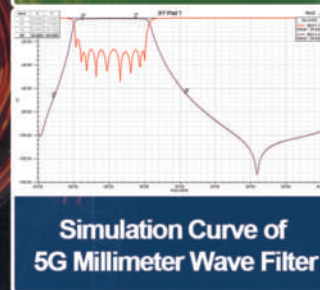
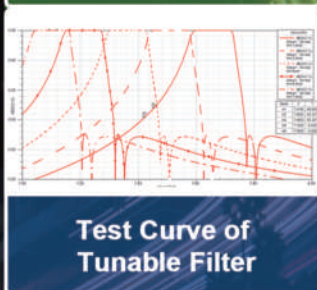
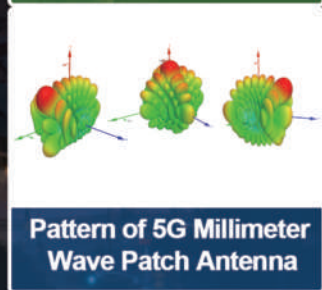
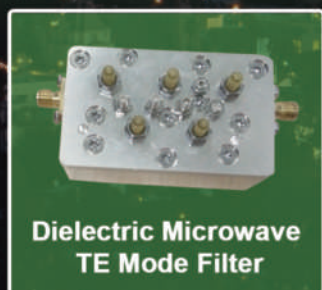
[mwjournal.com](http://mwjournal.com)

Content is copyright protected and provided for personal use only - not for reproduction or retransmission.  
For reprints please contact the Publisher.



# ***We are making high performance microwave and millimeter wave filter and antenna products for 4G and 5G applications.***

- Diplexers with Built in Coupler and OMT: Low insertion loss (  $< 1.0$  dB); high isolation (  $> 35$  dB); compact design.
- Tunable Filter: Large tuning range (  $> 10\%$ ); low VSWR; high out of band rejection; low insertion loss; constant bandwidth; compact design; high reliability.
- Dielectric TE Mode Filter: Ultra low insertion loss (  $Q > 10000$ ); ultra small temperature drift; small size.
- 5G Millimeter Wave Patch Array Antenna: Different array configuration; dual polarization; high gain; beam scanning.
- 5G Millimeter Wave Filter: Designed for 28 GHz system; low insertion loss (  $< 2.5$  dB); high out of band rejection (  $> 50$  dB); ultra small size; light weight (  $< 1$ g).



**PIVOTONE**

One Dream One World

[www.pivotone.com](http://www.pivotone.com)

Content is copyright protected and provided for personal use only - not for reproduction or retransmission.  
For reprints please contact the Publisher.



# RUGGED & RELIABLE

**MADE IN THE USA FOR OVER 57 YEARS!**

**M\*E\*C\*A\* - MICROWAVE EQUIPMENT COMPONENTS OF AMERICA**



- \* Airborne Radar & Communications
- \* Satellite Communications
- \* Test & Measurement
- \* L, S, C, X, Ka & Ku
- \* Missile Guidance
- \* Military Electronic Countermeasures
- \* Research & Development

## MI-SERIES PRODUCTS (COMMERCIAL OFF THE SHELF)

### Power Dividers/Combiners



20 MHz - 40 GHz  
SMA, 2.92, QMA, N, TNC, BNC,  
RPTNC 4.1/9.5 & 7/16 Up to 120 watts  
MIL-DT-23971 Available.

### Attenuators



Up to 40 GHz  
SMA, 2.92, QMA, N,  
TNC, BNC, RPTNC & 7/16  
Up to 150 watts.

### Directional Couplers/Hybrids



0.4 - 40 GHz  
SMA, 2.92, QMA, N, TNC, BNC,  
RPTNC & 7/16 Up to 500 watts  
MIL-DTL-15370 Available.

### Bias Tees



Up to 6 & 18 GHz  
SMA, 2.92mm, QMA,  
N, TNC, RP-TNC & 7/16 DIN.

### Terminations



Hz-18 GHz  
N, SMA & 7/16 Up to 250 watts  
MIL-DTL-3903E

### Circulators/Isolators



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



**MECA Electronics, Inc.**

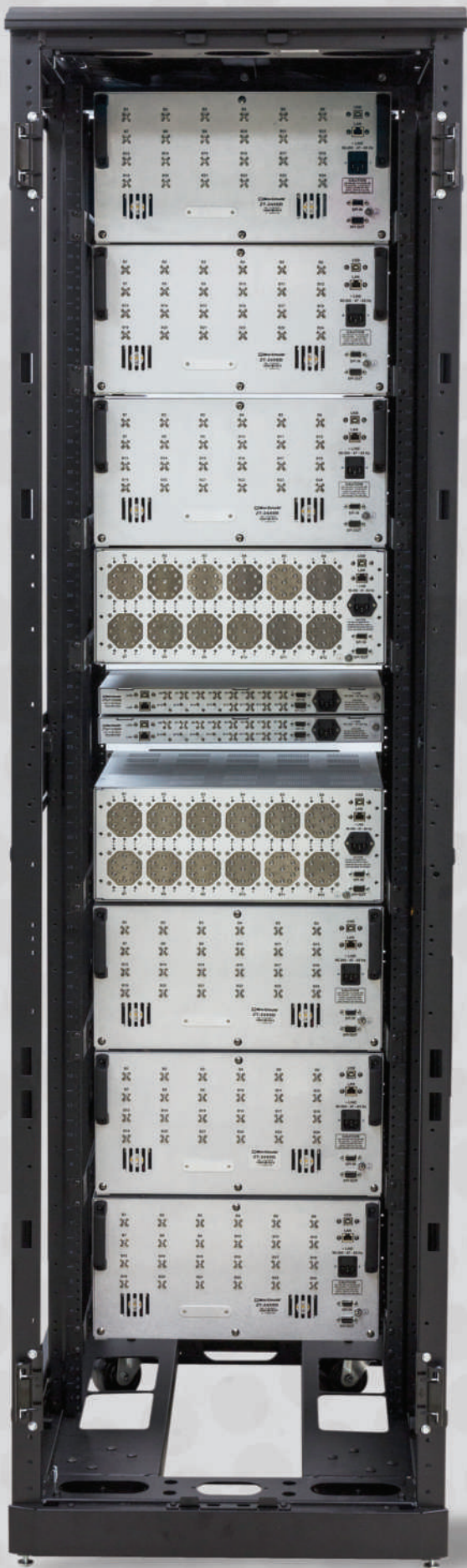
**Microwave Equipment & Components of America**

Content is copyright protected and provided for personal use only - not for reproduction or retransmission.  
For reprints please contact the Publisher.

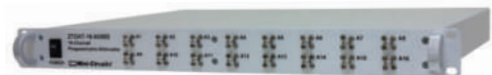
MECA Since 1961 Tel: 973-625-0661 • Fax: 973-625-9277 • sales@e-MECA.com



# Now up to 40 GHz! **TEST**



MODULAR TEST SYSTEMS



PROGRAMMABLE ATTENUATORS



NxM SWITCH MATRICES



PATCH PANELS



# SOLUTIONS

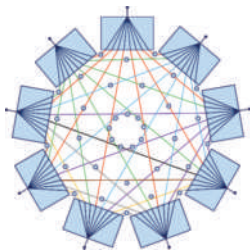
*Flexible, Reliable, Affordable & Fast*



MECHANICAL SWITCH MATRICES



SOLID STATE SWITCH MATRICES



MESH NETWORK TEST SYSTEMS



INSTRUMENTATION AMPLIFIERS



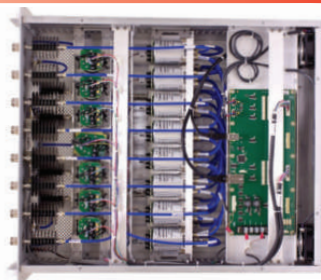
SIGNAL GENERATION,  
MEASUREMENT & CONTROL



HIGH POWER TEST SYSTEMS



SIGNAL DISTRIBUTION



CUSTOM SYSTEMS





# RF-LAMBDA

THE LEADER OF RF BROADBAND SOLUTIONS



Made in USA

## BROADBAND SSPA SOLID STATE POWER AMPLIFIERS

[WWW.RFLAMBDA.COM](http://WWW.RFLAMBDA.COM)

### 0.1-22GHz ULTRA BROADBAND SSPA

RFLUPA01M22GA  
4W 0.1-22GHz



RFLUPA0218GA  
10W 2-18GHz

### EMC BENCHTOP POWER AMPLIFIER



140W 6-18GHz  
SOLID STATE BROADBAND

### 0.01-6GHz VHF, UHF, L, S, C BAND

RFLUPA02G06GC  
100W 2-6GHz



RFLUPA0706GD  
30W 0.7-6GHz

### 6-18GHz C, X, KU BAND



RFLUPA08G11GA  
50W 8-11GHz

RFLUPA0618GC  
25W 6-18GHz

RFLUPA06G12GB  
25W 6-12GHz

### 18-50GHz K, KA, V BAND



RFLUPA18G47GC  
2W 18-47GHz

RFLUPA27G34GB  
15W 27-34GHz

RFLUPA28G42GA  
2W 28-42GHz

RFLUPA32G38GB  
8W 32-38GHz

### BENCHTOP RF MICROWAVE SYSTEM POWER AMPLIFIER



RAMP00G06GA - 30W 0.01-6GHz



RAMP39G48GA - 4W 39-48GHz



RAMP01G22GA - 8W 1-22GHz



RAMP27G34GA - 8W 27-34GHz

[www.rflambda.com](http://www.rflambda.com)

1-888-976-8880

San Diego, CA, US

Ottawa, ONT, Canada

Content is copyright protected and provided for personal use only - not for reproduction or retransmission.

For reprints please contact the Publisher.

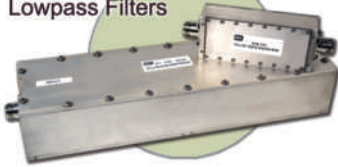




a DOVER company

# SUPPORTING OUR WARFIGHTERS SINCE 1971

High-Power  
Lowpass Filters



PIN Diode Switches

Phase Matched Filters



Multiplexers

- Filters DC to 94 GHz
- Bandpass
- Bandreject
- Lowpass
- Highpass
- Switched Filter Banks
- Tunable Filters
- Filter/LNA Assemblies
- Rugged Designs for Harsh Military Environments
- In-House MIL-SPEC Environmental Testing
- Multiplexers
- Non-Contiguous
- Contiguous
- Overlapping Bands



ENABLING COMMUNICATION AND SIGNAL CONTROL

Content is copyright protected and provided for personal use only - not for reproduction or retransmission.

For reprints please contact the Publisher.





# Let Amplical

*Jump Those Hurdles for You*

with our Complete In-House Design, Manufacturing and Test Capabilities

Customers can depend on us for quick order fulfillment, competitive pricing and dedicated service.

*Let us prove our commitment to you today.*

High performance standard and custom Control Components and Amplifiers to 40GHz.

- EW Systems
- Communications Systems
- Radar
- Test
- Simulation

#### Products:

- Switches
- Attenuators
- Phase Shifters
- Limiters
- Switch Matrices
- Broadband Amplifiers
- Low Noise Amplifiers
- High Power Amplifiers
- Custom Components and Sub-assemblies



Phone: 973-386-1119  
Fax: 973-386-1131  
E-mail: [info@amplical.com](mailto:info@amplical.com)  
web: [www.amplical.com](http://www.amplical.com)

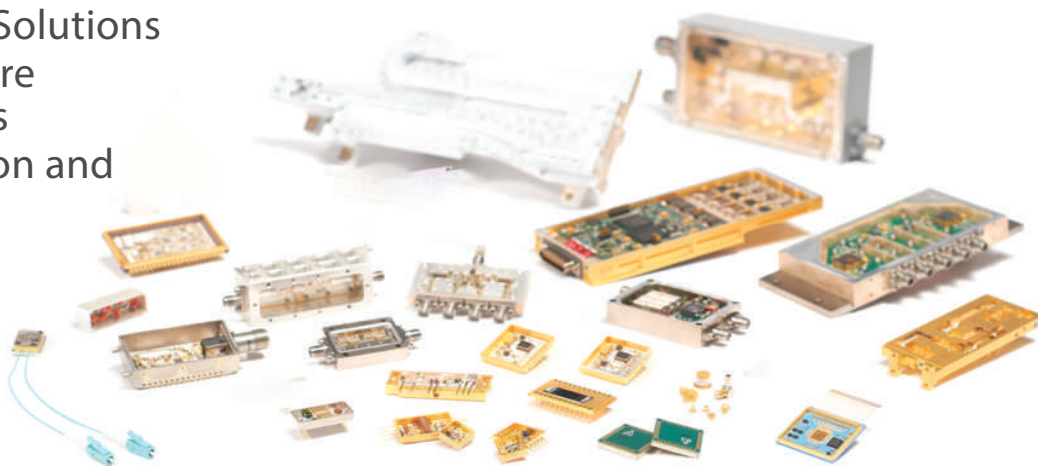




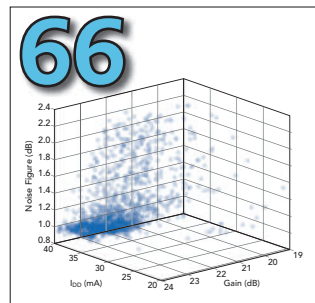
# RF, Microwave, Microelectronics & Power Solutions

Components, Modules, Integrated Assemblies and Subsystems.

- Amplifiers, Filters, Passive and Active Components
- Integrated Microwave Assemblies
- SAW Filters and Oscillators
- Optoelectronic Solutions
- High Temperature Microelectronics
- Power Conversion and Distribution







Look for this month's exclusive article online at [mwjournal.com](http://mwjournal.com)

### First-Pass Design of Ultra-Wideband Microwave and mmWave Filters for Multi-Stage Frequency Multiplication

H. M. Talasila, F. R. Morales, J. Paden, Center for Remote Sensing of Ice Sheets (CRSIS), The University of Kansas; N. D. Orloff, D. Gu, National Institute of Standards and Technology (NIST); M. Conte, University of Massachusetts Amherst; C. Oakley, Michigan State University; and M. McKeown, Hesse-Mechatronics Inc.

## Cover Feature

### 22 New Thermal Interface for High-Power Density GaN Devices in Space

Jordan Mizerak, JETCOOL Technologies Inc.

## Technical Features

### 54 Compact, Low Loss Switched Filter Bank Using MEMS Switches

Ian Burke, Menlo Microsystems Inc.; Purna Subedi, 3H Communications Systems Inc.

### 66 Removing MMIC Outliers in Production Test Using Real-Time Principal Component Analysis

Grace Remillard\*\*, Charles Trantanella\* and Michael Megan\*, Custom MMIC\*, University of Massachusetts-Lowell\*\*

### 82 The Phase Noise Challenge Pacing the Race to 5G

Bill Linstrom, Ron Parrott and Allen Sweet, VIDA Products

### 96 Design of a Broadband, Harmonically-Tuned Power Amplifier with Gate-Source Parasitic Compensation

Zhiqun Cheng, Hangzhou Dianzi University; Suzhou Institute of Nano-Tech and Nano-Bionics; Lei Xu, Guohua Liu and Han Feng, Hangzhou Dianzi University; Steven Gao, University of Kent

## Application Notes

### 110 DRFM Jammer Test Solutions

Yassen Mikhailov, Rohde & Schwarz

### 122 Reducing EMI/RFI in Microwave Cable Assemblies for A&D Systems

Paul Pino, W. L. Gore & Associates



# TOMORROW'S DESIGNS REQUIRE *SMARTER* SOFTWARE TODAY



NI AWR Design Environment software provides a seamless platform for developing next-generation wireless electronics and communications systems, from concept to product. Its powerful interface, integrated system, circuit, and electromagnetic simulation technologies, and design flow automation ensures your design success.

Visit [awr.com/smarterdesign](http://awr.com/smarterdesign) to learn more.





### Product Feature

## 126 Innovative Waveguide Connector Simplifies mmWave Packages

SAGE Millimeter

### Tech Briefs

## 130 10 MHz to 40 GHz Phase Noise Analyzer

Holzworth Instrumentation

## 131 30 kW Solid-State HPA for P-Band Radar

Daico Industries Inc.

## 132 High-Power Emitters for Open Air Range Threat Simulation

Empower RF Systems Inc.

## 133 Customizable 2 kW Broadband Jammer Covers HF to Microwave

Albrecht Telecommunications GmbH

### Departments

17 Mark Your Calendar	136 New Products
18 Coming Events	142 Book End
37 Defense News	144 Ad Index
41 Commercial Market	144 Sales Reps
44 Around the Circuit	146 Fabs and Labs
134 Software and Mobile Apps	

Microwave Journal (USPS 396-250) (ISSN 0192-6225) is published monthly by Horizon House Publications Inc., 685 Canton St., Norwood, MA 02062. Periodicals postage paid at Norwood, MA 02062 and additional mailing offices.

**Photocopy Rights:** Permission to photocopy for internal or personal use, or the internal or personal use of specific clients, is granted by Microwave Journal for users through Copyright Clearance Center provided that the base fee of \$5.00 per copy of the article, plus \$1.00 per page, is paid directly to the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923 USA (978) 750-8400. For government and/or educational classroom use, the Copyright Clearance Center should be contacted. The rate for this use is 0.03 cents per page. Please specify ISSN 0192-6225 Microwave Journal International. Microwave Journal can also be purchased on 35 mm film from University Microfilms, Periodic Entry Department, 300 N. Zeeb Rd., Ann Arbor, MI 48106 (313) 761-4700. Reprints: For PDF reprints, contact Barbara Walsh at (781) 769-9750.

**POSTMASTER:** Send address corrections to Microwave Journal, PO Box 1028, Lowell, MA 01853 or e-mail mwj@e-circ.net. Subscription information: (978) 671-0446. This journal is issued without charge upon written request to qualified persons working in the RF & microwave industry. Other subscriptions are: domestic, \$120.00 per year, two-year subscriptions, \$185.00; foreign, \$200.00 per year, two-year subscriptions, \$370.00; back issues (if available) and single copies, \$10.00 domestic and \$20.00 foreign. Claims for missing issues must be filed within 90 days of date of issue for complimentary replacement.

©2019 by Horizon House Publications Inc.  
Posted under Canadian international publications mail agreement #PM40612608

### STAFF

**Publisher:** Carl Sheffres

**Associate Publisher:** Michael Hallman

**Editor:** Patrick Hindle

**Technical Editor:** Gary Lerude

**Managing Editor:** Jennifer DiMarco

**Associate Technical Editor:** Cliff Drubin

**Copy Editor:** Ashleigh West

**Multimedia Staff Editor:** Barbara Walsh

**Contributing Editor:** Janine Love

**Electronic Marketing Manager:** Chris Stanfa

**Digital Content Specialists:**

Lauren Tully

Jaclyn Seigal

**Audience Development Manager:** Carol Spach

**Traffic Manager:** Edward Kiessling

**Director of Production & Distribution:**

Robert Bass

**Art Director:** Janice Levenson

**Graphic Designer:** Ann Pierce

#### EUROPE

**Office Manager:** Nina Plesu

#### CORPORATE STAFF

**CEO:** William M. Bazy

**President:** Ivar Bazy

**Vice President:** Jared Bazy

#### EDITORIAL REVIEW BOARD

Dr. I.J. Bahl

F.M. Bashore

A. Chenakin

H. Howe, Jr.

Dr. T. Itoh

Dr. S. Maas

R. Pengelly

Dr. Ajay K. Poddar

Dr. J. Rautio

Dr. U. Rohde

Dr. P. Staecker

D. Swanson

D. Vye

Prof. K. Wu

#### EXECUTIVE EDITORIAL OFFICE

685 Canton Street, Norwood, MA 02062

Tel: (781) 769-9750

FAX: (781) 769-5037

e-mail: mwj@mwjournal.com

#### EUROPEAN EDITORIAL OFFICE

16 Sussex Street, London SW1V 4RW, England

Tel: Editorial: +44 207 596 8730 Sales: +44 207 596 8740

FAX: +44 207 596 8749

#### SUBSCRIPTION SERVICES

Send subscription inquiries and address changes to:

Tel: (978) 671-0446

e-mail: mwj@e-circ.net



www.mwjournal.com

Printed in the USA



# ULTRA-PORTABLE. ULTRA-BROADBAND to 170 GHz.



Still small but mightier — Anritsu's Spectrum Master™ MS276xA family now offers the world's first and only broadband spectrum analyzer solutions to provide continuous coverage to 170 GHz.

## Pocket-sized spectrum analyzer delivers big performance

The form factor for measurements up to 170 GHz measurements is still a whole lot smaller, and so is the price tag. Anritsu's Spectrum Master MS2760xA is a family of broadband spectrum analyzer direct-connect solutions that deliver superior dynamic range and higher sensitivity in the millimeter-wave bands in a form factor that fits in your pocket! Nothing on the market comes close.

**Be a Leader** – Discover how you can get better measurement confidence with Anritsu. View our complete line of millimeter-wave testing solutions at [www.anritsu.com/test-measurement](http://www.anritsu.com/test-measurement)

### KEY FEATURES



mmWave test and measurement for radio astronomy, automotive radar, satellite, radio links, WiGig, and more



Ultra-portable benchtop power from a smartphone-sized instrument that fits in your pocket



Best-in-class dynamic range, sweep speed, and amplitude accuracy



DANL of -141/-136/-129/-122 dBm to 90/110/145/170 GHz (Spectrum Master MS2762A)



**Anritsu**

[www.anritsu.com](http://www.anritsu.com)

Content is copyright protected and provided for personal use only - not for reproduction or retransmission.  
For reprints please contact the Publisher.

© 2017 Anritsu Company



## LEARNING CENTER

Access webinars on-demand from the archived webinars and events page at [www.mwjournal.com/events](http://www.mwjournal.com/events)



### Executive Interviews

**Karim Hamed**, general manager of **Analog Devices'** microwave communications segment, discusses how ADI is supporting the communications market from "bits to antenna," including nascent mmWave and phased array opportunities.

**Jonathan Rowntree**, senior VP & GM, Advanced Connectivity Solutions at **Rogers Corporation**, discusses the challenges facing high frequency PCB designers and market demands for laminates to meet the demanding thermal and electrical requirements for 5G, satellite and automotive radar applications.



Check out MWJ's podcasts on iTunes and Google Play



<https://podcasts.microwavejournal.com/>

### Join Us Online

- Follow us
- @Pathindle
  - @MWJGary
  - @MWJEditor
- Join us at the RF and Microwave Community
- Become a fan at [facebook.com/microwavejournal](https://facebook.com/microwavejournal)

## WHITE PAPERS



Tips for Better Signal Generator Measurements



A Designer's Primer on Internet of Things (IoT)



5G  
RF MW Frontends

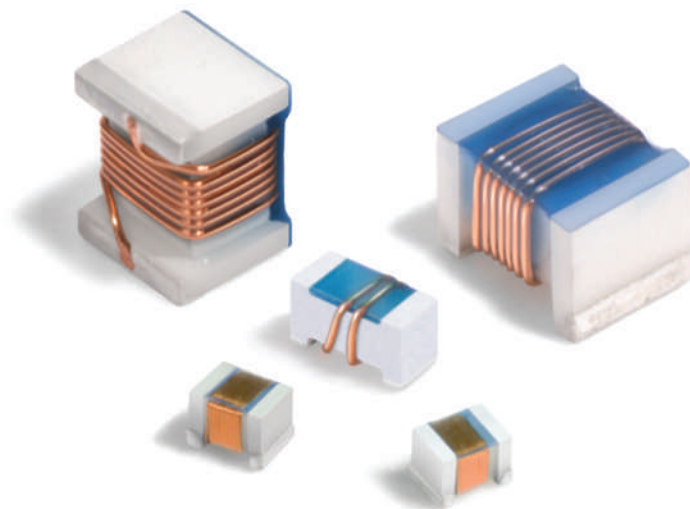


Catch *Frequency Matters*, the industry update from *Microwave Journal*, [microwavejournal.com/FrequencyMatters](http://microwavejournal.com/FrequencyMatters)

MWJ



# Blue Chip Performers



**Exceptionally high Q, low DCR and a wide range of inductance values make our wirewound chip inductors a sure bet!**

Engineers love our high-performance, low-cost, wirewound ceramic chip inductors; considered by most to be the best performing wirewounds available.

For example, our 0201HL Series is offered in seven inductance values ranging from 22 to 51 nH – the highest currently offered in an 0201 (0603) package – making them fully optimized for impedance matching in 700 MHz band LTE and 5G applications.

Our 0402DC and 0805HP Series provide the industry's highest Q factors in their respective sizes for super low loss in high frequency circuits. Select values from 2.6 to 820 nH, including 0.1 nH increments from 2.8 to 10 nH in the 0402DC Series.

Find out why our customers are so bullish on our wirewound ceramic chip inductors. Order your free samples today at **[www.coilcraft.com](http://www.coilcraft.com)**.



**WWW.COILCRAFT.COM**

Content is copyright protected and provided for personal use only - not for reproduction or retransmission.  
For reprints please contact the Publisher.



# MMIC AMPLIFIERS



**Now!**  
**up to ~~43.5~~ GHz**

*Ultra-Wideband, 22 to 43.5 GHz*

*Excellent Gain Flatness  $\pm 0.9$  dB*

*Low Noise, 3.5 dB typ.*

*Built-In Bypass and Shutdown*







# DECEMBER

MARK YOUR CALENDAR

## 4

**Call for Papers  
Deadline**



The IEEE MTT-S 2020 International Microwave Symposium (IMS2020) will be held June 21-26, 2020 in Los Angeles, Calif. IMS2020 is the centerpiece of Microwave Week 2020 comprising the RFIC Symposium and the ARFTG Conference. Microwave Week, with more than 9,000 participants and 600 industrial exhibits of state-of-the-art microwave products, is the world's largest gathering of RF and microwave professionals. Authors are invited to submit technical papers describing original work microwave, mmWave and THz theory and techniques.

<https://ims-ieee.org/authors-organizers>

## 7-11



Washington, DC

IEEE International Electron Devices Meeting (IEDM) is a preeminent forum for reporting technological breakthroughs in the areas of semiconductor and electronic device technology, design, manufacturing, physics and modeling. IEDM is the flagship conference for nanometer-scale CMOS transistor technology, advanced memory, displays, sensors, MEMS devices, novel quantum and nano-scale devices and phenomenology, optoelectronics, devices for power and energy harvesting, high speed devices, as well as process technology and device modeling and simulation.

<https://ieee-iedm.org>

## 10-13



Singapore

The 2019 Asia-Pacific Microwave Conference (APMC) will be held in Singapore, December 10-13, 2019. APMC will offer a rich scientific program of the highest quality with invited speakers from all over the world and provide a broad forum of exchange for both academia and industry alike. The conference will cover the entire scope of microwave and mmWave engineering, including RF/microwave/THz, antennas and propagation and EMC/EMI.

<https://apmc2019.miceapps.com/client/sites/view/SP8f993>

## 13-15

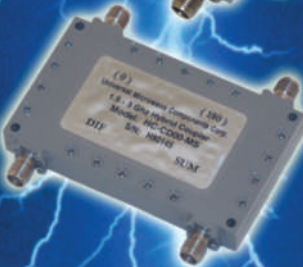


Mumbai, India

The IEEE MTT-S, with technical co-sponsorship from IEEE Bombay Section and IIT Bombay, announces the 7<sup>th</sup> IEEE MTT-S International Microwave and RF Conference (IMaRC) in Mumbai, India. This conference is held annually in India and provides a forum for the international community of microwave engineers to meet and present their latest technical achievements in the field of microwave and RF components, circuits, systems and modelling techniques.

<https://imarc-ieee.org/>

FOR DETAILS, VISIT [MWJOURNAL.COM/EVENTS](http://MWJOURNAL.COM/EVENTS)



**RF & Microwave Design and Manufacturing**  
Covering Frequencies from DC to 20 GHz  
Serving the Industry Since 1993

"Quality Products at Competitive Prices"  
"Custom Designs are Available"

**Product Line:**

- Solid State Variable Attenuators
- Solid State Switches
- Directional Couplers
- Hybrid Couplers (90/180 Deg)
- Power Dividers / Combiners
- DC-Blocks & Bias Tee's

5702-D General Washington Drive  
Alexandria, Virginia 22312 USA  
Tel: (703) 642-6332, Fax: (703) 642-2568  
Email: sales @ umcc111.com

**www.umcc111.com**

## Coming Events

### CALL FOR PAPERS

IEEE IMS2020  
December 4

EDI CON China 2020  
January 6, 2020

IEEE EMC+SIPI 2020  
January 13, 2020

IEEE IMBiOC 2020  
January 31, 2020

WAMICON 2020  
February 7, 2020

EuMC 2020  
February 7, 2020

95th ARFTG Microwave  
Measurement Symposium  
February 14, 2020

IEEE AUTOTESTCON 2020  
February 15, 2020

ITC 2020  
March 13, 2020

APMC 2020  
May 15, 2020

**mwjournal.com**



### NOVEMBER

**Space Tech Expo Europe 2019**  
November 19-21 • Bremen, Germany  
[www.spacetecheurope.eu/](http://www.spacetecheurope.eu/)

**IEEE WIE Forum USA East 2019**  
November 21-23 • Arlington, Va.  
<https://attend.ieee.org/wie-forum-usa-east-2019/>



### DECEMBER

**65th Annual IEEE International Electron  
Devices Meeting (IEDM)**  
December 7-11 • San Francisco, Calif.  
<https://ieee-iedm.org/>

**Asia Pacific Microwave Conference 2019**  
December 10-13 • Singapore  
<https://apmc2019.miceapps.com/client/sites/view/SP8f993>

**IEEE IMaRC 2019**  
December 13-15 • Mumbai, India  
<https://imarc-ieee.org/>



### JANUARY

**CES 2020**  
January 7-10, 2020 • Las Vegas, Nev.  
[www.ces.tech/](http://www.ces.tech/)

**94th ARFTG Microwave Measurement  
Symposium**  
January 26-29, 2020 • San Antonio, Texas  
[www.arftg.org](http://www.arftg.org)

**Radio and Wireless Week 2020**  
January 26-29, 2020 • San Antonio, Texas  
<https://radiowirelessweek.org/>

**DesignCon 2020**  
January 28-30, 2020 • Santa Clara, Calif.  
[www.designcon.com](http://www.designcon.com)



### FEBRUARY

**MWC Barcelona 2020**  
February 24-27, 2020 • Barcelona, Spain  
[www.mwcbarcelona.com/](http://www.mwcbarcelona.com/)



### MARCH

**SATELLITE 2020**  
March 10-12, 2020 • Washington, D.C.  
<https://2019.satshow.com/>

**GOMACTech 2020**  
March 17-18, 2020 • San Diego, Calif.  
[www.gomactech.net/2020/index.html](http://www.gomactech.net/2020/index.html)

**EMV 2020**  
March 17-19, 2020 • Cologne, Germany  
<https://emv.mesago.com/events/en.html>

**Microwave & RF 2020**  
March 18-19, 2020 • Paris, France  
[www.microwave-rf.com](http://www.microwave-rf.com)



### APRIL

**Expo Electronica 2020**  
April 14-16, 2020 • Moscow, Russia  
[www.expoelectronica.ru/en-GB](http://www.expoelectronica.ru/en-GB)

**WAMICON 2020**  
April 15-17, 2020 • Clearwater Beach, Fla.  
[www.wamicon.org/](http://www.wamicon.org/)



### MAY

**CS Mantech 2020**  
May 11-14, 2020 • Tucson, Ariz.  
<http://csmantech.org/>

**EDI CON China 2020**  
May 12-13, 2020 • Beijing, China  
[www.ediconchina.com](http://www.ediconchina.com)

**Space Tech Expo USA 2020**  
May 18-20, 2020 • Long Beach, Calif.  
[www.spacetecheurope.com/](http://www.spacetecheurope.com/)



# Don't Leave Radar Performance Up In The Air.

Wolfspeed, A Cree Company, introduces a new 50 V, 5 W GaN Power Amplifier, operating from 0.5-2.7 GHz, the CMPA0527005F. The part is ideal for multiple applications such as weather radar, ISM, communications radios, and Data Links. The GaN-on-SiC device can be operated in CW, pulsed and linear operation, as a pre-driver in a multi-stage power amplifier.

## FEATURES:

- Input Matched Discrete device specifically designed for 50 V pre-driver needs
- 20 dB of Small Signal Gain
- 15 dB of Associated Gain
- Over 5 W of CW power at  $P_{IN} = 24$  dBm



  
**Wolfspeed**®

A CREE COMPANY

 **RichardsonRFPD**  
An Arrow Company

**CMPA0527005F IS AVAILABLE  
NOW AT RICHARDSON RFPD**  
[richardsonrfpd.com/CMPA0527005F](http://richardsonrfpd.com/CMPA0527005F)



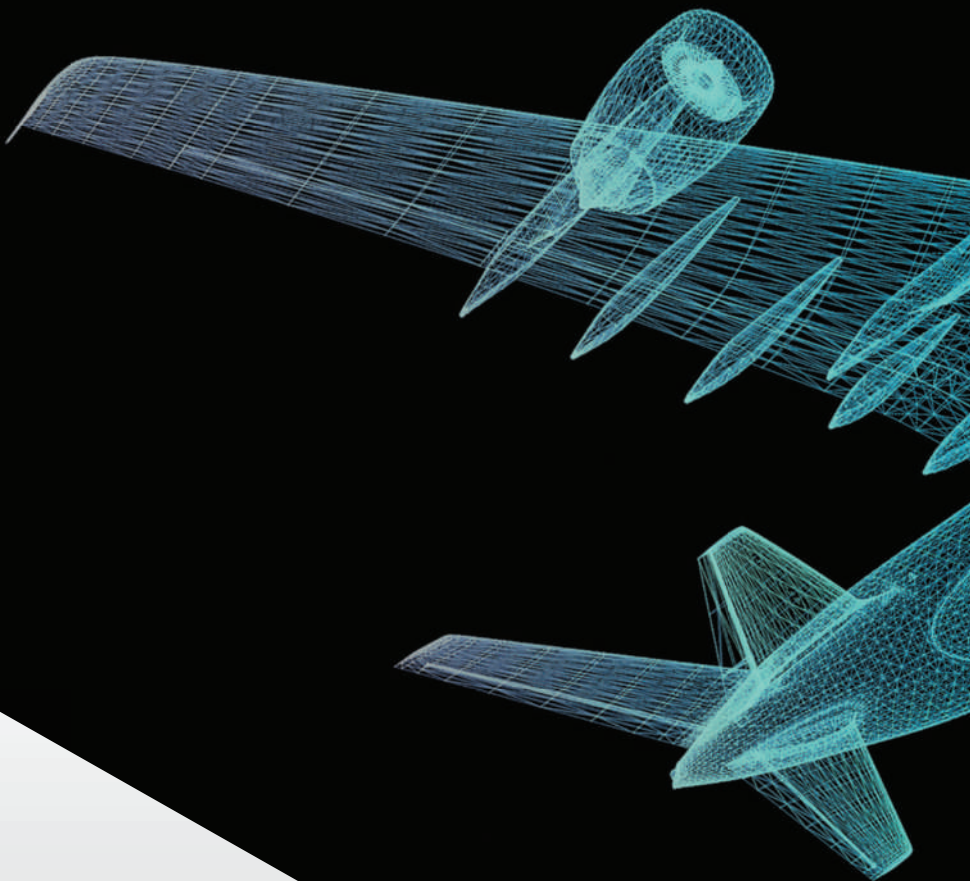
**Your Global Source for RF, Wireless, IoT & Power Technologies**

[www.richardsonrfpd.com](http://www.richardsonrfpd.com) | 800.737.6937 | 630.262.6800

© 2017 Wolfspeed, Inc. All rights reserved. This document is for informational purposes only - not for reproduction or retransmission.  
For reprints please contact the Publisher.



AHEAD OF WHAT'S POSSIBLE™



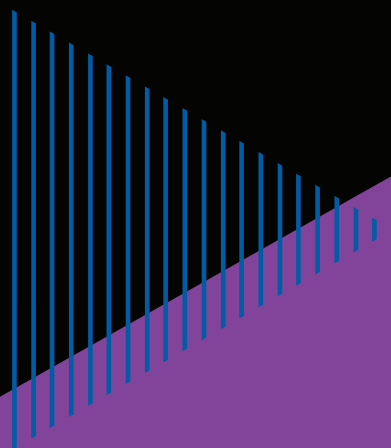
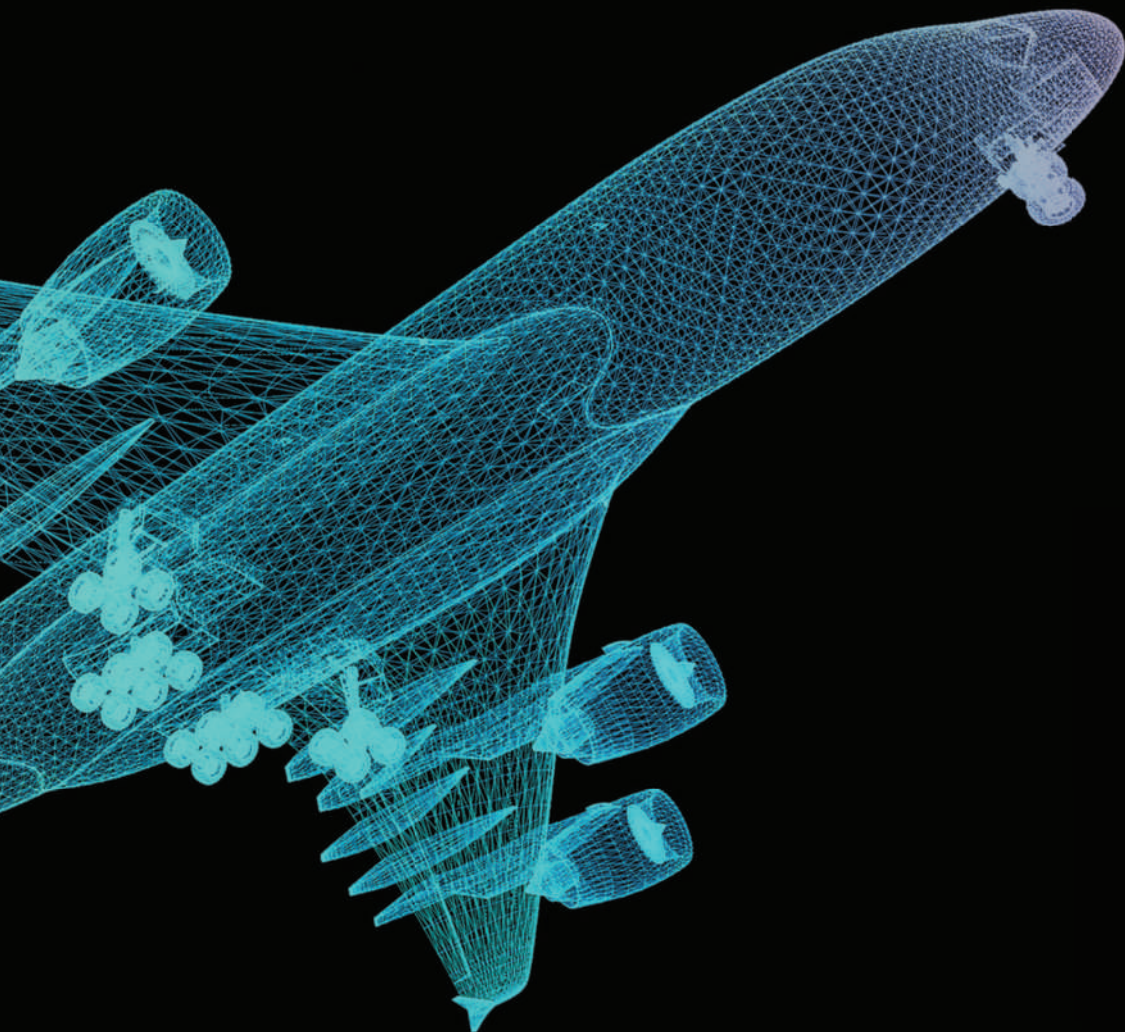
## **SUPERIOR TECHNOLOGY FOR WHEN THERE'S NO MARGIN FOR ERROR.**

Our full spectrum RF expertise in radar, communications, and avionics is trusted by aerospace and defense organizations around the world. And the sensory technology that keeps the skies safe has universal applications in creating a more secure global future. Learn more at [analog.com/ADEF](http://analog.com/ADEF).

Content is copyright protected and provided for personal use only - not for reproduction or retransmission.  
For reprints please contact the Publisher.



ANALOG



[ANALOG.COM/ADEF](http://ANALOG.COM/ADEF)

Content is copyright protected and provided for personal use only - not for reproduction or retransmission.  
For reprints please contact the Publisher.

# New Thermal Interface for High-Power Density GaN Devices in Space

Jordan Mizerak  
JETCOOL Technologies Inc., Littleton, Mass.

**T**he onset of GaN as a semiconductor material is enabling the next generation of electronic devices. Because GaN is a wideband gap (WBG) semiconductor material, it can sustain higher breakdown electric fields and electron drift velocities than conventional semiconductors such as Si and GaAs.<sup>1</sup> GaN also exhibits enhanced thermal characteristics, sustaining higher temperatures and more effectively conducting heat. Because of these desirable material properties, GaN devices can operate at higher frequencies and higher powers in smaller package sizes, an enabling development in the field of high-power semiconductors.

## SOLID-STATE POWER AMPLIFIERS

GaN has great promise to revolutionize solid-state power amplifiers (SSPA) for space applications. GaN is a particularly good fit in space applications due to its small size, light weight and radiation tolerance from enhanced atomic bond strength. In traditional satellite architectures, amplifying a signal for transmission has typically been achieved either by using travelling wave tube (TWT) amplifiers, which are relatively large in size and weight, or lower power GaAs SSPAs, which require numer-

ous units and additional signal combining hardware. With costs still near \$10,000 per pound to get into low Earth orbit (LEO),<sup>2</sup> the ability to shrink from ~150 in<sup>3</sup> TWT amplifiers to operationally equivalent ~0.05 in<sup>3</sup> GaN high-power amplifiers (HPA) will result in significant cost reductions as well as payload capability enhancements.

The byproduct, however, of shrinking the power amplifier to a package smaller than a penny is the increased power density. In SSPAs, device temperatures spike to very high local values at the microscopic gate fingers as power density increases, making the removal of heat a far more difficult task. Moreover, with an Arrhenius relationship between device mean time to failure (MTTF) and operating temperature, small changes in the device temperature can result in orders of magnitude differences in lifetime.<sup>3</sup> It is therefore critical in high value, low-maintenance space payloads to have a reliable and effective cooling technique compatible with the shrinking package sizes and increasing power densities of GaN HPAs.

With current power densities of HPAs on space payloads eclipsing 50 W/cm<sup>2</sup>, traditional heat spreading cooling methods are reaching their limits. Moreover, with the en-

hanced material properties of GaN devices, power densities over 1500 W/cm<sup>2</sup> are imminent in space payloads which is almost two orders of magnitude higher than those supported using standard thermal architectures. Therefore, a fundamentally different approach to thermal management is needed to fully capture the exceptional capabilities of GaN semiconductor devices while maintaining temperatures compatible with long-term, reliable operation on space platforms.

## FUNDAMENTAL HEAT TRANSFER CONSIDERATIONS

Radiation heat transfer, assuming a perfect view factor to the surrounding cold sky, is governed by the Stefan-Boltzmann Law:

$$\dot{q}_{\text{rad}} = \epsilon \sigma (T_H^4 - T_C^4)$$

where  $\dot{q}_{\text{rad}}$  is the radiative cooling flux (W/cm<sup>2</sup>) from a surface of emissivity  $\epsilon$  with temperature  $T_H$  (K), radiating to surrounding cold sky temperature  $T_C$  (K) often taken to be around 3 K. The Stefan-Boltzmann constant,  $\sigma$ , is a physical constant of proportionality denoting the total radiative transfer of a black body over all wavelengths, which takes the value

$$\sigma = 5.67 \times 10^{-12} \frac{\text{W}}{\text{cm}^2 \text{K}^4}$$



# COAXIAL AND WAVEGUIDE SWITCHES

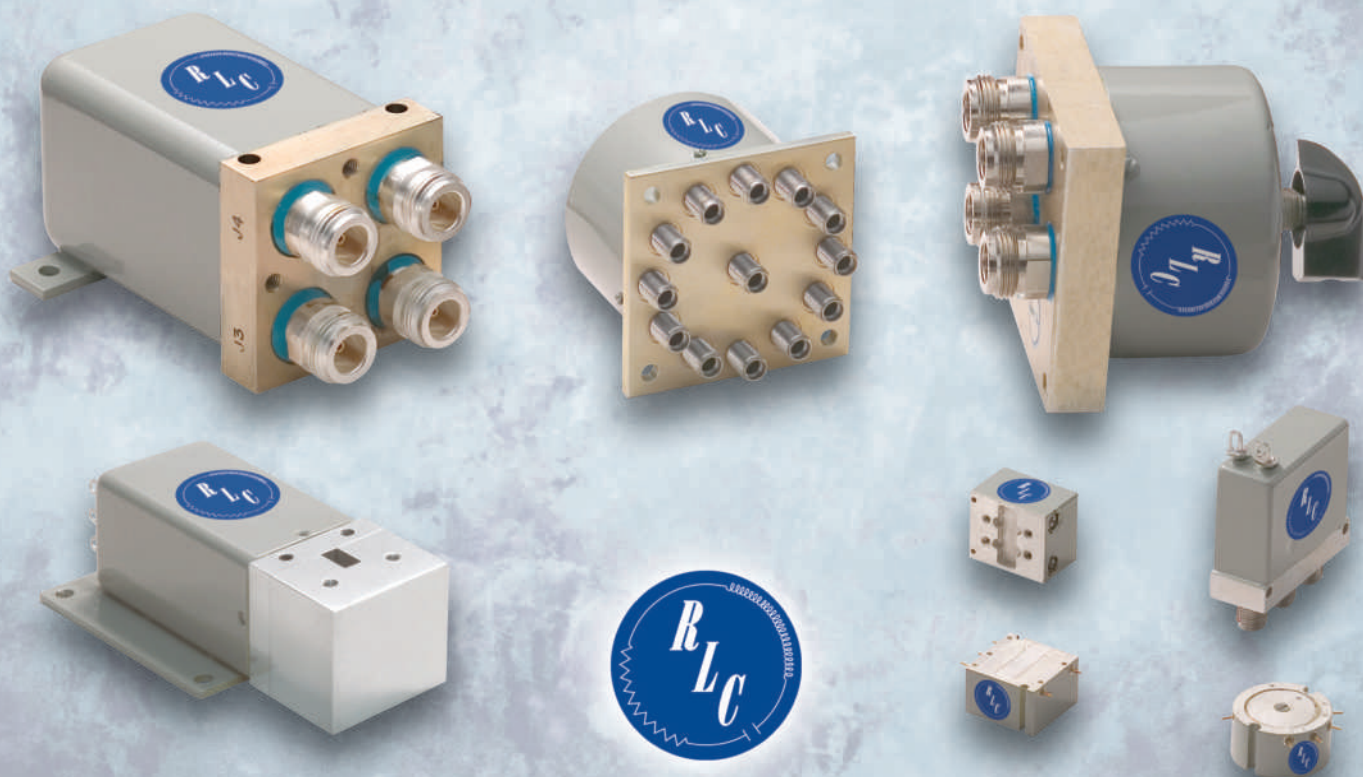
## RLC has the exact solution you're looking for.

RLC Electronics manufactures a complete range of RF switches including coaxial in the frequency range from DC to 65 GHz and rectangular or double ridge waveguide. The operating modes on all designs are failsafe, latching and manual.

Control options are DC voltages as low as 5V, TTL, BCD, RS232, and RS422. All switches have excellent repeatability and lifetimes in excess of one million operations. Many types are QPL listed per MIL-DTL-3928.

- SPDT to SP12T
- Transfer
- Low VSWR
- High Isolation
- Low Insertion Loss
- High Power
- Low Passive Intermodulation
- Surface Mount Options

*For more detailed information on coaxial and waveguide switches, visit our web site.*



### RLC ELECTRONICS, INC.

83 Radio Circle, Mount Kisco, New York 10549 • Tel: 914.241.1334 • Fax: 914.241.1753  
E-mail: [sales@rlcelectronics.com](mailto:sales@rlcelectronics.com) • [www.rlcelectronics.com](http://www.rlcelectronics.com)

ISO 9001:2000 CERTIFIED

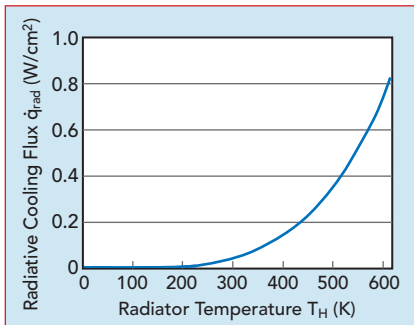
*RLC is your complete microwave component source...*

*Switches, Filters, Power Dividers, Terminations, Attenuators, DC Blocks, Bias Tees & Detectors.*

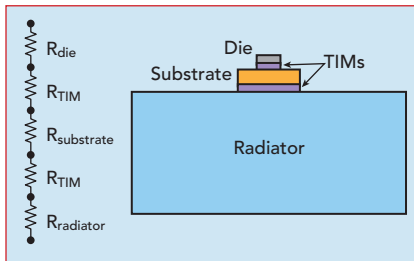
Content is copyright protected and provided for personal use only - not for reproduction or retransmission.

For reprints please contact the Publisher.





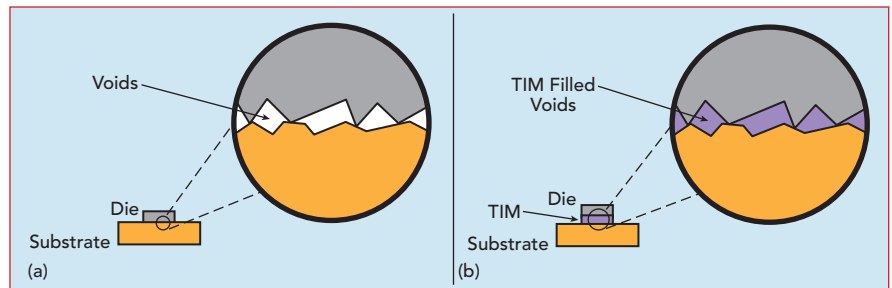
**▲ Fig. 1** Radiative cooling flux as a function of surface temperature, applying best case scenario of a 3 K cold sky with perfect emissivity and view factor.



**▲ Fig. 2** Schematic of conductive heat spreading thermal stackup. The heat generated in the die passes through multiple layers of interface materials and heat spreaders before reaching the radiator (not to scale).

Unlike conduction and convection, which are linear with temperature difference, radiation has a quartic dependence on absolute temperature. Because the Stefan-Boltzmann constant is small, radiation is negligible at temperatures typically seen on Earth. In space, however, radiation becomes the only viable option as an ultimate heat sink. Therefore, the hot radiator surface temperature  $T_H$  becomes the major determining factor in heat transfer capability per unit area in space, due to the quartic dependence in an otherwise low temperature, cold sky. Taking best case conditions at perfect emissivity  $\epsilon = 1$  and cold sky temperature  $T_C = 3$  K, the radiative cooling flux  $\dot{q}_{rad}$  can be plotted against hot surface temperature  $T_H$ .

Most GaN devices have recommended maximum operating temperatures of about 250°C (523 K). As seen in **Figure 1**, even at power densities of current devices, ~50 W/cm<sup>2</sup>, the power density of GaN SSPAs is far higher than the heat transfer capability of radiative techniques. This makes the required radiator area for a given SSPA much larger than the device footprint area, and often heat management



**▲ Fig. 3** Illustration of microscale roughness of adjoining surfaces, resulting in voids causing poor heat transmission between surfaces (a). TIMs are applied to fill in the gaps with a conductive intermediate layer, improving the thermal contact (b).

tradeoffs such as low duty cycle operation, onboard thermal storage and other indirect thermal pathways must be employed to keep the equilibrium temperature low.

It is therefore paramount to optimize the heat pathway from where the heat is being generated (microscopic hot spots on the die) to where it is ultimately rejected (the large area surface of the radiator). As power densities increase, temperatures on the die spike to very high local values, requiring high capability thermal management techniques to effectively transfer the heat to the radiator, which may be over a meter away. Minimizing the thermal resistance between the die and the radiator is what facilitates high-power density devices maintaining safe temperatures for high performance and long lifetime.

## CONDUCTIVE HEAT SPREADING APPROACH

The standard method of removing heat from PAs on space payloads relies on heat spreading via conduction. The PA die is attached to a heat spreader substrate with a matched coefficient of thermal expansion (CTE) via a thermal interface material (TIM), often a solder. This substrate is then attached to a large radiator via a second TIM, often a filler paste or epoxy. This thermal stackup is shown in **Figure 2**. As described previously, the radiator's surface area needs to be much larger than that of the die footprint. Therefore, there needs to be a method of connecting the die to the radiator in order to spread the heat out.

The most direct thermal pathway would be to attach the die directly to the radiator. The first issue is that, when attempting to mate surfaces, numerous voids are introduced due

to the inherent roughness of each surface at the microscale. These voids cause reduced contact area between the surfaces and result in an insulating layer, thereby inducing a large resistance for heat to flow. To remedy this, thermal interface materials are applied when mating two surfaces. The goal with TIMs is to fill those voids with a thermally conductive material to minimize the resistance for heat to flow from one surface to the next, as shown in **Figure 3**.

Attaching the die to the radiator via a TIM would be the next most direct thermal pathway. However, for the radiator to maximize heat rejection to the cold sky, it is ideally made of a high thermal conductivity material (aluminum, copper, etc.) to ensure a high surface temperature over the entirety of its area. Unfortunately, these high thermal conductivity materials often have large values for their CTE, introducing a mismatch with the lower CTE die. This will introduce high stress to the die and/or TIM, especially under conditions of thermal cycling seen from diurnal variations in space.

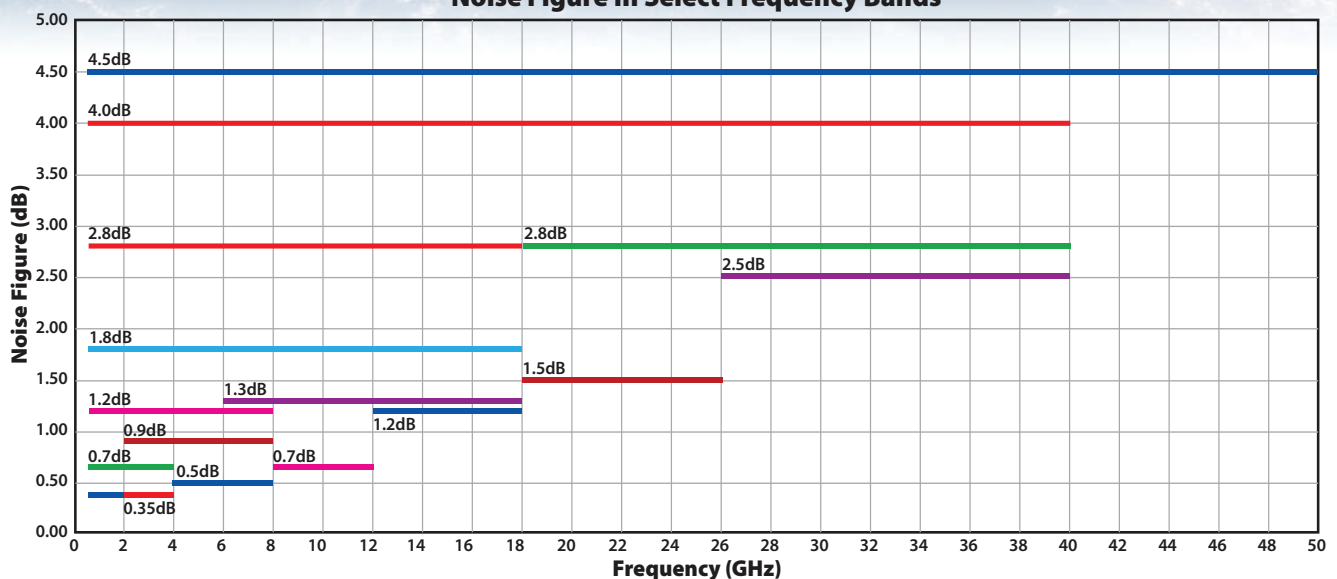
Therefore, the final solution is to attach the die to a CTE matched substrate via a first TIM, and subsequently, attach the substrate to the radiator via a second TIM. The substrate ideally has the highest thermal conductivity possible while matching the CTE of the die, which is typically a tradeoff as most CTE-matched substrate materials (Molybdenum, Tungsten, etc.) have low thermal conductivities. These substrates are made thicker to sustain stresses induced from the CTE mismatch to the high conductivity radiator, thereby relieving stress on the die while also offering some heat spreading as an intermediate step before the high conductivity radiator. Thermal con-



# Has Amplifier Performance or Delivery Stalled Your Program?



Noise Figure In Select Frequency Bands



**B&Z** TECHNOLOGIES  
Innovating to Excel

[www.bnztech.com](http://www.bnztech.com)

Content is copyright protected and provided for personal use only - not for reproduction or retransmission.  
For reprints please contact the Publisher.

**TABLE 1**

**THERMAL CONDUCTIVITY AND COEFFICIENT OF THERMAL EXPANSION (CTE) VALUES OF COMMON MATERIALS.<sup>4</sup>**

Table fill colors correspond to typical materials of layers shown in Figure 2

Type	Material	Thermal Conductivity (W/cm-K)	CTE (ppm/K)
Die	GaN	1.7	3.2
Die	SiC	3.9	2.8
Die	Si	1.3	2.6
Substrate	Copper Tungsten 10%/90% (CuW)	2.0	8.0
Substrate	Copper Molybdenum 30%/70% (CuMoCu)	1.9	7.6
Substrate	Cu-CuMo-Cu 1:4:1 (CPC)	2.2	7.1
Radiator	Copper (Cu)	4.0	17
Radiator	Aluminum (Al)	2.4	23

ductivity and CTE values of common materials in the stackup are shown in **Table 1**.

The drawbacks of this robust solution include three additional thermal resistances: one from the CTE matched substrate and two from the TIMs. The resistance of the substrate is not usually problematic—it is a relatively high thermal conductivity metal material, employed in a

manageable thickness. This typically adds a modest thermal resistance and may even help with initial heat spreading from the die. There are also promising new materials such as aluminum diamond and silver diamond which can be used (thermal conductivities up to 5 to 8 W/cm-K and CTE ~7.5 ppm/K) for even further reduction in resistance through the substrate.<sup>4</sup>

The TIMs, however, often become a bottleneck. Even though TIMs allow much improved conduction between surfaces compared to voids, in general, they are not very conductive. Most TIMs operate around 0.05 W/cm-K, which is a significant drop compared to the substrate and radiator materials over 2 W/cm-K. Even with attempts to enhance the conductivity of TIMs by adding complex metal microbeads or other high conductivity nanoparticles, it is rare to see filler based TIMs exceed 0.1 W/cm-K.

The thermal resistance of a TIM per unit area can be quantified based on its thermal conductivity and thickness. Taking a TIM thickness near 0.1 mm and thermal conductivity near 0.1 W/cm-K:

$$\frac{\Delta T_{TIM}}{\dot{q}_{device}} = (RA)_{TIM} = \frac{L_{TIM}}{k_{TIM}} = \frac{0.01 \text{ cm}}{0.1 \frac{\text{W}}{\text{cm-K}}} = 0.1 \frac{\text{K}}{\text{W/cm}^2}$$

Therefore, for a 50 W/cm<sup>2</sup> die, there is a ~5 K temperature jump

## SATELLITE TESTING

Test & measurement solutions for designing, evaluating and producing latest generation satellite systems.

- Satellite payload testing
- TRM and antenna testing
- Positioning, navigation and GNSS testing
- Ground station and ground terminal testing

More information: [www.rohde-schwarz.com/satellite](http://www.rohde-schwarz.com/satellite)



Visit us at:  
Space Tech Expo 2019  
Germany, Bremen  
Hall 5, Booth C96

**ROHDE & SCHWARZ**

Make ideas real





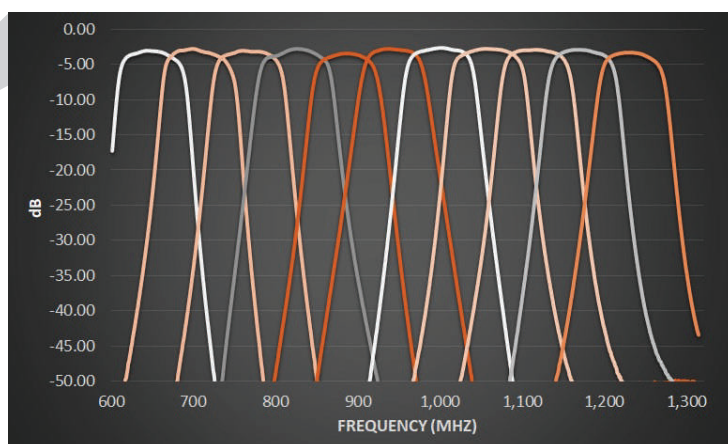


Serving Hi-Rel, Space and Defense, Public Safety, Satellite and Commercial Wireless Markets

## Miniature Ceramic Filter One-Size-Fits-All, UHF to L-Band

Constant Insertion Loss and Skirt Amplitudes (-40 to +85°C)

SAME LOW PROFILE PACKAGE  
.550" X .425" X .122"



**858.450.0468**

[mcv-microwave.com](http://mcv-microwave.com)

[sales@mcv-microwave.com](mailto:sales@mcv-microwave.com)

Locations:

San Diego, CA & Laurel, DE



**Made in USA**

### SPECIALIZING IN

High Performance Ceramic, Cavity, LC Filter

Smallest Footprint and Low profile

Narrow and Wide Bandwidth

Low PIM, 173 dBc @ 2 x 43 dBm

Contiguous Multiplexer

High Quality, On-time Delivery

Volume Production

Revolutionary Signal Integrity Solutions

Frequency from DC to mmWave

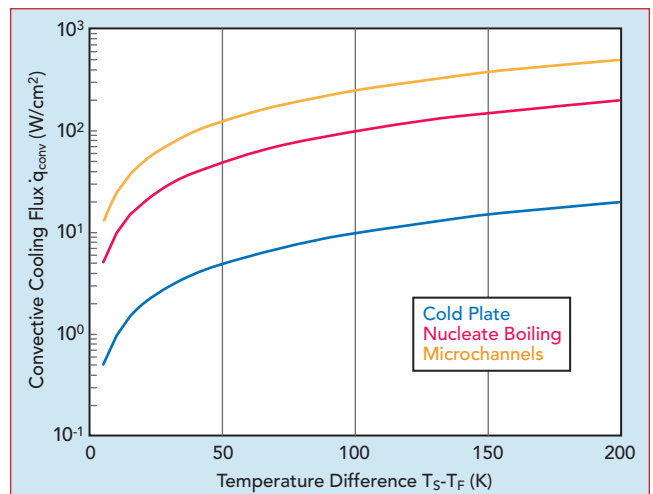
Content is copyright protected and provided for personal use only - not for reproduction or retransmission.  
For reprints please contact the Publisher.

## CoverFeature

across each TIM layer (depending on TIM type and level of spreading in the substrate). This results in needing yet a larger radiator, as the rejection temperature of the radiator cannot match the actual device temperature due to the intermediate resistances. At such power levels, a drop on the order of 10 K through the TIMs is salvageable. However, with upcoming power densities near 1500 W/cm<sup>2</sup>, a drop > 100 K across each TIM layer will be prohibitive.

In addition to the baseline heat transfer limitations at ideal conditions, there are a number of practical considerations which can make working with TIMs challenging. There are a variety of different types of TIMs applied in various circumstances depending on the application, including solders, low melting point alloys, structured carbons and various fillers (pastes, epoxies, adhesives). A few of the common challenges are listed below, some of which are more relevant to certain TIM types than others:<sup>5</sup>

- The interfacial contact resistance between the TIM and the substrate at the molecular level can add additional resistance beyond conduction through the bulk TIM. For example, carbon nanotube (CNT) TIMs have high thermal conductivity and good mechanical compliance, but often suffer from contact resistances at their interfaces with the adjacent substrates. Conceptually, this is similar to the voids that occur when no TIM is used, but at the molecular level.
- Some TIMs are challenging to integrate into the thermal stackup. Special tools, multi-step applica-

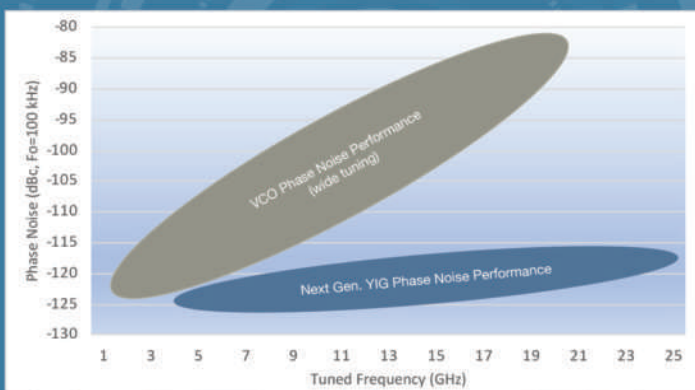


▲ Fig. 4 Semi-log plot showing achievable convective cooling fluxes from standard liquid convection methods.

tion procedures, high temperature/vacuum application conditions and long cure times are examples of things that may be required to achieve the TIM's rated performance.

- Even with perfect application, many TIMs experience outgassing/oxidation, causing dry out and degradation over time. This results in the performance of the electronic device faltering over its lifetime, likely experiencing premature failure. There is preliminary research underway to add nanoscale coatings of higher stability compounds to prevent degradation; this may help mit-

# Next Generation YIG Oscillators & Filters



## Oscillators

- Wide & octave tuning
- SMT package 0.3" high
- Outstanding phase noise



## Filters

- Narrow pass-band
- Tunable 2-5 GHz
- Six stage performance
- SMT package 0.3" high





# SMP Self-Lock connectors

Save installation time,  
gain reliability

Visit us at  
Space Tech  
Bremen, Germany  
**Hall 5, #H91**



Cost-effective, robust and providing dependable connectivity for aerospace, defense and industrial applications, the HUBER+SUHNER SMP Self-Lock flight ready connector is designed to speed installation with a secure locking mechanism that prevents accidental loss of connection. The innovative design provides a visual inspection feature to verify fully mated position, intended to reduce installation and inspection time during systems integration.

**Quick and reliable  
installation**



**MIL-STD qualified for  
space and defense**



**50% lower weight than  
other self-locking options**



[hubersuhner.com/en/solutions/space](https://hubersuhner.com/en/solutions/space)

**HUBER+SUHNER**

Content is copyright protected and provided for personal use only - not for reproduction or retransmission.  
For reprints please contact the Publisher.

igate the longevity concerns but may result in tradeoffs regarding cost and reduced bulk conductivity.

- Complex verification techniques must often be employed to ensure the TIM was applied properly. Because uniform coverage of the TIM over the entire footprint area with no voids is critical to the TIM's functionality, advanced inspection hardware such as scanning acoustic microscopes are

necessary to confirm the quality of each TIM layer in mission critical applications.

Short of TIMs that can match the thermal conductivity of the metals they bind, the conduction approach for heat spreading is starting to fall behind the capability of the devices to which they are being applied. A different technique will be necessary to support devices coming on the near horizon.

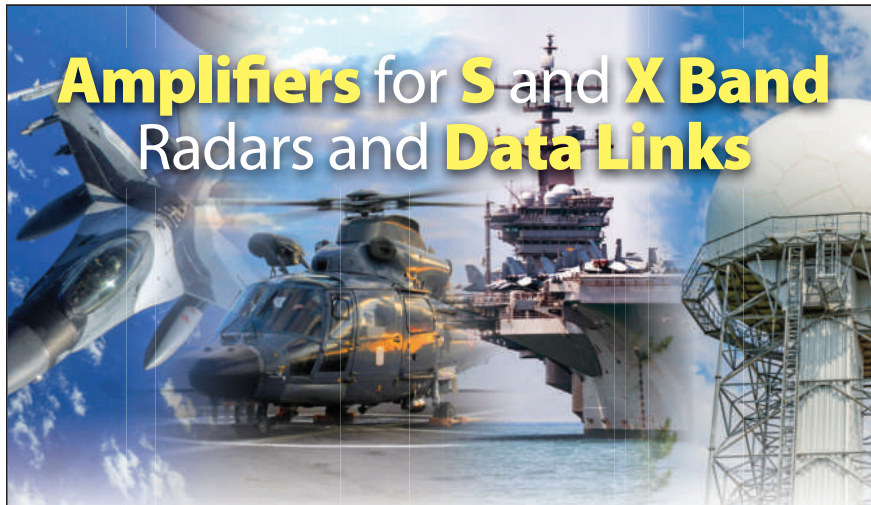
## DIRECT DIE CONVECTIVE COOLING

In seeking alternatives for conduction-based heat spreading methods, convection-based approaches may be promising candidates due to their high cooling capabilities. In terrestrial systems, a variety of convective approaches are employed, such as air natural convection, forced air convection, forced liquid convection and two-phase convection. Given the long desired operational lifetimes and the lack of a surrounding atmosphere in space, closed loop liquid convection approaches are the most likely candidates. Convective cooling flux  $\dot{q}_{\text{conv}}$  is prescribed as:

$$\dot{q}_{\text{conv}} = h(T_S - T_F)$$

In this equation,  $T_S$  is the temperature of the surface in contact with the coolant,  $T_F$  is the fluid coolant temperature, and  $h$  is the heat transfer coefficient, which denotes the cooling flux per degree of temperature difference achievable by a given cooling technique ( $\text{W}/\text{cm}^2\text{-K}$ ). Therefore, the convective cooling flux,  $\dot{q}_{\text{conv}}$ , is linearly proportional to the difference in temperature of the heated surface and the fluid coolant temperature. While in radiative cooling the cold sky is near 3 K, the fluid temperature cannot be taken to be as low in the convective case due to freezing considerations and the inherent thermal resistance of the radiator. **Figure 4** displays what cooling fluxes can be achieved for various common liquid cooling techniques over a range of practical surface-fluid temperature differences ( $T_S - T_F$ ).

The plot shows convective cooling fluxes up to  $500 \text{ W}/\text{cm}^2$  which appears promising for higher power density devices. However, an important distinction must be made as to the applicability of these cooling fluxes. Typical implementations of closed loop liquid cooling are not holistically different from the stack-up shown in Figure 2, for the same reasons of CTE match and high conductivity heat sink requirements. TIMs are still applied between the die and the substrate, and further from the substrate onto a convective cooling module. That is, even if liquid cooling methods can match



## Our Broadest Selection Ever of Gallium Nitride (GaN) Amplifiers

**Model BMC928958-1500/1000**  
1500/1000 Watts, X-Band, Pulsed  
Solid State Power Amplifier Module



**Model BMC318358-1000**  
3.1-3.5 GHz, 1000 Watt, S-Band,  
Solid State Power Amplifier Module



**X-Band Transmitter**  
TWT replacement  
8kW Shown

**4kW to  
16kW  
Available**

- Options for control of phase and amplitude to facilitate integration into high power systems utilizing binary or phased array combining techniques

- Power module options of 1000 & 1500 Watts

**Contact our sales & marketing department today to discuss your exact project needs.**

**Comtech...meeting needs, exceeding expectations.**



**Comtech PST** • 105 Baylis Road, Melville, NY 11747  
Tel: (631) 777-8900 • Fax: (631) 777-8877 • [www.comtechpst.com](http://www.comtechpst.com) • [sales@comtechpst.com](mailto:sales@comtechpst.com)

**Control Components Division** • 417 Boston Street, Topsfield, MA 01983  
Tel: (978) 887-5754 • Fax: (978) 887-7244 • [www.comtechpst.com/hill](http://www.comtechpst.com/hill) • [sales@hilleng.com](mailto:sales@hilleng.com)

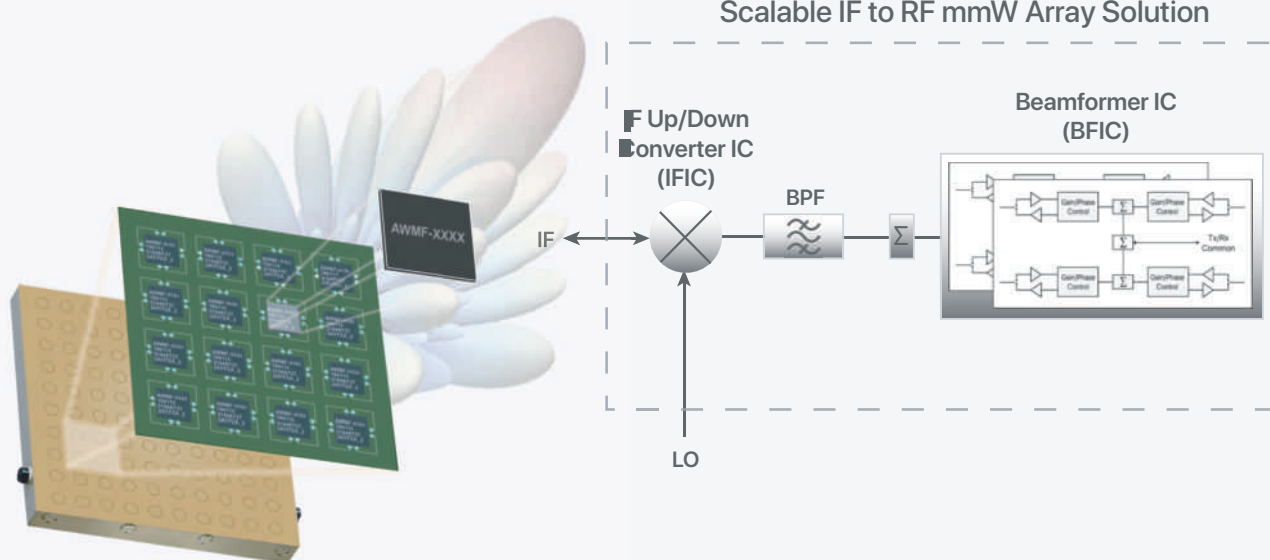


# 5G Active Antenna Design Options

## Complete Optimized RF Signal Chain for mmW Beamforming Arrays

- Single or Dual Polarization ICs in 24/26, 28 and 37/39 GHz bands
- System Level Performance Optimized for 5G
- Advanced Digital Features
- Low Cost Silicon CMOS

### Scalable IF to RF mmW Array Solution



**Base Stations  
Small Cell  
CPE/Repeater**

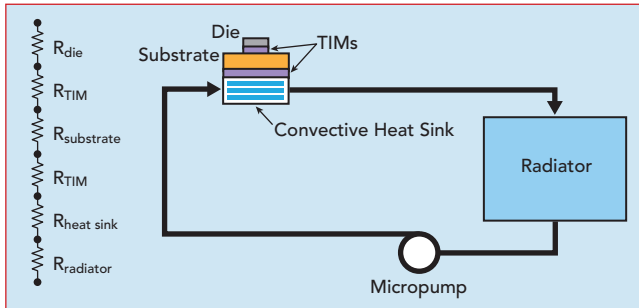
Content is copyright protected and provided for personal use only - not for reproduction or retransmission.

[www.anokiwave.com](http://www.anokiwave.com) [info@anokiwave.com](mailto:info@anokiwave.com)

## CoverFeature

the power density of a device, they often cannot be integrated into the system without using thermal inter-

face materials and suffer from the same thermal resistances as shown in **Figure 5**.



◀ **Fig. 5** Standard convective cooling implementation. The convective heat sink is not integrated at the die level and therefore suffers from the same TIM issues as conductive heat spreading approaches.

However, new methods of applying convection can change the paradigm of the thermal stackup altogether. A unique, new thermal interface concept is via direct die-attach, where the cooling module is configured such that the fluid impacts the die directly. In this methodology, fluid is brought directly to the die surface, which eliminates the TIMs and heat spreader substrates from the thermal pathway. To perform this task, the convective cooling method has two major requirements:

- It must be integrable with the die such that no intermediate affixing or spreading surfaces are required in its integration or operation.
- In order to cool devices without a heat spreader to expand the area, the convective cooling flux must match or exceed the power density of the device itself.

An emerging method called microconvective cooling by JETCOOL Technologies Inc. appears poised to meet these two requirements for cooling advanced GaN SSPAs in space. Microconvective cooling utilizes high momentum microscale fluid jets that impinge upon the heated die surface, causing strong thermal boundary layer suppression and resulting in high heat transfer capability.

This method has produced heat transfer coefficients over  $40 \text{ W/cm}^2\text{-K}$ , which at a 200 K surface to fluid temperature difference, achieves convective cooling fluxes over  $8000 \text{ W/cm}^2$ . The direct die-attach methodology with microconvective cooling has been successfully implemented and experimentally demonstrated cooling devices with power densities over  $5000 \text{ W/cm}^2$  in radar-based applications.<sup>6</sup> A schematic of the thermal stackup for this new technique is shown in **Figure 6**. By directly bringing the fluid in contact with a passivated die surface, multiple TIM layers and heat spreaders can be removed from the thermal stackup, greatly reducing thermal resistance to the radiator in high-power density applications.

As an additional benefit, because the fluid is now directly contacting the die, the cooling module does not need to be made of a thermally conductive material. Therefore, the cooling module can be a closely

HUNGRY FOR SOMETHING DIFFERENT?

*Try one of Lexatys' ~~Antenn~~ Converters!*

*\*not an edible sandwich*

- ▶ Built the way you like it!
- ▶ Pairs well with other ~~meats~~ *wideband receivers*
- ▶ Got a hungry crowd? Full rate manufacturing delivers more than 5 ~~sandwiches~~ *Units* per week

**LEXATYS**  
PRECISION ENGINEERED

Certified ISO9001:2015  
and AS9100D  
Made in USA

www.lexatys.com • P: 302.715.5029 • E: infoMWJ@lexatys.com



# Advance with Cobham



## Advanced Solutions for Air, Land, Sea and Space

Cobham Advanced Solutions designs and manufactures off-the-shelf and customized RF components, assemblies and subassemblies for aerospace, defense, wireless/mobile and fixed broadband, X-ray imaging, medical, industrial, and point of sale markets.

### Cobham Advanced Electronic Solutions

Advance with Cobham at: [www.cobham.com/caes](http://www.cobham.com/caes)

[CAES.BD@cobham.com](mailto:CAES.BD@cobham.com)

**COBHAM**

[cobham.com/caes](http://cobham.com/caes)

2121 Crystal Drive, Suite 625, Arlington, VA 22202  
T: +1 (703) 414 5300 E: [CAES.BD@cobham.com](mailto:CAES.BD@cobham.com)

Content is copyright protected and provided for personal use only - not for reproduction or retransmission.

For reprints please contact the Publisher.

## CoverFeature

matched CTE material, removing the tradeoff between thermal conductivity and CTE mismatch. Further, although the die-attach needs to be robust, it no longer needs to be perfect, as was the case in applying thermal interface materials. The thermal performance of the direct die-attach method is unaffected by the quality of the die-attach, mean-

ing the die-attach method can focus on a strong, robust attachment mechanism instead of a high quality workmanship solution requiring high thermal conductivity, minimal thicknesses and complete, void free coverage.

Of course, the ultimate heat sink will still be via radiation to the cold sky, so there needs to be a fluid

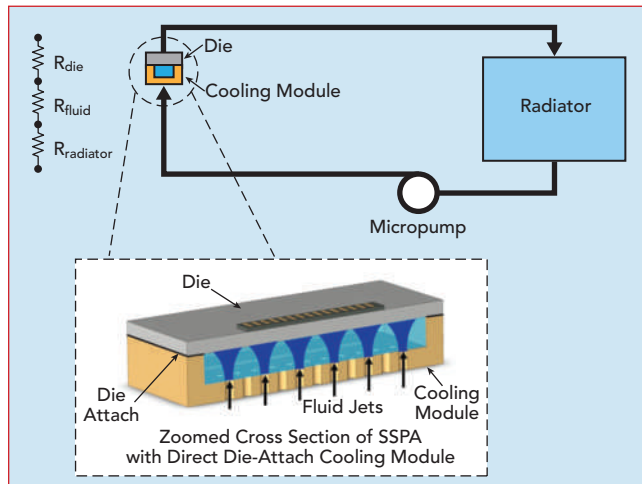
loop containing a pump and method of exchanging heat from the fluid to the radiator. Because the radiative cooling flux limitations still apply regardless of the thermal interface method, a large area radiator will still be required to reject the heat on the radiator side.

Continually advancing developments in 3D printing can be leveraged to produce optimal radiator

designs containing integral cooling channels, allowing seamless integration of fluid cooling loops into the radiator workflow at low size, weight and power (SWaP). As the die level heat rejection has been decoupled from the radiator, this methodology is fully compatible with thermal storage strategies and fits seamlessly with different duty cycles and temperature cycling, with minimal control and input power requirements.

## SUMMARY

With increasing power densities made possible via advanced semiconductor materials, adequate thermal management of devices is becoming increasingly challenging. The traditional method of cooling electronic devices via heat spreading through thermal interface materials and high conductivity heat spreaders is quickly reaching its limits. By employing direct die-attach cooling methodologies with high capability convective techniques, significant reductions in thermal resistance from the die to the radiator can keep devices at safe temperatures. One potential technique involving direct die-attach microconvective cooling via high velocity fluid jets shows promise as an enabling technique to facilitate devices with long lifetimes and low weight, enabling future cost-effective and highly capable space-based missions.■



▲ Fig. 6 Direct die-attach cooling methodology, integrated with ultra-high cooling effectiveness microconvective cooling including a zoomed 3D cross section of the die level cooling approach shown at the top.



## Enabling New Levels of Coverage and Higher Data Rates in Wireless Systems

5G 5G INFRASTRUCTURE



GPS

AUTOMOTIVE



MILITARY

CELLULAR BOOSTERS / DAS



WIFI



WIRELESS AUDIO

**Guerrilla Search™**

*Identify the Optimum Amplifier for Your Application*

www.guerrilla-rf.com • (336) 510-7840 • sales@guerrilla-rf.com



## References

1. J. Y. Tsao et al., "Ultrawide-Bandgap Semiconductors: Research Opportunities and Challenges," *Advanced Electronic Materials*, Vol. 4, No. 1, January 2018, Article No. 1600501.
2. M. LaMarche, "GaN SSPA Technology for Space-Based Applications," *Microwave Journal*, Vol. 62, No. 4, April 2019, pp. 20–28.
3. P. D. T. O'Connor, "Arrhenius and Electronics Reliability," *Quality and Reliability Engineering International*, Vol. 5, No. 4, 1989, pp. 255–255.
4. R. S. Pengelly et al., "A Review of GaN on SiC High Electron-Mobility Power Transistors and MMICs," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 60, No. 6, 2012, pp. 1764–1783.
5. K. M. Razeed et al., "Present and Future Thermal Interface Materials for Electronic Devices," *International Materials Reviews*, Vol. 63, No. 1, 2018, pp. 1–21.
6. S. M. Walsh et al., "Embedded Microjets for Thermal Management of High Power-Density Electronic Devices," *IEEE Transactions on Components, Packaging and Manufacturing Technology*, Vol. 9, No. 2, 2018, pp. 269–278.





AEROSPACE

## Aerospace Products

Whether aviation or spaceflight applications – Rosenberger is a qualified and trusted supplier of connectors and cable assemblies to the aerospace industry. Our aerospace products are designed and manufactured in accordance with ESCC, MIL-PRF 39012, or DIN EN 9100.

[www.rosenberger.com/aerospace](http://www.rosenberger.com/aerospace)

### Product range

- Cable assemblies
- Board-to-Board connections
- Board-to-Cable connections
- SMD types
- PCB connectors

# Rosenberger

# 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

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](http://www.ciaowireless.com) for our complete product offering.







## LM Skunk Works' Project Riot Demonstrates Multi-Domain Operations

**L**ockheed Martin (LM) Skunk Works®, the Missile Defense Agency and the U.S. Air Force successfully connected an F-35, U-2 and a multi-domain ground station in a ground-breaking test demonstrating multi-domain operations and the secure distribution of sensitive information across multiple platforms.

During the demonstration, called Project Riot, an F-35 detected a long-range missile launch with its on-board sensors and shared the information through the U-2 to the air defense commander on the ground, enabling the commander to quickly make the decision to target the threat. This next-level connectivity reduces the data-to-decision timeline from minutes to seconds, which is critical in fighting today's adversaries and advanced threats.



**Project Riot**  
(Source: Lockheed Martin)

In partnership with the Air Force Life Cycle Management Center at Hanscom Air Force Base in Massachusetts, and the Missile Defense Agency, Skunk Works' Project Riot builds on a series of open systems architecture demonstrations proving how incremental increases in capability can be rapidly fielded to enable a connected network across air, ground, sea, space and cyber domains.

"This demonstration continues our commitment to provide complete battlespace awareness and seamless interoperability to enable multi-domain operations," said John Clark, vice president of ISR & UAS at Lockheed Martin Skunk Works. "With its long-range standoff sensors, on-board processing and ability to operate in and around contested environments, the U-2 continues to play a critical role in demonstrating new capabilities today, while transforming operations for tomorrow's battlespace."

Leveraging common industry standards to drive down cost and shorten schedules, the team achieved four mission critical data points in less than four months:

- Demonstrated the ability to leverage F-35 sensor data for missile defense.
- Leveraged the modernized U-2's extensive payload capacity, modular design and open architecture to provide beyond line of sight communications between the F-35 and a multi-domain ground station.
- Established two new data paths to securely transmit 5<sup>th</sup> generation sensor data at multiple levels of security to the warfighter, enabling a multi-domain net-

work of legacy and 5<sup>th</sup> generation systems.

- Disseminated 5<sup>th</sup> generation data using the Air Force's Universal Command and Control Interface and Open Mission Systems standards for faster capability deployment and seamless connection between systems.

"The F-35, with its advanced sensors and connectivity, is able to gather and seamlessly share critical information enabling the joint force to be safer and more effective," said Greg Ulmer, Lockheed Martin vice president and general manager for the F-35 program. "No other fighter jet in the world has this capability—and this test was a critical step on the path to unlocking its full potential for multi-domain operations."

This demonstration builds on successful flight tests completed since 2013 that establish the foundation for a distributed, systems-of-systems architecture in the not-too-distant future.

## MBDA Working on New SPEAR-EW Electronic Warfare Weapon

**T**he compact size of the SPEAR family allows four weapons to be carried internally in each of the two internal weapons bays of the F-35, or three per station on the Eurofighter Typhoon. MBDA has been awarded a contract to demonstrate SPEAR-EW, a new electronic warfare (EW) version of the SPEAR weapon system family on order for the Royal Air Force (RAF).

SPEAR-EW is being developed by MBDA in partnership with Leonardo to complete a wide range of suppression of enemy air defense (SEAD) missions, under a Technical Demonstration Program (TDP) contract awarded by Defence Equipment & Support (DE&S). SPEAR-EW will integrate a cutting-edge miniaturized EW payload from Leonardo, which will act as a stand-in jammer to greatly increase the survivability of RAF aircraft and suppress enemy air defenses, acting as a significant force multiplier.

Defense Minister Anne-Marie Trevelyan said: "These state-of-the-art electronic jammers will confuse our adversaries and keep our pilots safer than ever in the air. Paired with the devastating power of precision Brimstone and Meteor missiles, our world-class F-35 and Typhoon jets will continue to rule the skies in the years to come."

Mike Mew, MBDA UK director of sales and business development, said: "SPEAR-EW is a revolutionary new capability that, alongside the existing SPEAR3 weapon, marks a fundamental change in the ability of friendly air forces to conduct their missions despite the presence of enemy air defenses. Our vision for SPEAR is to create a swarm of networked weapons able to saturate and neutralize the most sophisticated air defenses."



SPEAR-EW (Source: MBDA)

"Adding SPEAR-EW to the family alongside our existing SPEAR strike missile demonstrates the principle of introducing complementary variants to the SPEAR family that will add significant capability and force multiplication

without the need to repeat platform integration. We have an exciting roadmap of variants, spirals and technology insertions in the pipeline to further enhance the family as we move forward."

The core of SPEAR-EW's payload is Leonardo's advanced, miniaturized digital RF memory (DRFM) technology, which offers an advanced and future-proof electronic jamming and deception capability. It will complement the SPEAR network enabled miniature cruise missile, which is designed to precisely engage long range, mobile, fleeting and relocatable targets in all weather, day or night, in the presence of countermeasures, obscurants and camouflage, while ensuring a safe stand-off range

between the aircraft and enemy air defenses.

Powered by a turbojet engine the SPEAR missile offers over double the range, and a far more flexible operating envelope, when compared to a conventional glide weapon. SPEAR-EW utilizes this long endurance through its capacity to be launched at enhanced stand-off ranges and loiter while carrying out its jamming mission.

The compact size of the SPEAR family allows four weapons to be carried internally in each of the two internal weapon bays of the F-35, or three per station on the Eurofighter Typhoon. SPEAR-EW will keep the same form and fit as the baseline SPEAR to enable a single integration pathway and launcher solution. The SPEAR family complements MBDA's wider portfolio of strike weapons, filling the gap between the large and very-long range Storm Shadow deep strike missile and the highly accurate Brimstone close-air-support missile.

The SPEAR weapons system recently completed a set of ground trials and fit-checks of a loaded three-pack SPEAR launcher onto a Eurofighter Typhoon fighter aircraft. The work was undertaken by a joint engineering team from MBDA, BAE Systems and the Ministry of Defence's DE&S, and took place at BAE Systems' flight test site in Warton, Lancashire.

## M WAVE DESIGN CORPORATION

### M WAVE DESIGN CORPORATION

designs and manufactures in the U.S. and provides a broad range of custom passive microwave hardware from 100MHz to 50GHz.



### M WAVE DESIGN CORPORATION

is ISO9001 certified, ITAR compliant and provides superior customer service. **We are proud to celebrate our past 30 years and to support you in the next 30.**

## SUPPLYING HIGH-PERFORMANCE PASSIVE RF & MICROWAVE COMPONENTS SINCE 1988



### HIGH-POWER WAVEGUIDE ISOLATORS

S band through R band waveguide isolators Covering S-Band (2 GHz) through U-Band (50 GHz); our Isolator product line provides state of the art power handling and insertion loss. With available options of; high power terminations, multiple interface flanges, miniature versions, and integrated Forward and Reverse power monitoring.



### COAXIAL CIRCULATORS

Our full line of Coaxial circulators from 100 MHz to 40 GHz feature high power ratings (> 100 Kw), and low insertion loss (< 0.10 dB) depending upon the application. With many connector interfaces & package options, we can provide a solution to your needs.

M WAVE DESIGN CORPORATION | (805) 499-8825 | WWW.MWAVEDESIGN.COM | INFO@MWAVEDESIGN.COM



# Reactel, Incorporated

Reacting First to All Your Filter Needs.

## A SHEER DESCENT INTO THE NOISE

### High Performance Notch Filters

- High Q
- Bandwidths as low as 0.5%
- Frequency range up to 20 GHz
- Power levels up to 1000 W



Reactel manufactures a variety of notch filters suitable for most any application. Utilizing Discrete Component, Ceramic, Cavity, Waveguide or Microstrip technologies, we can create a unit which has extremely low pass band loss, contain up to 16 sections, and can have connectors or surface mount launch options. Contact us with your requirement and let us show you how sharp our notch filters can be.

8031 Cessna Avenue • Gaithersburg, Maryland 20879 • Phone: (301) 519-3660 • Fax: (301) 519-2447  
For general inquiries, please email [reactel@reactel.com](mailto:reactel@reactel.com) • <http://twitter.com/reacteljim> • Go online to [www.reactel.com](http://www.reactel.com) to download your Reactel catalog today.

Content is copyright protected and provided for personal use only - not for reproduction or retransmission.

For reprints please contact the Publisher.



reactel

@reacteljim

# MMIC SPLITTER/COMBINERS

up to **43.5 GHz**



## THE WIDEST SURFACE MOUNT BANDWIDTHS IN THE INDUSTRY!

- ▶ Power handling up to 2.5W
- ▶ Insertion loss, 1.1 dB typ.
- ▶ Isolation, 20 dB



[www.minicircuits.com](http://www.minicircuits.com) (718) 934-4500 [sales@minicircuits.com](mailto:sales@minicircuits.com)



596\_Rev A\_P

Content is copyright protected and provided for personal use only - not for reproduction or retransmission.  
For reprints please contact the Publisher.





## Pulsed RF Power Semiconductor Device Markets Will Exceed \$300M by 2024



While their association with consumer spending fuels the volatility of many global electronics markets, pulsed RF power device markets are supported by quite different priorities. Pulsed RF power transmitters generate tremendous amounts of power in small bursts that are useful for radar, airborne collision avoidance systems and military IFF equipment.

"Ampleon, NXP and Wolfspeed are among the RF power semiconductor manufacturers on a quest to find markets unrelated to the mobile wireless infrastructure," says Lance Wilson, research director, ABI Research. "Device prices in wireless infrastructure are flattening out and more profitable areas are being searched for."

The airborne transportation safety market and military market are both experiencing solid growth in pulsed RF power device shipments. The avionics transponder and air navigation market segments are also seeing growth, which is further lifted by the overall worldwide air traffic control upgrade. Intrinsically less "optional" than many consumer markets, these segments are therefore less sensitive to economic upheavals than consumer-driven markets, although they are not totally immune to the macro economy.

There are several vendors who are already focused to varying extents on the pulsed high-power marketplace, including Integra Technologies, Microsemi, Qorvo and again Wolfspeed, and several semiconductor manufacturers are attempting to enter this market space. Pulsed RF power device markets are becoming very competitive technologically: GaN devices are vying for market share along with the more established Si and GaAs-based technologies. Many companies are rushing into these markets and all vendors are developing GaN products of some form. Qorvo, Sumitomo Electric Device Innovations and Wolfspeed are already producing GaN devices in volume. ABI Research speculates that there may not be the market size to support them all.

## Future of 5G Lies in Enterprise, Not Consumer Market



In its new whitepaper, "The Five Myths of 5G," ABI Research finds that use cases across different vertical markets, such as industrial automation, cloud gaming, private LTE and smart transport systems, will become pervasive, and will unlock new opportunities for mobile service providers (MSP) along the way.

However, this bright and lucrative future may be hampered by 5G's past. That is because early 5G imple-

mentations were designed to fit the needs of the consumer market first. "The intent was to allow MSPs and their technology suppliers to harvest the low-hanging revenues of the consumer space before gradually extending the network's capabilities to meet the needs of the enterprise," explains Stuart Carlaw, CRO, ABI Research. Unfortunately, this process has proven a lot more costly and time consuming than initially thought. In fact, ABI Research estimates that if MSPs rely solely on consumers to justify their investments in 5G rollouts, it could take up to 15 years to realize any ROI.

MSPs have every hope that 5G will help them reduce the cost per gigabyte of bandwidth and improve ARPU compared to existing access technologies. But, 5G is expected to be much more expensive compared to its predecessors. This is due to the network densification it requires and the addition of a great number of new functions, both at the core and the access sides of the network. As a result, the implementation and democratization of 5G will come at very high costs, notably operational expenditures, which are already increasing at a very alarming pace.

Industrial telcos could potentially become the new cash cow for securing 5G ROI. Indeed, 5G is positioned to be a major component of enterprise digital transformation and a reliable wireless communication platform that could create trillions in economic value across many enterprise verticals. However, as things stand now, implementations for enterprise applications are far from optimized. As a result, MSPs have been unable to accelerate the enterprise digital transformation and unlock new business opportunities in this environment. "Network architecture flexibility, interoperability with legacy operation processes, cost effectiveness, network determinism, security and reliability will be equally important for the enterprise as providing bigger pipes—a value proposition that has long resonated well within the consumer market but is unlikely to attract industrial verticals," Carlaw points out.

The idea of building a 5G network capable of accommodating the needs of multiple markets and industries is a big fantasy of MSPs. "The reality is that the implementation approaches that have been designed for the consumer market will not adequately serve enterprise verticals. The "build it and they will come" approach is simply unrealistic and is one of the myths holding back the 5G market," concludes Carlaw.

## Future of AI in Industrial Manufacturing



Artificial intelligence (AI) has been touted as a powerful technology that will revolutionize the industrial manufacturing space. The sentiment has its validity, but the reality is extremely complex. AI in industrial manufacturing is a collection of various use cases at different phases of manufacturing, such as genera-

For More  
Information

Visit [mwjournal.com](http://mwjournal.com) for more commercial market news.

## CommercialMarket

tive design in product development, production forecasting in inventory management and machine vision, defect inspection, production optimization and predictive maintenance in the production phase.

"Since manufacturers are not comfortable having their data transferred to a public cloud, nearly all industrial AI training and inference workloads happen at the edge, namely on device, gateways and on-premise servers," says Lian Jye Su, principal analyst, ABI Research. To facilitate this, AI chipset manufacturers and server vendors have designed AI-enabled servers specifically for industrial manufacturing, and more and more industrial infrastructure is equipped with AI software or dedicated AI chipsets to perform AI inference.

Despite this, the implementation of AI has not been as seamless as was expected. Among the use cases, predictive maintenance and equipment monitoring are the most commercially implemented so far, due to the maturity of associated AI models. The total installed base for these two use cases alone is expected to reach 9.8 million and 6.7 million, respectively, by 2024. It is important to note that many AI-enabled industrial devices support multiple use cases on the same device due to advancements in AI chipsets. Key startups such as Uptake, SparkCognition, FogHorn and Falconry are introducing cloud- and edge-based solutions that monitor the overall performance of industrial manufacturing assets and process flows.

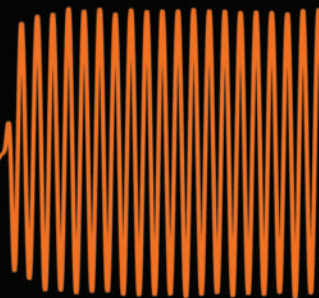
Another use case currently gaining momentum is defect inspection, with the total installed base expected to grow from 300,000 in 2019 to over 3.7 million by 2024. This is extremely popular in electronic and semiconductor manufacturing, where major manufacturers have been partnering with AI chipset vendors and software providers to develop AI-based machine vision to perform surface, leak and component-level defect detection, microparticle detection, geometric measurement and classification. Conventional machine vision technology remains popular in the manufacturing factory, due to its proven repeatability, reliability and stability; however, the emergence of deep learning technologies opens up expanded capabilities and flexibility. These algorithms can pick up unexpected product abnormalities or defects, go beyond existing issues and uncover valuable new insights for manufacturers.

At the moment, manufacturers are facing enormous competition in building and training in-house data science teams for AI implementation. Most AI talent prefers to work with webscale giants or AI startups, making talent acquisition a challenging task for industrial manufacturers. "As such, they are left with one viable option, which consists of partnering with other players in the AI ecosystem. The diversity in AI use cases necessitates the creation of partnerships," Su concludes.

# CHECK YOUR PULSE



← 50ns →



## THE **HSM** SERIES RF SYNTHESIZERS HAVE A VERY HEALTHY PULSE GENERATION

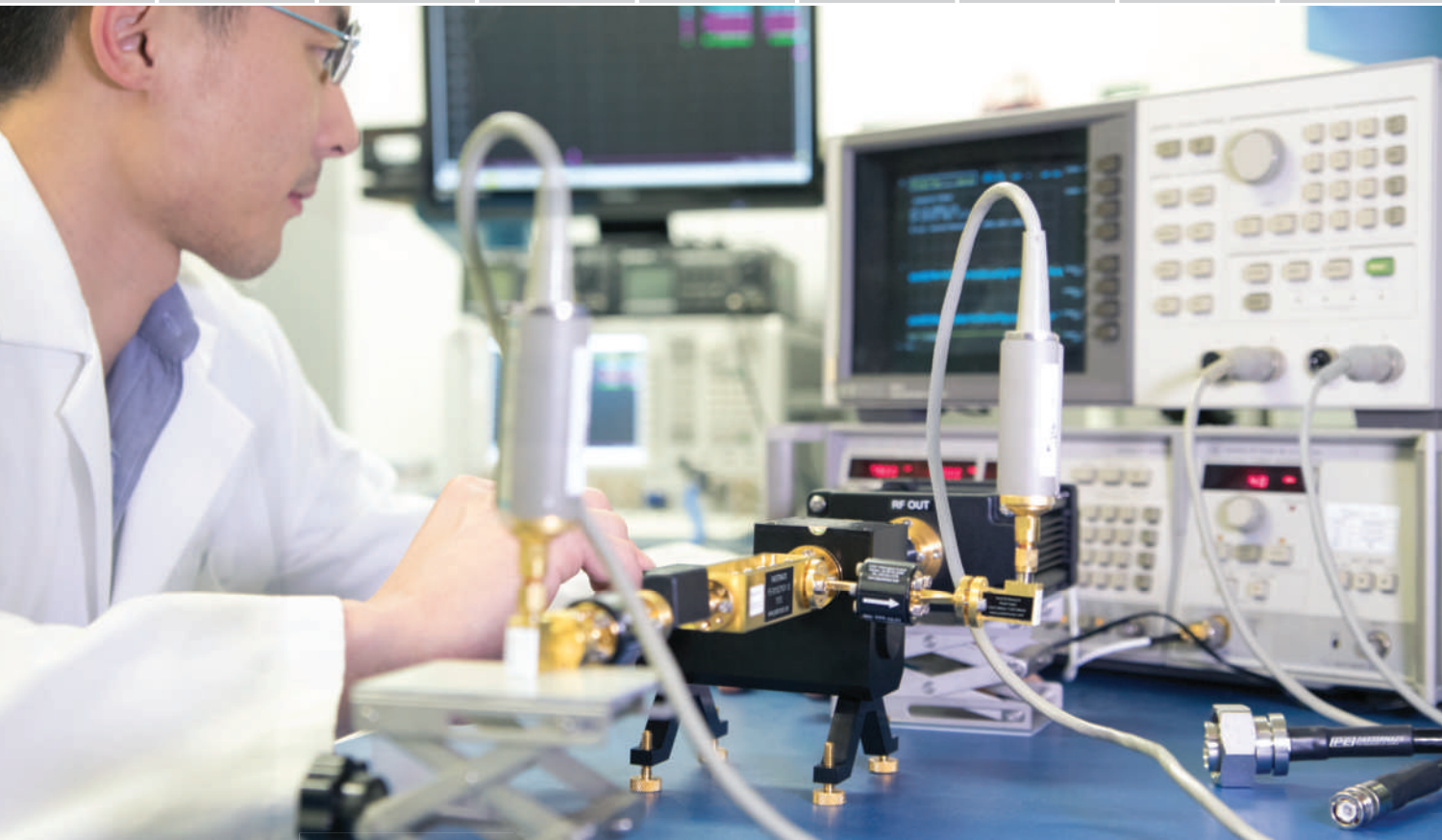
 **holzworth**  
instrumentation

phone: +1.303.325.3473

[www.holzworth.com](http://www.holzworth.com)



# *You Engineer the Future. We'll Supply the Components... Today!*



**Largest Selection ✓ Same-Day Shipping ✓ Expert Technical Support ✓**

Armed with the world's largest selection of in-stock, ready to ship RF components, and the brains to back them up, Pasternack Applications Engineers stand ready to troubleshoot your technical issues and think creatively to deliver solutions for all your RF project needs. Whether you've hit a design snag, you're looking for a hard to find part or simply need it by tomorrow, our Applications Engineers are at your service. Call or visit us at [pasternack.com](http://pasternack.com) to learn more.

**866.727.8376**  
**Pasternack.com**

**PE PASTERNAK**  
an INFINIT<sup>®</sup> brand

Content is copyright protected and provided for personal use only - not for reproduction or retransmission.  
For reprints please contact the Publisher.



## Around the Circuit

Barbara Walsh, Multimedia Staff Editor

### MERGERS & ACQUISITIONS

**Qorvo** announced that it has acquired **Cavendish Kinetics Inc.**, a provider of high-performance RF MEMS technology for antenna tuning applications. The Cavendish Kinetics team will continue to advance RF MEMS technology for applications across Qorvo's product lines and transition the technology into high-volume manufacturing for mobile devices and other markets. Qorvo has been a lead strategic investor in San Jose-based Cavendish Kinetics since 2015.

**dB Control** has acquired 100 percent of the stock of **TTT-Cubed Inc.** The acquisition of TTT will add high-end frequency locked oscillators, integrated digital control units, RF sources, detectors and controllers to dB Control's existing line of high-power TWT amplifiers (TWTA), microwave power modules (MPM) and high-voltage power supplies (HVPS) for defense and aerospace applications. Specific financial terms and details of the all-cash transaction were not disclosed. TTT will operate as part of dB Control and will relocate to its facility in Fremont, Calif. dB Control is part of HEICO's Electronic Technologies Group. Most of TTT's team will remain with the business post-closing.

**TPC Wire & Cable Corp.**, a portfolio company of Audax Private Equity, announced that it has completed the acquisition of **Cicoil LLC**. Based in Valencia, Calif., Cicoil's technology is widely used in mission critical applications within industries such as mil-aero, semiconductor and medical. This acquisition allows TPC to expand its market reach and strengthen its portfolio of specialized wire and cable solutions to sophisticated, high cost-of-failure environments.

**Avnet** has signed an agreement to acquire **Witekio**, formerly known as Adeneo Embedded. Witekio is a privately held company with expertise in software and embedded systems that helps developers overcome the technical challenges and complexity of developing IoT solutions. This announcement furthers Avnet's end-to-end IoT strategy by adding more capabilities and expertise in embedded software, edge computing and security, specifically from hardware to the cloud. This acquisition also underscores Avnet's commitment to helping companies reduce the time, cost and complexities of successfully bringing IoT products to market.

**SAGE Millimeter** will become **Eravant** in March 2020, a change that renews the company's commitment to the RF engineer. The new brand emphasizes building customer relationships on top of a long legacy of mmWave expertise. Read more about the upcoming transformation at [www.sagemillimeter.com](http://www.sagemillimeter.com).

### COLLABORATIONS

**Keysight Technologies Inc.** announced an extended collaboration with **Qualcomm Technologies Inc.**, a wholly owned subsidiary of Qualcomm Inc., to accelerate commercialization of Dynamic Spectrum Sharing (DSS) technology, which will enable mobile operators to quickly and cost-effectively roll out 5G new radio (NR) services. The collaboration utilizes Keysight's 5G network emulation solutions to accelerate the development of Qualcomm® Snapdragon™ 5G Modem-RF System to support DSS, an emerging technology that is part of the 3GPP Release 15. By 2020, mobile operators are expected to start implementing DSS on existing 4G LTE base stations, speeding nationwide deployments of 5G services.

**Modelithics Inc.** has expanded its partnership with **Mini-Circuits** to develop high-accuracy simulation models for Mini-Circuits' packaged reflectionless filters, power splitter/combiners and LTCC transformers. The substrate-selectable models for the filters are measured/ modeled to 40 GHz with the splitters and transformers measured/ modeled to 30 GHz. Ten new reflectionless filter models, six power splitter/combiner models and four LTCC transformer models are currently available for free individual download for Keysight Technologies' ADS from the Mini-Circuits MVP page on the Modelithics website. These models will also be available in the Modelithics COMPLETE Library and the Modelithics mmWave & 5G Library in future library releases.

**Aptiv** and **Hyundai Motor Group** have announced that they are forming an autonomous driving joint venture, which will advance the design, development and commercialization of SAE Level 4 and 5 autonomous technologies. The joint venture will start testing fully driverless systems next year, with a plan to have a production-ready autonomous driving platform available for robotaxi providers, fleet operators and automotive manufacturers in 2022. As part of the agreement, Aptiv and Hyundai Motor Group will each have a 50 percent ownership stake in the joint venture, which is valued at \$4 billion.

Mobile operators, enterprises, cities and other key IoT market players gain access to a wealth of new IoT use cases by combining two unlicensed connectivity technologies, as illustrated in a new white paper released by the **Wireless Broadband Alliance (WBA)** and the **LoRa Alliance®**. Developed with input from mobile carriers, telecom equipment manufacturers and advocates of both connectivity technologies, "Wi-Fi & LoRaWAN Deployment Synergies: Expanding Addressable Use Cases For The Internet of Things" illustrates new business opportunities that are created when Wi-Fi networks that are traditionally built to support critical IoT are merged with LoRaWAN networks that are traditionally built to support low data rate massive IoT applications.

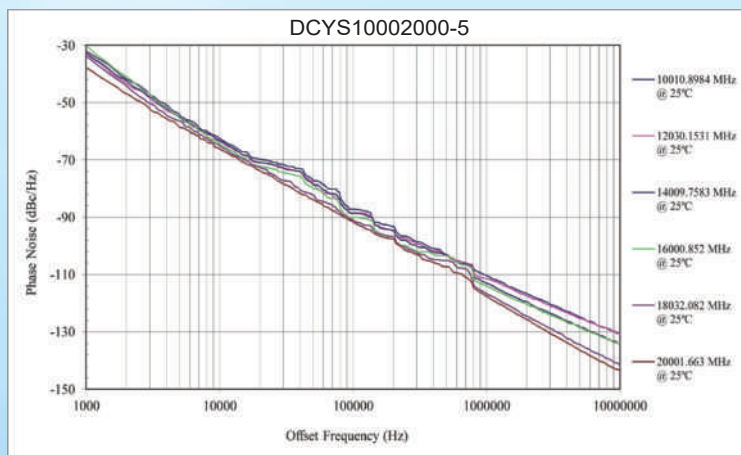
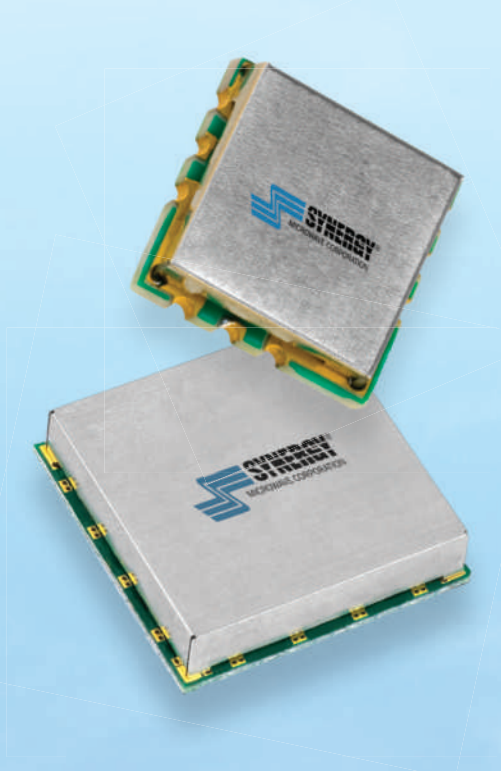
For More  
Information

For up-to-date news briefs, visit [mwjournal.com](http://mwjournal.com)



# L to K Band Ultra-Wideband Voltage Controlled Oscillators

Model Number	Frequency	Phase Noise @ 10 kHz offset	Phase Noise @ 100 kHz offset	Tuning Voltage	Output Power
	( GHz )	( dBc/Hz )	( dBc/Hz )	( V )	( dBm )
DCO100200-5	1 - 2	-95	-117	0 - 24	+1
DCYS100200-12	1 - 2	-105	-125	0 - 28	+4
DCO200400-5	2 - 4	-90	-110	0 - 18	-2
DCYS200400P-5	2 - 4	-93	-115	0 - 18	0
DCO300600-5	3 - 6	-75	-104	0 - 16	-3
DCYS300600P-5	3 - 6	-78	-109	0 - 16	+2
DCO400800-5	4 - 8	-75	-98	0 - 15	-4
DCO5001000-5	5 - 10	-80	-106	0 - 18	-2
DCYS6001200-5	6 - 12	-70	-94	0 - 15	> +10
DCYS8001600-5	8 - 16	-68	-93	0 - 15	> +10
DCYS10002000-5	10 - 20	-65	-91	0 - 18	> +10



## Features:

- > Superior Phase Noise
- > High Output Power
- > Small Size Surface Mount Package
- > Vcc: 5 volts
- > Future models up to 30 GHz

## Talk To Us About Your Custom Requirements.



Phone: (973) 881-8800 | Fax: (973) 881-8361

E-mail: [sales@synergymwave.com](mailto:sales@synergymwave.com) | Web: [www.synergymwave.com](http://www.synergymwave.com)

Mail: 201 McLean Boulevard, Paterson, NJ 07504

Content is copyright protected and provided for personal use only - not for reproduction or retransmission.

For reprints please contact the Publisher.

## Around the Circuit

**Leonardo** announced that they have been selected by the U.K.'s **Royal Air Force (RAF)** to support the next stage of their research and development program. The study will explore the current threat posed by hostile drones and how this is likely to evolve in future, as well as evaluating a range of technologies that could form a future RAF counter-drone capability. The program is expected to last three years and will commence in early 2020. The threat of rogue drones has been well-publicized in recent months, with small, affordable aircraft widely-available on the open market.

**Trimble** and **Qualcomm Technologies** have announced plans to work together to produce precise-positioning solutions for automotive applications. Trimble will work with Qualcomm Technologies to integrate its RTX technology with Qualcomm Snapdragon Automotive 4G and 5G platforms to deliver a highly accurate positioning solution essential for maintaining absolute in-lane positioning. This new solution will accelerate the adoption of road-level navigation and emergency services applications, as well as satisfy requirements for developing advanced driver-assistance systems (ADAS) and autonomous driving solutions. Qualcomm Technologies' Snapdragon 4G and 5G Automotive platforms feature integrated multi-frequency and multi-constellation high-precision GNSS technology.

**Diamond Microwave Limited (DML)** has announced a licensing deal with **Diamond Microwave Devices Ltd. (DMD)**. The deal allows DML to continue growing the commercial base for DMD's compact high-power microwave amplifiers, and to take DMD's proprietary technology into new markets. DML's commercial partnership with DMD will focus on the exploitation of the DMD amplifier technology in the global marketplace for high-power microwave systems. DML is a new U.K. company specializing in compact GaN-based high-power amplifiers, designed for application in demanding areas such as radar, communications and EW.

## ACHIEVEMENTS

**Rohde & Schwarz** has carried out 5G NR protocol conformance testing with the new R&S CMX500 radio communication tester. Global Certification Forum GCF has accepted these 41 test cases, defined by 3GPP, in different FR1 and LTE band combinations. By adding the R&S CMX500 to their existing LTE test setups, accredited test houses, cell phone and chipset manufacturers get a smooth upgrade path from LTE to 5G NR testing. The 5G NR protocol conformance tests were presented at GCF's Conformance Agreement Group (CAG) meeting 59. These tests are vital for next-generation mobile communication technology.

**WIN Semiconductors** has celebrated its 20<sup>th</sup> foundation day. Since the start of production from its first factory in Taoyuan, Taiwan, WIN has grown faster than the com-

pound semiconductor market and now operates three highly automated wafer fabs, employing nearly 3,000 people. The company has achieved sustained business growth through continuous investment in leading-edge III-V technologies, timely expansion of production capacity and flexible efficient manufacturing. These core competencies provide a competitive advantage for WIN's customers across a broad set of applications and end markets. Key to WIN's 20-year record of success is a portfolio of III-V technologies supporting diverse functions from RF and mmWave frequencies through light-wave applications.

Since its launch in 2017, **GlobalFoundries'** 45RFSOI platform has generated more than \$1 billion in design win revenue from more than 20 clients for 5G/mmWave mobile and wireless infrastructure applications. GlobalFoundries (GF) announced this milestone at its annual Global Technology Conference (GTC). GF has a long history of high frequency RF wafer and module test development and implementation. GF's engagement model offers clients comprehensive package design, thermal and electrical modeling services in partnership with leading outsourced assembly and test companies. For example, GF's turnkey testing and packaging services can perform accurate phase measurements between antenna ports for phased array multi-RF channel designs of more than 64 antenna elements.

**BAE Systems** has completed the first phase of a program to transfer short-gate GaN MMIC technology developed by the U.S. Air Force to its Advanced Microwave Products (AMP) center in Nashua, N.H.; the effort now moves to the second phase. At the end of phase 2, this process will be available to designers through an open foundry service, making the technology available for government programs. The short-gate GaN process provides high efficiency and broad bandwidth that can be integrated into next-generation radar, EW and communications systems.

**MCV Technologies Inc. DBA MCV Microwave** announced that their Delaware facility, MCV Microwave East has passed the rigorous standards for quality management systems to earn certification to ISO standard 9001:2015 for the design and manufacture of advanced dielectric resonators, RF microwave filters, antennas, connectors and cable assemblies. MCV Microwave was also successfully audited and certified to the AS9100 Rev D standard. This certification is necessary for all aerospace industry suppliers to meet the International Aerospace Quality Group (IAQG) quality initiatives.

## CONTRACTS

**Raytheon** will upgrade the Ballistic Missile Early Warning System (BMEWS) and Precision Acquisition Vehicle Entry Phased Array Warning System (PAVE PAWS) radars with solid-state T/R modules, receiving an **Air Force** contract worth \$495 million, if fully exercised. Raytheon will produce 148 qualification units during the first phase of the program, followed by production of some 40,000 T/R modules for all five radar sites, including spares, out of band replacements at the Fylingdales Royal Air Force Station and sensitivity improvement units.





## Compound Semiconductor Solutions for Tomorrow's Networks

**WIN's Advanced Technology Platforms Enable Multifunction ICs and Single Chip Front-Ends...Through mm-Wave**

### **Sub 6GHz MIMO**

- | GaN PA, MMIC or hybrid
- | Integrated passives on 150mm GaAs
- | Low Fmin GaAs pHEMT

### **High Bandwidth Fronthaul/Backhaul**

- | 0.1µm pHEMT with monolithic PIN and Schottky diode
- | Power and LN to 100GHz and above

### **Satellite Tx/Rx Arrays**

- | X/Ku/Ka power and low noise platforms with ESD protection and advanced assembly options
- | PA, LNA and mm-Wave PIN *on one chip*
- | Bump or hot via assembly

### **Contact WIN for more information.**

With unrivaled manufacturing scale and a broad portfolio of compound semiconductor solutions, WIN gets you there...FAST.

North America: [ieliashevich@use.winfoundry.com](mailto:ieliashevich@use.winfoundry.com)

Europe: [harryq@use.winfoundry.com](mailto:harryq@use.winfoundry.com)

[winfoundry.com/contactus](http://winfoundry.com/contactus)

[info@winfoundry.com](mailto:info@winfoundry.com)

Content is copyright protected and provided for personal use only - not for reproduction or retransmission.

For reprints please contact the Publisher.

## Around the Circuit

**Lockheed Martin** has been awarded a \$281 million contract by the **U.S. Army** to develop the Sentinel A4 radar system. Sentinel A4 is a high performance modification of the Sentinel A3 (AN/MPQ-64A3) air and missile defense radar that will provide updates to improve the existing Sentinel capability against cruise missiles, UASs, rotary-wing and fixed-wing threats. The new Sentinel A4 radar will provide improved surveillance, detection and classification capabilities against current and emerging aerial threats in order to protect Army maneuver formations and high-value static assets like command and control nodes, tactical assembly areas and geopolitical centers.

**CACI International Inc.** announced that it has been awarded a five-year task order, with a ceiling value of nearly \$70 million, to assist the **U.S. Navy** in assessing its weapons and integrated combat systems. Under this task order, CACI will provide engineering and information technology expertise, including combat systems acquisition readiness and performance assessment support, to the Naval Surface Warfare Center (NSWC) Corona Division. Awarded under the SeaPort-e contract vehicle, the task order represents continuing work for CACI. In the past year, as part of the Navy's "Clear Decks Initiative," CACI experts at the warfare center have made critical safety improvements to protect personnel during weapons testing.

Minneapolis-based **Humanetics Corp.** has entered into a \$6 million cooperative research agreement with the **U.S. DoD**, under the Joint Warfighter Medical Research Program. The agreement funds advanced development of BIO 301, a unique orally administered medical countermeasure to protect warfighters from lethal radiation exposure. BIO 301 is being developed as a prophylactic medical countermeasure that can be taken by warfighters prior to potential exposure to lethal radiation. Currently, no drugs are approved by FDA for this use. The drug may also benefit first responders who must be prepared to address domestic events related to nuclear accidents or terrorism.

**Comtech Telecommunications** has received a contract valued at more than \$1.8 million for Ku- and Ka-Band high-power traveling wave tube amplifiers (TWTAs) for a trailer-based SATCOM ground system. Comtech Telecommunications received the contract through its subsidiary, **Comtech Xicom Technology**, a part of Comtech's Commercial Solutions segment. The order was received during the fourth quarter of fiscal 2019 and the amplifiers are expected to ship during the 2020 fiscal year. Comtech Xicom Technology has been providing long-term support for important military communications missions with its rugged and high performance TWTAs.

**ZAF Energy Systems Inc.** announced that it has been awarded a \$1.4 million contract for a nickel-zinc (NiZn) battery system to support the **U.S. Air Force** Intercon-

# AMPLIFIER TECHNOLOGY



*for Radar  
Electronic Warfare  
and Communications*

CW	SKU	Frequency (MHz)	Pout(Watt)	Size
	2203	1 - 30	1000	R5U
	2162	20 - 1000	1000	R5U
	2180	1000 - 2500	2000	R8U
	2170	1000 - 3000	1000	R5U
	2223	600 - 6000	150	R5U
	2215	1900 - 6000	200	R5U

Pulse	SKU	Frequency (MHz)	Pout(Watt)	Size
	2210	150 - 450	12000 Pulse 20%	R19U
	2211	2700 - 3100	1200 Pulse 20%	R3U
	2217	5200 - 5900	8000 Pulse 20%	R17U
	2225	5200 - 5900	90000 Pulse 20%	R34Ux2
	2221	9000 - 10200	8000 Pulse 20%	R17U

### 48 VDC module family

SKU	Frequency (MHz)	Pout(Watt)	Size
1213	1 - 30	50 W LDMOS	7.0 x 4.0 x 1.12"
1193	20 - 1000	100 W LDMOS	
1211	500 - 2500	100 W GaN	
1199	1000 - 3000	100 W GaN	
1219	600 - 6000	30 W GaN	
1197	2000 - 6000	50 W GaN	





**EMPOWER'S AMPLIFIERS** are tactically deployed and operating on multiple levels in support of DoD missions




[www.EmpowerRF.com](http://www.EmpowerRF.com)

1(310)412-8100



**EMPOWER**  
RF SYSTEMS, INC.



## Ultra-Broadband Components

Designed and manufactured in the USA to meet the demands of all of your test and measurement applications.

**Custom solutions available.**



## Broadband RF Baluns

500 kHz to 67+ GHz (-3 dB)

Industry-best amplitude and phase match

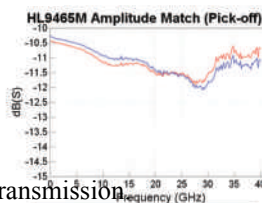
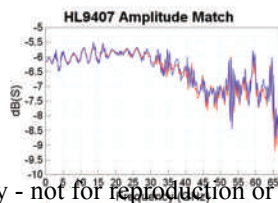
Available with SMA, 2.92 mm, 2.4 mm, or 1.85 mm connectors

## DC Pick-Off Tees

DC to 50+ GHz

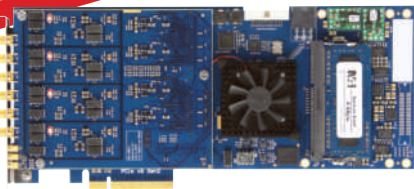
Available in matched pairs ( $\pm 0.1$  dB typ.)

Available with SMA, 2.92 mm, 2.4 mm, or 1.85 mm connectors





## 130 different digitizers

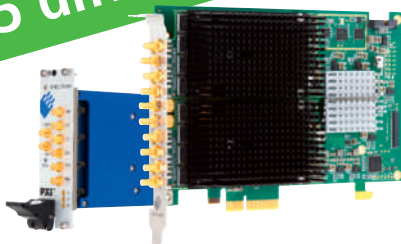


- 5 MS/s to 5 GS/s speed
- 1 to 8 channels (cards)
- 2 to 48 channels (Ethernet-units)



## 45 different AWGs

Now available with  $\pm 12$  VOLT Output level



- 40 MS/s to 1.25 GS/s speed
- 1 to 8 channels (cards)
- 2 to 48 channels (Ethernet-units)



**SPECTRUM**  
INSTRUMENTATION

Perfect fit – modular designed solutions

US: Phone (201) 562 1999 | Asia / Europe: Phone +49 (4102) 695 60

[www.spectrum-instrumentation.com](http://www.spectrum-instrumentation.com)

## Around the Circuit

tinental Ballistic Missile (ICBM) Ground Facility. ZAF's NiZn batteries are helping to meet customer demands for powerful, cost-effective and environmentally-friendly battery solutions and are uniquely positioned to respond quickly to power outages. The project, which will run for 24 months, is expected to result in a prototype stationary energy storage system capable of powering the silo's systems in the event of a power outage, and until standby generators can be started.

### PEOPLE



▲ Dr. William Conley

**Mercury Systems Inc.** announced that **William Conley, Ph.D.**, will join the company as senior vice president and CTO, effective immediately. In this role, Conley will direct and accelerate Mercury's technology vision and leadership in innovative technology that provides state-of-the-art solutions to the aerospace and defense industry. Conley brings to Mercury a wealth of experience in research, development, weapon system acquisition, technology road mapping, strategy development & implementation and government. Prior to joining Mercury, he was a member of the Federal Senior Executive Service, serving as the director for EW in the Office of the Secretary of Defense.



▲ Philip Knights

**RFMW** announced that **Philip Knights** has joined their organization as business development manager—RF Power products, reporting directly to Mike Carroll, VP—Global Sales. Knights joins RFMW with more than 35 years' experience in RF design engineering, new business development, sales management and marketing. Knights has a demonstrated history of strong

customer relationships, revenue growth and interpersonal skills in complex RF and microwave oriented organizations. Prior to RFMW, Knights served as an RF design engineer in multiple Plessey Semiconductor divisions and Powerwave UK, where he successfully authored and delivered white papers at well attended symposiums.



▲ Thomas Marzetta

**NYU WIRELESS** has appointed **Thomas Marzetta**—the originator of antenna technology that is enabling vast improvements in wireless communications—as director of the world-recognized research center at the NYU Tandon School of Engineering. He succeeds another researcher credited with seminal findings that underpin 5G: Theodore (Ted) S. Rappaport, who founded the research center in 2012. Before Rappaport published his 2013 paper, "Millimeter Wave Mobile Communications for 5G Cellular: It Will



5G

GaN Hybrid Power Amplifier Module

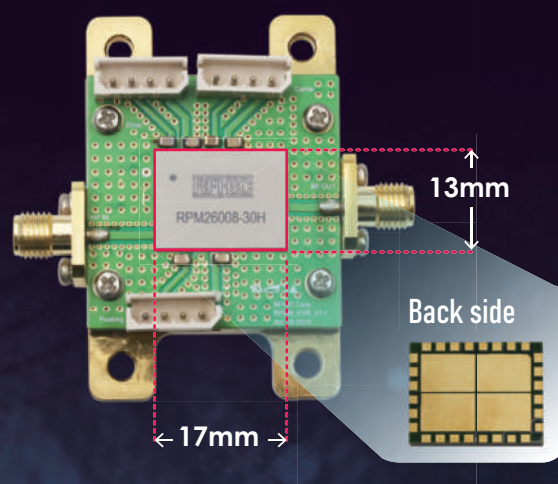
# RPM26008-30H

RFHIC's RPM26008-30H is a fully matched 2-stage hybrid doherty GaN power amplifier module designed for 5G Massive MIMO and Small Cell applications. This state of the art module requires minimal external components and offers a much smaller footprint.

- 2-Stage Doherty Amplifier
- Drain Efficiency **46%** @ Pavg 8W
- 50 Ohm RF I/O Matched
- 13 x 17 x 2.6 mm SMD Package
- Smaller Form Factor

# 8W

## 2515-2685MHz



#rfhic or RFHIC Corporation

**RFHIC**  
www.rfhic.comTo learn more contact us at [rfsales@rfhic.com](mailto:rfsales@rfhic.com)

## 5G Sub-6 GHz

### HPA, GaN 15W-25W, Internally Matched 4.4-5.0 GHz

Part No.	Vd (V)	Id (mA)	S21 (dB)	Psat (dBm)	PAE (%)	PKG
AGN0542D	28	150	32	42	53	Die
AGN0544D		300	30	44	50	

### LNA, 3.3-5.0 GHz

Part No.	Vd (V)	Id (mA)	S21 (dB) @ GHz	OIP3 (dBm) @ GHz	NF (dB) @ GHz	PKG
AHL5220T8	5	65	16 15 5.0	36 35 5.0	0.56 0.59 5.0	TDFN8
AHL5318T8		17	15.8 13.6 35	35 34 0.59	0.65 0.95	

NF measured at connector to connector

### Bypass LNA, 5.2-5.9 GHz

Part No.	Mode	Vd (V)	Id (mA)	S21 (dB) @ GHz	OIP3 (dBm) @ GHz	NF (dB) @ GHz	PKG
ABL5616T8	Amp Bypass	5	25 2.5	17.2 -3.5	15.8 -3.5	28 28 1.5	1.5 TDFN8

### Gain Block, 50-6000 MHz

Part No.	Vd (V)	Id (mA)	S21 (dB) @ MHz			OIP3 (dBm) @ MHz			NF (dB) @ MHz			PKG
			50	950	6000	50	950	6000	50	950	6000	
AHB361256	3	24	14	15.5	11.9	24.5	21.5	1.4	2.3		SOT363	
AHB3612T8		23	15	12	23.5	21.2	1.6	2.5		TDFN8		
AHB5614T8	5	80	14.3	14.6	14.4	36.7	37.5	30.2	2.5	2.5	3.4	
AHB561459			14.3	14.7	16.5	37.8	32.7	25.3	2.5	2.5	4.1	SOT89
AHB5616T8			15.9	16.3	15	37.2	37.7	27.3	1.9	1.9	2.9	TDFN8

### SPDT, 5-6000 MHz

Part No.	Vd (V)	Insertion Loss (dB) @ MHz	IP1dB (dBm)	IP3 (dBm) @ 1 GHz	Swit. Time (ns)	Ctrl. Bit	PKG
AHX5408D56	3	0.3 0.8	4000 6000	33 58	160	Dual	SOT363
AHX5408S56		0.3 0.8	-	33	450	Single	TDFN6
AHX5607DT6		0.3 0.5	0.7	32	160	Dual	
AHX5607ST6		0.3 0.5	0.7		450	Single	

## GPS High Precision

### Ultra Low Noise, 1.1-1.7 GHz

Part No.	Vd (V)	Id (mA)	Freq. (GHz)	Gain (dB)	NF (dB)	OIP3 (dBm)	PKG
AHL5216T8	1.8 / 3.3	10 / 35	1.1 1.7	19.5 / 21.9 15.5 / 18.2	0.45 / 0.32	18 / 29	TDFN8

NF measured at connector to connector

## CATV 5-1800 MHz

Type	Freq. (MHz)	Part No.
Single	5-700	ABU1513 (6 V), ABU1516 (5 V), ABU1519 (5 V), ASL380 (5 V), ASL390 (5 V), ASL580 (8 V), ASL590 (8 V), ASW220 (5 V)
	700-1800	ABU1513 (6 V), ABU1516 (5 V), ABU1519 (5 V), ABB1513 (6 V), ABB1516 (5 V), ABB1519 (5 V)
Push-pull	5-700	ASL39D2 (6.5 V), ASL331 (5 V)
	700-1800	ASL39D2 (6.5 V), ABB31D2 (5 V / 8 V), ABB31D7 (5 V / 8 V), ABB31D9 (5 V / 8 V)

### High Power, 50-1200 MHz

Part No.	Vd (V)	Id (mA)	S21 (dB)	Pout (dBm)	Test Condition	PKG	Remark
AGN922	24	485	22.5	118	@ CSO, CTB = 67, 60 dBc, CENELEC-42 ch flat	QFN 6x6	GaN Power Doubler
				115	BER < 1E-9, 138 ch 22 dB tilt, 256 QAM		
ABB817	12	365	17.3	111	@ CSO, CTB = 62, 61 dBc, 8 dB tilt, CENELEC-42 ch	TSSOP24	GaAs Push-pull
				109	BER < 1E-9, 138 ch 12 dB tilt, 256 QAM		

### Optical TIA with AGC, 50-1200 MHz

Part No.	Vd (V)	Id (mA)	S21 (dB)	Gain Flat. (dB)	EIN (pA/rtHz)	Po (dBm)	CSO (dBc)	CTB (dB)	MER (dB)	PKG
ASA307	5	260	33	±1	3.5	83	64	64	40	QFN 4x4

## HPA GaAs, GaN

### MMICs, Internally Matched

Part No.	Freq. (GHz)	S21 (dB)	Psat (dBm)	OIP3 (dBm)	PAE (%)	Vd (V)	Idq (mA)	PKG
ABX0618Q	6-18	23	31	36	22	7	700	QFN 6x6
ASX1037HG	8.5-10.5	22	36	42	39	7	1300	10-lead Flange
ASX1037		15	37	42	38			
AGN0942Q	7.7-10.7	23	41	-	38	24	200	QFN 6x6
AGN0944Q		18	43	-	32			QFN 6x6
AGN0944M	8.5-10	19	44	-	35	24	300	10-lead Flange
AGN0944D		19	44	-	38			Die
AGN1440	12.5-14.5	24	41	-	28	24	300	10-lead Flange
ASX1437	13.5-14.5	21	37	42	32	7	1300	10-lead Flange

### GaN HP Transistor @ 30-3000 MHz

Part No.	Freq. (MHz)	S21 (dB)	P3dB (W)	Eff. (%) @ P3dB	Vd (V)	Idq (mA)	PKG
AGT0510	30	21	10	66	28	60	QFN 6x6
	500	18.4	10.7	55			
AGT0515	30	20.4	10.5	67	28	55	
	500	18.3	20.8	62			

## Around the Circuit

Work," few experts acknowledged the possibilities of tapping that underutilized spectrum.

The **SOI Industry Consortium** has announced awards to two luminaries of the semiconductor industry: **Jim Cable**, chairman and CTO of **pSemi**, a Murata Company, and **Herb Huang**, CEO and GM of **Ningbo Semiconductor**. Both received awards for their contributions to the advancement of RF-SOI, a leading technology used extensively in chips for cellular communications. The awards were given during a gala following the SOI Consortium's annual RF-SOI Workshop in Shanghai. The Workshop, which was attended by over 450 industry leaders from China and around the world, is the largest of the SOI Consortium events.

## REP APPOINTMENTS

**PPM Systems**, the U.K.-based division of **Pulse Power and Measurement Ltd. (PPM)**, will now be the seller of RF products from U.S. manufacturer **Corry Micronics**, in the U.K. The new partnership will see the addition of Corry Micronics' RF amplifiers, RF switches, switch matrices, RF and microwave sub-systems added to PPM's existing portfolio of RF over fibre systems, antennas, software-defined radio (SDR) and more. Corry Micronics has its roots in the U.S. defence and security industries, the same sectors PPM has always been deeply committed to in the U.K. Its components are an ideal complement to PPM's suite of engineering services and products.

## PLACES

**Cree Inc.** announced plans to establish a SiC corridor on the East Coast of the U.S., with the creation of the world's largest SiC fabrication facility. The company will build a brand new, state-of-the-art, automotive-qualified 200 mm power and RF wafer fabrication facility in Marcy, N.Y., complemented by its mega materials factory expansion currently underway at its Durham headquarters. The new fabrication facility, part of a previously announced project to dramatically increase capacity for its Wolfspeed SiC and GaN business, will be a bigger, highly-automated factory with greater output capability.

**Altum RF** announced the opening of its application support and sales office in Dallas, Texas. The office space is ideally situated in the Telecom Corridor, a technology business center in Richardson, Texas, an inner-suburb of Dallas. Altum RF is an international company, with strategic partnerships and office locations that span the globe.





# Proven Technology Radar Components For Militaries World-wide

- Solid State Power Amplifiers
- Transmitters
- Integrated Microwave Assemblies
- Control Components
- Receiver Protectors
- TWTs
- Magnetrons
- Klystrons



**Contact the radar experts at CPI  
to upgrade your radar system today at  
[BMDMarketing@cpii.com](mailto:BMDMarketing@cpii.com)**

# Compact, Low Loss Switched Filter Bank Using MEMS Switches

Ian Burke

Menlo Microsystems Inc., Irvine, Calif.

Purna Subedi

3H Communications Systems Inc., Irvine, Calif.

*RF MEMS switches combine extremely low loss and high power-handling in a unique SP4T configuration, which enables the creation of miniaturized and very high performance switched filter banks (SFB).*

**S**FBs are becoming more and more common for both commercial and military applications with the proliferation of communications frequency bands and the deployment of more frequency-agile radios. Traditional SFBs that use semiconductor devices as the switching element to select discrete filters are increasingly preferred over their electromechanical counterparts. In some applications, however, the additional losses associated with semiconductor switches is prohibitive. This is problematic when considering that at least two switches are required, at both the input and output of the filter bank, which can drive losses from switching alone to 3 to 4 dB—or higher depending on the number of filter selections and the frequency range of operation. Such losses can create significant challenges for radio designers, especially in high-power applications where 3 dB corresponds to a significant amount of power dissipation (i.e., heat) that must be managed. Recently, RF MEMS switches have become available that combine extremely low loss and high power-handling capability in a unique SP4T configuration. This enables the creation of miniaturized and high performance SFBs. This article explores the underlying technology, design approach and resulting performance.

## THE GROWING NEED

RF filters are some of the most mission critical components in any wireless communications system. Smaller and lighter weight RF filters are desired to meet the demand for smaller and more capable mobile wireless communication devices whether they are used in handheld radios such as cell phones; inside a drone, an airplane, a satellite; or even on mountaintop cell towers.

The degree of rejection needed from a filter is unique to each radio, whether it is to suppress spurs or mitigate interference. This creates the need for custom filters. The significant advantages of SFBs have resulted in their widespread use in diverse applications such as radar, electronic warfare, communications and test and measurement. SFBs combine switches and filters in a single module, where a switch at the input is followed by a filter for each channel and followed by a switch at the output (see **Figure 1**).

SFBs have significant benefits compared to approaches in which discrete switches and filters are used. The most obvious is less board space and the ease of using a single integrated module. The modules contain all or most of the components required to perform the switching function, including a microcontroller, power management and amplifiers (if required).

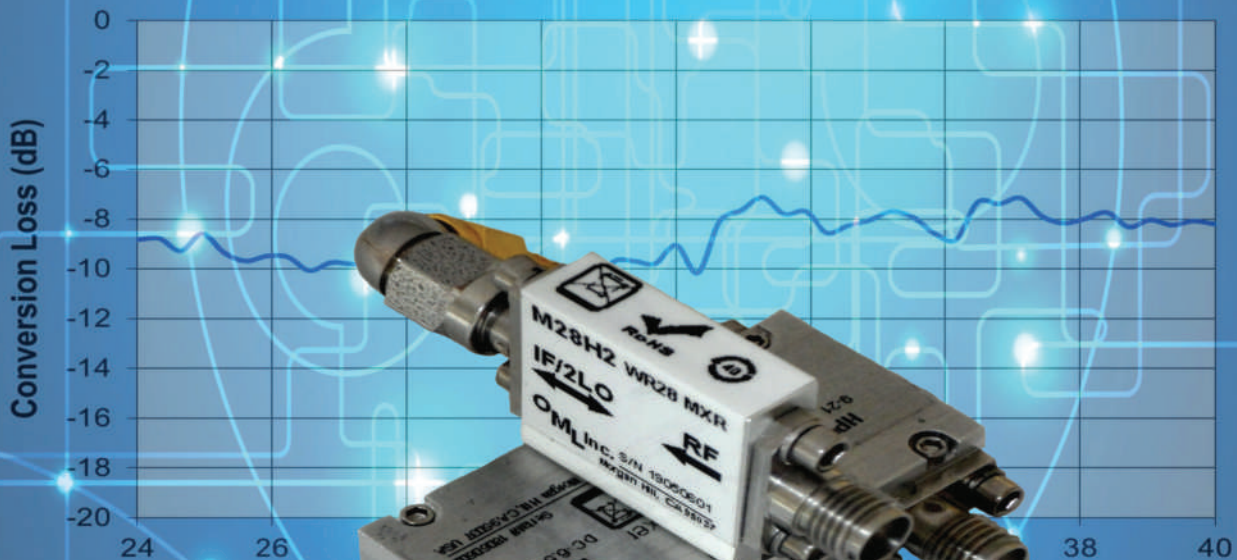


# 24 - 40 GHz Sub-Harmonic Pumped Mixer

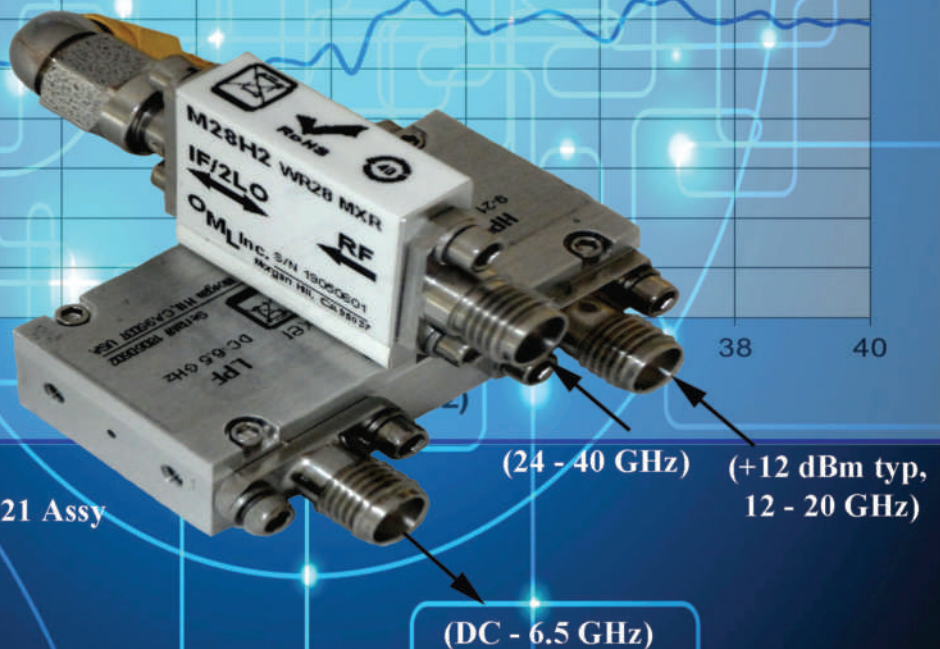
Ideal for testing and validating 5G solutions.



Typical M28H2KS Mixer Conversion Loss  
(LO = 11.5 - 19.5 GHz; IF = 1.0 GHz)



M28H2KS/ DPL921 Assy



Innovation in Millimeter Wave Solutions

[www.omlinc.com](http://www.omlinc.com)

(408) 779-2698

Content is copyright protected and provided for personal use only - not for reproduction or retransmission.  
For reprints please contact the Publisher.



An SFB also eliminates circuit transitions, which enables more precise impedance matching and lower insertion loss. Because the channels are internal to the module, better rejection and isolation are achieved. Any filter topology can be used based on the requirements of the application, including rejection, insertion loss and power handling.

In general, whether in the receive (Rx) or transmit (Tx) path, a key performance metric is insertion loss. To limit out-of-band interference, in receive, the SFB will usually be situated before any low noise amplifier; insertion loss from the SFB will contribute directly to the Rx system noise figure. In transmit, the SFB will be situated between the power

amplifier (PA) and antenna to limit spurious and other interference from being radiated. Low insertion loss and high linearity are key to system performance; insertion loss determines radiated power, and linearity determines interference levels and receiver sensitivity. An example of a switched filter bank application is shown in **Figure 2**.

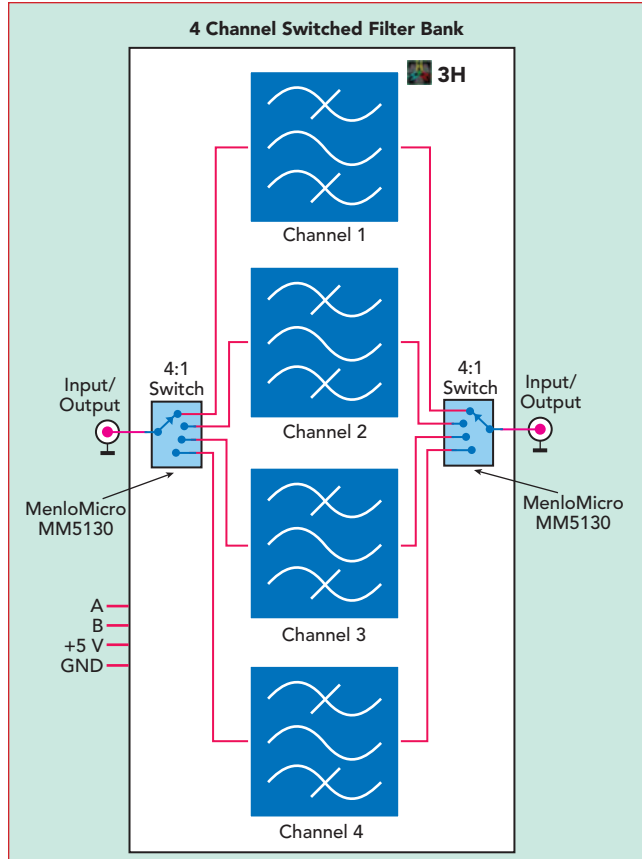
## RF MEMS SFB DESIGN

The four-channel blocking SFB shown in **Figure 3** uses two RF MEMS SP4T switches from Menlo Microsystems (MM5130) and four bandpass filters manufactured

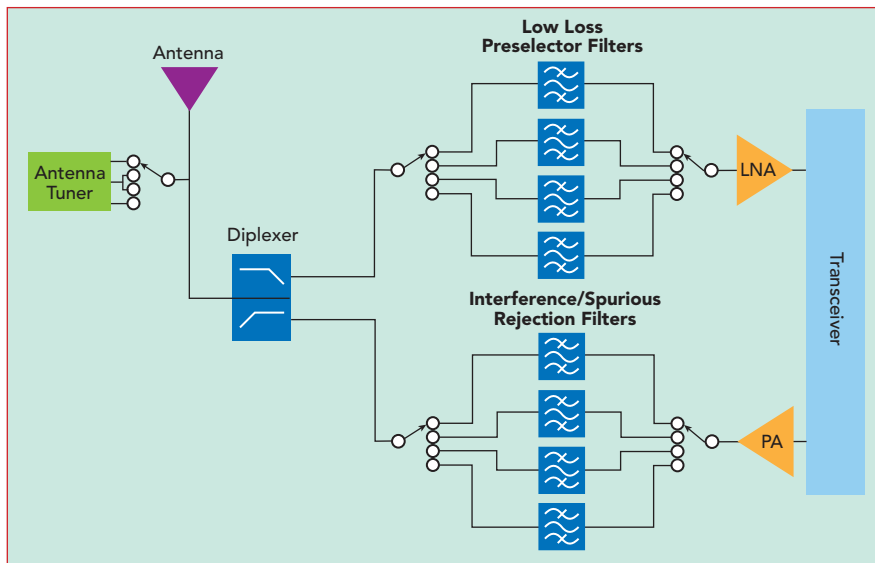
by 3H Communications Systems. The SFB contains all the components required to provide the drive voltages to turn on the switches, as well as a programmable microcontroller to control switching via either TTL or a PC application using USB control. The SFB measures 2.5 in. × 2.5 in. × 0.81 in. without connectors and weighs 6.5 oz. The specifications for the SFB are shown in **Table 1**.

The RF MEMS switches are activated via electrostatic force, requiring a high-voltage source for switching. The gate bias of the switch is set at 0 VDC, which places the metal cantilever beam in a non-deflected (off) state. Thus, the path between RF input and output is isolated with an air gap, similar to a traditional mechanical relay. When the gate is set to its actuation voltage of +88 V, the electrostatic force between the gate and cantilever beam is strong enough to cause it to deflect downward, forming a connection with the contact and closing the switch. This is the deflected (on) state. For the purpose of this design, the +88 V for both SP4T switches is supplied by an Analog Devices LT3482 step-up DC/DC converter that can provide up to 90 VDC output with about 2 mA of current (see **Figure 4**). Since the switches are electrostatic, requiring only nanoamps of current to operate, an entire switch matrix can be biased with a single boost circuit.

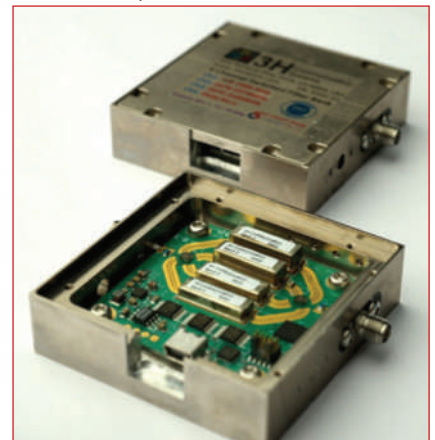
The output current of the LT3482 is converted to a filtered voltage through a fixed load resistor and bypass capacitor that is stable over the temperature range of the SFB. A Microchip HV513 8-channel high-



▲ **Fig. 1** Block diagram of a 4-channel switched filter bank.



▲ **Fig. 2** Switched filter bank use case.



▲ **Fig. 3** Four-channel switched filter bank with four lumped element filters and two SP4T MEMS switches.





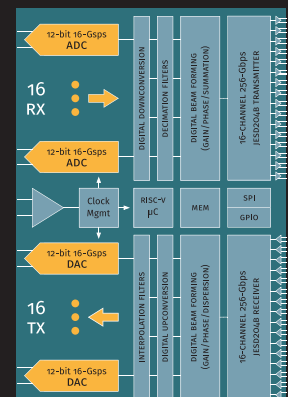
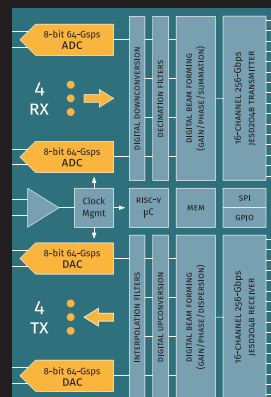
# ENABLING THE 5G REVOLUTION

Our communication networks are in upheaval as the demand for ever greater data bandwidth has exhausted our current systems. New software defined radio systems leveraging our unique **Antenna Processor Units** promise to drive the next generation of communications.

## FULL SPECTRUM CONVERSION™ ANTENNA PROCESSORS

F1000 APU

F800 APU



for further inquiries contact [sales@iqanalog.com](mailto:sales@iqanalog.com)

4x4 Transceiver  
32-GHz Addressable Bandwidth

16x16 Transceiver  
8-GHz Addressable Bandwidth

Content is copyright protected and provided for personal use only - not for reproduction or retransmission.

For reprints please contact the Publisher.

## HIGH POWER LIMITERS

LOW FREQUENCY BROAD BAND

# 100 WATT CW

10MHz - 3000 MHz



- Frequency range down to very low frequency (10 MHz).
- Available single unit covering 10 Mhz to 3 GHz (LS00130P100A).
- Low insertion loss and VSWR.
- 100 Watt CW and 1000 Watt Peak (1 Microsec pulse width ) power handling capability.
- Built-in DC Block @ input and output.
- Hermetically Sealed Module.

### Typical Performance @ + 25 Deg. C

Model	Freq Range <sup>1</sup> (MHz)	Max <sup>2</sup> Insertion Loss (dB)	Max <sup>2</sup> VSWR	Max <sup>2</sup> Input CW (Watts)
LS00105P100A	10 - 500	0.4	1.3:1	100
LS00110P100A	10 - 1000	0.6	1.5:1	100
LS00120P100A	10 - 2000	0.8	1.7:1	100
LS00130P100A	10 - 3000	1.0	2:1	100

**Note 1.** Insertion Loss and VSWR tested at -10 dBm.

**Note 2.** Power rating derated to 20% @ +125 Deg. C.

**Note 3.** Leakage slightly higher at frequencies below 100 MHz.

Other Products: Detectors, Amplifiers, Switches, Comb Generators, Impulse Generators, Multipliers, Integrated Subassemblies

Please call for Detailed Brochures



RoHS Compliant

Made in USA

ISO 9001-2015 Certified



155 Baytech Drive, San Jose, CA 95134  
Tel: (408) 941-8399 . Fax: (408) 941-8388  
Email: Info@herotek.com  
Website: www.herotek.com  
Visa/Mastercard Accepted

## Technical Feature

**TABLE 1**

**RF MEMS-BASED SFB SPECIFICATIONS**

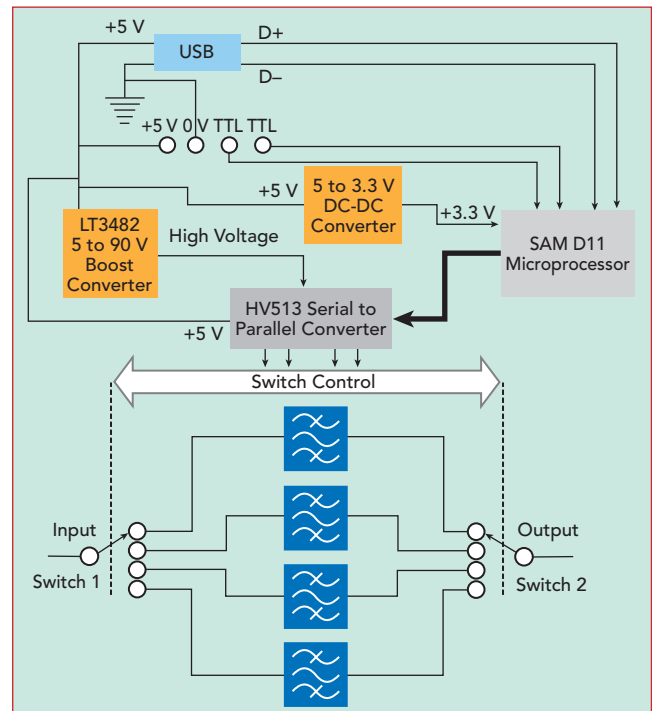
Specification	1	2	3	4
Band	1	2	3	4
Frequency Band (MHz)	740 to 1040	1676 to 2274	2970 to 3185	2525 to 2775
Insertion Loss (dB)	<2.7	<3.95	<5.2	<5.2
Rejection, Minimum (dBc)	>60	>60	>60	>60
Return Loss (dB)	>10	>10	>10	>10
Power Handling (W)	25			
Third-Order Intercept (dBm)	>85			
Control	TTL/USB			
Power Supply (VDC)	+5 V/USB			
Switching Time (us)	<10			
Current Consumption (mA)	65			
Size (mm)	63.5 (L) x 63.5 (W) x 12.7 (H)			
Operating Temperature (°C)	-40 to +85			
Vibration (10 to 500 Hz)	10G Mx			
Shock Duration	11 ms			

voltage driver routes the +88 V to each of the switch's four gate control pads. The input to the HV513 is managed by an Atmel ATSSAMD11 microcontroller, which can be controlled via USB or by direct +5 V TTL control. Other interface schemes can easily be implemented.

### Layout

The input SMA connector routes the signal to the center of switch 1 (see **Figure 5**). As the switch outputs are in the corners of the chip and need to maintain a ground-signal-ground (G-S-G) arrangement for best isolation, a grounded coplanar waveguide (GCPW) interconnection is used. This yields the best isolation while providing an optimum mounting configuration for the switch and bandpass filters. Two rows of vias are used on the ground sides of the GCPW that work to 18 GHz.

To avoid mismatch effects, sharp bends in the GCPW lines are avoided, with swept bends at least 3× the

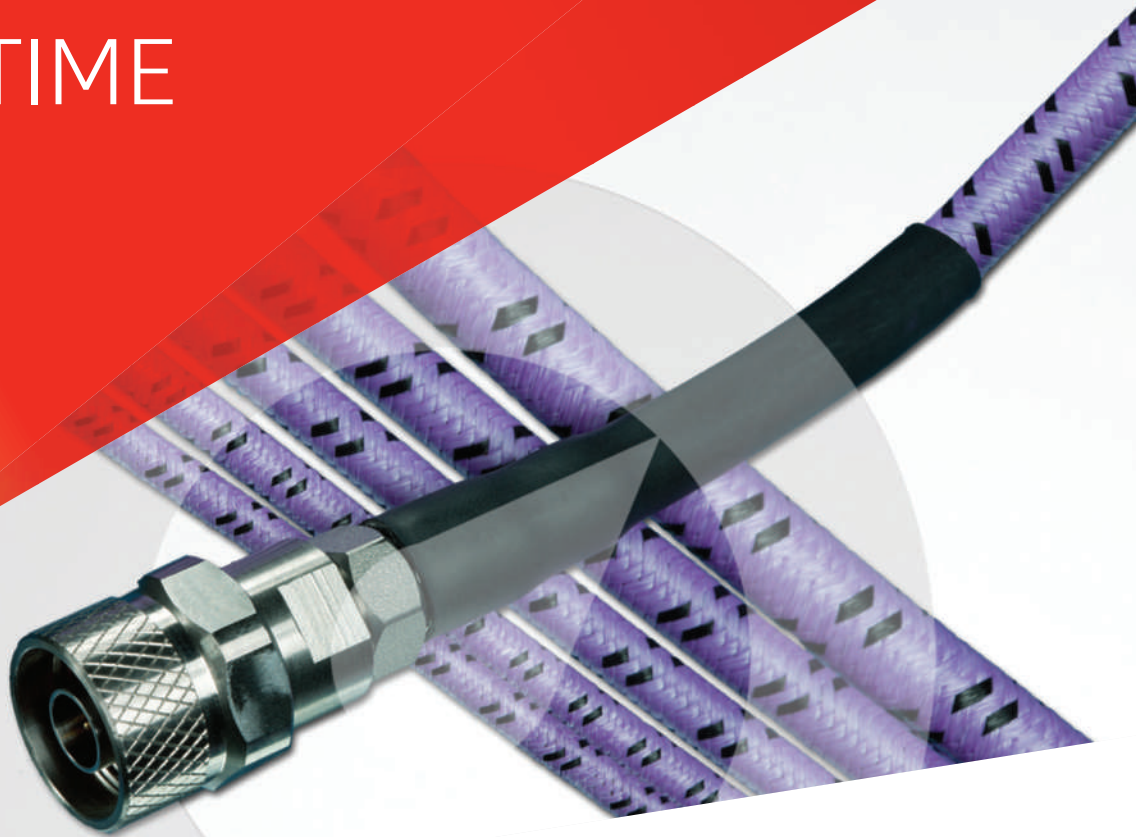


▲ Fig. 4 MEMS SFB control circuit.

line width. As the board incorporates RF and DC components, the top layer is typically an RF material such as Rogers 4003C, especially for operation at higher frequencies; the other board layers are typically FR-4. In this design, which only operates to 4 GHz, Isola FR408HR is used for both an RF and DC substrate, since it is a more stable and high performance version of FR-4. 6 mil diameter micro-vias are used under the switch to



# PERFORMANCE OVER TIME



## You can't trust the performance if you can't trust the test!

You can't afford to wonder if your cables are impacting your results. You expect your cables to be reliable. You need your cables to last.

But, with 75% of cables failing during installation or operation, your cable selection needs to be more than an afterthought. Choosing authentic GORE® Microwave/RF Test Assemblies is the only way to be sure your cables will stand up to the rigors of everyday use in demanding applications.

GORE® PHASEFLEX® Microwave/RF Test Assemblies – for proven performance, time and again. Learn what sets GORE® Microwave/RF Test Assemblies apart.

To learn more, visit [www.gore.com/test](http://www.gore.com/test)

GORE, PHASEFLEX, the purple cable, *Together, improving life* and designs are trademarks of W. L. Gore & Associates. ©2019 W. L. Gore & Associates, Inc.

***Together, improving life***

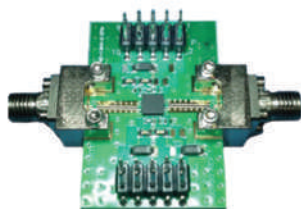
Content is copyright protected and provided for personal use only - not for reproduction or retransmission.  
For reprints please contact the Publisher.



## DC-24 GHz Power MMIC

- *Ideal for broadband driver amplifier designs*
- *Typ. +23dBm Psat*
- *Typ. +22dBm P1dB*
- *High power efficiency*
- *Ultra small 4mm<sup>2</sup> plastic package*

*In stock, ready to ship*



A plug-and-play evaluation board is available

4mm<sup>2</sup> QFN Package

FROM THE EXPERTS IN  
BROADBAND MMICs



www.eclipseMDI.com

## Technical Feature

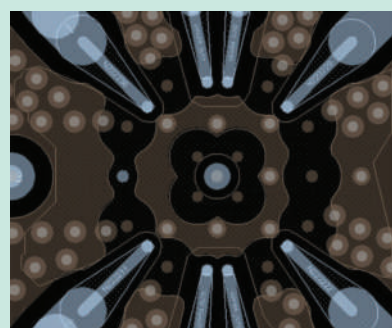
ensure optimum ground and maintain GCPW into the device.

### Design Considerations

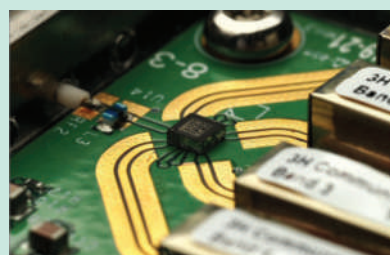
Depending upon the end application, it is necessary to choose a filter technology and topology to meet the minimum requirements. In this case, the filter vendor uses a proprietary technique where the filter has more zeros than poles, as opposed to traditional filter theory which requires the maximum number of zeros to be one less than the number of poles (i.e., for a n-section filter, the maximum number of zeros would be n-1). This causes the filter skirts of the passband to roll sharply, since many more zeros can be placed. As a consequence, the greater number of transmission zeros enables significantly smaller filters. These small filters used with the miniaturized, high performance RF MEMS switches reduce the size of the SFB significantly. To customize a uniquely different frequency response for each filter band, a lumped element technology with discrete zeros was chosen.

### PERFORMANCE

The insertion loss meets the target requirements and is slightly better than simulated (see **Figure 6**). The RF MEMS switch for this application adds almost negligible

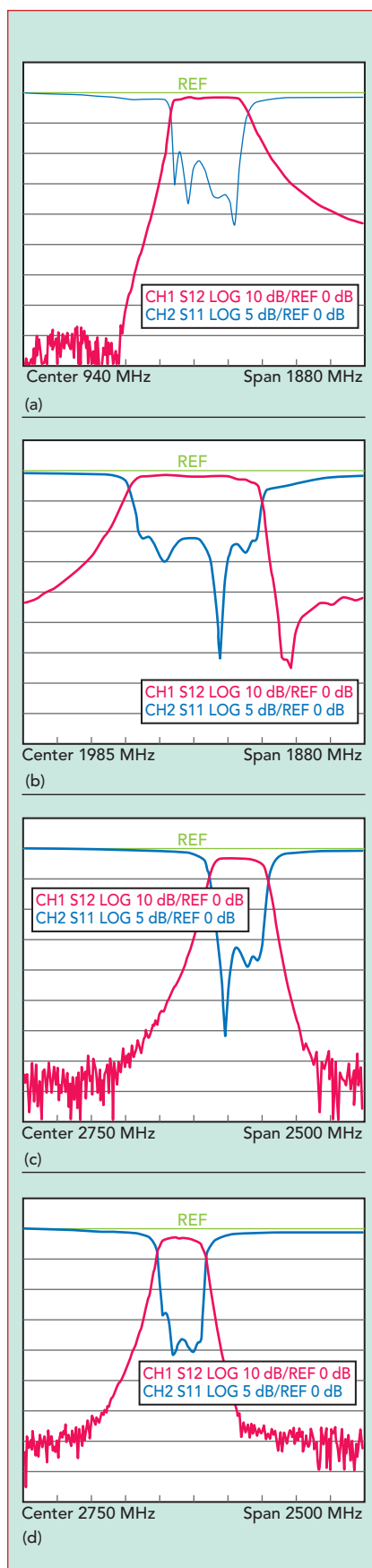


(a)



(b)

▲ **Fig. 5** SP4T RF MEMS switch layout (a) and zoom in of trace routing to the SFB (b).



▲ **Fig. 6** Insertion loss and return loss for all 4 SFB bands: Band 1 (a), Band 2 (b), Band 3 (c), Band 4 (d).





# Microwave Absorbers For Cavity Suppression and Free Space Applications

## Product Lines

### **C-RAM® RF/Microwave Absorbers**

*Featuring flat sheet and pyramidal, high power honeycomb material*

### **C-RAM® Anechoic & Free-Space materials**

### **C-STOCK® Low Loss Dielectric Materials**

**Turn-key Anechoic & EMC Chamber Design and Installation**

**Custom Formulations and Custom Fabrication Available**

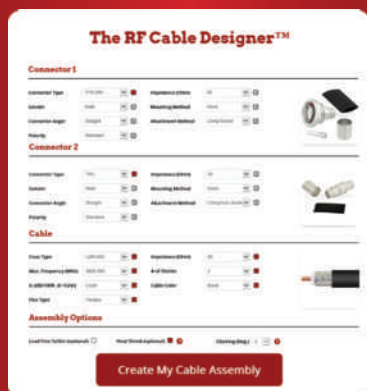
# Cuming Microwave



Cuming Microwave is an ISO 9001:2008 manufacturer of materials that absorb EMI/RFI between 10 MHz – 100 GHz

## Save Time with our RF Cable Designer™

Find the assembly you need or design your own from any combination of in-stock compatible connectors and cables.



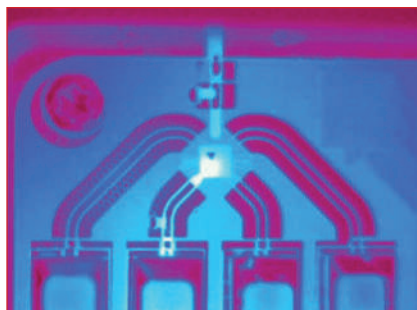
Try our Cable Designer today!  
fairviewmicrowave.com



**Fairview Microwave**  
an INFINITI® brand

## Technical Feature

TABLE 2 HIGH-POWER RF SWITCH PERFORMANCE			
Specification	PIN Diode (2 Cascaded)	GaN (2 Cascaded SPDT)	RF MEMS (MM5130)
Input Power, CW (W)	100	20	25
Insertion Loss (dB)	$2 \times 0.5 = 1.0$	$2 \times 0.7 = 1.4$	0.15
Switching Speed	1.5 $\mu$ s	0.05 $\mu$ s	10 $\mu$ s
Settling Time	N/A	0.15 $\mu$ s	N/A
Return Loss	15	15	20
Isolation (dB)	35	25	30
Switching Cycles	Unlimited	Unlimited	>3 billion
Third-Order Intercept (dBm)	75	60	>85
Switch Dimensions (mm)	4 x 4 x 1.5	4 x 4 x 1.4	2.5 x 2.5 x 0.9



▲ Fig. 7 Thermal profile of RF MEMS SFB under a 25 W CW load.

insertion loss to the overall SFB performance, using a much smaller and less complicated filter design than would normally be possible using solid-state switches.

The RF MEMS switch selected for this design exhibits a low insertion loss of 0.15 dB at 4 GHz and 0.75 dB at 12 GHz, a third-order intercept greater than 85 dBm and the capability to handle 25 W RF input power. Since it is configured as a native SP4T, there is no need to cascade switches, which can increase loss and, for high-power applications, the thermal load.

A comparison of the RF MEMS switch used in this design with traditional solid-state high-power switch technologies is shown in **Table 2**. It is very challenging to find comparable SP4T monolithic switches that can handle greater than 20 W, so this comparison assumes the use of multiple cascaded SPDT high-power switches on both the input and output of the filters to create 1:4 multiplexing.

The RF MEMS switch used in this design is uniquely manufactured with high temperature electrodeposited metal alloys. This addresses a well-known problem experienced by many previous MEMS switches, where the switch actuator tends to deform over time and high temperature, reducing operating life. In this case, the electroplated metal alloy has a yield strength orders of

magnitude greater than gold, which has been commonly used in the past for MEMS switch actuators. The results demonstrated in this SFB design show that these high temperature metal alloys are necessary to provide highly conductive and low loss signal paths and perform at elevated power levels, where some amount of self heating is inevitable.

**Figure 7** shows a thermal image of the SFB, including the RF MEMS switch. Operating with a 10 W CW input, it exhibits only a 20°C temperature rise above ambient.

The low losses exhibited in this SFB compared to solid-state designs translate to a significantly smaller and lighter weight assembly, since heat sinks or more complicated thermal management can be reduced—even eliminated. As an example, for an SFB on the transmit path, where the radio needs to deliver 25 W to the antenna, a solid-state version would require the PA to generate an extra 2 to 2.5 dB of power into the SFB compared to the RF MEMS version. Not only does this add cost and complexity to the PA, it forces the designer to manage 10 to 14 W of extra heat in the radio.

## SUMMARY AND DIRECTION

There are many ways to optimize the design. First, the high-voltage DC control section can be integrated into a single chip with minimal external passive components. There are many variants for high voltage drivers that can scale to 16, 32 or high-



# The Right RF Parts. Right Away.



We're RF On Demand, with over one million RF and microwave components in stock and ready to ship. You can count on us to stock the RF parts you need and reliably ship them when you need them. Add Fairview Microwave to your team and consider it done.

**Fairviewmicrowave.com**  
**1.800.715.4396**

 **Fairview Microwave**  
an INFINIT<sup>®</sup> brand

Content is copyright protected and provided for personal use only - not for reproduction or retransmission.  
For reprints please contact the Publisher.

# BBox™ The World's First 5G NR Beamforming Development Kit

## For Antenna Designers

Verify the design by connecting your antenna to BBox™.

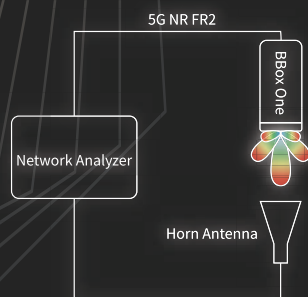
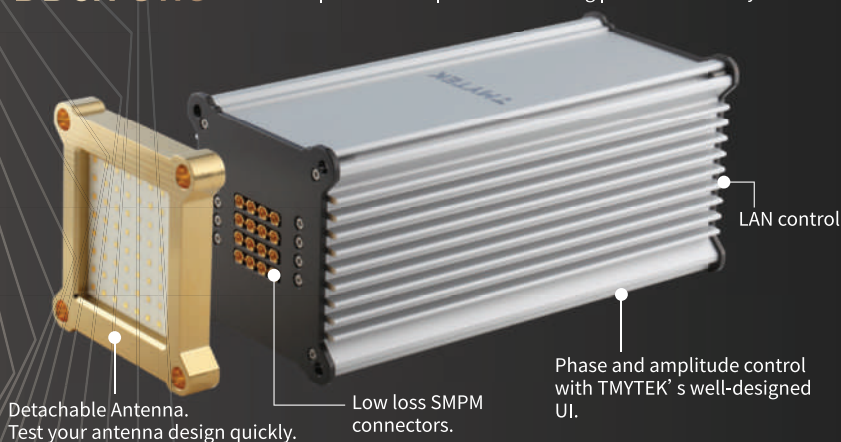
## For Baseband Designers

Verify 5G beam tracking algorithm and protocols by connecting BBox™ to TMYTEK UD Box and the baseband instrument.

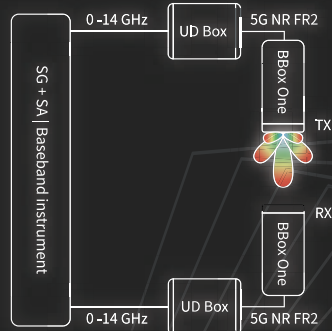
## For mmWave Production Line

BBox™ is an excellent RF probe to measure the beam profiles and the steering angles of DUTs. It speeds up production rate and saves cost.

## BBox One 5G NR FR2 | 16 channels | 2D beam steering | API control ready

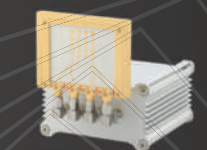


For Antenna Designers



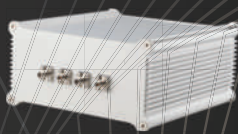
For Baseband Designers

## BBox Lite



5G NR FR2 | 4 channels

## UD Box



RF 24~44 GHz | IF 0~14 GHz  
LO 16~32 GHz | 1 or 2 channels



[www.tmytek.com](http://www.tmytek.com)



+886 2 8226 9168



[sales@tmytek.com](mailto:sales@tmytek.com)

er channels for applications where there are multiple SFBs to control or SFBs with more than four channels.

Additionally, the design can easily be scaled to accommodate a different number of frequency bands (i.e., more channels) and higher frequencies. For example, the SFB in this article can be increased from four to eight channels with center frequencies from DC to 18 GHz with a small penalty in insertion loss and board space. The savings in power dissipation and insertion loss for the overall SFB becomes even greater compared to solid-state when adding more channels.

Finally, there are other ways to take advantage of the extremely low  $R_{on}C_{off}$  characteristics of an RF MEMS switch. The on-resistance ( $R_{on}$ ) of the metal-to-metal contact is very small, typically less than  $0.5 \Omega$ , which provides the lowest possible insertion loss. The switch also has very low levels of parasitic capacitance in the off-state ( $C_{off}$ ), typically less than 15 fF, providing very low signal leakage when open. These unique characteristics provide opportunities where the switch can be used to select different resonators and "actively tune" a resonator to different frequency bands, employing one or multiple switch channels to connect series or shunt elements to the resonator. This type of tunable filter is extremely challenging using solid-state switches, given the non-ideal "on" and "off" characteristics of a transistor. This is especially true for high-voltage and high-power applications that stack transistors, which can significantly degrade the resonator Q-factor. Using RF MEMS for tuning enables further reduction in space over a straight SFB while maintaining very high Q.

Designers have a variety of choices when choosing an SFB. Most of the filter characteristics are determined by the switching element as well as the filter response required by the application. The RF MEMS switch is a new entrant in this market. Owing to its inherently superior electrical characteristics, it provides an appealing alternative for many RF subsystems, especially those where reducing the SWaP are mission critical. ■



# LITCC FILTERS



## ***Largest Selection in the Industry!***

- ▶ Now over 300 Models in Stock!
- ▶ Case Styles as small as 0202
- ▶ Rejection up to 52 dB
- ▶ Steep Skirts



0202 0402 0603 0805 1206 1210



(718) 934-4500 sales@minicircuits.com [www.minicircuits.com](http://www.minicircuits.com)  
Content is copyright protected and provided for personal use only - not for reproduction or retransmission.  
For reprints please contact the Publisher.



599 Rev A\_P



# Removing MMIC Outliers in Production Test Using Real-Time Principal Component Analysis

Grace Remillard\*\*, Charles Trantanella\* and Michael Megan\*  
Custom MMIC\*, Chelmsford, Mass.  
University of Massachusetts-Lowell\*\*, Lowell, Mass.

Many electrical components have wide performance specifications to allow for high yield in production testing. Such an approach, however, comes at a cost. The problem is the outliers, the out-of-family components which pass the electrical specifications but are noticeably different from the rest of the population. These outliers, which represent anywhere from 0 to 4 percent or so of the passing units (depending on the specific definition of an outlier), can often be identified when the data is analyzed in its entirety, post measurement. However, at this point, it may be impossible to separate the outliers from the “pass” population, especially if the units have been placed in storage, such as on tape and reel. Therefore, a preferred approach is to identify and remove outliers in real-time during the production test.

Outlier detection of integrated circuits has been examined in the past as detailed

by Stratigopoulos.<sup>1</sup> Here, the author presents a thorough discussion of outlier detection via machine learning, though the specifics of implementing a detection algorithm are not discussed. Others, such as Yilmaz,<sup>2</sup> have used outlier analysis to reduce the defective parts per million and the production test time. Jauhri<sup>3</sup> discussed the identification of outliers at the wafer level and used this information to unearth problems in the manufacturing process. Bossers<sup>4</sup> considered a univariate, real-time approach to detect outliers in production on a rolling basis, but under the assumption the units always followed a normal distribution. Finally, O’Neill<sup>5</sup> considered outlier detection using just one measured parameter, though this technique was intended for post-processing and not real-time.

**Table 1** has a summary of this previous work. As shown in the table, the previous work does not adequately address outlier

TABLE 1				
PCA ANALYSIS FOR OUTLIER DETECTION IN ICs				
Reference	Packaged Circuits	Multivariate	Applied During Measurement	Applied on Production Floor
2	YES	YES	YES	NO
3	NO	YES	YES	Unsure
4	YES	NO	YES	NO
5	YES	YES	NO	NO
This Article	YES	YES	YES	YES



# When Everything is Important... the NEW *Clarity*™ Series is the Clear Choice

## Applications:

Research & Development Labs  
VNA Test Port Extension Cables  
High Volume Production Test  
Bench or Portable Test equipment  
RF Module Testing



*Industry leading performance, unparalleled value,  
and stock to 4-week lead times.*



Phase stability <3.5°  
Guaranteed up to 50,000 flexes  
Super-sharp Sure-Grip™ knurl  
Ergonomically designed Sure-Grip™ molding



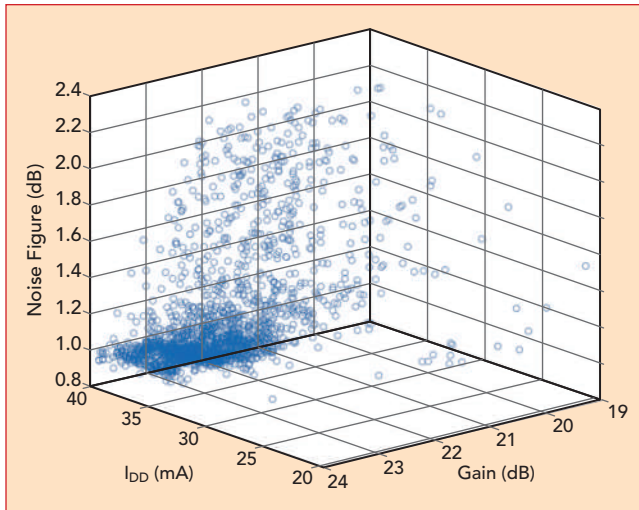
World Headquarters: 358 Hall Avenue, Wallingford, CT 06492 • Tel: 203-949-8400, 1-800-867-2629 Fax: 203-949-8423

International Sales: 1+ 203 949 8503 • 1+ 800 867 2629

China Sales: TMC Building 4, No. 318 Yuanshan Road, Xinzhuang Industrial Park, Shanghai, China 201108 Tel: 86-21-5176-1209 Fax: 86-21-64424098

[www.timesmicrowave.com](http://www.timesmicrowave.com)

Content is copyright protected and provided for personal use only - not for reproduction or retransmission.  
For reprints please contact the Publisher.



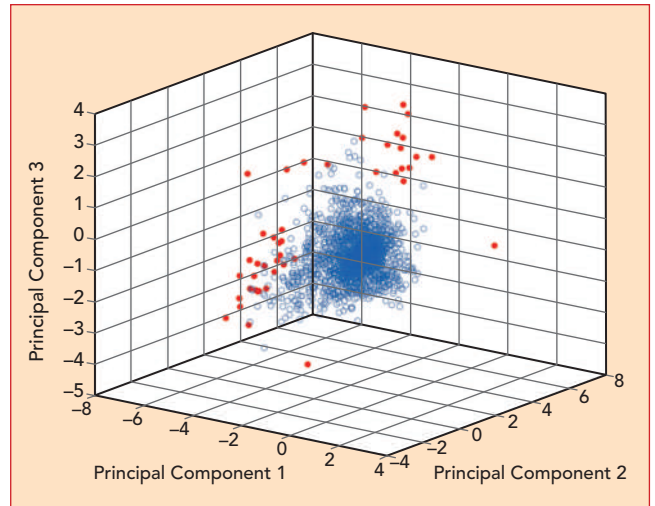
▲ **Fig. 1** Gain vs. noise figure vs.  $I_{DD}$  for 2,139 CMD132P3 LNAs.

detection on the production floor. Therefore, this article presents a real-time method for outlier detection using principal component analysis (PCA), beginning by describing the theory behind PCA. Next, we deploy PCA in a post-processing role to examine its ability to detect outliers, then describe a real-time imple-

mentation of a PCA algorithm on the production floor, showing the results. Finally, we offer conclusions and plans for future work.

## PCA AND OUTLIER DETECTION

PCA is a statistical method used to discover and quantify relationships between variables in a data



▲ **Fig. 2** T-matrix scores for the LNAs from Fig. 1, showing the outliers in red.

set.<sup>6-7</sup> Consider a set of measurements,  $S$ , organized into an  $m \times n$  matrix, where each of the  $m$  rows represents the measurement of one unit over  $n$  parameters.

For example, the CMD132P3, a commercially available low noise amplifier (LNA) from Custom MMIC, has  $n = 3$  measured parameters: gain, noise figure and supply current (IDD). From experience, we know there is some correlation between these parameters: if the gain of the CMD132P3 is low, the noise figure may be higher than average; if the current is high, the gain may be high as well. But this correlation is not easily identified. **Figure 1** is a scatter plot of gain versus noise figure versus current for one lot of CMD132P3 LNAs ( $m = 2189$  units). Each circle in the figure represents a unit that passed the electrical specifications. Note the data is not clustered tightly, instead spread over the acceptable range of the three parameters, making it difficult to discern the outliers. With PCA, however, we can quantify the relationship between the measured parameters and more easily discover the outliers.

The first step deploying PCA is to normalize the data in  $S$  and generate a new matrix,  $X$ . Normalization effectively removes the unit of measure from the data. Without this step, measurements that produce large numbers, such as an IDD of 35 mA, would completely overshadow smaller measured values, such as a noise figure of 1.5 dB, even though

# EXODUS

## ADVANCED COMMUNICATIONS

*Best in Class RF Amplifier SSPA's*




### Designed for harsh environmental applications



**High Power Solid State Power Amplifiers**

Chip & Wire Hybrid Assemblies, Modules & Systems

Broadband, CW, Pulse & Linear Applications

10kHz to 51GHz, 3KW CW, 10KW Pulse

**Medium Power Amplifiers**

10kHz to 51GHz, 2W P1dB and below

**Low Noise Amplifiers**

**Block Up Converters**

**Exodus Advanced Communications**  
 3674 E. Sunset Road, Suite 100  
 Las Vegas, Nevada 89120 USA  
 Tel : 1-702-534-6564  
 Fax : 1-702-441-7016  
 Email : sales@exoduscomm.com

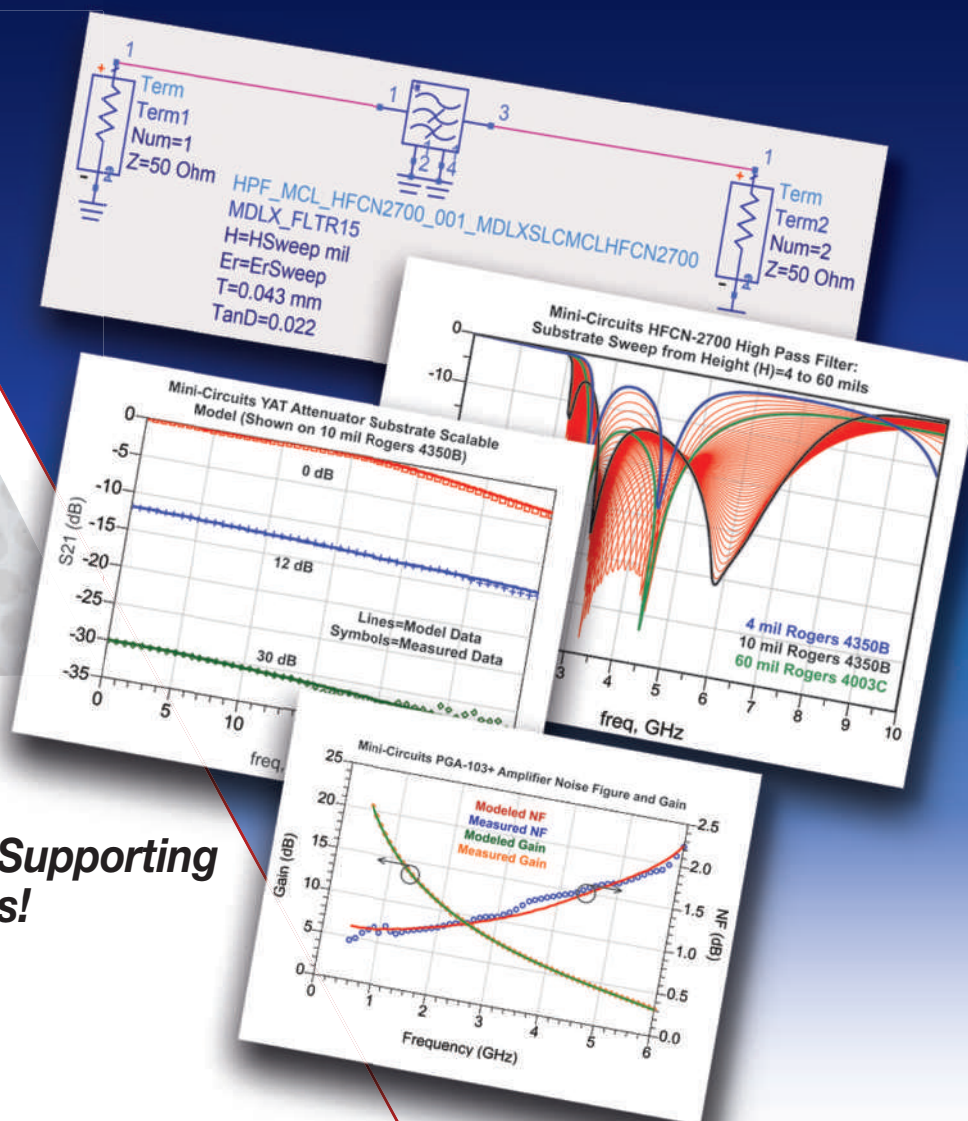


**EXODUS ADVANCED COMMUNICATIONS**



# ADVANCED SIMULATION MODELS

Accelerate RF Design Success for Mini-Circuits Components



**Now Over 50 Models Supporting  
Over 100 Components!**

► Attenuators



► Amplifiers



► Filters



► Splitters



► Transformers



Download  
Free Models  
for PathWave ADS



[www.modelithics.com/MVP/Mini-Circuits](http://www.modelithics.com/MVP/Mini-Circuits)

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

617 RevOrig\_P

Content is copyright protected and provided for personal use only - not for reproduction or retransmission.  
For reprints please contact the Publisher.

**TABLE 2**

**VARIABLE DEFINITIONS AND MATRIX SIZE**

Variable	Description	Matrix Size
m	Total Number of Units Tested	—
n	Number of Measurements (i.e., Idd, Gain, Noise Figure)	—
S	Complete Set of Measured Data	m x n
S <sub>k</sub>	Measured Data Vector for k <sup>th</sup> Unit (k = 1...m)	1 x n
X	Complete Normalized Set of Measured Data	m x n
X <sub>k</sub>	Normalized Data Vector for k <sup>th</sup> Unit (k = 1...m)	1 x n
X*	Covariance Matrix	n x n
Y	PCA Coefficient Matrix (Ranked Eigenvectors of X*)	n x n
T	PCA Score Matrix	m x n
T <sub>k</sub>	PCA Score Vector for k <sup>th</sup> Unit (k = 1...m)	1 x n

each measurement is equally important. Normalization is accomplished through a straightforward calculation:

$$X_{ij} = \frac{S_{ij} - \bar{S}_j}{\sigma_j} \quad (1)$$

Here, (i,j) is the row and column identifier of the elements in X and S,

S<sub>j</sub> is the mean of column j, and σ<sub>j</sub> is the standard deviation of column j, where j = 1, 2, ..., n, and i = 1, 2, ..., m. The result of this normalization is each column of X now has zero mean and a standard deviation of 1. Once X has been generated, the covariance matrix, X\*, is formed:

$$X^* = \text{Cov}(X) = X^T X \quad (2)$$

We then find the eigenvalues and eigenvectors of X\* and sort the column eigenvectors by the highest to lowest eigenvalue, creating a new matrix, Y. The columns of this sorted matrix, Y, are referred to as the principal component axes. Formally, matrix Y is an orthonormal set of basis functions (i.e., principal components) onto which we can project the normalized measured data. Matrix Y is also called the PCA coefficient matrix. Once we have generated the coefficient matrix, Y, we determine the PCA score matrix, T, for the data set through a simple matrix multiplication:

$$T = XY \quad (3)$$

Matrix T is an m × n matrix, the same size as the initial data set, S, and each row represents the projection of the normalized measured data onto the n orthogonal principal components. Outliers will generate high scores in their respective row of the matrix T, where normal or typical measurements will generate low scores. We can then set a maximum PCA score to remove the outliers from the population.

**Figure 2** plots the elements of T from the CMD132P3 data set used to create Figure 1. The majority of the measured data is clumped around the (0,0,0) coordinate, and a number of outliers (shown in red) can clearly be seen on the fringes of the graph. For this example, the outliers were defined as having a PCA score greater than 7. Analyzing several different LNA data sets using this same approach, in all cases the T-matrix scores identified outliers in a similar manner. For reference, **Table 2** provides a summary of the variable definitions and their matrix sizes.

## REAL-TIME PCA ALGORITHM

The approach used to generate Figure 2 followed a typical post-processing application of PCA, where the data set was processed as a whole after all measurements were complete. The implementation of PCA in a real-time environment, however, requires a slightly different approach. **Figure 3** shows a flow-chart of a real-time PCA algorithm.

The first step in the algorithm is to load the PCA coefficient matrix,



# MiniRF

Passives with a Passion for Performance

## NEW 3 GHz & Beyond Products!

- Enables DOCSIS 3.1 & full duplex requirements
- Achieve max RF output power w/ MiniRF passives
- Repeatability & reliability - a MiniRF trademark
- 100% RF test, local design & support

### Standard & Custom Components

#### COUPLERS



**MRFCP6762**

1.8 GHz BW  
3 & 4 port models with optional coupling factors for Broadband / CATV Systems.

#### SPLITTERS



2.5 GHz BW, 2/3&4 way power splitters designed for both 50 & 75 ohm applications.

#### TRANSFORMERS



50 Ω & 75 Ω supporting a wide range of applications with impedance ratios of 1:1, 1:2, 1:4, 1:8, 1:16.

#### RF CHOKES



Precision inductors & chokes with wire diameters from 0.060~5mm single & multilayer, air-core, coil configurations.

[www.minirf.com](http://www.minirf.com) | [sales@minirf.com](mailto:sales@minirf.com) | (408) 228-3533





# Open foundry services from a trusted DoD supplier

We proudly offer U.S. defense contractors access to our foundry services. Our expertise and technology, including some of the highest performance GaAs and GaN processes in the world, support both small development and full production projects. When efficiency, high power, high frequency, and low noise are crucial, we provide the key technologies and support to give you discriminating performance at an affordable price.

## Join us

We're looking for talented scientists to join our team and support the mission. Learn more at [jobs.baesystems.com](https://jobs.baesystems.com).

[baesystems.com/foundry](https://baesystems.com/foundry)

**BAE SYSTEMS**

BAE SYSTEMS is a registered trademark of BAE SYSTEMS plc. All other trademarks are the property of their respective owners. This advertisement is provided for personal use only and is not for reproduction or redistribution. For reports please contact the Publisher.

## The New N623 VCXO

High Performance.  
High Precision.  
High Reliability.

**SATCOM**  
**INSTRUMENTATION**  
**M/W COMMUNICATIONS**

**ULTRA-LOW PHASE NOISE**  
&  
**LOW G-SENSITIVITY**



- ✦ Frequency: 100 MHz
- ✦ Output: Sinewave
- ✦ Supply: 5.0 VDC
- ✦ Control: 0 to 5.0 VDC
- ✦ Frequency Pulling:  $\pm 30$  ppm
- ✦ Linearity: 10%
- ✦ Phase Noise:
 

10Hz	-85 dBc/Hz
100Hz	-115 dBc/Hz
1kHz	-140 dBc/Hz
10kHz	-162 dBc/Hz
Floor	-175 dBc/Hz



frequency control solutions

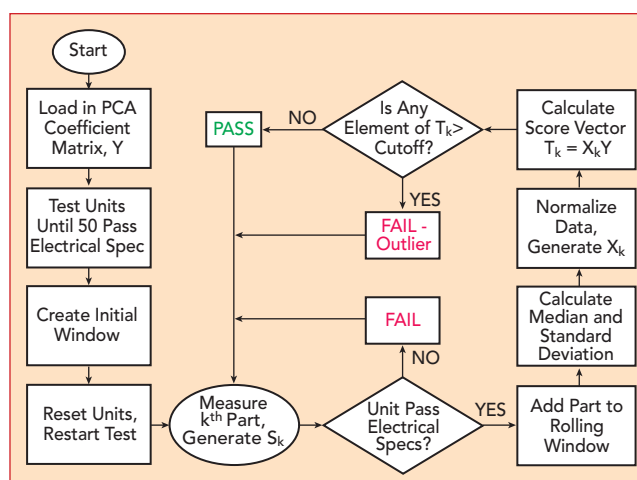
Call 717-766-0223  
[www.greenrayindustries.com](http://www.greenrayindustries.com)

CERTIFIED TO  
ISO 9001:2015 +AS9100D

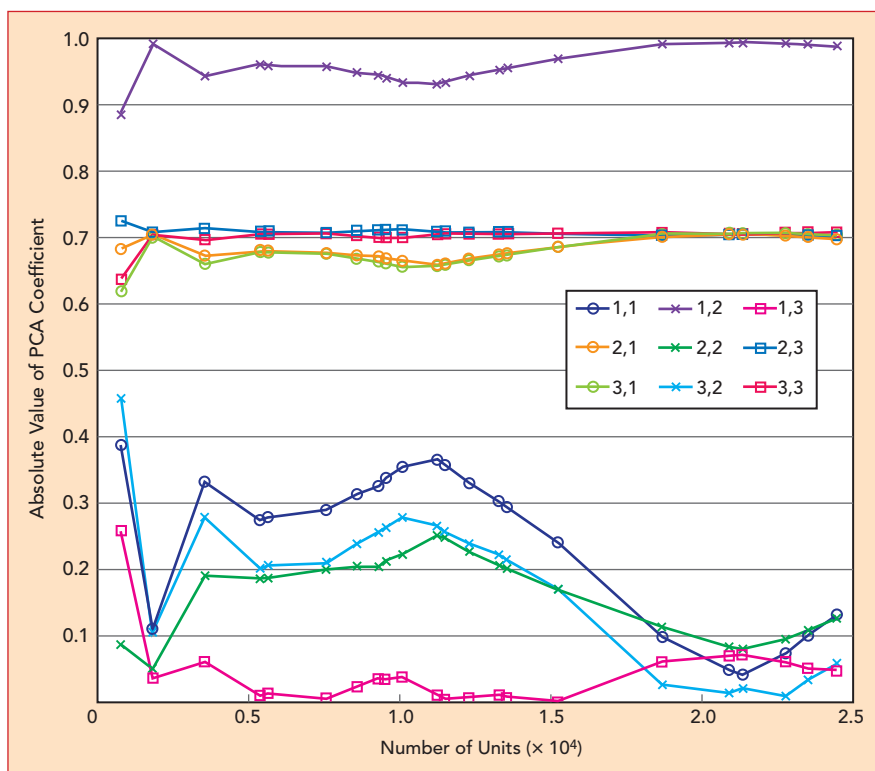
## Technical Feature

Y, into the automated test equipment. To determine Y, we discounted a real-time method, since the calculations to generate this matrix are computationally expensive and not conducive to a production environment. Instead, we used a series of previous measurements of the same LNA type to determine Y using the method described by Equations 1 through 3. For example, consider the CMD185P3 LNA with  $n = 3$  (IDD, gain and noise figure). **Figure 4** shows the absolute value of each element in the Y-matrix as a function of the number of units in the calculation. Note that as the number of units increases, the coefficients begin to converge, especially the larger ones. While convergence is not universal, this result suggests that using a larger set of training data is preferred over a smaller set.

The second step in the algorithm is to run the production test until a fixed number of units pass the electrical specifications. Recall that Equation 1 requires statistics for each of the  $n$  parameters to perform the normalization, so an initial set of measurements is needed to generate these statistics. Note that the median instead of the mean is used in the normalization equation, as this approach led to slightly better identification of outliers. The size of the initial window is variable, so



▲ Fig. 3 PCA algorithm for real-time outlier removal at production test.



▲ Fig. 4 Absolute value of the PCA coefficients for the CMD185P3 LNA. The legend shows the row, column entry of the Y-matrix.



# RF-LAMBDA

THE LEADER OF RF BROADBAND SOLUTIONS

EUROPE

DEUTSCHLAND



## RF SWITCHES

### MM / MICROWAVE DC-90GHz

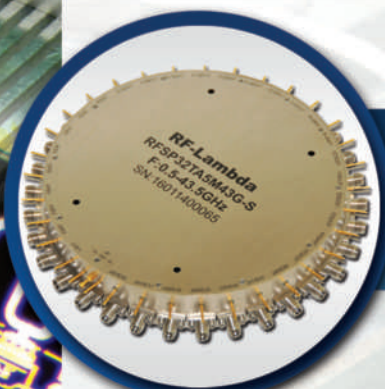


**160 CHANNELS**  
**mm/Microwave**

**0.05-20GHz**

**Filter Bank Switch Matrix**

**For Phase Array Radar Application Satellite communication.**

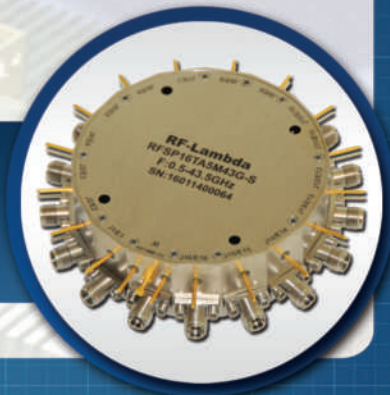


**PN: RFSP32TA5M43G**

**SP32T SWITCH 0.5-43.5GHz**

**PN: RFSP16TA5M43G**

**SP16T SWITCH 0.5-43.5GHz**



**www.rflambda.com**  
**sales@rflambda.com**

**1-888-976-8880**

**1-972-767-5998**

**San Diego, CA, US**

**Plano, TX, US**

**Ottawa, ONT, Canada**

**Frankfurt, Germany**

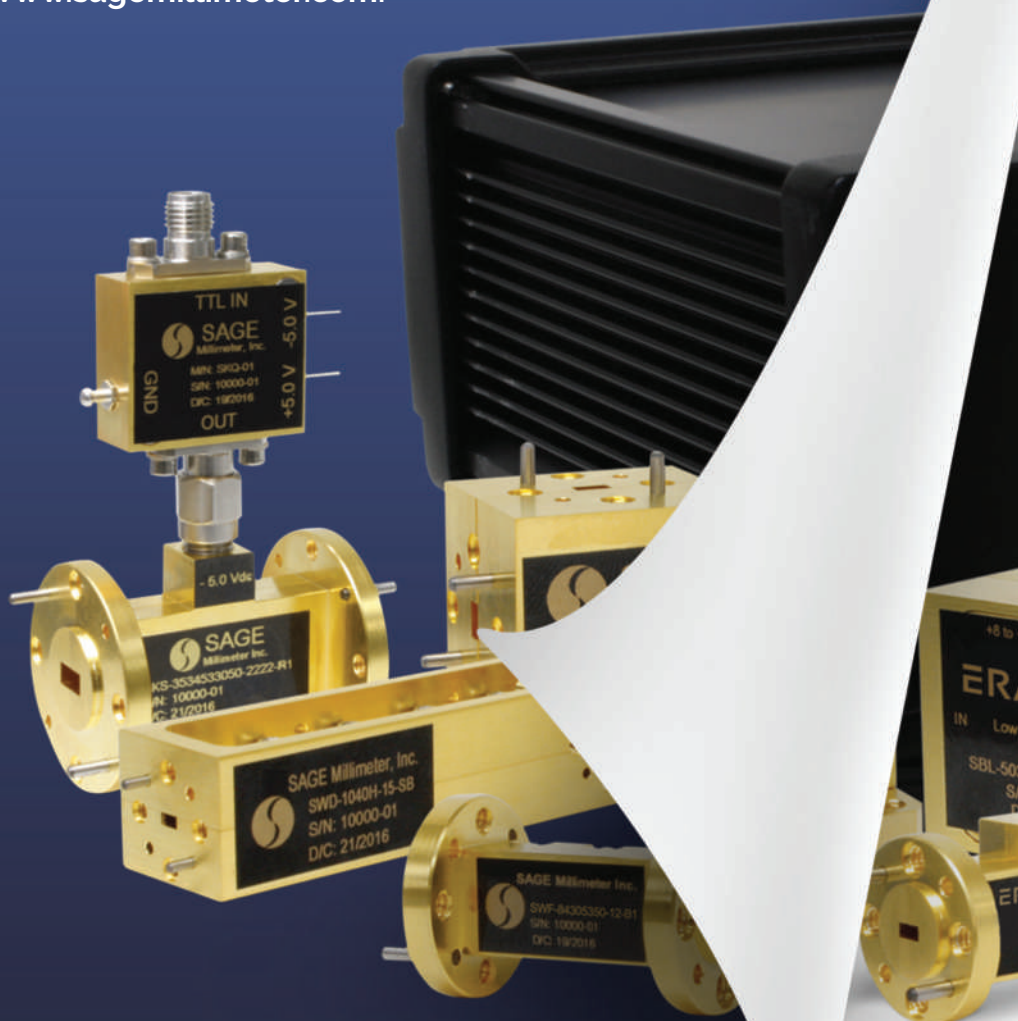
Content is copyright protected and provided for personal use only - not for reproduction or retransmission.  
For reprints please contact the Publisher.





SAGE Millimeter will become Eravant in March 2020, a change that renews our commitment to the millimeter-wave industry. Since 2011, we have been delivering quality products and energizing the customer experience to respond to the next generation of RF engineers.

As we continue to grow into an industry leader, we want a new identity that reflects our vision for enabling tomorrow's technology. **Read more about our upcoming transformation at [www.sagemillimeter.com](http://www.sagemillimeter.com).**



[www.sagemillimeter.com](http://www.sagemillimeter.com)

[www.sagemillimeter.com](http://www.sagemillimeter.com) 3043 Kashiwa St. Torrance, CA 90505  
T: 424-757-0168 F: 424-757-0188 [sales@SAGEMillimeter.com](mailto:sales@SAGEMillimeter.com)

Content is copyright protected and provided for personal use only - not for reproduction or retransmission.  
For reprints please contact the Publisher.



# SAGE IS BECOMING ERAVANT

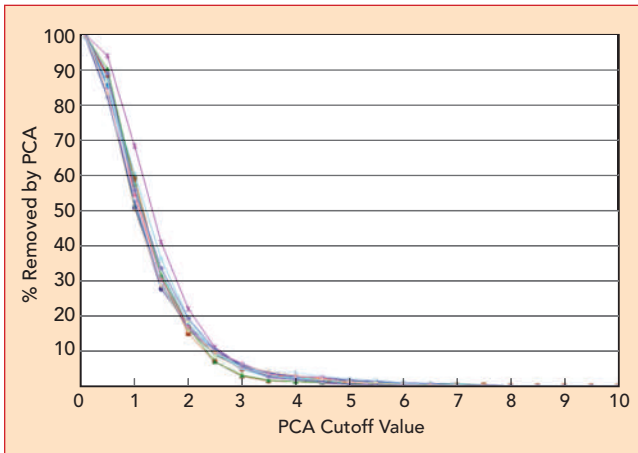
NEXT GENERATION MILLIMETERWAVE SOLUTIONS



[WWW.ERAVANT.COM](http://WWW.ERAVANT.COM)

03-01-2020

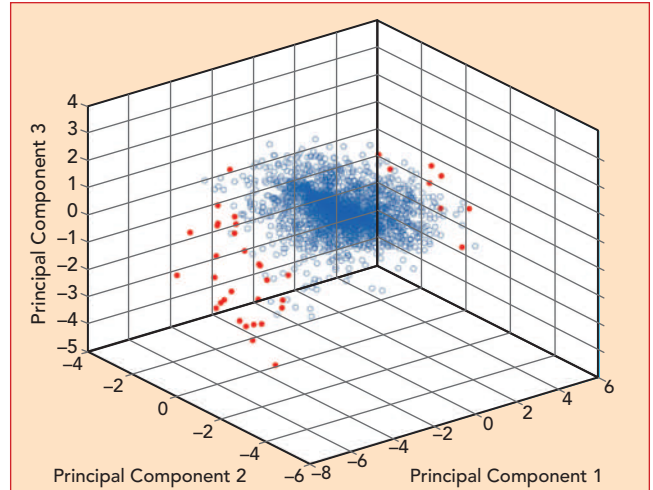
Content is copyright protected and provided for personal use only - not for reproduction or retransmission.  
For reprints please contact the Publisher.



▲ **Fig. 5** Simulated percentage of LNAs removed by PCA vs. the cutoff value, using measured data from 16 lots of the CMD132P3 LNA.

after some experimentation, we chose 50 units as a compromise between having enough data to generate the statistics and not requiring an excessive amount of test time, since these units are returned to the untested population prior to outlier detection using PCA.

The third step is to restart the production test and apply PCA to each measurement. The  $k^{\text{th}}$  unit is measured, and if any values in the vector  $S_k$  fail their respective electrical specifications, the unit is placed in the "fail" bin without further analysis. If the unit passes electrical specifications, its performance is combined with the previous



▲ **Fig. 6** Real-time  $T_k$  vector scores for each CMD185P3 LNA tested in production, with cutoff parameter scores > 4 shown in red.

49 passing units to determine a new median and standard deviation. By using a rolling window and computing a new median and standard deviation with each unit, the algorithm accounts for a slight drift with time in the measured data. The  $S_k$  vector is then normalized to generate  $X_k$ , which is multiplied by the Y-matrix to determine the  $T_k$  vector score. If any of the values in  $T_k$  are outside the PCA cutoff parameter, this unit is considered an outlier and is placed in the fail bin. Otherwise, the unit is placed in the pass bin, and the test moves to the next unit in the

## Wright Technologies

Broadband Frequency Operation

### Power Amplifiers

**AT-P40B-20-42 GHz**  
IN +30 dBm  
OUT +31 dBm  
1319 5QT61 S/N 0001

**ST-P40B-3533**  
IN >31 Psat 20-41 Ghz  
OUT >32 Psat 21-34 Ghz  
2319 5QT61 S/N 0001

**20-42 GHz +30 P-1dB typ.**  
**20-42 GHz +33 dBm Psat typ.**  
**Great Power in a Small Package**

**P-1dB**

**Psat**

Updated Website!

Battle Tested & Built to Last

### Frequency Multipliers

**ASX40-B220L**  
X2-18-40 Ghz

**ASX50-420**  
X4-33-50 Ghz

**ASX65-415**  
X4-40-65 Ghz

5218 5QT61 S/N 0125

### Low Noise Amplifiers

**ASL40B-3030**  
IN 1-40 Ghz +12V  
OUT +5.5 dB NF

**ASL50B-3008**  
IN 1-50 Ghz +12V  
OUT +6.3 dB NF

1019 5QT61 S/N 0014

**1-40 GHz 5.5 dB NF**  
**1-50 GHz 6.3 dB NF**  
**Low Noise Broadband**

**NF**

**P-1dB**

www.wrighttec.com

NEW! "Desktop Option"

Performance Data Available (916) 773-4424



# New ATC 560L Ultra-Broadband UBC™ SMT Capacitors

*Ultra-Broadband Performance  
from 16 KHz to 40+ GHz*

## Advantages:

- Ultra-Broadband Performance
- Ultra-Low Insertion Loss
- Flat Frequency Response
- Excellent Return Loss
- Rugged Ceramic Construction
- Unit-to-Unit Performance Repeatability



## Features:

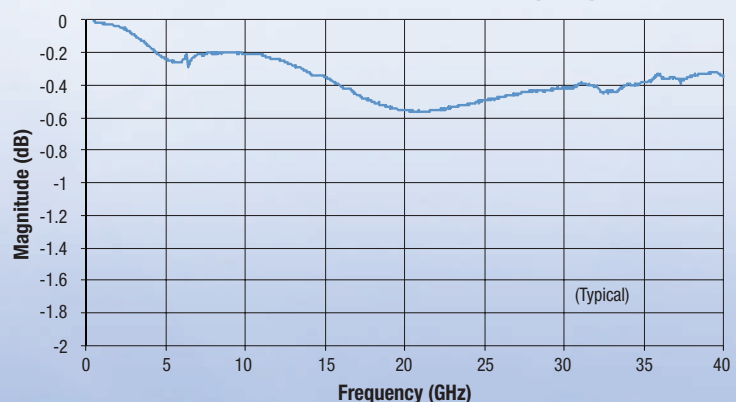
- EIA 0402 Case Size
- Capacitance: 100 nF
- Operating Frequency: 16 KHz to 40+ GHz
- Insertion Loss: <0.6 dB typ.
- Orientation Insensitive
- One Piece Construction
- Voltage Rating: 16 WVDC
- Gold Complaint Terminations
- RoHS Compliant

## Applications:

- Optoelectronics / High Speed Data
- Transimpedance Amplifiers
- ROSA / TOSA†
- SONETT††
- Broadband Test Equipment
- Broadband Microwave Millimeter-wave

† Receive and Transmit Optical Sub-Assembly  
†† Synchronous Optical Network

560L Insertion Loss (S21)



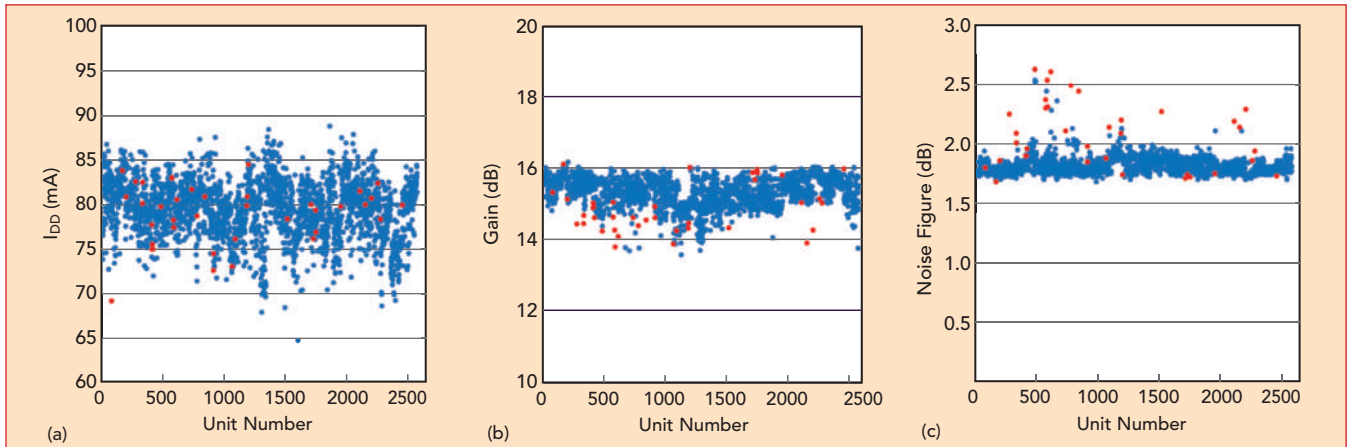
sequence. The algorithm is repeated until all units in the lot have been tested.

A major variable is the PCA cutoff parameter. A low cutoff removes too many parts, a high cutoff removes too few. To determine an appropriate value, several simulations were run using the algorithm of Figure 3, where the PCA cutoff parameter was varied to determine the number of outliers removed. **Figure 5** shows the results of one set of simulations involving 17 lots of data for the CMD132P3 LNA, where each lot contained 1000 to 5000 units. The plot shows the percentage of units removed as outliers versus the cutoff value, which was varied from 0 to 10.

Although not shown, very similar results were generated from simulations of other LNAs. Based on these simulations, we chose to implement a cutoff score of 4 in the real-time application of the algorithm, which should categorize approximately 1% to 3.5% of the units as outliers and place them in the fail bin.

### ALGORITHM ON THE PRODUCTION FLOOR

The algorithm shown in Figure 3 was implemented during a recent production test of a lot of CMD185P3 LNAs containing 2575 units. Again, the measured parameters were gain, noise figure and  $I_{DD}$  ( $n = 3$ ), and



▲ **Fig. 7** Measured  $I_{DD}$  (a), gain (b) and noise figure (c) of the CMD185P3 LNA, showing the outliers removed by the algorithm in red.

# Are you pushing the limits?

## Our Chip Attenuators TS06 Series can help!

**Best performing, smallest footprint attenuator series available**

- Compact size with superior frequency response
- Space-saving 0603 footprint with high power handling capability
- Rated for DC-20 GHz with excellent broadband performance
- Available in multiple attenuation values and surface finishes for RoHS and tin lead solder applications

[more > smithsinterconnect.com](http://smithsinterconnect.com) | [in](#) [twitter](#) [facebook](#)



# CUSTOM DESIGNED FOR YOUR APPLICATION



Exceed Microwave's  
custom designed WZ-Series  
waveguide bandpass filters offer high  
frequency selectivity with very low  
insertion loss, while handling kWatts of  
power for narrowband applications.



**EXCEED  
MICROWAVE**

Phone +1 (424) 558-8341  
[sales@exceedmicrowave.com](mailto:sales@exceedmicrowave.com)  
[www.exceedmicrowave.com](http://www.exceedmicrowave.com)



Content is copyright protected and provided for personal use only - not for reproduction or retransmission.  
For reprints please contact the Publisher.

## Exceed Microwave STANDARD COMPONENTS

- Adapters
- Filters
- Circulators
- Diplexers
- Isolators

## IN STOCK AT



**HASCO Components**

Phone +1 (888) 498-3242  
[sales@hasco-inc.com](mailto:sales@hasco-inc.com)

[www.hasco-inc.com](http://www.hasco-inc.com)

the window size was 50 and the PCA cutoff score set at four. **Figure 6** is a graph of the  $T_k$  vector scores for each unit, where the circles in blue represent a pass, while the red circles represent the units identified as outliers and sent to the fail bin. The algorithm failed 38 outliers and passed 2454 units, an outlier removal rate of 1.5%. An additional 83 units did not pass the electrical specifications and were ignored by the algorithm.

**Figure 7** shows this data in a slightly different form: each of the measurements as a function of unit number using the same color scheme, i.e., blue represents a unit that passed and red an outlier that failed. The vast majority of units removed by the algorithm had higher than average noise figure, and many of those correlated with lower gain. The algorithm did not add any time to the production test.

### CONCLUSION

We have described a real-time PCA algorithm deployed on the production floor to remove outliers from the testing of the CMD185P3 amplifiers. Of the LNAs meeting the electrical specifications, the algorithm identified 1.5 percent as outliers, which was consistent with the expectation, given the cutoff score of four. We are continuing to deploy this algorithm on the production floor with numerous LNAs as we work to refine the coefficient matrix,  $Y$ , and examine the cutoff score to more effectively remove outliers from the passing population. We are also working to deploy the algorithm


on other MMICs, such as driver and power amplifiers, distributed amplifiers and switches. ■

### ACKNOWLEDGMENTS

The authors acknowledge the following for their contributions to this work: Dr. Kavitha Chandra of the University of Massachusetts-Lowell, for her guidance and introduction to PCA. This work would not have been successful without her help. Sarah McKinley and Emma Fournier of Custom MMIC helped run and improve the MATLAB simulations, and Helen Leung of Custom MMIC who deployed the algorithm on the production test equipment.


### References

1. H. Stratigopoulos, "Machine Learning Applications in IC Testing," 23<sup>rd</sup> IEEE European Test Symposium, 2018.
2. E. Yilmaz, S. Ozev and K. Butler, "Adaptive Multidimensional Outlier Analysis for Analog and Mixed Signal Circuits," *Proceedings of the 2011 IEEE International Test Conference*, 2011.
3. A. Jauhri, B. McDanel and C. Connor, "Outlier Detection for Large Scale Manufacturing Process," *IEEE International Conference on Big Data: Big Data 29*, 2015, pp. 2771–2774.
4. H. C. M. Bossers, J. L. Hurink and G. J. M. Smit, "Online Univariate Outlier Detection in Final Test: A Robust Rolling Horizon Approach," *Proceedings of the 16<sup>th</sup> IEEE European Test Symposium*, 2011, p. 201.
5. P. O'Neill, "Production Multivariate Outlier Detection Using Principal Components," *Proceedings of IEEE International Test Conference*, 2008.
6. B. Deschamp, "Analysis of Mammalian Cell Culture Data, Ph.D. Dissertation," *University of Massachusetts-Lowell*, 2018.
7. A. Nahar, R. Daasch and S. Subramaniam, "Burn-In Reduction Using Principal Component Analysis," *Proceedings of the IEEE International Conference on Test*, 2005.




# Ducommun

## RF Switching Solutions from DC-110 GHz




**PIN diodes from 30MHz to 110 GHz**

- SPST, SPDT
- SP4T, SP6T, SP8T
- Broadband, Narrowband
- High-Power



**Coax Switches from DC to 46 GHz**

- SPDT, Transfer
- SP3T-SP10T
- Non-terminated & Terminated
- 50Ω and 75Ω impedances



**Ducommun offers Switch Matrix Solutions!**

[www.ducommun.com/engineeredolutions/rfproducts](http://www.ducommun.com/engineeredolutions/rfproducts)  
 For additional information contact our sales team at: 310-513-7233 or [rfsales@ducommun.com](mailto:rfsales@ducommun.com)



# Microwave / RF Ceramic Capacitor

**DLC70 Series**  
High Q, NPO,  
RF/Microwave MLCC



#### Product Features

- ✓ High Q
- ✓ Zero TCC
- ✓ Low ESR/ESL
- ✓ Low Noise
- ✓ Ultra-Stable Performance
- ✓ Extended WVDC available

**SIZE:** 0402, 0603, 0505, 0805,  
0710, 1111, 2225, 3838 for  
RF/Microwave;  
6040, 7575, 130130 for High  
RF Power

**DLC75 Series**  
Ultra-Low ESR, High Q,  
NPO, RF/Microwave MLCC



#### Product Features

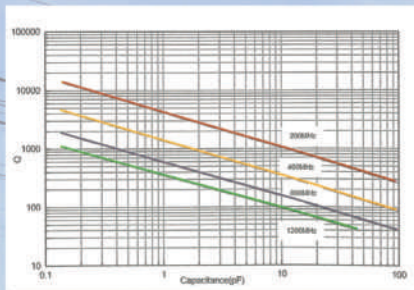
- ✓ Ultra-Low ESR
- ✓ High working voltage
- ✓ High Self Resonance  
Frequency

**SIZE:** 0603, 0805, 1210

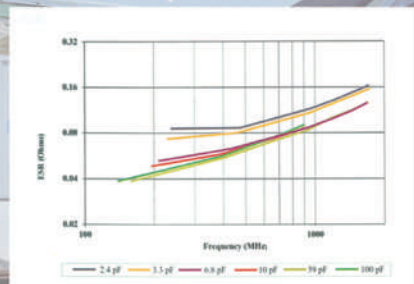
# Dalicap

Dalicap Tech. is a professional enterprise specializing in R&D, manufacturing and sales of multi-layer ceramic capacitors (MLCC). Dalicap is also a leading supplier of Hi-Q, ultra-low ESR RF/Microwave MLCC, applied especially on the fields of MRI, semiconductor device, industrial laser equipment, testing and analyzing instruments, balise and 4G/5G PA etc.

Dalicap is committed to providing high-performance, high-reliability products to customers. The R&D and engineering teams have extensive experience to quickly support and response to customized request. The company has an unique RF lab, by RF simulation and individual RF testing method to guarantee product realization.



DLC70A(0505) Q Value  
and Capacitance Curve



DLC75P(0603) Equivalent  
Series Resistances (ESRs)

# The Phase Noise Challenge Pacing the Race to 5G

Bill Linstrom, Ron Parrott and Allen Sweet  
VIDA Products, Rohnert Park, Calif.

*The wireless communication industry's move toward mmWave frequencies, driven by 5G cellular, is posing a challenge to existing oscillator technologies, particularly phase noise. New techniques and approaches may be required.*

**5**G is pushing the state-of-the-art in virtually every area of cellular radio technology, including higher channel frequencies. To meet the most ambitious 5G goals, including peak data rates of 10 Gbps, cell edge data rates of 100 Mbps and 1 ms end-to-end latency, near-mmWave frequency bands above 20 GHz are needed in the U.S. One of the many challenges posed by near-mmWave frequencies is managing radio link noise and interference. In

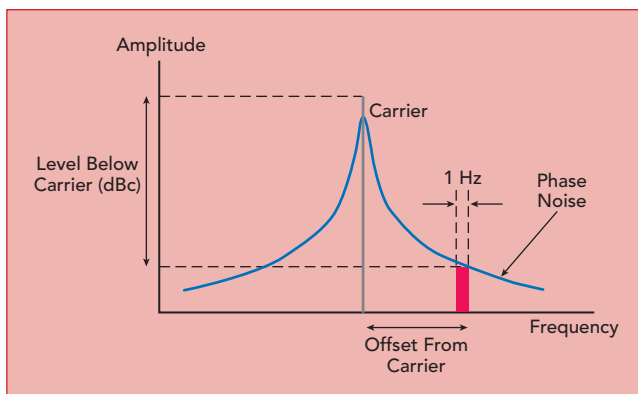
1948, Claude Shannon showed that radio system capacity depends not only on the signal strength and bandwidth, but also on the radio link noise level.<sup>1</sup>

$$\text{Channel Capacity} = \text{Signal Bandwidth} * \log_2 \left( 1 + \frac{\text{Signal Power}}{\text{Noise Power}} \right) \quad (1)$$

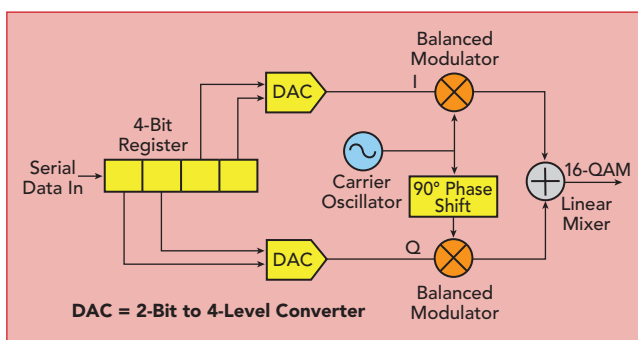
Radio link noise has two broad sources: internal and external. External noise, also termed interference, is related to the environment, while internal noise is related to the radio system's electronic circuitry. The main interest of this article is the internal noise generated in the local oscillator (LO), i.e., the phase noise. From Shannon's Law, it is the key limiter of radio channel capacity. Quoting James Buckwalter, a professor at the University of California Santa Barbara, "Oscillator phase noise is a silent killer in interference limited systems."<sup>2</sup>

Oscillator phase noise is defined as the oscillator's short-term instability resulting in random fluctuation in the frequency or phase of its output (see **Figure 1**). Phase noise is measured as the power spectral density for each 1 Hz frequency of a single sideband relative to the power spectral density of the oscillator's central frequency, in dBc/Hz. A well-known empirical model for phase noise, the Leeson equation was developed to describe and predict LC tank circuit phase noise performance.<sup>3</sup>

$$L_{(\Delta\omega)} = 10 \log \left[ \frac{2FkT}{P_{\text{sig}}} \cdot \left[ 1 + \left( \frac{\omega_0}{2Q\Delta\omega} \right)^2 \right] \cdot \left( 1 + \frac{\omega_1}{|\Delta\omega|} \right) \right] \quad (2)$$



▲ **Fig. 1** Oscillator phase noise.



▲ **Fig. 2** Typical QAM (I/Q) modulator.



GaAs

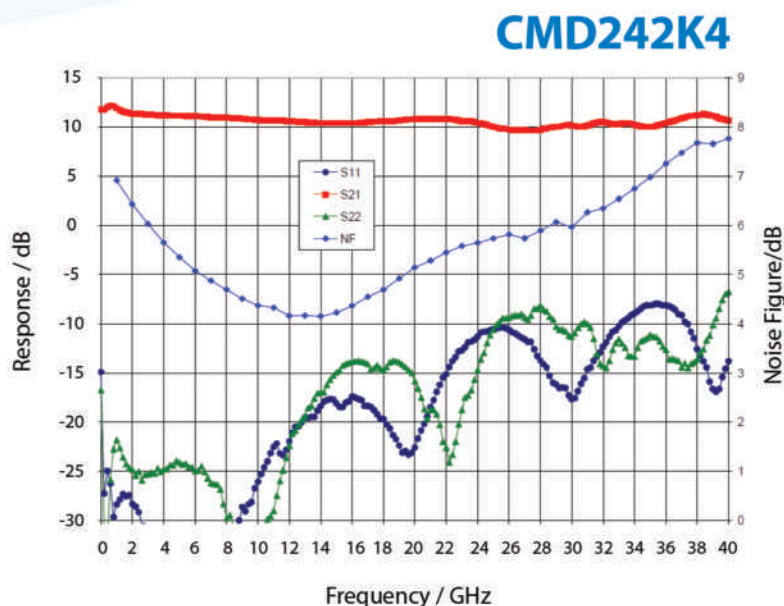
# DISTRIBUTED AMPLIFIERS

WIDE BANDWIDTH DC - 40 GHz



**High Frequency Surface Mount Packaging Available**

Custom MMIC now offers select products, over 20 GHz, in plastic surface mount air-cavity QFN packages. This new "K" series package maintains performance similar to die level and can be tested with our easy to use evaluation boards. Order one today!



## Delivering performance without compromise

The CMD242K4 is a wideband GaAs Distributed Amplifier that operates from DC to 40 GHz, providing customers with a broad frequency range of operation and industry leading performance making this MMIC perfect for EW, Test/Instrumentation and a host of other millimeter wave applications.

*Where can we take you next?*

 **Custom  
MMIC**  
CustomMMIC.com

In Leeson's equation,  $F$  is an empirically determined constant for curve fitting,  $k$  is Boltzmann's constant,  $T$  is the absolute temperature in Kelvin,  $P_{sig}$  is the tank power dissipation,  $\omega_0$  is the oscillation frequency,  $Q$  is the loaded oscillator quality factor,  $\Delta\omega$  is the offset from the oscillation frequency and  $\omega_1$  is the corner frequency between the 30 dB/decade and 20 dB/decade slope regions.

## EFFECT OF LO PHASE NOISE

LO phase noise performance is critical to modern radio system performance, especially to high data rate orthogonal frequency division multiplexing (OFDM) systems.<sup>4</sup> OFDM is the data modulation technique used by most data transmission systems today, including LTE (4G cellular), Wi-Fi, cable and DSL networks. OFDM enables transmis-

sion systems to operate close to the Shannon theoretical capacity, overcoming frequency specific interference but susceptible to oscillator phase noise.

In an ideal OFDM modulator, the data stream is mixed with the ideal oscillator frequency (labeled carrier oscillator in **Figure 2**) to produce ideal modulated symbols (see **Figure 3a**). In real life, however, the LO generates the carrier frequency and additional close-in frequencies called additive phase noise. These frequencies, i.e., the carrier plus the additive phase noise, are mixed with the data to produce the modulated signal. The addition of the phase noise around the central carrier frequency

## Millimeter-Wave HPAs: Higher Bandwidth to Combat New Threats at 70,000 ft Above Sea Level

High-power amplifiers designed and tested for harsh environments and high altitudes

- 26.5-40.0 GHz, 125W MPM dB-3201
- 27.5-31.0 GHz, 200W MPM dB-3202
- 34.5-35.5 GHz, 700W TWT Amplifier dB-3860
- 32.0-36.0 GHz, 400W TWT Amplifier dB-3861
- 34.5-35.5 GHz, 700W TWT Amplifier dB-3709i

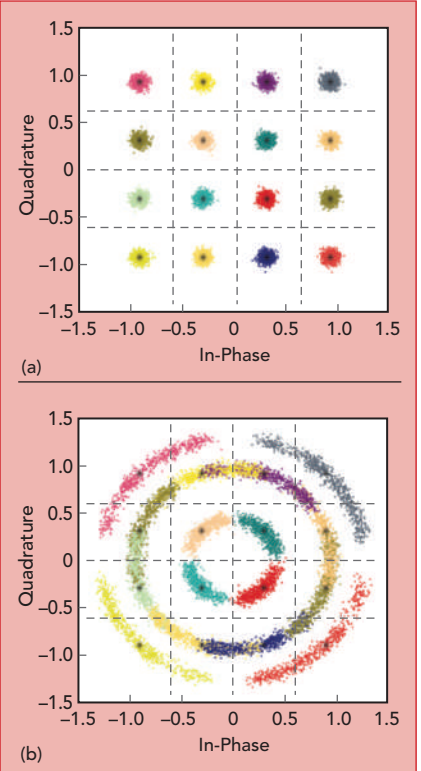


**dB Control**  
a HEICO company  
Reliability by Design®

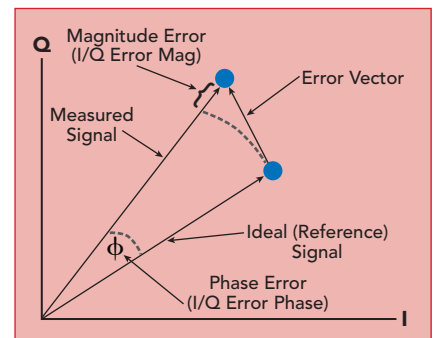
For specs and customization info, call 510-565-2325  
or email [info@dBControl.com](mailto:info@dBControl.com)

© 2019 dB Control Corp

US Air Force photo by Senior Airman Luke Milano



▲ **Fig. 3** I/Q constellation (a). If the inter-symbol interference is too high, accurate demodulation is impossible (b).



▲ **Fig. 4** Error vector magnitude.





# Planar Monolithics Industries, Inc.

## Integrated RF/Microwave Assemblies & Modules

PMI offers the highest quality multi-function modules and integrated microwave assemblies for industrial and military applications in frequency ranges up to 50 GHz. Built to your specifications with functions that include amplification, attenuation, filtering, switching, phase shifting, power detection, modulation, coupling, limiting and digital/analog control. PMI offers many other standard models with various options that are available at:

<https://www.pmi-rf.com/categories/integrated-mic-mmic-assemblies>

Amplifiers

Attenuators

Bi-Phase Modulators

Couplers

Detectors - RF / Microwave

DLVAs, ERDLVAs & SDLVAs

Filters & Switched Filter Banks

Form, Fit, Functional Products & Services

Frequency Converters

Frequency Sources

Frequency Discriminators & IFM

Frequency Synthesizers

Gain & Loss Equalizers

Integrated MIC/MMIC Assemblies

IQ Vector Modulators

Limiters - RF / Microwave

Miscellaneous Products

Monopulse Comparators

Multifunction Integrated Assemblies

Phase Shifters

Power Dividers

Rack & Chassis Mount Products

Receiver Front Ends & Transceivers

Single Side Band Modulators

SMT & QFN Products

Switch Matrices

Switch Filter Banks

Switches - Solid-State

Systems - Radar Sense & Avoid

Systems - Fly Eye Radar

USB Style Product

### 3U Open VPX Transceiver

#### PTRAN-100M18G-SER-3UVPX-10HP-MAH

<http://www.pmi-rf.com/mod>

- 100 MHz to 18.0 GHz
- Integrated Up and Down Converters
- IF up to 4 GHz
- Time Gated SDLVA for Pulse Blanking
- -80 to -10 dBm Input Dynamic Range
- Customizable Switched
- 0 to +10 dBm Transmit Power
- 100 ns Switching Speed
- Fits into a 3U open VPX form factor utilizing the high speed VITA 67 RF connector.
- CW Immunity

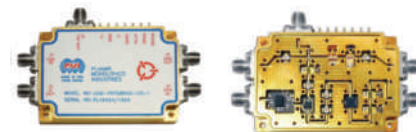


### Amplified RF Downconverter Modules

#### LCM-7R7G8R2G-CD-1 & LCM-16G100MBW-CD-1

<https://www.pmi-rf.com/model-no-lcm-7r7g8r2g-cd-1>

<https://www.pmi-rf.com/model-no-lcm-16g100mbw-cd-1>



- Customized Frequency Range
- LCM-7R7G8R2G-CD-1: 7.7 to 8.2 GHz
- LCM-16G100MBW-CD-1: 16.0 GHz  $\pm$  50 MHz
- IF range of DC to 10 KHz
- Features a 20 dB voltage programmable attenuator and a 360° phase shifter.
- Designed for low spectral noise and high reverse isolation
- Slim line housing measuring only 2.5" x 1.75" x 0.4"

### Phase and Amplitude Matched Integrated Modules in sets of four

#### PCAM-05G18G-INT-S5F

<https://www.pmi-rf.com/product-details/pcam-05g18g-int-s5f>



- Operating Frequency Range of 5.0 to 18.0 GHz
- Built in sets of four, phase and amplitude matched to industry leading levels of  $\pm 10^\circ$  and  $\pm 1.5$  dB over the frequency range.
- Incorporates limiters, LNAs, switches, and variable digital attenuators.
- These units allow for high and low gain paths, a calibration input, and an auxiliary channel.
- A low noise figure and high output P1dB of +15 dBm are achieved by utilizing system analysis software and in-house hybrid/MIC processes.
- SMA Female connectors and small housing configuration.

### Quad Phase and Amplitude Matched Diplexer Gain Module

#### DGM-18G40G-292FF-DS

<https://www.pmi-rf.com/model-dgm-18g40g-292ff-ds>



- Operating Frequency Range: 18.0 to 40 GHz.
- Switched output and an integrated power divider feeding the four antenna inputs via a 20 dB coupler for ease of system integration.
- Band select function not only switches bands, but allows the amplified bands not in use to be turned off to reduce power consumption.
- Designed to have better than 60 dB harmonic suppression.

### CW Immune EW Detector Modules

#### EWDM-2G8G-65-70MV & EWDM-8G18G-65-70MV

<https://www.pmi-rf.com/product-details/ewdm-2g8g-65-70mv>

<https://www.pmi-rf.com/product-details/ewdm-8g18g-65-70mv>



- Customized Frequency Ranges:  
EWDM-2G8G-65-70MV: 2.2 to 8.0 GHz  
EWDM-8G18G-65-70MV: 8.0 to 18 GHz
- Internal switch used to switch between the Bit IN and RF IN with input blanking on both ports.
- RF output port is provided with a gain of 33 dB minimum
- Video output is designed to drive a 150 ft. cable with input dynamic range of 65 dB & TSS of -71 dBm

### Active, Filtered, Frequency Doubler Modules

#### PFDM-3R66R65-13-7R5DC-SFF

<https://www.pmi-rf.com/active-filtered-frequency-doubler-module-3-6ghz-to-13-7ghz>



- Frequency Range: Input: 3.6 - 6.65 GHz  
Output: 3.6 - 13.3 GHz
- Dual RF Output - TTL Switchable, Switching Speed: < 20 ns
- RF Output #1 to RF Output #2 Isolation: >35 dB
- Slim line housing measuring only 3.0" x 1.5" x 0.375"
- Other Frequency Ranges and Output Power Levels Available.

### West Coast Operation:

4921 Robert J. Mathews Pkwy, Suite 1

El Dorado Hills, CA 95762 USA

Tel: 916-542-1401, Fax: 916-265-2597

### East Coast Operation:

7311-F Grove Road

Frederick, MD 21704 USA

Tel: 301-662-5019, Fax: 301-662-1731

[sales@pmi-rf.com](mailto:sales@pmi-rf.com) • [www.pmi-rf.com](http://www.pmi-rf.com)

Content is copyright protected and provided for personal use only - not for reproduction or retransmission.

For reprints please contact the Publisher.

ISO 9001:2015 REGISTERED

**TABLE 1**

**ERROR VECTOR MAGNITUDE REQUIREMENTS**

Modulation	Max EVM (%)
QPSK	18.5
16-QAM	13.5
64-QAM	9.0
256-QAM	4.5

produces an error in the phase angle of the resulting symbol, called its error vector magnitude (EVM)<sup>5</sup>, leading to a shift in the placement of the symbol in the constellation (see **Figure 4**). Too great an error obscures the symbol, making demodulation questionable or impossible, as shown in Figure 3b.

The EVM, an expression of the symbol position in the decoded constellation relative to ideal, is an

important specification that cellular system equipment must meet to qualify for commercial use<sup>6</sup> (see **Table 1**). Symbol position errors, measured as EVM, have multiple causes. The most important source of vector error for high data rate OFDM radio communications is LO phase noise.<sup>7</sup> Symbol vector errors lead to inter-symbol interference, which is measured as symbol error rate. Symbol errors, which corrupt the data stream, slow the data rate by forcing some data to be resent, degrading link performance. In this way, LO phase noise degrades radio link performance.

## Phase Noise Power

Total phase noise power is key to understanding the impact of oscillator phase noise on radio link performance. Shannon's Law says with the noise power equal to the signal power, the channel capacity is equal to the bandwidth of the broadcast signal, e.g., 1 Mbps for a 1 MHz broadcast bandwidth. It also says that with every reduction of noise power by a factor of 10 relative to the signal power, the channel capacity goes up by a factor of 3.3. If the noise power is 10 percent of the carrier's power, the channel capacity is 3.3× the bandwidth of the broadcast signal, e.g., 3.3 Mbps for a 1 MHz broadcast bandwidth. If the noise power is 1 percent of the carrier's power, the channel capacity is 6.6× the bandwidth and so on.

From Equation 2, the LC tank circuit oscillator phase noise power increases with the square of the frequency. For example, comparing the phase noise of 2 and 20 GHz VCOs (see **Figure 5**), the total phase noise power for the 2 GHz VCO is -46 dBc, while the total phase noise power for the 20 GHz VCO is -27 dBc, 19 dBc higher. The results in the figure were calculated using a piecewise linear model assuming the phase-locked loop (PLL) is flat at -70 dBc in both cases. Considering only the phase noise power and not other interference sources, the calculated channel capacity of the system with the 2 GHz VCO and a signal bandwidth of 1 MHz is 15.3 Mbps, while the capacity of the system with the 20 GHz VCO and the same signal bandwidth is only



**NORDEN  
MILLIMETER**

## Choose Norden Millimeter for LNA, 5G, E & V Band, and Military Amplifiers

- 5G**
  - Wideband covering multiple 5G Bands
  - LNAs & Power Amplifiers
  - GaN & GaAs COTS Designs
- LNA**
  - Broadband & Narrow Band 500 MHz to 110 GHz
  - Connectorized & Waveguide
  - Custom Designs
- E & V Band**
  - Incorporate Multipliers- X2, X4, X8
  - LNAs & Power Amplifiers
  - Broadband & Narrow Band
- Military**
  - -40° to +85° Operating Temps
  - Compact hermetic cases for airborne applications
  - Thermal Compensation, Internally regulated, and Gain control options available

**www.NordenGroup.com**  
**(530) 642-9123 Ext. 1#**



# RF

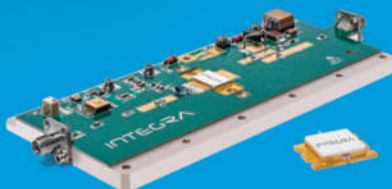
## EFFICIENT

Optimize your HPA with Integra's innovative GaN/SiC RF power solutions for defense radars, air traffic control, avionics, weather radar and ISM applications. Our patented, thermally-enhanced transistors and pallets deliver up to 85% efficiency with best-in-class output power and gain. Exceed your most demanding performance requirements with Integra's standard and semi-custom GaN/SiC solutions.

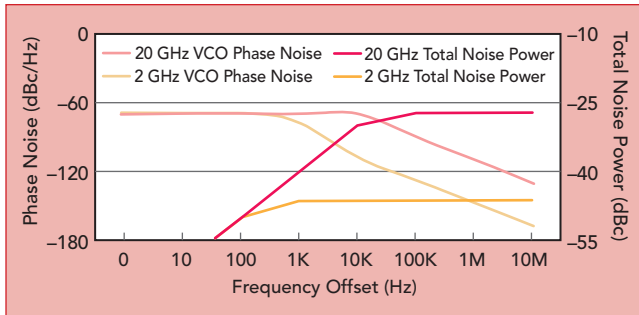


# MW ER

# DEVICES



# INTEGRA

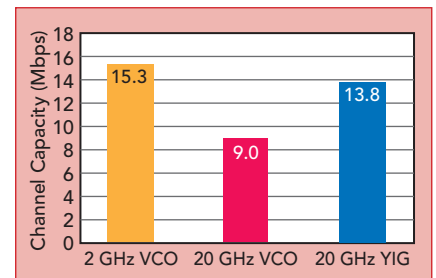


▲ Fig. 5 Phase noise and total noise power of 2 and 20 GHz VCOs.

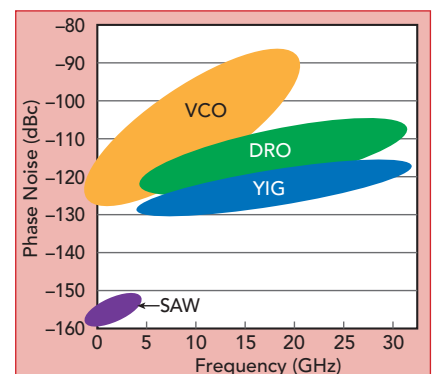
9 Mbps, a 41 percent reduction in channel capacity (see **Figure 6**). The reduced capacity is due to the significantly higher phase noise power of the 20 GHz VCO compared to the 2 GHz VCO, i.e., 19 dB or almost 80×.

## Challenges at mmWave Frequencies

A fundamental question for 5G and other high modulation density radio systems is what oscillator technology to use. **Figure 7** illustrates today's available technologies: SAW, VCO, dielectric resonance oscillator (DRO) and YIG. Tunability is an important feature, as is phase noise. Today's commercially available VCOs, although tunable, suffer increased phase noise between 2 and 3 dBc per GHz, free running, based on publicly available data sheets for commercial VCOs. Phase locking with a PLL will improve noise performance, which is how VCOs are typically used in these applications. SAW oscillators have good phase noise performance, but they are not available above 6 GHz, nor are they tunable. Neither the VCOs nor SAW oscillators appear to be ideal for frequencies above 20 GHz. DROs perform better than VCOs above 20 GHz; however, they also are not tunable. The question of which oscillator technology is best for high bandwidth connections in the near-mmWave spectrum has not been answered. Significant research continues to focus on finding a solution, including exotic VCO/PLL architectures, advanced SAW oscillators, micro/chip-scale atomic clocks



▲ Fig. 6 Oscillator channel capacity comparison at 1 MHz signal bandwidth.



▲ Fig. 7 Oscillator technology phase noise vs. frequency at 100 kHz offset.

## ACCOMPLISH YOUR MISSION WITH THE SMALLEST MOST COST EFFECTIVE CUSTOM RF/MICROWAVE FILTERS

Miniature SMT, Cavity Filters, available from 5.0 to 25 GHz

Nano, SMT Filters, 40 MHz to 6.0 GHz, in LC and Ceramic Topologies

Pico, SMT Filters, available from 5.0 GHz to 27 GHz

Miniature Filters, Mil-Std-202; compliant with RoHS or NON-RoHS options.

When an off-the-shelf filter could compromise your mission, call on the support of **3H Communication Systems**. 3H specializes in high-performance custom RF/microwave filter solutions from DC to 50GHz.

- Extensive experience with defense and prime contractors
- Cavity, Lumped Component and Ceramic topologies, connectorized and/or SMT formats; printed, suspended substrate, switch filter banks and multi-function assemblies
- ISO9001:2015 certified facilities; 5-year product warranty

Talk to one of our engineers.  
**Call 949.529.1583 or visit**  
**3HCommunicationSystems.com.**



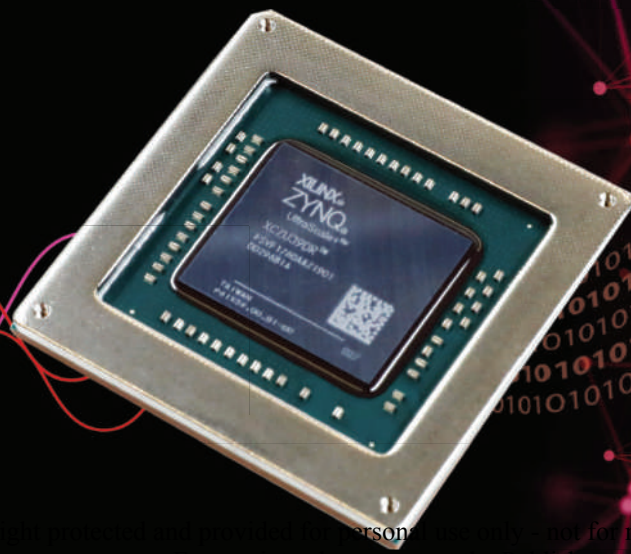
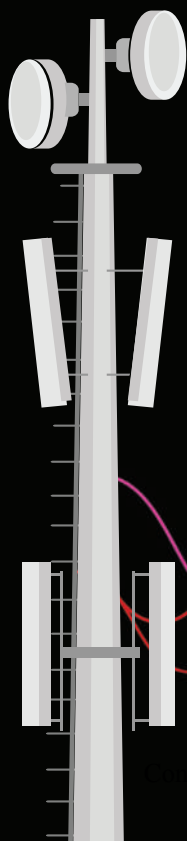


# 3<sup>rd</sup> Generation Zynq® UltraScale+™ RFSoc

---

World's Only Single-Chip Adaptable Radio Platform  
Now with **Full Sub-6GHz** Direct-RF Support

Watch the Video  
[www.xilinx.com/rfsoc/gen3](http://www.xilinx.com/rfsoc/gen3)



and YIG-tuned oscillators. As published in *Microwave Journal*, "The technical approach for supporting mmWave frequencies in handsets is being developed, but the technology is not as mature as for the sub-6 GHz bands."<sup>8</sup>

### YIG Oscillators

Of the technological options to provide high quality frequency sources in the near-mmWave and mmWave frequencies, YIG may be

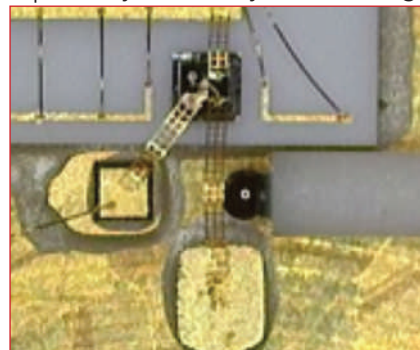
a promising option. As background, YIG-tuned oscillators exploit the property that YIG RF permeability is variable, depending on the strength of the encompassing DC-biased magnetic field. The frequency at peak YIG RF permeability tracks the strength of the encompassing magnetic field linearly, at a rate of 2.8 MHz/gauss and is modeled as a parallel resonant inductor and capacitor (i.e., LC tank circuit), with the inductor value varying with the

magnetic field strength. The peak YIG RF permeability frequency has very high Q (> 1000), resulting in low phase noise when the YIG is used as an oscillator tank circuit. While an electrically-coupled tank circuit depends on electron movement to realize the resonant frequency, a magnetically-coupled tank circuit depends on an oscillating magnetic field to couple energy in and out of the tank circuit at the resonant frequency of the tank. Instead of direct electron flow of the electrically connected tank, the magnetically connected tank operates as a transformer, inductively conducting energy between two electrically unconnected inductors.

Traditional YIG-tuned oscillators use a "negative resistance" topology to create a high performance oscillator. The negative resistance topology has been proven for decades and is optimized for power, size and performance. However, traditional YIG oscillator designs have not progressed significantly in more than 20 years, since Verticom introduced permanent magnet biasing in 1997.<sup>9</sup> In addition, with micro-formed wire loops hand-placed and hand-tuned, traditional YIG devices are inherently high cost, with manual assembly and tuning a barrier for high volume applications (see **Figure 8**). YIG-tuned oscillator design is ripe for innovation.

### Next-Generation YIG Oscillators

Next-generation YIG-tuned oscillators use an oscillator design integrated onto a custom MMIC to couple to the YIG resonator. This design approach enables high performance, increased functionality, low power, SMT packaging and low-cost. Although it has been tried repeatedly over the years, the neg-



▲ Fig. 8 Traditional YIG assembly.



# MilliBox™

MMWAVE RADIATION PATTERN TEST CHAMBER

#### FEATURES:

- Compact & Economical
- Modular design: 80-200cm far-field
- 18-95 GHz applications
- 2-axis 360° gimbal
- Open-source SW controller

#### APPLICATIONS:

- 5G (NR) mmWave
- 60GHz, 802.11ad, 802.11ay
- 77GHz automotive radar
- Misc mmWave designs



#### MILLIWA VE SILICON SOLUTIONS

Phone: +1 408 892 9595  
Email: [millibox@milliwave.com](mailto:millibox@milliwave.com)  
Web: [www.millibox.org](http://www.millibox.org)





# Where Performance Counts



Bandpass • Bandreject • Highpass • Lowpass • Transmit • Receive • Duplexers • Multiplexers

Eastern Wireless TeleComm understands just how much is on the line with each and every product we make. We continually provide the highest quality filter products, design support, and service to our customers each and every time. Where Performance Counts, Count on EWT.

Specializing in custom design and manufacturing of RF and Microwave filters and filter based products to 50 GHz.

**Military • Commercial  
Wireless • Space**

**[www.ewtfilters.com](http://www.ewtfilters.com)**

Eastern Wireless TeleComm, Inc.  
Tel: 410.749.3800 Fax: 410.749.4852  
[sales@ewtfilters.com](mailto:sales@ewtfilters.com)





ative resistance topology used for traditional YIG oscillators has never been successfully integrated onto an IC. This failure is due, in part, to the relatively low RF power in the circuit, requiring a long sense wire to couple the electromagnetic energy back and forth between the YIG and the negative resistance driver circuit. Next-generation YIG-tuned oscillators using a differential resonant ring topology<sup>10,11</sup> overcome

the limitations of the negative resistance topology (see **Figure 9**). By controlling the RF power of the YIG-tuned circuit and controlling parasitic reactances and magnetic interference modes, high performance, low power, small size and low-cost oscillators can be produced.

Critical elements of the design of the MMIC-based YIG oscillator include: assuring a uniform magnetic bias field, efficiently coupling

the RF energy into and out of the YIG sphere, achieving 360 degree loop phase shift and managing stray magnetic fields from circuit conductors. The DC magnetic bias field is based on the proven combination of permanent and tunable electro-magnets to minimize power and size. RF magnetic coupling is managed within the MMIC, where power levels and impedances are tightly managed with a combination of design elements and active control.

A key difference between the negative resistance and differential resonant ring architectures is the operational mode of the YIG sphere. In the negative resistance circuit, the YIG sphere is modeled as a magnetically-coupled parallel tank circuit. In the differential resonant ring architecture, the YIG sphere is used as a filter element, where only the energy at the tuned frequency is transmitted between the loops in the ring. Naturally, the design of the oscillator must conform to the basic tenants: the loop phase shift must be an integer multiplier of 360 degrees and the loop gain must be greater than 1 at the frequencies of interest.

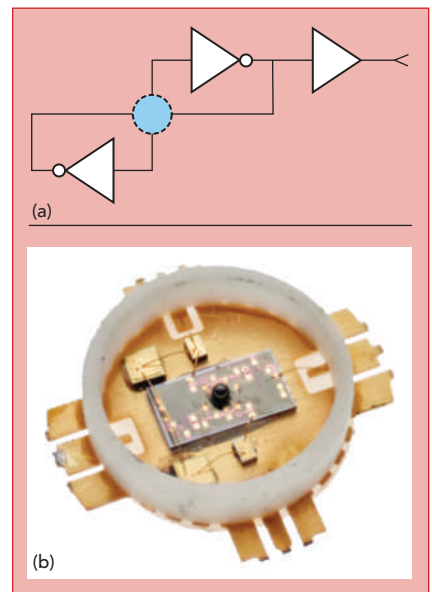
The differential resonant ring MMIC architecture simplifies the oscillator magnetic design, greatly reducing stray electromagnetic flux. Reducing the stray flux has eliminated the need for the mitigations necessary with traditional YIG oscillators.



**XMA** POWERED BY Omni Spectra®

*Solutions Come Standard*

- Attenuators
- Terminations
- DC Blocks
- Adapters
- Equalizers
- Power Dividers
- Directional Couplers
- Cryogenic RF Components
- Custom Solutions



**▲ Fig. 9** Differential resonant ring oscillator schematic (a) and early prototype (b).



# ACE THE TEST WITH KAEPLUS!

[ANALYZER CALIBRATION EXTENDER]

- ✓ SELF-CALIBRATE KAEPLUS PIM ANALYZERS IN THE FIELD
- ✓ SUCCESSFUL CALIBRATION IN LESS THAN ONE HOUR
- ✓ CALIBRATE MULTIPLE IPA, ITA, IQA (B & C SERIES) IBA AND SI E-SERIES INSTRUMENTS WITH ONE ACE UNIT



The **Kaelus ACE-1000A** is the industry's first calibration extender that allows customers to self-calibrate their PIM analyzers in the field. Reducing downtime to less than one hour, the ACE-1000A following a successful calibration, will extend your analyzer's calibration date to 12 months. The calibration fee is charged prorated, allowing to calibrate at any time.

***Same-day shipping now available!***



Kaelus ACE-1000A

For more information contact us:  
US: +1 303 768 8080, Australia: +61 (0) 7 3907 1200,  
China: +86 512 6296 0028, Europe: +44 784 244 7532  
[www.Kaelus.com](http://www.Kaelus.com).

**kAelus**  
an INFINIT® brand

Content is copyright protected and provided for personal use only - not for reproduction or retransmission.  
For reprints please contact the Publisher.

## Technical Feature

tors, eliminating any need for hand tuning. A direct consequence of eliminating hand tuning is the ability to use advanced manufacturing assembly processes used for ICs and multi-chip modules. Next-generation YIG oscillators are designed to use this manufacturing flow to keep assembly costs low and yields high.

Beyond the basic improvements achieved with IC integration, next-generation YIG oscillators will offer

additional features and functionality, capitalizing on Moore's Law. For example, with the differential resonant ring architecture, doubling the frequency is much simpler compared to traditional single-ended YIG oscillators, as well as dividing the frequency. Combining a new topology with IC manufacturing processes, the next-generation YIG oscillator can evolve into microwave and mmWave synthesizers on a chip. ■

*Hundreds of Miles of Cable*  
*Thousands of Connectors*  
*Millions of Piece Parts*  
*Billions of Possibilities:*  
**One Clear Choice**

**KOAXIS.com**  
RF Cable Assemblies



**Build It, See It, Buy It online**

Made in the USA

+1 (610) 222-0154

## References

1. C. Shannon, "A Mathematical Theory of Communication," *The Bell System Technical Journal*, Vol. 27, No. 3 and 4, pp. 379-423, 623-656, July, October, 1948.
2. J. Buckwalter, "Reciprocal Mixing: The Trouble with Oscillators," [Online]. Available: [www.ece.ucsb.edu/Faculty/rodwell/Classes/ece218c/notes/Lecture4\\_ReciprocalMixing.pdf](http://www.ece.ucsb.edu/Faculty/rodwell/Classes/ece218c/notes/Lecture4_ReciprocalMixing.pdf). [Accessed 1 April 2019].
3. D. B. Leeson, A Simple Model of Feedback Oscillator Noise Spectrum, Vol. 54. No. 2, *Proceedings IEEE*, February 1966, pp. 329-330.
4. M. R. Khanzadi, "Phase Noise in Communication Systems Modeling, Compensation, and Performance Analysis," Chalmers University Technology, Göteborg, Sweden, 2015.
5. A. Georgiadis, "Gain, Phase Imbalance, and Phase Noise Effects on Error Vector Magnitude," *IEEE Transactions on Vehicular Technology*, Vol. 53, No. 2, pp. 443-449, March 2004.
6. European Telecommunications Standards Institute (ETSI), "5G," European Telecommunications Standards Institute (ETSI), [Online]. Available: <https://www.etsi.org/technologies/5g>. [Accessed 3 April 2019].
7. A. G. Armada, "Understanding the Effects of Phase Noise in Orthogonal Frequency Division Multiplexing (OFDM)," *IEEE Transactions on Broadcasting*, Vol. 47, No. 2, pp. 153-159, 2001.
8. B. Thomas, "5G Brings New RF Challenges for Handsets," *Microwave Journal*, October 9, 2018. [Online]. Available: [www.microwavejournal.com/articles/print/31177-g-brings-new-rf-challenges-for-handsets](http://www.microwavejournal.com/articles/print/31177-g-brings-new-rf-challenges-for-handsets). [Accessed 21 3 2019].
9. Verticom, Inc. (1997). Microwave Ferrite Resonator with Parallel Permanent Magnet Bias. 5,677,652.
10. R. Parrott and A. A. Sweet, "A Wide band, Low Phase Noise Differential YIG Tuned Oscillator," WAMICON, pp. 1-3, June 2014.
11. M. van Delden, N. Pohl, K. Aufinger, C. Vaer and T. Musch, "A Low-Noise Transmission-Type Yttrium Iron Garnet Tuned Oscillator based on a SiGe MMIC and Bond-Coupling Operating up to 48 GHz," *IEEE Transactions on Microwave Theory and Techniques*, Accepted but not yet published, 2019.

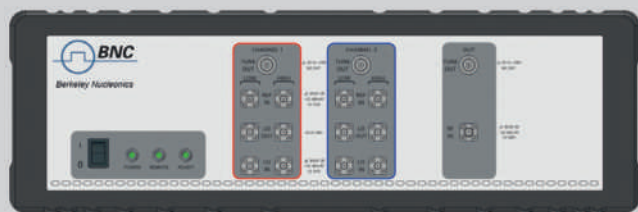


# AnaPico Ltd. of Switzerland.

**We make  
the difference**

**Swiss made RF / Microwave Signal Generators and  
Analyzers available in the U.S. from Berkeley Nucleonics!**

AnaPico Ltd. of Switzerland designs and manufactures instruments with unique features for demanding RF / Microwave applications. Our experienced engineering team continues to outperform in critical areas like low phase noise, fast switching and compact designs. These state-of-the-art designs are now available in the US market from Berkeley Nucleonics.



## MODEL 7300

### All-In-One Compact Measurement System!

Covering frequency up to 7 / 26 / 40 GHz, direct and additive phase noise and amplitude noise measurement, transient analysis, short- and long-time frequency stability analysis, one-step VCO characterization, baseband FFT, spectral analysis. Access to two internal references (HW) available with the new option LO.

- Input Power Range: -10 to +20 dBm
- Range: 100 MHz to 7, 26 and 40 GHz
- Analysis Offset: 0.01 Hz to 100 MHz

#### For US Customers:

Call: 800-234-7858

Email: [info@berkeleynucleonics.com](mailto:info@berkeleynucleonics.com)

Visit: [www.berkeleynucleonics.com](http://www.berkeleynucleonics.com)

#### For Non-US Customers:

Email: [sales@anapico.com](mailto:sales@anapico.com)

Visit: [www.anapico.com](http://www.anapico.com)



Content is copyright protected and provided for personal use only - not for reproduction or retransmission.

For reprints please contact the Publisher.

# Design of a Broadband Harmonically-Tuned Power Amplifier with Gate-Source Parasitic Compensation

Zhiquan Cheng

Hangzhou Dianzi University, Hangzhou, China, Suzhou Institute of Nano-Tech and Nano-Bionics, Suzhou, China

Lei Xu, Guohua Liu and Han Feng

Hangzhou Dianzi University, Hangzhou, China

Steven Gao

University of Kent, Canterbury, U.K.

A 1.5 to 2.6 GHz broadband power amplifier (PA) based on a GaN HEMT is designed to achieve high-power and efficiency. The transistor's gate-source parasitic effect is reduced with a novel parasitic compensation circuit at the input. To achieve a broadband harmonic match and expand its bandwidth at the fundamental, radial microstrip theory is employed in a harmonic control network. The output power is between 43.4 and 45.6 dBm, and its drain efficiency is 65 to 76.9 percent from 1.5 to 2.6 GHz. Gain is above 10 dB. Second and third harmonic suppression levels are  $-15.6$  to  $-26.1$  and  $-19.4$  to  $-40.5$  dBc, respectively. The measured results are consistent with the simulation.

**W**ith the development of wireless communication technology, the need for higher data rates and correspondingly wider bandwidths is growing rapidly. At the RF transceiver, this puts a greater demand on the PA. As it consumes the most prime power, PA efficiency has a large impact on the operating budget of a communications system.

Traditional PAs, i.e., classes A, AB and B, are inefficient. To save energy and increase signal coverage, communication system PAs usually employ high efficiency and high output modes, such as classes D,<sup>1</sup> E,<sup>2</sup> F<sup>3-5</sup> and inverse class F.<sup>6</sup> They also leverage the excellent performance of third-generation semiconductor transistor technology, such as GaN HEMT.<sup>7-8</sup>

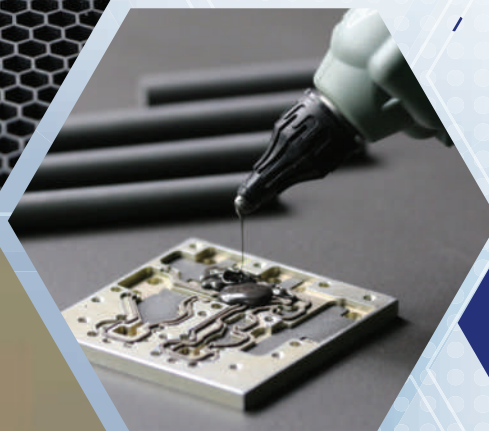
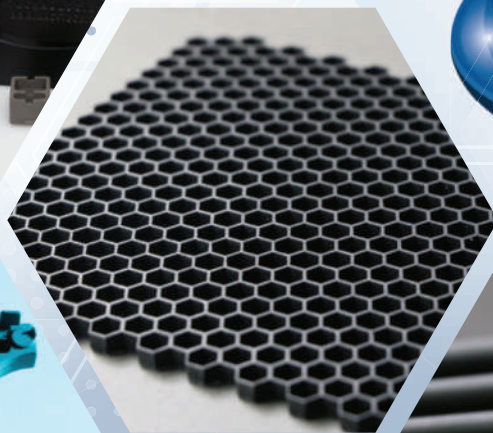
## CLASS F PA ANALYSIS AND DESIGN

Since the PA operates in a large signal state, harmonics are inevitably generated, reducing output power and efficiency. Class F PAs, however, achieve good performance through harmonic control. The voltage and current waveforms at the transistor drain are shaped with a harmonic control network so the voltage waveform is a square wave, and the current waveform is a half sine wave. The waveforms of the drain voltage and current are expressed as

$$V(\theta) = V_{DD} + V_1 \sin \theta + \sum_{n=3,5,7}^{\infty} V_n \sin \theta \quad (1)$$

$$I(\theta) = I_{dc} - I_1 \sin \theta - \sum_{n=2,4,6}^{\infty} I_n \cos \theta \quad (2)$$





# Better Solutions for EMI/RF Interference

ARC Technologies, a Hexcel company, provides an array of standard and custom materials including:

- RF Absorbers
- Hot Melt Absorbers
- Injection-Molded Plastics
- Structural Composites
- Testing, Plating and Machining Capabilities
- Conductive Solutions
- High Frequency EMI Vents

**Our materials make the difference!**

**Learn more about our material solutions at [www.hexcel.com/arc-tech](http://www.hexcel.com/arc-tech)**

For questions and inquiries call us at (978) 388-2993 or email us at [sales@arc-tech.com](mailto:sales@arc-tech.com)



To request a Engineer's Survival Kit with samples of ARC Technologies materials, scan the QR code or visit [www.hexcel.com/products/survival-kit](http://www.hexcel.com/products/survival-kit)

Content is copyright protected and provided for personal use only - not for reproduction or retransmission.

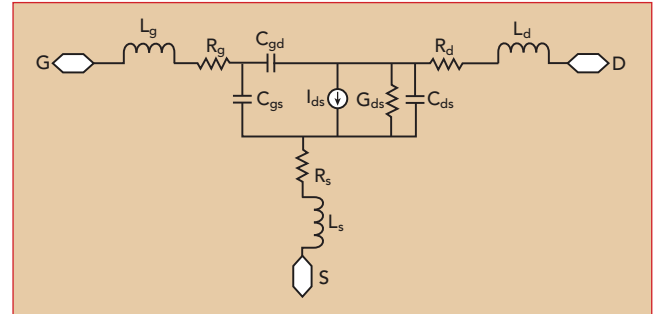
For reprints please contact the Publisher.

According to theory,<sup>5,9</sup> even harmonics are matched to  $0\ \Omega$ , odd harmonics to infinity and the fundamental to  $50\ \Omega$ . Due to deficiencies of the class F PA in practical designs, this work describes two improvements: one, because the gate-source parasitics of the GaN HEMT transistor degrade the output power and efficiency of the PA, a gate-source parasitic compensation circuit is employed. And two, because the traditional class F PA uses a high Q output impedance matching transformer, limiting its bandwidth, this work uses low Q radial microstrip lines to control harmonics.

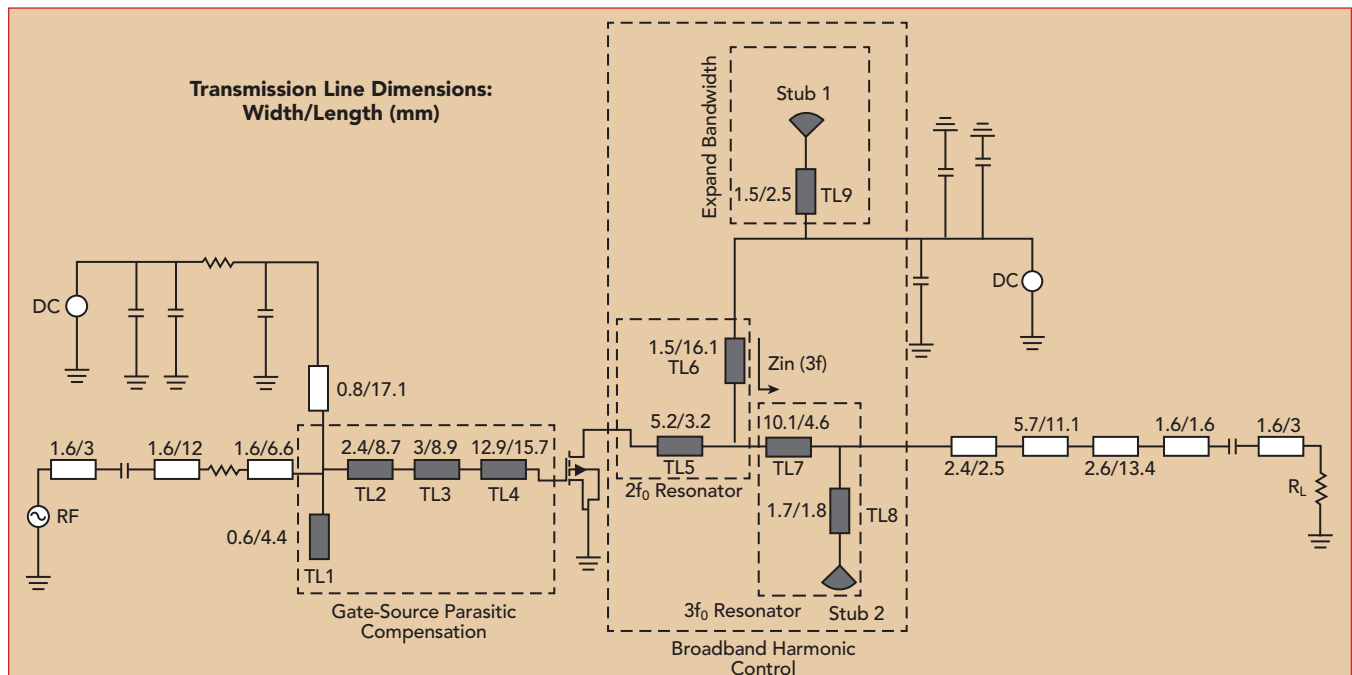
## Gate-Source Parasitic Compensation

The GaN HEMT used in this article is an active non-linear device, with harmonics caused by its parasitics.

Gate-to-source parasitics cause the input of the transistor to deviate from a pure sinusoidal wave, reducing PA performance. The transistor model, shown in **Figure 1**,



▲ Fig. 1 GaN HEMT model.



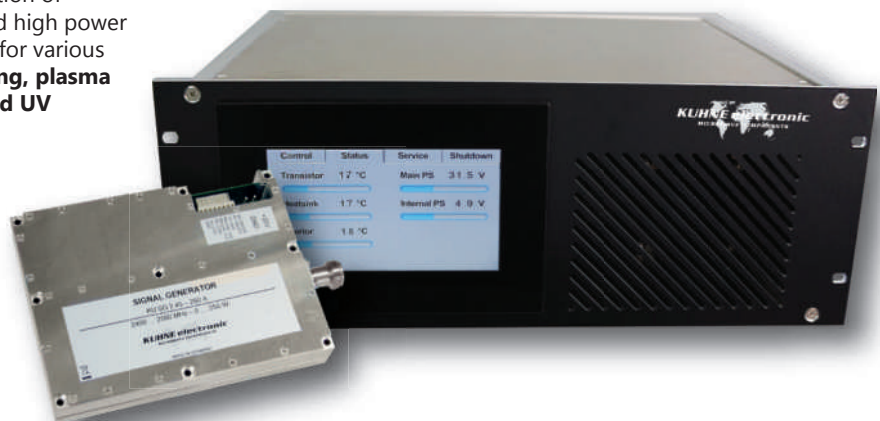
▲ Fig. 2 PA matching circuit design.

## High Power Solid State Microwave Generator Solutions

Kuhne electronic carries a significant selection of off-the-shelf as well as customized low and high power solid state microwave generator solutions for various kind of applications e.g. **microwave heating, plasma generation, ion implantation, PECVD and UV lighting.**

### FEATURES

- 915 MHz, 2.45 GHz, X-Band
- Remote control (LAN, serial)
- CW or pulsed operation
- Adjust frequency and output power
- Monitoring forward & reflected power
- Operational safety through numerous protection circuits e.g. circulator



[www.kuhne-electronic.com](http://www.kuhne-electronic.com)

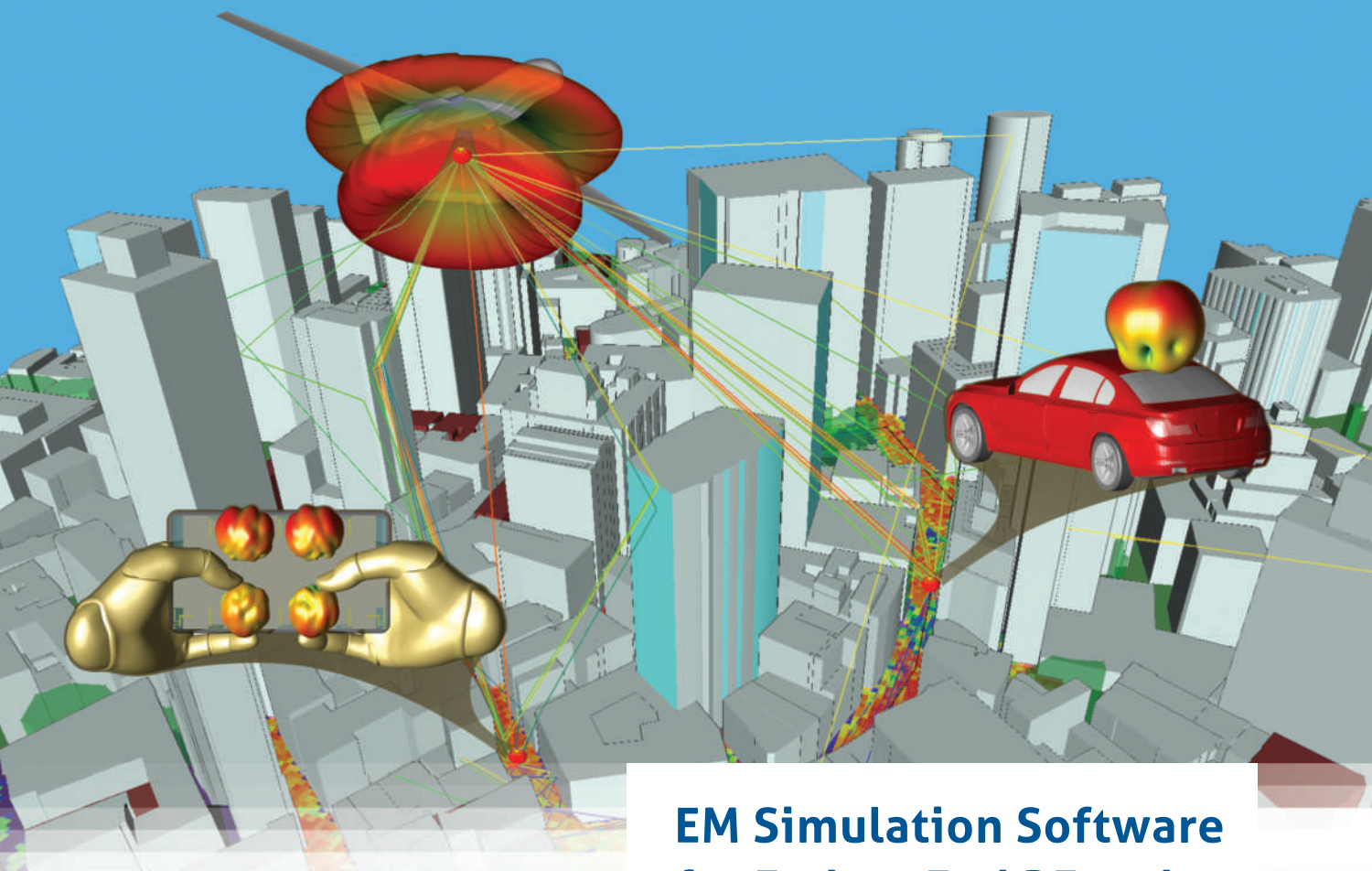
Kuhne electronic GmbH  
Scheibacker 3

Scheibacker 3  
95180 Berg - Germany

info@kuhne-electronic.de  
+49 (0)9293 800 640

**KUHNE electronic**  
MICROWAVE COMPONENTS





## EM Simulation Software for End-to-End RF and Wireless Design



Remcom's products work together to streamline the design of complex devices and wireless communication systems.

- High frequency antenna modeling for intricate devices
- Wireless communication and 5G network planning
- Massive MIMO beamforming and fixed wireless access
- Drive test simulation of automotive radar sensors
- Remcom's Simulation Platform unites WaveFarer® and XFDTD® in a common interface

Subscribe to receive product updates | [www.remcom.com/communications](http://www.remcom.com/communications) >>>

+1.888.7.REMCOM (US/CAN) | +1.814.861.1299 | [www.remcom.com](http://www.remcom.com)



includes the parasitic as well as intrinsic elements. Gate-source parasitic parameters include the gate-source capacitance,  $C_{gs}$ , gate parasitic inductance,  $L_g$ , and parasitic resistance,  $R_g$ .  $C_{gs}$  is given by the expression

$$C_{gs} = \frac{\epsilon Z_g}{d} \quad (3)$$

$$\left[ L_g + \frac{\epsilon (V_{bi} + V_{dg})}{q(N_{cap} Y_{cap} + N Y_A) - \sqrt{(1.6 q \epsilon N_{cap}) - q n_s}} \right]$$

where  $\epsilon$  is the dielectric constant of the GaN material, and  $d$  is the equivalent depletion depth. The gate parasitic inductance and parasitic resistance are found from

$$L_g = \frac{\mu_0 d Z_g}{m^2 L_g}$$

$$R_g = \frac{\rho Z_g}{3 m^2 h L_g} \quad (4)$$

where  $m$  is the grid index,  $\mu_0$  is the permeability in a vacuum and  $\rho$  is the conductivity of the gate metal.

The gate-source parasitic parameters are calculated from Equations 3 and 4 and are used in the design of the input circuit (see **Figure 2**). Microstrip lines TL2,

TL3 and TL4 compensate for the influence of  $C_{gs}$  at the input, where the use of stepped-impedance matching increases the bandwidth. Microstrip line TL1 offsets the effect of parasitic inductance  $L_g$  and resistance  $R_g$ . The gate-source compensation suppresses the input harmonics, which increases output power and efficiency.

## Broadband Harmonic Control

A radial microstrip line, commonly found in mixers and filters, is used in the active bias circuit. The radial microstrip stub input reactance is given by the equations

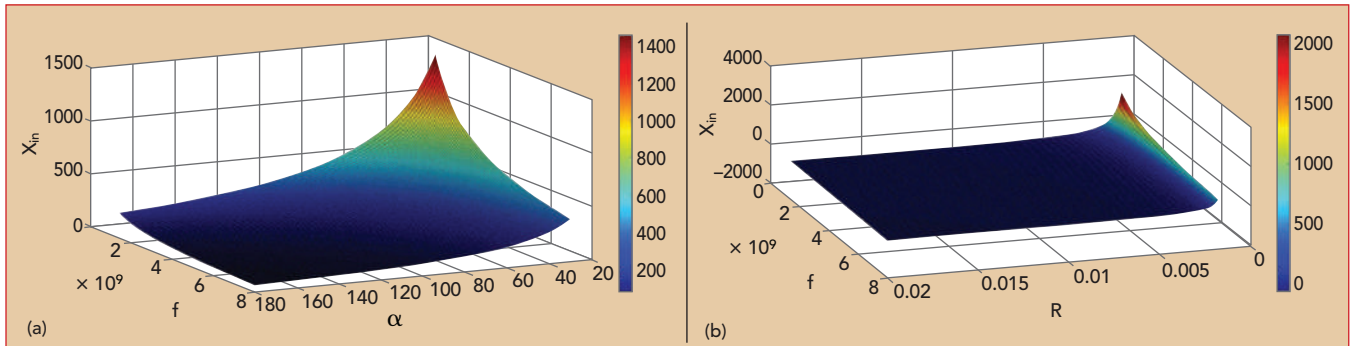
$$X_{in} = \frac{h}{2\pi r_1} Z_0(r_1) \frac{360 \cos(\theta_1 - \phi_2)}{\alpha \sin(\phi_1 - \phi_2)} \quad (5)$$

$$\tan \theta_1 = \frac{N_0(kr_1)}{J_0(kr_1)}, \tan \phi_i = -\frac{J_1(kr_1)}{N_1(kr_1)}, i = 1, 2 \quad (6)$$

$$Z_0(r_1) = \frac{120\pi}{\sqrt{\epsilon_r}} \left[ J_0^2(kr_1) + N_0^2(kr_1) \right]^{1/2} \quad (7)$$

$$\cdot \left[ J_1^2(kr_1) + N_1^2(kr_1) \right]^{-1/2}$$

$$k = 2\pi \sqrt{\epsilon_{re}} / \lambda_0 \quad (8)$$



▲ **Fig. 3** Radial microstrip stub  $X_{in}$  vs. frequency and angle (a) and  $X_{in}$  vs. frequency and radius (b).

# ERZIA



- Fast Delivery
- From DC to 100 GHz
- Rugged design under MIL-STD
- ITAR Free
- High Reliability: 3 Years Warranty
- ISO 9001: 2015 & EN 9100:2016 Certified



## RF Amplifiers and Integrated Assemblies

Aerospace / Defence / Laboratory / Research

High Power Amplifier	Freq (GHz)	Pout (dBm)	Gain (dB)
ERZ-HPA-3300-4700-29	33-47	29	30
ERZ-HPA-2600-4000-33	26-40	33	35
ERZ-HPA-3000-4000-32-E	30-40	32	39
ERZ-HPA-1500-2700-29-E	15-27	29	34
ERZ-HPA-0850-0980-55	8.5-9.8	55	38
ERZ-HPA-0790-0840-37-E	7.9-8.4	37	36

Low Noise Amplifier	Freq (GHz)	NF (dB)	Gain (dB)
ERZ-LNA-0200-5000-22-6	2-50	5	22
ERZ-LNA-0100-4000-45-5	1-40	5	45
ERZ-LNA-2600-4000-30-2.5	26-40	2.5	30
ERZ-LNA-0200-1800-18-4	2-18	3	20
ERZ-LNA-0050-1800-15-3	0.5-18	3.5	15
ERZ-LNA-0270-0310-30-0.5	2.7-3.1	0.5	30



ERZIA Technologies  
Santander, Spain Tel: +34 942 29 13 42

sales@erzia.com  
www.erzia.com

ERZIA Technologies of America  
Arlington, VA, US. Tel: +1 202-899-9717





# High Customised Multi-Coax Interconnections for High Speed Digital Testing!

Multi-Coax Series up to 50GHz  
Cables and Adaptors up to 110GHz

Economy type End Launch



Compression Solder-less



Customised Connectors & Adaptors



Multi Coax up to 50GHz



Connectors and Cable Assemblies up to 110GHz



**Frontlynk Technologies Inc.**

Tel: +886-6-356-2626 Fax: +886-356-6268

[www.frontlynk.com](http://www.frontlynk.com)

E-mail: [info@frontlynk.com](mailto:info@frontlynk.com)



**CERNEX&CernexWave**  
AS9100D & ISO9001

RF, MICROWAVE & MILLIMETER-WAVE  
COMPONENTS AND SUB-SYSTEMS  
UP TO 500GHz



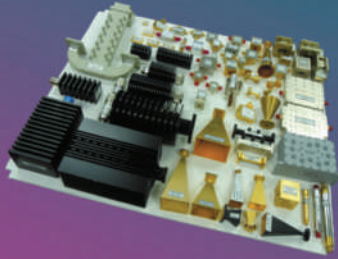
AMPLIFIERS UP TO 110GHz  
FREQUENCY MULTIPLIERS/DIVIDERS  
(UP TO 160GHz)

CONVERTERS UP TO 110GHz  
ANTENNAS UP TO 220GHz

COUPLERS UP TO 220GHz  
FERRITE PRODUCTS  
(ISOLATORS/CIRCULATORS)  
UP TO 160GHz

FILTERS/DIPLEXERS  
SOURCES UP TO 160GHz

SWITCHES UP TO 160GHz  
PHASESHIFTERS UP TO 160GHz



TRANSITIONS/ADAPTERS (UP TO 325GHz)  
WAVEGUIDE PRODUCTS UP TO 325GHz

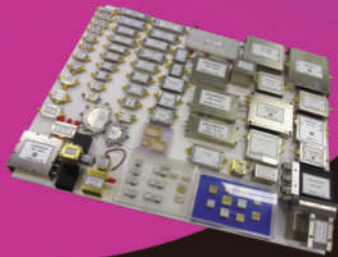
TERMINATIONS/LOADS UP TO 160GHz  
MIXERS (UP TO 110GHz)

ATTENUATORS (UP TO 160GHz)  
DETECTORS (UP TO 160GHz)

LIMITERS (UP TO 160GHz)  
BLAS TEE (UP TO 100GHz)

POWER COMBINERS/DIVIDERS EQUALIZERS

CABLES  
ASSEMBLIES/CONNECTORS (UP TO 100GHz)  
SUB-SYSTEMS (UP TO 100GHz)



www.cernex.com sales@cernex.com  
Add: 1710 Zanker Road, Suite 103 San Jose, CA 95112  
Tel: (408) 541-9226 Fax: (408) 541-9229

www.cernexwave.com sales@cernexwave.com  
Add: 1710 Zanker Road, Suite 202 San Jose, CA 95112  
Tel: (408) 773-8855 Fax: (408) 773-8858

## Technical Feature

where  $J_i(x)$  and  $N_i(x)$  are  $i$ -order Bessel functions of the first and second classes,  $\alpha$  is the angle of the radial microstrip line,  $\epsilon_{re}$  is the equivalent dielectric constant and  $\lambda_0$  is the free space wavelength.  $r$  and  $R$  are the inner and outer radii of the radial microstrip line, respectively, and  $h$  and  $w$  are the dielectric substrate thickness and microstrip width, respectively. The relationship between frequency, impedance, radius and angle of the radial microstrip line is shown in Figure 3.5-8 The open microstrip line is the equivalent of a capacitor.

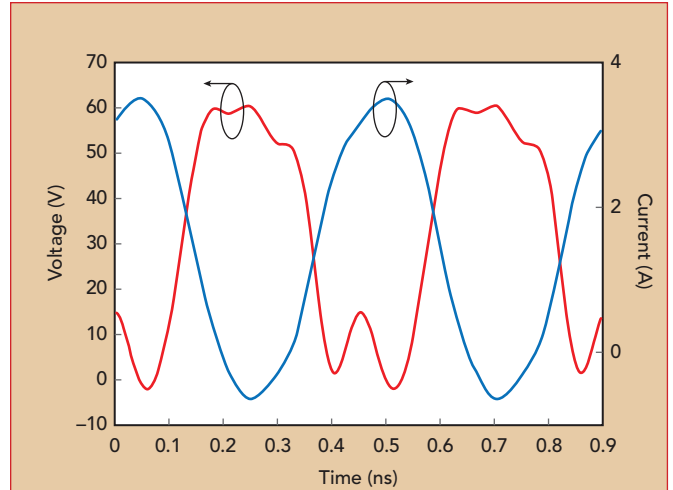
In the broadband harmonic control network topology shown in Figure 2, the third harmonic impedance can be obtained from

$$Z_{in} + (3f) = jZ_7 \quad (9)$$

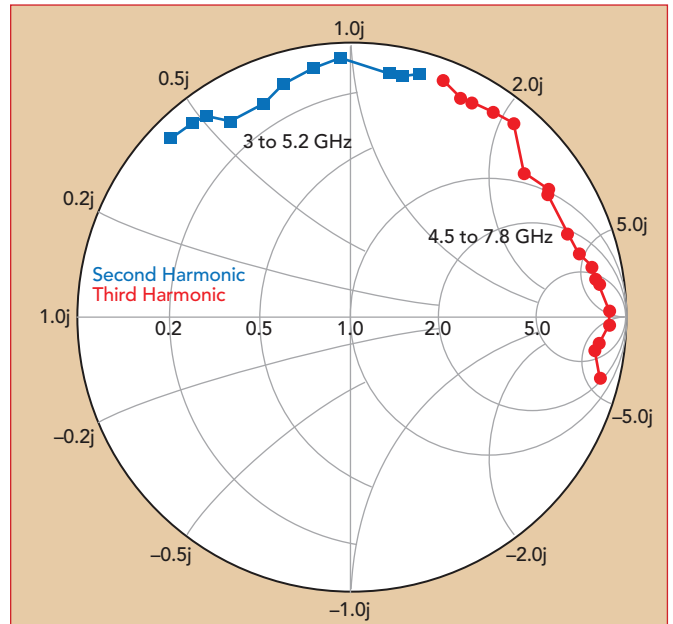
$$\frac{X_{in} + Z_8 \tan \frac{2\pi}{\lambda} l_8 + Z_7 \tan \frac{2\pi}{\lambda} l_7 \left( 1 - \frac{X_{in}}{Z_8} \tan \frac{2\pi}{\lambda} l_8 \right)}{Z_7 \left( 1 - \frac{X_{in}}{Z_8} \tan \frac{2\pi}{\lambda} l_8 \right) - \left( X_{in} + Z_8 \tan \frac{2\pi}{\lambda} l_8 \right) \tan \frac{2\pi}{\lambda} l_7}$$

$$l_7 + l_8 + l_{stub2} \approx \lambda / 12 \quad (10)$$

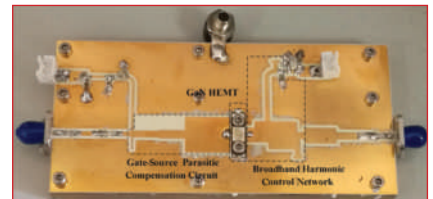
where  $Z_7$  and  $Z_8$  are the characteristic impedances of microstrip lines TL7 and TL8. The dimensions  $l_7$  and  $l_8$  are the lengths of the microstrip lines, respectively. The lengths are determined by Equation 10 so the third harmonic is open circuited. At  $2f_0$ , the microstrip lines TL5 and TL6



▲ Fig. 4 Drain voltage and current waveforms simulated with ADS.



▲ Fig. 5 Simulated second and third harmonic impedances with broadband harmonic matching and gate-source parasitic compensation.



▲ Fig. 6 Fabricated PA.



# PROVEN RELIABILITY. TRUSTED PERFORMANCE.

## Thick & Thin Film Resistor Products

- Faithful scheduled deliveries under 2 weeks
- Values from 0.1 Ohm to 100G Ohm
- Abs. tolerance to  $\pm 0.005\%$ , matching to  $\pm 0.0025\%$
- TCR's to  $\pm 2\text{ppm}/^\circ\text{C}$ , tracking to  $\pm 1\text{ppm}/^\circ\text{C}$
- Operating frequencies to 40GHz
- High performance at cryogenic temperatures
- Case sizes to 0101
- Space level QPL's, F.R.-"S", per MIL-PRF-55342
- Zero failures with over 200 million life test hours
- ISO 9001:2000 certified
- Full line of RoHS compliant products
- 24-hour quote turnaround

## Electronic Package Products

- Hi Reliability Hermetic Packages:
  - Lightweight glass sidewall flatpacks, S0-8, and S0-14 packages
  - Surface mount and plug-in packages
  - Metal flatpacks, leadless chip carriers (LCC), ceramic quad flatpacks (CQFP)
- Hermeticity per MIL-STD-883, Method 1014, Condition A4 (less than  $10^{-10}$  atm cc/sec)
- Plating per MIL-DTL-45204 and QQ-N-290 for standard packages (unless otherwise specified)
- Custom design available
- RoHS and DFARS compliant

When it comes to today's military, aerospace, and medical applications, the reliability and performance requirements of electronic components have never been so demanding. By delivering superior-quality products for over forty five years, it's easy to see why Mini-Systems is a supplier of choice among design engineers.



**MINI-SYSTEMS, INC.**  
SINCE 1968

**508-695-0203**

**mini-systemsinc.com**  
**info@mini-systemsinc.com**

is not to be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or by any information storage and retrieval system, without permission in writing from Mini-Systems, Inc. All rights reserved. For reprints please contact the Publisher.

## PIN DIODE CONTROL DEVICES

### PIN DIODE

## ATTENUATORS

- 0.1–20GHz
- Broad & narrow band models
- Wide dynamic range
- Custom designs

Attenuator types offered are: Current Controlled, Voltage Controlled, Linearized Voltage Controlled, Digitally Controlled and Digital Diode Attenuators.

### PIN DIODE

## SWITCHES

- Broad & narrow band models
- 0.1–20GHz
- Small size
- Custom designs

SPST thru SP8T and Transfer type models are offered and all switches are low loss with isolation up to 100dB. Reflective and non-reflective models are available along with TTL compatible logic inputs. Switching speeds are 1 $\mu$ sec.—30nsec. and SMA connectors are standard. Custom designs including special logic inputs, voltages, connectors and package styles are available. All switches meet MIL-E-5400

### PIN DIODE

## PHASE SHIFTERS

- 0.5–20GHz
- Switched Line
- Varactor Controlled
- Vector Modulators
- Bi-Phase Modulators
- QPSK Modulators
- Custom Designs

## SUBASSEMBLIES

Passive Components and Control Devices can be integrated into subassemblies to fit your special requirements. Call for more information and technical assistance.

### Custom Designs

CALL OR WRITE

**waveline**  
SOLID STATE INC.

P.O. Box 718, West Caldwell, NJ 07006  
(973) 226-9100 Fax: 973-226-1565  
E-mail: wavelineinc.com

## Technical Feature

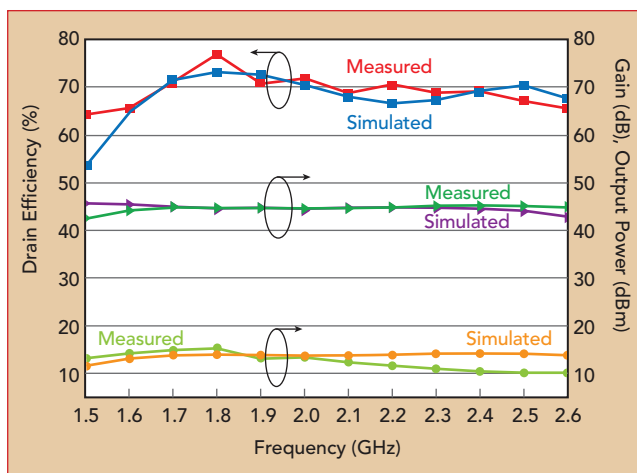
are stepped to match the second harmonic impedance to 0. Radial stub 1 plays a role expanding the bandwidth.

Simulations of the drain voltage and current waveforms (see **Figure 4**) show the voltage and current do not overlap in the crests and troughs, which enhances efficiency. By compensating the gate-source parasitic effect and using the broadband harmonic matching circuit, the second and third harmonic impedances of the PA are maintained in the low and high impedance regions, respectively, as shown in **Figure 5**.

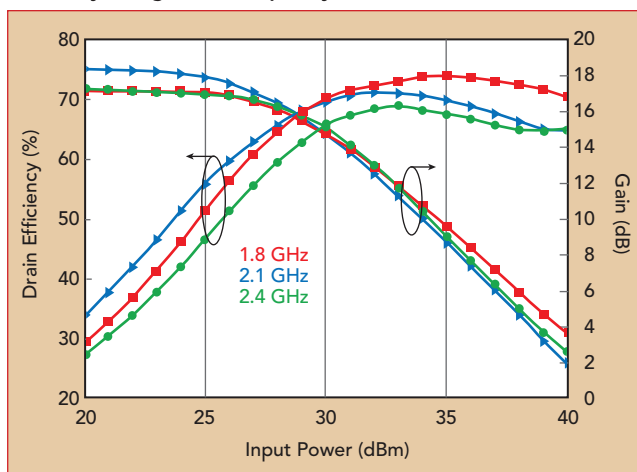
### FABRICATION AND MEASUREMENT

The GaN HEMT used in this design is Wolfspeed's CGH40025F. The broadband PA is fabricated on a Rogers 4350B substrate, which has a dielectric constant of 3.66 and a thickness of 0.762 mm (see **Figure 6**). The gate bias is -3 V, operating the device class B. To obtain higher power, the drain voltage is set to 32 V instead of the recommended 28 V. The amplifier is operated CW.

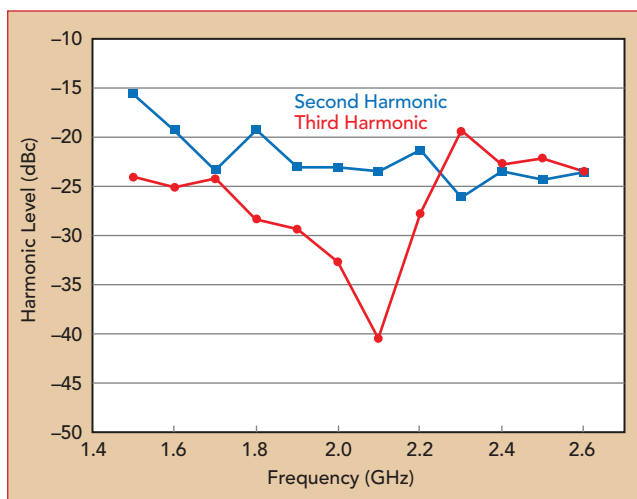
The measured output power, drain efficiency and gain are shown in **Figure 7** and compared with the simulated performance. The measured output power is between 43.4 and 45.6 dBm between 1.5 and 2.6



▲ **Fig. 7** Measured vs. simulated output power, drain efficiency and gain vs. frequency.



▲ **Fig. 8** Measured drain efficiency and gain vs. input power at 1.8, 2.1 and 2.4 GHz.



▲ **Fig. 9** Second and third harmonic suppression vs. frequency.

GHz, with the drain efficiency between 65 and 76.9 percent. The gain is greater than 10 dB. The maximum measured output power is 45.6 dBm at 1.5 GHz, and the minimum is 43.4 dBm at 2.6 GHz. The



# IN AN EMERGENCY- REDUCE NETWORK DOWNTIME

# Emergency

Menu

Ctrl

Quality RF and Data Line Surge Protection Products Available for Same-Day Shipping!



## COUNT ON POLYPHASER

**PolyPhaser is on Standby Readiness to Support Your Network**

- Quality RF and data line surge protection products available for online purchase
- Reliable surge solutions in stock for same-day shipping
- 24/7 live customer support
- Nationwide engineering support to deliver the right technology for your network
- More than 40 years of expertise in mission critical communications



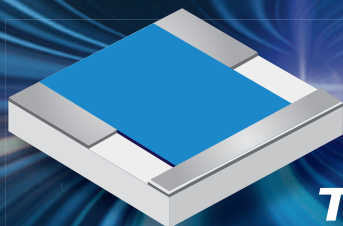
*When network reliability is a requirement, count on PolyPhaser! Contact PolyPhaser online at [www.polyphaser.com](http://www.polyphaser.com) or directly at +1 (208) 635-6400.*

Content is copyright protected and provided for personal use only - not for reproduction or retransmission.  
For reprints please contact the Publisher.

**PolyPhaser**  
an INFINIT® brand

**TABLE 1**  
COMPARISON WITH SIMILAR WORK

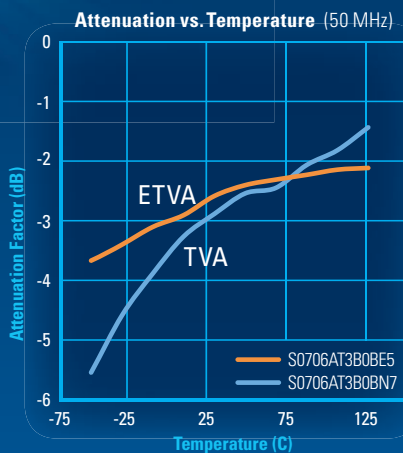
Reference	Bandwidth (GHz)	Power (dBm)	Gain (dB)	Drain Efficiency (%)
10	1.6 to 2.2	39	>10	55
11	1.4 to 2.6	39	10	60 to 70
12	1.6 to 2.5	39	>10	55 to 70
4	1.1 to 2.1	40	>10	60 to 73
This Article	1.5 to 2.6	43.4 to 45.6	>10	65 to 77



## Temperature Variable Attenuators

TVAs from the recognized leader in high reliability resistive components offer:

- Two case sizes:  
0.150" x 0.125" x 0.018" (to 6 GHz)  
0.075" x 0.065" x 0.018" (to 18 GHz)
- Three TCA values: -0.003, -0.007, and -0.009 dB/dB/°C
- Enhanced slope ETVAs with a TCA value of -0.005 dB/dB/°C
- Attenuation values from 1-10 dB
- Solderable or wire bondable terminations



When the mission is critical, choose **State of the Art.**



**State of the Art, Inc.**

RESISTIVE PRODUCTS

[www.resistor.com](http://www.resistor.com) Made in the USA.

2470 Fox Hill Road, State College, PA 16803-1797  
Phone: 800-458-3401 or 814-355-8004 • Fax: 814-355-2714  
E-mail: [sales@resistor.com](mailto:sales@resistor.com) • Source code: 56235

QUALIFICATIONS ISO9001 & AS9100 • MIL-PRF-55342 • MIL-PRF-32159 • MIL-PRF-914

maximum measured drain efficiency is 76.9 percent at 1.8 GHz.

Measured drain efficiency and gain versus output power at 1.8, 2.1 and 2.4 GHz, respectively, is plotted in **Figure 8**. These frequencies are chosen to represent the entire frequency range, with 1.8 and 2.4 GHz the lower and higher frequencies, 2.1 GHz the center. As the input power increases, the drain efficiency gradually increases; when the input power reaches a certain level, the gain begins to drop rapidly. The decrease in gain indicates a linear loss and shows that high efficiency and high linearity are difficult to obtain simultaneously. The two parameters must be weighed in the PA design.

**Figure 9** shows measured second and third harmonic distortion levels relative to the fundamental. Suppression of the second and third harmonics are 15.6 to 26.1 and 19.4 to 40.5 dBc, respectively.

For comparison, recent broadband PA results are shown in **Table 1**. The design described here demonstrates greater output power and drain efficiency with equivalent gain over a similar operating band.

## CONCLUSION

This article discusses two innovative improvements in wideband PA design: a novel gate-source parasitic compensation circuit reduces the influence of harmonics caused by GaN HEMT gate-source parasitics. At the same time, a broadband harmonic control network increases PA bandwidth. Overall performance results demonstrate an advance in the state of the art. ■



## Enabling a new world of Active Antenna Design with the Millimeter-Wave **Intelligent Gain Blocks**

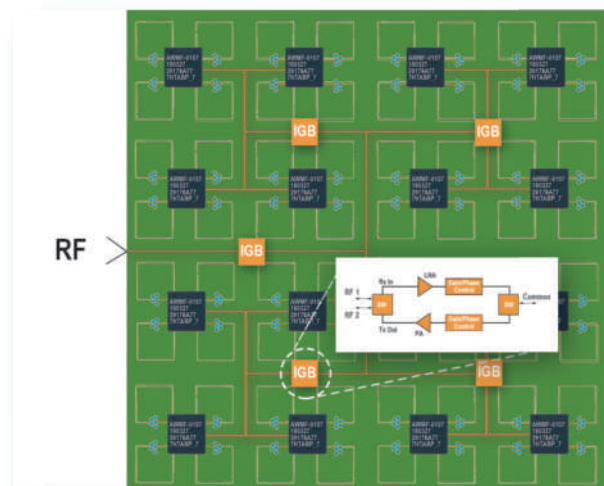
### Use Case: Core Distribution ICs in Active Antennas

**Problem:**

Active antenna beamforming networks can experience gain and phase mismatch as the RF signal is distributed.

**Solution:**

IGBs can be placed within the beamforming network to compensate for gain degradation and phase mismatches of the RF signal.



Optimize your system with the versatile millimeter-wave  
**Intelligent Gain Blocks** enabling a wide range of mmW systems

mmW Si  
Core ICs

Active Antenna  
ASICs

mmW  
Front End ICs

## ACKNOWLEDGMENT

This work is supported by Key Project of Zhejiang Provincial Natural Science Foundation of China (No. LZ16F010001), Zhejiang Provincial Public Technology Research Project (No. 2016C31070) and National Natural Science Foundation of China (No. 61306100).

## References

1. T. Ge and J. S. Chang, "Filterless Class D Amplifiers: Power-Efficiency

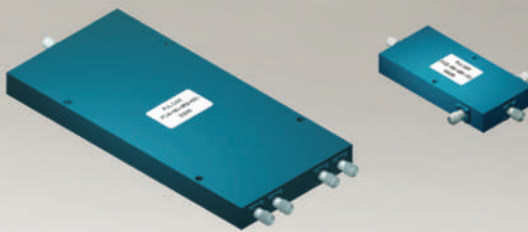
and Power Dissipation," *IET Circuits, Devices & Systems*, Vol. 4, No. 1, January 2010, pp. 48–56.

2. K. Chen and D. Peroulis, "Design of Highly Efficient Broadband Class-E Power Amplifier Using Synthesized Low-Pass Matching Networks," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 59, No. 12, December 2011, pp. 3162–3173.
3. M. Hayati, A. Sheikhi and A. Grebennikov, "Class-F Power Amplifier with High Power Added Efficiency Using Bowtie-Shaped Harmonic Control

Circuit," *IEEE Microwave and Wireless Components Letters*, Vol. 25, No. 2, February 2015, pp. 133–135.

4. M. Iqbal and A. Piacibello, "GaN HEMT Based Class-F Power Amplifier with Broad Bandwidth and High Efficiency," *International Conference on Integrated Circuits and Microsystems*, November 2016, pp. 131–134.
5. E. Cipriani, P. Colantonio, F. Giannini, A. Raffo, V. Vadalà, G. Bosi and G. Vannini, "Extended Operation of Class-F Power Amplifiers Using Input Waveform Engineering," *47th European Microwave Conference*, October 2017, pp. 144–147.
6. S. Goto, T. Kunii, A. Ohta, A. Inoue, Y. Hosokawa, R. Hattori and Y. Mitsui, "Effect of Bias Condition and Input Harmonic Termination on High Efficiency Inverse Class-F Amplifiers," *31st European Microwave Conference*, September 2001.
7. M. Zhang, X. Wang, M. Peng, X. Liu and R. Wang, "Effect of Field Plate Length on DC Characteristics of High Breakdown Voltage GaN HEMTs for Power Switching Application," *10th IEEE International Conference on Solid-State and Integrated Circuit Technology*, November 2010, pp. 1356–1358.
8. P. M. Cabral, J. C. Pedro and N. B. Carvalho, "Nonlinear Device Model of Microwave Power GaN HEMTs for High Power-Amplifier Design," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 52, No. 11, November 2004, pp. 2585–2592.
9. Q. Li, S. He, Z. Dai and W. Shi, "A Method for Designing Generalized Continuous Power Amplifier," *IEEE MTT-S International Microwave Workshop Series on Advanced Materials and Processes for RF and THz Applications*, July 2016.
10. K. Mimis, K. A. Morris, S. Bensmida and J. P. McGeehan, "Multichannel and Wideband Power Amplifier Design Methodology for 4G Communication Systems Based on Hybrid Class-J Operation," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 60, No. 8, August 2012, pp. 2562–2570.
11. P. Wright, J. Lees, J. Benedikt, P. J. Tasker and S. C. Cripps, "A Methodology for Realizing High Efficiency Class-J in a Linear and Broadband PA," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 57, No. 12, December 2009, pp. 3196–3204.
12. L. Ma, F. You and X. Hou, "An Output Match Design Method for High Efficiency and Broadband Class-J PA," *IEEE Topical Conference on Power Amplifiers for Wireless and Radio Applications*, June 2014, pp. 43–45.

# Microwave Multi-Octave Power Dividers Up to 70 GHz



Power Division	Freq. Range (GHz)	Insertion Loss (dB)	Isolation (dB)	Amplitude Balance	Model Number
2	1.0-27.0	2.5	15	0.5 dB	PS2-51
2	0.5-18.0	1.7	16	0.6 dB	PS2-20
2	1.0-40.0	2.8	5-40 GHz 13	0.6 dB	PS2-55
2	2.0-40.0	2.5	1-5 GHz 10	0.6 dB	PS2-54
2	15.0-40.0	1.2	13	0.8 dB	PS2-53
2	8.0-60.0	2.0	10	1.0 dB	PS2-56
2	10.0-70.0	2.0	10	1.0 dB	PS2-57
3	2.0-20.0	1.8	16	0.5 dB	PS3-51
4	1.0-27.0	4.5	15	0.8 dB	PS4-51
4	5.0-27.0	1.8	16	0.5 dB	PS4-50
4	0.5-18.0	4.0	16	0.8 dB	PS4-17
4	2.0-18.0	1.8	17	0.5 dB	PS4-19
4	15.0-40.0	2.0	12	0.8 dB	PS4-52
8	0.5-6.0	2.0	20	0.4 dB	PS8-12
8	0.5-18.0	7.0	16	1.2 dB	PS8-16
8	2.0-18.0	2.2	15	0.6 dB	PS8-13

10 to 30 watts power handling, visit website for complete specifications.  
SMA and Type N connectors available to 18 GHz.

**PULSAR**

MICROWAVE CORPORATION

[www.pulsarmicrowave.com](http://www.pulsarmicrowave.com)

48 Industrial West, Clifton, NJ 07012 | Tel: 973-779-6262 • Fax: 973-779-2727 | sales@pulsarmicrowave.com





**RELCOMM**  
TECHNOLOGIES, INC.

## A Leading Provider of RF Coaxial Relays

RelComm Technologies, Inc. designs and builds  
RF relay component products for the  
communications and instrumentation marketplace....

# EXCELLENCE BY DESIGN

Design Enhanced Application Specific RF Coaxial Relays

Military Defense Fixed/Mobile/Shipboard

Commercial Telecommunications Infrastructure

Satellite Communications Ground Stations

Test and Measurement Instrumentation from DC to 40 GHz



**RF  
Relay  
Store**

[www.rfrelaystore.com](http://www.rfrelaystore.com)

The RF Relay Store provides the most convenient, dependable and cost effective way to procure small quantities of RF coaxial relays.

RelComm Technologies now makes available standard building block part types for shipment from stock.

RF Coaxial Relays - Extremely low loss from DC to 18GHz.  
1P1T, 1P2T, 2P2T, Transfer, and Multi-Throw.  
PCB Mount, SMA, and N-Type Connectorized

RelComm Technologies, Inc. - 610 Beam Street, Salisbury, MD 21801

P: (410) 749-4488 - F: (410) 860-2327 - [www.relcommtech.com](http://www.relcommtech.com) - [sales@relcommtech.com](mailto:sales@relcommtech.com)

Content is copyright protected and provided for personal use only - not for reproduction or retransmission.

For reprints please contact the Publisher.

# DRFM Jammer Test Solutions

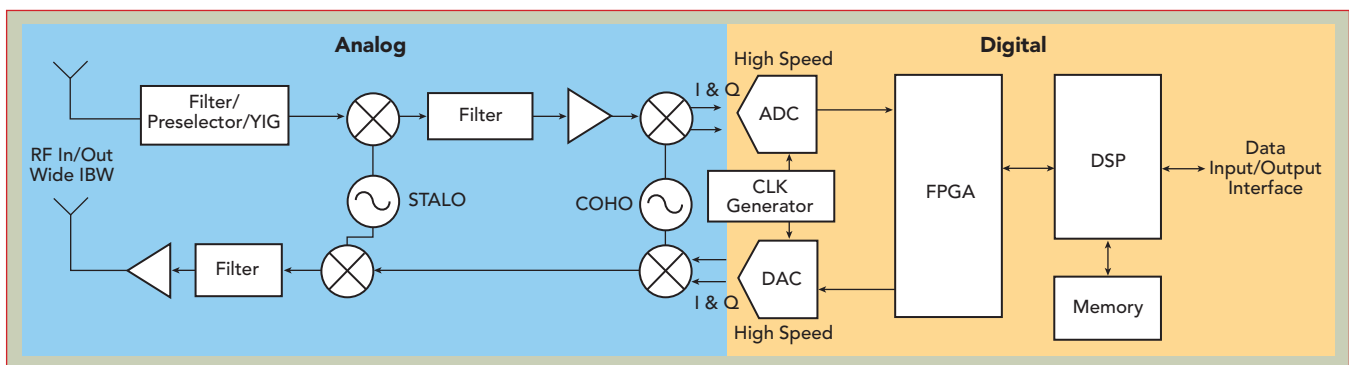
Yassen Mikhailov  
Rohde & Schwarz, Munich, Germany

*This article highlights the test requirements and challenges for digital RF memory (DRFM) jammers, describing the available solutions and pointing out their benefits. The focus is on the three main test areas for DRFMs: system tests, RF/IF stage tests on the module and subsystem and exploration of the digital backend.*

**D**RFM jammers play an essential part in the electronic attack (EA) suite and are instrumental in ensuring mission success and improving platform survivability. DRFMs have been present for quite some time—the earliest reference appears in an article by Sheldon Spector called “A Coherent Microwave Memory Using Digital Storage: The Loopless Memory Loop,” published in the January/February 1975 issue of *Electronic Warfare*, a publication of the Association of Old Crows.

During World War II, radar engineers developed the pulse compression technique. Upgrades in radar range resolution came

with improvements in signal-to-noise ratio (SNR). This combination, along with phase-coherent klystron-based transmitters, gave radar engineers an advantage that made barrage jamming relatively ineffective, due to the high output requirements for broadband stand-off jammers. In the early development stages, a DRFM jammer was a simple device consisting of a receive path, signal processing with modification and a transmit path. The main objective of the DRFM jammer was to digitally capture and retransmit an altered RF radar return signal with sufficient fidelity to deceive the radar processor.



▲ Fig. 1 DRFM block diagram.



Now  
available with  
**LabVIEW!**



# Micro Lambda

## Simple and Easy to Use!

### MLBS-Synthesizer Test Box – 600 MHz to 20 GHz

Standard models cover the 0.6 to 2.5 GHz, 2 to 8 GHz, 8 to 20 GHz and 2 to 20 GHz frequency bands. All versions of the MLSP synthesizer product family can be easily inserted into the test box. Tuning consists of a control knob, key pad, USB and Ethernet connections. Units provide +10 dBm to +13 dBm output power levels and are specified over the lab environment of +15°C to +55°C and are CE certified.

Units are provided with a power cord, USB cable, Ethernet cable, CD incorporating a users manual, quick start guide and PC interface software.

### MLBF-Filter Test Box – 500 MHz to 50 GHz

Standard models utilize any Bandpass or Bandreject filter manufactured by Micro Lambda today. Bandpass filter models cover 500 MHz to 50 GHz and are available in 4, 6 and 7 stage configurations. Bandreject (notch) filter models cover 500 MHz to 20 GHz and are available in 10, 12, 14 and 16 stage configurations. Units are specified to operate over the lab environment of +15°C to +55°C and are CE certified.

Units are provided with a power cord, USB cable, Ethernet cable, CD incorporating a users manual, quick start guide and PC interface software.

### See our complete line of wideband, low noise components



**MLSP-series  
Synthesizers**  
600 MHz to 20 GHz



**MLSW-series  
Synthesizers**  
600 MHz to 16 GHz



**MLTO-series  
TO-8  
Oscillators**  
2 to 16 GHz



**MLSMO-series  
Surface Mount  
Oscillators**  
2 to 16 GHz

[www.microlambdawireless.com](http://www.microlambdawireless.com)



**MICRO LAMBDA  
WIRELESS, INC.**

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



▲ Fig. 2 Test system for DRFM characterization.

With advancements in semiconductor technology in the 1980s, new signal processing techniques for radar were widely adopted. These techniques, such as moving target and stationary target indication, gave the radar several improvements, one of which was significant signal processing gain. As a result, it became extremely difficult to jam or deceive a radar.

The electronic warfare (EW) community responded by developing complex EW pods and deception techniques to counter radar advancements, giving birth to the modern DRFM jammer. Today, DRFM is an essential part of the EW attack suite. The basic architecture of a DRFM module remains the same: receive, data processing and transmit. A coherent oscillator ensures that both paths have a constant phase difference, the same frequency and the same waveform. Modern DRFMs are characterized by wideband RF front-ends (RFFE) with instantaneous bandwidths exceeding 2 GHz. Wideband analog signals are digitized using high speed analog-to-digital converters (ADC), processed and retransmitted back via high speed digital-to-analog converters (DAC). Access to vast processing power using field-programmable gate arrays (FPGA), digital signal processors (DSP) and flexible, freely configurable deceptive techniques generators make DRFM a formidable asset in the EA arsenal.

A critical requirement of electronic countermeasure (ECM) systems is to provide RF return signals to a radar with sufficient fidelity of the Doppler shift, range and radar cross section to ensure that the radar interprets the return signal as a "real" target. Phase correction is used to correct phase discontinuities resulting from a range update during the coherent processing interval. For the RFFEs, modern DRFMs employ a range of receiver architectures. One of the highest performance architectures is the channelized receiver, which offers a good compromise between bandwidth, sensitivity and cost. Latency for modern DRFMs is on the order of nanoseconds. A rule of thumb for radar developers is that one microsecond corresponds to roughly 150 m range.

A critical requirement of electronic countermeasure (ECM) systems is to provide RF return signals to a radar with sufficient fidelity of the Doppler shift, range and radar cross section to ensure that the radar interprets the return signal as a "real" target. Phase correction is used to correct phase discontinuities resulting from a range update during the coherent processing interval.

For the RFFEs, modern DRFMs employ a range of receiver architectures. One of the highest performance architectures is the channelized receiver, which offers a good compromise between bandwidth, sensitivity and cost. Latency for modern DRFMs is on the order of nanoseconds. A rule of thumb for radar developers is that one microsecond corresponds to roughly 150 m range.

## TEST REQUIREMENTS

For this discussion, the device schematic is divided into analog and digital components (see **Figure 1**). The three main areas of DRFM testing are:

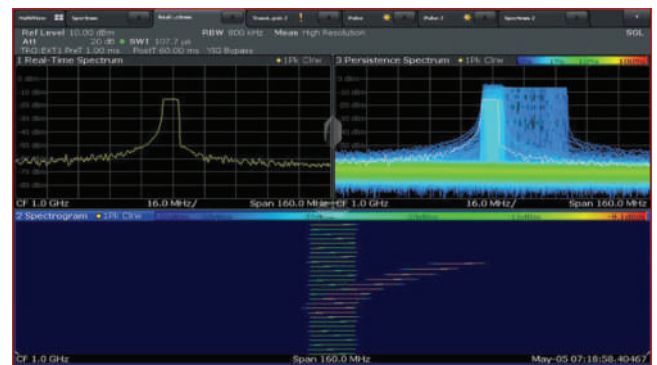
**System level** or verification and final system test. At this stage, development engineers typically perform an analysis of the deception techniques to ensure proper operation. These tests include direction finding (DF), to

ensure the system identifies emitter direction; output stability of the DRFM module (both phase and amplitude); latency; spectral purity; error vector magnitude and global navigation satellite system. Also, electromagnetic compatibility (EMC) measurements are important to ensure the system's EMC compliance.

**RF/IF stage** or tests focused at the submodule and component levels. Several measurements are performed here, including component and submodule characterization of spurious, dynamic range, compression point, gain and phase response with frequency, noise figure, IP3, receiver sensitivity, quadrature error, local oscillator performance (phase noise, leakage and stability) and antenna radiation.



▲ Fig. 3 Screen shot of range gate pull-off.



▲ Fig. 4 Screen shot of velocity gate pull-off.



▲ Fig. 5 Spurious measurement.



# DUAL or SINGLE LOOP SYNTHESIZER & PLO MODULES

## Features:

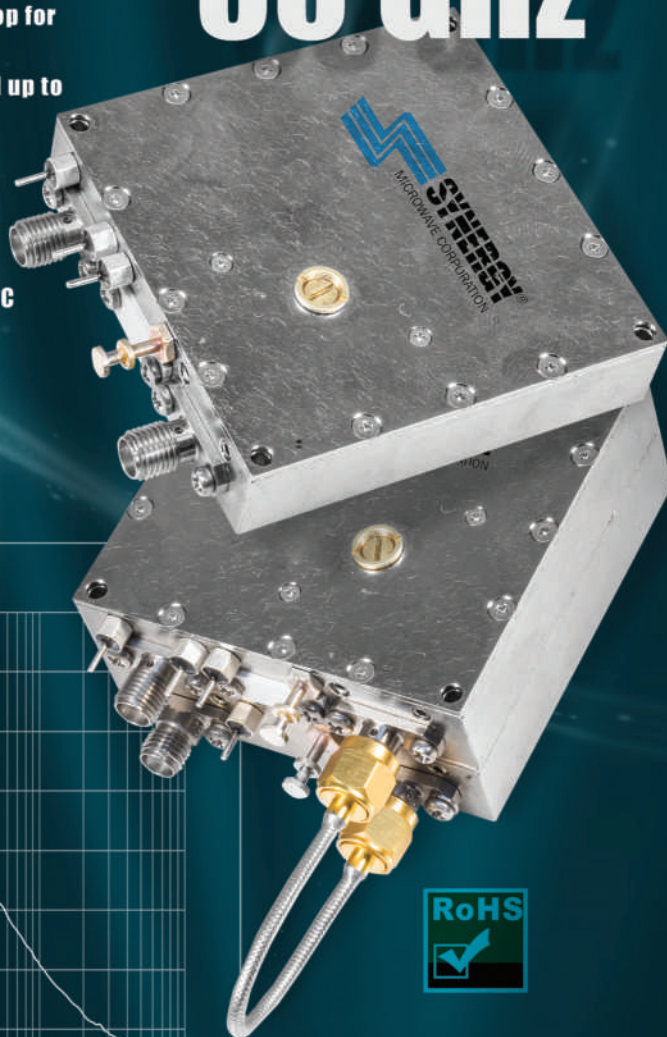
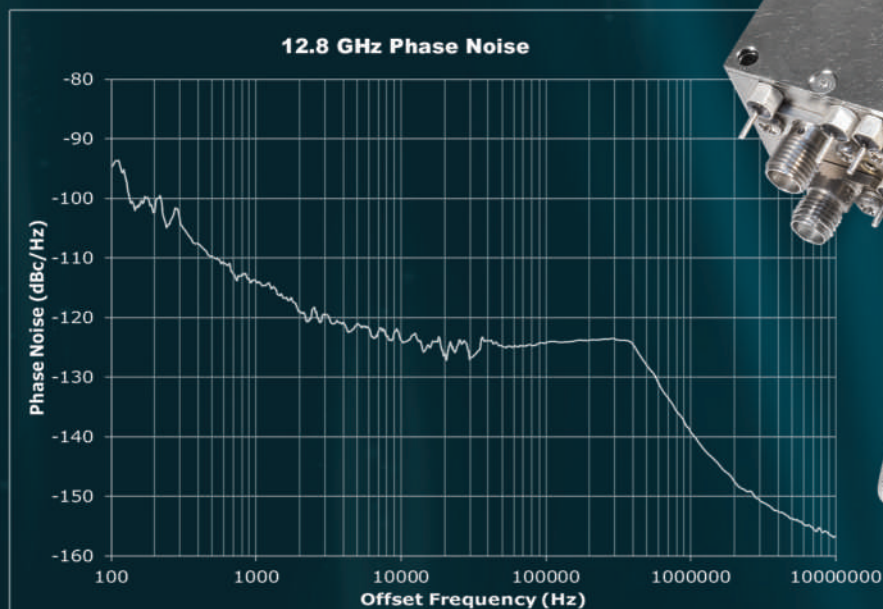
- Proprietary digital Integer and Fractional PLL technology
- Lowest digital noise floor available -237 dBc/Hz figure of merit
- Output frequencies from 100 MHz locked crystal to 30 GHz
- Available with reference clean up dual loop, or single loop for very low noise reference
- Parallel fixed band stepping or SPI interface synthesized up to octave bandwidths
- Reference input range 1 MHz to 1.5 GHz
- Dual RF output or reference sample output available
- +12 dBm standard output power +16 dBm available
- Standard module size 2.25 X 2.25 X 0.5 Inches (LxWxH)
- Standard operating temperature -10 to 60 °C, -40 to +85 °C available

Up to  
**30 GHz\***

## Applications:

- SATCOM, RADAR, MICROWAVE RADIO

\* 16 - 30 GHz with added x2 module < 1" in height.



**Talk To Us About Your Custom Requirements.**



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

Content is copyright protected and provided for personal use only - not for reproduction or retransmission.  
For reprints please contact the Publisher.

**Digital stage testing** comprises parameters such as clock jitter, timing and power integrity. A noisy power supply will affect overall performance and can be a beacon for electronic counter-countermeasures (ECCM). Typical measurements include power integrity, clock jitter, latency, timing, equalizer flatness, electromagnetic interference debugging, FPGA, DSP and data converters.

## SYSTEM LEVEL TESTS

The spectrum analyzer and signal generator are typical test instruments. In addition, simulating a complex electromagnetic environment is important for stress testing, verification and debugging. To ensure proper emitter location, more advanced DRFM systems perform angle of arrival measurements, which require signals time and phase aligned at a reference plane.

Rohde & Schwarz offers a test system for DRFM testing (see **Figure 2**), based on the R&S SMW vector signal generator and R&S SGS signal source generator, giving the user the ability to generate up to eight coherent emitters at 20 GHz. Adding the complementary R&S Pulse Sequencer with electromagnetic environment simulation software gives complete control over the system and the ability to generate complex emitter scenarios. The system is calibrated using the R&S NRP-Z81 wideband power sensor to ensure the desired phase at the reference plane. For precise phase accuracy and stability, the multichannel phase-coherent system includes R&S SMW signal generators synchronized via a common local oscillator provided by the R&S SMA100B analog signal generator. The combination of a very low phase noise and high output power makes the R&S SMA100B well suited for this task. A dense emitter environment scenario can be generated using the R&S Pulse Sequencer software. The DF systems are based exclusively on commercial off-the-shelf technology. This provides improved availability, serviceability and the flexible use of test equipment when it is not dedicated to DF tests.

The main purpose of the DRFM system is to deceive the hostile sensor. This task is performed through several deception techniques. Proper design and programming require realistic simulations of the dense emitter environments in which DRFMs operate, with careful analysis of the signals transmitted by the system and comparison with the waveform generated by the hostile emitter. For this, Rohde & Schwarz offers several analysis tools for fast and repeatable results. These tools include a pulse analysis option with automatic pulse capturing and examination, transient signal analysis of signals with time-changing behavior, pulse Doppler waveform streaming to simulate the complex emitter environment and pulse stability analysis to ensure the jammer introduces no unwanted distortion.

**Figure 3** shows an example of an EA scenario where the jammer

# Cover your bases with KRYTAR



KRYTAR, Inc., founded in 1975, specializes in the design and manufacturing of ultra-broadband microwave components and test equipment for both commercial and military applications.

Products cover the DC to 67 GHz frequency range and are designed for a wide range of applications including:

- ❑ Test Equipment
- ❑ Simulation Systems
- ❑ SATCOM & SOTM
- ❑ Jammers for Radar & IEDs
- ❑ Radar Systems
- ❑ EW: ECM, ECCM & ESM

KRYTAR has a commitment to technical excellence and customer satisfaction.



These principles form the basis for the steady growth that has earned KRYTAR an enviable reputation in the microwave community.

**Cover your bases.** Contact KRYTAR today for more information.

## MIL-Qualified RF, Microwave & mmW Components

- ❑ **NEW! Directional Couplers to 110 GHz**
- ❑ **3 dB 90° Hybrid Couplers to 44 GHz**
- ❑ **3 dB 180° Hybrid Couplers to 40 GHz**
- ❑ **Beamforming Networks to 18 GHz**
- ❑ **Power Dividers to 45 GHz**
- ❑ **Detectors to 40 GHz**
- ❑ **NEW! Space Applications**
- ❑ **Custom Applications**



[www.krytar.com](http://www.krytar.com)

1288 Anvilwood Avenue • Sunnyvale, CA 94089

Toll FREE: +1.877.734.5999 • FAX: +1.408.734.3017 • E-mail: [sales@krytar.com](mailto:sales@krytar.com)





**Adapters, Attenuators, Blind Mate Connectors, Cable Assemblies, Connectors, Delay Lines, Duplexers Equalizers, Fine Grain Equalizers, Gain Amplitude Equalizers, Line Stretchers, Machines, Phase Adjusters Push - On Connectors & Adapters, Quick Connections Terminations, Tools, Waveguide to Coax-Adapters ..... etc., etc.**

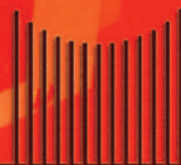


**Phase-  
Adjusters  
DC to  
65 GHz**

**You need one?  
We deliver one!**

**You need thousands?  
We deliver thousands!**

**when Quality is needed**



**Spectrum**  
Elektrotechnik GmbH

**80905 Munich, Germany**

**P.O. Box 450533**

**Telephone: +49-89-3548-040**

**Facsimile: +49-89-3548-0490**

**WWW.SPECTRUM-ET.COM \***

**Email: sales@spectrum-et.com**

Content is copyright protected and provided for personal use only - not for reproduction or retransmission.

For reprints please contact the Publisher.

PhaseShiftersFPE2

pulls off the radar range gate. All deception techniques are time-based and require careful synchronization of several parameters. The scenario is created with the pulse sequencer software, transmitted via a function generator, and analyzed with the R&S FSW K6 pulse measurements option. The range gate pull-off or capture and walk technique normally works with velocity gate pull-off (see **Figure 4**),

where the jammer tries to pull off the Doppler gate.

Timing is essential for successful pull-off. If the pulse repetition interval (PRI) or Doppler is pulled off too fast or too far, it might leave the range or velocity gate and alert the radar that it is being jammed. Timing parameters of the PRI or Doppler walk must be carefully considered, so it is important to look at the trend of the selected parameter, which is

available in the pulse analysis option. Complex analysis is simplified with a flexible and freely configurable user interface. To speed the measurement, most of the tasks are automated. Nevertheless, one can manually change and configure the setup to fit specific requirements.

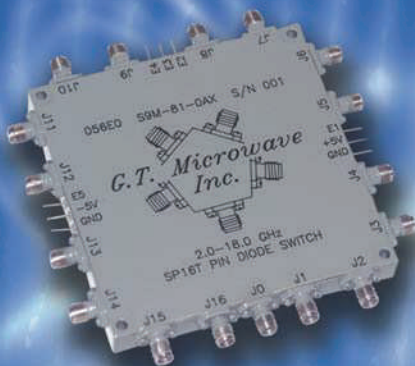
Take, for example, the verification of the pulse train transmitted by a jammer in response to a pulse radar with pulse compression used to improve the time-bandwidth product, the range resolution or both. Capturing such a complex signal, modifying some of its parameters and playing it back without disturbing important factors such as phase, compression ratio or sidelobe level is not easy. To ensure that no additional disturbances are introduced by the jammer, one can upgrade the pulse analysis option with the R&S FSW K6S and automatically measure the compression parameters of the modulated pulse transmitted by the system. The main lobe versus sidelobe level and the time difference between them are summarized in a results table. The user can upload reference pulse waveforms in I/Q format and compare phase and frequency within a pulse with the measured values.

### RF/IF STAGE TESTING

Spurious emissions ultimately determine jammer effectiveness. Unwanted radiation puts additional strain on the RF systems and acts as a beacon for ECCM. Normally, spurious emissions measurements are tedious, time consuming and expensive. To maximize the analyzer's performance, engineers must manually adjust parameters such as resolution bandwidth and frequency. Using the R&S FSW K50 option, this task is simple: enter a few constraints, such as frequency range and desired spurious level. The instrument then performs the measurements automatically, indicating either a pass or a fail (see **Figure 5**). The complexity of the task is drastically reduced while the measurement speed is increased by up to 20× compared to the traditional, manual method.

Phase noise measurements are not simple; the more accuracy required, the more complicated the

## GET THE PERFORMANCE YOU NEED ULTRA BROADBAND SWITCHES



- SP1T to SP128T
- DC - 26.5 GHz
- Reflective
- Absorptive
- Switch Matrixes
- Custom Designs

### OPTIONS

- Optimized Narrow Bands
- Up to 120 dB Isolation
- High & Low Power Models
- Phase & Amplitude Matched
- Switching Speed 20  $\mu$ sec max
- Custom Logic

### Electrical Specifications

MODEL	FREQUENCY GHz	MAX INSERTION LOSS	V.S.W.R. MAX
SP1T	2-18 GHz	2.3	2:1
SP2T	2-18 GHz	2.5	2:1
SP4T	2-18 GHz	2.8	2:1
SP8T	2-18 GHz	4.0	2:1
SP16T	2-18 GHz	7.0	2:1

Absorptive • 60dB isolation • 1 $\mu$ sec switching speed • + 20 dBm cw, 1 w max

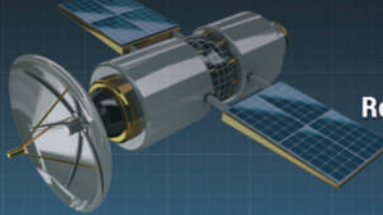


2 Emery Avenue  
Randolph, NJ 07869 USA  
973-361-5700 Fax: 973-361-5722  
www.gtmicrowave.com  
e-mail: sales@gtmicrowave.com



# RF-LAMBDA

THE POWER BEYOND EXPECTATIONS



ITAR & ISO9000  
Registered Manufacture  
Made in USA



## RF T/R MODULE UP TO 70GHz

DREAM? WE REALIZED IT

LOW LOSS **NO MORE CONNECTOR**  
GaN, GaAs SiGe **DIE BASED BONDING**  
SIZE AND **WEIGHT REDUCTION 90%**

**HERMETICALLY SEALED**  
**AIRBORNE APPLICATION**

### SATCOM TR MODULE RX 50GHz TX 22GHz



#### TX/RX MODULE Connectorized Solution

#### RF RECEIVER

DC-67GHz  
RF Limiter

0.05-50GHz LNA  
PN: RLNA00M50GA

RF Mixer

OUTPUT

#### RF TRANSMITTER

RF Switch 67GHz  
RFSP8TA series

RF Filter Bank

0.01- 22G 8W PA  
PN: RFLUPA01G22GA

0.1-40GHz  
Digital Phase Shifter  
Attenuator  
PN: RFDAT0040G5A

#### LO SECTION

Oscillator

RF Mixer

INPUT

[www.rflambda.com](http://www.rflambda.com)  
[sales@rflambda.com](mailto:sales@rflambda.com)

1-888-976-8880

1-972-767-5998

San Diego, CA, US

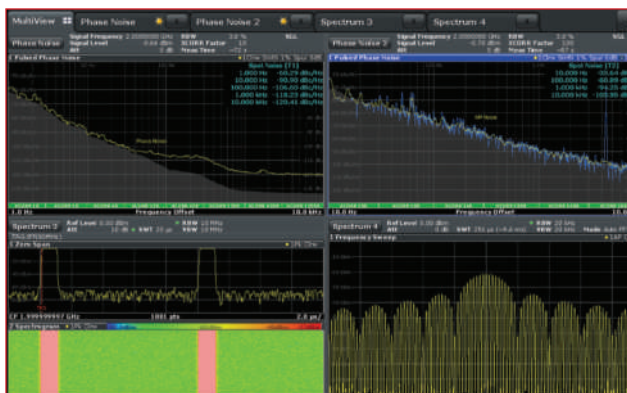
Plano, TX, US

Ottawa, ONT, Canada

Frankfurt, Germany

Content is copyright protected and provided for personal use only - not for reproduction or retransmission.  
For reprints please contact the Publisher.





◀ Fig. 6 Phase noise measurement.

measurements become. With the R&S FSWP phase noise analyzer, however, complicated setups, such as pulsed additive phase noise, are accomplished in minutes with high accuracy (see **Figure 6**). This is also a fully functional spectrum analyzer and voltage-controlled oscillator (VCO) tester. If, for example, the DRFM is acting as a smart (follower) jammer on a hopping signal, then the user must characterize VCO tuning and settling.

Internal DC sources can be used for VCO characterization, providing all VCO parameters at a glance, such as frequency, current, power and sensitivity. Ensuring coherence between transmit and receive paths and the performance of stability measurements are essential parts of the DRFM developer's toolkit. The R&S FSWP phase noise analyzer uses the Allan variance (AVAR) to analyze the time-domain stability of oscillators.

Pulse train stability of the jammer must also be considered. Too much jitter and the return could be filtered by the radar's false alarm rate algorithm—or worse, classified as a jamming signal. Many factors affect pulse stability, for example, memory effects, mismatch between different stages, poor thermal dissipation planning and/or clock/oscillator jitter. The R&S FSWP provides an accurate way to measure phase and amplitude stability, helping optimize jammer design. Typical parameters are difference to average for both amplitude and phase, and 3D visualization makes it easy to spot potential problems.

The free space transducer will always be used, no matter how far digitalization progresses. Even with direct RF-to-digital conversion, an antenna plays the key role in transferring the RF energy to the desired destination. Here, the R&S ZNA vector network analyzer adds fast, non-dedicated receivers for antenna characterization with excellent receiver sensitivity.

## DIGITAL STAGE MEASUREMENTS

Testing at the digital stage is as important as performing system level verification or qualifying RF components, sub-modules and

# SPACE LABS INC.

## MM-WAVE TECHNOLOGY

### DELIVERING YOUR MILLIMETER-WAVE REQUIREMENTS AT EVERY LEVEL

### COMPONENTS

10-110 GHz

- Broadband Detectors
- WG/Coax Adapters
- Gunn Oscillators
- Waveguide & Planar Mixers
- Low-Noise & Power Amplifiers
- Active & Passive Multipliers
- Low, High & Band-Pass Filters

### SUBSYSTEMS

10-110 GHz

- Receivers
- Transmitters
- Transceivers
- Block Converters
- Up & Down Converters
- Phase-Lock Sources
- Radiometer Front-Ends

### SYSTEMS

10-110 GHz

- Frequency Synthesizers
- Frequency Extenders
- Switching Arrays
- Multi-Channel Transceivers
- Ka & W-Band Cloud Radar
- Custom Integrated Assemblies

## NEW!

Check out our new website with added features like **QUICK SHIP!**

[www.spaceklabs.com](http://www.spaceklabs.com)

An ISO 9001:2015 Company

[www.spaceklabs.com](http://www.spaceklabs.com) | 212 East Gutierrez Street, Santa Barbara CA 93101  
e-mail: sales@spaceklabs.com | tel (805) 564-4404 | fax (805) 966-3249

Made in the USA



# MILITARY AND AEROSPACE INTERCONNECTS AT THE READY



From high-volume production, to low-volume customized products, MilesTek is your source for military, aerospace, communications and industrial interconnect solutions. With quick turnaround and same-day shipping from our stock of more than 10,000 highly reliable products, MilesTek is at the ready to help meet your project deadlines.

## The MilesTek Advantage:

- Large In-Stock Inventories
- Same-Day Shipping
- Prototype Development
- CAD Design Capabilities
- Multiple Testing Solutions
- Expert Technical Support
- AS9100 Certified
- SO 9001:2008 Registered



866-524-1553 • MilesTek.com

**MilesTek**  
an INFINIT® brand

**Available for Same-Day Shipping!**

Content is copyright protected and provided for personal use only. All rights reserved. For reprints please contact the Publisher.



◀ Fig. 7  
Power integrity  
measurement.

modules. Among the key elements are power and signal integrity, clock jitter, latency, timing and qualifying the signal converting components, such as the ADC and DAC. On the digital side, the oscilloscope is the centerpiece of the test kit.

Power integrity tests ensure clean power and no additional coupling of noise or hum on the RF lines. Typical performance parameters are ripple, noise and power distribution network impedance (see **Figure 7**).

With deeper strides into the digital world, clock synchronization becomes critical. Imagine an active electronically scanned array architecture with thousands of transmit-receive modules, where a significant portion of the calibration time is spent on timing synchronization and clock calibration. Eliminating clock jitter at the design stage simplifies the calibration process in final testing and verification, ensuring a fully functional product.

ADC and DAC measurements are just as important. For the RF side, the R&S FSWP phase noise analyzer or the R&S SMA100B analog signal generator may be used. For the DAC side, testing signal quality, modulation quality and phase noise is common. For the ADC, general testing with CW and real test signals qualify the component for its intended purpose. Wideband tests can be performed with the 2 GHz baseband bandwidth of the R&S SMW vector signal generator. Two RF channels in the same R&S SMW instrument can be stitched together to provide a 4 GHz wide signal with optimal RF performance.

## CONCLUSION

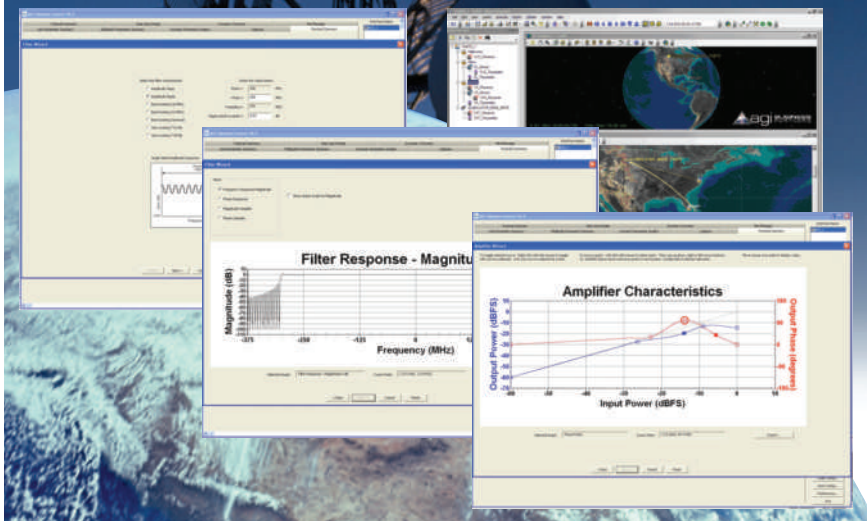
The DRFM jammer is an essential and highly complex element of the EA suite. It has evolved from a simple repeater with some fading capabilities to a sophisticated EA asset. Critical test areas involve the operation and timing of deception techniques at the system level, qualifying the individual components, sub-modules and modules at the RF/IF level and ensuring that clock jitter and power integrity are addressed early in the design stage.■

# Powerful Payload & RF Link Emulator



600 MHz  
bandwidth

- ◆ Link emulation: Delay, Doppler, AWGN, Phase shift
- ◆ Real time control for Aerial Vehicle (UAV) testing
- ◆ Payload: MUX, Compression, Phase noise, Group delay
- ◆ Multipath: 12 paths per channel
- ◆ Up to sixteen synchronous channels with correlation



RF Test Equipment for Wireless Communications

email: [info@dbmcorp.com](mailto:info@dbmcorp.com)

dBmCorp, Inc

32A Spruce Street ◆ Oakland, NJ 07436

Tel (201) 677-0008 ◆ Fax (201) 677-9444

[www.dbmcorp.com](http://www.dbmcorp.com)



SIX DAYS ■ THREE CONFERENCES ■ TWO FORUMS ■ ONE EXHIBITION

# SUBMIT YOUR PAPER ONLINE

## EUROPEAN MICROWAVE WEEK 2020

To electronically submit a technical paper for one or more of the three conferences, all you have to do is:

1. Log on to [www.eumweek.com](http://www.eumweek.com)
2. Click on 'Conferences' to view the individual conference details
3. Click on 'Paper Submission' for author's instructions on how to submit a summary

**EUROPEAN  
MICROWAVE WEEK**  
**JAARBEURS UTRECHT**  
**THE NETHERLANDS**  
**13-18 SEPTEMBER 2020**  
**[www.eumweek.com](http://www.eumweek.com)**

# EuMA

European Microwave Association

Official Publication:



Organised by:



Supported by:



Co-sponsored by:



Co-sponsored by:



The 15th European Microwave Integrated Circuits Conference

Co-sponsored by:



The 50th European Microwave Conference

Co-sponsored by:



The 17th European Radar Conference

Co-sponsored by:



Submit summaries online by 14th February 2020 at [www.eumweek.com](http://www.eumweek.com)

For reprints please contact the Publisher.

# Reducing EMI/RFI in Microwave Cable Assemblies for A&D Systems

Paul Pino  
W. L. Gore & Associates, Newark, Del.

**M**itigating electromagnetic interference (EMI) and RF interference (RFI) is a growing concern in aerospace and defense applications. Consumer communications technology is rapidly moving to over-the-air (OTA) transmission, with the need for more information to be communicated over longer distances, driving wider bandwidth, higher frequency and greater transmit power. Defense systems such as electronic warfare (EW) and radar have similar trends toward higher frequency and greater power, placing more stringent demands on the shielding of cable assemblies and electronic components. As the RF environment, which is already filled with noise sources and interference, becomes even more crowded, systems and components resistant to EMI and RFI will play a greater role in system reliability.



▲ **Fig. 1** Troubleshooting signal interference problems is challenging, especially in an aircraft.

## IMPACT OF EMI/RFI ON CABLE PERFORMANCE

EMI describes noise or interference over a very broad frequency spectrum. For example, the noise source could be a vacuum cleaner motor emitting low frequency interference in the double-digit range. RFI is associated with emissions within the RF spectrum, nominally from 20 kHz to 300 GHz.

For microwave cable assemblies, EMI and RFI are two-way streets. If a cable assembly can produce sizable amounts of interference, it will also be susceptible to receiving the same. The objective of cable shielding is to keep the noise and signals outside of the cable and keep in the signal of interest. When a cable assembly is sensitive to EMI/RFI, the signal of interest—the signal propagating through the cable assembly—can be compromised, even rendered unintelligible by interference.

As frequency increases, between 300 MHz and 300 GHz for microwave applications, shielding a cable assembly becomes more challenging. Higher frequency signals, coupled with increased transmit power, will increase the power radiated through any leakage in the shield. This combination increases the risk of interference with electronic equipment and cable runs adjacent to the radiating component. Troubleshooting a signal interference problem, especially in an aircraft, can be daunting (see **Figure 1**). Highly effective shielding is critical to system performance.

With cellular communications, 5G OTA testing requires new cell phone designs to





▲ **Fig. 2** RF leakage from a cable assembly can degrade an EW system's capability detecting and countering threats.

be validated without a cable connection to the device under test (DUT). Instead, all test signals are transmitted OTA in a controlled environment, to approximate real world conditions. In this environment, microwave cable assemblies with poor shielding will be prone to radiating and receiving unwanted signals, which could negatively influence a design validation.

Cable assemblies susceptible to EMI/RFI can have an especially profound effect on airborne EW applications. Modern EW systems gather large amounts of data from the electromagnetic environment surrounding the aircraft, using it to determine threat type, location, proximity and severity. Poorly shielded cable assemblies, or those with compromised shields, can degrade the signals from the system's antennas and the system's ability to identify and determine how to respond to a potential threat—particularly since the design goal for threat detection is to detect a threat with a minimum of 2x the threat's lethal striking distance.

With an EW system, the critical nature of processing time is apparent by considering this scenario (see **Figure 2**): An aggressor fighter aircraft has just launched a subsonic air-to-air missile against a friendly fighter, as the two rapidly close on one another. At launch, the two aircraft were 4 miles apart, converging at 1200 mph. From the time of launch and at the current closing speed, the friendly aircraft's EW system has less than 12 seconds to identify the threat and determine a course of action, including displaying the threat and its position to the pilot and launching countermea-

asures. With poorly shielded cable assemblies, the EW system may not extract the threat signal from the cacophony of electromagnetic noise and interference—not unlike trying to pick out a single voice in a stadium full of cheering spectators.

### MITIGATING EMI/RFI

With any technical problem, the first step toward resolution is understanding, which comes through testing and characterization. W. L.

Gore & Associates performs shielding effectiveness testing of its cable assemblies using the latest mode-stirred chamber technology and incorporates these findings into its cable assembly and connector designs and termination techniques. Shielding effectiveness is not strictly a cable phenomenon; the connector and cable termination are part of the equation (see **Figure 3**).

For defense aircraft applications, EMI/RFI challenges can be addressed

# ADVANCE Your Mission



NuPower™ Broadband Power Amplifiers					
Part Number	Freq (MHz)	Gain (dB)	Power Out (W)	Size (inches)	
NW-PA-11B02A	100 - 2550	40	10	2.34 x 1.96 x 0.62	
NW-PA-VU-4-G01	225 - 512	35	10	2.34 x 2.34 x 0.70	
NW-PA-11C01A	225 - 2400	40	15	3.00 x 2.00 x 0.65	
NW-PA-13G05A	800 - 2000	45	50	4.50 x 3.50 x 0.61	
NW-PA-15D05A	800 - 2500	44	20	4.50 x 3.50 x 0.61	
NW-PA-12B01A	1000 - 2500	42	20	3.00 x 2.00 x 0.65	
NW-PA-12B01A-D30	1000 - 2500	12	20	3.00 x 2.00 x 0.65	
NW-PA-12A03A	1000 - 2500	37	5	1.80 x 1.80 x 0.50	
NW-PA-12A03A-D30	1000 - 2500	7	5	1.80 x 1.80 x 0.50	
NW-PA-12A01A	1000 - 2500	40	4	3.00 x 2.00 x 0.65	
NW-PA-LS-100-A01	1600 - 2500	50	100	6.50 x 4.50 x 1.00	
NW-PA-12D05A	1700 - 2400	45	35	4.50 x 3.50 x 0.61	
NW-PA-C-10-R01	4400 - 5100	10	10	3.57 x 2.57 x 0.50	
NW-PA-C-20-R01	4400 - 4900	43	20	4.50 x 3.50 x 0.61	

NuPower Xtender™ Broadband Bidirectional Amplifiers					
Part Number	Freq (MHz)	Gain (dB)	Power Out (W)	Size (inches)	
NW-BA-VU-4-GX02	225 - 512	35	10	2.34 x 2.34 x 0.70	
NW-BA-12B04A	1000 - 2500	35	10	3.00 x 2.00 x 1.16	
NW-BA-12C04A	1000 - 2500	35	15	3.00 x 2.00 x 1.16	
NW-BA-C-10-RX01	4400 - 5100	10	10	3.57 x 2.57 x 0.50	
NW-BA-C-20-RX01	4400 - 4900	43	20	5.50 x 4.50 x 0.71	

Broadband High Intercept Low Noise Amplifiers (HILNA™)					
Part Number	Freq (MHz)	Gain (dB)	OIP3 (dBm)	Size (inches)	
HILNA-HF	2 - 50	30	30	3.15 x 2.50 x 1.18	
μHILNA-V1	50 - 1500	20	31	1.00 x 0.75 x 0.50	
HILNA-V1	50 - 1000	20	32	3.15 x 2.50 x 1.18	
HILNA-G2V1	50 - 1000	40	31	3.15 x 2.50 x 1.18	
HILNA-LS	1000 - 3000	50	33	2.50 x 1.75 x 0.75	
HILNA-GP5	1200 - 1600	32	30	3.15 x 2.50 x 1.18	
HILNA-CX	5000 - 10000	35	21	1.77 x 1.52 x 0.45	

**NuWaves**  
engineering  
Trusted RF Solutions™

www.nuwaves.com  
**513.360.0800**  
Middletown, OH

through the following tactics:

- Use appropriate shielding enclosure designs for the application.
- Where cable installation or aircraft servicing can potentially damage cables, use ruggedized microwave cable assemblies with proven shield designs capable of withstanding installation and servicing.
- Ensure all coaxial connections are clean and tightened to the proper torque.
- In high vibration environments, ensure cables are properly secured using locking connector coupling nuts or coupling nuts drilled for lock wire holes.
- In microwave cable airframe installations, do not stretch a cable that “last little bit” to make a connection; use properly sized P-clamps to secure cables.
- As cable placement is critical, do not position cables close to antennas transmitting high-power.
- In commercial applications, in-

- struct technical personnel on microwave cable assembly care and handling. This is particularly important when using non-ruggedized or general-purpose cable assemblies, as they are considerably more fragile than their ruggedized counterparts.
- Cable shielding problems often result from damage caused by improper handling. Discourage repeatedly bending cables just behind the connector or coiling cables in tight loops for storage, which exposes them to unnecessary wear.
- When bundling cables with plastic zip-ties, use just enough force to contain the bundle; zip-ties can exert damaging crush forces if cinched tightly.
- To maintain performance, proper microwave connector care and maintenance are key to preserving mechanical and electrical integrity.

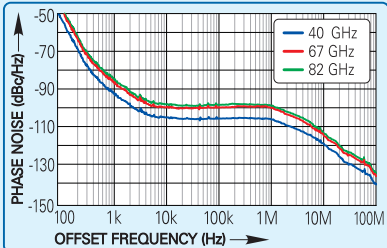
# QuickSyn Synthesizers Now Extended to mmW

Low Phase Noise and Fast Switching  
With USB/SPI Control



We've extended our popular QuickSyn Lite frequency synthesizers to three commonly used mmW bands—27 to 40 GHz, 50 to 67 GHz, and 76 to 82 GHz for high-speed short-range data links, WirelessHD, IEEE 802.11ad, digital radios, automotive radars, etc. QuickSyn mmW frequency synthesizer modules are ideal for demanding application environments like field trials and embedded systems where bulky benchtop solutions were the only choice.

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



[ni-microwavecomponents.com/quicksyn](http://ni-microwavecomponents.com/quicksyn)

877 474 2736



© 2015 National Instruments. All rights reserved. National Instruments, NI, and ni.com are trademarks of National Instruments. Other product and company names listed are trademarks or trade names of their respective companies.

## THE RIGHT CABLE & CONNECTOR

Microwave cable assemblies are often the last component to be designed in a system, often treated as ideal or near-ideal components, assuming not much difference among cables. The common thinking is cables simply link one critical system to another. However, a microwave cable assembly is a critical system itself, capable of causing unintended results that may degrade the per-



▲ Fig. 3 The cable, connector and cable termination determine the shielding effectiveness of an RF cable assembly.



formance of the system. It is rarely considered how poor design or construction can degrade a cable assembly's performance with improper handling, damage inflicted during installation or time.

System designers and program managers should consider the following when selecting microwave cable assemblies for their systems:

- What environmental conditions will the cable assembly be exposed to (i.e., temperature, pressure, humidity)?
- Will the cable assembly be exposed to vibration or excessive flexing, either by hand or mechanized?
- What phase and loss stability over temperature is needed?
- What shielding effectiveness is required and at what frequency?
- What is the expected average power that the connector-cable combination will carry under the prevailing use conditions?
- What is the loss budget for the cable run? What is the VSWR budget?
- Will the cable assembly be subjected to rough handling, either during its service life or installation? If so, consider a ruggedized design.
- Will the cable assembly be housed in the unpressurized portion of an aircraft? If so, consider a sealed assembly to ensure stable phase and loss performance with altitude (i.e., pressure).
- Will the cable assembly be exposed to extreme temperature and moisture? If so, consider a sealed assembly.
- Will the cable assembly be exposed to oil, fuel and chemicals? If so, consider a sealed, ruggedized assembly resistant to chemicals.
- Non-ruggedized or general-purpose cable assemblies will cost less, yet they are vulnerable to damage. Carefully evaluate the risks versus the cost savings when selecting a general-purpose assembly rather than ruggedized.

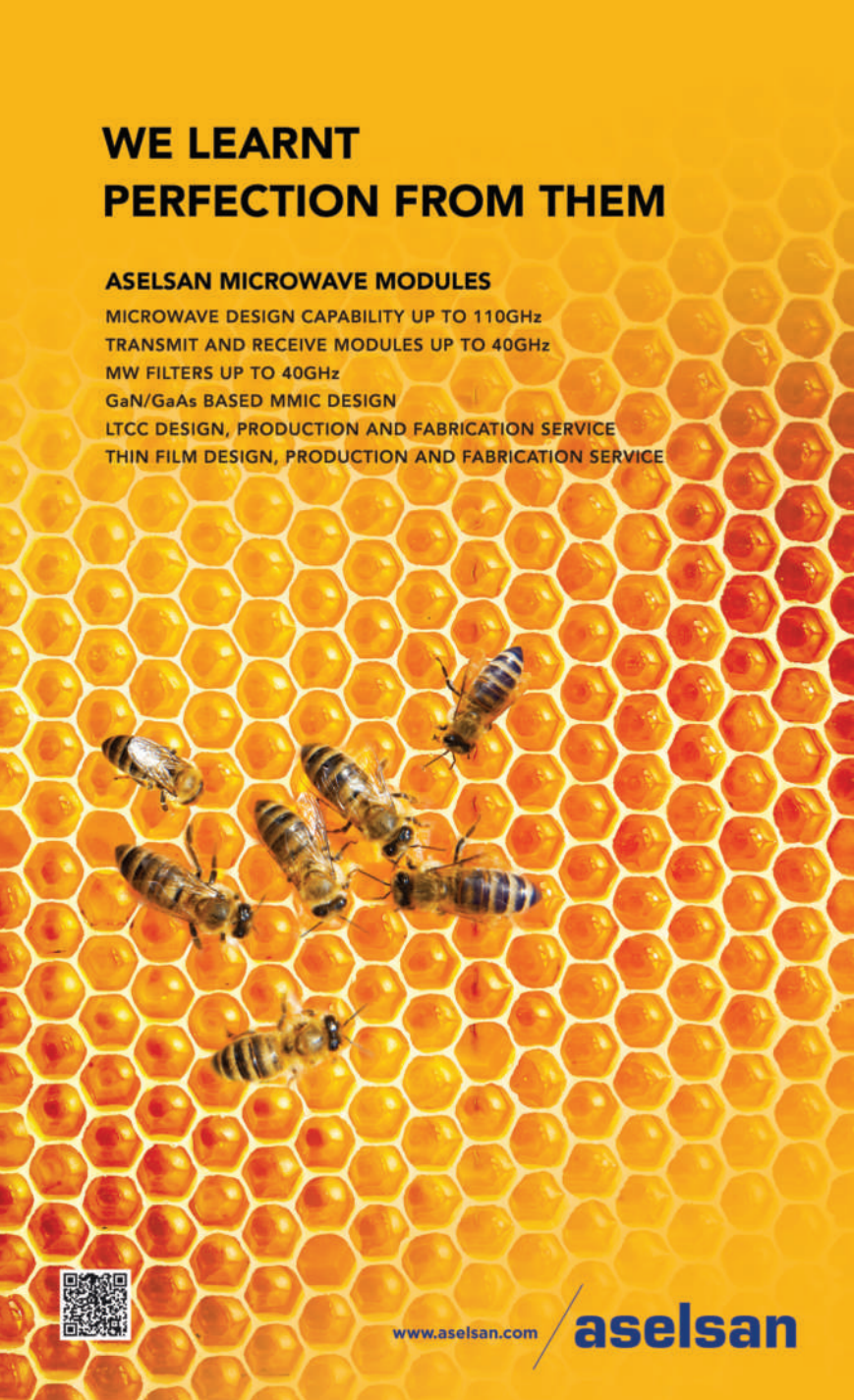
Consider the connectors selected for the cable assembly, as this drives a myriad of performance aspects inherent to the assembly. As the connector type influences a cable assembly's shielding effectiveness, overall RF performance and me-

chanical durability, system designers should consider the following when selecting a connector type during the initial design process, then performing thorough testing to ensure the entire interconnect will perform reliably in the intended application.

- Size of the internal components.
- Number of connectors in the entire link.
- Distance between connectors.
- Ease and consistency of termination.

- Noise margin availability.
- Electrical performance of the connector with the selected cable assembly.


Choosing the right microwave cable assembly and connector type that will perform consistently after installation, during use and over time, is well worth the effort and any additional expense, which will pay dividends in system reliability and performance.■



**WE LEARNT  
PERFECTION FROM THEM**

**ASELSAN MICROWAVE MODULES**

MICROWAVE DESIGN CAPABILITY UP TO 110GHz  
TRANSMIT AND RECEIVE MODULES UP TO 40GHz  
MW FILTERS UP TO 40GHz  
GaN/GaAs BASED MMIC DESIGN  
LTCC DESIGN, PRODUCTION AND FABRICATION SERVICE  
THIN FILM DESIGN, PRODUCTION AND FABRICATION SERVICE

 [www.aselsan.com](http://www.aselsan.com) / **aselsan**



# Innovative Waveguide Connector Simplifies mmWave Packages

SAGE Millimeter  
Torrance, Calif.

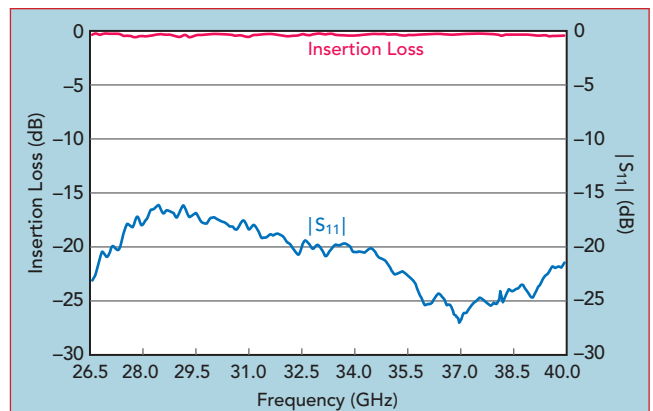
*SAGE Millimeter will become Eravant in March 2020.*

**M**icrowave and mmWave packaging can turn from mostly routine to highly challenging when waveguide ports are required. Integrated waveguide ports typically require a costly process that is difficult to model and build. An extensive collection of package designs may be needed to accommodate different waveguide bands and numerous port configurations. A common alternative is to employ external coax-to-waveguide transitions. Unfortunately, these can be mechanically cumbersome, and they may have high insertion loss or marginal signal integrity.

The patent pending Uni-Guide™ waveguide connectors from SAGE Millimeter lowers many of these design and manufacturing hurdles. They provide compact, reliable and cost-effective waveguide flanges that are simply added to standard coaxial ports. Easily swapped with coaxial connectors, they



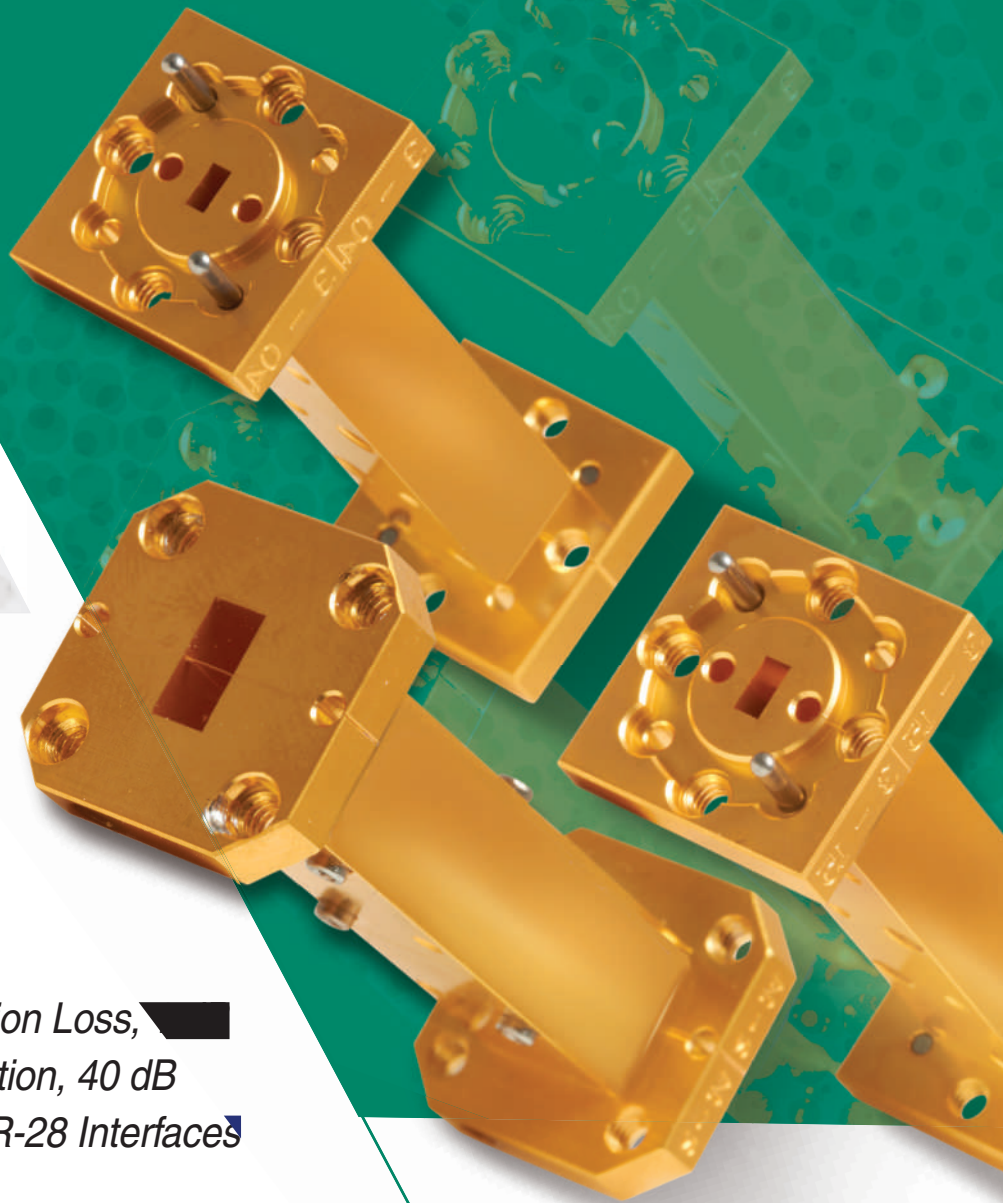
▲ **Fig. 1** The Uni-Guide uses the same common RF interface for coaxial connectors, a glass bead hermetically soldered in the housing wall.





▲ **Fig. 2** Typical insertion loss and  $|S_{11}|$  of the Ka-Band Uni-Guide connector.



*INSTRUMENT GRADE*  
**WAVEGUIDE FILTERS**  
*to 86 GHz*



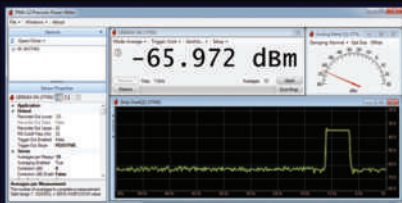
- ▶ Low Passband Insertion Loss, 
- ▶ High Stopband Rejection, 40 dB
- ▶ WR-12, WR-15, & WR-28 Interfaces 



## Continuous Measurements With No Drift

### LB5940A Power Sensor

- Thermally Stable
- Fast, Accurate, Traceable
- Field Calibration Tables
- Includes Complete Software
- ATE Friendly - USB-SPI-I2C
- U2000 Compatible
- SCPI, VISA & USBTMC



Since 2004  
Santa Rosa, CA  
707-546-1050

LadyBug-Tech.com



In Stock

## ProductFeature

enable greater flexibility for component manufacturers and end-users.

### HERMETICAL WAVEGUIDE SOLUTION

A common type of signal port used in hermetic packages uses a glass bead positioned mid-way between a pair of threaded mounting holes (see **Figure 1**). The threaded holes support a coaxial connector that is easily attached or replaced. This common configuration is used by several connector families, including SMA, 2.92 mm (K), 2.4 mm, 1.85 mm (V), 1.35 mm (E) and 1 mm.

The Uni-Guide waveguide connector joins this group. If the package is designed and manufactured to be hermetically sealed for coaxial connectors, it will retain its hermeticity when using a Uni-Guide waveguide connector. This eliminates the need for an expensive hermetic waveguide process.

A trio of Uni-Guide connectors is available for coaxial ports with a 12 mil center pin and two mounting holes spaced 0.48 in. apart, the same arrangement widely used with the 2.92 mm (K) and 2.4 mm connectors. The model SUF-2812-480-S1 is a WR-28 connector covering 26.5 to 40 GHz with 0.5 dB typical insertion loss. The SUF-2212-480-S1 WR-22 connector covers 33 to 50 GHz and has 0.6 dB insertion loss, and the SUF-2812-480-S1 WR-19 connector, covering 40 to 60 GHz, has 0.7 dB insertion loss. All three have 20 dB typical return loss and handle 100 W RF power. The measured insertion loss and  $|S_{11}|$  of the Ka-Band Uni-Guide is shown in **Figure 2**.

Additional Uni-Guide models designed for glass beads with pin diameters of 9, 15, 20 and 50 mils and various mounting configurations are being developed to cover all standard waveguide bands from 8.2 to 110 GHz.



**Fig. 3** Pairs of Uni-Guide connectors can be combined to create band-to-band adapters or 90 degree twists.

## Precision Right Angle Adapters in Stock

 <b>C5540 \$135 N</b> 18 Ghz VSWR 1.25	 <b>C2563 \$130 TNC</b> 18 Ghz VSWR 1.25	 <b>C7054 \$165 3.5</b> 33 Ghz VSWR 1.25	 <b>C7035 \$220 2.92</b> 40 Ghz VSWR 1.25
 <b>C3435 \$60 SMA</b> 27 Ghz VSWR 1.15	<b>Fast Delivery!</b> <b>Low VSWR!</b> <b>Huge Inventory!</b>		
 <b>C7552 \$297 2.4</b> 50 Ghz VSWR 1.40	 <b>C3239 \$45 SMA</b> 18 Ghz VSWR 1.25	 <b>C3407 \$60 SMA</b> 27 Ghz VSWR 1.15	 <b>C3557 \$150 N-SMA</b> 18 Ghz VSWR 1.20
 <b>C7051 \$220 2.92</b> 40 Ghz VSWR 1.25			

**CentricRF™** [www.CentricRF.com](http://www.CentricRF.com) 1-800-399-6891



## ProductFeature

### PORT TYPE & ORIENTATION CHANGES

While they provide an easy way to implement waveguide ports, Uni-Guide connectors have additional benefits. Rotating them yields a 90 degree change in port orientation to form various integration options, and a polarity inversion is achieved when a connector is rotated 180 degrees. Pairs of Uni-Guide connectors can be cascaded to create common waveguide components, such as band-to-band waveguide adapters or 90 degree twists (see **Figure 3**). A center pin bridges the signal path between back-to-back connectors, yielding a compact component that rivals the performance of larger and more costly alternatives.

In many situations, Uni-Guide connectors allow component manufacturers to offer various port configurations so that either coaxial or waveguide test equipment can be implemented. This can reduce the number of costly test systems required for a flexible production environment.

### TIME AND MONEY

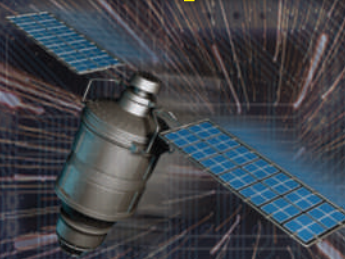
A custom package design requires electromagnetic simulation, mechanical modeling, design, machining and validation, which can easily take 12 to 16 weeks. A second iteration, if required, extends the development time to 20 to 26 weeks. Using the Uni-Guide waveguide connector with a standard coaxial housing can provide any waveguide port needed—instantaneously, without design or prototyping.

To handle a portfolio of waveguide sizes and port interfaces, a manufacturer could have tens to hundreds of package sizes and styles, building costly inventory that becomes large and wasteful. Now, only a few standard housings and Uni-Guide connectors will support many coaxial, waveguide or mixed interface products. The flexibility of the Uni-Guide waveguide connector eliminates many adapters, transitions and waveguide twists.



**SAGE Millimeter**  
Torrance, Calif.  
[www.sagemillimeter.com](http://www.sagemillimeter.com)

## Need Space and Mil-Qualified Parts?



**Search No Further.** Weinschel Associates (WA) delivers solutions for your toughest requirements - on-time and in compliance. Look to WA to launch your next program with Space and MIL-Qualified RF and Microwave Components.

### Space and Mil-Qualified Components

- **Attenuators** - Now up to 50 GHz!
- **Terminations** - Now up to 50 GHz!
- **Dividers**
- **DC Blocks**
- **Tuners**
- **High Performance Designs**
- **Power Handling to Design Specifications**
- **Frequency Range: Now DC to 50 GHz!**



Visit our new website with interactive catalog and online RFQ!

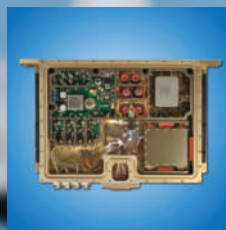
[www.WeinschelAssociates.com](http://www.WeinschelAssociates.com)

2505 Back Acre Circle  
Mount Airy, MD 21771  
Voice: 301.963.4630  
Fax: 301.963.8640  
[sales@WeinschelAssociates.com](mailto:sales@WeinschelAssociates.com)



## CUSTOM INTEGRATED MICROWAVE ASSEMBLIES

ULTRA LOW NOISE FREQUENCY SOURCES,  
FREQUENCY CONVERSION & SYNTHESIS



- 5 MHz to 18 GHz
- ULN or Golden Phase Noise Performance to -190 dBc/Hz
- Low G-Sensitivity to 2E-11/g per axis
- Custom or Standard Housings
- Ruggedized for Dynamic Environments
- Designed and Tested to Customer Specifications
- Screened to MIL Requirements and Temperature Range
- Electronic Warfare, Radar, Communications, Defense, Aerospace and Commercial Applications

"Quietly the Best"



**Wenzel Associates, Inc.**  
2215 Kramer Lane, Austin, Texas 78758  
512-835-2038 • [sales@wenzel.com](mailto:sales@wenzel.com)  
[www.wenzel.com](http://www.wenzel.com)



**T**he Holzworth HA7062D Real-Time Phase Noise Analyzer is born from the company's history of industry leading phase noise analyzers with proven accuracy, high-reliability, automation and flexibility. The real-time engine covers the full measurement bandwidth with extremely fast measurement speeds to reduce product development time and optimizes ATE manufacturing throughput.

The HA7062D base model operates from 10 MHz to 26 GHz with a frequency extension available to 40 GHz. The RF input measurement level ranges from -5 to +20 dBm. For phase noise measurements, RF tracking range is typically  $\pm 10$  ppm,

# 10 MHz to 40 GHz Phase Noise Analyzer

offset frequency ranges from 0.1 Hz to 100 MHz and the phase noise uncertainty is  $\pm 4$  dB from 1 Hz to 10 Hz,  $\pm 3$  dB from 10 Hz to 1 kHz and  $\pm 2$  dB from 1 kHz to 100 MHz.

While many companies provide a measurement confidence factor, which is often misinterpreted as the noise floor of the instrument, Holzworth has architected the instrument's front-end so that the noise floors limits can be measured. The unique architecture of the HA7062D allows for direct access to key internal modules in order to measure the actual noise floor of the analyzer at any given frequency versus minimum frequency offset and number of correlations.

The HA7062D has high-speed digital processors for speed, but the proven accuracy and speed starts with the analog front-end. A key

component of the analog front-end is a pair of Holzworth HSX Series RF Synthesizers as the test system's internal LOs. These ultra-low noise RF sources not only complement the dual core FFT engine to provide one of the most advanced phase noise analyzers available, but they are also made available to the user at the front panel's LO Output ports.

The HA7062D has a 1U high, rack mountable chassis form factor. The fully shielded, fan-less chassis eliminates ground loops and troublesome microphonics for uncompromised performance and repeatability. A universal rack mount bracket kit is an available accessory.

**VENDORVIEW**

**Holzworth Instrumentation  
Boulder, Colo.**

**[www.holzworth.com](http://www.holzworth.com)  
[sales@holzworth.com](mailto:sales@holzworth.com)**



Catch up on the latest industry news with the bi-weekly video update **Frequency Matters** from Microwave Journal @ [www.microwavejournal.com/frequencymatters](http://www.microwavejournal.com/frequencymatters)

**Microwave  
Journal**

Frequency Matters.

Sponsored By **MACOM**  
Partners from RF to Light

EuMW Show Wrap-Up

Vol. 62 • No. 11

November 2019

Reducing EMI/RFI in Microwave  
Cable Assemblies for A&D Systems

**Microwave  
Journal**

New Thermal Interface for  
High Power Density GaN  
Devices in Space

DRFM Jammer Test  
Solutions





# 30 kW Solid-State HPA for P-Band Radar

**D**aico Industries has developed a solid-state high-power amplifier (HPA) for P-Band radar systems, which is scalable to other bands and applications. The CTX09651 delivers 30 kW peak pulsed power and 40 percent power-added efficiency (typical) from 850 to 942 MHz, transmitting pulse widths to 64  $\mu$ s up to 5 percent duty cycle. Pulse rise and fall times are less than 800 ns, pulse droop no greater than 0.25 dB and phase variation during a pulse no greater than 6 degrees.

The HPA combines seven, 4.2 kW solid-state HPAs using Daico's patented (m+n)ART™ architecture.

With hot swap capability, if the CTX09651's control system detects a failure in one of the seven, it substitutes an eighth HPA to maintain uninterrupted operation. If more than one HPA fails, the multiple amplifier design exhibits graceful degradation. The CTX09651 will not fail with a short or open on the output and, using LDMOS and GaN transistors, achieves 80,000 hours mean time between critical failure.

Spurious signals from the CTX09651 are no greater than -60 dBc from 962 to 1212 MHz, and harmonics are no greater than -30 dBc (second) and -40 dBc (third). The RF input and output connectors

are TNC and 7/16 DIN, respectively, with an RS-485 interface for digital control and monitoring. The HPA weighs 175 lb and measures 12.2 in.  $\times$  18.4 in.  $\times$  12.2 in., achieving a power density of nearly 20 kW/ft<sup>3</sup>.

Daico's solid-state designs outperform klystron and other TWT amplifiers, a result of the (m+n)ART design approach, which is flexible, maintainable and scalable for other bands and power levels. Daico's HPAs meet the requirements of mission-critical applications.

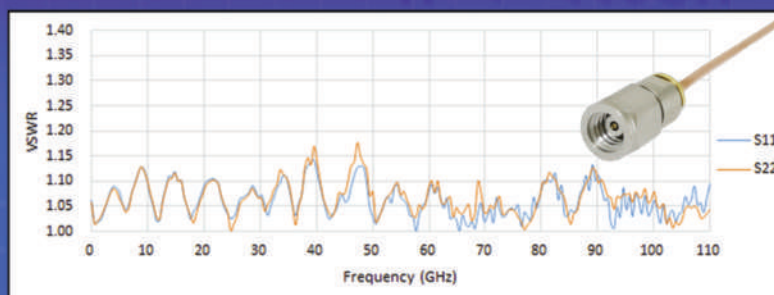
**Daico Industries Inc.**  
**Carson, Calif.**  
**[www.daico.com](http://www.daico.com)**



[www.arance-rf.com](http://www.arance-rf.com)

- VNA Test Assemblies
- Low Loss Cable Assemblies
- Calibration Kits
- RF Coaxial Adapters
- RF Coaxial Loads
- DC Blocks

**Up to 110GHz**





# High-Power Emitters for Open Air Range Threat Simulation

Open air range testing simulates complex and reactive threats that cannot be simulated with one-dimensional, indoor test amplifiers. To address this, Empower RF Systems has developed its Next Generation family of high performance solid-state amplifiers with embedded high speed computing for precise power control, pulse replication and multi-mode operation. The result is a dynamically configurable transmitting amplifier for generating real-time threat scenarios.

System integrators can take advantage of the hardware and software capability and commonality across the commercial off-the-shelf (COTS) Next Generation product

family, with features that simplify system integration and enable faster dynamic threat mode changes. The Next Generation architecture overcomes the historical reliance on single purpose and mission specific amplifiers in system designs. The architecture is a well-conceived combination of hardware engineering—achieving size reductions not seen at these power levels—and a microprocessor/FPGA software architecture, enabling multi-mode, multi-mission support.

A critical requirement in many high-power applications is emitter mobility and reliability. The Next Generation electro-mechanical architecture eliminates virtually all internal connectors, achieving an in-

herently rugged COTS amplifier with lower losses in the RF chain for improved efficiency and power density.

This Next Generation family offers scalability through an expandable system hardware architecture with electronic phase adjustment: the embedded software adjusts the phase, so any number of like models can be combined in any order without manual phase matching. The scalable architecture makes it straightforward to provide very high power emitters for threat simulation, CW and pulse radars, jamming and broadband communications.

**VENDORVIEW**

**Empower RF Systems Inc.**  
Inglewood, Calif.  
[www.empowerrf.com](http://www.empowerrf.com)

<ul style="list-style-type: none"> <li>Calibration Kits &amp; Automatic Cal. Module</li> </ul> <b>26.5 GHz</b>	<ul style="list-style-type: none"> <li>High Speed Multicoax Cable Assemblies</li> </ul> <b>67 GHz</b>	<ul style="list-style-type: none"> <li>SMPM Connectors</li> </ul> <b>67 GHz</b>
<h2>RF &amp; Microwave Solution for 5G</h2>		
<ul style="list-style-type: none"> <li>T-Probe &amp; Positioner</li> </ul> <b>40 GHz</b>	<ul style="list-style-type: none"> <li>Vertical Launch Connectors</li> </ul> <b>67 GHz</b>	<ul style="list-style-type: none"> <li>End Launch Connectors</li> </ul> <b>67 GHz</b>
<ul style="list-style-type: none"> <li>MW Cable Assemblies</li> </ul> <b>67 &amp; 110 GHz</b>	<ul style="list-style-type: none"> <li>Precision MW Adapters</li> </ul> <b>67 GHz</b>	<ul style="list-style-type: none"> <li>Flexible Microwave Absorber</li> </ul> <b>20 &amp; 40 GHz</b>

**withwave**  
Versatile RF & MW Solutions

[sales@with-wave.com](mailto:sales@with-wave.com) | [www.with-wave.com](http://www.with-wave.com)

Distributed Exclusively in the USA by:



[www.ecmstockroom.com](http://www.ecmstockroom.com)

**FEATURED**

# WHITE PAPERS

The information you need, from industry experts

**KEYSIGHT TECHNOLOGIES**  
Tips for Better Signal Generator Measurements

**NATIONAL INSTRUMENTS** **AWR**  
A Designer's Primer on Internet of Things (IoT)

**ROHDE & SCHWARZ**  
Make ideas real

**5G**  
RF MW Frontends

Check out these new online Technical Papers featured at **MWJournal.com**

**MicroWave Journal**  
Frequency Matters.





# Customizable 2 kW Broadband Jammer Covers HF to Microwave

**A**lbrecht Telecommunications has developed a digital, broadband jammer for communications jamming and a range of electronic warfare (EW) scenarios. With ultra-fast digital synthesizers, the SAJ-2000MD covers HF to microwave, its output power adjustable to 2 kW. Individual frequencies or frequency bands can be jammed using frequency-agile techniques such as fast frequency hopping and spread spectrum. The customizable jammer can be configured to handle multiple threats, simultaneously transmitting at different frequencies while protecting specific frequencies or bands defined by a blocking list.

Frequency lists can be downloaded from a search receiver for spot jamming. Various modulation sources are available so the jammer can be used as a decoy. Spoofing can operate on one or multiple channels simultaneously in near real-time.

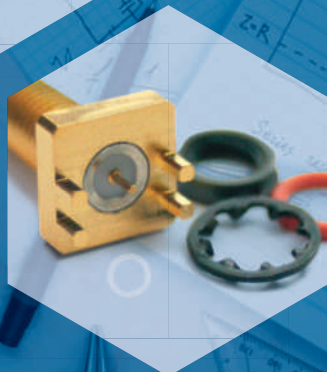
The SAJ-2000MD is controlled via computer and a graphical interface, with the synthesizer fully programmable from a PC. For remote control, Albrecht provides wired or an optional wireless control channel, including encrypted VPN. Using encrypted remote control, the jammer can be operated securely in unmanned locations. A comprehensive built-in test system monitors the status of the system, automatically reporting errors with a full description of the issue.

The SAJ-2000MD will operate autonomously as a stand-alone system or can be integrated within a larger EW system. The rack-mounted unit is portable, suitable for the lab or on platforms in the field, including airborne and shipboard. With a modular architecture, the jammer can be customized and upgraded to incorporate changing tactical requirements and new technology.

In addition to communications jamming, the SAJ-2000MD can be used as a programmable transceiver, expanding the applications.

**Albrecht Telecommunications GmbH**  
Hünenberg, Switzerland  
[www.albrecht-telcom.ch](http://www.albrecht-telcom.ch)

## Precision RF Components



- Wide range of high-spec, stainless steel connectors, In-Series and Between-Series Adapters
- Used where signal integrity and quality are important and a high level of reliability is required
- Precision products include high frequency and can run to 18, 40 or 50 GHz
- Interfaces include K-Type, N, SMA, TNC, 2.9mm, 2.4mm, BMA, SSMA and many others
- Solderless connectors for semi-rigid cable also available

For more information, please contact one of our sales teams at:

USA: +1 (931) 707-1005 [info@intelliconnectusa.com](mailto:info@intelliconnectusa.com)

UK: +44 (0) 1245 347145 [sales@intelliconnect.co.uk](mailto:sales@intelliconnect.co.uk)

### IntelliConnect

A different kind of Interconnect Solutions Provider

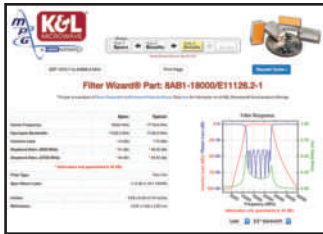
RF and Microwave Connectors, Adaptors and Cable Assemblies

[www.intelliconnectusa.com](http://www.intelliconnectusa.com) | [www.intelliconnect.co.uk](http://www.intelliconnect.co.uk)

### On-Line Filter Synthesis Tool

K&L Microwave's Filter Wizard® filter synthesis and selection tool streamlines identification of filter products meeting customer specifications across a large portion of K&L's standard product offerings. Filter Wizard® accelerates user progress from specification to RFQ for RF and microwave filters spanning an ever-increasing range of response types, bandwidths and unloaded Q values. Provide the application with your desired specifications, and the software will return a list of products that match, placing response graphs, outline drawings and downloadable S-parameters at your fingertips. Visit their website to get started today.

**K&L Microwave**  
[www.klfilterwizard.com](http://www.klfilterwizard.com)



### MCL Microwave Calculator App

**VENDORVIEW**

The MCL Microwave Calculator, developed by Mini-Circuits, performs 21 calculations commonly needed by RF and microwave system designers in a wide range of applications. Quickly compute the effect of VSWR or return loss on transmitted power; cascaded gain and noise figure for up to five amplifier stages; and power-to-voltage conversion. It is the perfect tool to help you solve problems and save time, whether you are working in the lab or in the field.

**Mini-Circuits**  
[www.minicircuits.com/applications/microwave\\_calculator.html](http://www.minicircuits.com/applications/microwave_calculator.html)



### COMPLETE Library™ v19.5

**VENDORVIEW**

Modelithics has released Version 19.5 of the COMPLETE Library for use with Keysight Technologies' PathWave Advanced Design System (ADS) software. This update includes 16 new models and compatibility with PathWave ADS 2020. The COMPLETE Library is backward compatible with previous versions of the library as well. This release launches the addition of 16 new models enhancing the library content representing over 700 models for more than 17,000 components. New Microwave Global Models™ for passive components are available for Coilcraft and DLI (Knowles) as well as four new capacitors for Exxelia.

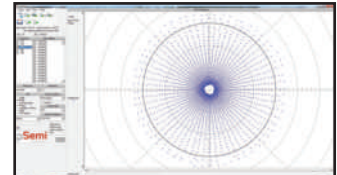
**Modelithics Inc.**  
[www.modelithics.com/](http://www.modelithics.com/)



### sNpViewer to Assist 5G and RF Measurements

pSemi Corp. (formerly Percegrine Semiconductor), a Murata company, is offering the industry free beta software for viewing S-parameters. The pSemi sNpViewer allows for in-depth S-parameter viewing graphically. This comprehensive viewer includes Smith, polar, magnitude, phase and phase vs. amplitude charting. Time-domain analysis is also available. The pSemi sNpViewer allows you to perform searches through thousands of S-parameter files to determine and record optimal performance. The LUT feature can be especially useful for 5G beamforming or for any other device where a phase and/or amplitude LUT is required.

**pSemi Corp.**  
[www.psemi.com/snpviewer](http://www.psemi.com/snpviewer)



### Real-Time Spectrum Analyzer

With the introduction of Signal Hound's SM200B, the company now offers 160 MHz instantaneous bandwidth (IBW) I/Q capture, accessible via an API. The SM200B still has the dynamic range, phase noise, 1 THz/s sweeps and 100 kHz to 20 GHz range that made the SM200A popular, but now features two seconds of segmented I/Q capture memory with triggering options such as frequency mask triggering (FMT) to satisfy the ever-increasing analysis bandwidth demands of the wireless industry. Available now for \$12,300.

**Signal Hound**  
<https://signalhound.com>



### VSim 10

Tech-X Corp. announces the release of VSim 10. Use VSim's radiation generation feature in design and manufacture of high-power (THz) RF devices ranging from spectrometers to oscillators for applications in fields as diverse as biophysics and radio astronomy. VSim for Microwave Devices accurately models particle beams with space charge, simple to complex field absorbers and conformal dielectrics.

**Tech-X Corp.**  
[www.txcorp.com](http://www.txcorp.com)



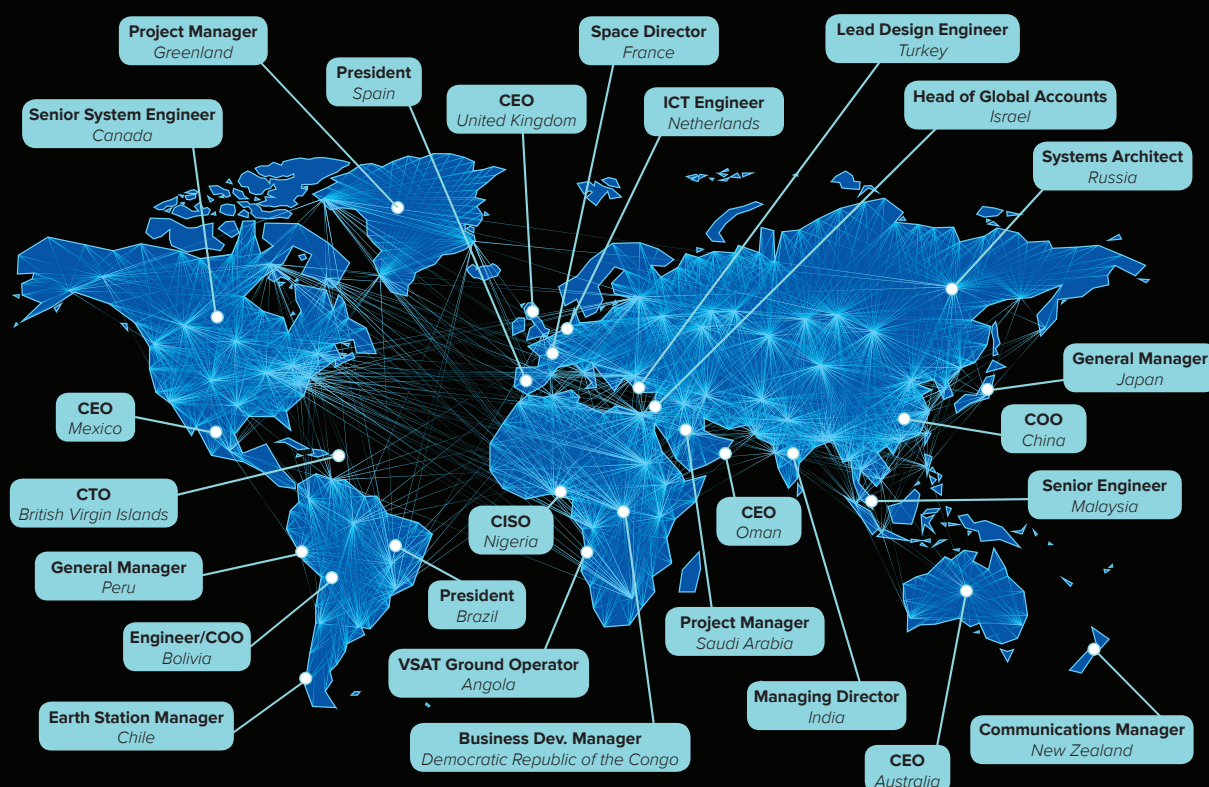


# SATELLITE 2020®

Conference: March 9-12 | Exhibition: March 10-12 | Washington, DC

## BE PART OF SOMETHING BIG

This is your chance to BUILD, CONNECT, and UNITE  
with 15,000+ attendees from around the world!



**ARE YOU READY TO ADD YOUR NAME TO THE MAP?**

Early Bird discounts expire December 12th at 11:50 PM ET!  
Register with **VIP Code: MJOURNAL20** to save up to \$600!

	Through December 12		On-Site
Executive All-Access	<del>\$2599</del>	\$2399	\$2999
Track Pass	<del>\$1299</del>	\$1199	\$1499
Exhibit Hall Only	FREE		\$199

Register now at [www.SATShow.com](http://www.SATShow.com)

# NEW PRODUCTS

FOR MORE NEW PRODUCTS, VISIT [WWW.MWJOURNAL.COM/BUYERSGUIDE](http://WWW.MWJOURNAL.COM/BUYERSGUIDE)  
FEATURING **VENDORVIEW** STOREFRONTS

## COMPONENTS

### Frequency Multipliers



Cernexwave's CFM series active frequency multipliers cover the frequency range of 10 MHz to 500 GHz. They can be designed to multiply an RF signal 2, 3, 4 or as many as 36x with their custom multiplier chain assemblies. These multipliers utilize state-of-the-art MIC and MMIC technologies to provide highly stable, reliable and efficient frequency extenders for system applications.

**Cernexwave**  
[www.cernexwave.com](http://www.cernexwave.com)

### High-Power Coaxial Packaged Limiter

Fairview Microwave Inc. has expanded its line of broadband, high-power coaxial packaged limiters. Typical applications for these RF limiters include military communications, EW, fiber optic communication systems, instrumentation, SATCOM, radar, telecom,



point-to-point wireless and R&D applications. Fairview's line of high-power RF limiters is now made up of 13 unique models that are designed to help protect sensitive components in the receive chain and other microwave circuits in close proximity to high-power signals.

**Fairview Microwave Inc.**  
[www.fairviewmicrowave.com](http://www.fairviewmicrowave.com)

### Digital Phase Shifter



Kratos General Microwave manufactures a complete line of broadband fast switching phase shifters. Model 7929 offers a full tuning range of 360°

covering a frequency range of 18 to 40 GHz. Excellent phase accuracy and PM/AM performance are achieved by utilizing double balanced bi-phase linear amplitude modulators. Standard unit designed to operate over -54°C to +95°C. Its small size and high-reliability make it ideal for use in demanding shipboard/airborne environmental conditions. Optional optimized performance is available over a narrower frequency range.

**Kratos General Microwave Corp.**  
[www.kratosmed.com](http://www.kratosmed.com)

### Amplified Switched Filter Bank



Lexatys' new three-channel amplified Switched Filter Bank has stopbands extending beyond 40 GHz to help eliminate

undesired harmonics. With a compact size of 1.08 × 0.54 × 0.24 in. and paired with high speed switching between channels, the Filter Bank has a low profile with high impact. It features a solderless interconnect to help reusability within prototype assemblies to allow performance to be evaluated before being integrated into the design. This part is also compatible with the X-Microwave prototyping system.

**Lexatys**  
[www.lexatys.com](http://www.lexatys.com)

### Broadband 6 to 18 GHz, 3-Way Power Divider



MECA's 3-way Wilkinson power divider has been optimized for excellent performance covering; 6 to 18 (P3S-12.000) with specifications such as

isolation of 20 dB min/25 dB typical, VSWR 1.4:1 max, 0.7 dB max insertion loss and amplitude balance of 0.4 dB max all in a compact package of 1 × 1.5 × 0.4 in. Made in the U.S. with 36 month warranty.

**MECA Electronics Inc.**  
[www.e-MECA.com](http://www.e-MECA.com)

### Bus Couplers

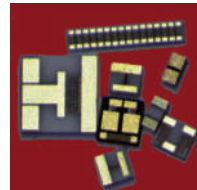


MilesTek's RoHS compliant MIL-STD-1553B bus couplers can be used in mil/aero and ground vehicle applications. To address the

growing demand for RoHS compliant products, MilesTek stocks a wide range of MIL-STD-1553B box style bus couplers with 1-8 stub options and models with single, double or no bus jacks. These bus couplers feature a transformer ratio of 1.41:1 with stub resistor values of 59 Ω, 2 W, 1 percent. These new bus couplers are in-stock and available for same-day shipping.

**MilesTek**  
[www.milestek.com](http://www.milestek.com)

### Broadband Resistors



PPI broadband resistors are specifically designed to operate at frequencies up to 67 GHz. With special microwave laser-trimming used to ensure a tight tolerance at

high frequencies, these broadband resistors are wire bondable, solderable and can be used in a flip-chip configuration. Applications include optical transceiver modules, broadband receiver, TOSA/ROSA, broadband test equipment, low noise amplifiers and MMIC amplifiers.

**Passive Plus Inc.**  
[www.passiveplus.com](http://www.passiveplus.com)

### Frequency Dividers



Pasternack has launched a new line of frequency divider modules that cover broadband frequencies from 0.1 to 20 GHz. A comprehensive

selection of 28 different models is offered with a variety of fixed divide-by-ratios from 2 to 40. These prescalers are ideal for use in phase locked loop (PLL) and frequency synthesizer circuit designs, as well as test instrumentation. Typical applications include use in aerospace and defense, SATCOM, VSAT, test & measurement equipment and point-to-point radio networks.

**Pasternack**  
[www.pasternack.com](http://www.pasternack.com)

### Absorptive Switch



PMI Model No. P4T-0R1G20G-80-T-SFF is a single pole, four throw, absorptive switch



operating over the frequency range of 0.1 to 20 GHz. It has a max insertion loss of 5 dB and a min isolation of 80 dB. This model is outfitted with SMA female connectors in a

housing that measures 1.25 × 1.25 × 0.7 in.  
**Planar Monolithics Industries Inc.**  
[www.pmi-rf.com](http://www.pmi-rf.com)



## NewProducts

### HEMP Tested RF Surge Protection Devices



PolyPhaser has released an innovative line of RF surge protection devices engineered and tested to protect equipment from high-altitude

electromagnetic pulse (HEMP) and high-level RF weapons. The PolyPhaser HEMP tested product family includes solutions that protect sensitive equipment from intentional electromagnetic interference (IEMI) as specified by the Department of Homeland Security.

**PolyPhaser**  
[www.polyphaser.com](http://www.polyphaser.com)

### 4 Channel Down-Converter



RFE's new cost-effective solution for block translating a 28 to 40 GHz RF signals down into the 6 to 18 GHz range with a single

band giving extended frequency coverage to many existing systems. Four phased matched channels present identical channel-to-channel performance for various instrumentation and/or military applications. The down-converter features an internal low phase noise high side fixed LO and the option to accept an external phase reference. Each channel includes an activity threshold detector, all in a ruggedized compact housing.

**RFE Inc.**  
[www.rfe-mw.com](http://www.rfe-mw.com)

### SMT Circulators



RFMW announced design and sales support for a robust lead circulator from Skyworks Ireland. The SKYFR-001692 is offered in a 10 mm

diameter package measuring 7 mm in height. Designed for wireless infrastructure and power amplifier applications, this circulator operates over the frequency range of 3400 to 3600 MHz. Operating temperature range is -40°C to +105°C, making it ideal for 5G massive MIMO and small cell applications. Accommodates automated SMT placement for ease of use.

**RFMW**  
[www.rfmw.com](http://www.rfmw.com)

### High-Power 18 GHz SPDT Switch



RLC Electronics announced the addition of a high-power 18 GHz SPDT switch with N connectors to its product capabilities. The switch can handle

IMPROVE YOUR COMMUNICATIONS DYNAMIC RANGE

## Upgrade Your UHF SATCOM With MUOS



**FMB-232**  
Dual Diplexer



**FMA-123**  
Antenna Diplexer



**FAM-232T**  
Antenna Diplexer LNA



**AM-212D4**  
Low Noise Amplifier



**FAM-232M**  
Antenna Diplexer LNA



**DFP-106AM**  
Dual Diplexer Preamplifier

## MPI METROPOLE PRODUCTS, INC

[ THE FREQUENCY OF INNOVATION ]

2040 Jefferson Davis Hwy., Stafford, Virginia 22554

540.659.2132 • fax 540.659.2133 • [sales@metropoleproducts.com](mailto:sales@metropoleproducts.com)

AS 9100:2016 and ISO 9001:2015 CERTIFIED

[MetropoleProducts.com](http://MetropoleProducts.com)

# NEW

## Traveling Wave Tube Amplifiers

# COMPACT COMMERCIAL SERIES

### FEATURES:

- Low Noise, High PRF
- Available for Rugged applications
- Increased durability
- Improved control system
- Optional touch-screen interface
- High-powered for pulsed CW operations
- Fully customizable

**Quarterwave** provides top-notch innovation, quality service and specialized one-on-one approach by our team of expert engineers. With over 30 years experience in the industry, Quarterwave's Traveling Wave Tube Amplifiers (TWTAs), High Voltage Power Systems, and Microwave Tube testing equipment has proven to be unbeatably reliable and versatile.

Quarterwave Corporation, 1500 Valley House Dr. #100, Rohnert Park, CA 94928  
[Quarterwave.com](http://Quarterwave.com) | T.1(707)793-9105 | F.1(707)793-9245 | [Sales@quarterwave.com](mailto:Sales@quarterwave.com)



## Splitter Combiner Unit

**K-band and  
Ka-band  
128-way or  
64-way**



- 4-to-64 way  
1-to-64 way,  
8-to-128 way,  
2-to-128 way,  
or any combination
- Thermal Vacuum
- High Isolation
- Optional Integrated  
Bias-T, LNA, LNB,  
Filters, Switches

Parameter	Unit	Value
Uplink Frequency Band	GHz	26 to 32
Dowlink Frequency Band	GHz	18 to 24
Max Insertion Loss	dB	4 Downlink 5 Uplink
I/P & O/P VSWR		1.6:1
Gain Flatness	dB	1.0
Port to Port Variation	dB	1.0
Port to Port Isolation	dB	25



50 Intervale Road, Boonton, NJ 07005  
Tel: 973-394-1719 • Fax: 973-394-1710

[www.etiworld.com](http://www.etiworld.com)

## NewProducts

1000 W at 100 MHz, 200 W at 4 GHz and 125 W at 18 GHz, and provides high-reliability, long life and excellent electrical performance characteristics over the frequency range (including high isolation). Options on the switch include operating mode (failsafe or latching) and coil voltage (12 or 28 VDC), as well as indicator circuitry and a TTL Driver.

**RLC Electronics**  
[www.rlcelectronics.com](http://www.rlcelectronics.com)

### Temperature Variable Attenuators



Smiths Interconnect Thermopad® temperature variable attenuators are a totally passive, easy to implement solution for gain compensation

designed specifically for demanding high-reliability applications. The Thermopad® can be used in place of a standard chip attenuator to combine level setting or buffering and temperature compensation in a single chip design. This will reduce component count, increase reliability and lower costs. Applications include power amplifiers, mixers, MMIC amplifiers, directional couplers and diode detectors.

**Smiths Interconnect**  
[www.smithsinterconnect.com](http://www.smithsinterconnect.com)

### 15 dB 2 to 18 GHz Coupler



Werbel Microwave model C-1182-dB is available as 10, 15, 20 and 30 dB models covering the full 2 to 18 GHz band with typical 0.5 dB frequency sensitivity. Typical directionality is 17 dB and typical VSWR is 1.2:1. Designed conservatively to handle 20 W input power.

**Werbel Microwave**  
[www.werbelmicrowave.com](http://www.werbelmicrowave.com)

## CABLES & CONNECTORS

### Johnson™ 2.92 mm Connector Series



Cinch Connectivity Solutions announced an extension to its Johnson 2.92 mm series coax connectors, with the addition of solder end launch/

straddle mount jacks. The new connectors provide additional board option thicknesses of 0.016, 0.042, 0.062 and 0.093 in. The Johnson 2.92 mm end launch/straddle mount series offers a low VSWR of 1.25 up to 26.5 GHz and 1.5 max from 26.5 to 40 GHz, also utilizing air dielectric and support bead for higher cutoff frequency that enable for advanced frequency performance and signal integrity.

**Cinch Connectivity Solutions**  
[www.belfuse.com/cinch](http://www.belfuse.com/cinch)

### Coaxial Adapter Mates 1.85 mm-F to 2.92 mm-F Connectors



Mini-Circuits' 185F-KF+ is a coaxial 1.85 mm-F to 2.92 mm-F adapter, supporting a wide range of applications from DC to 40 GHz.

This model provides 1.05:1 VSWR and 0.13 dB insertion loss with flat response over its full frequency range. The unit features rugged, passivated stainless steel construction and measures 0.82 in. in length.

**Mini-Circuits**  
[www.minicircuits.com](http://www.minicircuits.com)

### Coaxial Adapter

Model SCT-DF1F-UB is a SMPM (GPPO) female to 1 mm female coaxial adapter that covers the frequency range of DC to 65 GHz. This coaxial adapter offers efficient transitioning between the coaxial



connectors with a high return loss and typical insertion loss of 1 dB. The impedance of the adapter is 50 Ω. Other configurations are available under different model numbers.

**SAGE Millimeter**  
[www.sagemillimeter.com](http://www.sagemillimeter.com)

## SEMICONDUCTORS

### E-Series SiC MOSFETs



Richardson RFPD Inc. announced the availability and full design support capabilities for a robust family of SiC semiconductor devices from

Wolfspeed, a Cree Company. The E-Series line of SiC MOSFETs represents the industry's first automotive-qualified, PPAP-capable and humidity-resistant MOSFETs. The E-Series MOSFETs are optimized for use in EV battery chargers and high voltage DC/DC converters for on-board automotive power conversion systems, off-board charging, solar inverters and other outdoor applications.

**Richardson RFPD Inc.**  
[www.richardsonrfpd.com](http://www.richardsonrfpd.com)

## AMPLIFIERS

### Tactical Booster Amplifiers



Maintaining clear, dependable communications is essential to the successful completion of

missions—and often saves lives. Forces around the globe rely on lightweight AR Modular RF tactical booster amplifiers for long-range communications and connectivity in even the most extreme conditions. With available man-pack, vehicle-mounted and airborne models, AR Modular RF's line of



## NewProducts

battle tested tactical booster amplifiers supports uninterrupted communication on the ground, at sea and in the air.

**AR Modular RF**  
www.arww-modularrf.com

### Solid-State Power Amplifier Module



COMTECH PST introduced its latest addition to its GaN solid-state power amplifier product line. Comtech's latest

development continues to expand on its integrated RF GaN power amplifier designs by offering a small form factor (SFF) module. Consistent with its planned technology development roadmap, Comtech proudly introduces the latest in GaN-based 6 to 18 GHz RF amplifier for TWT/MPM Replacement. This highly integrated design is ideal for use in communication, EW and radar transmitter systems, where space, cooling and power are limited.

**Comtech PST**  
www.comtechpst.com

### Pulse Amplifier

**VENDORVIEW**



Exodus Advanced Communications' Pulse Amp (2 to 4 GHz; 2, 4 and 8 KW Pulse) series is designed for Lab Pulse/HIRF Mil-Std 461/464 test applica-

tions. Other frequency ranges and power levels available. The unit can produce different power levels based on configuration implementation. The design provides excellent band flatness, reliable robust performance with outstanding pulse fidelity. Rack integrated for ease of application integration.

**Exodus Advanced Communications**  
www.exoduscomm.com

### Front-End Modules

**VENDORVIEW**



Skyworks introduced the SKY65725-11 and the SKY65728-11, shielded GPS low-noise amplifier front-end modules (FEM) for mobile appli-

cations such as smartphones and tablets. Both devices feature high linearity, excellent gain and superior noise figure to enable design flexibility and high levels of integration. Pre-filters provide the low in-band insertion loss and excellent rejections of the cellular, PCS and WLAN frequency bands. The SKY65725-11 is ideal for GPS/GNSS/BDS receivers while the SKY65728-11 works well for GPS L5 applications.

**Skyworks Solutions Inc.**  
www.skyworksinc.com

### Low Noise Amplifier

Model ALN3325-41-3525 is a low-cost, 2.92 mm connectorized low noise amplifier (LNA) module offering 35 dB linear gain and



2.5 dB noise figure over the entire Ka-Band frequency range from 26.5 to 40 GHz with excellent gain flatness and input/output return

loss. The unit has built in voltage regulator and reverse polarity protection circuitry. It operates with a single DC power supply voltage from +10 to +15 V. The package size of the amplifier is 1.5 x 0.85 x 0.375 in.

**Wenteq Microwave**  
www.wenteq.com

## SOURCES

### High Performance Oscillators



Pletronics presents the new PRONTO® oscillator series offering a 2 x 1.6 mm package. The PRONTO® series state-of-the-art design is able to provide any

frequency with lead times in days not weeks. The small form and footprint of the 2 x 1.6 mm with endless frequency options up to 200 MHz and superior jitter performance makes this an ideal device to service all application phases from board design to production volumes. The PRONTO® series



**Get Up to Speed  
— Fast!**

### RF Technology Certification

Next Session Starts Soon! - Online

**Register Now!**

### Applied RF Engineering I

Next Session Starts Soon! - Online

### mmWave RFIC and MMIC Design Techniques

February 24 to 26, 2020, San Diego, CA

### 5G, mmWave Antennas: Propagation and Phased Arrays

February 27 to 28, 2020, San Diego, CA

### Phased Array Radar

February 24 to 26, 2020, San Diego, CA

### RF Power Amplifier Design Techniques

Please visit our website for the latest schedule

### Radio Systems: RF Transceiver Design from Antenna to Bits & Back

Please visit our website for the latest schedule

### 5G Radio Systems and Wireless Networks

Please visit our website for the latest schedule

### System Design for Digital Communication, Radar, & Cognitive Radio

Please visit our website for the latest schedule

**www.BesserAssociates.com**

## Corporate Training Services

**Besser Associates can provide our online and traditional classroom courses exclusively for your team. Our instructors can present almost any course from our full catalog at your domestic or international location. Contact us for more details!**





On-demand courses available online. Start Anytime! Visit our website for details.



**www.besserassociates.com**

**info@besserassociates.com**

 <b>Statement of Ownership, Management, and Circulation</b> <b>(All Periodicals Publications Except Requester Publications)</b>			
1. Publication Title Microwave Journal		September 30, 2019	
4. Issue Frequency Monthly		5. Number of Issues Published Annually 12	
7. Complete Mailing Address of Known Office of Publication (Not printer) (Street, city, county, state, and ZIP+4®) HORIZON HOUSE PUBLICATIONS, INC. 685 Canton Street Norwood, MA 02062-2610		6. Annual Subscription Price Domestic: \$120.00 Foreign: \$200.00	
8. Complete Mailing Address of Headquarters or General Business Office of Publisher (Not printer) same as above		Contact Person Barbara Walsh Telephone 781-769-9750 x2025	
9. Full Names and Complete Mailing Addresses of Publisher, Editor, and Managing Editor (Do not leave blank)			
Publisher (Name and complete mailing address) Carl S. Shreffers, Horizon House Publications, Inc., 685 Canton Street, Norwood, MA 02062-2610			
Editor (Name and complete mailing address) Patrick Hindle, Horizon House Publications, Inc., 685 Canton Street, Norwood, MA 02062-2610			
Managing Editor (Name and complete mailing address) Jennifer DiMarco, Horizon House Publications, Inc., 685 Canton Street, Norwood, MA 02062-2610			
10. Owner (Do not leave blank. If the publication is owned by a corporation, give the name and address of the corporation immediately followed by the names and addresses of all stockholders owning or holding 1 percent or more of the total amount of stock. If not owned by a corporation, give the names and addresses of the individual owners. If owned by a partnership or other unincorporated firm, give its name and address as well as those of each individual owner. If the publication is published by a nonprofit organization, give its name and address.)			
Full Name		Complete Mailing Address	
Horizon House Publications, Inc.		685 Canton Street, Norwood, MA 02062-2610	
William M. Bazy, CEO		" " " " " " " "	
Ivar A. Bazy, President		" " " " " " " "	
Jared M. Bazy, Vice President		" " " " " " " "	
Joan B. Egan, EVP		" " " " " " " "	
11. Known Bondholders, Mortgagees, and Other Security Holders Owning or Holding 1 Percent or More of Total Amount of Bonds, Mortgages, or Other Securities. If none, check box <input checked="" type="checkbox"/> None			
Full Name		Complete Mailing Address	
12. Tax Status (For completion by nonprofit organizations authorized to mail at special rates) (Check one) The purpose, function, and nonprofit status of this organization and the exempt status for federal income tax purposes: <input type="checkbox"/> Has Not Changed During Preceding 12 Months <input type="checkbox"/> Has Changed During Preceding 12 Months (Publisher must submit explanation of change with this statement)			
13. Publication Title Microwave Journal		14. Issue Date for Circulation Data Below YTD September 30, 2019	
15. Extent and Nature of Circulation 50K		Average No. Copies Each Issue During Preceding 12 Months	
a. Total Number of Copies (Net press run)		35,826	
		31,951	
b. Paid Circulation (By Mail and Outside the Mail)			
(1) Mailed Outside-County Paid Subscriptions Stated on PS Form 3541. (Include paid distribution above nominal rate, advertiser's proof copies, and exchange copies)		26,843	
(2) Mailed In-Country Paid Subscriptions Stated on PS Form 3541 (include paid distribution above nominal rate, advertiser's proof copies and exchange copies)		0	
(3) Paid Distribution Outside the Mails Including Sales Through Dealers and Carriers, Street Vendors, Counter Sales, and Other Paid Distribution Outside USPS®		5,748	
(4) Paid Distribution by Other Classes of Mail Through the USPS (e.g. First-Class Mail®)		0	
c. Total Paid Distribution (Sum of 15b(1), (2), (3), and (4))		32,591	
		28,923	
d. Free or Nominal Rate Distribution (By Mail and Outside the Mail)			
(1) Free or Nominal Rate Outside-Country Copies included on PS Form 3541		635	
(2) Free or Nominal Rate In-Country Copies Included on PS Form 3541		0	
(3) Paid Distribution Outside the Mails Including Sales Through Dealers and Carriers, Street Vendors, Counter Sales, and Other Paid Distribution Outside USPS®		0	
(4) Free or Nominal Rate Distribution Outside the Mail (Carriers or other means)		2,536	
e. Total Free or Nominal Rate Distribution (Sum of 15d(1), (2), (3) and (4))		3,171	
		2,944	
f. Total Distribution (Sum of 15c and 15e)		35,762	
		31,867	
g. Copies not Distributed (See Instructions to Publishers #4 (page #3))		65	
		84	
h. Total (Sum of 15f and g)		35,826	
		31,951	
i. Percent Paid (15c divided by 15f times 100)		91.13%	
		90.76%	
16. Publication of Statement of Ownership <input checked="" type="checkbox"/> If the publication is a general publication, publication of this statement is required. Will be printed in the November, 2019 issue of this publication. <input type="checkbox"/> Publication not required.			
17. Signature and Title of Editor, Publisher, Business Manager, or Owner  Carl S. Shreffers, Publisher		Date September 30, 2019	
I certify that all information furnished on this form is true and complete. I understand that anyone who furnishes false or misleading information on this form or who omits material or information requested on the form may be subject to criminal sanctions (including fines and imprisonment) and/or civil sanctions (including civil penalties).			

## NewProducts

demonstrates outstanding performance in applications, such as 5G, IoT and digital communications.

**Pletronics Inc.**  
[www.pletronics.com](http://www.pletronics.com)

### Low Noise VCO



The DCR0240270-5 is an optimized bandwidth VCO covering a frequency range of 2400 to 2700 MHz in 12 V of tuning voltage. This device operates with +5 V bias voltage and a current draw of only 23 mA max. Other specifications include min output power of +3 dBm, typical tuning sensitivity of 28 to 38 MHz/V and typical harmonic suppression of 23 dB. The typical

phase noise performance is -103 and -123 dBc/Hz at 10 and 100 kHz offsets.

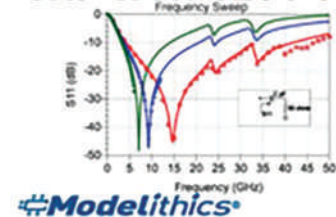
**Synergy Microwave Corp.**  
[www.synergymicrowave.com](http://www.synergymicrowave.com)

## SOFTWARE

**Microwave Global Model™**

**VENDORVIEW**

**NEW MODEL**  
**CAP-WTH-0201-001**



Modelithics has introduced a new equivalent circuit-based scalable Microwave Global Model for Würth Elektronik WCAP-CSRF 0201 surface mount chip capacitor family. The model is validated up to 50 GHz and features substrate, pad and part value scaling over the full range of the surface

mount chip capacitor series, 0.2 to 33 pF. Würth Elektronik is a Sponsoring MVP and is sponsoring free 90-day trials of all available Modelithics models for Würth Elektronik parts by request and with approval.

**Modelithics**  
[www.Modelithics.com](http://www.Modelithics.com)

## TEST & MEASUREMENT

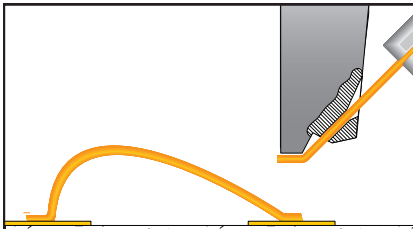
### Analyzer Calibration Extender



Kaelus has released new functionality for the Analyzer Calibration Extender (ACE). It now supports the Range-to-Fault (RTF) module used for locating PIM and return loss faults in RF infrastructure. ACE allows customers to self-calibrate their Kaelus PIM instruments in the field. Reducing down-time of calibration to less than one hour, ACE extends the calibration due date by 12 months.

**Kaelus**  
[www.kaelus.com](http://www.kaelus.com)

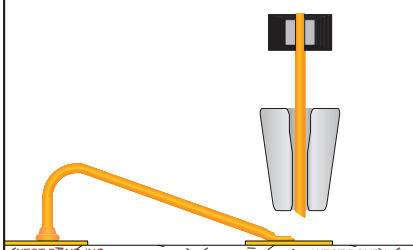




BOND

**WIRE BOND**

WEST BOND INC.



www.westbond.com

**Find Reps, Engineers  
and Used Equipment.**

Post your listing on the  
MWJ classified section.

**Microwave  
Journal**

**Classified**

Help Wanted

Executives

www.mwjjournal.com/classifieds

## MICRO-ADS

### RF Amplifiers, Isolators and Circulators from 20MHz to 40GHz

- Super low noise RF amplifiers
- Broadband low noise amplifiers
- Input PIN diode protected low noise amplifiers
- General purpose gain block amplifiers
- High power RF amplifiers and broadband power amplifiers




- RF isolators and circulators
- High power coaxial and waveguide terminations
- High power coaxial attenuators
- PIN diode power limiters
- Active up and down converters

**Wentek Microwave Corporation**  
138 W Pomona Ave, Monrovia, CA 91016  
Phone: (626) 305-8666, Fax: (626) 602-3101  
Email: sales@wentek.com, Website: www.wentek.com

### Waveguide and Coaxial Switches

We offer Switches for any application:  
HI-REL, MILITARY, COMMERCIAL

From design to delivery, all under one roof.  
Offering the Finest in Microwave Switches Since 1974.



The only bright spot to go!

**Sector Microwave Ind., Inc.**  
(631) 242-2300 Phone (631) 242-8158 Fax  
www.SectorMicrowave.com

### Frequency SYNTHESIZERS

- Frequencies to 34 GHz
- Excellent performance
- Miniature package
- Custom configurations

### Phase-Locked OSCILLATORS

- Frequencies to 34 GHz
- Dielectric Resonator
- Ceramic Resonator
- Voltage Controlled
- Crystal



### Custom Source Assemblies

We commit to high quality at a great value!

www.luffresearch.com  
Tel: 516-358-2880 USA **Luff RESEARCH**

### REVOLUTIONARY HERMETIC SMP CONNECTORS

These SMPs meet the requirements of MIL-STD-348, but utilize unique housing interface features, which significantly improves reliability and production assembly yields. Proprietary techniques are used to independently control plating thickness on pin and housing.



**For use with Aluminum, Kovar and other package materials**

**SHP** **SPECIAL HERMETIC PRODUCTS, INC.**  
PO BOX 269 - WILTON - NH - 03086  
(603) 654-2002 - Fax (603) 654-2533  
E-mail: sales@shp-seals.com  
Web: www.shp-seals.com

### ELECTRICALLY CONDUCTIVE COATINGS

**Ideal for EMI/RFI Shielding**

- MB600G Graphite filler
- MB600S Silver filler
- MB600SCN Silver coated nickel filler

**MASTERBOND®**  
ADHESIVES | SEALANTS | COATINGS

www.masterbond.com

### ES MICROWAVE LLC.

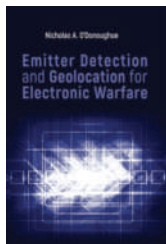
Since 1985 we have offered our custom design filters and sub-assemblies in combine, interdigital and suspended-substrate technologies.

**Broadband**  
**Suspended-Substrate**  
Filters, Diplexers, Triplexers, Quadruplexers, Quintuplexers, Sextuplexers...



**DC-40 GHz Filters Multiplexers & Switch Filter Banks**

**ES Microwave, LLC**  
8031 Cessna Avenue, Gaithersburg, MD 20879  
P: 301-519-9407 F: 301-519-9418  
www.esmicrowave.com



## Emitter Detection and Geolocation for Electronic Warfare

Nicholas O'Donoghue

**T**his comprehensive resource provides theoretical formulation for detecting and geolocating non-cooperative emitters. Implementation of geolocation algorithms are discussed, as well as performance prediction of a hypothetical passive location system for systems analysis or vulnerability calculation. Comparison of novel direction finding and geolocation algorithms to classical forms are also included. Rooted in statistical signal processing and array processing theory, this book also provides an overview of the application of novel detection and estimation algorithms to real-world problems in electronic warfare (EW).

The book is divided into three parts: detection, angle of arrival estimation and

geolocation. Each section begins with an introductory chapter covering the relevant signal processing theory (either detection or estimation), then provides a series of chapters covering specific methods to achieve the desired end-product. MATLAB® code is provided to assist readers with relevant probability and statistics, RF propagation, atmospheric absorption and noise, giving readers an understanding of the implementation of the algorithms in the book, as well as developing new approaches to solving problems. Packed with problem sets and examples, this book strikes a balance between introductory texts and reference manuals, making it useful for novice as well as advanced practitioners.

### To order this book, contact:

Artech House  
www.artechhouse.com  
Email: [artech@artechhouse.com](mailto:artech@artechhouse.com)  
US 800-225-9977  
UK +44 (0)20 70596 8750

ISBN: 978-1-63081-564-6  
348 pages

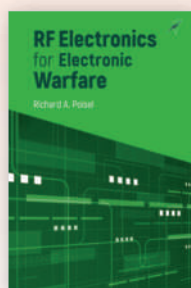
\$139/£119

Use code **ODO25** to  
receive **25% discount** on this  
title! (expires 12/31/2019)

## Top Resources for Government and Military

MWJ subscribers receive **30% off** print books\* use promo code **MWJ30**

For a limited time. Cannot be combined with any other discount offers.



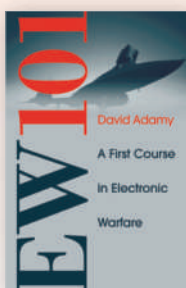
### RF Electronics for Electronic Warfare

Richard A. Poisel

ISBN: 978-1-63081-705-3

Hardcover • 600 pp.

\$179 / £149



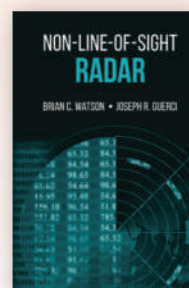
### EW 101: A First Course in Electronic Warfare

David Adamy

ISBN: 978-1-58053-169-6

Hardcover • 328 pp.

\$129 / £112



### Non-line-of-Sight Radar

Brian C. Watson and Joseph R. Guerri

ISBN: 978-1-63081-531-8

Hardcover • 225 pp.

\$149 / £130

**U.S.: Call** 1-800-225-9977 (in the U.S. or Canada)  
or 1-781-769-9750, ext. 4030  
**Fax** 1-781-769-6334  
**E-mail** [artech@ArtechHouse.com](mailto:artech@ArtechHouse.com)

**U.K.: Call** +44 (0)20 7596 8750  
**Fax** +44 (0)20 7630-0166  
**E-mail** [artech-uk@ArtechHouse.com](mailto:artech-uk@ArtechHouse.com)

For complete descriptions and to order,  
visit **ArtechHouse.com**



**ARTECH HOUSE**  
BOSTON | LONDON

685 Canton Street, Norwood, MA 02062, USA  
16 Sussex Street, London SW1V 4RW, UK





*Connecting Minds. Exchanging Ideas.*

JOIN US IN  
**LOS ANGELES**  
FOR IMS2020

**21-26 JUNE 2020**

# HOW DOES CONNECTIVITY MATTER TO YOU?

**IMS2020 is where Connectivity Matters.**



5G/6G Systems



Autonomous Vehicles



Rural/Underserved Communities



Aerospace



Digital Economy



**Visit us in Stand A065!**



[www.ims-ieee.org](http://www.ims-ieee.org)

Content is copyright protected and provided for personal use only - not for reproduction or retransmission.  
For reprints please contact the Publisher.



Advertiser	Page No.	Advertiser	Page No.	Advertiser	Page No.
3H Communication Systems.....	88	Frontlynk Technologies Inc.....	101	Pivotone Communication Technologies, Inc.....	COV 2
American Technical Ceramics.....	77	G.T. Microwave Inc.....	116	Planar Monolithics Industries, Inc.....	85
Amplical.....	8	Greenray Industries, Inc.....	72	PolyPhaser.....	105
Analog Devices.....	20-21	Guerrilla RF.....	34	Pulsar Microwave Corporation.....	108
AnaPico AG.....	95	HASCO, Inc.....	79	Quarterwave Corporation.....	137
Anokiwave.....	31, 107	Herotek, Inc.....	58	Reactel, Incorporated.....	39
Anritsu Company.....	13	Holworth Instrumentation.....	42	RelComm Technologies, Inc.....	109
API Technologies.....	9	Huber + Suhner AG.....	29	Remcom.....	99
Arance Electronics.....	131	HYPERLABS INC.....	49	RF-Lambda.....	6, 73, 117
ARC Technologies, Inc.....	97	IEEE MTT-S International Microwave Symposium 2020.....	143	RFHIC.....	51
Artech House.....	142	Integra Technologies, Inc.....	87	Richardson RFPD.....	19
ASB, Inc.....	52	Intelliconnect Ltd.....	133	RLC Electronics, Inc.....	23
ASELSAN.....	125	IQ-Analog.....	57	Rohde & Schwarz GmbH.....	26
B&Z Technologies, LLC.....	25	K&L Microwave, Inc.....	7	Rosenberger.....	35
BAE Systems.....	71	Kaelus.....	93	SAGE Millimeter, Inc.....	74-75
Besser Associates.....	139	Koaxis, Inc.....	94	Satellite 2020.....	135
CentricRF.....	128	KRYTAR.....	114	Sector Microwave Industries, Inc.....	141
Cernex, Inc.....	102	KUHNE electronic GmbH.....	98	Smiths Interconnect.....	78
Ciao Wireless, Inc.....	36	LadyBug Technologies LLC.....	128	Spacek Labs Inc.....	118
Cobham Advanced Electronic Solutions.....	33	Lexatys.....	32	Special Hermetic Products, Inc.....	141
Coilcraft.....	15	Luff Research, Inc.....	141	Spectrum Elektrotechnik GmbH.....	115
Comtech PST Corp.....	30	M Wave Design Corporation.....	38	Spectrum Instrumentation GmbH.....	50
CPI Beverly Microwave Division.....	53	Master Bond Inc.....	141	State of the Art, Inc.....	106
Cuming Microwave Corporation.....	61	MCV Microwave.....	27	Synergy Microwave Corporation.....	45, 113
Custom MMIC.....	83	MECA Electronics, Inc.....	3	Times Microwave Systems.....	67
Dalian Dalicap Co., Ltd.....	81	Metropole Products, Inc.....	137	TMV Technology, Inc.....	64
dB Control Corp.....	84	Micro Lambda Wireless, Inc.....	111	Universal Microwave Components Corporation.....	18
dBm Corp, Inc.....	120	Microwave Journal.....	130, 132, 140, 141	VIDA Products Inc.....	28
Ducommun Labarge Technologies, Inc.....	80	MilesTek.....	119	W.L. Gore & Associates, Inc.....	59
Eastern Wireless TeleComm, Inc.....	91	Milliwave Silicon Solutions.....	90	Waveline Inc.....	104
Eclipse MDI.....	60	Mini-Circuits.....	4-5, 16, 40, 65, 69, 127, 145	Weinschel Associates.....	129
EDI CON CHINA 2020.....	COV 3	Mini-Systems, Inc.....	103	Wenteq Microwave Corporation.....	141
Empower RF Systems, Inc.....	48	MiniRF Inc.....	70	Wenzel Associates, Inc.....	129
ERZIA Technologies S.L.....	100	National Instruments.....	11	Werlatone, Inc.....	COV 4
ES Microwave, LLC.....	141	NI Microwave Components.....	124	West Bond Inc.....	141
ET Industries.....	138	Norden Millimeter Inc.....	86	WIN Semiconductors Corp.....	47
EuMW 2020.....	121	NuWaves Engineering.....	123	Withwave Inc.....	132
Exceed Microwave.....	79	OML Inc.....	55	Wright Technologies.....	76
Exodus Advanced Communications, Corp.....	68	Pasternack.....	43	Xilinx, Inc.....	89
Fairview Microwave.....	62, 63			XMA Corporation.....	92

## Sales Representatives



### Eastern and Central Time Zones

Michael Hallman  
Associate Publisher  
(NJ, Mid-Atlantic, Southeast,  
Midwest, TX)  
4 Valley View Court  
Middletown, MD 21769  
Tel: (301) 371-8830  
FAX: (301) 371-8832  
mhallman@mwjournal.com

Jaime Leger  
Northeast Reg. Sales Mgr.  
(New England, New York,  
Eastern Canada)  
685 Canton Street  
Norwood, MA 02062  
Tel: (781) 619-1942  
FAX: (781) 769-5037  
jleger@mwjournal.com

### Pacific and Mountain Time Zones

Brian Landy  
Western Reg. Sales Mgr.  
(CA, AZ, OR, WA, ID, NV, UT,  
NM, CO, WY, MT, ND, SD, NE &  
Western Canada)  
144 Segre Place  
Santa Cruz, CA 95060  
Tel: (831) 426-4143  
FAX: (831) 515-5444  
blandy@mwjournal.com

### International Sales

Richard Vaughan  
International Sales Manager  
16 Sussex Street  
London SW1V 4RW, England  
Tel: +44 207 596 8742  
FAX: +44 207 596 8749  
rvaughan@horizonhouse.co.uk

### Germany, Austria, and Switzerland (German-speaking)

WMS Werbe- und Media Service  
Brigitte Beranek  
Gerhart-Hauptmann-Street 33,  
D-72574 Bad Urach  
Germany  
Tel: +49 7125 407 31 18  
FAX: +49 7125 407 31 08  
bberanek@horizonhouse.com

### France

Gaston Traboulsi  
Tel: 44 207 596 8742  
gtraboulsi@horizonhouse.com

### Korea

Young-Seoh Chinn  
JES MEDIA, INC.  
F801, MisahausD EL Tower  
35 Jojeongdae-Ro  
Hanam City, Gyeonggi-Do  
12918 Korea  
Tel: +82 2 481-3411  
FAX: +82 2 481-3414  
yschinn@horizonhouse.com

### China

Shenzhen  
Michael Tsui  
ACT International  
Tel: 86-755-25988571  
FAX: 86-755-25988567  
michaelt@actintl.com.hk

### Shanghai

Linda Li  
ACT International  
Tel: 86-021-62511200  
lindal@actintl.com.hk

### Beijing

Cecily Bian  
ACT International  
Tel: +86 135 5262 1310  
cecilyb@actintl.com.hk

### Hong Kong, Taiwan, Singapore

Mark Mak  
ACT International  
Tel: 852-28386298  
markm@actintl.com.hk

### Japan

Katsuhiro Ishii  
Ace Media Service Inc.  
12-6, 4-Chome,  
Nishiiku, Adachi-Ku  
Tokyo 121-0824, Japan  
Tel: +81 3 5691 3335  
FAX: +81 3 5691 3336  
amskatsu@dream.com



# MMIC FIXED EQUALIZERS

## DC to 20 GHz

- ▶ Absorptive
- ▶ 2x2mm QFN and Bare Die

### DC to 6 GHz

Model	Slope, (dB)
EQY-0-63+	0
EQY-1-63+	1.2
EQY-2-63+	2.1
EQY-3-63+	3.2
EQY-4-63+	4.2
EQY-5-63+	5.0
EQY-6-63+	6.5
EQY-8-63+	8.2
EQY-10-63+	10.2

### DC to 20 GHz

Model	Slope, (dB)
EQY-0-24+	0
EQY-2-24+	2.1
EQY-3-24+	3.1
EQY-5-24+	5.1
EQY-6-24+	6.3
EQY-8-24+	8.3
EQY-10-24+	10.2
EQY-12-24+	12



# FAB\$ and LAB\$

## Keysight's Atlanta Software Design Center: Improving Workflows with Software Platform



With the increasing complexity of the industry's test & measurement (T&M) needs, Keysight recognized that single function T&M products cannot fully assess system-level performance. The industry needs "smarter" T&M solutions that integrate multiple instruments with software, with the ability to measure system parameters and simulate system performance, whether it is a radar barraged by noise jamming or a mmWave 5G smartphone in an urban canyon connecting to a massive MIMO base station. To address this challenge, Keysight moved to strengthen its software competency. In 2016, it announced plans to form a stand-alone software design center in Atlanta, a start-up with a software-centric, agile culture.

For a company headquartered in Santa Rosa, whose roots are in Palo Alto, starting a new venture across the country in Atlanta, far from the corporate center, may seem risky. Yet the choice was intentional. Steve Chen, who moved from Santa Rosa to lead the initiative, says isolation and independence were important in choosing the location. "We needed to circumvent the corporate immune system," he quips, explaining that many large companies try to kill new ventures falling outside the mainstream business and culture. Another constraint on the location was proximity to an excellent university, as Keysight planned to recruit two-thirds of the new staff from college, the other third with industry experience. Georgia Tech has an excellent reputation, strong ties to Keysight and a corporate innovation center to assist new ventures. More broadly, Atlanta has a tech community of software engineers supporting a growing number of companies working in cloud management and "big data" applications.

Chen and a handful of Keysight employees recruited some 50 to the center during the first year, and the team now exceeds 70. To support planned growth, the design center moved mid-summer to the 19<sup>th</sup> floor of a 21-story office

tower across the street from Georgia Tech, offering expansive views of the city and enough space to house over 200.

The mission of Keysight's software design center is to develop a common software platform—Chen compares it to a modular chassis—which Keysight's businesses use to develop more comprehensive T&M solutions and get to market faster. Branded PathWave, the software is the foundation of Keysight's ambitious strategy to integrate design, test, measurement and analysis across the life cycle of a customer's products, from development through manufacturing. PathWave combines design simulation and layout, instrument control and test routines into a comprehensive workflow with an integrated data base. An open development environment, PathWave works with third-party software and hardware, enabling users to set up test routines for their unique environments. The platform includes tools for analyzing equipment status and usage, so companies can monitor the health and availability of their test systems, improving efficiency and the return on investment in T&M.

As a part of PathWave, the Atlanta team is developing a cloud-based edition to increase scalability, availability and parallel processing of large data sets. They are also helping Keysight move into nascent markets such as electric vehicles, working on battery management, vehicle connectivity and security.

In just three years, the Atlanta Software Design Center has created a high-performance team with an unique software culture, recognized as one of the top places to work in Atlanta by *The Atlanta Journal-Constitution*. Helping customers improve their workflows is the maximum value Keysight can provide, and the Atlanta team is integral to Keysight's strategy to do that—building a "PathWave" to Keysight's goal of becoming a solutions company.

<https://jobs.keysight.com/atl/#section-keysight-software-design-center>



# CALL FOR ABSTRACTS



## 2020

**Electronic Design Innovation Conference**

# 电子设计创新大会

**May 12-13, 2020**

**China National Convention Center, Beijing, China**

**Submit a proposal for a 30 minute technical session in one of these tracks:**

- ▶ **5G/Advanced Communications**
- ▶ **mmWave Technologies**
- ▶ **Amplifier Design**
- ▶ **EMC/EMI**
- ▶ **Low Power RF and IoT**
- ▶ **Front End Design**
- ▶ **Power Integrity**
- ▶ **Radar and Defense**
- ▶ **RF and Microwave Design**
- ▶ **Signal Integrity**
- ▶ **Simulation and Modeling**
- ▶ **Test and Measurement**



**Share Your Expertise! Reach 3000+ attendees. English language talks welcome.**

<https://www.ediconchina.com/submit-an-abstract/>

Content is copyright protected and provided for personal use only - not for reproduction or retransmission.

Due: January 6, 2020  
For reprints please contact the Publisher.

# WE ARE HIGH POWER

## 500 - 8000 MHz COUPLERS, COMBINERS, & HYBRIDS

In-Phase & Hybrid Designs ✦ *Mismatch Tolerant®* Designs ✦ Lowest Loss & Smallest Size

### Directional Couplers

Model	Type	Frequency (MHz)	Power (W CW)	Coupling (dB)	Insertion Loss (dB)	Mounting Style	Size (inches)
C8000	Bi	600-6000	100	30	0.40	SMA-Female	1.8 x 1.0 x 0.56
C10799	Dual	700-6000	100	40	0.20	N-Female	2.0 x 2.0 x 1.06
C10117	Dual	700-6000	250	40	0.20	N-Female	2.0 x 2.0 x 1.06
C10526	Dual	700-6000	300	40	0.20	N Female	2.0 x 2.0 x 1.06
C10364	Dual	700-6000	500	50	0.20	7/16-Female	2.15 x 2.0 x 1.36
C10614	Dual	700-6000	500	60	0.20	7/16-Female	2.15 x 2.0 x 1.36
C10996	Dual	700-6000	700	50	0.20	7/16-Female	2.15 x 2.0 x 1.36
C11555	Dual	700-6000	1,000	50	0.20	7/16-Female	2.15 x 2.0 x 1.36
C10695	Dual	700-6500	500	50	0.20	7/16-Female	2.15 x 2.0 x 1.36

### 0° (In-Phase) Combiners/Dividers

Model	Type	Frequency (MHz)	Power (W CW)	Isolation (dB)	Insertion Loss (dB)	Mounting Style	Size (inches)
D11911	2-Way	600-6000	100	15	0.60	N-F / SMA-F	2.00 x 2.0 x 1.00
D11959	2-Way	600-6000	100	Non-Isolated	0.40	N-F / SMA-F	2.00 x 2.0 x 1.00
D11958	4-Way	600-6000	100	18 (PI*)	0.60	N-F / SMA-F	4.00 x 2.0 x 1.00
D11149	4-Way	700-6000	300	Non-Isolated	0.60	N-Female	4.35 x 3.9 x 1.15
D11832	2-Way	700-6000	500	Non-Isolated	0.60	7/16-Female	5.50 x 2.4 x 1.06
D10803	2-Way	700-6500	300	Non-Isolated	0.60	N-Female	5.50 x 2.4 x 1.06

(PI\*) references Partial Isolation

### 90° Hybrid Couplers

Model	Type	Frequency (MHz)	Power (W CW)	Amp. Bal. (±dB)	Insertion Loss (dB)	Mounting Style	Size (inches)
QH11687	90°	500-6000	150	0.7	0.75	SMT	1.28 x 1.08 x 0.13
QH11443	90°	600-6000	150	0.8	0.70	SMT	1.30 x 1.30 x 0.13
QH10756	90°	700-6000	100	0.6	0.55	SMT	0.74 x 0.45 x 0.09
QH10541	90°	700-6000	150	0.6	0.50	SMT	0.86 x 0.66 x 0.09
QH10827	90°	1000-7500	100	0.7	0.65	SMT	0.86 x 0.61 x 0.09
QH10828	90°	1000-8000	100	0.7	0.90	SMT	0.65 x 0.50 x 0.07

