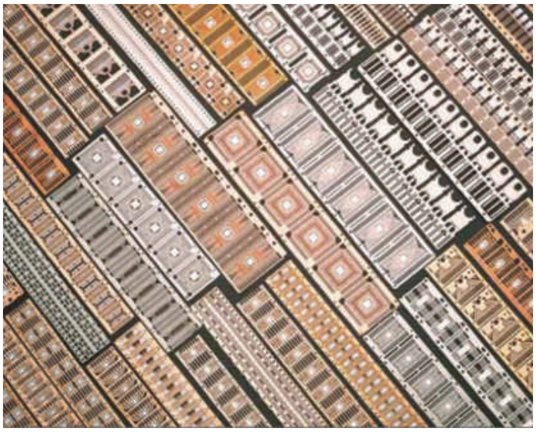
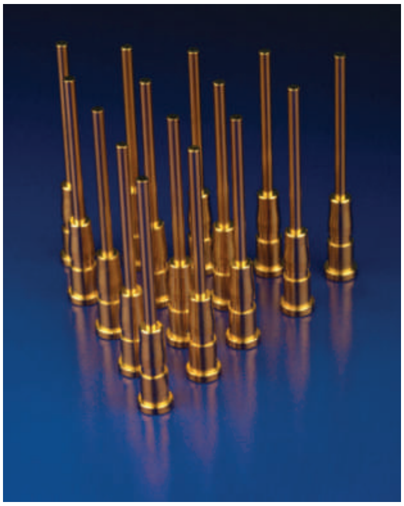
Vol. 63 • No. 10
October 2020

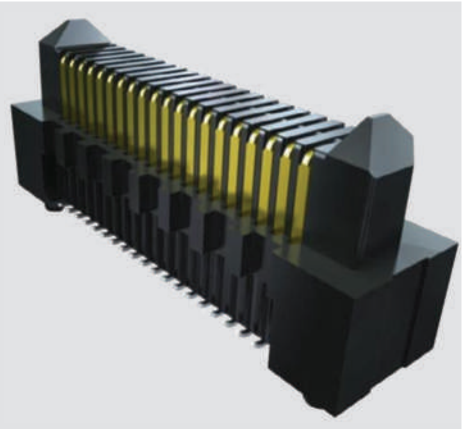
Microwave Journal

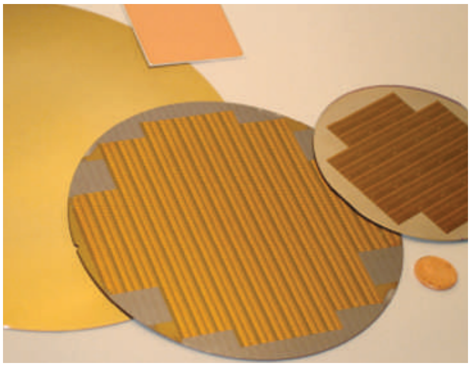
horizon house®
Founded in 1958
mwjournal.com

Maximize Precious Metal Scrap Recoveries









- ISO certified plant & laboratory
- Fully insured and permitted facility, ITAR compliant
- Can accept and process most precious metal containing haz. waste items
- Capability to treat high grade and lower grade precious metal bearing items
- Processes include: thermal reduction, milling, screening, blending, melting & shredding
- Payment flexibility: wire transfers, physical metal & pool account credits
- Pricing options
- Open transparent reporting
- Logistics assistance shipping materials

Metals Recycled:
Gold, Silver, Platinum, Palladium, Rhodium, Ruthenium, Iridium and Copper.

We supply 50 gallon drums or 5 gallon pails depending on your material types and grades.

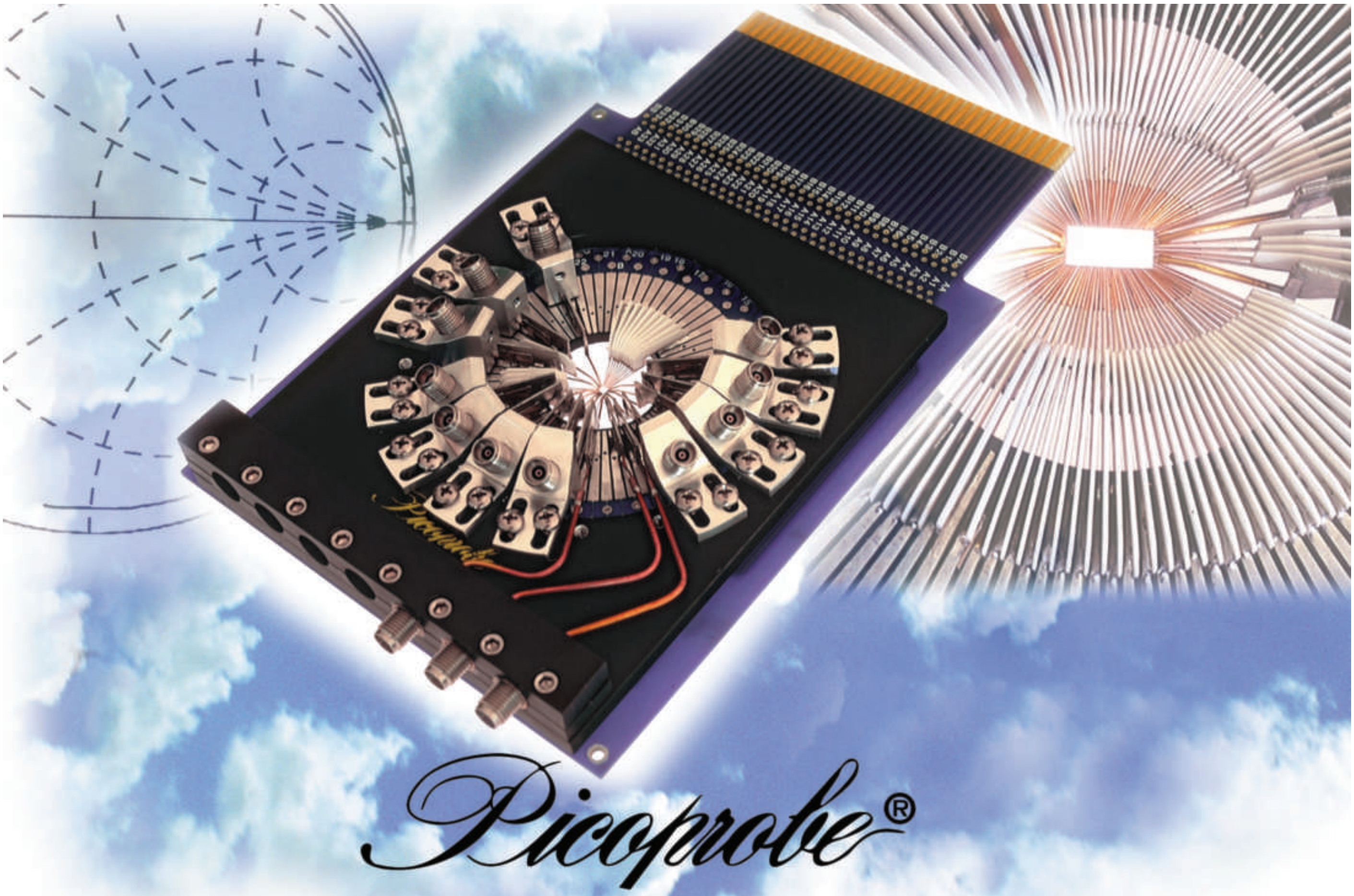
Knowledgeable staff to ensure our clients reclamation needs are met.

Call us today to get the most out of your metal!

QML

Professional Precious Metal Recovery

Corporate Office (401) 490-4555 Plant Operations (401) 762-0094 sales@qml.us www.qml.us

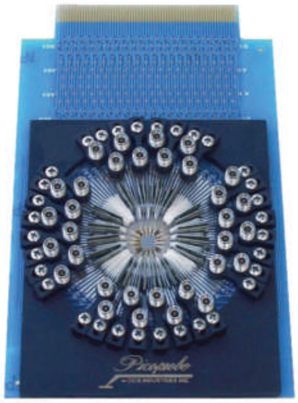


Picoprobe elevates probe cards to a higher level…

(…110 GHz to be exact.)

Since 1981, GGB Industries, Inc., has blazed the on-chip measurement trail with innovative designs, quality craftsmanship, and highly reliable products. Our line of custom microwave probe cards continues our tradition of manufacturing exceptional testing instruments.

Through unique modular design techniques, hundreds of low frequency probe needles and a variety of microwave probes with operating frequencies from DC to 40, 67, or even 110 GHz can be custom configured to your layout.



Our patented probe structures provide the precision and ruggedness you require for both production and characterization testing. And only Picoprobe® offers the lowest loss, best match, low inductance power supplies, and current sources on a single probe card.

Our proven probe card design technology allows full visibility with inking capability and ensures reliable contacts, even when probing non-planar structures.

Not only do you get all the attractive features mentioned, but you get personal, professional service, rapid response, and continuous product support--all at an affordable price so your project can be completed on time and within budget.

Typical Specs	10GHz	20GHz	40GHz
Insertion Loss	0.6 dB	0.8 dB	1.3 dB
Return Loss	22 dB	18 dB	15 dB

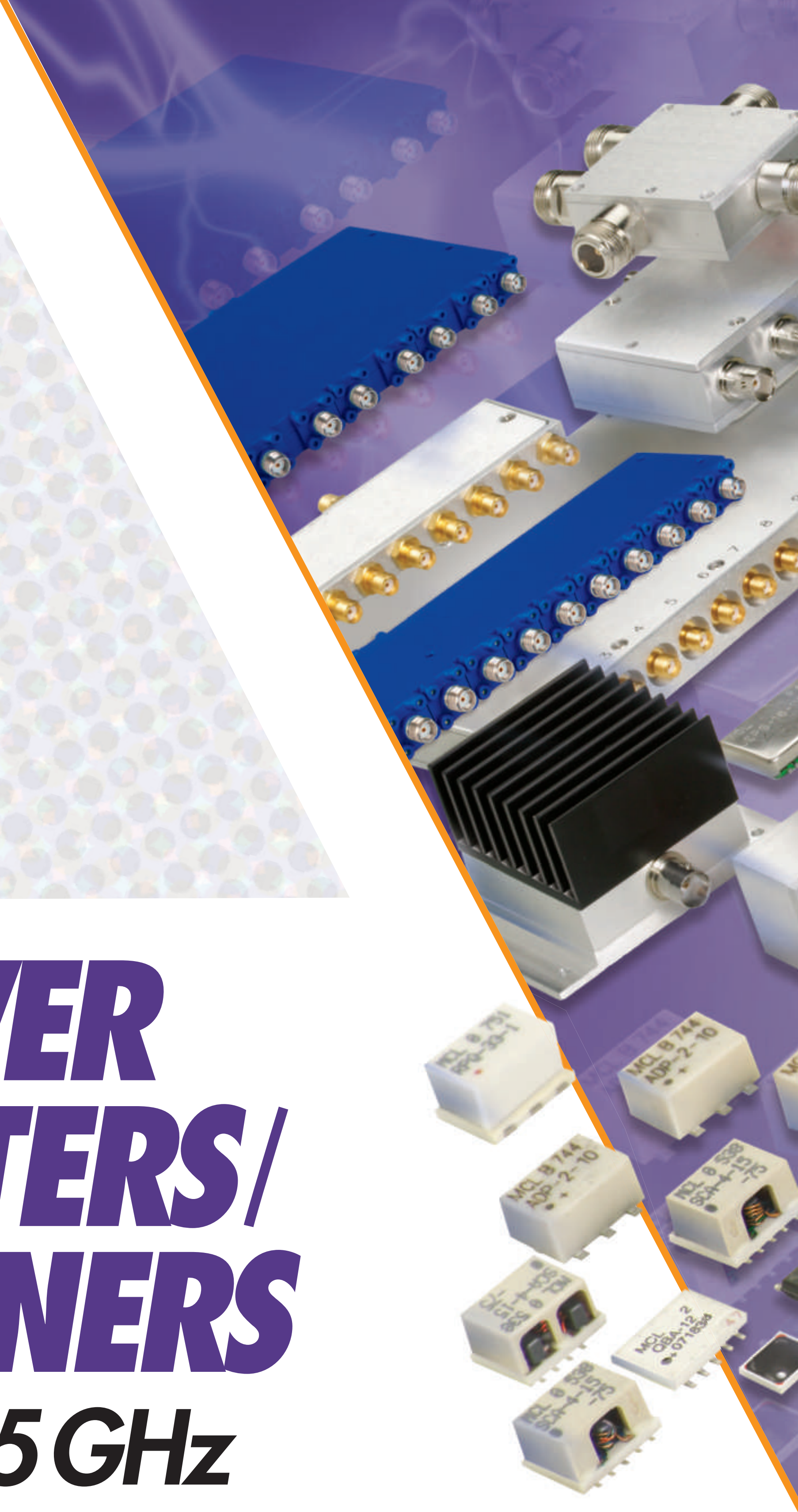
For technical assistance, custom product designs, or off-the-shelf delivery,call GGB Industries, Inc., at (239) 643-4400.

GGB INDUSTRIES, INC. • P.O. BOX 10958 • NAPLES, FL 34101

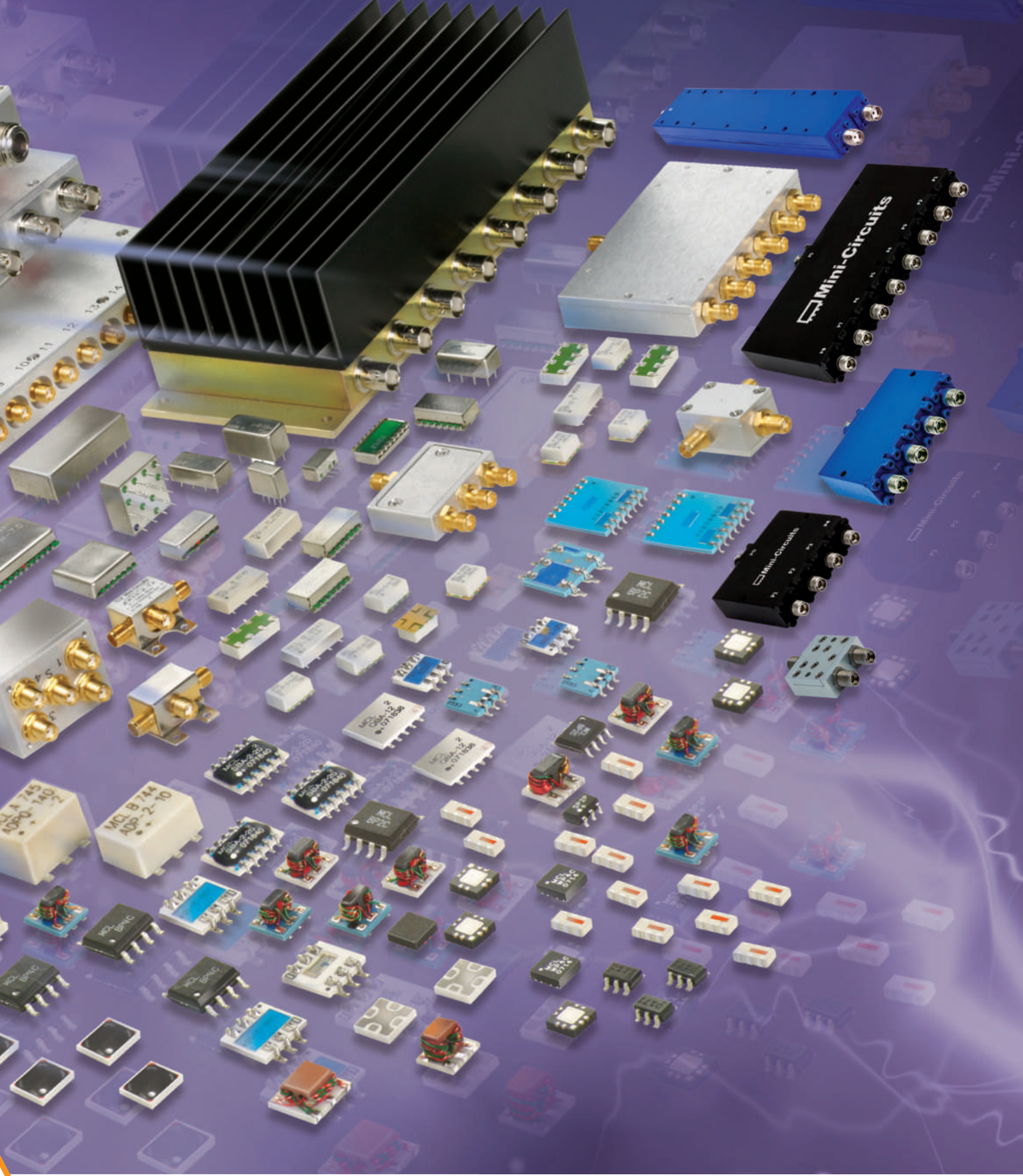
Telephone (239) 643-4400 • Fax (239) 643-4403 • E-mail email@ggb.com • www.picoprobe.com

POWER SPLITTERS/ COMBINERS

from DC to 65 GHz



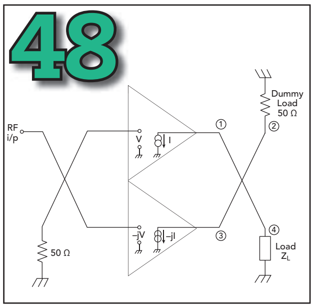
- Over 600 Models in Stock
- 2-Way up to 24-Way Models
- Input Power up to 100W
- 0°, 90° and 180° Phase Configurations
- LTCC, MMIC, Microstrip, Stripline, Core & Wire, and Resistive Designs

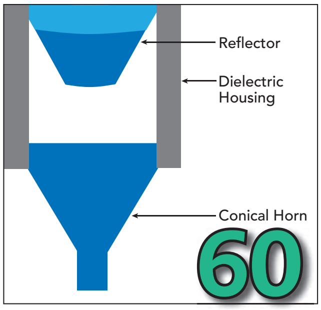

Mini-Circuits

Microwave Journal

CONTENTS

October 2020
Vol. 63 • No. 10
Passive & Control Components
mwjournal.com





online spotlight

Look for this month's exclusive article online at mwjournal.com

Planar Cavity-Backed Self-Triplexing Slot Antenna for Planar Integration

Arvind Kumar, Sharwan Ram and Mu'ath Al-Hasan

Cover Feature

Technical Features

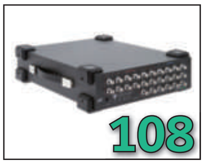
Special Report

63 YEARS OF PUBLISHING EXCELLENCE


Has Amplifier Performance or Delivery Stalled Your Program?
Noise Figure In Select Frequency Bands
Noise Figure (dB)
Frequency (GHz)
4.5dB
4.0dB
2.8dB
2.8dB
2.5dB
1.8dB
1.5dB
1.3dB
1.2dB
1.2dB
0.9dB
0.7dB
0.7dB
0.5dB
0.35dB
B&Z TECHNOLOGIES
Innovating to Excel
www.bnztech.com

CONTENTS

mwjournal.com



Product Features

Tech Briefs

Departments

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.

POSTMASTER: Send address corrections to Microwave Journal, PO Box 1028, Lowell, MA 01853 or e-mail mwj@e-circ.net.com. 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.

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: Kelley Roche
Multimedia Staff Editor: Barbara Walsh
Contributing Editor: Janine Love
Electronic Marketing Manager: Chris Stanfa
Senior Digital Content Specialist: Lauren Tully
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. Bazzy
President: Ivar Bazzy
Vice President: Jared Bazzy

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

BPA WORLDWIDE

www.mwjournal.com

Printed in the USA

Microwave Journal Online

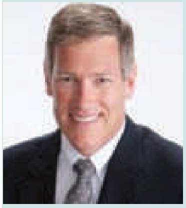
Visit us @ mwjournal.com

E LEARNING CENTER

An Innovative Differential Delay Shifter Design with Applications for Beam Steering Antennas
Sponsored by: Menlo Micro 10/22

Which Material Properties Have the Most Impact in High Speed Digital Applications
Sponsored by: Rogers Corporation 10/29

Executive Interview



Chris Dugan, president of **Knowles Precision Devices**, discusses the history of the company, its capabilities and products, and the markets it serves.

Catch *Frequency Matters*, the industry update from *Microwave Journal*,
microwavejournal.com/FrequencyMatters

WHITE PAPERS

ANALOG DEVICES — AHEAD OF WHAT'S POSSIBLE™	Phased Array Antenna Patterns—Part 2
HUBER+SUHNER	Screening Effectiveness and Transfer Impedance of (N)EMP Protection Components in the Installed Condition
knowles	Tolerance and Size Analysis for mmWave Filter Manufacturing
ROHDE&SCHWARZ — Make ideas real	5G Evolution - on the Path to 6G - From a Service, Air Interface and Network Perspective
	Antenna Array Testing - Conducted and Over the Air: The Way to 5G
SPECTRUM	Advantages of Multi-channel Modular Arbitrary Waveform Generators
GORE — Creative Technologies Worldwide	Improve 5G Testing with Reliable Microwave/RF Cable Assemblies

Join Us Online

Follow us
@Pathindle
@MWJGary
@MWJEditor

Join us at the RF and Microwave Community

Become a fan at facebook.com/microwavejournal

FEATURED eBooks

mwjournal.com/ebooks

COM

NOVEMBER MARK YOUR CALENDAR

WEBINAR

9-29 to 11-3

Latest Insights in RF Amplifier Design from World's Leading Experts – Fundamentals and Applications – "Live" Webinar Course

This six-week lecture series is intended to give a broad overview of state-of-the-art RF PA techniques with practical aspects for working professionals together with students for future RF PA designers, from fundamentals to applications. From review of RF power amplifier concepts then teaches handset PA design techniques, issues and solutions faced with designing RF PAs for mobile applications to GaAs/GaN MMIC level mmWave amplifier design tutorials and techniques including foundry/technology selection, load-pull, load line analysis and simulations with EDA tools, attendees will help sharpen current skill sets as well as initiate the RF PA design with better confidence.

https://www.microwavejournal.com/events/1965

WEBINAR

10

Ten Tips for Reducing On-Board DC-DC Converter EMI for IoT/Wireless Devices

With the world headed towards "everything wireless" in full swing, it comes with problems with EMI. That is, EMI from the product itself interfering with sensitive on-board cellular, GPS/GNSS and Wi-Fi/Bluetooth receivers. One of the predominant sources of this self-interference comes from today's DC-DC converters running between 1 and 3 MHz. This webinar will describe ten tips for reducing this interference from DC-DC converters.

signalintegrityjournal.com

VIRTUAL

2-5

The 42nd Annual Meeting and Symposium of the Antenna Measurement Techniques Association (AMTA) will include high-quality technical papers presented on a continuous basis, a full-day short course related to antenna measurement, exhibits showcasing antenna and RCS measurements, networking opportunities with industry experts and more.

www.amta2020.org

VIRTUAL

8-11

BCICTS will unify the complementary technical legacies of BCTM (31 years) and CSICS (39 years) into one exemplary symposium. Anchoring the contributing sessions will be sixteen invited talks arranged by the technical subcommittees of BCICTS, including coverage of the latest topics and advances in the rapidly progressing field of semiconductor technology and circuits unmatched by any other conference.

www.bcicts.org

10-12

VIRTUAL

Global MilSatCom provides an unparalleled opportunity to meet with senior decision makers from defense agencies, militaries, governments and industry from across the globe, providing fantastic interactive opportunities through conference sessions, virtual exhibition hall and networking receptions. This year, Global MilSatCom highlights SATCOM resilience, hybrid capability, payload delivery, the impact of emergent LEO mega constellations and more, providing a holistic view of the future of connectivity.

www.globalmilsatcom.com

FOR DETAILS, VISIT MWJOURNAL.COM/EVENTS

Coming**Events**

CALL FOR PAPERS

IEEE International Conference on Communications
October 12

IEEE MTT-S IMS2021
December 9

CS MANTECH 2021
December 18

mwjournal.com

OCTOBER

AUVSI's Xponential
October 5–8 • Virtual
www.xponential.org

EDICON Online
October 6, 13, 20 & 27 • Virtual
www.edicononline.com

COMSOL Conference 2020
October 7–8 • Virtual
www.comsol.com/conference/north-america

EDI CON China 2020
October 13–14 • Beijing, China
www.ediconchina.com

NOVEMBER

AMTA 2020
November 2–5 • Virtual
www.amta2020.org

2020 IEEE BiCMOS and BCICTS
November 8–11 • Virtual
www.bcicts.org

Global MilSatCom
November 10–12 • Virtual
www.globalmilsatcom.com

DECEMBER

APMC 2020
December 8–11 • Virtual
www.apmc2020.org

2020 IEEE International Electron Devices Meeting
December 12–16 • Virtual
https://ieee-iedm.org/

JANUARY 2021

European Microwave Week (EuMW)
January 10–15 • Utrecht, The Netherlands
www.eumweek.com

Radio & Wireless Week (RWW)
January 17–20 • San Diego, Calif. & Virtual
www.radiowirelessweek.org

96th ARFTG Microwave Measurement Symposium
January 17–20 • Virtual
https://www.arftg.org/index.php/upcoming-conference/future-conferences

FEBRUARY 2021

International Conference on Computing, Communication, and Intelligent Systems (ICCCIS)
February 19–20 • Greater Noida, India
http://www.icccis.in/

MARCH 2021

MWC Barcelona
March 1–4 • Barcelona, Spain
www.mwcbarcelona.com

2021 IEEE Aerospace Conference
March 6–13 • Big Sky, Mont.
https://aeroconf.org/

Satellite 2021
March 15–18 • Washington D.C.
www.satshow.com

EMV
March 23–25 • Stuttgart, Germany
https://emv.mesago.com/stuttgart/en.html

APRIL 2021

DesignCon 2021
April 13–15 • San Jose, Calif.
https://www.designcon.com/en/home.html

2021 IEEE Conference on Technologies for Sustainability (SusTech)
April 22–24 • Virtual
https://ieee-sustech.org/

COVER FEATURE
INVITED PAPER

Intensifying Technology Competition in the Acoustic Wave Filter Market

Stéphane Elisabeth
System Plus Consulting

Cédric Malaquin
Yole Développement (Yole)

Until now, surface acoustic wave (SAW) and bulk acoustic wave (BAW) filters have been well suited for distinct frequency bands. SAW filters are best suited to lower frequencies and BAW filters for higher frequencies in the cellular market. As Yole Développement has shown in its description of the state-of-the-art technology in ***Figure 1***, SAW filters were well adopted in the low frequency range, from 0.4 to 1.2 GHz. In the middle (from 1.2 to 2.2 GHz), both SAW and BAW filters were struggling in the market. State-of-the-art BAW filters offered better performance where SAW filters were cheaper with acceptable performance. For high frequency applications (from 2.2 to 6.0 GHz), BAW filters were the leader.

This situation is no longer the case in the market as several companies have developed technologies that will disrupt the filter market. Several trends can be observed:

- Asian-based companies are offering their own SAW technology which is lower cost compared to other competitors
- U.S.-based companies mainly offer high performance SAW filters
- Market leaders, with the development of new technology, are increasing the frequency range of well know devices such as

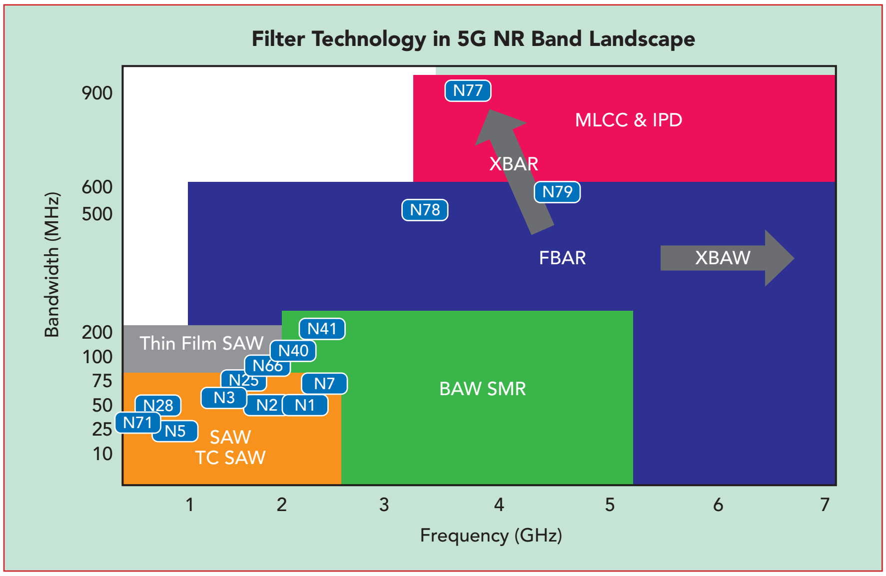


Fig. 1 Acoustic wave filter technology in the 5G NR landscape. *Source:* Yole Developpement, 2019.

SAW and film bulk acoustic resonator (FBAR)-BAW filters

- With the rise of 5G and Wi-Fi 6E, almost all market leaders are looking for BAW solutions
- In the middle frequency ranges, SAW companies are looking for cost effective solutions with high performance: temperature-compensated SAW (TC-SAW) filters, thin film SAW (TF-SAW), etc.

In this article, the acoustic filter technology currently available on the market is described including the costs for both SAW and BAW devices followed by an overview of the upcoming technologies for future applications, including new structures and costs.

In the filter family, the substrate is the first means of differentiation between the players. The most suitable substrate technology for smartphones and other small form factor applications is a piezoelectric material. The filters based on this technology rely on the electro-mechanical effect of the material to propagate the RF signal and filter it at a certain frequency. Two main technologies split the market for piezoelectric filters, BAW and SAW. For standard SAW, eight companies that supply such devices are included in a comparative report shown in ***Figure 2***. For TC-SAW, the number of manufacturers drops to four. More than half of them are U.S.-based companies: Qorvo and Skyworks, that only provide TC-SAW components using in-house design, and Qualcomm, with a complete portfolio from legacy SAW to SMR-BAW filters. The fourth is an Asian-based company, Murata.

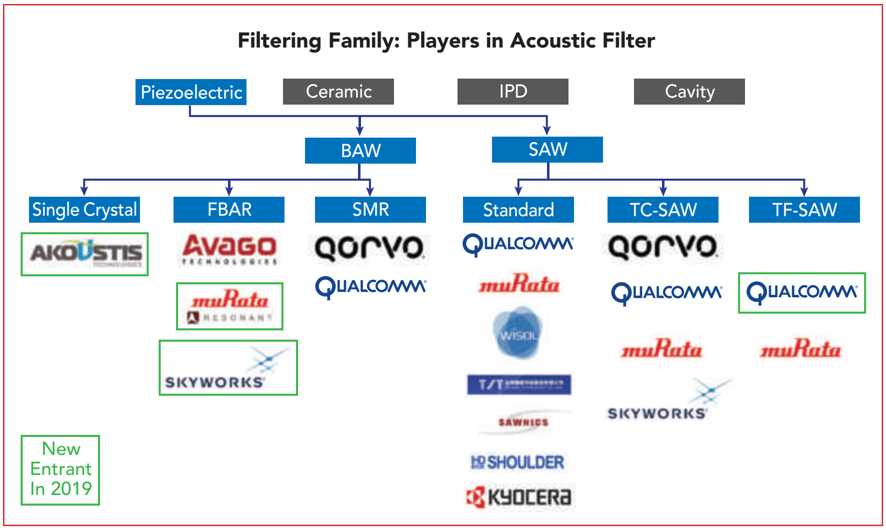
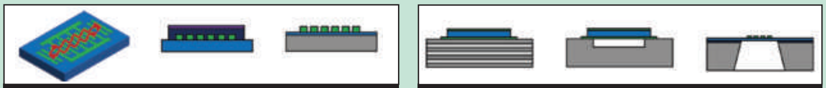


Fig. 2 Acoustic wave filter market players and their technologies. *Source:* System Plus Consulting, 2020.

At low frequencies, SAW filter technology is well known and small companies are competing with the market leaders to create an alternative filter ecosystem. As SAW filters use lateral propagation of the high frequency waves, it only requires simple manufacturing processes. Several Asian-based companies have risen over the past few years to introduce their own technology at a low cost, to be integrated into the Chinese domestic market in discrete models like Vivo, Huawei, etc. This has spawned new companies, like Resonant, that provide simulation tools to enable fabless companies to quickly develop filters and foundry services to manufacture them. Wisol, a Korean-based company that provides discrete filters and modules to OEMs like Samsung, has supplied a module with a single die SAW duplexer designed by Resonant for a low-end smartphone, the XCover 4. This standard technology is usually based on metal electrode (aluminum, titanium, gold, copper) forming the interdigital transducer (IDT) on a single crystal piezoelectric like lithium tantalate (LT) as shown in ***Figure 3***. The

Acoustic Filter Technology Overview



SAW	TC-SAW	TF-SAW	BAW-SMR	BAW-FBAR	BAW-XBAR
Lateral Propagation			Vertical Propagation		
Application					
4G	4G	4G/5G)	4G/5G	4G/5G	4G/5G
Cost (– High Cost, + Low Cost)					
+++	++	+	+	–	(Est.) ++
Process Steps (+ Complex, – Simple)					
–	+	++	+++	++	+++
Structure					
Air Cavity	Oxide	Air Cavity	Air Cavity	Air Cavity	Air Cavity
Single Crystal Piezo	Single Crystal Piezo	Single Crystal Piezo	Polycrystal Piezo	Polycrystal Piezo	Polycrystal Piezo
		Backside Parasitic	Backside Parasitic	Air Cavity	Air Cavity
Substrate					
Single Crystal Piezo	Single Crystal Piezo	Piezo on Insulator	Silicon	Silicon	Piezo on Insulator

Fig. 3 **Acoustic wave filter construction overview.** ***Source:*** **System Plus Consulting, 2020.**

result of such a simple process is a very low cost device that fits low frequency filtering requirements but is not suitable for selected high frequencies like band 8, 26 or 13 on the LTE protocol, or better performance demanded by 5G.

For more challenging bands, TC-SAW filters are required and fewer companies supply these. The gap between some frequency bands is very tight, so performance drift, mainly due to thermal changes on the structure, must be controlled to avoid filtering overlaps. TC-SAW filters have been built specifically for these cases. TC-SAW technology still uses a thin film deposition manufacturing process. However, the process adds features to enhance the isolation, by adding thermo-compensation layers. At the substrate level, the change can be seen compared to a standard SAW filter, with the use of a lithium niobate substrate that provides better acoustic wave velocity (see Figure 3). Also, to enhance the performance of the IDT structure, other materials are considered for the electrode. These materials, such as silver, platinum, molybdenum or chromium, offer better acoustic impedance while handling higher power. To isolate the IDT from any environmental changes (like temperature), the structure is usually covered with silicon oxide and sometimes with an additional silicon nitride layer. Of course, these enhancements have a cost: TC-SAW adds 60 percent cost premium compared to traditional SAW filters.

Finally, in the SAW filter segment, there is a new technology called TF-SAW filter that provides very high performance compared to the standard SAW filter. The performance can even compete with BAW filters in some frequency bands. This technology relies on piezoelectric material deposited on an insulator. In this technology, the thermal compensation mechanism comes directly from the substrate.

In 2020, two major companies are providing TC-SAW devices, Qualcomm and Murata. Murata first introduced the technology, which has already been commercially adopted, and Qualcomm added this technology to its portfolio in the beginning of 2020. Only a few substrate sup-

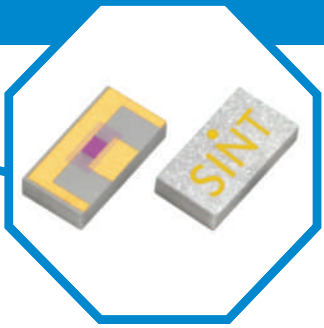
smiths interconnect

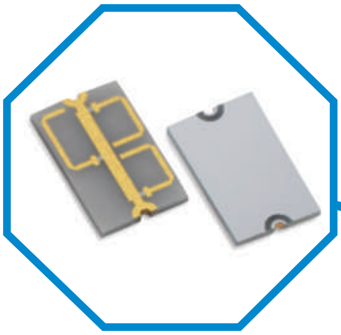
Beyond Connectivity

High-Performance RF & MW Components

CTX SMT Series - Chip Terminations

- Patented high frequency surface mount chip terminations up to 67 GHz
- High power handling in a small lightweight package, up to 1 Watt CW of input power



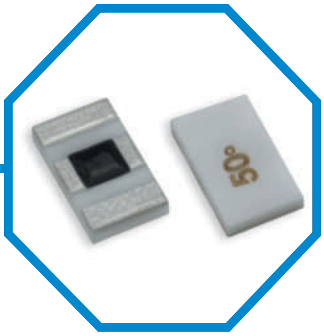


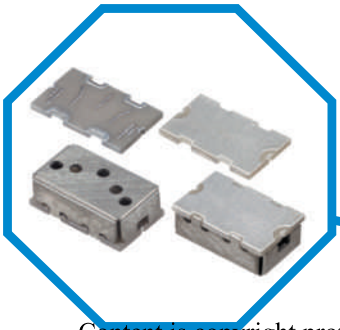
CEX Series - Chip equalizers

- Multiple slope options (1-4 dB) and excellent slope linearity (±0.25 dB or better)
- Frequency offering up to 40 GHz supporting a wide array of markets and applications

CXH Series - Outrigger Resistors

- Patented resistive product designed to handle more power than the conventional flip chip resistor
- Multiple footprint configurations, resistance values and power handling options are available to support a wide array of applications





Planar X Series - RF Filters

- Bandpass, bandstop, lowpass and highpass configurations up to 18 GHz (Ku-Band) offering premium performance in a small package
- Ideal solutions for pick and place and harsh environment applications

more > smithsinterconnect.com

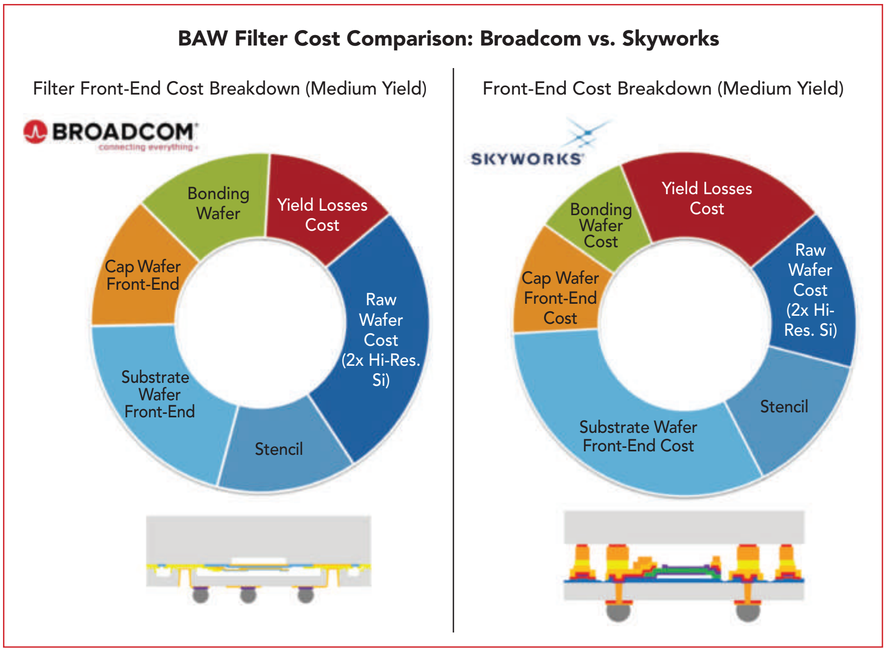


Fig. 4 **SAW filter cost per area by technology.** ***Source:*** **System Plus Consulting, 2020.**

pliers currently manufacture and offer this material. The manufacturing of the substrate relies on two main process technologies: one with a grinded LT substrate on silicon and the other with Piezo-on-Insulator substrate using a Smart-Cut®-like process from Soitec. This new technology provides a great opportunity for substrate manufacturers, such as NGK and Soitec. Other advantages of this technology are lower losses, wider bandwidths and higher frequency than traditional SAW filters. It also allows the integration of multiple filters on one device reducing the total footprint.

By analyzing the main SAW technology from various players, the relationship of the SAW filter cost per area has been calculated and is shown in ***Figure 4***. It appears that there is a linear increase in cost for each technology, irrespective of the manufacturer. The only differences are the SAW technology used. TC-SAW or high performance SAW filters are almost two times costlier than standard SAW filters. TF-SAW has an even higher cost, mainly due to the substrate manufacturing process. However, TF-SAW is very attractive notwithstanding the cost compared to a BAW filter. The performance of a TF-SAW filter is very close to that of a BAW filter in some bands where the BAW filter is the leading technology. For example, in LTE Band 40, the ultraSAW technology from Qualcomm achieves better insertion losses than competing BAW filters. Moreover, the thermal handling is better for TF-SAW than BAW filters. For ultra-high frequency (3.3 to 6 GHz), the BAW filter is still the leader in performance, even more with the implementation of 5G.

The main difference between BAW and SAW filters, besides the structure, is the piezoelectric material that the filters rely on. SAW

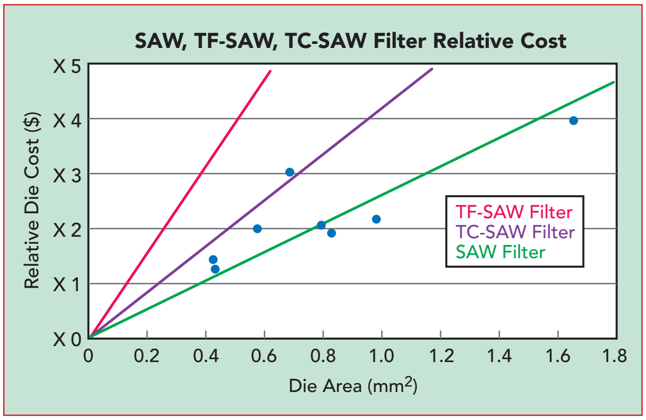


Fig. 5 **Cost comparison of BAW filters.** ***Source:*** **System Plus Consulting, 2020.**

TEST & MEASUREMENT

Test, Measurement & Calibration

RF and microwave components from Rosenberger play a key role in a variety of test, measurement and calibration applications. RF high precision connectors, adaptors & devices, PCB connections – solderless, modular system or even spring loaded products – calibration kits, microwave test cables, VNA test port cables or automated test equipment products – renowned companies trust the precision and quality of Rosenberger test & measurement products.

Product range

- Microwave measurements & VNA calibrations
- Lab testing
- Factory testing
- PCB connections
- Semiconductor test applications & high-speed digital testing
- Network testing
- Test & measurement equipment
- Service and support

www.rosenberger.com

Rosenberger

filters use a single crystal piezoelectric like LiTaO3 or LiNbO5 as a substrate where BAW filters use polycrystal aluminum nitride that provides higher coupling coefficient and higher wave velocity in the material. For several years, the BAW filter market has been dominated by four leaders, Avago Technologies, Qorvo, Taiyo Yuden and Epcos. In the past few years, however, the market has changed a bit through acquisitions and joint ventures. Avago is now part of Broadcom and Epcos joined TDK, which is now part of RF360, owned by Qualcomm.

This year, the market could experience more competition with the entrance of new players with new technologies for BAW filters. Skyworks has started its introduction into high volume products of its in-house FBAR technology. Like Broadcom's FBAR technology, the die is packaged using wafer level chip scale packaging technology using through silicon vias (TSV) and two silicon substrates. However, its structure has an air cavity realized using a sacrificial oxide on top of the silicon substrate, unlike Broadcom, which etches the silicon substrate to realize a "swimming pool" under the resonator.

Another player, Akoustis, will ramp up this year in the CPE market with a product that relies on a single crystal piezoelectric material. The main product of the company is a FBAR-type structure with a piezoelectric growth step using metal organic chemical vapor deposition deposition technology. The single crystal material allows for a better coupling factor and low insertion losses. This enables very good performance at higher frequencies, such as 5.2 to 5.6 GHz. There are other players, like Murata with Resonant, which have developed an XBAR device that completes the offerings of the company and has a similar structure to FBAR with piezoelectric on top of an air cavity. However, the resonator is different because of the use of a thin film piezoelectric material and IDT-like electrodes. These two technologies are emerging in the market but the cost is expected to be higher for XBAW from Akoustis and similar for XBAR from Murata/Resonant.

By looking at the actual FBAR-BAW filter market, cost differences between Skyworks and Broadcom have been evaluated and shown in ***Figure 5***. According to the simulation, Skyworks appears to be twice as costly as Broadcom. This cost difference is due to two main reasons: first, the number of etching steps in the process from substrate wafer front-end to realization of the resonator and second, the cost of the TSV and the manufacturing of the sealing frame.

Another way to implement BAW technology is to develop a resonator solidly mounted on silicon substrate. This technology, called SMR, is used by Qorvo and Qualcomm. To propagate the acoustic wave through the thin film while isolating it from substrate parasitics, an acoustic mirror is realized using mul-


ANALOG DEVICES
AHEAD OF WHAT'S POSSIBLE™
The Trust and Agility to Win the New Space Race.
Reach on-orbit faster by leveraging our 40 years of space heritage, coupled with our rapidly expanding space-qualified portfolio.
End-to-End Signal Chain
Class S & K/QMLV Technologies
Commercial Space Solutions
Get on-orbit faster at analog.com/space

tiple silicon oxide layers and a metal layer beneath the resonator structure. This is realized without any micromachining of the silicon substrate but requires specific packaging features to protect the resonator from the environment. In the case of Qorvo's SMR technology, the resonator is protected using an epoxy-based wall and cover that forms an air cavity on top of the resonator area. For Qualcomm, the air cavities are realized using sacrificial oxide and SiN with an air vent. After the sacrificial etching, a polyimide film is deposited on the structure sealed with another SiN layer. In both devices, the redistribution of the electrode from the resonator is made with copper pillars which are lower loss interconnects than solder balls.

According to Yole Développement, the overall mobile handset filter market was valued at $7B in 2019, with SAW- and BAW-based technologies accounting for $4.7B and $1.9B, respectively. The remaining filter business is based on non-acoustic filter technologies (MLC and IPD). As the number of supported bands in a handset keeps increasing and more complex filter functions with carrier aggregation are required plus support for 5G new radio while ensuring coexistence with other radios is posing additional stress for the performance of the filter, the market for higher performance filters will grow. Therefore, BAW and TF-SAW filters will have the largest growth rate, explaining the rising interest of market leaders in these technologies, while legacy SAW filters will only have an organic growth.

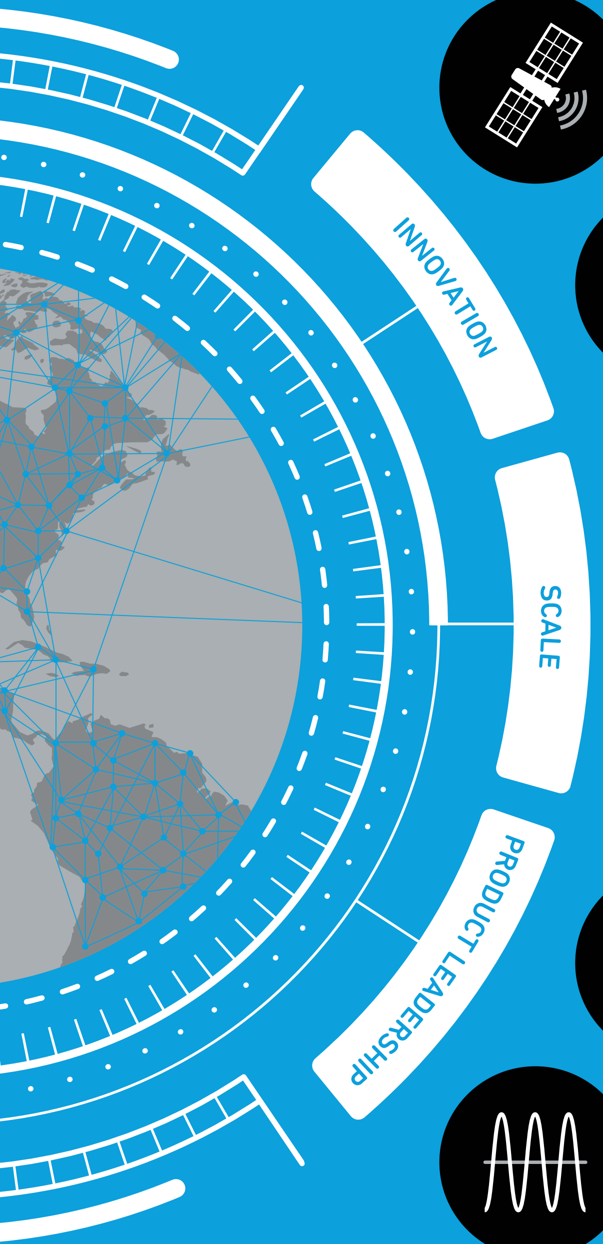
The actual front-end module market is well settled at this point. Market leaders Broadcom, Qorvo, Skyworks, Qualcomm and Murata are sharing the throne and small players are taking legacy market share. Each company has developed its own technology and relies on its technological position. Broadcom, with its FBAR-BAW filter, still dominates the high performance filtering market but Qorvo and Skyworks are following closely behind. In the first instance by providing the same degree of performance at Power Amplifier Integrated Duplexer level thanks to packaging innovation and a new type of FBAR-BAW filter that could compete with the other two players.

One of the Asian-based companies that is growing every year, Murata is a company to follow. With the inclusion of TF-SAW in its portfolio and development of XBAR in partnership with Resonant, the company is moving close to the same level of a component provider as Qualcomm and could became a top competitor. With the recent U.S. ban of Huawei, the company has increased its sales volume by garnering a lot of design wins for smartphones from Chinese OEMs. As no settlement is yet being agreed between the two countries, we could expect a rise in the number of Chinese filter manufacturers in partnership with active device manufacturers, like Maxscend, to provide front-end modules and replace components that rely on the U.S. manufacturers.■

ARE YOU WORKING WITH THE LEADER IN

AEROSPACE AND DEFENSE?

Qorvo® Connects, Protects and Powers™ the Systems All Around You®



Space qualified,
highest level of reliability

Demonstrated MTTF reliability with
200°C/107 hrs

Over 9 million
GaN products shipped to date

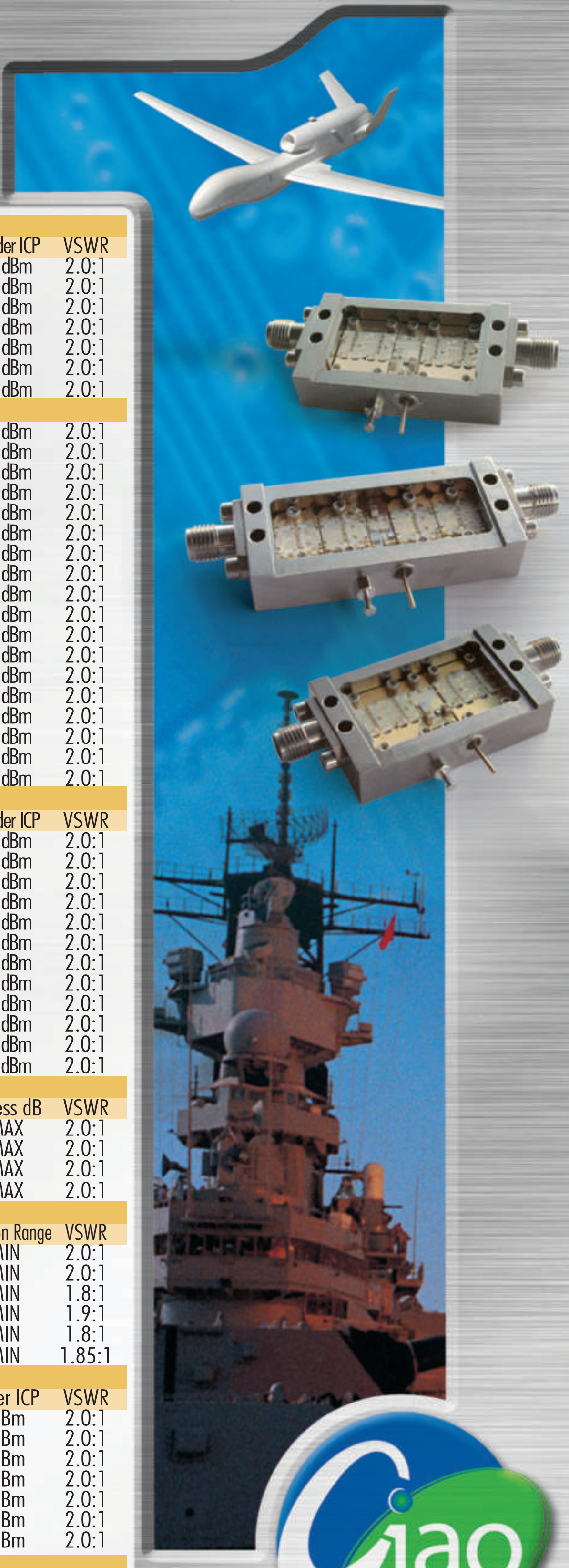
#1 GaN-on-SiC supplier
in defense since 1998

4 GaN process nodes at **MRL 10**
using USAF MRA tool

Broadest portfolio range
20 MHz~100 GHz

Join us at Qorvo.com/design-hub to explore:
Blogs | Videos | e-Books | Design tools | Tech docs

qorvo®
all around you



AlphaDogfight Trials Foreshadow Future of Human-Machine Symbiosis

A small Maryland company took first place in the recent AlphaDogfight Trials Final event, a three-day competition designed to demonstrate advanced algorithms capable of performing simulated, within visual range air combat maneuvering—commonly known as a dogfight. Heron Systems' F-16 AI agent defeated seven other companies' F-16 AI agents and then went on to dominate the main event—a series of simulated dogfights against an experienced Air Force F-16 pilot—winning 5-0 through aggressive and precise maneuvers the human pilot couldn't outmatch.

"The AlphaDogfight Trials were a phenomenal success, accomplishing exactly what we'd set out to do," said Col. Dan "Animal" Javorsek, program manager in DARPA's Strategic Technology Office. "The goal was to earn the respect of a fighter pilot—and ultimately the broader fighter pilot community—by demonstrating that an AI agent can quickly and effectively learn basic fighter maneuvers and successfully employ them in a simulated dogfight."

The trials were designed to energize and expand a base of AI developers for DARPA's Air Combat Evolution (ACE) program. ACE seeks to automate air-to-air combat and build human trust in AI as a step toward improved human-machine teaming.

Eight participating companies, ranging from major defense contractors to a four-person firm, spent less than a year developing and teaching their AI agents how to fly and excel in simulated aerial combat. The teams were Aurora Flight Sciences, EpiSys Science, Georgia Tech Research Institute, Heron Systems, Lockheed Martin, Perspecta Labs, PhysicsAI and SoarTech. AI agents developed by Lockheed Martin, Aurora Flight Sciences and PhysicsAI rounded out the top four teams.

"The AlphaDogfight Trials outcome shows great promise for future airborne combat systems and concepts involving human-machine symbiosis," said Tim Grayson, director of DARPA's Strategic Technology Office (STO). "As part of STO's Mosaic Warfare vision of distributed manned and unmanned systems, the trials laid a strong foundation for further algorithm development in the ACE program as it moves now from a simulation environment to testing algorithms and measuring pilot trust on actual aircraft."

Dogfight (Source: DARPA)

The ACE program seeks to increase trust in combat autonomy by using human-machine collaborative dogfighting as its challenge problem. This also serves as an entry point into complex human-machine collaboration. ACE will apply existing artificial intelligence technologies to the dogfight problem in experiments of increasing realism. In parallel, ACE will implement methods to measure, calibrate, increase and predict human trust in combat autonomy performance. Finally, the program will scale the tactical application of autonomous dogfighting to more complex, heterogeneous, multi-aircraft, operational-level simulated scenarios informed by live data, laying the groundwork for future live, campaign-level Mosaic Warfare experimentation.

In a future air domain contested by adversaries, a single human pilot can increase lethality by effectively orchestrating multiple autonomous unmanned platforms from within a manned aircraft. This shifts the human role from single platform operator to mission commander. ACE aims to deliver a capability that enables pilots to attend to a broader, more global air command mission while their aircraft and teamed unmanned systems are engaged in individual tactics.

> "Virtual finale showcases AI's impressive abilities in simulated F-16 aerial combat."

ACE creates a hierarchical framework for autonomy in which higher-level cognitive functions (e.g., developing an overall engagement strategy, selecting and prioritizing targets, determining best weapon or effect, etc.) may be performed by a human, while lower-level functions (i.e., details of aircraft maneuver and engagement tactics) is left to the autonomous system. For this to be possible, the pilot must be able to trust the autonomy to conduct complex combat behaviors in scenarios such as the within visual range dogfight before progressing to beyond visual range engagements.

ACE demonstrations bridge the gap from simple physics-based automated systems currently in use to complex systems capable of effective autonomy within highly dynamic and uncertain environments at mission speeds.

The technology development on the ACE program addresses four primary challenges:

1. Increase air combat autonomy performance in local behaviors (individual aircraft and team tactical)
2. Build and calibrate trust in air combat local behaviors
3. Scale performance and trust to global behaviors (heterogeneous multi-aircraft)
4. Build infrastructure for full-scale air combat experimentation

For More Information
Visit mwjournal.com for more defense news.

Next Generation Radar for the RAF Typhoon

BAE Systems and Leonardo have been awarded a contract to develop the Active Electronically Scanned Array (AESA), the European Common Radar System Mark 2 (ECRS Mk2) radar, to a standard ready to be integrated on to RAF Typhoons.

The ECRS2 is a multi-functional array that will give U.K. Typhoons a world-leading electronic warfare capability, in addition to traditional radar functions, including wide band electronic attack. It will equip RAF pilots with the ability to locate, identify and suppress enemy air defenses using high-powered jamming. They can engage targets while beyond the reach of threats—even when looking in another direction—and operate inside the range of opposing air defenses, remaining fully protected throughout.

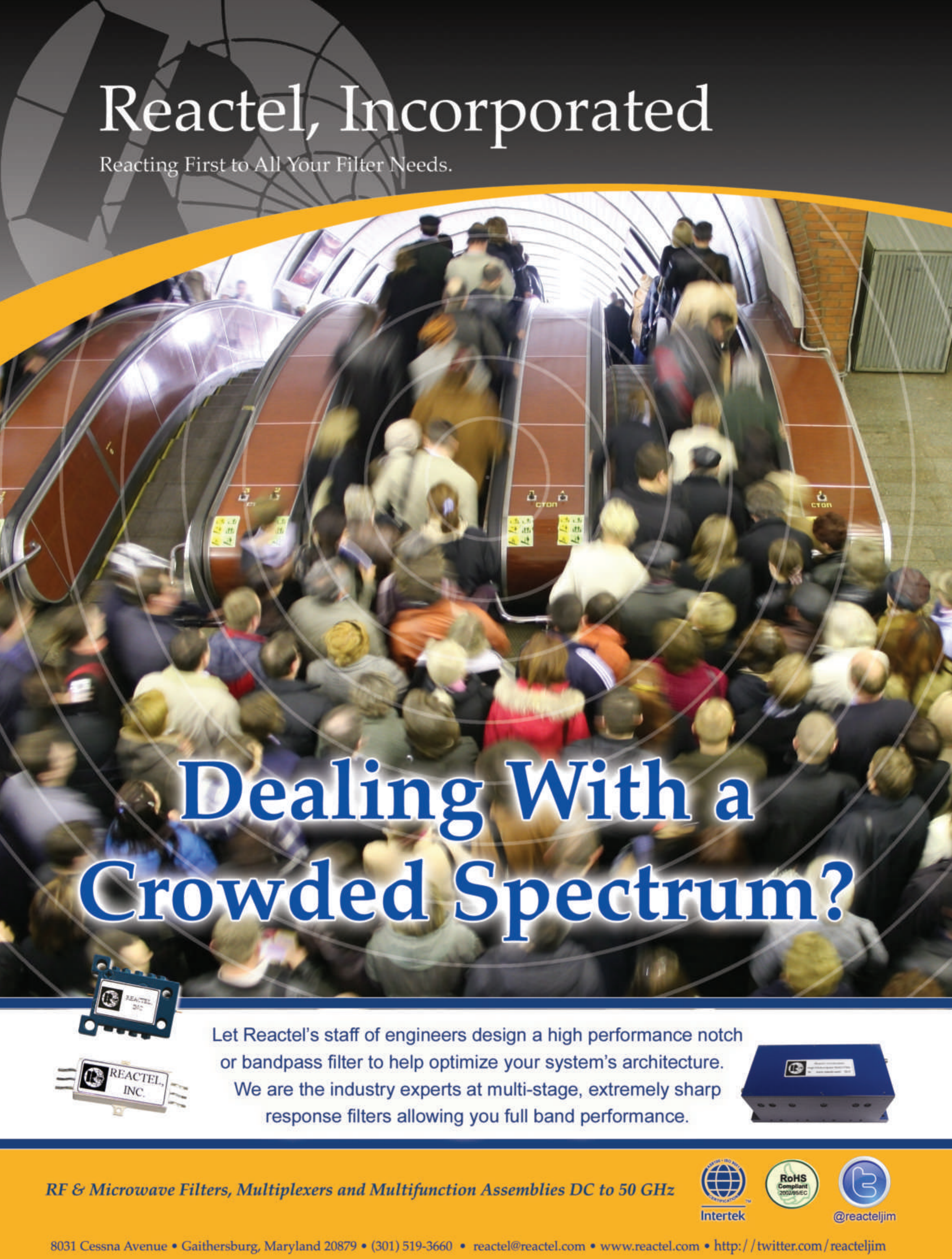
This game-changing capability will replace the mechanically-scanning radar that RAF Typhoons are currently equipped with and will ensure the U.K. retains the freedom to deliver air power wherever and whenever it is needed. It also enables the Typhoons to link up with future data-driven weapons to combat rapidly evolving air defences, ensuring that U.K. Typhoons can continue to dominate the battlespace for years to come.

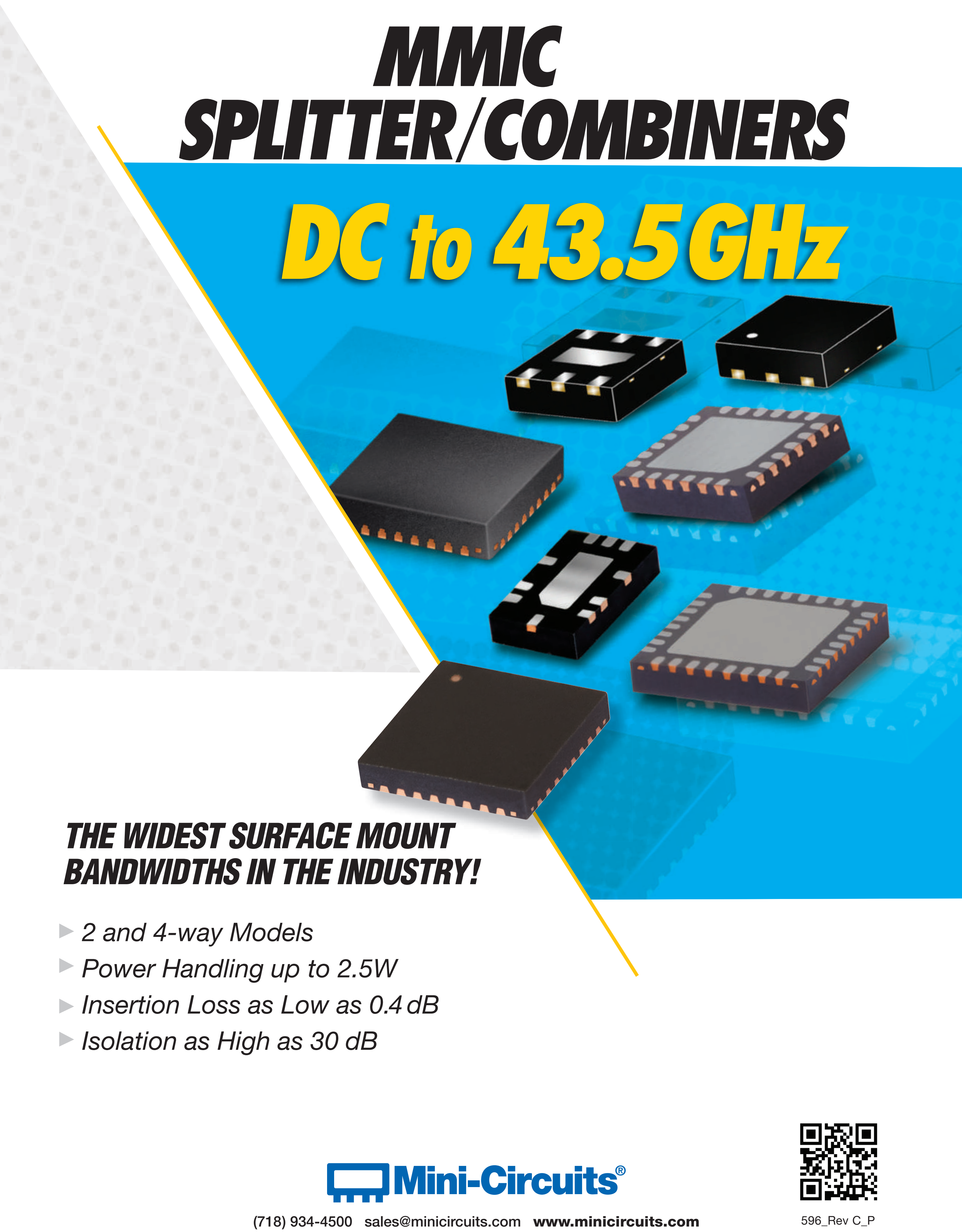
It has significantly more Transmit-Receive Elements than other radars, making Mk2 the most capable fighter AESA radar in the world, maintaining the same power and precision of traditional radars but also enabling the simultaneous operation of its wide band electronic warfare functionality.

Both companies are currently working as part of a four-nation development program alongside Eurofighter consortium partners in Germany, Spain and Italy on a baseline version of the AESA radar. The ECRS Mk2 is a completely new approach designed to meet the operational needs of the RAF and future export customers.

The U.K.'s commitment follows a similar commitment from Germany and Spain to deliver their own national requirements for an AESA radar.

Typhoon (Source: BAE Systems)


Reactel, Incorporated
Reacting First to All Your Filter Needs.
Dealing With a Crowded Spectrum?
Let Reactel's staff of engineers design a high performance notch or bandpass filter to help optimize your system's architecture. We are the industry experts at multi-stage, extremely sharp response filters allowing you full band performance.
REACTEL, INC.
RF & Microwave Filters, Multiplexers and Multifunction Assemblies DC to 50 GHz
Intertek
RoHS Compliant
@reacteljim
8031 Cessna Avenue • Gaithersburg, Maryland 20879 • (301) 519-3660 • reactel@reactel.com • www.reactel.com • http://twitter.com/reacteljim


MMIC
SPLITTER/COMBINERS
DC to 43.5 GHz
THE WIDEST SURFACE MOUNT
BANDWIDTHS IN THE INDUSTRY!
2 and 4-way Models
Power Handling up to 2.5W
Insertion Loss as Low as 0.4 dB
Isolation as High as 30 dB
Mini-Circuits®
(718) 934-4500 sales@minicircuits.com www.minicircuits.com
596_Rev C_P

Mobile Antenna Competition Intensifies as 5G RAN Deployment Grows

Competition in the antenna vendor market is heating up as 5G rolls out and market share is coming under serious pressure. In its recent analysis of the worldwide mobile cellular 4G and 5G antennas market, ABI Research found that Huawei remains the market leader in the base station antenna market, retaining a first place in both the market share and vendor rankings. Following Huawei, other companies within the top five for market share include, CommScope, Kathrein Mobile Communication, Rosenberger and ACE Technologies. Together, these five vendors comprise more than 70 percent of the total market in terms of revenue. While the names of the top five remain the same, there has been a shuffle in the order with CommScope taking the second position in 2019.

2019 was the year that 5G started to roll out and be trialed. By the end of 2019, South Korea reported more than 90,000 5G base stations had been deployed and China had built out more than 130,000. "The move toward the 5G rollout is creating new challenges as the antenna and radio must be integrated for optimal utilization of site space and network performance. The successful performance of the 5G network will increasingly depend on the antenna, making it an essential component in the operator's network," explained Dean Tan, research analyst at ABI Research.

ABI Research forecasted the growing demand for a higher-order number antenna ports, such as six and eight ports and 10 to 16 ports. These two segments will make up more than 80 percent of antenna shipments by 2025. In preparation for 5G, most antenna vendors (e.g., Huawei, Kathrein and RFS) have released their own versions or are working with OEMs for development. Massive MIMO is key to achieving the higher capacity gains and throughput that 5G is expected to bring. However, challenges, such as limited site space and difficulty of acquiring new sites, requires vendors to develop innovative ideas for the 5G deployment. "With the deployment of 5G, we have seen remarkable growth and innovation in the integrated active antenna segment. To tackle the challenges of 5G deployment, there is a vital need for antenna vendors and OEMs to work closely in an integrated fashion," said Tan.

Aside from the 5G focus, antenna vendors continue to develop innovative solutions to overcome physical challenges. Kathrein released their "378-antenna platform" that generates air vortices to reduce the wind load experienced by an antenna. Wind load is a key challenge that antenna vendors wrestle with to ensure reliability and safety of the antenna and its tower.

Asset Tracking Device Shipments Drive IoT Expansion

Asset tracking is one of the highest growth application segments for the Internet of Things (IoT). According to a new report by ABI Research, asset tracking device shipments will see a 51 percent year-on-year device shipment growth rate through 2024. Expanding LPWAN coverage, technological maturity and the associated miniaturization of sophisticated devices are key to moving asset tracking from traditionally high-value markets to low-value high volume markets, which will account for most of the tracker connection and shipment numbers.

"Hardware devices for the asset tracking market are primarily dominated by the need to balance power consumption, form factor and device cost. Balance and compromise between these three must be achieved based on the use-case and are dictated by the business case and possible return on investment for the customer," said Tancred Taylor, research analyst at ABI Research. "As these constraints are marginalized by greater volumes of adoption, by emerging technologies like eSIM or system-on-chip and by increasingly low-power components and connectivity, so too will the limitations on the business case."

Expanding technological and network foundations drive the number of use-cases, and OEMs are responding by diversifying their hardware offerings. Some OEMs such as CoreKinect, Particle, Mobilogix or Starcom Systems are innovating in this space by taking a reference-architecture or modular approach to device design for personalized solutions. Others such as BeWhere, Roambee, Sony and FFLY4U are going to market with off-the-shelf or vertically-focused devices for quickly scalable deployments.

Early adoption of asset tracking was in the fleet, container and logistics industries to provide basic data on the location and condition of assets in transit. The total addressable market for these industries remains extensive, particularly as the solutions trickle down from the largest enterprises to small- and medium-sized companies. Increased device functionality combined with component miniaturization is key to driving the next generation of low-cost tracking devices. This will enable granular tracking at the pallet, package or item level and open new markets and device categories, such as disposable trackers. Emerson, Sensitech, CoreKinect and Bayer are among companies driving innovation in this field.

Mobile network operators are playing a significant role in driving adoption through increased verticalization, with Verizon, AT&T and Orange among those offering subscription models for end-to-end solutions—comprising device, connectivity, software and managed service offerings. This model is additionally gaining traction among OEMs, with Roambee as an early adopter for a

For More Information Visit mwjournal.com for more commercial market news.

subscription-only model, and others such as Mobilogix following suit. This service-based model will gain additional traction as OEMs move down the value-chain by developing in-house capabilities or partner networks to simplify the ecosystem and consumer's solution.

Regional & Global Markets for mmWave Radios and Transceivers into 5G 'Xhaul'

Engalco-Research recently released a report on mmWave radios into 5G xhaul. According to the firm's Senior Researcher Terry Edwards, "mmWave links are already strategically important in many countries worldwide and they have found that very strong market growth can be expected over the next eight years and beyond."

mmWave subsystems are increasingly important for "xhaul" (mainly backhaul) in 5G base stations. mmWave radio links can be installed rapidly and in a less costly manner than (for example) fiber optics. Available bandwidths are much smaller than those of fiber but are eminently suitable for 5G xhaul purposes where information rates up to and above 10 Mbps are increasingly encountered. Frequencies range from around 24 to over 90 GHz and designated bands within this wide range are: K/Ka, V, E and W. To date most of the interest and activity has been on the K/Ka-Bands—notably with Verizon in the U.S., but activity is also increasing for the higher bands. V-Band (unlicensed and centered on 60 GHz) and the 'lightly-licensed' E-Band are particularly important.

The report provides data and analysis on total addressable markets for all classes of mmWave radios and transceivers into APAC, China, Europe and North America from 2020 through 2028. Global totals range from a few $B in 2020 growing annually to well exceed $9B in 2028. Overall CAGR is 12.6 percent. Regional contributions vary considerably but the APAC region leads in most instances.

> Strong market growth forecast for the next eight years and beyond.

Thirty five OEMs and network providers are identified and almost all are profiled, including Aviat Networks, BridgeWave, Ceragon, Maja Systems and Siklu. A total of 40 CSPs are also identified, ranging from A1Telekom Austria to Vodafone (U.K.). Profiles are provided for selected CSPs, those either known to be adopting at least some mmWave links and some considered likely to do so.

PRECISION COMPONENTS. PRECISION MEASUREMENTS.

Make complex measurements where limited solutions exist

Anritsu's metrology-grade coaxial W1 components delivers precision performance and repeatability.

Unlike solutions from other vendors whose products are based on banded waveguide frequencies, Anritsu's family of millimeter-wave components provide frequency range from DC to 110 GHz and improve repeatability of measurements by removing the need for a waveguide interface.

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**

KEY FEATURES

- Broadband solution from DC to 110 GHz
- Coaxial solution removes complexity and increases ease-of-use
- W1 connectors intended for broadband scalability and mode free performance to 110 GHz
- Metrology-grade solution provides optimal connector tolerances and design for highest performance

FOLLOW THE LEADER
220 GHz
ANRITSU

Anritsu

www.anritsu.com

Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

COLLABORATIONS

Modelithics announced it is now a member of the **GLOBALFOUNDRIES® (GF®)** RFwave™ Partner Program. The partnership between GF and Modelithics will enable mutual clients to accelerate the launch of new products, based on accurate testing results and the ready availability of Modelithics to assist GF and its clients in modeling activities. GF's RFwave program is an ecosystem of partners that provide unique mmWave test and characterization capabilities along with design services, IP and EDA solutions that will enable designers to build highly optimized RF solutions for a range of wireless applications such as Internet-of-Things (IoT), wireless connectivity, 5G and automotive radar.

Anokiwave Inc. and **hiSky** have announced a collaboration to enable the next generation of low-cost, voice, data and IoT SATCOM terminals. As part of this collaboration, Anokiwave will provide its advanced low-cost silicon core ICs in Ku- and K/Ka-Band and hiSky will provide small form factor terminal based phased array antennas for commercial and industrial applications. hiSky brings its innovative business models, technical expertise for implementation of satellite communication systems, while Anokiwave provides its silicon beamformer ICs that enable small form factor flat panel active antennas for SATCOM. hiSky's Smartellite™ solutions, utilizing Anokiwave ICs, offer an industry leading, small, portable and cost-effective flat panel satellite terminal for mass market.

Atmosic™ Technologies, an innovator in ultra-low-power wireless technology for IoT, and **SMK Electronics Corp.**, a global designer and manufacturer of advanced OEM electronic components, announced a strategic partnership to integrate Atmosic's M3 system-on-chip (SoC) into a range of connected devices from SMK. These IoT solutions, which will include remote controls and sensors, integrate Atmosic's Controlled Energy Harvesting, in addition to the company's lowest power radio and on-demand wake-up receiver, to enable forever battery life and eliminate the need for battery replacement. SMK and Atmosic are also working on an IoT module integrated with the Atmosic M2 SoC for industrial and commercial IoT applications.

Automotive technology company **Veoneer Inc.** and **Qualcomm Technologies Inc.** have decided to collaborate on the delivery of scalable advanced driver assistance systems (ADAS), collaborative and autonomous driving (AD) solutions powered by Veoneer's next-generation perception and driving policy software stack and Qualcomm® Snapdragon Ride™ ADAS/AD scalable portfolio of SoC and accelerators. This ranges from L1 to L4 systems uniquely designed to create an open platform for Tier-1 suppliers and automakers. Designed to address the growing complexities associated with developing ADAS, including safety compliance, the integrated software and SoC platform aims to address the growing needs of the automotive ecosystem for scalable and upgradable solutions.

ZTE Corp., in collaboration with **MediaTek**, have taken the lead to complete the industry's first 5G carrier aggregation verification of 700 MHz and 2.6 GHz spectrum based on commercial terminal chips in Xi'an, China. Based on ZTE's commercial 5G wireless base stations and its latest 5G core network equipment, along with the 5G test terminal featuring MediaTek Dimensity 800U 5G-integrated SoC, ZTE and MediaTek have verified dual-carrier aggregation of 30 MHz over 700 MHz and 100 MHz over 2.6 GHz, achieving an effective downlink data throughput of 1.849 Gbps.

ACHIEVEMENTS

Keysight Technologies Inc. announced that **Meizu** has selected Keysight's Radio Frequency Automation Toolset to validate enhanced mobile broadband (eMBB) performance critical in delivering multimedia applications in 5G smartphones. Meizu, a Chinese smartphone designer and producer, selected Keysight's 5G device test solutions to address a growing global 5G market. These solutions, based on Keysight's UXM 5G Wireless Test Platform, enable Meizu to verify 5G devices across the workflow, from early R&D to design verification, conformance validation and manufacturing. Meizu relies on 5G new radio standalone mode to support applications and connectivity capabilities used by consumers and industry verticals, such as manufacturing, logistics, transportation and gaming.

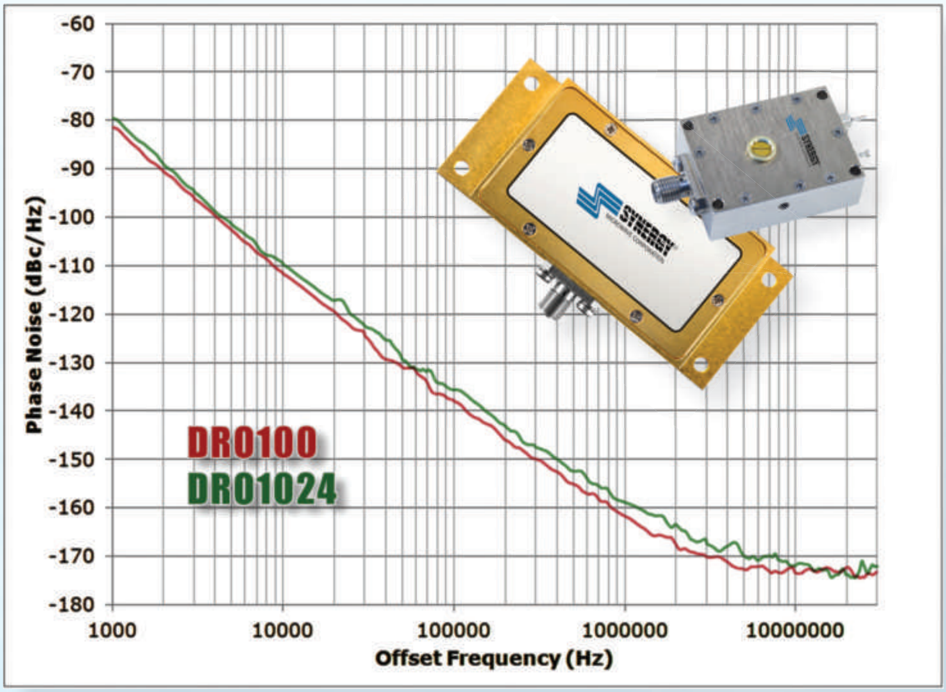
HUBER+SUHNER has announced the release of its new SENCITY positive train control (PTC) antenna which boasts the highest number of heavy-rail certifications in the industry. Deployed throughout the U.S., PTC systems are designed to monitor and, if necessary, take control of railway vehicles to provide railway operators with increased safety. The new SENCITY PTC antenna offers advanced features such as high voltage and high current protection, added protection for the antenna and RF path from catenary line strikes which can destroy electronic devices. The antenna meets the highest requirements for mechanical robustness and fire safety according to the EN 50155 and NFPA-130 standards.

Inc. Magazine revealed **Guerrilla RF** is No. 421 on its annual Inc. 5000 list, a prestigious ranking of the nation's fastest-growing private companies. The list represents a unique look at the most successful companies within the American economy's most dynamic segment—its independent small businesses. Intuit, Zappos, Under Armour, Microsoft, Patagonia and many other well-known names gained their first national exposure as honorees on the Inc. 5000. Not only have the companies on the 2020 Inc. 5000 been very competitive within their markets, but the list as a whole shows staggering growth compared with prior lists as well.

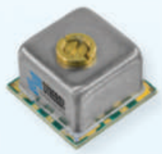
For More Information | **For up-to-date news briefs, visit mwjournal.com**

Exceptional Phase Noise

Dielectric Resonator Oscillator



Available In Surface Mount.



SDRO Series
0.75" x 0.75 x 0.53"

Patented Technology

Model	Frequency (GHz)	Tuning Voltage (VDC)	DC Bias (VDC)	Typical Phase Noise @ 10 kHz (dBc/Hz)
Surface Mount Models				
SDRO800-8	8.000	1 - 10	+8.0 @ 25 mA	**-110**
SDRO900-8	9.000	1 - 10	+8.0 @ 25 mA	**-112**
SDRO1000-8	10.000	1 - 15	+8.0 @ 25 mA	**-107**
SDRO1024-8	10.240	1 - 15	+8.0 @ 25 mA	**-105**
SDRO1118-7	11.180	1 - 12	+5.5 - +7.5 @ 25 mA	**-104**
SDRO1121-7	11.217	1 - 12	+5.5 - +7.5 @ 25 mA	**-106**
SDRO1130-7	11.303	1 - 12	+5.5 - +7.5 @ 25 mA	**-106**
SDRO1134-7	11.340	1 - 12	+5.5 - +7.5 @ 25 mA	**-107**
SDRO1250-8	12.500	1 - 15	+8.0 @ 25 mA	**-104**
Connectorized Models				
DRO80	8.000	1 - 15	+7.0 - +10 @ 70 mA	**-114**
DRO8R95	8.950	1 - 10	+7.0 - +10 @ 38 mA	**-109**
DRO100	10.000	1 - 15	+7.0 - +10 @ 70 mA	**-111**
DRO1024	10.240	1 - 15	+7.0 - +10 @ 70 mA	**-109**
DRO1024H	10.240	1 - 15	+7.0 - +10 @ 70 mA	**-115**
KDRO145-15-411M	14.500	*	+7.5 @ 60 mA	**-100**

* Mechanical tuning only ±4 MHz

Talk To Us About Your Custom Requirements.

SYNERGY® MICROWAVE CORPORATION

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

Around the **Circuit**

CONTRACTS

The **U.S. Air Force** awarded **Booz Allen Hamilton** one of several positions on an indefinite-delivery, indefinite-quantity contract valued at $950 million to support development of the Advanced Battle Management System (ABMS) which will enable rapid decision making and all-domain command and control. Part of the Department of Defense's Joint All-Domain Command and Control (JADC2) concept, ABMS aims to enable all services to operate together as part of a joint team—connecting sensors, decision makers and weapons through a secure data network to engage across multiple domains more effectively.

Ameresco Inc. announced that the **U.S. Army** has awarded to **Duke Energy** and Ameresco's Federal Solutions Group a utility energy service contract to implement power generation and facility efficiency improvements at Fort Bragg. In partnership with Duke Energy, Ameresco will deploy a 1.1 megawatt (MW) floating solar photovoltaic (PV) system on the Big Muddy Lake at Camp Mackall. A 2 MW battery energy storage system will provide seamless transition to on-site generation during utility provider outages. Under the $36 million design-build contract, Duke secures third-party financing to fund construction, and the U.S. Army pays down the financing annually with the utility savings that the project generates over the term of the contract.

PEOPLE

▲ *Mike Kahn*

Cobham Advanced Electronic Solutions announced the appointment of **Mike Kahn** as chief executive officer (CEO) effective immediately. Kahn takes over for Shawn Black, who is leaving the business to pursue other opportunities. Kahn has held a number of senior positions within the aerospace and defense industry, and most recently served as the sector VP and general manager for Weapon Systems at Northrop Grumman, following the acquisition of Orbital ATK where he was president of Defense Systems. During his nearly 40 years in aerospace and defense, Kahn has been the recipient of numerous awards and is widely recognized as a leader within the sector.

▲ *Tom Artinian*

Hitachi Cable America (HCA), a manufacturer of premise, fiber optic and specialty cables, announced the addition of **Tom Artinian** as executive vice president, Performance Cable Systems and Materials Division effective immediately. Artinian joins HCA from Southwire Canada where he served as vice president of sales. With over 22 years of experience in the wire and cable industry, his career has evolved in leadership roles in both Canada and the U.S. In this role, Artinian will oversee all facets of operations for HCA's Performance Cable Systems and Materials Division located in Manchester, N.H.

Around the **Circuit**

▲ *Vikas Choudhary*

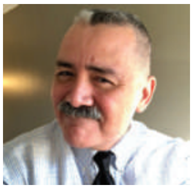
pSemi Corp. announced that **Vikas Choudhary** has joined the company as vice president of sales and marketing. Choudhary will lead pSemi's worldwide sales, applications engineering, marketing and marketing communications teams, and he will be responsible for driving pSemi's unique RF, power and sensor products into existing and emerging markets. Choudhary has more than 25 years of broad experience in the global semiconductor, IC, hardware architecture and systems engineering industries. He has held numerous leadership positions of progressive responsibility while heading marketing, engineering and strategy spanning eMobility and inertial sensors at Analog Devices. He was instrumental in establishing a R&D center for PMC Sierra India as a country manager.

▲ *Fin Farrelly*

Filtronic announced that it has strengthened its commercial team with the appointment of **Fin Farrelly** as marketing manager. Farrelly has worked in a number of marketing and business development roles for engineering and manufacturing companies, most recently for a company in the complex structural steel fabrication market that specializes in bridges for the highways and rail sectors. Based at Filtronic's facility in Sedgefield, U.K., Farrelly will work closely with the sales team, establishing the marketing strategy that will drive the next stage of market development, and helping to strengthen the Filtronic brand through marketing communications and digital growth.

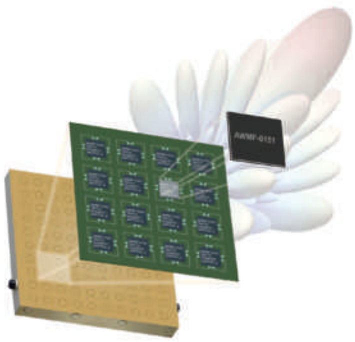
▲ *Bill Nicklin*

Richardson Electronics Ltd. announced the addition of two new field sales engineers in the western U.S. for the Power & Microwave Technologies Group. **Bill Nicklin** brings vast experience in RF and microwave design and sales to his new role at Richardson Electronics. He will be responsible for growing business in Northern California and the Pacific Northwest. With a degree in engineering geophysics and a decade of engineering experience, **Cambrey Cammon** moved into sales and management roles in the Colorado area. She successfully designed in RF and other components from companies including MACOM and Infineon.



▲ *Bob Chaidez*

RFMW announced the addition of a new field sales representative in the Midwest; **Bob Chaidez** will be supporting the growing Midwest territory and focusing on major accounts in the region. In this new position, Chaidez will focus on major accounts allowing RFMW's Midwest team to be more effective covering the large geographic territory.



Chaidez previously held a position at Tech-Tron Sales, a manufacturer's representative organization in Schaumburg, Ill., as a field sales representative. Chaidez has also worked at prestigious RF/microwave representative firms Cain-Forlaw and Beacon Electronics where his experience with the industry, customers and markets honed his sales acumen.

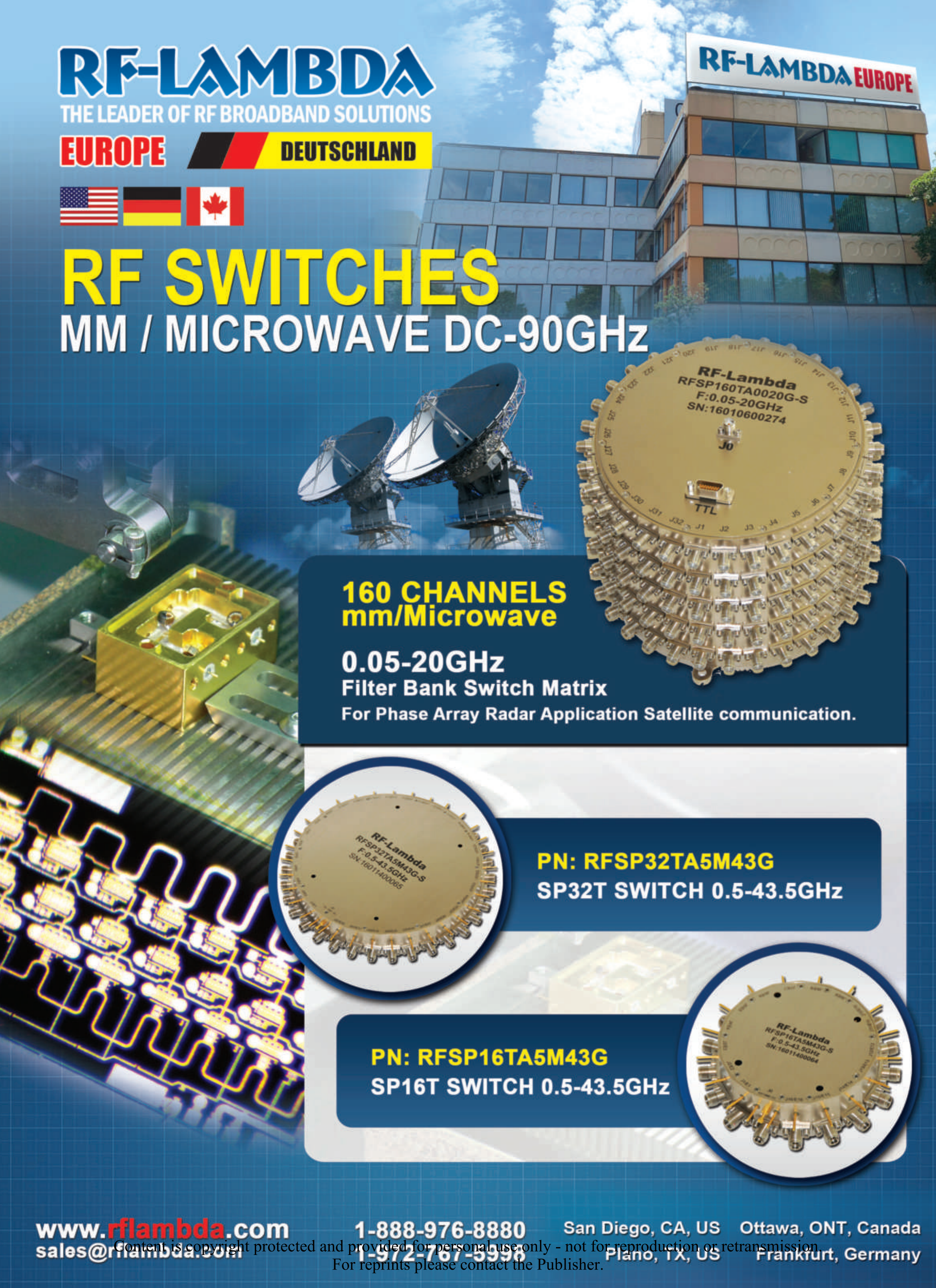
REP APPOINTMENTS

AR RF/Microwave Instrumentation has played a major role in the success of companies in China. AR provides total RF test solutions by offering customers RF test instrumentation, RF test systems, EMC test software and chambers. In addition to the complete array of products comes world class customer service and application support. From calibration and regular maintenance, to troubleshooting and repairs, you can depend on AR. Their local representative for China is **Yifeng Tech Co. Ltd.** Representing AR for Sales & Service is, General Manager/CEO Alvin Li, alvin_li@yifengtech.com.cn +86 10 6788 6078 / 6789 1690, www.yifengtech.com.cn.

Rogers Corp.'s Advanced Connectivity Solutions (ACS) business announced the introduction of a new distribution channel in North America with the addition of **Bonding Source,** a Krayden Company, to their sales and service team effective immediately. ACS provides global customers with market-leading high performance and high reliability RF material solutions. Bonding Source has built a reputation as a global source for microelectronics and RF/microwave materials servicing defense, satellite, aerospace and a range of electronics markets. Bonding Source differentiates itself by working with customers to forecast needs and stocks material to offer immediate delivery with no minimum quantities, excellent customer service and unparalleled technical support.

PLACES

NAI, a designer and manufacturer of custom interconnect solutions that deliver power and signals to monitor data, connect people and keep equipment operating, has announced the opening of a new customer support solutions center in Penang, Malaysia. This new solutions center has been created to provide quick-response support to NAI's customer base in the Southeast Asia region. This local presence allows for face-to-face communication between NAI engineers and customers. The new solutions center, which has also been referred to as a Center of Excellence, will be manned by application engineers and technicians and is expected to be operational in September 2020.



RF-LAMBDA
THE LEADER OF RF BROADBAND SOLUTIONS
EUROPE
DEUTSCHLAND
RF-LAMBDA EUROPE
RF SWITCHES
MM / MICROWAVE DC-90GHz
RF-Lambda
RFSP160TA0020G-S
F:0.05-20GHz
SN:16010600274
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
1-888-976-8880
San Diego, CA, US
Ottawa, ONT, Canada
Plano, TX, US
Frankfurt, Germany

Analyzing the VSWR Withstand Capability of a Balanced Amplifier

John Walker and James Custer
Integra Technologies, El Segundo, Calif.

Malcolm Edwards
Cadence, El Segundo, Calif.

It is shown both theoretically and by simulation that a balanced amplifier has a lower VSWR withstand capability than that of the transistors used in its construction, meaning the maximum VSWR before the transistor will fail or its reliability degraded. A revised VSWR withstand capability should be adopted for a balanced amplifier to prevent device failure.

High power amplifiers often require the combining of multiple transistors. This can be done using in-phase combining with Wilkinson or Gysel combiners, anti-phase combining (i.e., push-pull) with baluns or quadrature combining (i.e., balanced amplifiers) with quadrature or hybrid couplers (e.g., branch-line or Lange). The combining structure determines the amplifier's ability to withstand large VSWR mismatches, which affects the amplifier's ruggedness and reliability. Other methods may be used for power combining, in addition to the three noted above, such as serial combining[1] and traveling-wave combining,[2] but these are seldom, if ever, used when combining just two transistors.

In-phase combining provides the same VSWR withstand capability as for each individual transistor, disregarding losses through the combiner. Considering the fundamental properties of the scattering matrix of a lossless, reciprocal, three-port network, such as a balun, a push-pull amplifier also has the same VSWR withstand capability as the individual transistors. The situation for a balanced amplifier, however, is more complex and is the focus of this article.

IMPACT OF VSWR

A balanced amplifier consists of two identical amplifiers operated in-phase quadrature. A quadrature coupler or splitter creates a 90 degree phase difference between the signals applied to the two amplifiers. A second quadrature coupler at the output removes this phase differential, so the amplifier outputs combine in phase.[3] One of the advantages of a balanced amplifier is it provides excellent VSWR at the external terminals, even if the two internal amplifiers have poor terminal VSWRs.

This article examines the converse problem, namely determining the VSWR presented to the two internal amplifiers—hence transistors—when a mismatch is presented at the amplifier's external port. An analytical calculation is made of the VSWR presented to the active devices of a balanced amplifier, and the results are verified through simulation using Cadence® AWR Design Environment® software. In the presence of a mismatch at the amplifier output, one amplifier or transistor, sees an improved VSWR and the other is subjected to a larger mismatch. From *a priori* knowledge of the transistor's VSWR withstand capability, one can deter-

Portable Handheld Field Solutions
Expand your choice of 5G spectrum analysis capabilities
-Coax or Waveguide
24 to 40 GHz
With > 6GHz If Bandwith
M28H2ADC
M28H2ADC-K
26 GHz (24.25 to 27.5 GHz)
28 GHz (27.5 to 28.35 GHz)
38 GHz (37 to 38.6 GHz)
39 GHz (38.6 to 40 GHz)
Innovation in Millimeter Wave Solutions
www.omlinc.com
(408) 779-2698
OML

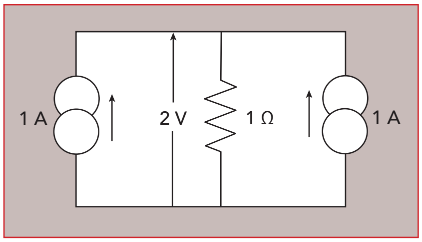


Fig. 1 Different physical and electronic loads seen by an amplifier.

mine the impact of impedance mismatch on the ruggedness and reliability of the balanced amplifier.

PREVIOUS WORK

Determining the VSWR presented to the two internal amplifiers when a mismatch is presented at the balanced amplifier's external port has been previously considered by both Cripps[4] and Raab.[5] Cripps' analysis remains unpublished while Raab used a combination of a Ruthroff transformer and a balun to create a quadrature hybrid, a concept probably unfamiliar to most microwave engineers. Raab's and Cripps's analyses, however, are in total agreement with the results presented here.

The problem was considered more recently by Jung et al.[6] However, their analysis calculates the value of the physical load that each internal amplifier sees, not the value of the electronic load; so their analysis cannot determine the VSWR withstand capability of a balanced amplifier. The significance is illustrated in ***Figure 1***. Each current generator sees a physical load of 1 Ω, but the voltage across the resistor is 2 V. Hence, each current generator sees an electronic load of 2 Ω, rather than 1 Ω. In the case of the balanced amplifier (see ***Figure 2***), it is essential to calculate the load seen by each amplifier while both amplifiers are ***simultaneously*** injecting current into the coupler, i.e., the electronic load.

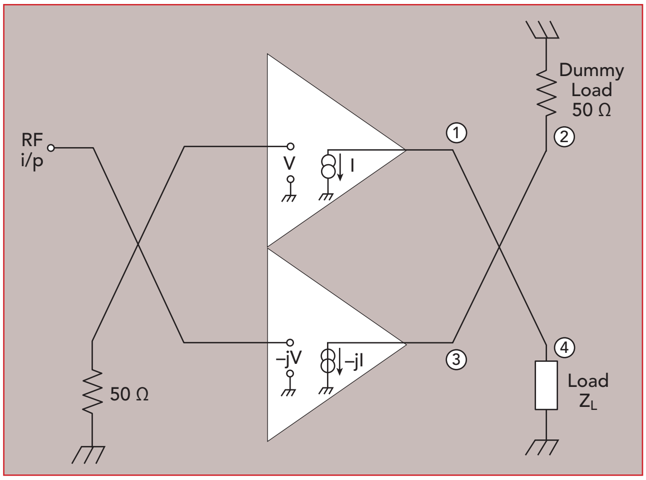


Fig. 2 Balanced amplifier.

MEASUREMENT OF VSWR WITHSTAND CAPABILITY

The traditional method of measuring VSWR withstand capability is to steadily increase the RF input power to the transistor in a test fixture until the RF output power reaches its full rated value. The load is then replaced with an attenuator terminated in a short circuit and preceded by an adjustable transmission line stretcher or suitable phase

UNMATCHED DYNAMIC RANGE.
UNMATCHED PERFORMANCE.

VDI's Mini VNAX modules are one-quarter the volume of standard modules making them well suited for probe station and antenna measurement applications.

BRIDGING THE THz GAP JUST GOT SMALLER.

VDI's VNA Extenders provide high performance frequency extension of vector network analyzers from 26GHz to 1.5THz. These modules combine high test port power with exceptional dynamic range and unmatched stability.

VDI's mini-modules are reduced in size, but yield the same industry leading performance as our original designs. The compact form factor and simplified power supply make them the recommended solution for most applications.

Mini-modules are currently available in standard waveguide bands for 26GHz to 500GHz with higher frequency bands under development.

Waveguide Band (GHz)	WR28 26-40	WR15 50-75	WR12 60-90	WR10 75-110	WR8 90-140	WR6.5 110-170	WR5.1 140-220	WR4.3 170-260	WR3.4 220-330	WR2.8 260-400	WR2.2 330-500	WR1.5 500-750	WR1.0 750-1,100
Dynamic Range (BW=10Hz, dB, typ)	120	120	120	120	120	120	120	115	115	100	110	100	65
Dynamic Range (BW=10Hz, dB, min)	110	110	110	110	110	110	110	110	105	80	100	80	45
Magnitude Stability (±dB)	0.15	0.15	0.15	0.15	0.15	0.25	0.25	0.3	0.3	0.5	0.5	0.4	0.5
Phase Stability (±deg)	2	2	2	2	2	4	4	4	6	6	6	4	6
Test Port Power (dBm)	13	13	13	18	6	13	6	-2	1	-10	-3	-25	-30

Virginia Diodes, Inc.
979 2nd St. SE, Suite 309
Charlottesville, VA 22902
434.297.3257

vadiodes.com

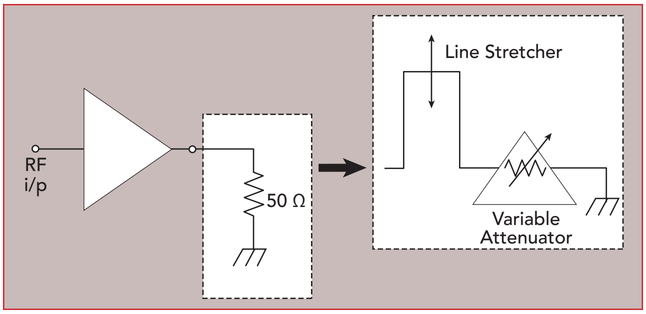


Fig. 3 Setup for measuring the VSWR withstand capability of an amplifier.

shifter (see ***Figure 3***). The line stretcher is adjusted to sweep the phase of the load through 360 degrees. The attenuation is then reduced in stages and the process repeated until the transistor fails. Strictly speaking, this method measures the VSWR withstand capability of the transistor in its particular test fixture, including any losses from the test fixture's output matching network. As the losses in the output network are normally minimized to maximize amplifier efficiency and output power, this method does actually determine the VSWR withstand capability of the transistor to a good approximation. The VSWR withstand capability is quoted with reference to a 50 Ω load and not the load impedance the transistor sees.

An alternative method of measuring VSWR withstand capability more suitable for a production environment is to insert at least a wavelength long slot line between the test fixture and the load, then insert a quarter-wave impedance transformer—commonly referred to as a slug—which can be slid along the length of the slot line.

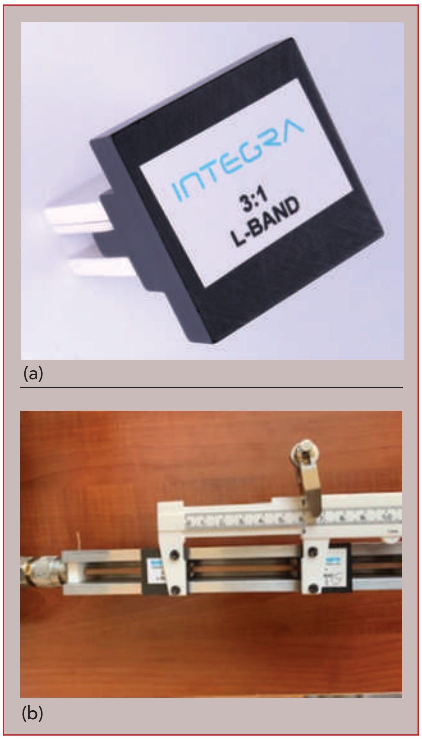


Fig. 4 3:1 VSWR slug (a) and 2:1 and 5:1 slugs cascaded λ/4 apart to present 10:1 VSWR (b).

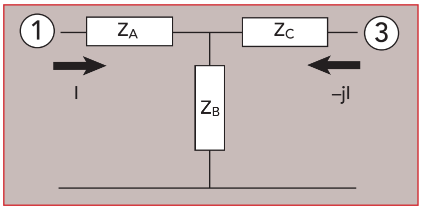


Fig. 5 Equivalent network seen by the two amplifiers.

Planar Monolithics Industries, Inc.

Gain & Loss Equalizers

PMI offers a wide range of RF and Microwave Gain & Loss Equalizer products that operate from DC up to 40 GHz. PMI offers many standard models with various options that are available at:
https://www.pmi-rf.com/categories/gain-equalizers

- Amplifiers - Solid State
- Attenuators - Variable/ Programmable
- Bi-Phase Modulators
- Couplers (Quadrature, 180, Directional)
- 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 (IMAs)
- IQ Vector Modulators
- Limiters - RF / Microwave
- Log Amps
- Miscellaneous Products
- Monopulse Comparators
- Multifunction Integrated Assemblies (IMAs)
- Phase Shifters & Bi-Phase Modulators
- Power Dividers/Combiners (Passive & Active)
- Pulse Modulators - SP1T
- 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
- Threshold Detectors
- USB Products

EQL-DC20-3-SFF
EQL-DC40-6-292FF
EQL-DC40-10-292FF

EQL-17D5G21D5G+4DB-292MF
EQL-17D5G21D5G+8DB-292MF
EQL-17D5G21D5G+10DB-292MF

EQL-17D6G21D6G-2DB-292MF
EQL-17D6G21D6G-4DB-292MF
EQL-17D6G21D6G-8DB-292MF

EQL-17D6G21D6G-10DB-292MF
EQL-26D5G40G-1D5DB-292MF

2-IN-1 - Dual Use Connectorized or Surface Mount

PMI Model No.	Frequency Range (GHz)	Maximum Input Power	Insertion Loss (dB)	Slope (dB)	VSWR	Size (Inches) Connectors
EQL-DC20-3-SFF https://www.pmi-rf.com/product-details/eql-dc20-3-sff	DC - 20	1 W CW	0.5	+3.0	2.0:1 Max 1.8:1 Typ	0.53" x 0.56" x 0.18" SMA (F) Removable
EQL-DC40-6-292FF https://www.pmi-rf.com/product-details/eql-dc40-6-292ff	DC - 40	1 W CW	2.5	+6.0	1.8:1 Max 1.6:1 Typ	0.53" x 0.56" x 0.18" 2.92mm (F) Removable
EQL-DC40-10-292FF https://www.pmi-rf.com/product-details/eql-dc40-10-292ff	DC - 40	1 W CW	2.0	+10.0	1.8:1 Max 1.6:1 Typ	0.53" x 0.56" x 0.18" 2.92mm (F) Removable
EQL-17D5G21D5G+4DB-292MF https://www.pmi-rf.com/product-details/eql-17d5g21d5g-4db-292mf	17.5 - 21.5	0.5 W CW	2.0	+4.0	2.0:1 Max	1.10" x 0.67" x 0.22" 2.92mm Male (J1), 2.92mm Female (J2) 2.92mm (M/F) Removable
EQL-17D5G21D5G+8DB-292MF https://www.pmi-rf.com/product-details/eql-17d5g21d5g-8db-292mf	17.5 - 21.5	0.5 W CW	2.0	+8.0	2.0:1 Max	1.10" x 0.67" x 0.22" 2.92mm Male (J1), 2.92mm Female (J2) 2.92mm (M/F) Removable
EQL-17D5G21D5G+10DB-292MF https://www.pmi-rf.com/product-details/eql-17d5g21d5g-10db-292mf	17.5 - 21.5	0.5 W CW	2.0	+10.0	2.0:1 Max	1.10" x 0.67" x 0.22" 2.92mm Male (J1), 2.92mm Female (J2) 2.92mm (M/F) Removable
EQL-17D6G21D6G-2DB-292MF https://www.pmi-rf.com/product-details/eql-17d6g21d6g-2db-292mf1	17.6 - 21.6	0.5 W CW	2.0	-2.0	2.0:1 Max	1.10" x 0.67" x 0.22" 2.92mm Male (J1), 2.92mm Female (J2) 2.92mm (M/F) Removable
EQL-17D6G21D6G-4DB-292MF https://www.pmi-rf.com/product-details/eql-17d6g21d6g-4db-292mf1	17.6 - 21.6	0.5 W CW	2.0	-4.0	2.0:1 Max	1.10" x 0.67" x 0.22" 2.92mm Male (J1), 2.92mm Female (J2) 2.92mm (M/F) Removable
EQL-17D6G21D6G-8DB-292MF https://www.pmi-rf.com/product-details/eql-17d6g21d6g-8db-292mf1	17.6 - 21.6	0.5 W CW	2.0	-8.0	2.0:1 Max	1.10" x 0.67" x 0.22" 2.92mm Male (J1), 2.92mm Female (J2) 2.92mm (M/F) Removable
EQL-17D6G21D6G-10DB-292MF https://www.pmi-rf.com/product-details/eql-17d6g21d6g-10db-292mf1	17.6 - 21.6	0.5 W CW	2.0	-10.0	2.0:1 Max	1.10" x 0.67" x 0.22" 2.92mm Male (J1), 2.92mm Female (J2) 2.92mm (M/F) Removable
EQL-26D5G40G-1D5DB-292MF https://www.pmi-rf.com/product-details/eql-26d5g40g-1d5db-292mf	26.5 - 40	0.5 W CW	1.5	-5.5	2.0:1 Max	1.10" x 0.67" x 0.22" 2.92mm Male (J1), 2.92mm Female (J2) 2.92mm (M/F) Removable

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

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

sales@pmi-rf.com • www.pmi-rf.com

ISO9001-2015 REGISTERED

The slug is created by inserting an appropriate length section of dielectric between the center and ground conductors (see ***Figure 4a***). The thickness and dielectric constant are chosen to give the required VSWR mismatch; for example, a slug with 2:1 mismatch has an impedance of 35 Ω.

For normal testing of power, efficiency and gain, the slug is not inserted and the small residual loss of the air filled slot line is calibrated out. The advantage of this measurement method is that no dismantling and reconstruction of the test bench is required, and VSWR withstand testing can be incorporated as a standard part of production testing. ***Figure 4b*** shows an Integra L-Band GaN transistor being tested for VSWR withstand with a 10:1 mismatch, created by cascading 2:1 and 5:1 slugs spaced a quarter wavelength apart.

These two techniques are not equivalent. In the first method, the mismatch presented to the transistor is constant at all frequencies. In the second, the same mismatch is presented at the fundamental and all odd harmonics, but a 50 Ω load is presented at the even harmonics. In most situations of practical interest, the two techniques give essentially the same result.

BALANCED AMPLIFIER VSWR WITHSTAND CAPABILITY

The scattering matrix (S-matrix) of an ideal quadrature coupler at band center is given by

$$(S) = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 1 & 0 & -j \\ 1 & 0 & -j & 0 \\ 0 & -j & 0 & 1 \\ -j & 0 & 1 & 0 \end{pmatrix} \quad (1)$$

where the port numbers of the hybrid coupler are defined in Figure 2. For a balanced amplifier, the two internal amplifiers see a two-port network formed by the directional

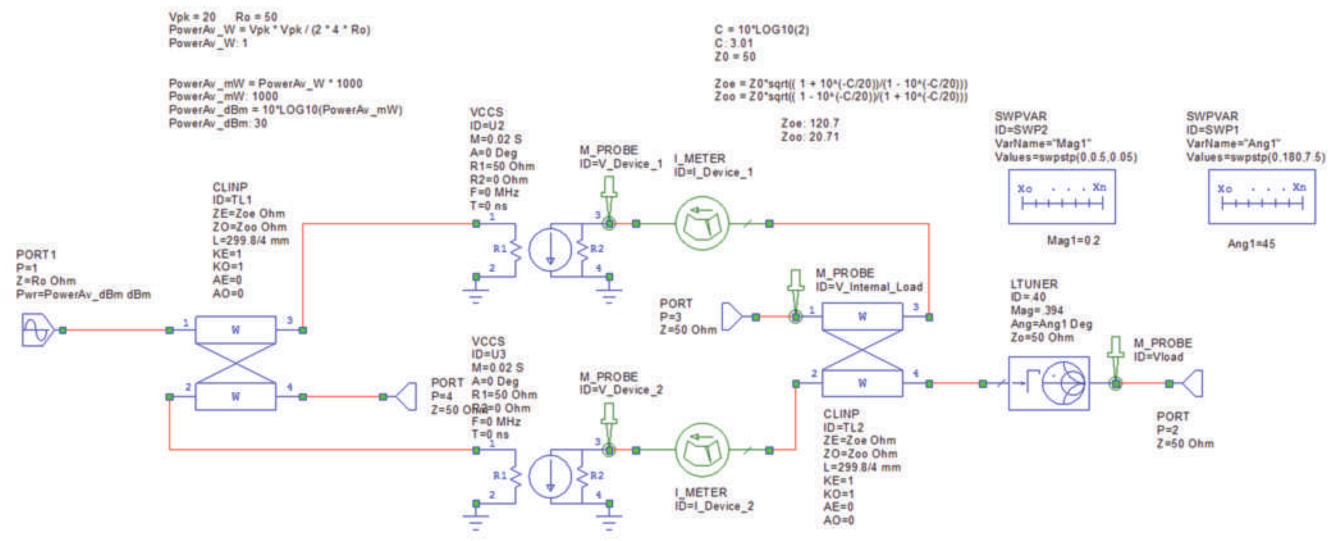


Fig. 6 Simulating an ideal balanced amplifier with swept load impedance.

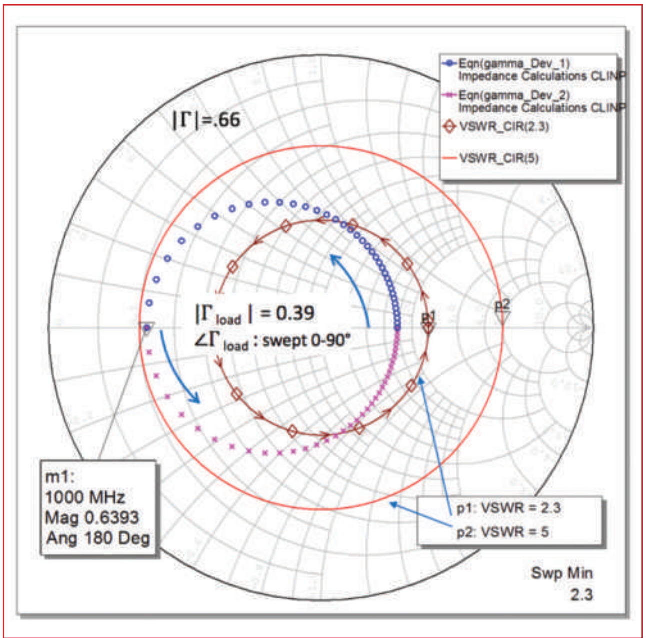


Fig. 7 Reflection coefficient seen by the two transistors with a fixed $|\Gamma_L| = 0.39$ and swept $\angle\Gamma L$ from 0 to 180 degrees.

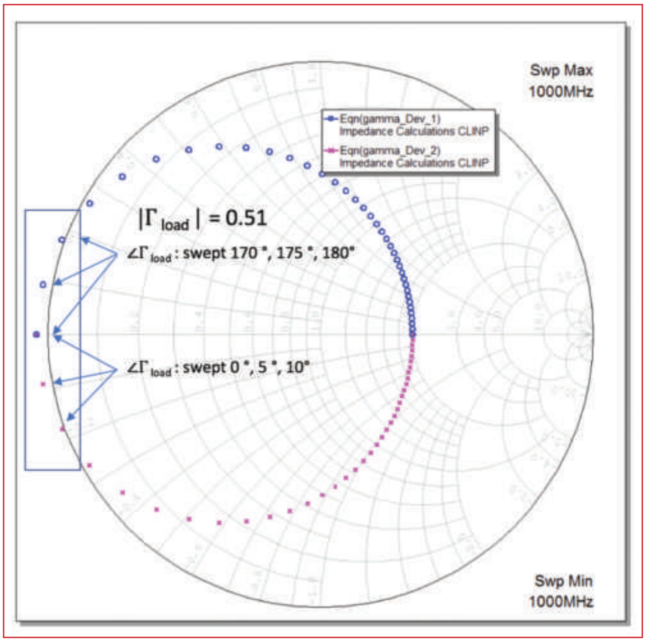


Fig. 8 Negative resistance at the transistor ports for $|\Gamma_L|$ >0.50 and swept $\angle\Gamma L$ <10 degrees or >170 degrees.

CPI Beverly Microwave Division

Delivering Radar Expertise

We are the world's largest manufacturer of receiver protectors. We offer a complete range of control components designed by the most experienced technical staff in the radar industry.

- UHF to Ka-Band
- Up to megawatts peak power and kilowatts average power
- Active, passive, and quasi-active designs
- Solid state, plasma, multipactor, and ferrite technologies
- Multi-function subassemblies including controlled attenuation, excess noise generation, low noise amplifiers, integrated passive functions, and BITE/fault monitoring

CPI

See why CPI Beverly Microwave Division is recognized as the go-to supplier for the world's premier radar manufacturers. Contact the us to upgrade your system today at BMDMarketing@cpii.com

150 Sohier Road • Beverly, MA USA 01915 • +1(978)922-6000 • www.cpii.com/BMD

coupler, with port 2 terminated in a 50 Ω load, providing a reflection coefficient of $\Gamma = 0$, and port 4 terminated in a variable load with a reflection coefficient of $\Gamma = \Gamma_L$. The two-port network has a scattering matrix given by

$$(S) = \frac{\Gamma_L}{2}\begin{pmatrix} -1 & -j \\ -j & 1 \end{pmatrix} \quad (2)$$

The S-matrix of equation (2) can be converted to a Z matrix, given by

$$(Z) = Z_0\begin{pmatrix} 1-\Gamma_L & -j\Gamma_L \\ -j\Gamma_L & 1+\Gamma_L \end{pmatrix} \quad (3)$$

At band center, the two amplifiers see the simple equivalent two-port network shown in ***Figure 5***, where the element values are given by

$$\begin{aligned} Z_A &= Z_0\left(1-\Gamma_L + j\Gamma_L\right) \\ Z_B &= -jZ_0\Gamma_L \\ Z_C &= Z_0\left(1+\Gamma_L + j\Gamma_L\right) \end{aligned} \quad (4)$$

To this point, no assumption is made about the amplitude or phase relationship of the signals applied to ports 1 and 3 in Figure 5. If the amplifiers are assumed ideal and consist of just a current generator, as shown in Figure 2, the electronic load seen by the two transistors is given by

$$Z_{electronic\ load} = Z_0\left(1 \pm 2\Gamma_L\right) \quad (5)$$

which, when expressed as a reflection coefficient, is given by

$$\Gamma_{electronic} = \frac{\pm\Gamma_L}{1 \pm \Gamma_L} \quad (6)$$

Consequently, while one transistor sees an improved VSWR, the other sees a worse VSWR.

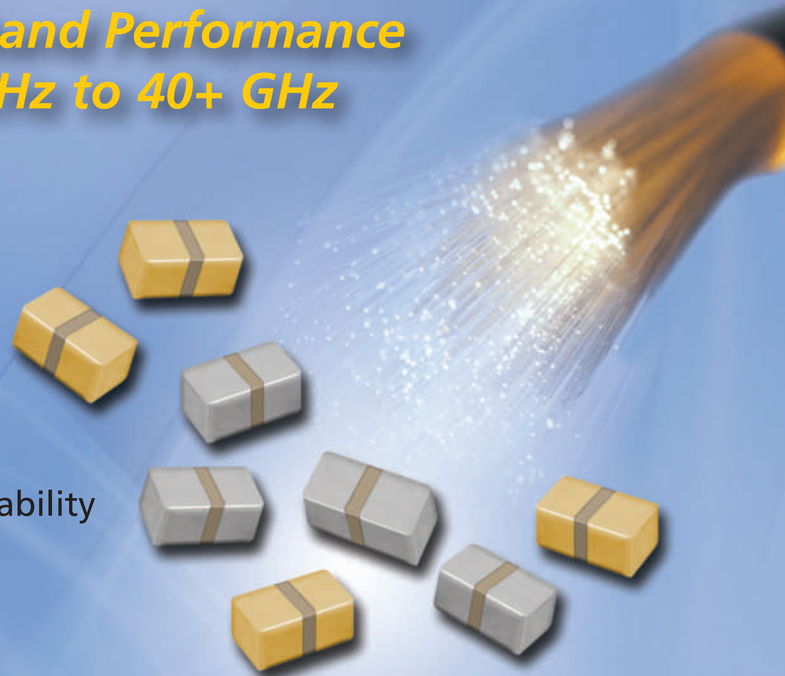
To demonstrate the impact of the electronic load on amplifier ruggedness and reliability, consider a balanced amplifier with each transistor having a VSWR withstand capability of 5:1, i.e., $|\Gamma_{electronic}| = 0.66$. From equation 6, the maximum VSWR withstand capability of the balanced amplifier at the load port is only 2.3:1, i.e., $|\Gamma_L| = 0.39$.

These results are verified using circuit simulation with an ideal hybrid coupler model and voltage-controlled current source models to represent the balanced amplifier in a virtual test setup with a variable load impedance, typically used in load-pull simulations. ***Figure 6*** shows the simulation schematic in the AWR® Microwave Office® circuit simulator. ***Figure 7*** shows the reflection coefficient seen by the two transistors. The magnitude of the reflection coefficient at the load is fixed at a gamma equivalent to a 2.3:1 VSWR, while the phase is varied from 0 to 180 degrees in 7.5 degree increments. The simulation agrees with the theory predicted by equation 6.

With a mismatch, one of the transistors will experience a higher mismatch than seen at the output to the balanced amplifier, potentially exceeding the transistor's VSWR withstand rating for maximum power output. From equation 5, if the external mismatch exceeds 3:1 (i.e., $|\Gamma_L| = 0.5$), one of the transistors may see a negative resistance depending on the phase of Γ_L (see ***Figure 8***). While a mathematically correct deduction, this will not arise in prac-

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:

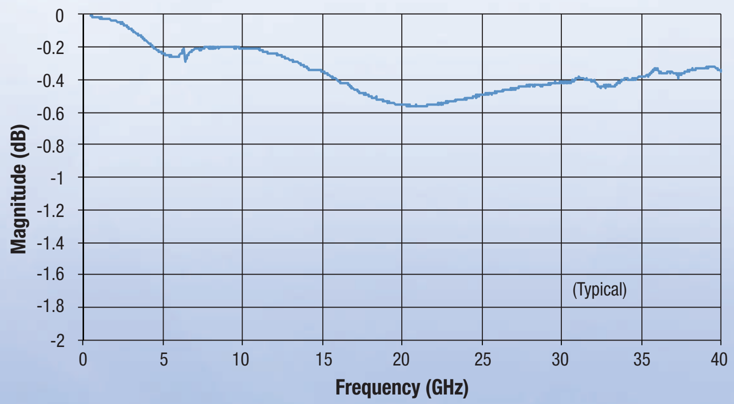
- EIA 0402 Case Size
- Capacitance: 100 nF
- Operating Frequency: 16 KHz to 40+ GHz
- Insertion Loss: <0.6 dB typ.
- Orientation Insensitive
- One Piece Construction
- Voltage Rating: 16 WVDC
- Gold Complaint Terminations
- RoHS Compliant

Applications:

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

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

560L Insertion Loss (S21)



THE ENGINEERS' CHOICE®
ISO 9001 REGISTERED COMPANY

AMERICAN TECHNICAL CERAMICS
AN AVX GROUP COMPANY

RoHS Compliant

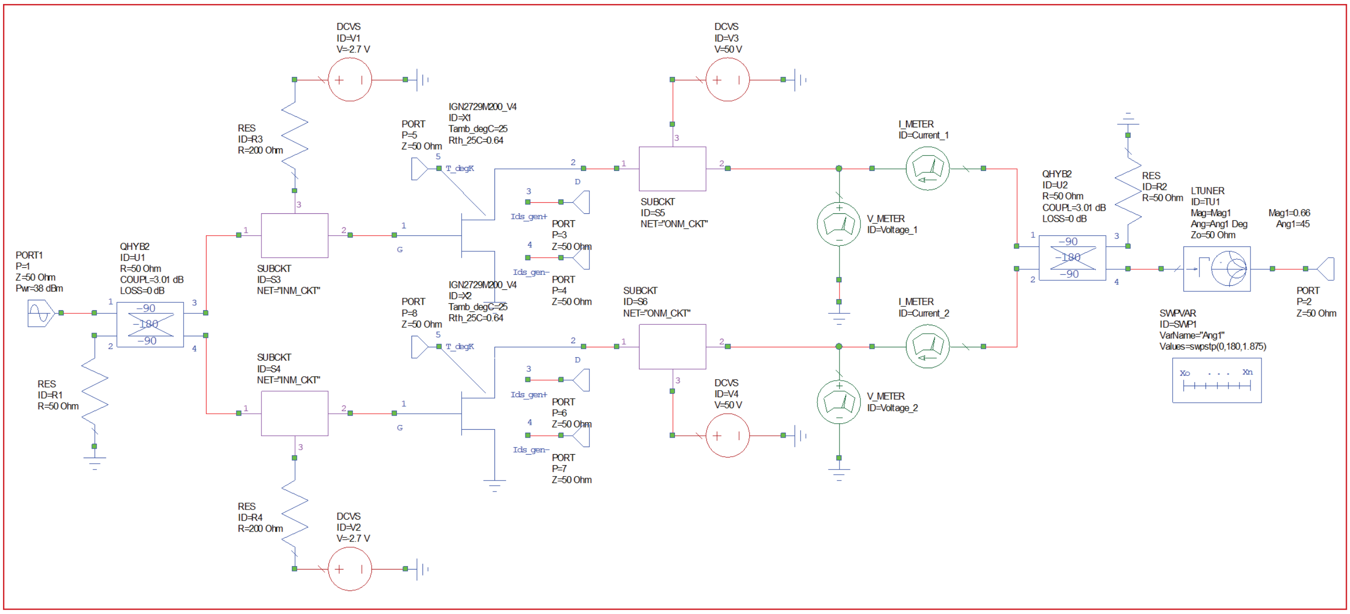


Fig. 9 Simulating a balanced amplifier using the IGN2729M200 devices.

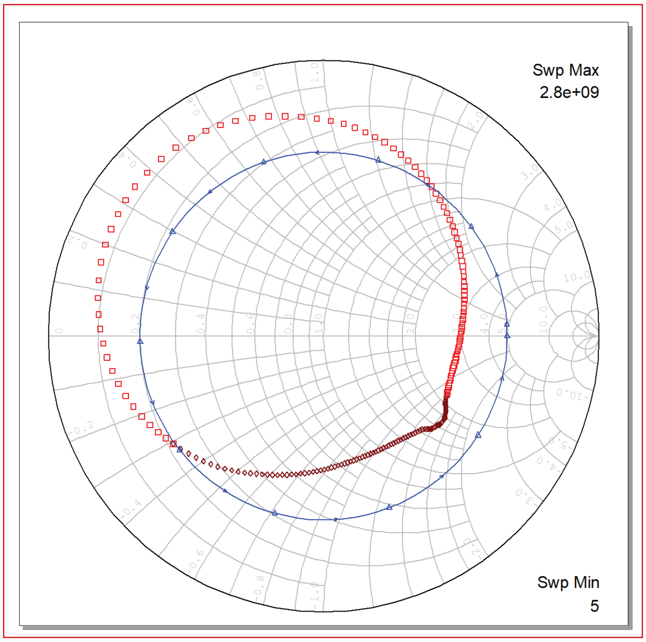


Fig. 10 VSWR circle and loads seen by each side of the balanced amplifier under a 5:1 output mismatch, as the phase of the external mismatch is rotated through 180 degrees.

tice unless the transistor can survive an infinite VSWR mismatch, as the transistor will already have failed at a lower value of external VSWR mismatch. However, one of the transistors may see a negative resistance under small-signal conditions in the presence of an external mismatch, which may cause instability.

REALISTIC TRANSISTOR MODEL

The previous analysis uses a simple model for the transistor and amplifier, resulting in a simple expression to illustrate the problem. The analysis is repeated using real amplifier and transistor models. The IGN2729M200 is a 2.7 to 2.9 GHz transistor capable of delivering 200 W output power over this frequency range with a 100 µs pulse length and 10 percent duty cycle. Integra's full nonlinear electrothermal model for this device was used and embedded within a model for the input and output matching networks of the two amplifiers. The quadrature coupler is assumed to be an ideal lossless device with a center frequency of 2.8 GHz. ***Figure 9*** shows the Microwave Office circuit schematic, which may be compared with the simplified model shown in Figure 6.

Figure 10 shows the reflection coefficient seen by the two internal amplifiers as the phase is swept from 0 to 180 degrees and a 5:1 VSWR mismatch is applied to the balanced amplifier's output port. As before, one amplifier or transistor sees an improved mismatch while the other sees a considerably worse mismatch—in this case as high as 10:1 at some phases of the external mismatch.

CONCLUSION

In this article, the VSWR withstand capability of a balanced amplifier was calculated and verified through simulation, showing a balanced amplifier has a lower VSWR withstand capability than the individual transistors used in its construction. This should be accounted for in the design of a balanced amplifier to prevent device failure.■

References

1. K.J. Russell, "Microwave Power Combining Techniques," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 27, No. 5, May 1979, pp. 472–478.
2. A.G. Bert and D. Kaminsky, "The Travelling-Wave Divider/Combiner," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 28, No. 12, December 1980, pp. 1468–1473.
3. K. Kurokawa, "Design Theory of Balanced Transistor Amplifiers," *Bell System Technical Journal*, Vol. 44, No. 8, October 1965, pp. 1675–1698.
4. S.C. Cripps, private communication.
5. J.L.B. Walker, D.P. Myer and F. H. Raab (Editors), "Classic Works in RF Engineering: Combiners, Couplers, Transformers and Magnetic Materials," Artech House, 2006.
6. I. Jung, M. Seo, J. Jeon, H. Kim, M. Cho, H. Lee and Y. Yang, "Analysis on the Balanced Class-E Power Amplifier for the Load Mismatch Condition," *Semantic Scholar*, 2012, Web. https://www.semanticscholar.org/paper/Analysis-on-the-Balanced-ClassE-Power-Amplifier-for-Jung-Seo/179657496159b462bd2e6dcd7b2b2cf51de5b99c.

INVITED PAPER

Demystifying Popular Waveguide Antennas for mmWave Applications

Peter McNeil
Pasternack, Irvine, Calif.

In the past, the vast mmWave spectrum was used sparingly, compared to today's onslaught of new mmWave applications: the recent WiGig standard (802.11ad) in the 60 GHz ISM band, the many new 5G mmWave frequency allocations, Ka-Band and beyond space transponders for higher satellite capacity and many new radar applications, including 77 to 79 GHz automotive radar. Although many of these use cases use planar antenna structures, waveguide antennas are critical for system characterization, and waveguide antennas are used in radar, point-to-point communications and many more applications. While a library of literature is dedicated to the theory behind these antennas, this article provides a general discussion, intended to be useful when considering the range options for various applications.

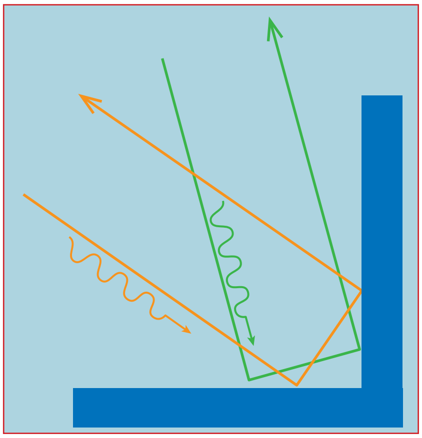


Fig. 1 Corner reflectors scatter a signal back toward the source.

CORNER REFLECTORS

Corner reflectors function on the principle that incident electromagnetic (EM) waves reflect off conductive sheets in a direction parallel to the incident beam and with the same polarization as the incident

TABLE 1
APPROXIMATE RCS OF SIMPLE OBJECTS[2]

Object	Orientation	RCS	Symbol
Sphere	Any	$\pi\alpha^2$	a = Radius
Cone	Axial	$\frac{\lambda^2}{16\pi}\tan^4\theta$	θ = Cone Half Angle
Paraboloid	Axial	$\pi\alpha^2$	a = Apex Radius of Curvature
Cylinder	Normal to Axis	$\frac{2\pi L^2\alpha}{\lambda}$	L = Length a = Radius λ = Wavelength
Dihedral	Maximum Direction	$\frac{8\pi\alpha^2 b^2}{\lambda^2}$	a, b = Length of Side λ = Wavelength
Trihedral	Maximum Direction	$\frac{4\pi\alpha^4}{3\lambda^2}$	a = Length of Edge λ = Wavelength
Square Trihedral	Maximum Direction	$\frac{12\pi\alpha^4}{\lambda^2}$	a = Length of Edge λ = Wavelength


5G

TABLE 2
WAVEGUIDE ANTENNA PARAMETERS[3]

Horn Antenna Type Orientation		Gain (dBi)	Horizontal/Vertical Beamwidth (°)
	Pyramidal	10 to 25	9 to 55
	Conical	10 to 25	9 to 55
	Sectoral	0 to 6	45 to 180
	Horn Lens	32 to 40	1 to 4
	Scalar Feed	10 to 17	25 to 55
	Probe Waveguide	~6	60 to 115
	Omnidirectional	0 to 7.5	30 to 360

wave. This, in effect, reduces the cost of a radar or communications system, as signal transmission does not require a power supply or any additional components often found in a transmission chain (e.g., mixer, LO, amplifiers, filters, converters).

The corner reflecting antenna can either be in a dihedral or trihedral configuration. In the dihedral topology (see ***Figure 1***), two highly reflective plates are perpendicular to one another and scatter a signal back toward the source, increasing the radar cross section (RCS). Following the same logic, a trihedral antenna structure uses three reflective surfaces joined at right angles. In this case, a reflected wave can theoretically arrive from any direction and still be returned directly back toward its source.

This is particularly useful in point-to-point marine navigation, where ships can accurately determine their relative positions from an interrogation via precisely placed reflectors, known as monostatic scattering.[1] The backscatter cross section is straightforward to determine due to the simple geometries of the corner reflectors. In this way, the RCS remains high over a wide range of incoming wave angles. ***Table 1*** shows the approximate RCS of some objects in the resonance region, where the dimensions of the object are large compared with the wavelength of the signal. In these cases, the RCS can be approximated by the product of the effective gain of the object and its physical area.[2] For example, the RCS for a triangle reflector at 30 GHz (λ = 10 mm) and a corner length of 6 in. is about 22 m^2.

APERTURE ANTENNAS

Aperture antennas are particularly useful in aerospace applications, as they can be flush with the skin of an aircraft or spacecraft. These antennas provide gradual transitions from the radio and transmission lines or waveguide to free space, with impedance matching between the aperture and the waveguide, as well as between the aperture and free space. ***Table 2*** shows the gain and beamwidth of some common waveguide aperture antennas.

The horn antenna is a popular choice for high gain and directivity for radar and mmWave applications. It has a large aperture tapered at one end with a waveguide flange to connect to the antenna feed. Variants of the horn antenna include pyramidal, sectoral, conical, scalar (exponential), corrugated, gain and feed. The horn acts as a guiding system from the waveguide mode to free space, where the axial length and aperture can be adjusted for optimal gain and directivity.

The EM field is determined by solving Maxwell's equations to satisfy the boundary conditions at the conducting walls of the horn for the fundamental and higher order modes. The horn should be considered separately, versus apply-

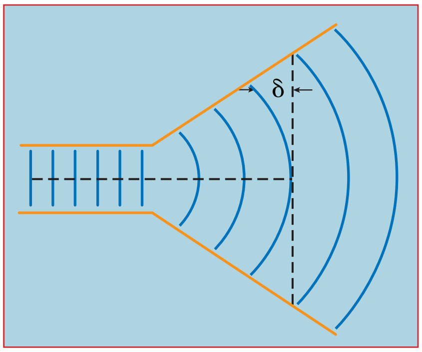
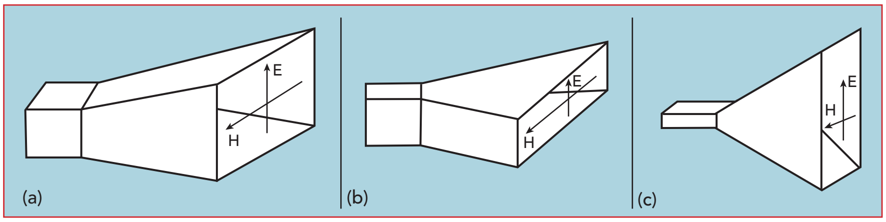


Fig. 2 Radiation from a horn antenna.[4]

ing waveguide aperture antenna theory, as phase errors occur from the difference between the length along the center of the feed versus the length to the horn edge (see ***Figure 2***). The field lines shift from the dominant mode planar wave to a curved wave front, where the path difference between the curved wave front and the ideal plane wave creates a phase difference or error that must be addressed mathematically.[4] Approximations for radiation patterns, given antenna dimensions, have been developed for various horn antennas; using them, the antenna gain can be closely matched to calculations, assuming precise manufacturing.



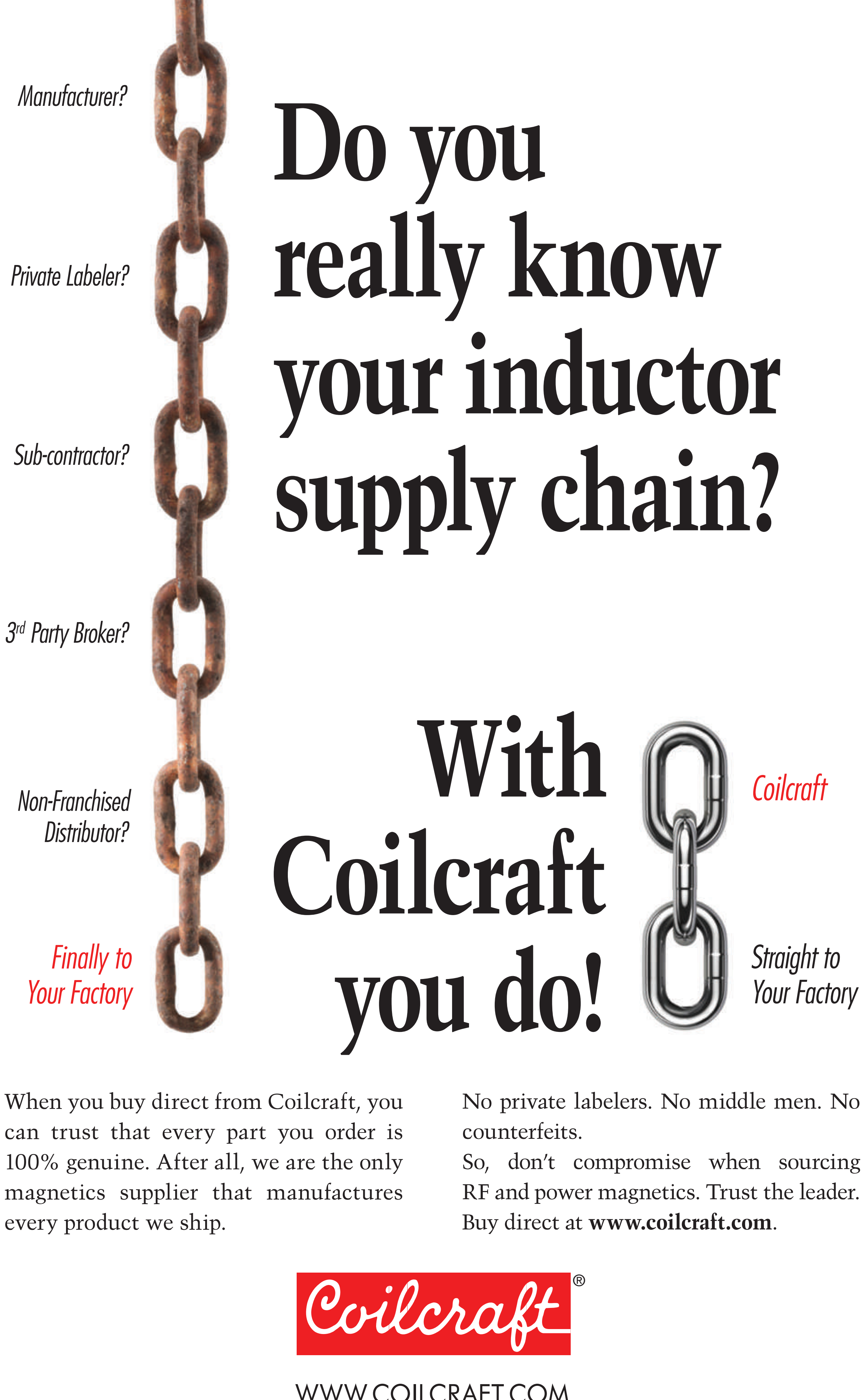
▲ Fig. 3 **Rectangular horn antennas: pyramidal (a), H-plane sectoral (b) and E-plane sectoral (c).**

In the waveguide-to-horn transition, the plane EM wave front (TE_{10} or TE_{01} for rectangular waveguide) shifts to a curved wave. This wave front—cylindrical for a sectoral horn and spherical for a conical horn—emanates from the horn, and the flaring imparts directionality: a wider flare provides a wider beamwidth and lower gain, compared to a smaller flare with higher gain due to the smaller beamwidth and more focused beam.

For a sectoral horn (see ***Figure 3***), a fan-shaped beam is generated in the plane containing the flare. Generally, rectangular horn antennas such as pyramidal and rectangular have the downside of significant sidelobes, and the abrupt transition from waveguide to flare predominantly contributes to the overall reflection coefficient. This leads to using nonlinear flaring configurations (i.e., a soft horn), such as corrugations, dielectric wall linears or strips laid out transverse to the direction of propagation of the EM field.

Conical Gain Horns

The conical gain horn antenna generally has a much narrower bandwidth compared with its rectangular counterparts; however, because of its axial symmetry, the conical horn can handle any polarization of the dominant TE_{11} mode and is particularly useful for applications that require circular polarization (e.g., space communication). Like the rectangular horn antenna, the circular horn uses a flare to achieve a smooth impedance transformation. Typical gains are between 10 and 25 dBi, with horizontal and vertical half-power beamwidths between 10 and 60 degrees and narrow bandwidths —1.3:1 maximum, compared to 2:1 for rectangular horns.


Manufacturer?
Private Labeler?
Sub-contractor?
3rd Party Broker?
Non-Franchised Distributor?
Finally to Your Factory
Do you really know your inductor supply chain?
With Coilcraft you do!
Coilcraft
Straight to Your Factory
When you buy direct from Coilcraft, you can trust that every part you order is 100% genuine. After all, we are the only magnetics supplier that manufactures every product we ship.
No private labelers. No middle men. No counterfeits.
So, don't compromise when sourcing RF and power magnetics. Trust the leader. Buy direct at www.coilcraft.com.
Coilcraft®
WWW.COILCRAFT.COM

Scalar Feed Horns

Aside from more complex manufacturing processes and higher associated costs, scalar feed horn antennas offer high power handling capability and high directivity with low loss over a wide bandwidth. They are ideal as antenna feeds for radar and communications systems, such as radio telescopes that use parabolic dish reflectors, as they are able to provide relatively even illumination of the surface while minimizing signal leakage past the reflector, maximizing overall antenna efficiency. The radiation pattern of the feed antenna must be customized to the specific shape of the parabolic reflector.

For antenna patterns in the far field, the desired polarization is known as co-polarization while the orthogonal component is known as cross-polarization.[4] Cross-polarization is particularly relevant for parabolic dish reflector feed horn antennas because the feed aperture is typically located at, or slightly in front of, the reflector focal point, which is the theoretical point where all incoming rays parallel to the paraboloid axis are reflected through the focus (see ***Figure 4***). The wide angle scalar feed horn in the focal plane of parabolic dish reflector must exhibit a uniform radiation pattern in the far field to minimize cross-polarization and maximize overall antenna efficiency.

Scalar feed horns take advantage of a hybrid mode of propagation to achieve high axial beam symmetry, low sidelobes and low cross-polarization. The hybrid mode differs from the TE or TM modes of propagation within a waveguide, as neither the electric nor magnetic fields is purely transverse to the direction of propagation. In the hybrid mode, or balanced hybrid, condition, symmetric E- and H-plane patterns are generated where the TE and TM components are matched in a singular hybrid mode and propagate with a common velocity. In this way, the paraboloid receives the complete field pattern from the feed with uniform fields across the aperture of the reflector.[5] Linear E-fields cannot be produced by a radiation pattern purely TE or TM mode; corrugations in the horn modify both the electric and magnetic fields to satisfy the hybrid mode condition.

Horn Lenses

Typically mounted at the aperture, dielectric lenses modify the radiation

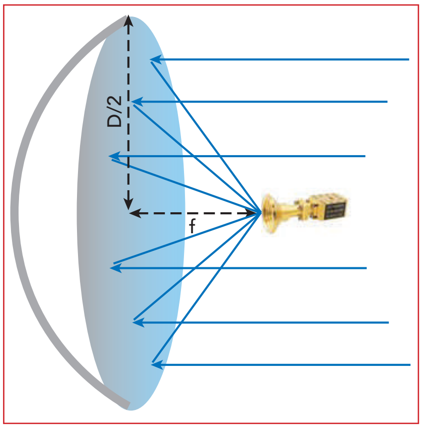
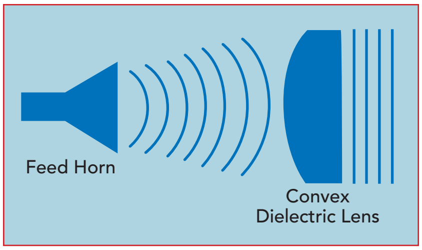
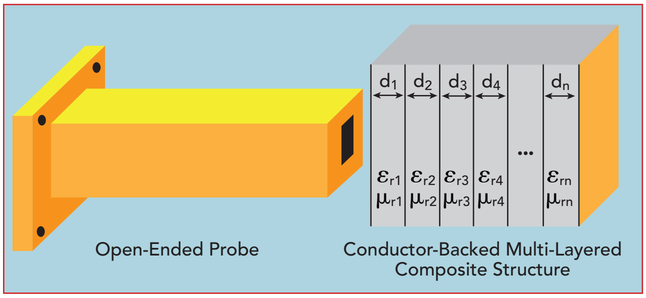


Fig. 4 Wide angle scalar feed horn in the focal plane of a parabolic dish reflector.



▲ Fig. 5 A convex dielectric lens alters the spherical or cylindrical wave from the feed horn aperture to form a planar wave.



▲ Fig. 6 Open-ended probe radiates EM energy into the composite substrate, used for non-destructive testing.

performance, often correcting the phase over a wide bandwidth or limited axial length. They also represent cost-effective alternatives to soft horns and corrugated horns, as lenses are much simpler to manufacture and mount onto the waveguide cap. The concept of focusing EM waves stems from the interference and diffraction light patterns of the Fresnel lens.

In general, convex dielectric lenses collimate incident divergent energy to focus a spherical or cylindrical wave front to a planar wave front, essentially controlling the taper of the field distribution, with the additional ability to shape the amplitude of the output EM radiation (see ***Figure 5***). Typically, low permittivity and low loss tangent dielectrics such as Teflon, polyethylene, polypropylene, polystyrene and quartz are used to reduce the thickness and weight. Variants of the horn lens include constructing the horn solely of dielectric material. In this case, the phase errors at the aperture are higher than with a metallic horn, due to the lower propagation velocity, which ultimately reduces the achievable gain of these antenna structures.[6] The typical gains of horn lens antennas fall between 30 and 40 dBi, with horizontal and vertical half-power beamwidths between 1 and 4 degrees and narrow bandwidths of approximately 1.1:1.

WAVEGUIDE PROBES

Waveguide probes are ideal for near-field measurements such as non-destructive testing and evaluation. The relatively straightforward construction involves an open-ended waveguide with a finite flange and a signal source sends EM energy down the waveguide to the device under test (DUT). As shown in ***Figure 6***, the EM energy propagates from the horn to penetrate the object in front of the open-ended waveguide. Understanding the dielectric properties of the DUT, the test can detect variations such as voids and cracks.

While this method can analyze materials in the field without disassembly (e.g., aircraft fuselages and radomes), it is not as accurate as measurements made with transmission lines. The waveguide aperture must be flush against the planar (or locally planar) dielectric substrate. Full-wave EM models are often generated to determine the reflection coefficient at the aperture of the waveguide, where it radiates into the dielectric structure. The accuracy of the technique is degraded with thin, low permittivity and low loss tangent materials; in such cases, alternative measurement methods using a probe station or test fixturing may yield better results.

OMNIDIRECTIONAL ANTENNAS

An omnidirectional radiation pattern can be generated with a waveguide antenna. This is often accomplished with the classical feed horn configuration propagating an EM wave in the TM_{01} or TE_{01} mode toward a metallic conical reflector a predetermined distance from the conical waveguide aperture (see ***Figure 7***). The conical reflector radiates the energy horizontally 360 degrees around the axis of the reflector, creating an omnidirectional pattern. The parabolic shape of the reflecting surface, in turn, creates a phase correction for the reflected spherical wave.[7] This structure is often placed within a dielectric holder made of a low loss tangent material, to maintain the distance between the waveguide and the reflector.

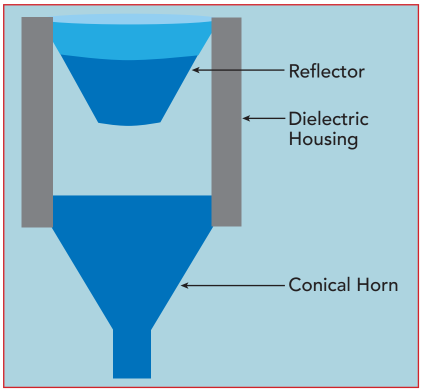


Fig. 7 Omnidirectional waveguide antenna.

SUMMARY

The combination of high power handling capability, directionality and mmWave coverage makes waveguide antenna structures pertinent for contemporary RF and mmWave systems, particularly with increased use of the mmWave spectrum. Understanding the basic performance of waveguide antennas can be useful when choosing an antenna for a mmWave system or test setup.■

References

1. A. Macikunas, S. Haykin and T. Greenlay, *Trihedral Radar Reflector*, 1984, US4843396A.
2. W. Chen, *The Electrical Engineering Handbook*, Elsevier, 2004.
3. R. Poisel, *Antenna Systems and Electronic Warfare Applications*, Artech House, 2012.
4. J. Volakis, *Antenna Engineering Handbook*, McGraw-Hill, Fourth Edition, 2007.
5. J. De Miguel-Hernández and R. J. Hoyland, "Fundamentals of Horn Antennas with Low Cross-Polarization Levels for Radioastronomy and Satellite Communications," *Journal of Instrumentation*, Vol. 14, No. 08, August 2019.
6. J. Thornton and K. C. Huang, *Modern Lens Antennas for Communications Engineering*, John Wiley & Sons, 2013.
7. G. Dienes, *Broadband Omnidirectional Microwave Antenna*, 1995, EP0678930A2.

INVITED PAPER

Engineering SOI Substrates for RF to mmWave Front-Ends

F. Allibert, L. Andia, Y. Morandini and C. Veytizou
Soitec, Bernin, France

M. Rack, L. Nyssens and J. P. Raskin
ICTEAM, Université Catholique de Louvain, Louvain-la-Neuve, Belgium

E. Augendre
CEA-LETI and Université Alpes Grenoble, Grenoble, France

5G and Wi-Fi 6(E) are creating new user experiences that require unprecedented network capacity with on-demand data throughput at record low latencies. To address these requirements, spectral resources from 100s of MHz to mmWave frequencies have been assigned to these standards. Gbps data rates are offered at these bands using record high waveform complexity, tightening RFIC linearity specifications to minimize signal distortion.

Over the last two decades, silicon on insulator (SOI) has proven to be the semiconductor solution of choice for highly linear, power efficient, integrated wireless systems. At the same time, the world's near to endless CMOS capacity and the demonstrated large-scale manufacturability of RF-SOI substrates have enabled cost effective solutions for 4G/LTE and Wi-Fi. Today, 5G and Wi-Fi 6(E) are benefiting from this demonstrated capability. This article reviews the continuous innovation of SOI engineered substrates to address the challenges of today's and future wireless systems.

HR-SOI TO TRAP-RICH SOI

Compared to bulk silicon technology, SOI's key advantages for RF applications have led to its general adoption in smartphone front-end modules over the past decade, spearheaded by RF switches. SOI wafers are composed of a thin silicon layer, usually 50 to 150 nm where the active devices are built, fully isolated from the underlying or "handle" wafer by a buried oxide (BOX) layer.

This configuration has major benefits. First, the shallow trench isolation reaches the BOX and effectively eliminates any conduction path between devices. This, in turn, enables transistor stacking to a level unsustainable using junction isolation. It also drastically improves the isolation between circuit blocks. The second benefit is the ability to engineer the handle wafer specifically for communication applications without degrading the quality of the active device layer, leading to high resistivity (HR) silicon being implemented as the handle wafer material. Decreasing the concentration of free carriers in the handle wafer reduces the attenuation or insertion loss (IL) of the propagated signal, resulting in better power transmission efficiency. It also reduces the power of the parasitic signals generated at the harmonic frequencies of the carrier signal, i.e., harmonic distortion (HD) or, when multiple signals are involved, intermodulation distortion (IMD).


ANALOG DEVICES
AHEAD OF WHAT'S POSSIBLE™
Power for your world.
Simplify your designs by leveraging ADI's highly integrated power solutions.
Integrated Solutions
Local Design Support
Easy to Use Tools
Find your competitive advantage at analog.com/power

TABLE 1

300 MM RF-SOI SUBSTRATE SPECIFICATIONS

	HR-SOI	RFeSI	RFeSI_T Low Linearity Drift vs. Temperature	Trap Rich RF-SOI >10 GHz
Substrate Type	High Resistivity 1-3 kΩ·cm	High Resistivity 1-10 kΩ·cm	Low Resistivity p-type	High Resistivity 1-10 kΩ·cm
Trap-Rich	N/A	Thin to Thick	Ultra-Thick	Ultra-Thin to Thick
BOX Thickness (nm)	100 to 1000	200 to 400	200	30 to 200
Top Si Thickness (nm)	75 to 145	75 to 145	75 to 145	50 to 75
Top Si Thickness Uniformity (nm)	±3.5	±3.5	±3.5	±3.5
2nd Harmonic Power (dBm)	<–50	–70 to –90	–70 to –120	–60 to –90

Though the HR handle is highly beneficial, the HR-SOI wafer has an inherent capacitor-like configuration, which results in the possible creation of a low resistivity, free carrier accumulation or inversion layer underneath the BOX, dubbed the parasitic surface conduction (PSC) layer.[1] This issue can be circumvented with an engineered layer between the BOX and HR handle containing a high density of electrically active traps.[2,3] Three game-changing effects of this trap-rich (TR) layer are the Fermi level pinning induced by the traps, the trapping of free carriers from the base wafer and the reduction of mobility. A higher level of signal fidelity can be achieved: the isolation is improved because the conductive coupling below the BOX is suppressed, leaving only capacitive coupling. The fluctuation of carrier concentration below the BOX is suppressed, as the Fermi level is pinned close to the middle of the semiconductor's gap, linearizing the handle's resistance and capacitance and drastically reducing HD. Finally, the constant HR further reduces IL.

The following section discusses Soitec's TR SOI family of substrates and how the RF performance compares to HR-SOI for different wireless applications (see ***Table 1***). The measurements shown throughout the article, unless otherwise stated, are performed on 2.1 mm long coplanar waveguide (CPW) at a fundamental frequency of 900 MHz. The DC bias refers to the bias applied between the central line and ground lines; the latter connected to the substrate backside. The second harmonic power levels are referenced to a fundamental frequency output power of 15 dBm at a default DC bias of 0 V.

RF-SOI SUBSTRATES FOR RF FRONT-ENDS

Depending on the intended function in the RF front-end (RFFE), the diverse RF circuits impose different requirements on the RF-SOI substrate, i.e., for large signal (linearity, power handling) or small signal and immunity to interferers (crosstalk, digital noise).[4–6] Given the increasing complexity of the RFFE, high density integration of digital logic, memory and RF functions must also be carefully considered. The final system application—such as infrastructure or mobile user equipment (UE)—will also dictate specifications including ruggedness and robustness.

Large-signal switching, shaping and amplification can introduce signal distortion because of the inherent nonlinear nature of active RF circuits. Soitec's RFeSI™ substrates help minimize distortion by reducing parasitics, as previously explained. ***Figure 1*** shows the harmonic and intermodulation products generated on three RFeSI TR SOI substrates with guaranteed second harmonic power below -100 dBm (RFeSI100), -90 dBm (RFeSI90)

and -80 dBm (RFeSI80). The IMD performance is measured with two 20 dBm tones at 900 and 955 MHz.[7]

The complexity of the digital and control content of the RFFE has been steadily increasing. For example, several 26 MHz—up to 52 MHz—MIPI RFFE^{SM} bus instances are required to control the radios in the modern smartphone, including 5G, Wi-Fi, Bluetooth, GNSS and NFC. Even with the complexity, the control and digital signals must not interfere with the RF and vice versa.

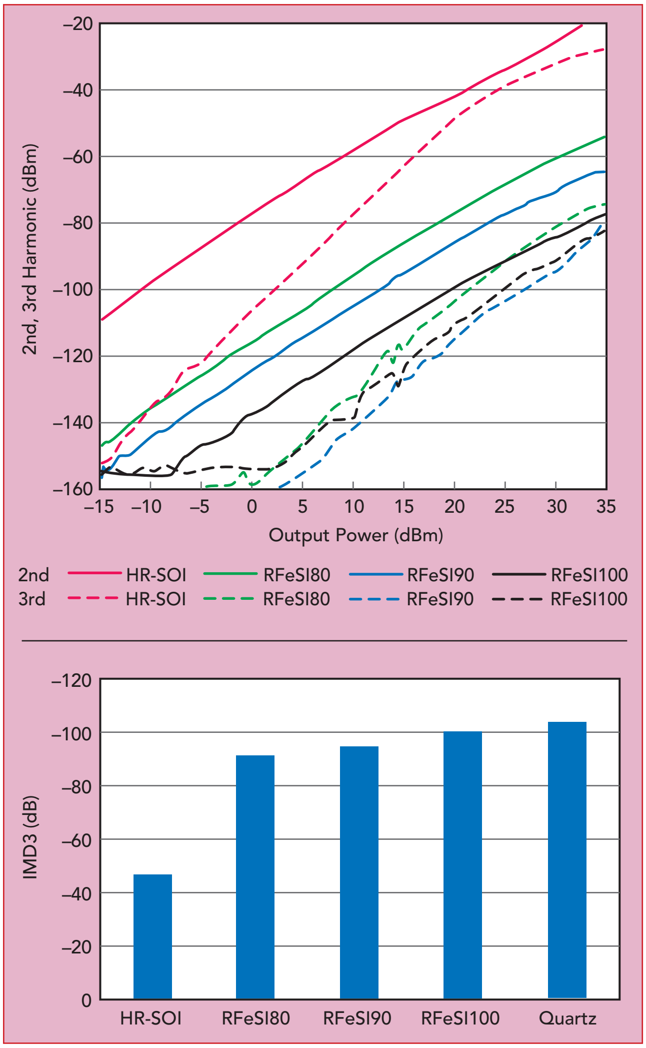


Fig. 1 RF-SOI substrate second and third harmonics (a) and 845 MHz IMD3 (b).

A good RF substrate should help prevent unwanted signals conducting from one part of the system to another—whether control, digital or RF—as they can disrupt system operation. Crosstalk and digital noise immunity are very important when designing RF and mmWave front-ends, and the design starts with the substrate (see ***Figure 2***).[5]

Smartphone antenna impedance and aperture variation due to external elements, such as the position of the user's hand, have been widely studied, leading to the use of antenna tuners (AT) in the RFFE to dynamically compensate such variation. ATs are implemented as close to the antennas as possible and are the first RFFE elements that must withstand large VSWR. Depending on the design, ATs may require the RF-SOI substrate BOX to withstand voltages greater than 100 V. Some RFeSI substrates offer BOX soft breakdowns greater than 150 V by tuning the BOX layer thickness appropriately (see Table 1).

When comparing RF, mmWave and integration capabilities, Figures 1 and 2 show a clear advantage of TR SOI over HR-SOI. TR RF-SOI has greatly contributed to the success of CMOS in RF and mmWave front-ends. As RFFEs evolve, TR SOI substrates must also evolve to address more stringent requirements. Higher frequency measurements, substrate modeling and material developments are being pursued for future applications, and these are described in the following sections.

MMWAVE CHARACTERIZATION

Signal attenuation in transmission lines, particularly CPW lines, is strongly affected by the free carriers in the underlying substrate. The total propagation loss, which comprises metallic losses in the lines as well as losses from the substrate, is often used to compare the RF per-

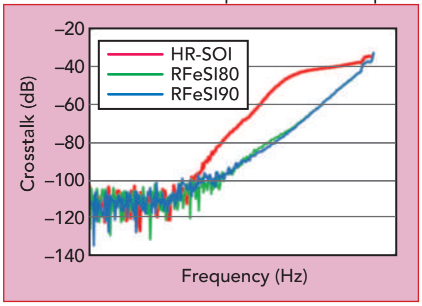


Fig. 2 RF-SOI substrate crosstalk immunity.

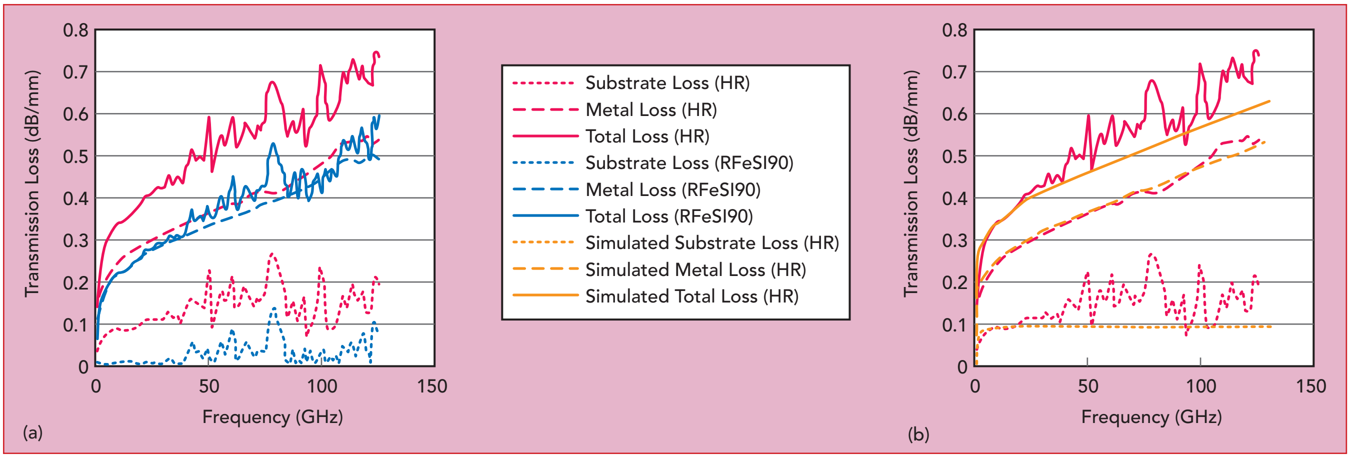
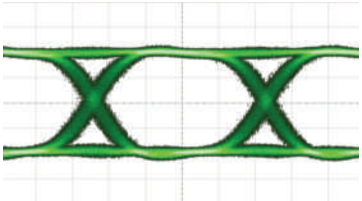
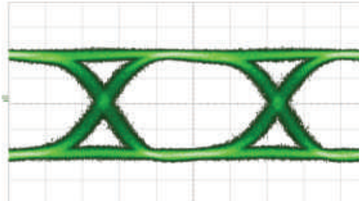


Fig. 3 Measured insertion loss on HR-SOI and RFeSI90 substrates (a) compared to simulated HR-SOI substrate model (b).

HYPERLABS™
Innovation at Hyperspeed since 1992

NEW: ULTRA-BROADBAND BIAS TEES (67 GHz)


INPUT: 32 GBPS PRBS31


OUTPUT: 32 GBPS PRBS31

- Options available from 70 KHz to 67+ GHz
- 1.25 dB max insertion loss to 67 GHz at 175 mA
- 175 mA option available now; higher currents coming soon
- Matched pairs available

PICK-OFF TEES

- Options from DC to 67+ GHz
- Excellent return loss on all ports
- Matched pairs available
- Highest bandwidth on the market

DC BLOCKS

- Options from 35 kHz to 67+ GHz
- 0.75 dB insertion loss to 67 GHz
- 11 V and 30 V options
- Matched pairs available

BALUNS

- Options from 500 kHz to 67+ GHz (3 dB BW)
- Excellent phase matching
- Unrivaled amplitude matching
- Industry leading product

RISE TIME FILTERS

- Options from DC to 40+ GHz
- Absorptive design
- Gaussian response (BT 4th order)
- Custom designs available on request

ULTRA-BROADBAND

We offer some of the broadest band components on the market.

Our engineers are constantly working on new designs and expanding our product line.

INDUSTRY LEADING

Components that are "invisible" with regards to bandwidth roll-off and jitter performance keep pulse and eye fidelity at their best.

We design our products specifically to achieve these goals over the broadest band possible.

DEMOS AVAILABLE

Demos are in stock for most offerings, and we will get them in your lab quickly for a "hands on" evaluation.

CUSTOM DESIGNS

Don't see exactly what you need? Our engineers may be able to help.

Many of our products can be modified or adapted to your specific needs quickly and with low minimum order quantities.

HL OREGON

13830 SW Rawhide Ct.
Beaverton, OR 97008

HL COLORADO

315 W South Boulder Rd.
Suite 206
Louisville, CO 80027

www.hyperlabs.com

PUT HYPERLABS IN YOUR LAB

formance of different substrates. ***Figure 3*** plots the propagation loss (α) versus frequency of CPW lines on different silicon substrates, showing the separate contributions from the metallic and substrate losses. For a 50 Ω transmission line, α is equivalent to the IL per unit length.

CPW lines with different lengths (i.e., 426, 906, 2106, 2526, 2826 µm) and the same cross section were measured and the multiline thru-reflect-line (mTRL) algorithm applied to extract the propagation constant.[8] The mTRL algorithm with redundant line measurements increases the extraction accuracy by reducing the measurement noise, which is inherently larger at mmWave frequencies. The separation of the metallic and substrate losses was obtained using a procedure described by L. Nyssens et al.[9], which is valid at mmWave frequencies.

The different samples were manufactured with the same CPW pattern, such that they have similar metallic losses versus frequency. The increasing IL with frequency is caused by the skin effect, a metallic loss mechanism. The introduction of HR silicon improved the IL by reducing the number of free carriers in the handle substrate. Nevertheless, the presence of the PSC at the oxide-silicon interface degrades the IL. This is suppressed when a TR layer is used, as with the RFeSI90 wafer. Therefore, the TR SOI substrates combining a HR handle silicon substrate and TR layer have negligible substrate-related losses. At sufficiently high frequencies, when the slow-wave mode is suppressed—above a few tens of MHz for TR substrates and above 10 to 20 GHz for HR substrates—the substrate losses are frequency independent and agree with the substrate model. The improvement in IL for the RFeSI substrates is valid across the entire mmWave frequency range.

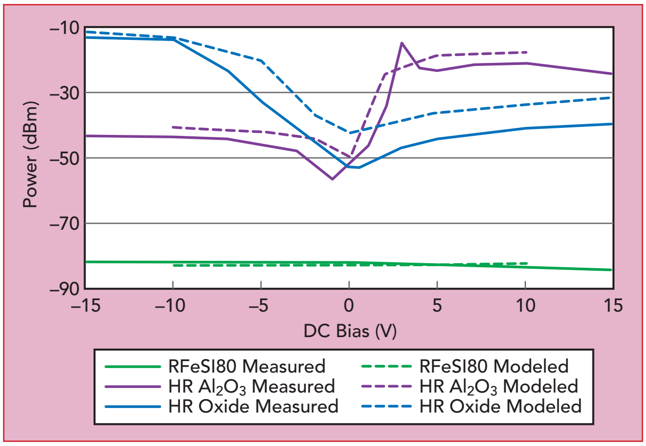


Fig. 4 Measured vs. simulated second harmonic power.

SIMULATING RF-SOI SUBSTRATES

Developing engineered materials for advanced applications is a complex, time- and resource-consuming process, which is more efficient with calibrated simulation. Accurate small-signal modeling has been developed using a combination of electromagnetic (EM) and technology computer-aided design (TCAD) tools to account for the lossy nature of the silicon substrates and conductive interfaces.[10,11] While simulating a semiconductor substrate's large-signal behavior is more of a challenge, the authors have developed the capability to link material properties to RF performance. To model the distortion induced by the substrate on a CPW line's signal, modeling is based on simplified EM propagation models which are complementary to solving the semiconductor transport equations and trapping phenomena in a transient, large-signal, time-domain TCAD approach. The model has been validated with several HR and TR samples having key differences in material parameters, enabling the relative importance of such differences on the linearity of the RF substrates to be assessed.

Figure 4 shows the second harmonic power levels versus DC bias for three substrates, comparing measured and modeled performance. The DC bias induces a mirror charge below the BOX. An RFeSI80 TR wafer is shown for reference; the other two wafers are HR,

Keeping it down *above 30 GHz...*

Loss is critical in millimeter wave applications,

and **IW** manufactures the range of **lowest attenuation/phase stable** coax to maintain your signal's integrity. From **K-band** to **E-band**, our family of coax was developed using **IW's proprietary EPTFE lamination** process to ensure the lowest cable loss across the mmWave spectrum:

Cable Type	Operating Freq. (GHz)	Atten. (max) dB/ft. dB/m
1801	30	0.49 / 1.62
1701	38	0.57 / 1.88
1571	40	0.64 / 2.09
1501	40	0.75 / 2.46
1401	50	1.02 / 3.34
1251	70	2.14 / 7.02
0471	110	4.95 / 16.23

With a broad selection of interconnects including **3.5mm**, **2.92mm**, **2.4mm**, **1.85mm, SMP and SMPM interfaces**, plus jacketing and armoring options, **IW Microwave** delivers reliable **custom cable assembly solutions** to suit a diverse range of applications from **satellite communications systems** to **5G test**.

Talk to us or your local representative about how you can ***get connected*** at **millimeter wave frequencies** with the **lowest attenuation cable** available!

AS9100 Rev. D & ISO9001:2015 certified.

INSULATED WIRE, INC.
203.791.1999
www.iw-microwave.com
sales@iw-microwave.com

Scan code to find out how you can ***get connected***

We're how the microwave industry ***gets connected!***

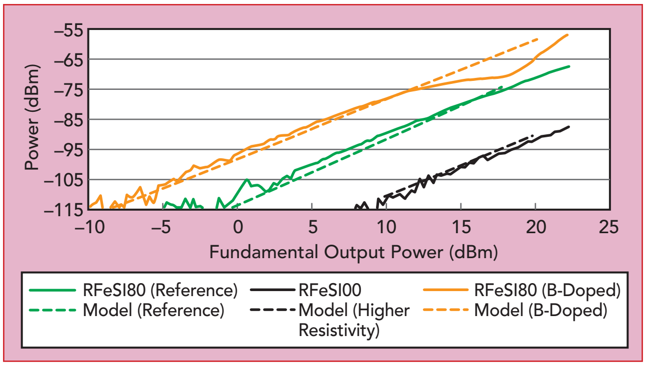


Fig. 5 Measured vs. simulated second harmonic power of two modified trap-rich wafers and the reference RFeSI80 sample.

each with a different BOX material: the first oxide, the second alumina (Al2O3). Oxide-silicon interfaces are known to have a positive, fixed interfacial charge density, reflecting the creation of an electron PSC,[1,3] while the charge density is negative at alumina-silicon interfaces, reflecting creation of a hole PSC. The interfacial fixed charge densities of the HR Oxide and HR Al_2O_3 samples were extracted from low frequency CV measurements of classical MOS capacitor devices at 8 × 10^{11} and -6 x 10^{11} cm^{-2}, respectively (not shown), and the same values were used in the model. The model correlates well with the measured data, accurately capturing the strong dependence on bias voltage and fixed charge.

By introducing trap energy states in the polysilicon TR layer, modeling predicts the increase in effective resistivity, as well as the decrease in power of the generated harmonic. ***Figure 5*** plots the second harmonic versus fundamental output power for three RFeSI substrates, comparing measured and modeled performance. One primary material parameter difference distinguishes each substrate from the others, and the model captures the relative impact of each parameter on the harmonics generated by that substrate. As a reference, the RFeSI80 substrate was modeled and measured. Using a more resistive polysilicon layer and handle wafer, an RFeSI100 was fabricated and modeled. Tailoring the resistivity in the model is almost sufficient to justify the 20 dB difference in the second harmonic power levels between these two substrates. Finally, the RFeSI80, introduced significant Boron contamination within the polysilicon layer, confirmed by SIMS and SRP data (not shown). Boron degrades the substrate impedance and raises the harmonic levels; adding the Boron profile into the model generates accurate estimates of harmonic performance.

This physical modeling gives key insights into the effect of the fundamental material parameters on RF loss and linearity performance and is a useful tool when designing substrates to meet given RF specifications.

BETTER PERFORMANCE AND TEMPERATURE STABILITY

RF-SOI substrates need to evolve to support new and more stringent RF requirements. Today, RFFE linearity is often not limited by the substrate, yet a large field of RF applications would benefit from RF-SOI substrates with better HD and IMD specifications. RFeSI linearity may be enhanced by improving the handle wafer resistivity and polycrystalline silicon trapping efficiency (see RFeSI100 in Figure 1). However, there are limits to the resistivity level that can be achieved with bulk silicon while guaranteeing stability, mechanical strength and affordability.

Other limitations of HR silicon are its relatively small bandgap and high dielectric constant. A 1.1 eV bandgap implies that the number of intrinsic carriers in the bulk silicon, which increases with temperature, becomes higher than the residual wafer doping in the range from 50°C to 90°C. Above this temperature, the resistivity and associated RF performance start degrading (see ***Figure 6***). While this is not an issue for most applications, some require performance stability to 150°C, such as grade 1 and 2 automotive. These applications require materials with resistivity independent of temperature.

Soitec has built SOI wafers with

MiCable

High Accuracy Butler Matrix for WiFi 6E Test

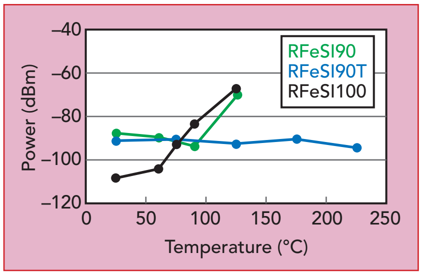
	Model	Frequency Range (GHz)	VSWR Max.(:1)	Insertion Loss* Max.(dB)	Amplitude Bal. Max.(dB)	Amplitude Flatness Max.(dB)	Phase Accuracy Max.(Deg)	Isolation Min.(dB)
4x4	SA-07-4B01	2.4~2.5	1.4	7.3	±0.5	±0.3	±4	14
		5.18~5.83	1.5	7.7	±0.6	±0.4	±5	13
		5.9~7.25	1.5	7.8	±0.7	±0.5	±6	13
8x8	SA-07-8B01	2.4~2.5	1.5	11.2	±0.6	±0.4	±8	13
		5.18~5.83	1.5	11.6	±0.8	±0.5	±10	12
		5.9~7.25	1.55	11.8	±0.9	±0.7	±12	12

* Theoretical IL. Included

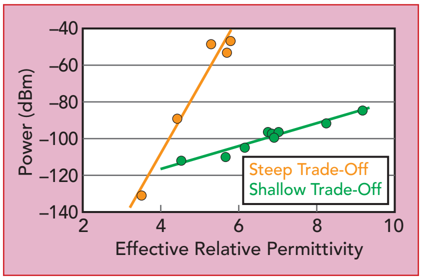
More Information-
Scan the QR Code

affiliated with SSi Cable Corp.

Fuzhou MIcable Electronic Technology Co.,Ltd.
Tel: +86-591-87382856 Email: sales@micable.cn Website: www.micable.cn



▲ Fig. 6 RFeSI second harmonic power vs. temperature.



▲ Fig. 7 Second harmonic vs. ε for porosification setups yielding steep and shallow trade-offs.

a porous silicon layer, which can be viewed as thin silicon membranes separated by gaps. It presents a huge surface area, on the order of 500 m^2/cm^3, so the many dangling bonds and surface states act as traps. Because the silicon membranes are so thin, all carriers are within trapping distance of the surface and are also subject to coulomb scattering. This ensures a low free carrier concentration and mobility, even when the temperature rises. The benefits of porous silicon for RF applications are well known, with demonstrated temperature stability on relatively thick layers, usually greater than 50 µm.[12,13]

Using SOI wafers and a thin buried porous silicon layer, to our knowledge, Soitec is the first to demonstrate very low HD levels and complete independence versus temperature up to 200°C, as shown in Figure 6. This performance has an added benefit: because porous silicon is essentially a composite material of silicon and empty spaces, its permittivity is lower than the usual 11.7. Thus, the transmitted signal sees a material with a reduced effective permittivity, which benefits HD, IL and signal isolation.

The effective RF performance and permittivity of porous silicon layers is dependent on the porosification process and material properties, such as porosity level, structure type, pore size, surface state and thickness. This is illustrated in ***Figure 7***, which shows second harmonic power versus permittivity when different trade-off configurations are used to fabricate the porous silicon layer. The figure shows obtaining adequate performance, temperature stability and low permittivity requires the proper fabrication process.

CONCLUSION

This article illustrates how substrate engineering brings additional linearity and value for RF and mmWave applications. Measurement setup and extraction procedures enable evaluating the substrate performance through representative metrics. With a physical understanding of material properties, the EM behavior of the sub-

strates can be accurately modeled, reproducing the effects of material parameters on HD. Leveraging these developments enables a path to better linearity, temperature-independent properties and tuned permittivity, which can be implemented in new engineered substrates to meet even higher performance requirements and the needs of future applications.■

References

1. Yunhong Wu, S. Gamble, B. M. Armstrong, V. F. Fusco and J. A. C. Stewart, "SiO2 Interface Layer Effects on Microwave Loss of High-Resistivity CPW Line," *IEEE Microwave and Guided Wave Letters*, Vol. 9, No. 1, Jan. 1999, pp. 10–12. SSN: 1558-2329. DOI: 10.1109/75.752108.
2. H.S. Gamble et al., "SOI Substrates with buried Tungsten Silicide Layers," *Proceedings of the 1st European meeting on SOI Devices*, EUROSOI, 2000.
3. D. Lederer and J.P. Raskin, "New Substrate Passivation Method Dedicated to HR SOI Wafer Fabrication with Increased Substrate Resistivity," *IEEE Electron Device Letters*, Vol. 26, No. 11, Nov. 2005, pp. 805–807, ISSN: 1558-0563, DOI: 10.1109/LED.2005.857730.
4. E. Desbonnets, C. Didier and N. Pautou, "Innovative RF-SOI Wafers for Wireless Applications," Soitec Whitepaper, 2013.
5. K. Ben Ali, C. Roda Neve, A. Gharsallah and J. P. Raskin, "RF Performance of SOI CMOS Technology, on Commercial 200-mm Enhanced Signal Integrity High Resistivity SOI Substrate," *IEEE Transactions on Electron Devices*, Vol. 61, No. 3, March 2014.
6. "Soitec's Engineered Substrates for 5G," Soitec, March 2020, https://www.soitec.com/media/documents/173/file/soitec_5g_march_2020.pdf.
7. M. Emam, "RF-SOI Substrates and Technology Characterization," *SOI Consortium Workshop & Tutorial – Nanjing*, September 21–22, 2017, https://soiconsortium.org/events/september-21st-22nd-2017-nanjing-soi-workshop-tutorial/.
8. R. B. Marks, "A Multiline Method of Network Analyzer Calibration," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 39, No. 7, July 1991, pp. 1205–1215.
9. L. Nyssens, M. Rack and J.-P. Raskin, "Effective Resistivity Extraction of Low-Loss Silicon Substrates at Millimeter-Wave Frequencies," *International Journal of Microwave and Wireless Technologies*, 2020. pp. 1–14.
10. M. Rack, L. Nyssens and J.P. Raskin, "Silicon-Substrate Enhancement Technique enabling High-Quality Integrated RF Passives," *2019 IEEE MTT-S International Microwave Symposium (IMS)*, June 2019.
11. M. Rack, L. Nyssens, J.P. Raskin, et al., "Device Layout Dimension Impact on Substrate Effective Resistivity," *2018 IEEE SOI-3D-Subthreshold Microelectronics Technology Unified Conference (S3S)*, Oct. 2018, pp. 1–2. DOI: 10.1109/S3S.2018.8640211.[MR1].
12. H. Contopanagos, F. Zacharatos and A.G. Nassiopoulou, "RF Characterization and Isolation Properties of Mesoporous Si by On-chip Coplanar Waveguide Measurements," *Solid-State Electronics 52*, 2008, pp.1730–1734.
13. M. Rack, Y. Belaroussi, K. Ben Ali, G. Scheen, B. Kazemi Esfeh and J.P. Raskin, "Small- and Large-Signal Performance Up To 175°C of Low-Cost Porous Silicon Substrate for RF Applications," *IEEE Transactions on Electron Devices*, Vol. 65, No. 5, May 2018, pp. 1887–1895, DOI: 10.1109/TED.2018.2818466.

INVITED PAPER

Low Noise Oscillator Based on a Conventional Dielectric Resonator

Vladimir M. Gevorkyan and Yuri A. Kazantsev
Moscow Power Engineering Institute, Moscow, Russia

This article describes an algorithm for the design of a voltage-controlled oscillator (VCO) with an active structure controlled by a sequential feedback circuit containing a high-quality open dielectric resonator. Its effectiveness is illustrated with the design of an X-Band oscillator that meets modern requirements for phase-locked loop (PLL) frequency control systems.

A microwave oscillator is typically based on a microwave assembly comprising an active two-port amplifier and a resonator, such as a dielectric resonator (DR). Oscillation is normally achieved with parallel feedback (FB). Design techniques for oscillators based on assemblies with parallel FB are well described by Bunin et al.[1,2] Properties of active elements with inherent (i.e., internal) FB are not readily available to oscillator device developers; however, this information is not critical to the design.

In this work, we describe an oscillator development algorithm and verify its efficacy with the design of an X-Band VCO using inherent feedback. The oscillating system is formed by an open DR electromagnetically coupled to a varactor diode (VD) through a microstrip resonator (MSR). The main goal of the dielectric resonator oscillator (DRO) design is to achieve low phase noise, i.e., not to exceed -90 dBc/Hz at 10 kHz offset from the carrier. This level corresponds to or is better than the performance of similar products from leading manufacturers.[3-7] The main application is low phase noise PLL frequency sources,[8] where there is high interest and demand.[9]

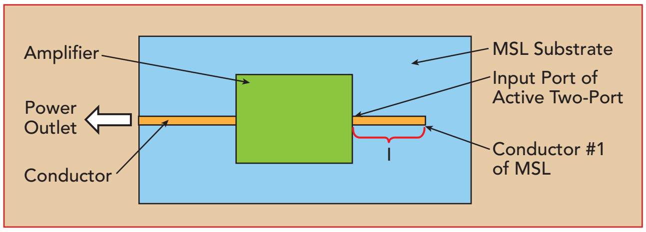


Fig. 1 **Oscillator topology.**

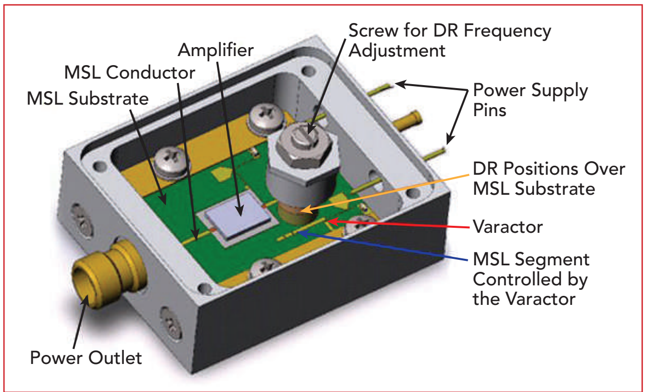


Fig. 2 **Oscillator assembled in a housing.**

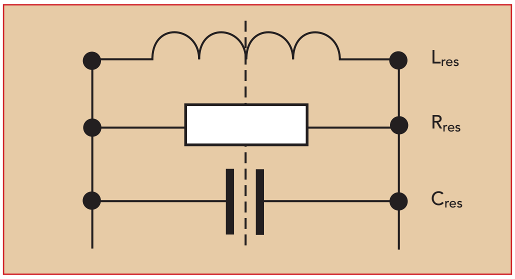


Fig. 3 **DR equivalent circuit.**


DELTA
Electronics Mfg. Corp.
Aerospace & Defense
A.E. Petsche Co.
Distributed by A.E. Petsche Co.
A Delta Channel Partner
contactAEP@aepetsche.com
www.aepetsche.com
(844) AEP-7600 or (844) 237-7600
SMP
SMPM
SMPS
High Performance
Interconnects to 65 GHz
that Guide & Protect
978-927-1060 sales@deltarf.com deltarf.com

OSCILLATOR DESIGN

The proposed algorithm for DRO design with inherent FB greatly simplifies DRO development. This algorithm consists of two stages: First, one creates a microstrip oscillator on a dielectric substrate using the topology and physical configurations shown in ***Figures 1*** and ***2***. The required oscillation frequency is achieved by trimming the length of microstrip line (MSL) connected to the input port of the active two-port device, shown as conductor 1 in Figure 1. The oscillation frequency is measured and the length, l, of MSL 1 is recorded. Second, in the housing cup threaded hole, a screw is placed on one end of a dielectric body (e.g., a quartz cylinder) attached to a dielectric disk (i.e., a DR). Moving the case cup along the substrate axis and varying the distance between the DR edge and the substrate surface controls the electromagnetic coupling between conductor 1 and the DR. VCO implementation is enabled by adding an MSR coupled to the DR and connected to a VD.

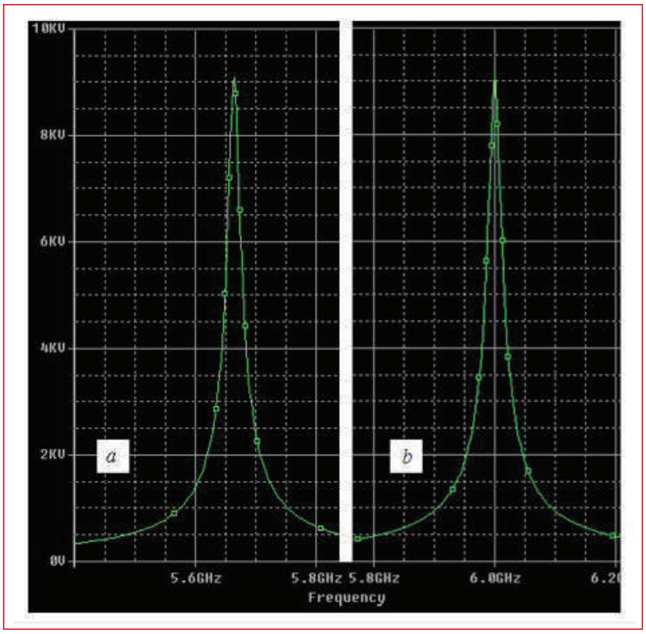


Fig. 4 Magnitude of the MSR impedance vs. frequency, with C_{VD} = 0.1 (a) and 0.01 (b) pF.

Selection of the optimal DR position and coupling to the VD is accomplished by a simplified approach, which is demonstrated with the design of an 8 to 10 GHz DRO. The DR equivalent circuit is shown in ***Figure 3***. The characteristics of the coupling structure are defined by the resonant frequency f_0 and the inherent Q-factor, Q_0:

$$Q_0 = \frac{R_{res}}{\rho} = \frac{R_{res}}{\sqrt{L_{res} / C_{res}}} \quad (1)$$

By selecting

$$\rho = \sqrt{L_{res} / C_{res}} = 1\Omega, Q_0 = R_{res}$$

The microstrip transmission line model is described by its length, l, longitudinal resistance per unit length, R_0, inductance per unit length, L_0, transverse conductance per unit length, G_0, and capacitance per unit length, C_0. These values can be calculated knowing the MSL wave resistance, Z_w; propagation constant, γ; damping in the line, α; and wavelength, λ_w, in accordance with following:

$$\gamma = \alpha + j\beta = \left(\frac{R_0}{2}\sqrt{\frac{C_0}{L_0}} + \frac{G_0}{2}\sqrt{\frac{L_0}{C_0}}\right) + j\omega\sqrt{L_0 C_0}, \frac{1}{m}, \quad (2)$$

$$Z_w = \sqrt{\frac{L_0}{C_0}}, \ \Omega; \lambda_w = \frac{\lambda_0}{\sqrt{\varepsilon_{eff}}}, \ m, \quad (3)$$

where λ_0 is the wavelength and ε_{eff} the effective permittivity of the MSL substrate.

$$\alpha = \alpha_1 + \alpha_2 = \frac{R_0}{2}\sqrt{\frac{C_0}{L_0}} + \frac{G_0}{2}\sqrt{\frac{L_0}{C_0}}, \quad (4)$$

where $\alpha_1 = \frac{R_0}{2}\sqrt{\frac{C_0}{L_0}} = \frac{R_0}{2Z_w}$

is the damping due to losses in the line metal and

$$\alpha_2 = \frac{G_0}{2}\sqrt{\frac{L_0}{C_0}} = \frac{G_0}{2Z_w}$$

is the damping due to losses in the dielectric.

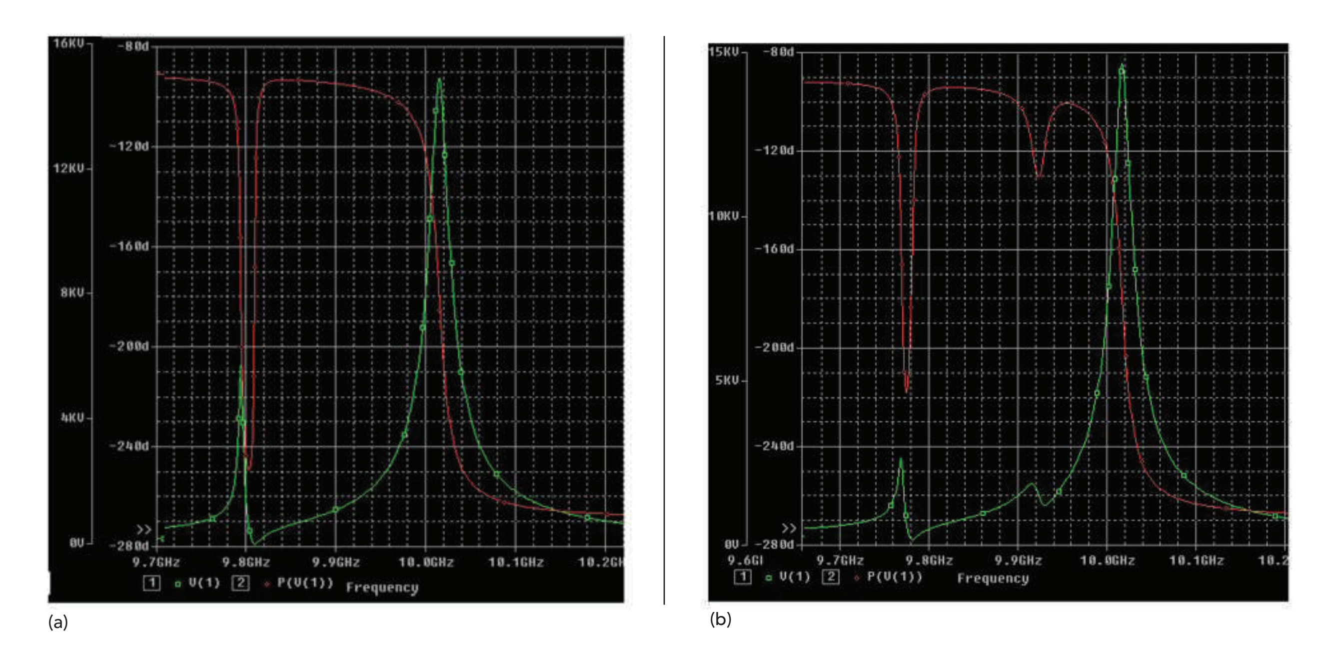


Fig. 5 Magnitude (green) and phase (red) of the MSL impedance with C_{VD} = 0.01 (a) and 0.1 pF (b).

For example, for an MSL on a polycor substrate with Z_w = 50 Ω, $\sqrt{\varepsilon_{eff}} \approx 2.5$ and known values of α_1 and α_2, one obtains: L_0 = 0.41667 µHn/m, C_0 = 0.16667 nF/m, R_0 = 30 Ω/m, G_0 = 0.01 Sim/m and

$$\lambda_w = \frac{\lambda_0}{\sqrt{\varepsilon_{eff}}} = \frac{C_0}{2.5 f_0} \approx \frac{3\cdot 10^8}{2.5 f_0} = \frac{1.2\cdot 10^8}{f_0} m \quad (5)$$

Figure 4 shows the calculated frequency dependence of the MSR. With a decrease of VD capacitance, by changing the VD voltage, the resonant frequency of the MSR increases, consistent with the theory.

Modeling of coupling between the DR and MSL assumes an ideal transformer (IT), which characterizes the coupling between the DR and the transmission line. The IT properties are defined by

$$Zin = \frac{V1}{I1} = \frac{1}{n^2}\frac{V2}{I2} = \frac{1}{n} Zout \quad (6)$$

The coupling coefficient β is determined by

$$\beta = \frac{n^2 R_{res}}{2Z_w} \quad (7)$$

Using the coupling model between the DR and MSL, one can calculate the scattering matrix co-

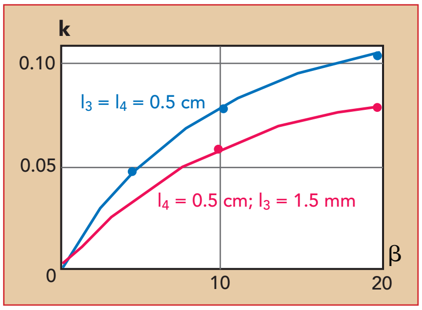


Fig. 6 Dependence of the coupling coefficient, k, on the relative position of the DR to the MSR.

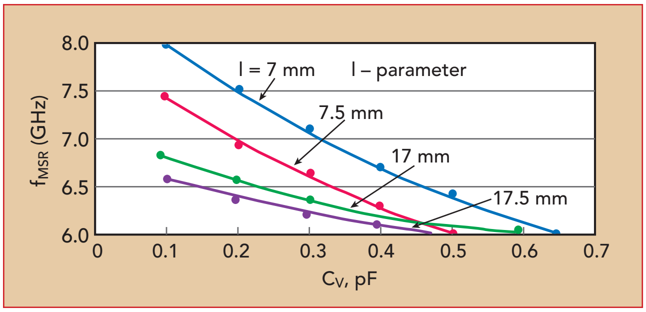


Fig. 7 MSR frequency response vs. C_V and MSR length.

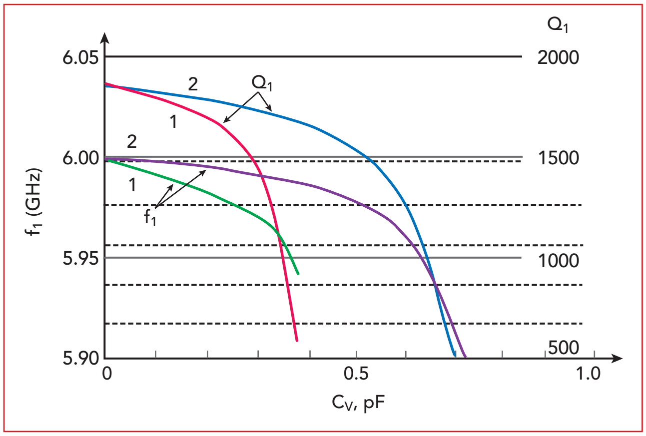


Fig. 8 Coupling frequency, f_1, and associated Q-factor, Q_1, vs. C_V, with l_4 = 0.2 cm (1) and 0.3 cm (2).

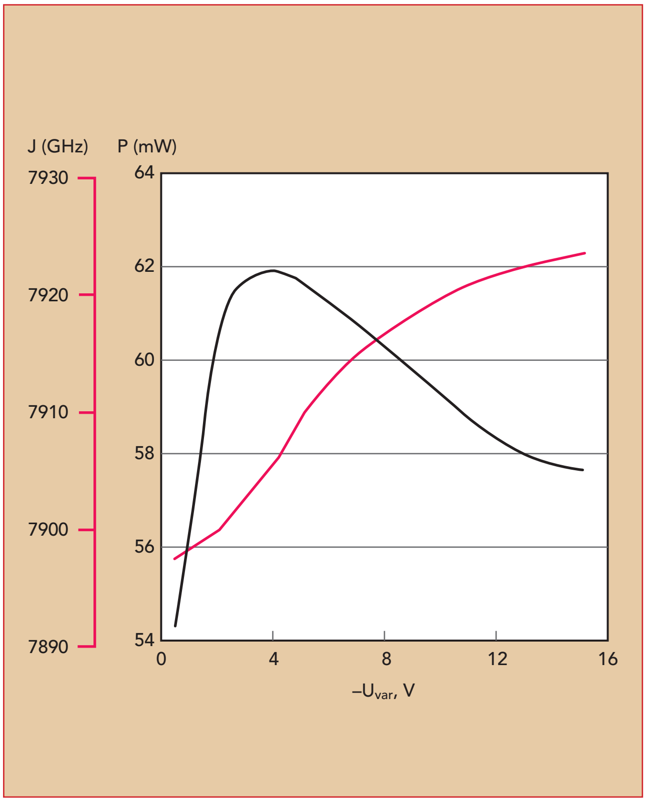


Fig. 9 Power and frequency vs. tuning voltage.

efficients, which correspond to the theoretical results obtained from the wave equations for the transmission line. The desired resonant frequency of 10 GHz is achieved by varying the VD capacitance between C_{VD} = 0.01 and 0.1 pF respectively (see ***Figure 5***). Changing the VD capacitance changes the electrical length of the microstrip resonator (i.e., its resonant frequency), which changes the coupling frequencies of the associated oscillator system (i.e., the entire frequency response). The entire frequency response change is quite small, on the order of several MHz.

The dependence of the coupling coefficient, k, between the DR and MSR is shown in ***Figure 6***. Lengths l_3 and l_4 are parts of the overall microstrip resonator length (i.e., $l = l_3 + l_4$), indicating the position of the DR with respect to the microstrip resonator.

$$k = (f_2 - f_1) / f_0 \quad (8)$$

where f_1 and f_2 are coupling frequencies that define the frequency tuning of the oscillator.

The frequency response curves


STRONG, CONSISTENT
WIDEBAND
POWER
ALL THE WAY THROUGH YOUR BAND
Wideband High Power Amplifiers (WHPAs)
WIDEBAND
2-18 GHz
P_{out}: 30 dBm
K BAND
15-27 GHz
P_{out}: 29 dBm
Ka BAND
17-43 GHz
P_{out}: 22 dBm
Ka BAND
24-40 GHz
P_{out}: 22 dBm
Q BAND
33-47 GHz
P_{out}: 29 dBm
W BAND
75-83 GHz
P_{out}: 27 dBm
erzia.com/microwave/WHPA

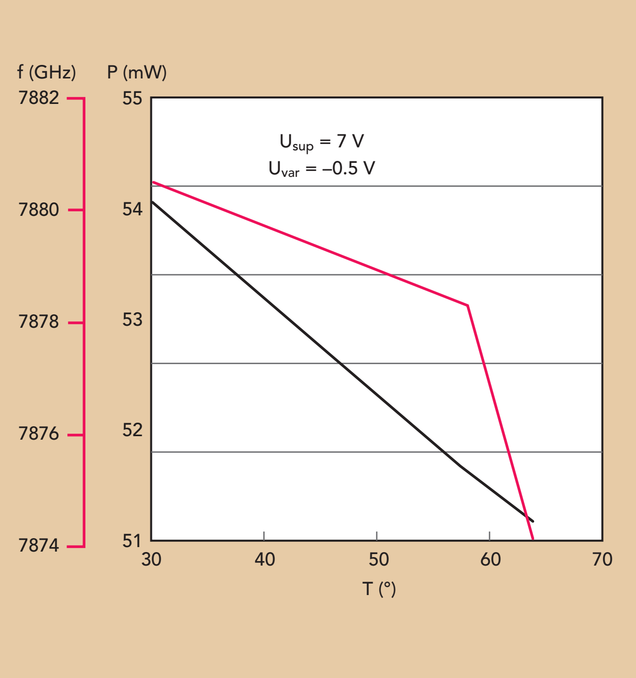


Fig. 10 Power and frequency vs. temperature.

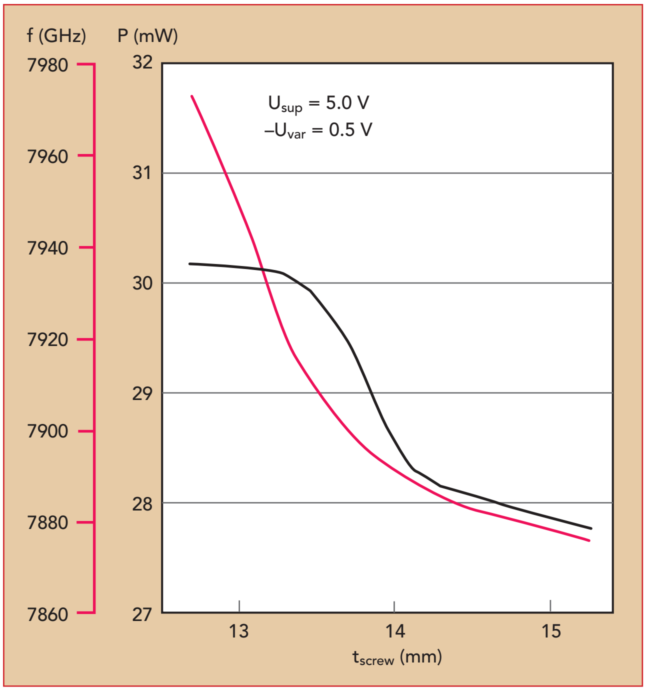


Fig. 11 Power and frequency vs. tuning screw position.

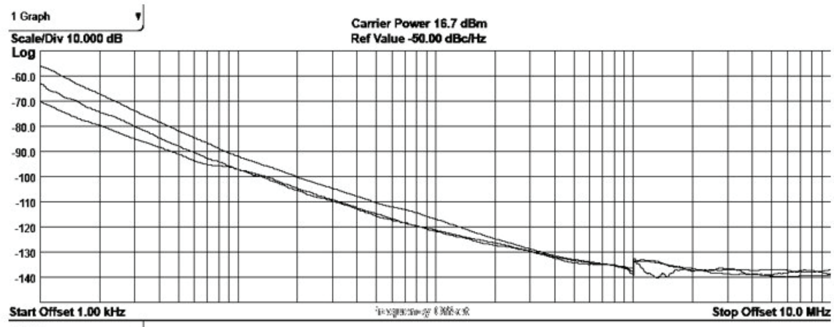
of the oscillating system MSL-to-VD interface with various MSR lengths are shown in ***Figure 7***. ***Figure 8*** shows the frequency dependence of the coupling frequency, f1; the Q-factor, Q; and the transfer function versus C_{VD}.

From the electrical design parameters, Figures 6, 7 and 8 provide dielectric substrate and DR topologies to achieve the optimal, i.e., maximum, effective Q-factors for the oscillating system at a given frequency. The results were verified using ANSYS, the finite-element electromagnetic simulator. The analysis determines the geometric size of the conductor and its position on the polycore substrate, as well.

MEASUREMENTS

Experimental results show that conditions for oscillation are met over a wide range of circuit parameters, i.e., up to 30 percent from the calculated values. This includes DR position with respect to MSL conductor length, resonant frequency, DC bias voltages from 5 to 9 V and VD tuning voltage. DRO characteristics versus VD tuning voltage, temperature variation and mechanical tuning screw position are shown in ***Figures 9, 10*** and ***11***, respectively.

DRO phase noise heavily depends on the oscillation system Q-factor and, more precisely, on the Q-factor of the resonance curves of the coupling frequency where oscillation occurs. Therefore, considering the low Q-factor of the VD—which does not exceed



2 Table

Frequency Offset	Vtun=1 V 9.838 20 GHz	Vtun=5 V 9.840 96 GHz	Vtun=15 V 9.846 74 GHz
1.00 kHz	-69.92 dBc/Hz	-62.80 dBc/Hz	-55.70 dBc/Hz
10.0 kHz	-96.91 dBc/Hz	-96.95 dBc/Hz	-91.73 dBc/Hz
100 kHz	-121.17 dBc/Hz	-121.62 dBc/Hz	-116.76 dBc/Hz
1.00 MHz	-137.92 dBc/Hz	-139.28 dBc/Hz	-136.52 dBc/Hz
10.0 MHz	-139.17 dBc/Hz	-139.10 dBc/Hz	-137.03 dBc/Hz

Fig. 12 Phase noise performance.

500—the phase noise depends mainly on the required frequency tuning range. The measured phase noise for the 40 MHz tuning range is about -80 to -85 dBc/Hz at 10 kHz offset from a 10 GHz oscillation frequency. For the 10 MHz frequency tuning range, the phase noise drops to -92 dBc/Hz at the same oscillation and offset frequencies (see ***Figure 12***). This tuning range is sufficient for a PLL to compensate for temperature frequency drift, which should not exceed the electrical tuning range.

CONCLUSION

A method for the analysis of complex microwave oscillating systems enables the development of a DRO that meets phase noise and frequency tuning range requirements.■

ACKNOWLEDGMENTS

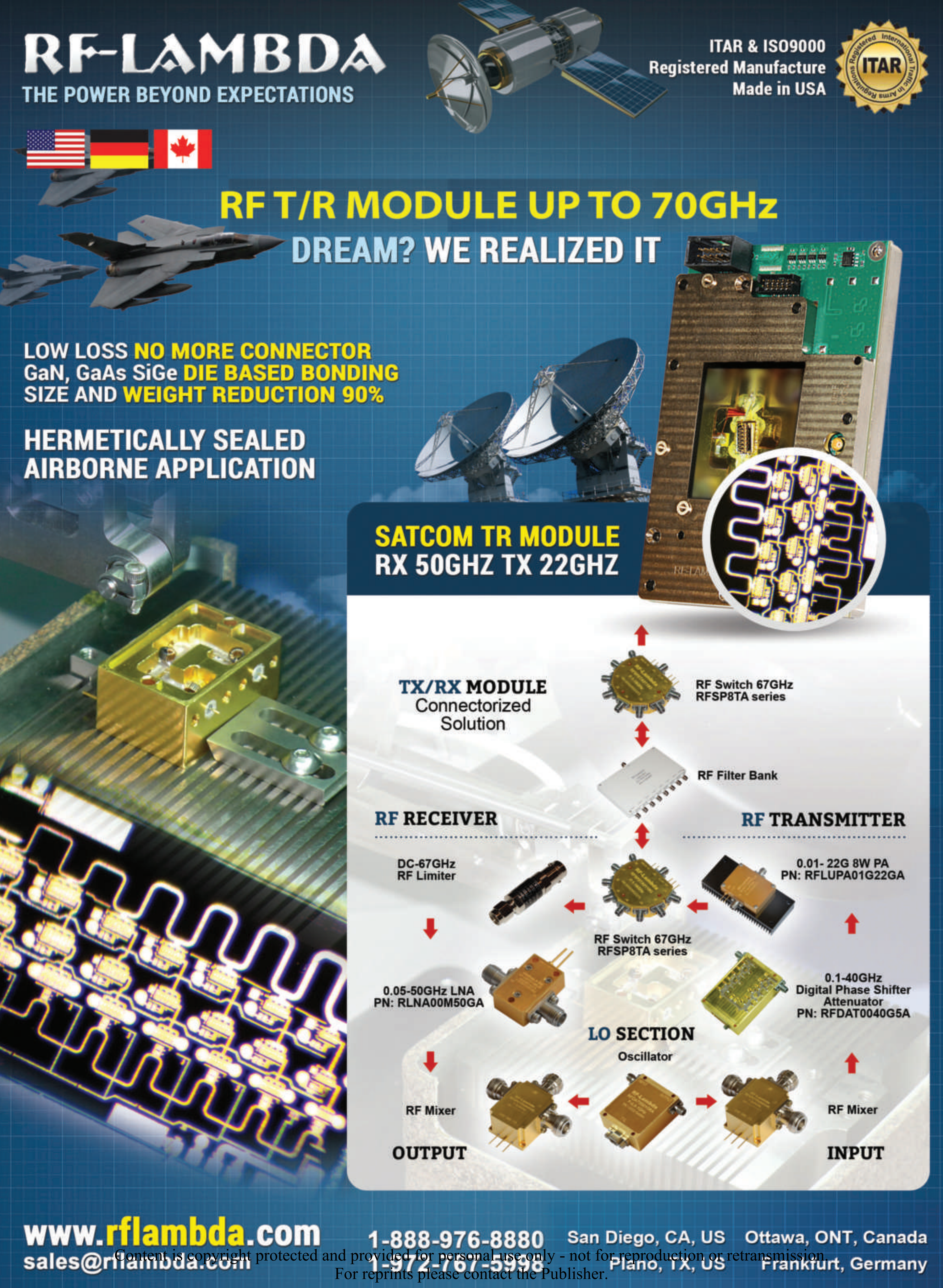
The authors would like to thank Dr. Alexander Chenakin of Anritsu Company for his review and valuable feedback.

References

1. A. V. Bunin, S. V. Vishnyakov, V. M. Gevorkyan and J. A. Kazantsev, "Design of an Oscillator System for Millimeter-Wave Generator," *Proceedings of the 15th International Crimean Conference*, September 2005.
2. A. V. Bunin, S. V. Vishniakov and V. M. Gevorkyan, "Design of a Millimeter-Wave Oscillator," (in Russian), *Electronics NTB*, No. 6, 2008, pp.106–111.
3. Miteq, internet resource, Web. www.nardamiteq.com/.
4. Eravant, internet resource, Web. www.eravant.com/.
5. Microwave Communications Laboratories Inc., internet resource, Web. www.mcli.com/.
6. Nexyn Corporation, internet resource, Web. www.nexyn.com.
7. Raditek International, internet resource, Web. www.raditek.com.
8. A. Gorevoy, "A Low Noise Oscillator Based on a Conventional Dielectric Resonator," *Microwave Journal*, Vol. 56, No. 11, November 2013, pp. 84–94.
9. U. L. Rohde and A. K. Poddar, "DROs Drop Phase Noise," *Microwaves & RF*, January 2013.

Vladimir M. Gevorkyan *received an engineering degree from the Moscow Power Engineering Institute (National Research University) in 1971 and a PhD in electrophysics in 1979. Since then, he has been teaching at the Moscow Power Engineering Institute and is also engaged in research in the field of electrophysics and microwave technology. Currently he is a professor and the head of the Laboratory of Electrophysics.*

Yuri A. Kazantsev *received an engineering degree from the Moscow Power Engineering Institute in 1970 and a PhD in electrophysics in 1976. Since then, he has been working and teaching as a professor at the Moscow Power Engineering Institute. His research interests are in electrophysics and microwave technology.*


RF-LAMBDA
THE POWER BEYOND EXPECTATIONS
ITAR & ISO9000
Registered Manufacture
Made in USA
ITAR
Registered International Traffic in Arms Regulations
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 Switch 67GHz
RFSP8TA series
RF Filter Bank
RF RECEIVER
RF TRANSMITTER
DC-67GHz
RF Limiter
0.01- 22G 8W PA
PN: RFLUPA01G22GA
RF Switch 67GHz
RFSP8TA series
0.05-50GHz LNA
PN: RLNA00M50GA
0.1-40GHz
Digital Phase Shifter
Attenuator
PN: RFDAT0040G5A
LO SECTION
Oscillator
RF Mixer
RF Mixer
OUTPUT
INPUT
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

INVITED PAPER

Modernizing mmWave Measurements with 110 GHz Coaxial Components

Charles Tumbaga
Anritsu, Morgan Hill, Calif.

With the rollout of 5G and 6G discussions already beginning, it's no surprise that the only known for new telecommunication standards will be higher frequencies, well into the mmWave frequencies beyond 100 GHz. Whether in the RF or optical domains, R&D development is ongoing, raising the question: how will engineers address broadband and mmWave measurements moving forward? In parallel with the many interesting 110 GHz and higher use cases, the idea of modernizing measurements from the instrument to the device under test is a relevant topic of conversation. To enable new test systems to address these changing frequency requirements, we must migrate from the nearly 100-year-old waveguide to newer coaxial solutions. While the idea of modernizing measurements has its roots in reducing the complexity of test setups, frequency and time domain measurements will benefit by moving to coaxial solutions for mmWave measurements.

This article explores the drivers for mmWave application development, discusses technologies for performing measurements to 110 GHz, identifies the trade-offs between waveguide and coaxial technology and acknowledges the new coaxial solutions coming on the market.

EMERGING MARKETS

We're seeing significant development in the telecommunications sector fueling the need for mmWave frequency coverage. Denser networks using microwave backhaul, fronthaul and fixed wireless are predicted to exceed 100 GHz to support the deployment of 5G and development of 6G and beyond.[1] These frequency requirements come from new antennas and transceivers to provide more accessibility and data to users, as well as the optoelectrical components needed to move tremendous amounts of data from the radio through the network, parallel developments to provide 800G or 1.6T Ethernet capabilities.

Another market active for some time is automotive radar. Short- and long-range automotive radar uses the 76 to 81 GHz band and, like all radar, includes a transceiver that requires testing of internal components like amplifiers, mixers and antennas. While the radar frequencies fall within the band addressed by the new 1.35 mm connector, which spans DC to 90 GHz, there is no component support currently, other than adapters. The new applications are not limited to the consumer: electronic warfare and satellite transmission use W-Band frequencies. As semiconductor process technologies improve, device characterization requires measurement coverage from near DC to 110 GHz.

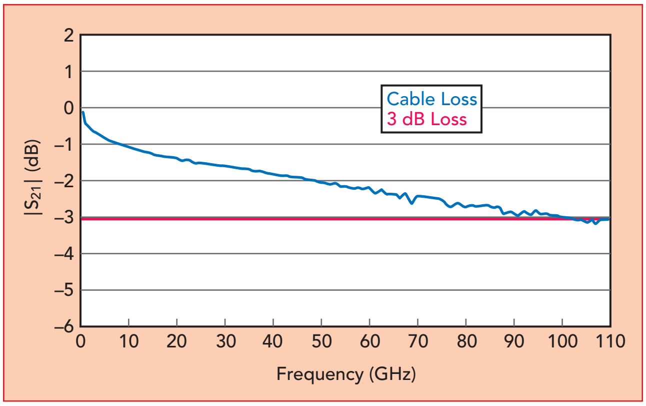


Fig. 1 **Typical 110 GHz cable loss vs. frequency.**

WHERE DO MEASUREMENTS FIT?

While these new applications are at the forefront of technology, the supporting measurements often rely on older technology.

Before discussing improving the measurements for these applications, consider the test equipment used for these measurements. For example, before a power sensor can be used in the field, it undergoes various manufacturing tests and calibration—such as a leveling loop calibration, which uses a reference sensor as the correlation standard for the power sensor as both measure a test signal.[2] For broadband characterization, from kHz/MHz to the 110 GHz range, it would take many components and adapters to perform this testing without using a broadband coaxial component. And there are other measurements and functionality tests required in production to assure the test instrument is ready to use. All would also benefit from using coaxial components to simplify testing and improve measurement accuracy.

In addition to the test equipment, the components used for various measurements include:

- Intermodulation distortion (IMD) and related measurements that require equal signal distribution using a power divider
- Antenna and active device biasing through a bias tee or Kelvin bias tee
- Spurious signal sampling or optical modulator mismatch correction using a directional coupler
- Receiver compression avoidance or test port VSWR improvement with attenuators
- Gain, compression and isolation using a power splitter

These are not exhaustive, just a few of the many measurements needed to quantify performance and harder to make at mmWave frequencies, where the components may be scarce or unavailable.

MEASUREMENT CHALLENGES

Can you imagine a future where only books are used for information, even though we have the internet? Or driving only gasoline-powered automobiles when electric and hybrid models are available? Of course not. When options exist, the use case dictates which one we use. The same is true of measurements, particularly the choice of components, as technology moves forward.

Waveguide was developed in the 1930s and used widely during World War II. Waveguide components continue to be the de facto standard for high-power signals and frequencies above 70 GHz. Unlike coaxial components, waveguide has nearly zero signal loss, as it is not resistive. This is important because the signal is conserved. Unfortunately, waveguide only operates in specific frequency bands, which precludes broadband measurement.

For frequencies higher than 70 GHz, there are few choices for components other than waveguide. To provide alternatives, the industry is developing new coaxial components, such as the V connector (1.85 mm), However, the V connector has a theoretical limit of 73.3 GHz; the performance above the theoretical limit suffers from over-moding. Over-moding refers to a notable resonance that manifests as an attenuation spike over a small bandwidth. It occurs where the input signal energy changes modes due to impedance and velocity mismatches at the dielectric support bead and air dielectric interface—which is not desirable. This is one of the rare times where a coaxial structure behaves like a waveguide, i.e., not in a single mode.

Users desiring to stay in a native coaxial environment often create makeshift components. One example is using a DC to 110 GHz cable to create an attenuator with broad frequency coverage. A 10 cm long cable provides 3 dB of attenuation at the upper frequency, around 100 GHz (see ***Figure 1***). To create an attenuator with 10 dB loss, three cables could be used, requiring multiple interconnects between the cables and creating measurement uncertainty. A good attenuator is generally flat, i.e., within 1 dB of the desired level across its frequency band. The flatness of a series of cables cannot be guaranteed, however. With three cables, a large attenuation swing will occur, much higher and lower than 10 dB at various frequencies. Not only will the measurement certainty be degraded by multiple interconnects and varying attenuation, the power delivery versus frequencies will vary due to the frequency slope of the cables. This is not an ideal measurement setup. This highlights how users try alternatives to construct useful coaxial components.

Even using waveguide components is a compromise. Consider active device testing. A waveguide cannot conduct a DC voltage or current; it is an inherent DC block and cannot bias anything. For characterizing active devices, the bias can be added through a test port via a probe during development. However, when the device is part of an assembly in a test jig, a waveguide cannot pass both RF and DC power.

Time domain analysis is a common tool used for device characterization. While we focus on frequency domain measurements, emerging applications will also use the time domain, as it can provide insight into impedance characteristics and discontinuities (lowpass time domain), faulty areas in the setup (bandpass time domain) and the electrical quality of a signal through a device or component (an eye diagram).

Many components used in high speed communications are characterized with both time and frequency plots. Return loss and insertion loss are equally impor-

TABLE 1

WAVEGUIDE-COAXIAL COMPARISON

Parameter	Waveguide	Coaxial
Signal Loss	Minimal Loss	Suffers Loss
Frequency Domain	Dispersion and Group Delay from TE/TM Modes	TEM Mode Not Susceptible to Dispersion or Group Delay
Time Domain	Limited Functionality Because of Narrower Bandwidth	Broadband, Enabling Time Domain Functionality
Setup Complexity	Complex: Fastening Screws, Alignment, Adapter Loss	Simple: Coax-to-Coax Interface
Robustness	Rugged, Hard to Damage	Requires Gentle Handling and Proper Care

▲ Fig. 2 **Anritsu 110 GHz components.**

tant with the eye diagram and impedance profile. For lowpass time domain and eye diagram processing, low frequency and broad frequency coverage are important. The low frequency component is used for extrapolating the DC term and the broad frequency coverage for resolution of the trace to find any issues. Since a waveguide is band limited, a high frequency waveguide such as W-Band will not have a low frequency component, nor can it provide broad frequency coverage.

TRADE-OFFS

Although waveguide is nearly 100 years old, it still serves a purpose, providing some properties that coaxial solutions cannot. Comparing these two technologies shows the trade-offs between them, trade-offs which can be summarized by physical and electrical parameters (see ***Table 1***).

Physical

Waveguide is made from solid metal, and this design quality enables it to be very rugged. Waveguide is not easily damaged and can be dropped without much worry of electrical performance changes, assuming the flange interface is not bent. In comparison, coaxial components with a W connector (1.00 mm) require gentle handling and proper care when using them.

Waveguide has repeatability issues, even with many mechanical mechanisms in place to prevent them. Common knowledge for waveguide users, different users can get different results with the exact same setup. A user can spend a significant amount of time aligning apertures, fastening and torqueing screws and taking other steps to get the best performance from the waveguide component. A coaxial-to-coaxial setup—connecting the test instrument directly to the component—minimizes setup time and ensures repeatability.

Electrical

An advantage of waveguide over coaxial components is transferring higher power across a nearly lossless interface. Coaxial components have lower limits for power transfer, and their structures are resistive, which leads to signal loss. With many setups used for mmWave measurements, an adapter is used to connect between coaxial and waveguide components, and the loss of the coaxial interface reduces some of the advantage of the nearly lossless waveguide. Many applications operate at low power, which is compatible with either waveguide or coaxial components.

Because they are broadband, coaxial components enable more time domain analysis options and support active measurements that require DC bias. The propagation in coaxial components is transverse electromagnetic (TEM), so they do not suffer the effects of dispersion.[3] Dispersion affects group delay and impedance, which are concerns using waveguide, as the propagation is either transverse electric or transverse magnetic.

EXTENDED REACH

Over the last year, we've seen new 110 GHz coaxial components introduced for the mmWave market, including bias tees, DC blocks and directional couplers. Supporting this push to higher frequencies, Anritsu has also introduced various coaxial components including fixed attenuators, a three resistor power divider, a two resistor power splitter, directional coupler, standard and Kelvin bias tees and a broadband DC block (see ***Figure 2***). Anritsu's components are metrology-grade, with excellent electrical and environmental performance, designed to be used with any measurement equipment that provides coverage to 110 GHz. Such an array of components makes modernizing a test setup straightforward and capable of supporting these new mmWave applications.■

References

1. D. Gentina, *Vision And Future Use of High Millimetre-Wave Bands*, 2017.
2. R. Collier and A. Skinner, *Microwave Measurements*, London: Institution of Engineering and Technology, Third Edition, 2007, p. 148.
3. R. Collier and A. Skinner, *Microwave Measurements*. London: Institution of Engineering and Technology, Third Edition, 2007, p. 339.

RF/Microwave EDA Tools Address Requirements for 5G Design, Simulation and Verification

Keysight Technologies
Santa Rosa, Calif.

The Keysight PathWave Design 2021 suite of EDA tools focuses on 5G design, simulation and verification. For RF/microwave applications, the PathWave Advanced Design System (ADS) addresses three critical requirements for 5G product development, requirements not satisfactorily met by other EDA tools:

- Assembling and performing 3D electromagnetic (EM)-circuit co-simulation on multi-technology modules
- Simulating performance with modulated signals and verifying performance with 5G modulation standards
- Analyzing the stability of multi-device amplifiers under small- and large-signal operation

INDUSTRY TRENDS

From 4G to 5G, operating frequencies have increased by a factor of 40, i.e., from the 700 to 2600 MHz bands to the 28 to 40 GHz bands. The density and complexity of system integration are increasing—adding phased array antennas, for example—and digital modulation has replaced analog. The implications of these changes for RF/microwave component designs are many:

Multi-technology Components – Design flows need to support the assembly and interconnect of multi-technology components—RFICs, MMICs, wafer-level packages, phased array antennas, laminates and PCBs—into dense, complex RF modules and subsystems. Design rule checking (DRC) and layout vs. schematic (LVS) for manufacturing sign-off must extend across the entire multi-technology structure.

3D EM Effects – EM effects at mmWave degrade circuit performance, increasing loss and coupling and shifting frequency. Circuit designers need to understand these 3D EM effects from packages and interconnects during design exploration, tuning and optimization, not just at the final verification of the completed design, when unexpected performance may force a redesign.

EVM Simulation – Digitally modulated RF signals require error vector magnitude (EVM) as the new figure of merit for circuit design and optimization. Traditional analog rules for 3G and 4G can lead to performance not meeting spec or over designing circuits, leading to greater power consumption.

Stability – Combining higher transistor gain, which is increased to offset high frequency losses at mmWave, with unwanted coupling from densely integrated circuit can lead to unstable amplifiers. Analyzing amplifier stability under nonlinear large-signal conditions is required to avoid unstable hardware.

Historic design flows are not adequate to ensure design success for 5G, automotive radar and other mmWave applications. Each component in a system cannot be designed stand-alone; they must be analyzed together, as an integrated system. From the transistor to the antenna far field, the EM, circuit and electrothermal analyses should be integrated across technology boundaries. It is not trivial to analyze ICs in packages with present design tools, and it is nearly impossible to analyze EM and real signals to understand the effects of modulated waveforms in a multi-technology 3D structure. Keysight developed PathWave ADS 2021 to address these difficulties, tapping its domain expertise in both measurement and simulation.

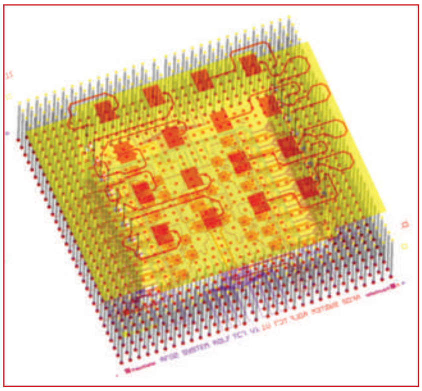


Fig. 1 A multi-technology, 60 GHz, WiGig module, assembled and simulated in ADS. *Source:* Global Foundries and Fraunhofer IIS/EAS/IZM.

MULTI-TECHNOLOGY MODULE CO-SIMULATION

ADS 2021 is an open EDA platform based on the open access (OA) database architecture for the efficient assembly and routing of 3D integrated RF module structures:

- RFIC and chip-scale antenna layouts based on OA (e.g., Virtuoso, EMPro)
- PCB and laminate layouts based on ODB++ (e.g., Allegro, Expedition, Zuken)
- ADS native MMIC and RF layouts

A unique assembly technology called SmartMount automatically handles different units (e.g., μm and nm for ICs; mm, mils and inches for PCBs and laminates), orientation (e.g., top/bottom mount, flip chip) and adjacent technology stack-up definitions. After assembly, ADS layout behaves as both a package and IC layout tool: building hierarchical sub-structures like an IC tool and "avoidance route" 3D interconnects like a package tool. This makes building and assembling packages straightforward, as well as accounting for package effects on the IC's performance (see ***Figure 1***). Another unique capability called module-level DRC and LVS ensures the correctness of the multi-technology module for building the hardware.

RFPro in ADS 2021 is an automated 3D EM-circuit co-simulation capability, enabling easy analysis of the EM performance of any portion of a design, without layout cookie cutting and tedious setup of ports, ground references and 3D EM simulation parameters. The 3D EM results are automatically combined with the circuit simulation to immediately analyze the EM effects of packaging, interconnect and coupling on circuit performance. This enables the circuit designer to perform 3D EM analysis and EM-circuit co-simulation seamlessly, without manual setup errors or waiting for scarce experts to perform the EM analysis. The result is orders-of-magnitude faster EM-circuit co-simulation, from weeks and months to seconds and minutes.

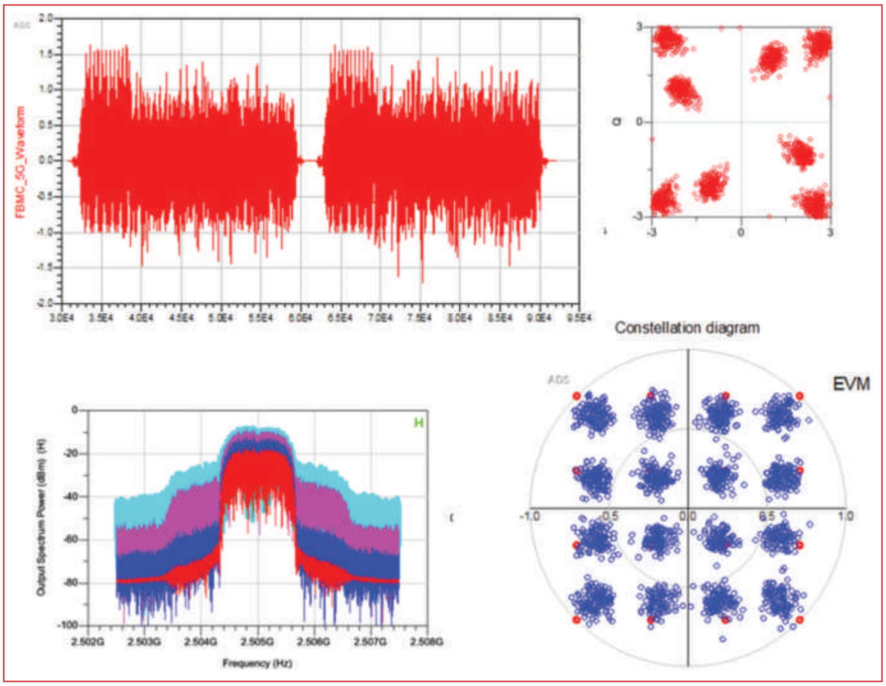


Fig. 2 ADS 2021 enables fast EVM simulation of circuits with digitally modulated signals using Keysight's test signal and distortion EVM algorithms.

CIRCUIT EVM SIMULATION

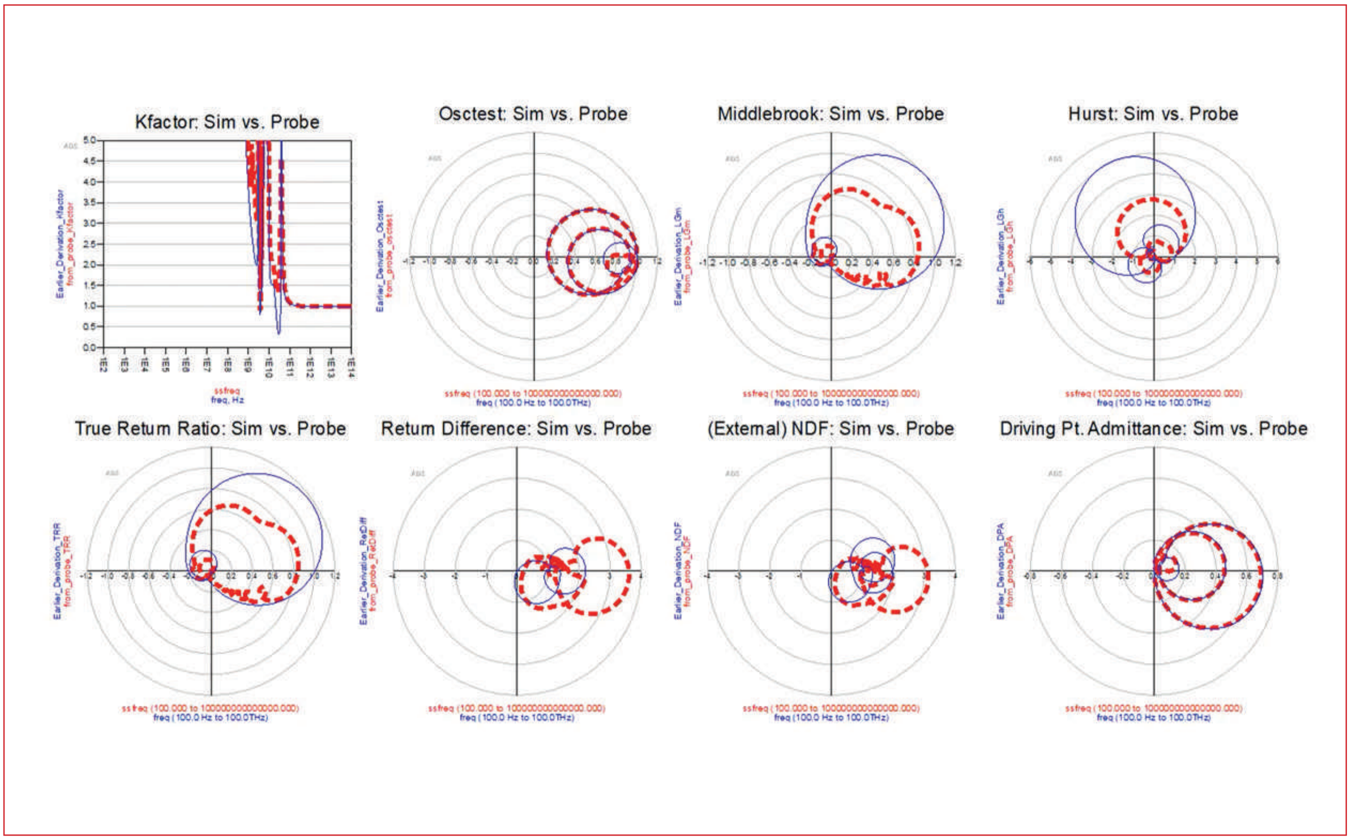
5G, automotive radar, Wi-Fi 6E and IoT—almost all wireless applications—employ digitally modulated signals, and EVM is the common figure of merit for measuring the linearity performance of a circuit or system with digital modulation. Particularly with increasing signal bandwidth and modulation density, traditional rules of thumb like P1dB or IP3 as indicators of linearity are obsolete.

ADS 2021 has the first circuit EVM simulation, using Keysight's fast EVM measurement and compact test signal algorithms (see ***Figure 2***). The capability enables designers to tune and optimize a design for EVM, removing inaccurate rules of thumb and guesswork when designing components or systems with digitally modulated signals.

ADS 2021 also offers Keysight's instrument grade 5G sources and demodulation algorithms in a pre-configured 5G virtual test bench (VTB), which eliminates the complicated setup for 5G compliance tests. VTBs provide accurate compliance verification for RF component designs before the hardware is built, establishing confidence early in the development cycle.

LARGE-SIGNAL STABILITY

With applications well into



▲ Fig. 3 **The Winslow stability analysis in ADS 2021 unifies all traditional stability tests with one simulation.**

mmWave frequencies—5G and automotive radar at 40 and 77 GHz, respectively—transistor gains have increased to offset mmWave losses. However, high gain with dense integration increase the risk of unstable amplifiers from unintended coupling. ADS 2021 provides a unique amplifier stability analysis called the Winslow technique, a unified simulation replacing 28 separate techniques (see ***Figure 3***). This single, all-encompassing stability analysis assesses amplifier stability under both small- and large-signal operating regions.

SUMMARY

Pathwave ADS 2021 enables the design, simulation and verification of RFIC, MMIC, RF module and RF PCB components and subsystems for 5G and other wireless applications, with capabilities not available in competing EDA tools. Using ADS 2021 for design, a company can have more confidence in the capability of its design process and achieve early design wins.

Keysight Technologies
Santa Rosa, Calif.
www.keysight.com

European Microwave Week 2020

The only European event dedicated to the Microwave and RF industry

The European Microwave Week 2020 takes place in the historic city of Utrecht. Bringing industry and academia together, the European Microwave Week 2020 is a SIX day event, including THREE cutting edge conferences, THREE Forums and ONE exciting trade and technology Exhibition featuring leading players from across the globe. EuMW 2020 provides access to the very latest products, research and initiatives in the microwave sector. It also offers you the opportunity for face-to-face interaction with those driving the future of microwave technology. EuMW 2020 will see an estimated 1,500 conference delegates, over 4,000 attendees and in excess of 300 international exhibitors (inc. Asia & US).

The Exhibition

Registration to the exhibition is FREE!

- Over 300 International Companies - meet the industry's biggest names and network on a global scale
- Cutting-edge Technology - exhibitors showcase their latest product innovations, offer hands-on demonstrations and provide the opportunity to talk technical with the experts
- Industrial Workshops - get first hand technical advice and guidance from some of the industry's leading innovators
- MicroApps - attend our annual European Microwave Week Microwave Application Seminars (MicroApps)

Be There

Exhibition Dates	Opening Times
Tuesday 12th January 2021	09:30 - 18:00
Wednesday 13th January 2021	09:30 - 17:30
Thursday 14th January 2021	09:30 - 16:30

The Conferences

The EuMW 2020 consists of three conferences, three forums and associated workshops:

- European Microwave Integrated Circuits Conference (EuMIC) 11th – 12th January 2021
- European Microwave Conference (EuMC) 12th – 14th January 2021
- European Radar Conference (EuRAD) 13th – 15th January 2021
- Plus Workshops and Short Courses (From 10th January 2021)
- In addition, EuMW 2020 will include the Defence, Security and Space Forum, the Automotive Forum and the 5G Forum

The three conferences specifically target ground breaking innovation in microwave research. The presentations cover the latest trends in the field, driven by industry roadmaps. The result is three superb conferences created from the very best papers submitted. For the full and up to date conference programme including a detailed description of the conferences, workshops and short courses, please visit www.eumweek.com. There you will also find details of our partner programme and other social events during the week.

How to Register

Registering as a Conference Delegate or Exhibition Visitor couldn't be easier. Register online and print out your badge in seconds onsite at the Fast Track Check In Desk. Online registration is open now, up to and during the event until 15th January 2021.

- Register online at **www.eumweek.com**
- Receive an email receipt with barcode
- Bring your email, barcode and photo ID with you to the event
- Go to the Fast Track Check In Desk and print out your badge
- Alternatively, you can register onsite at the self service terminals during the registration.

Please note: NO badges will be mailed out prior to the event.

Registration opening times:

- Saturday 9th January 2021 (16:00 - 19:00)
- Sunday 10th – Thursday 14th January 2021 (08:00 - 17:00)
- Friday 15th January 2021 (08:00 - 10.00)

Registration Fees

Full Week ticket: Get the most out of this year's Microwave Week with a Full Week ticket. Combine all three conferences with access to the Defence, Security and Space and the 5G forum (the Automotive forum is not included), and top your week off with Workshops or Short Courses of your choosing. To keep you fueled, lunch is included everyday, as are of course the social events: the EuMIC Get-Together, the Welcome reception and the EuRAD seated lunch.

Registration at one conference does not allow access to the sessions of the other conferences.

Reduced rates are offered if you have society membership to any of the following: EuMA*, GAAS, IET or IEEE. Reduced rates for the conferences are also offered if you are a Student/Senior (Full-time students 30 years or younger and Seniors 65 or older as of 18th September 2020). The fees shown below are invoiced in the name and on behalf of the European Microwave Association. Fees invoiced by EuMA with respect to the European Microwave Week 2020 are exempt from Dutch VAT. All payments must be in € (Euros) – cards will be debited in € (Euros).

CONFERENCES REGISTRATION	**ADVANCE DISCOUNTED RATE** (FROM 13TH SEPTEMBER UP TO & INCLUDING 6th DECEMBER 2020)				**STANDARD RATE** (FROM 7th DECEMBER 2020 & ONSITE)			
	Society Member*		**Non-Member**		**Society Member***		**Non-Member**	
1 Conference	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.
EuMC	€ 480,-	€ 130,-	€ 680,-	€ 190,-	€ 680,-	€ 190,-	€ 950,-	€ 260,-
EuMIC	€ 370,-	€ 120,-	€ 520,-	€ 170,-	€ 520,-	€ 170,-	€ 730,-	€ 240,-
EuRAD	€ 330,-	€ 110,-	€ 460,-	€ 160,-	€ 460,-	€ 160,-	€ 650,-	€ 220,-
2 Conferences	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.
EuMC + EuMIC	€ 680,-	€ 260,-	€ 960,-	€ 360,-	€ 960,-	€ 360,-	€ 1.340,-	€ 500,-
EuMC + EuRAD	€ 650,-	€ 250,-	€ 910,-	€ 350,-	€ 910,-	€ 350,-	€ 1.280,-	€ 480,-
EuMIC + EuRAD	€ 560,-	€ 240,-	€ 780,-	€ 330,-	€ 780,-	€ 330,-	€ 1.100,-	€ 460,-
3 Conferences	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.
EuMC + EuMIC + EuRAD	€ 830,-	€ 370,-	€ 1.160,-	€ 520,-	€ 1.160,-	€ 520,-	€ 1.630,-	€ 730,-
Full Week Ticket	€ 1.280,-	€ 750,-	€ 1.690,-	€ 970,-	€ 1.630,-	€ 920,-	€ 2.180,-	€ 1.200,-

* BECOME A MEMBER – NOW!

EuMA membership fees: Professional € 25,–/year, Student € 15,–/year.

One can apply for EuMA membership by ticking the appropriate box during registration for EuMW. Membership is valid for one year, starting when the subscription is completed. The discount for the EuMW fees applies immediately.

Members have full e-access to the International Journal of Microwave and Wireless Technologies. The printed version of the journal is no longer available.

EUMA KNOWLEDGE CENTRE
The EuMA website has its Knowledge Centre which presently contains over 20,000 papers published under the EuMA umbrella. Full texts are available to EuMA members only, who can make as many copies as they wish, at no extra-cost.

SPECIAL FORUMS AND SESSIONS REGISTRATION		**ADVANCED DISCOUNTED RATE** (UP TO & INCLUDING 6th DECEMBER 2020)		**STANDARD RATE** (FROM 7th DECEMBER 2020 & ONSITE)	
	Date	**Delegates***	**All Others****	**Delegates***	**All Others****
Automotive Forum	12th January 2021	€ 260,-	€ 360,-	€ 320,-	€ 420,-
5G Forum	15th January 2021	€ 60,-	€ 90,-	€ 80,-	€ 100,-
Defence, Security & Space Forum	13th January 2021	€ 20,-	€ 60,-	€ 20,-	€ 60,-
European Microwave Student School	12th January 2021	€ 40,-	€ 40,-	€ 40,-	€ 40,-
Tom Brazil Doctoral School of Microwaves	14th January 2021	€ 40,-	€ 40,-	€ 40,-	€ 40,-

* those registered for EuMC, EuMIC or EuRAD ** those not registered for a conference

Workshops and Short Courses

Despite the organiser's best efforts to ensure the availability of all listed workshops and short courses, the list below may be subject to change. Also workshop numbering is subject to change. Please refer to www.eumweek.com at the time of registration for final workshop availability and numbering.

NL MoD Reduced Rate

For the EuMW 2020 only, personnel of the NL MoD can register at a reduced rate. This very attractive rate includes access to EuRAD, the DSS Forum and the exhibition, lunch boxes on Wednesday and Thursday and the seated EuRAD lunch. The Advance Discounted rate for this is € 100,- (up to and including 6th December 2020), and € 140,- from 7th December 2020 onwards. No further options or combined discounts will be available.

SUNDAY 10th January 2021			
WS-01	EuMIC	Full Day	High Performance GaN MMICs
WS-02	EuMIC/EuMC	Full Day	Advanced RF Technologies for 5G
WS-04	EuMC	Full Day	Recent Advances in Additive Manufacturing of Microwave Components
WS-05	EuMIC	Full Day	Integrated Doherty PAs for Cellular and mmWave Applications
WS-07	EuMIC	Full Day	Sub-mmWave On-Wafer Measurements
WS-08	EuMIC	Half Day PM	mmWave Phased Array Front-End ICs for 5G
WS-09	EuMIC/EuMC	Half Day PM	Advanced Measurement Techniques for Next Generation Communication Systems
SS-01	EuMIC	Full Day	Fundamentals of Microwave PA Design
MONDAY 11th January 2021			
WM-01	EuMC	Full Day	Microwave Wearable Circuits and Systems for Biomedical Applications
WM-02	EuMC/EuRAD	Half Day AM	Advanced Applications of In-Band Full-Duplex Technology
WM-03	EuMC	Full Day	Antenna/Modules in Package for mmWave for 5G
WM-04	EuMC	Full Day	High-Power Microwave Industrial Applications
WM-05	EuMC	Full Day	Measurements at mmWave and Terahertz Frequencies of Three Measurement Quantities: S-Parameters, Power, and Complex Permittivity of Dielectric Materials
WM-06	EuMIC/EuMC	Half Day PM	From Enabling GaN Technology to High-Performing Space-Borne SSPAs at mmWave
SM-01	EuMIC/EuMC	Half Day AM	From Device Characterisation to Amplifier Design: Advanced Large Signal Measuring, Fast and Accurate Modelling, and Reliable Designing
SM-02	EuMC/EuRAD	Half Day PM	Multibeam Antennas and Beamforming Networks
SM-03	EuMC	Half Day PM	Intuitive Microwave Filter Design with EM Simulation
TUESDAY 12th January 2021			
WTu-01	EuMC	Full Day	Digital Predistortion for 5G MIMO Wireless Transmitters
WTu-02	EuMC/EuRAD	Half Day PM	Advanced mmWave Radar System Solutions for Industrial and Consumer Sensing Applications
WEDNESDAY 13th January 2021			
WW-02	EuMIC/EuMC	Full Day	High-Efficiency Linear Power Amplifiers for High Bandwidth, High PAR Signals
WW-03	EuRAD	Half Day PM	Automotive Radar Networks and Sensor Fusion
SW-01	EuMIC/EuMC	Half Day AM	High Power Amplification for Space Applications
SW-02	EuMIC/EuMC	Full Day	Quantum Computing for Electrical Engineers
THURSDAY 14th January 2021			
WTh-01	EuRAD	Half Day AM	High Resolution Radar for Automotive
WTh-02	EuMC	Full Day	5G and Beyond: Enabling RF Architectures and Technologies for Emerging Wireless Systems
WTh-03	EuRAD	Half Day PM	Recent Advances in Micro-Doppler Radar and its Applications
FRIDAY 15th January 2021			
WF-01	EuMC	Half Day AM	Wireless Power Transmission Recent Research Advances
WF-02	EuMC	Half Day AM	Recent Advances in Topologies, Technologies and Practical Realizations of Microwave Sensors
WF-03	EuMC	Half Day AM	Recent Advances on Microwave Filters
WF-04	EuMC	Full Day	Practical Aspects of Running a Microwave Laboratory and How to Make Good Measurements Every Time
SF-01	EuRAD	Half Day AM	Cognitive Radar Signal Processing
SF-02	EuRAD	Half Day PM	Introduction to MIMO Radar

WORKSHOPS AND SHORT COURSES	**IN COMBINATION WITH CONFERENCE REGISTRATION**				**WITHOUT CONFERENCE REGISTRATION**			
	Society Member		**Non-Member**		**Society Member**		**Non-Member**	
	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.
Half Day	€ 100,-	€ 70,-	€ 130,-	€ 100,-	€ 130,-	€ 100,-	€ 170,-	€ 130,-
Full Day	€ 140,-	€ 100,-	€ 190,-	€ 140,-	€ 190,-	€ 140,-	€ 250,-	€ 190,-

Multi-Channel AWG and Digitizer in One Box

Spectrum Instrumentation GmbH
Grosshansdorf, Germany

The hybridNETBOX is a new instrumentation platform for applications that require simultaneous signal generation and acquisition. Six models are available, offering the choice of two, four or eight pairs of matched arbitrary waveform generator (AWG) and digitizer channels, with output and sampling rates of 40, 80 and 125 MSPS (see ***Figure 1***).

With the ability to create and acquire signals at the same time, these products are tailored for measurement systems that perform automated closed loop or stimulus-response testing. For example, they can reproduce and capture "echo" signals, such as radar, sonar, lidar and ultrasound. With multi-channel capability, they can test these systems even when arrays of transmitters and receivers are used. The hybridNETBOX is also suited to automated test equipment applications where component and subassembly test is fast and automated. They can quickly determine the functionality and tolerance of units being tested by exercising them with numerous, easily adjusted, complex signals. This powerful testing process can be deployed in a host of applications like bus testing, MIMO communications, circuit verification, mechatronics and robotics.

For accurate, low noise waveform generation and acquisition, the units use the latest 16-bit digital-to-analog and analog-to-digital converter technology. All channels are synchronized with a common clock and trigger. The AWG channels can produce almost any waveform with signal amplitudes to ±6 V into 50 Ω or ±12 V into a high impedance load. Waveform output modes include single shot, loop, first in first out (FIFO) streaming, gated replay and sequence replay. This permits easy creation of test routines from simple to complex.

The digitizer channels handle a wide range of input signals, with variable input ranges from ±200 mV to ±10 V and fully programmable offset, as well as selectable input impedance, i.e., 50 Ω or 1 MΩ. Single-ended and differential measurement modes are available. Like the AWG channels, the digitizer supports several operating modes, including single shot, FIFO streaming, multiple recording, gated sampling and sample rate switching (ABA). To ensure an important event is never missed, the digitizers have several flexible trigger modes: channel, external, software, window, pulse, re-arm, spike, logic and delay.

In addition to the digitizer and AWG chan-

Fig. 1 The front panel of the hybridNETBOX contains the digitizer and AWG channels, with digital I/O connectors to integrate the box into a test system.

nels, the front panel of each hybridNETBOX includes multiple digital I/O connectors, so it is easy to integrate units into a larger test system. For example, synchronous marker outputs can be used on the AWG channels for precise control of other devices or instruments. Similarly, the unit can be synchronized with other equipment by applying an external clock and triggers. The hybridNETBOX instruments are fully LXI compliant, so they are easily controlled and operated by connecting to a PC or network using the rear panel Gbit Ethernet port.

The instruments come with all tools to start generating waveforms and acquiring signals. Each hybridNETBOX includes Spectrum's control software—SBench 6—for signal generation, acquisition, display, signal processing, storage and reporting (see ***Figure 2***). Using SBench 6, waveforms can be created using standard functions and mathematical equations. Data can be acquired with the digitizer portion of the instrument, then transferred to the AWG for replay. Data sharing with other programs or devices, such as oscilloscopes, is possible using the built-in import and export functions, using binary, ASCII or Wave formats. Fully programmable, the hybridNETBOX comes with drivers for Windows and Linux operating systems, as well as programming examples for C++, LabVIEW, MATLAB, Visual Basic .NET, Python and other popular programming languages.

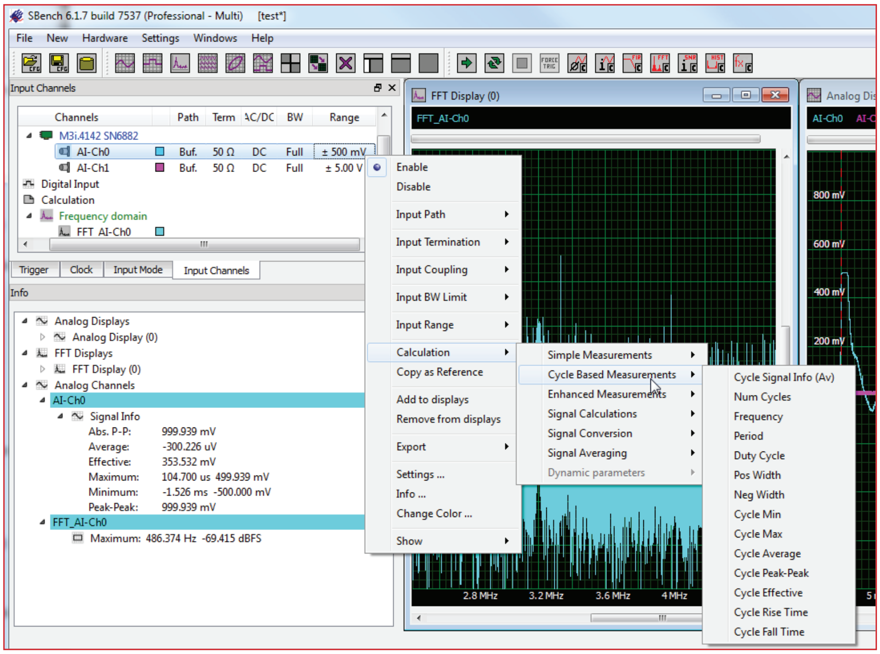


Fig. 2 The hybridNETBOX includes SBench 6, software for signal generation, acquisition, display, signal processing, storage and reporting.

With more than 30 years designing and building fast AWGs and digitizers, Spectrum offers an industry-leading five year warranty for customer peace of mind. This includes free software and firmware updates during the lifetime of each unit. Customers can get support directly from Spectrum's hardware and software engineers.

Spectrum created the hybridNETBOX series for engineers and scientists who require precise, simultaneous waveform generation and signal acquisition in manual, automated or remotely controlled applications. These portable LXI instruments offer unique hardware and software capabilities, enabling users to tailor the instruments to their specific testing requirements while speeding up testing. The hybridNETBOX is available now, with delivery typically two to three weeks after receipt of a purchase order.

VENDORVIEW

Spectrum Instrumentation
Grosshansdorf, Germany
www.spectrum-instrumentation.com

70 GHz Linear-in-dB RMS Power Detector

The LTC®5597 is a high accuracy RMS power detector that provides a very wide RF input bandwidth, from 100 MHz up to 70 GHz. This makes the device suitable for a wide range of RF and microwave applications, such as point-to-point microwave links, SATCOM, instrumentation, military radio, Wi-Fi, LTE/5G and power control applications.

The DC output voltage of the detector is an accurate representation of the average signal power applied to the RF input, independent of input waveforms with different crest factors such as CW, WCDMA and OFDM (LTE and Wi-Fi) signals. The response is linear-in-dB with 28.5 mV/dB logarithmic slope over a 35 dB dynamic range with typically better than ±1 dB accuracy.

The LTC5597 can measure signals down to -37 dBm, about 10 dB better than any Schottky device which can save the expense of an amplifier in the signal path. It has ±2 dB flat frequency response up to 60 GHz, enables accurate measurement of very broadband signals and minimizes need for calibration (single frequency may be sufficient). The LTC5597 evaluation board uses a 5 mils thick layer of Rogers RO3003 material for the top substrate to achieve low dielectric losses up to 7 GHz.

The detector is well suited for measurement of waveforms with crest factor as high as 12 dB and waveforms that exhibit a significant variation of the crest factor during measurement. To achieve higher accuracy and lower output ripple, the averaging bandwidth can be externally adjusted by a capacitor connected between the FLTR and OUT pins. The enable interface switches the device between active measurement mode and a low power shutdown mode.

The LTC5597 is a unique RMS detector operating above 40 GHz, enabling accurate power measurement in Q- and V-Band SATCOM, point-to-point links and a range of instrumentation and ATE equipment. It is a much more compact, higher performance solution than alternative discretely built and tuned Schottky detectors and other competing solutions.

VENDORVIEW

Analog Devices
Norwood, Mass.
www.analog.com

Easily Extend Low Frequency Test Equipment to mmWave

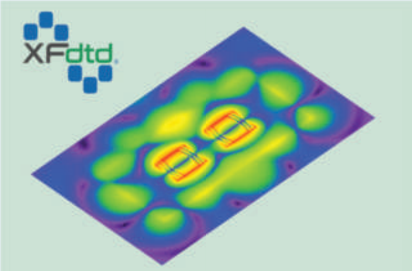
Today's communication standards, such as 5G, are using higher frequencies and wider bandwidths. To support testing these new wireless standards, the thinkRF™ D4000 RF Downconverter/Tuner extends the performance of lower frequency RF test equipment to 40 GHz. Using thinkRF's tuner technology, the D4000 is the industry's first 40 GHz RF down-converter and tuner. The high performance, plug-and-play, portable platform enables mobile operators and system integrators to use existing field, lab and manufacturing test equipment, which extends the life of their investments while reducing the time to market for the new generation of 5G systems.

The D4000 covers 24 to 40 GHz — the currently defined FR2 bands for 5G — with 500 MHz of analog bandwidth. It has a single IF output, enabling easy integration with lower frequency spectrum analyzers and receivers, and the built-in local oscillator eliminates the need for an external synthesizer. Sophisticated pre-select filtering rejects out-of-band signals and reduces spurs which could interfere with the "real" signals within the analysis band.

Multiple D4000 units can be synchronized to create a compound signal monitoring system, particularly when more than 500 MHz instantaneous bandwidth must be monitored. 10 MHz input and output clock references enable clock synchronization with external equipment. Using complementary thinkRF receivers, a monitoring system can be extended to cover lower frequencies, such as the sub-6 GHz 5G bands.

The D4000 is controlled with standard configuration protocols using SCPI commands over an Ethernet interface. The size of the unit is 7.6 in. x 7.6 in. x 1.6 in., and it weighs 3.7 lbs. — making the D4000 RF Downconverter/Tuner portable, as well as versatile and easy to use.

thinkRF
Ottawa, Canada
www.thinkrf.com



mmWave Antenna Design Advancements in XFdtd

The new version of XFdtd® 3D EM Simulation Software includes features to address 5G mmWave antenna design challenges, adding support for high performance tuners and singularity correction. Also, enhancements to importing printed circuit boards (PCB) save time in the design workflow.

As mobile devices grow in complexity, engineers are challenged to include more antennas in less space while maximizing efficiency. Multi-port RF devices such as tuners and switches are used to optimize band coverage. To accommodate these innovations, XFdtd's Circuit Element Optimizer now includes multi-port device functionality, enabling engineers to incorporate and test these components in matching network simulations.

Singularity correction is a sophisticated meshing method that accurately captures highly varying electromagnetic fields around the conductive edges of geometries such as antennas and transmission lines. XFdtd adjusts the electric and magnetic field values adjacent to metallic edges during time stepping. For higher frequency and mmWave designs, where numerous antennas and components create high spatial field variations, singularity correction can significantly improve the accuracy and increase confidence in the expected behavior of a device.

This new XFdtd release also includes enhancements to importing PCBs, enabling the documentation layers to be imported alongside the geometry. These layers typically include useful manufacturer information, such as the build date of the device and ID number. Lumped circuit components specified in ODB++ and BRD files are also imported, eliminating the need to manually add them.

VENDORVIEW

Remcom Inc.
State College, Pa.
www.remcom.com

CatalogUpdate

Learn About ERZIA's Latest Products Inside the 2020 Product Guide

VENDORVIEW

ERZIA Technologies has released its new Product Guide for 2020. The new product guide presents a newly expanded product portfolio in an easy-to-access format. The PDF contains links directly to the web page for each product so you can quickly and painlessly get to the product information that matters to you most. The current lineup of ERZIA products includes some of the most robust devices and modules available. The guide details LNAs and HPAs by bandwidth and lists all of ERZIA's microwave assemblies.

ERZIA Technologies
https://www.erzia.com

Wide Range of Products for Space Connectivity Solutions

VENDORVIEW

HUBER+SUHNER has published an updated edition of their catalogue for space applications which includes a variety of cable assemblies, connectors and solutions designed specifically for space flight, satellite communication applications and ground testing in clean rooms or thermal-vacuum environments. Sourcing, traceability and assembly processes are performed according to ESA, NASA and MIL standards. Benefit from vast heritage and expertise in developing and manufacturing state-of-the art microwave components offering outstanding electrical and mechanical performance.

HUBER+SUHNER AG
hubersuhner.com

Download K&L Microwave's Product Catalogs Today!

K&L Microwave designs and manufactures a full line of RF and microwave filters, duplexers and subassemblies, including ceramic, lumped element, cavity, waveguide and tunable filters. K&L supplies many of today's most significant military and homeland security electronics programs. Applications include space flight, radar, communications, guidance systems and mobile radio base stations, as well as air traffic communication and control.

K&L Microwave
www.klmicrowave.com

New Product Guide

VENDORVIEW

Mini-Circuits continues to release new products at a record pace. The Q4 2019 New Product Guide showcases some of the company's latest model releases including ultra-wideband coaxial amplifiers up to 43.5 GHz, MMIC splitter/combiners with multi-octave bandwidths from DC to 43.5 GHz, connectorized passives up to 65 GHz, new LTCC products and more.

Mini-Circuits
www.minicircuits.com

Brochure: Aerospace, Security & Defence

Rosenberger provides a comprehensive portfolio of high-reliable interconnect components and devices qualified for spaceflight, aerospace, security and defence applications. A wide range of products fulfill the stringent requirements of MIL-PRF 39012 standard, DIN EN 9100 or even ESCC Certification of the European Space Agency. A new brochure showcases Rosenberger's wide product range qualified for this area—RF coaxial components, microwave components and cable assemblies, RF test and measurement products or fibre optic connectivity components.

Rosenberger
www.rosenberger.com/aerospace

Extend the Range of Your Existing RF Equipment to 40 GHz, Economically

Enhance the lifetime of your RF systems with small, versatile, cost-effective, networkable and low power thinkRF D4000 RF Downconverter/Tuner. 500 MHz analog bandwidth, built-in local oscillators, pre-select filtering and single IF output in smaller than a notebook and light (3.7 lb.) form factor. Mobile operators, system integrators, defence and aerospace agencies can retain existing critical EW RF platforms, field, lab and manufacturing test equipment, extend the life of their investment, reduce time to market and costs when measuring 5G signals.

thinkRF
https://thinkrf.com/products/rf-downconverters/d4000-rf-downconverter/

NEW PRODUCTS

FOR MORE NEW PRODUCTS, VISIT WWW.MWJOURNAL.COM/BUYERSGUIDE
FEATURING VENDORVIEW STOREFRONTS

COMPONENTS

Bandpass Filter Bank

VENDORVIEW

AM3152 is a miniature digitally tunable bandpass filter bank covering the 0.4 to 8 GHz frequency range in a 6 mm QFN package. The device contains three tunable filter bands each with 256 discrete cutoff states and a low-loss filter bypass path. AM3152 is an excellent front-end for a receiver providing both low insertion loss and valuable flexibility for tuning center frequency and bandwidth. Its small size, weight and power consumption make it an attractive choice for demanding applications requiring low SWaP components.

Atlanta Micro Inc.
www.atlantamicro.com

Mini Air Core Inductors

Coilcraft has released their latest mini air core inductors, the 1512SP/2712SP Series. Specs for the series include inductance values from 2.5 to 150 nH (tolerances as low as 2 percent), tight tolerance can eliminate circuit tuning, acrylic jacket provides a flat top for pick and place, exceptionally high Q over a wide frequency range, solder coated leads ensure reliable soldering, wide range of standard EIA inductance values, available in two sizes.

Coilcraft
www.coilcraft.com

Three-Way Power Divider/Combiner

Model P03N003180 is a three-way 0.3 to 18 GHz DC pass through power divider/combiner, it has 2.7 dB maximum insertion loss, 16 dB minimum isolation, 1.5: 1 maximum VSWR, ±0.6 dB amplitude balance and ±5 phase balance. The input power as the power divider is 20 W average. As combiner, it can stand for 5 W average input power. The size is 279.4 × 40.6 × 12.7 mm, the operating temperature is -54° to +85°C.

Fuzhou MIcable Electronic Technology Co. Ltd.
www.micable.cn

mmWave Controlled Components

General Microwave Corp. is a key partner with major OEM's and primes, having been chosen for their broad and comprehensive understanding of mmWave controlled components. General Microwave offers a wide range of mmWave products operating in the 18 to 40 GHz frequency range including catalog attenuators, switches and phase shifters as well as integrated microwave assemblies. If it is a standard catalog unit or a highly customized mmWave product designed specifically for high performance, General Microwave can provide products to support your requirements.

Kratos General Microwave Corp.
wwwkratosmed.com

26 to 34 GHz, 20 dB Directional Couplers

VENDORVIEW

MECA expanded its offering of 5G mmWave products. Featuring 10 dB couplers covering 26 to 34 GHz with 2.92 mm interfaces. Typical specifications of 1.5:1 VSWR, 15 dB directivity, 1 dB insertion loss and 0.4 dB frequency sensitivity. Also available are attenuators, terminations, bias tee's, DC blocks and adapters. Additionally octave and multi-octave models covering up to 50 GHz built by J-Standard certified assemblers and technicians. Made in U.S. and 36-month warranty.

MECA Electronics Inc.
www.e-meca.com/mmwave-products/couplers

MLBF-Filter Test Box

500 MHz to 50 GHz standard models utilize any bandpass or band reject filter manufactured by Micro Lambda are available today. Bandpass filter models cover 500 MHz to 50 GHz and are available in four, six and seven stage configurations. Band reject (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, are CE certified and LabVIEW compatible.

Micro Lambda Wireless
www.microlambdaWireless.com

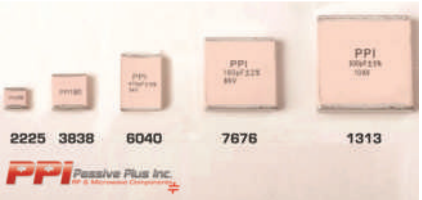
Switch Matrix Controls

VENDORVIEW

Mini-Circuits' model RC-2SPDT-A26 is a broadband single-pole, double-throw (SPDT) switch matrix well suited for systems and test applications from DC to 26.5 GHz. It consists of a pair of independent absorptive SPDT electromechanical switches with Ethernet and USB connectivity that can be controlled directly from a personal computer or over a network with user-friendly software for Windows operating systems. The 50 Ω switches operate with 25 ms typical switching speed in failsafe, make-before-break configurations on a +26 V DC supply at operating temperatures from 0 to +40°C.

Mini-Circuits
www.minicircuits.com

High Power Capacitors



Passive Plus, Inc. (PPI) is known for their outstanding customer service, high-quality product line, competitive pricing and quick delivery times. While other companies are pushing out their lead-times for product delivery, PPI is committed to being able to deliver your needs as quickly as possible. As PPI tries to keep a full inventory in stock, depending on the capacitor and quantities needed, delivery times can be stock to eight weeks.

Passive Plus Inc.
www.passiveplus.com

Phase Modulators

VENDORVIEW

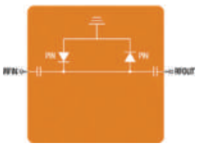
Pasternack has just launched a new line of bi-phase modulators that includes a comprehensive selection of nine different models covering broad octave frequency bands ranging from 0.5 to 40 GHz. Bi-phase modulators take a TTL level digital bits stream that is encoded onto the RF carrier using 2 Phase Shift Keying (2PSK) modulation, where the two phases are separated by 180 degrees. This performance is desirable in communications systems,

microwave radio, radar, high-data-rate test and measurement, serial data transmission, base station infrastructure and other industrial and military applications.
Pasternack
www.pasternack.com

RF Limiter
VENDORVIEW

PMI model no. LM-20M18G-100 W-15 DBM is an RF limiter that operates in the frequency range of 20 MHz to 18 GHz. This limiter can handle up to 100 W CW more than 20 MHz to 18 GHz, for all temperatures (-55°C to +85°C). The energy input provides leaks of +15 dBm maximum. This model has a low insertion loss of 2.60 dB and a maximum recovery time of 100 ns, limiting threshold (P1dB) +5 dBm minimum and VSWR of 2.0:1 maximum at -10 dBm input power.
Planar Monolithics Industries Inc.
www.pmi-rf.com

Dual PIN Limiter Diode Module



Skyworks introduced a high linearity, low threshold, dual PIN limiter diode module that addresses the growing need for receiver protection in cellular infrastructure (including 5G) and microwave radio communications. The SKY16603-632LF is a fully integrated module comprised of two PIN limiter diodes and two DC blocking caps designed for use as a passive receiver protector in wireless systems up to 6 GHz. It can also be used in broad market wireless systems including VSAT, S-Band radar, military communications transceivers, jammers, GPS, test instruments, automotive and Wi-Fi applications.
Skyworks Solutions Inc.
www.skyworksinc.com

CABLES & CONNECTORS

Aluminum Flat Wires

Bruker-Spaleck supplies the engineered flat wire solution out of aluminum (also high purity aluminum Al99,99) for your requirements, no matter if you want to bond circuit boards, connect several electrical components (e.g. in battery modules or cables) for spring applications or save weight and metal costs. They are able to produce the finest dimensions in the range t = 0.050 ... 0.400 mm / w = 0.400 ... 4.000 mm. Several customers are already using their flat wire out of aluminum in their products.
Bruker-Spaleck
www.bruker-spaleck.com

Adaptor Series

Response Microwave Inc. announced the availability of between-series 1.0 mm to 1.85 mm to its comprehensive adaptor series for use in ATE and production applications. Operational from DC to 65 GHz, the new product offers maximum VSWR of 1.25:1 and insertion loss of 0.07 $\times \sqrt{f} \times$ 0.5 dB maximum. Units withstand the -55°C to +105°C temperature range and configurations are available in all gender combinations for each interface.
Response Microwave Inc.
www.responsemicrowave.com

AMPLIFIERS

Broadband Amplifier
VENDORVIEW

The model 1000A400 is a solid-state, self-contained, air-cooled, broadband amplifier designed for applications where instantaneous bandwidth, high gain and linearity are required. The model 1000A400, when used with a sweep generator, will provide a minimum of 1,000 W of RF power. Included is a front panel gain control which permits the operator to conveniently set the desired output level. The RF amplifier stages are protected from over-temperature by removing the DC voltage to them if an over-temperature condition occurs due to cooling blockage or fan failure.
AR RF/Microwave Instrumentation
www.arworld.us

Amplifier
VENDORVIEW

Exodus AMP2120-3 is designed for broadband EMI-Lab, Comm. and EW applications. Ultra-wide frequency range, class A/AB linear design for all modulations and industry test standards. Covering 1 to 18 GHz, producing 20 W minimum and 25 W typical with a minimum gain of 43 dB. Excellent gain flatness, optional monitoring parameters for forward/reflected power, VSWR, voltage, current and temperature sensing with superb reliability and ruggedness.
Exodus Advanced Communications
www.exoduscomm.com

18 to 42 GHz Connectorized Low-Noise Amplifier

Richardson RFPD Inc. announced the availability of a new wideband low-noise amplifier from ERZIA Technologies S.L. The ERZ-LNA-1800-4200-24-6 provides a gain of 24 dB with a noise figure of 5 dB. The device's compact size and modularity make it ideal for a wide range of applications, including industrial, SATCOM, aerospace and military.
Richardson RFPD
www.richardsonrfpd.com

NewProducts

SOURCES

SFS Series PLOs

VENDORVIEW

Z-Communciations' SFS series PLOs offer high performance and quick integration for various RF applications. The SFS2400E-LF offers a fixed frequency output of 2.4 GHz, with a user supplied reference of 10 MHz. For a higher form of integration, the RFS15000C-LF, with its on-board reference, will speed up design and time to market. Provide a 5 Vcc and 3 Vcc supply to generate a fixed frequency of 15 GHz. Further optimization is available through custom reference source and loop bandwidth filter designs.

Z-Communications
www.zcomm.com

SOFTWARE

3D Geometry Models

VENDORVIEW

Modelithics introduces 19 full-wave EM capable 3D geometry models for the TDK MLG0603S series surface mount inductor. The models are now available within Modelithics COMPLETE+3D Library for Ansys® HFSS™. Individual 3D models are available from 0.9 to 100 nH and are validated against multi-substrate measured S-parameters through 20 GHz and ESR, as well as against the corresponding Modelithics CLR Global Circuit model. TDK is a Sponsoring Modelithics Vendor Partner and is sponsoring free 90-day trials of all available Modelithics TDK models.

Modelithics
www.modelithics.com/mvp/tdk

TEST & MEASUREMENT

MilliBox Products

VENDORVIEW

The mini-chambers fit on lab benches as a personal test setup. Construction is easily customizable and configurable with robust and lightweight material for everyday use. Features include: compact and economical, 80 cm far-field distance, gimbal and horn mounts included, laser guided alignment, open software controller interface over USB. Designed for applications between 18 to 95 GHz. Best suited for 24 GHz radar, 5G (NR) UE, 60 GHz modules. MilliBox products are cost effective test tools and accessories specially designed for mmWave over-the-air measurements.

Milliwave Silicon Solutions Inc.
www.millibox.org

Ultra 3U VPX Modul Dynamic Engagement System

SPEC has expanded its tactical and range systems to include the ADEP T4000 ultra 3U VPX module dynamic engagement system, which pairs a 100 MHz to 20 GHz VPX transceiver with a digital signal processing board. The flight-qualified system can generate up to 4,000 false targets and a kinematic scenario programming environment. Includes features such as: multiple output channels for complex simulations, MTI and SAR simulation, 1 GHz instantaneous bandwidth, <60 dB dynamic range and multiple resolution options.

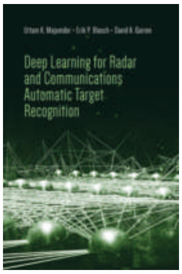
Systems & Processes Engineering Corp. (SPEC)
www.spec.com

Downconverter/Tuner

Increase frequency performance of your RF test equipment to 40 GHz without buying a whole new suite of analyzers, a large capital investment and requiring any intensive training. The D4000 RF downconverter/tuner has 500 MHz of analog bandwidth—the widest on the market in this compact (7.6"×7.6"×1.6"), light (1.7 lb.) form factor. D4000 requires low power; ideal for spectrum monitoring, antenna pattern and beamforming airborne verification application, interference hunting, signal acquisition and RF drive-testing.

thinkRF
www.thinkrf.com

MICRO-ADS



Deep Learning for Radar and Communications Automatic Target Recognition

Uttam K. Majumder, Erik P. Blasch, David A. Garren

This authoritative resource presents a comprehensive illustration of modern artificial intelligence/machine learning (AI/ML) technology for radio frequency data exploitation. It identifies technical challenges, benefits and directions of deep learning based object classification using radar data, including synthetic aperture radar (SAR) and high range resolution (HRR) radar. The performance of AI/ML algorithms is provided from an overview of ML theory that includes history, background primer and examples. Radar data issues of collection, application and examples for SAR/HRR data and communication signals analysis are discussed. In addition, *Deep Learning for Radar and Communications Automatic Target Recognition* presents practical considerations of deploying such techniques, including performance evaluation, energy-efficient computing and the future unresolved issues.

To order this book, contact:

Artech House
www.artechhouse.com
Email: artech@artechhouse.com
US 800-225-9977
UK +44 (0)20 70596 8750

ISBN: 978-1-63081-637-7
290 pages
$179
£146
Use code MAJ25 to receive 25% discount on this title! (expires 10/31/2020)

https://us.artechhouse.com/Deep-Learning-for-Radar-and-Communications-Automatic-Target-Recognition-P2074.aspx

SIX DAYS ■ THREE CONFERENCES ■ ONE EXHIBITION

EUROPE'S PREMIER MICROWAVE, RF, WIRELESS AND RADAR EVENT

EuMW 2021 United in Microwaves
EUROPEAN MICROWAVE WEEK
EXCEL, LONDON
10-15 OCTOBER 2021
www.eumw2021.com

COME JOIN US...

EUROPEAN MICROWAVE WEEK 2021

EXCEL LONDON EXHIBITION
& CONVENTION CENTRE, LONDON, UK
10TH – 15TH OCTOBER 2021

THE 24TH EUROPEAN MICROWAVE WEEK COMBINES:

- The European Microwave Conference (EuMC)
- The European Microwave Integrated Circuits Conference (EuMIC)
- The European Radar Conference (EuRAD)

PLUS:

- Workshops, Short Courses and Special Sessions
- The Defence, Security and Space Forum
- The Automotive Forum
- The Beyond 5G Forum
- Student Activities
- The European Microwave Exhibition

EuMA European Microwave Association

Official Publication: Microwave Journal

Organised by: horizon house

Supported by: IET The Institution of Engineering and Technology

Co-sponsored by: MTT-S

Co-sponsored by: IEEE

EuMIC 2021
The 16th European Microwave Integrated Circuits Conference
Co-sponsored by: GAAS, Electron Devices Society

51st European Microwave Conference 2021
The 51st European Microwave Conference
Co-sponsored by: AP-S, EurAAP, APMC 2021

EuRAD 2021
The 18th European Radar Conference
Co-sponsored by: AP-S, EurAAP

INTERESTED IN EXHIBITING? CALL +44(0) 20 7596 8742 OR VISIT WWW.EUMW2021.COM

Advertising**Index**

Sales Representatives

Eastern and Central Time Zones
Carl Sheffres
Publisher
(New England, New York, Eastern Canada)
685 Canton Street
Norwood, MA 02062
Tel: (781) 619-1949
FAX: (781) 769-5037
csheffres@mwjournal.com

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

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

Israel
Dan Aronovic
Tel: 972 50 799 1121
aronovic@actcom.co.il

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

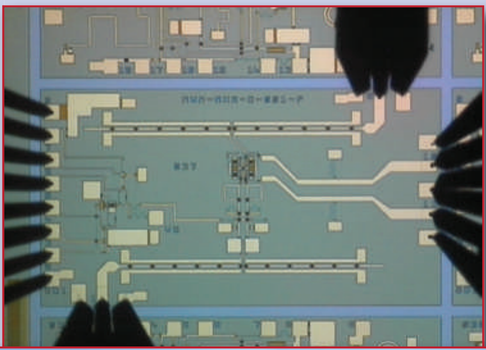
Hong Kong, Taiwan, Singapore
Mark Mak
ACT International
Tel: 852-28386298
markm@actintl.com.hk

Japan
Katsuhiro Ishii
Ace Media Service Inc.
12-6, 4-Chome,
Nishiiko, Adachi-Ku
Tokyo 121-0824, Japan
Tel: +81 3 5691 3335
FAX: +81 3 5691 3336
amskatsu@dream.com

Ed Kiessling • Traffic Manager • 685 Canton Street, Norwood, MA 02062 • Tel: (781) 619-1963 FAX: (781) 769-6178 • ekiessling@mwjournal.com

FABS and LABS

PRFI: Developing Microwave and mmWave MMICs, RFICs and Modules

PRFI is an independent design house specializing in the design and development of microwave and mmWave RFICs, MMICs and modules. Unusual in the sector of high frequency components and subsystems, PRFI has no catalog of standard products. Instead, it sells its design services to equipment manufacturers, as well as the component manufacturers themselves. To suit precise customer requirements, most of its designs are application specific and some technology demonstrators to establish the feasibility of new techniques or the ability to meet emerging requirements, like 5G mmWave beamforming.

Formerly known as Plextek RFI, the company's highly experienced team of eight design engineers has developed more than 100 custom microwave and mmWave ICs using a range of GaAs and GaN processes and foundries, including GCS, Qorvo, Sanan IC, UMS, WIN Semiconductors and Wolfspeed. Among the MMIC designs: mmWave 5G ICs and modules for the world's leading telecom companies, including a single chip front-end module for 28 GHz 5G. The team simulates designs using Keysight ADS, for which PRFI's senior designers are "certified experts."

This IC design expertise is complemented by practical experience with mmWave surface-mount packaging, including overmolded and air-cavity plastic and custom laminate. PRFI has a track record developing high frequency packaging solutions proven for volume production. The team has also developed many microwave and mmWave modules and subsystems, including high power amplifiers and gain and phase control modules.

PCB fabrication and assembly, chip and wire assembly and prototype module production are all subcontracted, in many cases to local specialist companies around Cambridge, U.K., near PRFI's labs and offices. Subcontract packaging of PRFI-designed ICs occurs both in the U.K. and offshore. Testing of ICs and modules, with tuning and adjustments to modules, can be performed on site. PRFI's 2,800-square-foot facility in Great Chesterford includes two laboratories: a mmWave clean room for measuring bare die using direct, on-wafer probing and an RF lab for measuring connectorized modules and packaged components. Test capabilities include S-parameters, power compression, IP3 and noise figure to 50 GHz.

PRFI's clients are an international "Who's Who" of the microwave industry, names such as Analog Devices, Inmarsat, Qorvo, Sony, Raytheon, Thales, pSemi, Samsung, TDK and BAE Systems. Many customers, including Sony and Qorvo, have engaged multiple successful designs with PRFI. Sony cites "professionalism, attention to detail and their ability to quickly grasp the project requirements and key targets" among its reasons for collaborating with PRFI. Raytheon says it is "very impressed by the level of MMIC design experience at PRFI, where the team demonstrated both in-depth technical knowledge and a detailed commercial understanding."

The name change to PRFI in July 2020 was motivated to avoid confusion with Plextek Services Ltd., with whom it still shares the site. PRFI has been an independent limited company since 2015, originally formed from the RF Integration Group within Plextek Ltd. In its 20-year history, PRFI has been recognized across the world as an innovator designing microwave and mmWave RFICs, MMICs and modules.

www.prfi.com

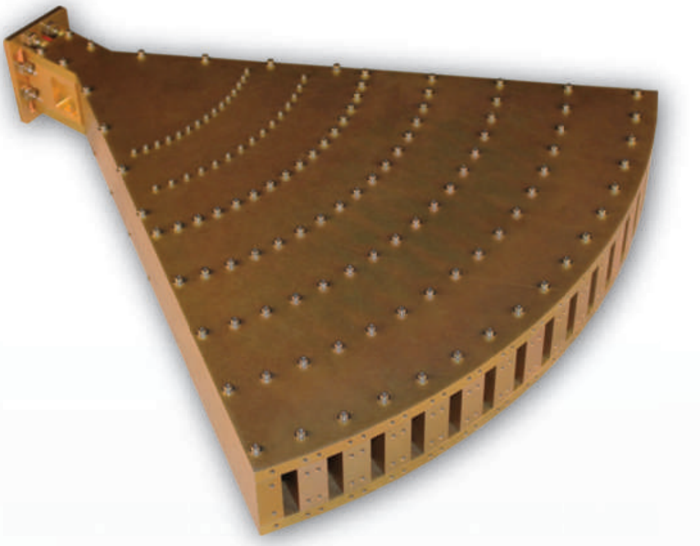

EDI
CON
ONLINE
LEARN FROM
INDUSTRY
EXPERTS FOR FREE

WERLATONE®

WE ARE HIGH POWER

NEW E-PLANE COMBINERS

Higher CW Power & Increased Duty Cycle Relative to Radial Combiners



C-Band
E-Plane 16-Way Combiner
5300 - 5900 MHz
12,000 W CW, 2.5 MW Peak
WR159 Output, Half Height WR159 Inputs

- Combine Multiple High Power Solid State Power Amplifiers
- Planar Structures
- N-Way Architectures
- Coaxial or Waveguide Inputs
- Extremely Low Insertion Loss
- Scalable for S, C, X, Ku, Ka Bands
- Patented Werlatone Technology

*** CW & Peak Power of E-Plane Limited by Power Handling of Waveguide Output Connector Rating.**

Frequency	Output Waveguide	Radial Combiners	E-Plane Combiners
S-Band	WR284	≈ 2.0 kW CW	**≈ 36.0 kW CW**
C-Band	WR159	≈ 1.6 kW CW	**≈ 12.0 kW CW**
X-Band	WR90	≈ 0.55 kW CW	**≈ 2.4 kW CW**
Ku-Band	WR62	≈ 0.42 kW CW	**≈ 1.4 kW CW**
Ka-Band	WR28	≈ 0.02 kW CW	**≈ 0.4 kW CW**

Werlatone, Inc. 17 Jon Barrett Road Patterson, NY 12563 845-278-2220 sales@werlatone.com www.werlatone.com