Vol. 61 • No. 6
June 2018

# Microwave Journal


Celebrating
Wireless Innovation

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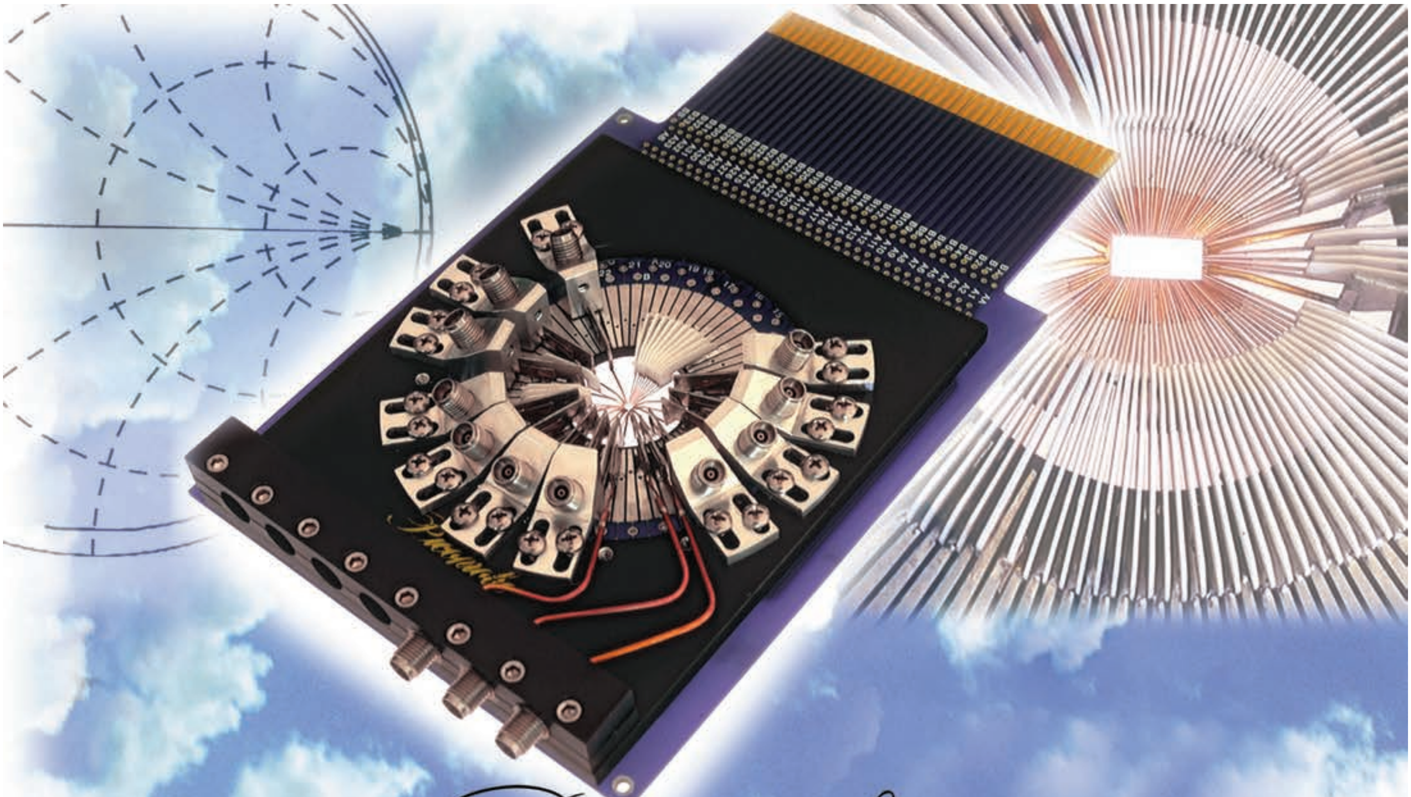
mwjournal.com



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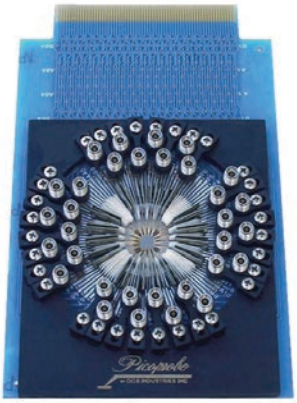

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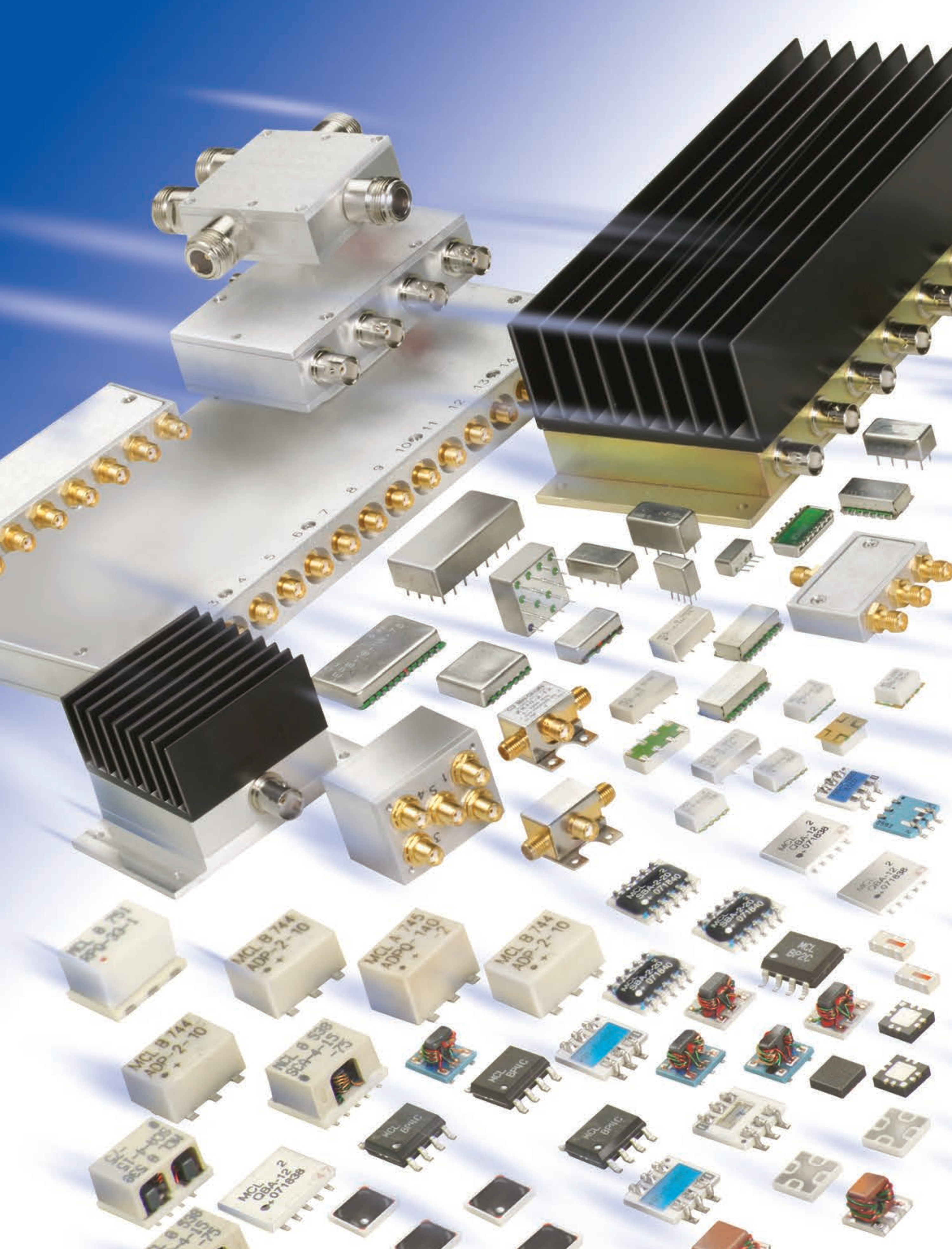
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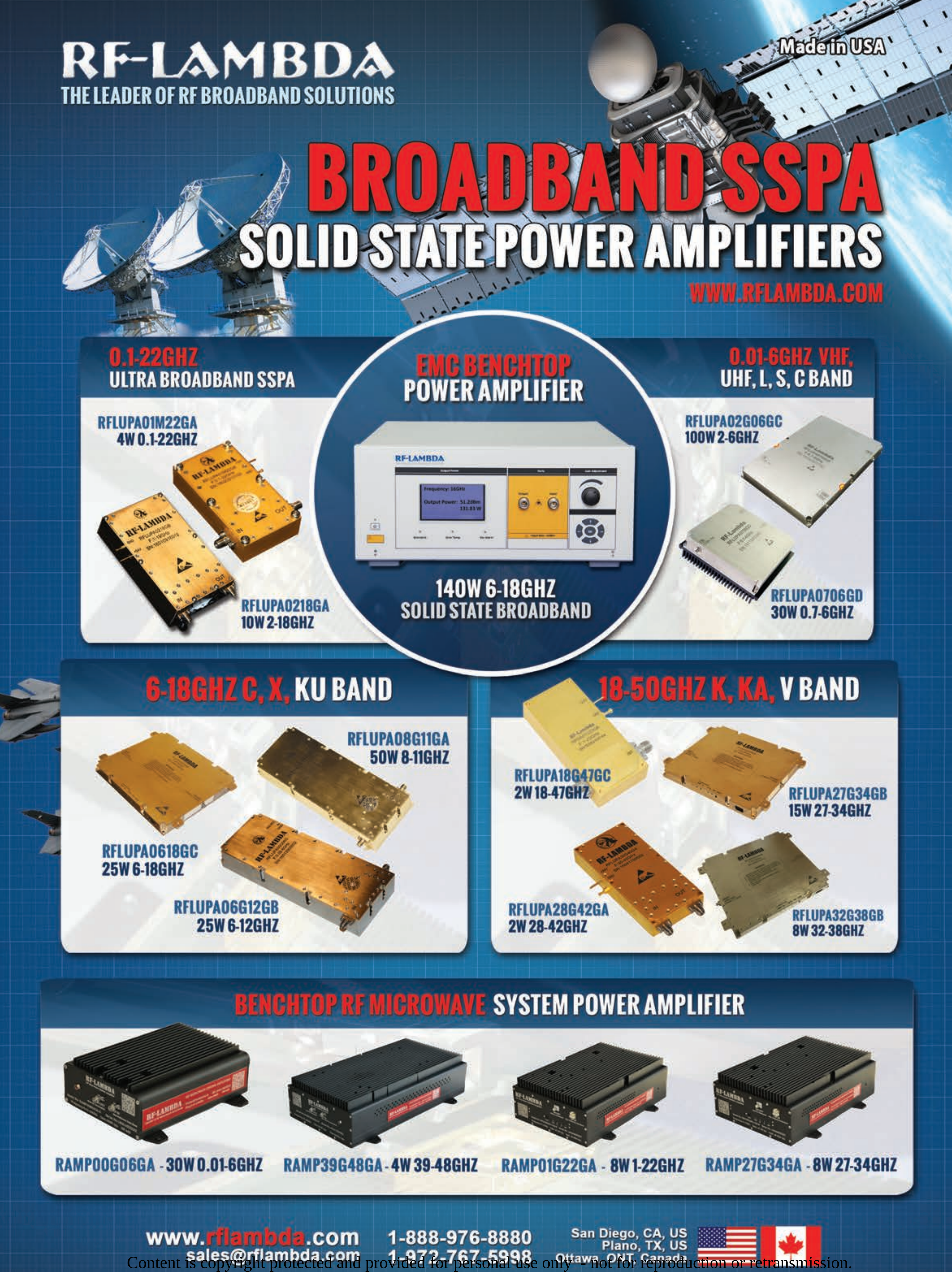
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June 2018
Vol. 61 • No. 6
Diamond Anniversary Issue +
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## On This Month's Cover

*Microwave Journal* celebrates its 60th year in publishing with its Diamond Anniversary issue featuring how diamond materials are used in advanced RF/microwave semiconductor applications. The diamond on the cover features four key scientists on its facets that paved the way for the wireless industry in the early 1900s. Pictured from left to right are Guglielmo Marconi, Nikola Tesla, Heinrich Hertz and James Clerk Maxwell.

View animation: mwjournal.com/diamond

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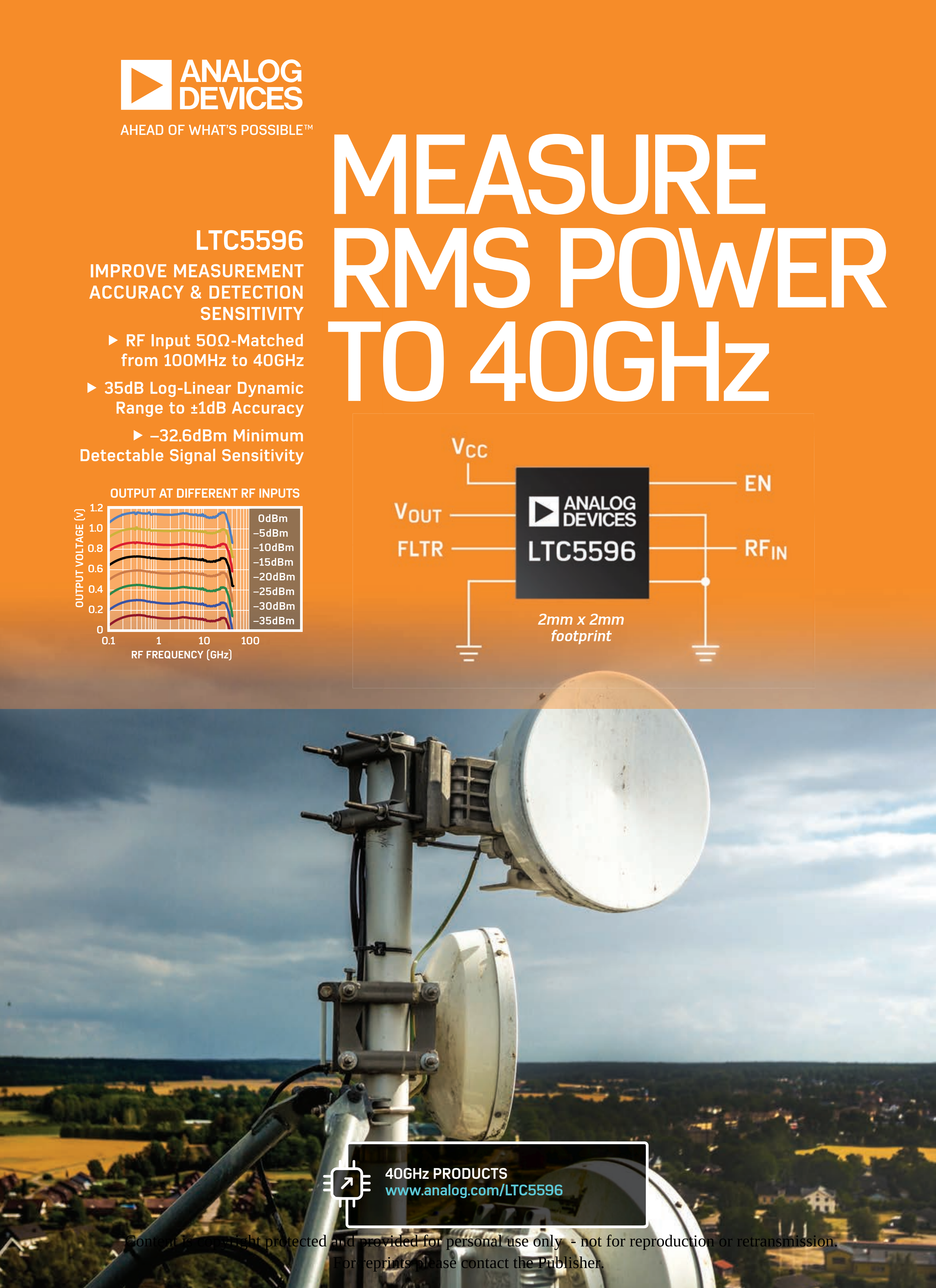
61 YEARS OF PUBLISHING EXCELLENCE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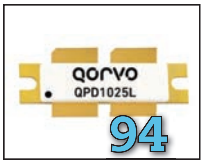


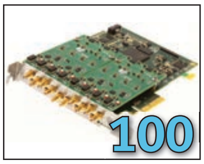


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## E LEARNING CENTER


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**MIMO Radars and Their Conventional Equivalents**
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*Sponsored by: Rohde & Schwarz* 6/28

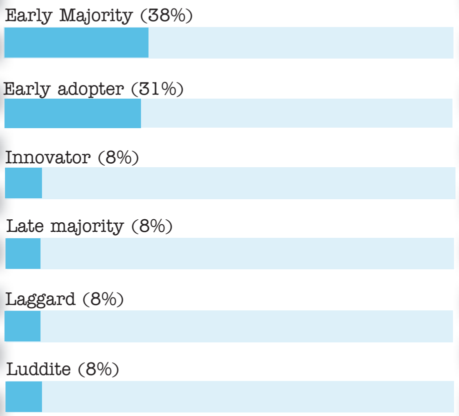

## Web Survey

What microwave innovation from the 1950s had the most impact on the industry?

Look for our multiple choice survey online at mwjournal.com

### April Survey

Where do you (personally) fall on the technology adoption curve?




## Executive Interviews


**Michael Maslana**, founder and CEO of RFE, and **Mike England**, president and CTO, discuss how **Spinnaker Microwave** became **RFE** and the capabilities and products the reinvented company is bringing to market.


**Analog Devices' John Cowles**, GM of RF and microwave products, and **Bryan Goldstein**, GM of aerospace and defense, discuss how their businesses are solving market problems using ADI's breadth of technology.

## WHITE PAPERS

Altair — 5G Antenna Design for 5G Communications

JFW — When Choosing Test Equipment, Don't Forget the Interface

Rohde & Schwarz — Millimeter-Wave Beamforming: Antenna Array Design Choices & Characterization

Rohde & Schwarz — LTE-Advanced Pro Introduction eMBB Technology Components in 3GPP Release 13/14

SAGE Millimeter, Inc. — The Challenges of Using Direct Reading Attenuators and Current Solutions

TRM Microwave — Passive RF and Microwave Beamformer Networks

# JULY

## MARK YOUR CALENDAR

# 6

**Call for Papers Deadline**

I MaRC

IEEE IMaRC is held annually in India to provide a forum for the international community of microwave engineers to meet and present their latest technical achievements in microwave and RF components, circuits, systems and modelling methods. Papers submitted to IMaRC 2018 will be peer reviewed and those presented will be submitted for publication in IEEE Xplore.
**https://imarc-ieee.org**

TRAINING:

# 11-12

CST

**Scalable Active Sensor Architectures**
Framingham, Mass.

TRAINING:

# 18-19

CST

**CST STUDIO SUITE - EMC/EMI Training**
Dearborn, Mich.

# 10-12

SEMICON WEST
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San Francisco, Calif.

SEMICON West connects the entire extended microelectronics supply chain from materials, equipment, design, manufacturing, system integration and demand channels to new verticals and adjacencies. With several hundred exhibitors, more than 100 hours of diverse programming and dozens of networking opportunities, the conference provides the insights, access and technical and business intelligence needed to get ahead in today's disruptive, fast-changing business environment. **www.semiconwest.org**

# 23-25

ELECTRONICS RESURGENCE INITIATIVE
San Francisco, Calif.

DARPA's ERI Summit brings together those most impacted by the coming inflection in Moore's Law to jump-start innovation and foster forward-looking collaborations across the U.S. electronics community. The ERI Summit is an opportunity to discuss and explore the future of electronics systems with senior representatives from the commercial sector, defense industrial base, academia and government. **www.eri-summit.com**

# 24

Signal Integrity Journal WEBINAR

**Practical PCB Layout for SI/PI/EMC: What an EE Needs to Know to Survive PCB Manufacturing**
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# 24

**Call for Papers Deadline**

RWW Radio & Wireless Week
20 - 23 January 2019
Orlando, Florida

Authors are invited to submit papers for presentation at RWW2019. All papers accepted will be published in a digest and included in IEEE Xplore. Radio & Wireless Week consists of six related conferences that focus on the intersection between wireless communication theory, systems, circuits and device technologies. This creates a unique forum for engineers to discuss various technologies for state-of-art wireless systems and their end-use applications.
**www.radiowirelessweek.org**

FOR DETAILS, VISIT MWJOURNAL.COM/EVENTS

# Coming**Events**

## CALL FOR PAPERS

IEEE IMaRC
July 6, 2018

Radio and Wireless Week 2019
July 24, 2018

IEDM 2018
August 1, 2018

EMV 2019
August 13, 2018

IEEE MTT-S IMS 2019
December 1, 2018

WAMICON 2019
February 1, 2019

**mwjournal.com**

## JUNE

**Sensors Expo 2018**
June 26–28, 2018 • San Jose, Calif.
www.sensorsexpo.com

**MILSATCOM USA 2018**
June 27–28, 2018 • Arlington, Va.
www.smi-online.co.uk/defence/northamerica/MilSatCom-USA

## JULY

**SEMICON West 2018**
July 10–12, 2018 • San Francisco, Calif.
www.semiconwest.org

**ERI Summit 2018**
July 23–25, 2018 • San Francisco, Calif.
www.eri-summit.com

**IEEE Symposium on EMC+SIPI 2018**
July 30–Aug. 3, 2018 • Long Beach, Calif.
www.emc2018usa.emcss.org

## AUGUST

**IEEE MTT-S NEMO 2018**
August 8–10, 2018 • Reykjavik, Iceland
https://nemo-ieee.org/

**IEEE RFIT 2018**
August 15–17, 2018 • Melbourne, Australia
http://rfit2018.org/

**Metamaterials 2018**
August 27–Sept. 1, 2018 • Espoo, Finland
www.congress2018.metamorphose-vi.org

## SEPTEMBER

**PCB West 2018**
September 11–13, 2018 • Santa Clara, Calif.
www.pcbwest.com/

**MWC Americas 2018**
September 12–14, 2018 • Los Angeles, Calif.
www.mwcamericas.com

**IEEE AUTOTESTCON**
September 17–20, 2018 • National Harbor, Md.
www.autotestcon.com

**EuMW 2018**
September 23–28, 2018 • Madrid, Spain
www.eumweek.com

## OCTOBER

**2018 IEEE BCICTS**
October 14–17, 2018 • San Diego, Calif.
https://bcicts.org/

**EDI CON USA 2018**
October 17–18, 2018 • Santa Clara, Calif.
www.ediconusa.com

**MILCOM 2018**
October 29–31, 2018 • Los Angeles, Calif.
https://events.afcea.org/MILCOM18/Public/enter.aspx

**ESC Minneapolis**
October 31–Nov.1, 2018 • Minneapolis, Minn.
www.escminn.com

## NOVEMBER

**AMTA 2018**
November 4–9, 2018 • Williamsburg, Va.
https://amta2018.org/

**Global MILSATCOM 2018**
November 6–8, 2018 • London, U.K.
www.globalmilsatcom.com

**APMC 2018**
November 6–9, 2018 • Kyoto, Japan
https://apmc2018.org/

**electronica 2018**
November 13–16, 2018 • Munich, Germany
https://electronica.de/index.html

**IEEE IMaRC 2018**
November 28–30, 2018 • Kolkata, India
https://imarc-ieee.org

## DECEMBER

**IEDM 2018**
December 1–5, 2018 • San Francisco, Calif.
https://ieee-iedm.org

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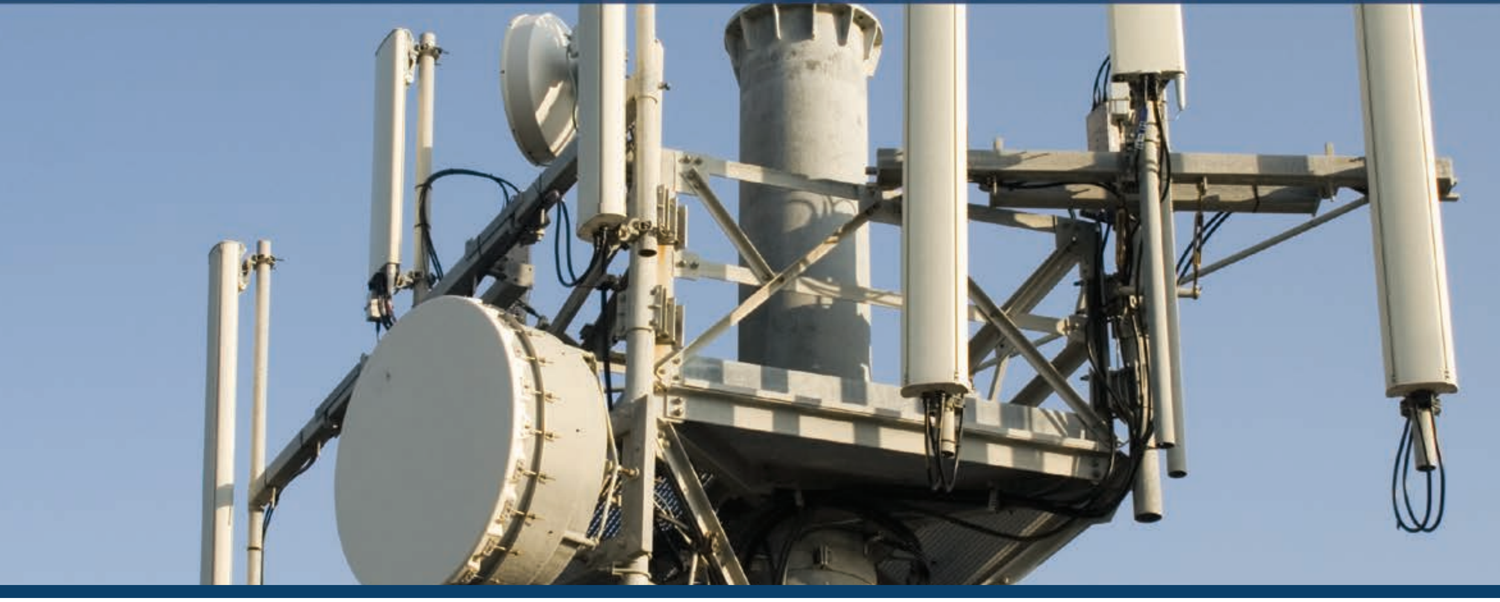

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| AD9364 | 70 MHz to 6 GHz | 56 MHz | 1 Rx, 1 Tx | JESD207 CMOS/LVDS | <1.5 W |
| AD9371 | 300 MHz to 6 GHz | 100 MHz Rx, 250 MHz Tx | 2 Rx, 2 Tx, 2 ORx, 3 SnRx | 6 Gbps JESD204B | <5 W |
| AD9375* | 300 MHz to 6 GHz | 100 MHz Rx, 250 MHz Tx | 2 Rx, 2 Tx, 2 ORx, 3 SnRx | 6 Gbps JESD204B | <5 W |

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# Celebrating Industry Diamond Anniversaries

*Pat Hindle*, Microwave Journal *Editor*


In July of 1958, a group of industry pioneers led by William "Bill" Bazzy and Theodore "Ted" Saad launched *Microwave Journal*. This month we celebrate our diamond anniversary in our 60th year of publishing with a cover feature focused on diamond technologies used in RF/microwave applications from GaN on diamond to diamond passive devices, to diamond materials in packaging. We would also like to celebrate other companies and organizations celebrating their diamond anniversaries this year including W.L. Gore, Rosenberger, C.W. Swift, DARPA and NASA.

*Microwave Journal* staff have designed a special cover for this celebration, using a matte finish background and a glossy surface treatment on the diamond graphic to accentuate the diamond's "shine." On the facets of the diamond, we celebrate some of the key inventors and engineers who laid the groundwork and science for the wireless industry: Marconi, Tesla, Hertz and Maxwell. In addition, we have implemented augmented reality on the cover using the free app, Layar.


Download Layar and scan the cover to experience our short animated tribute to these wireless innovators and the founders of *Microwave Journal*.


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## *MICROWAVE JOURNAL*—THE FIRST RF/MICROWAVE INDUSTRY JOURNAL

In the 1950s as radar and communications technology transformed into commercial applications after the war, the microwave community was expanding quickly. Many of these companies were looking for new customers and applications. Several forward-looking people came to believe that a new publication was needed to share information about the technology and the issues faced by these young businesses since this was not the focus of existing IEEE publications. They felt discussion within the community would open up new markets and generate new design techniques for microwave devices and components.

Ted Saad became a leading advocate for publishing technical information as he witnessed how the RadLab series from MIT Radiation Labs had become a foundation of microwave engineering at the time. By 1958, Ted had gained some editorial experience working with the *IEEE Transactions*, and had knowledge of technical article editing and reviewing.

Bill Bazzy learned communications and electronics engineering while serving in the military in the 1940s. As a young radio and television broadcast engineer in Boston, he participated in the growth of national broadcast networks, including working at RCA Technologies. Seeing a need for technology information to serve professionals in the broadcasting and communications industries, Bill and his brother Emil, who had a printing press, organized Horizon House Inc. to pursue their publishing venture.

Bazzy and Saad teamed up and made the decision to publish a trade magazine about microwave technology. The Bazzy brothers would handle the production of the magazine and the business of selling advertising. Bazzy would be the publisher and Saad would serve as the magazine's first technical editor. They brought together a team of engineering colleagues that would solicit and review articles from the community at large, with notable contributions from industry pioneers such as Seymour Cohn, Henry Jasik, Ben Lax, Marshall Pease, Tore Anderson and Gershon Wheeler—and *Microwave Journal* was born.

In the 1970s, Horizon House/*Microwave Journal* worked with IEEE MTT-S to launch an exhibition for the MTT-S International Microwave Symposium (IMS), managing the event for close to 30 years until 2009. Horizon House/*Microwave Journal* continued to expand its exhibition activities, managing European Microwave Week on behalf of the European Microwave Association since 2003 and launching its own event platform, Electronic Design Innovation Conference (EDI CON), in China in 2013 and in the U.S. in 2016. In 2012, *Microwave Journal* launched a Chinese language version, *Microwave Journal China*, and in 2017, *Signal Integrity Journal* was introduced as an online magazine to serve high speed, digital design engineers, as the demand for design information about signal integrity, power integrity and EMI increased.

Today, Horizon House consists of *Microwave Journal/Signal Integrity Journal*; Telecom Media Group, with its M2M events and IoT council; and leading technical book publisher Artech House. Horizon House has an office in London in addition to its Norwood, Mass. headquarters—all of which started with Bill and Ted's vision for *Microwave Journal* 60 years ago.

## W.L. GORE—A TEAM-ORIENTED CULTURE

W.L. Gore & Associates is a global materials science company that has been transforming industries and improving lives for 60 years. The company got its start developing products for the wire and cable industry. Their first product was an insulated ribbon cable, Multi-Tet cable, that won Gore a contract from the Denver Water Co. in 1960. Almost all of their products are based on the material polytetrafluoroethylene (PTFE) and started in founder Bill Gore's basement in 1958, but over the years have expanded into a variety of industries with its unique physical and electrical properties.

Since then, Gore has built a reputation for solving complex technical challenges in the most demanding environments—from revolutionizing the outerwear industry with GORE-TEX® fabric to creating medical devices that improve and save lives, to enabling new levels of performance in the aerospace, pharmaceutical and mobile electronics markets, among other industries. Gore employs more than 10,000 employees at over 50 facilities around the world, and is known for its strong, team-oriented culture and continued recognition from the Great Place to Work® Institute.

Their organization is completely flat, with everyone carrying the title of associates and managers called sponsors. This non-traditional organizational structure and culture has been shown to be a significant contributor to Gore's employee satisfaction and retention, with one of the best retention rates in the world (full-time volunteer turnover is only about 3 percent). Gore is easily recognized in many labs and trade shows by their iconic purple color and is well-known for making some of the highest performance, most rugged cables in the industry.

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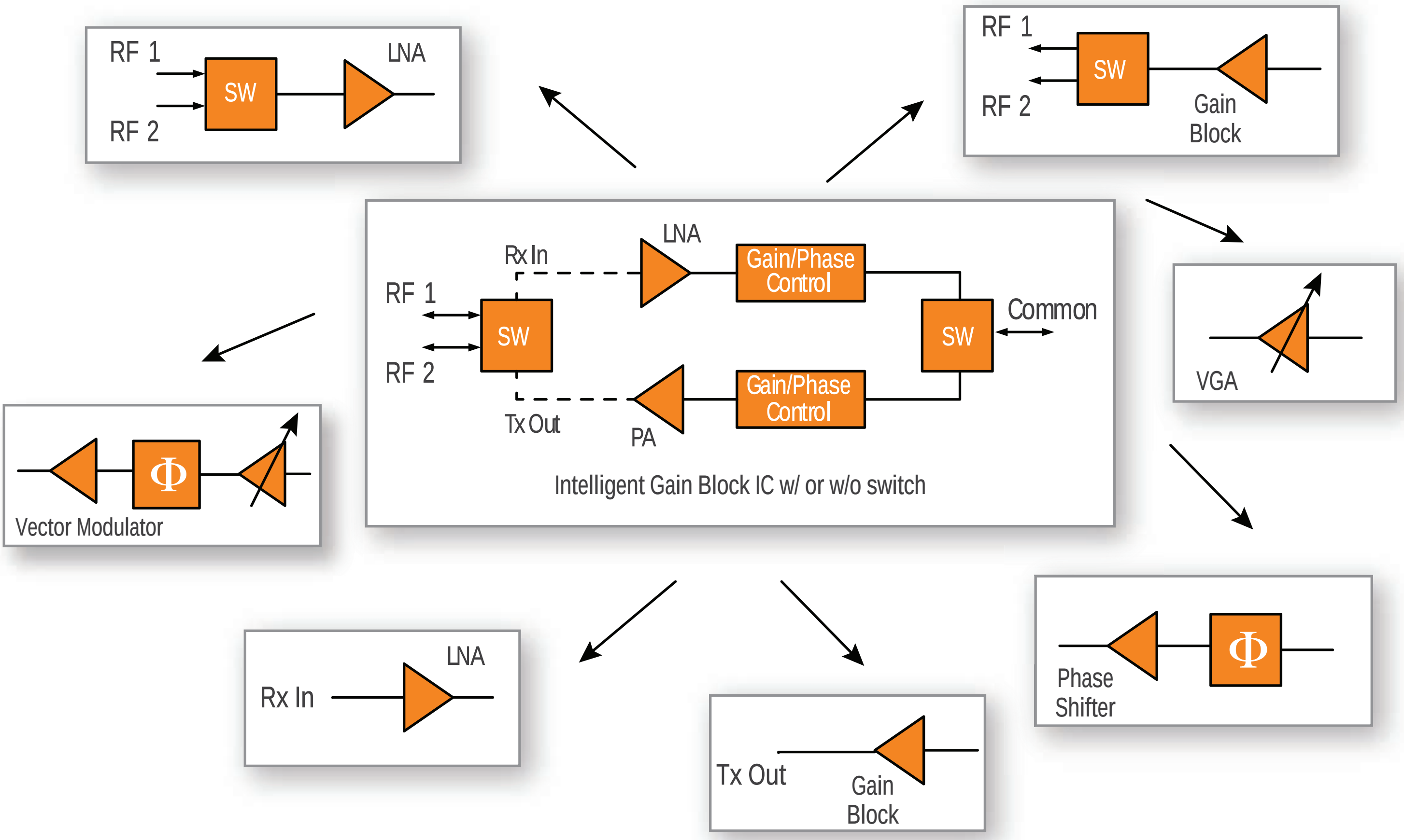


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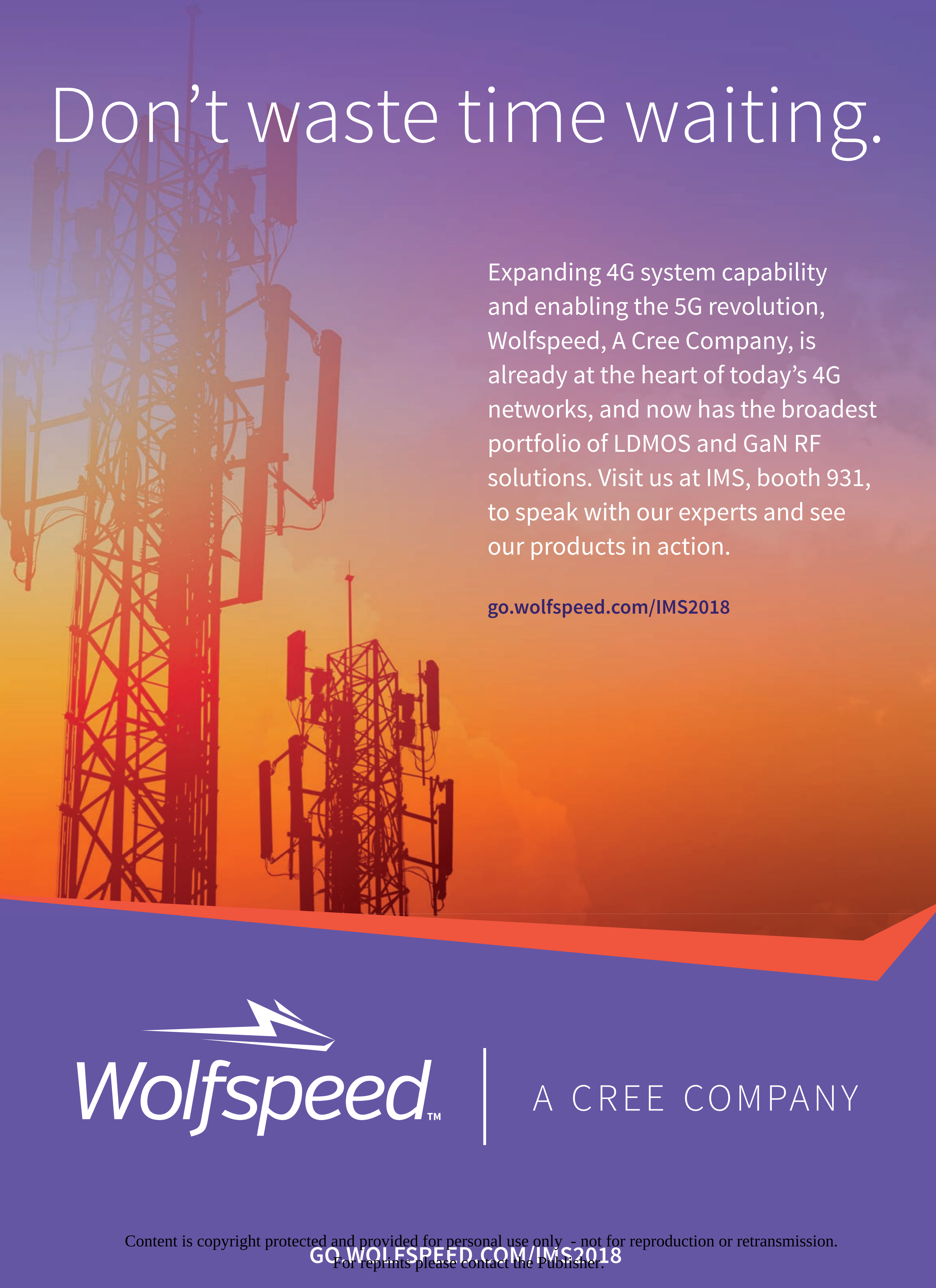
Rosenberger was founded by Hans Rosenberger Sr. in Tittmoning, Germany and is still a family-owned enterprise. In 1968, the company moved to its current headquarters in neighboring Fridolfing and entered the high frequency technology sector. In the 1970s, high frequency products became Rosenberger's main source of revenue and started large scale manufacturing of miniature connectors. The 1990s saw a rapid expansion with offices opening in the U.S., South America, China and Singapore.

Worldwide, the Rosenberger group operates manufacturing and assembly locations as well as Rosenberger sales offices in Europe, Asia and North and South America, where about 10,000 employees develop, produce and sell its products.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## C.W. SWIFT—A FAMILY AFFAIR

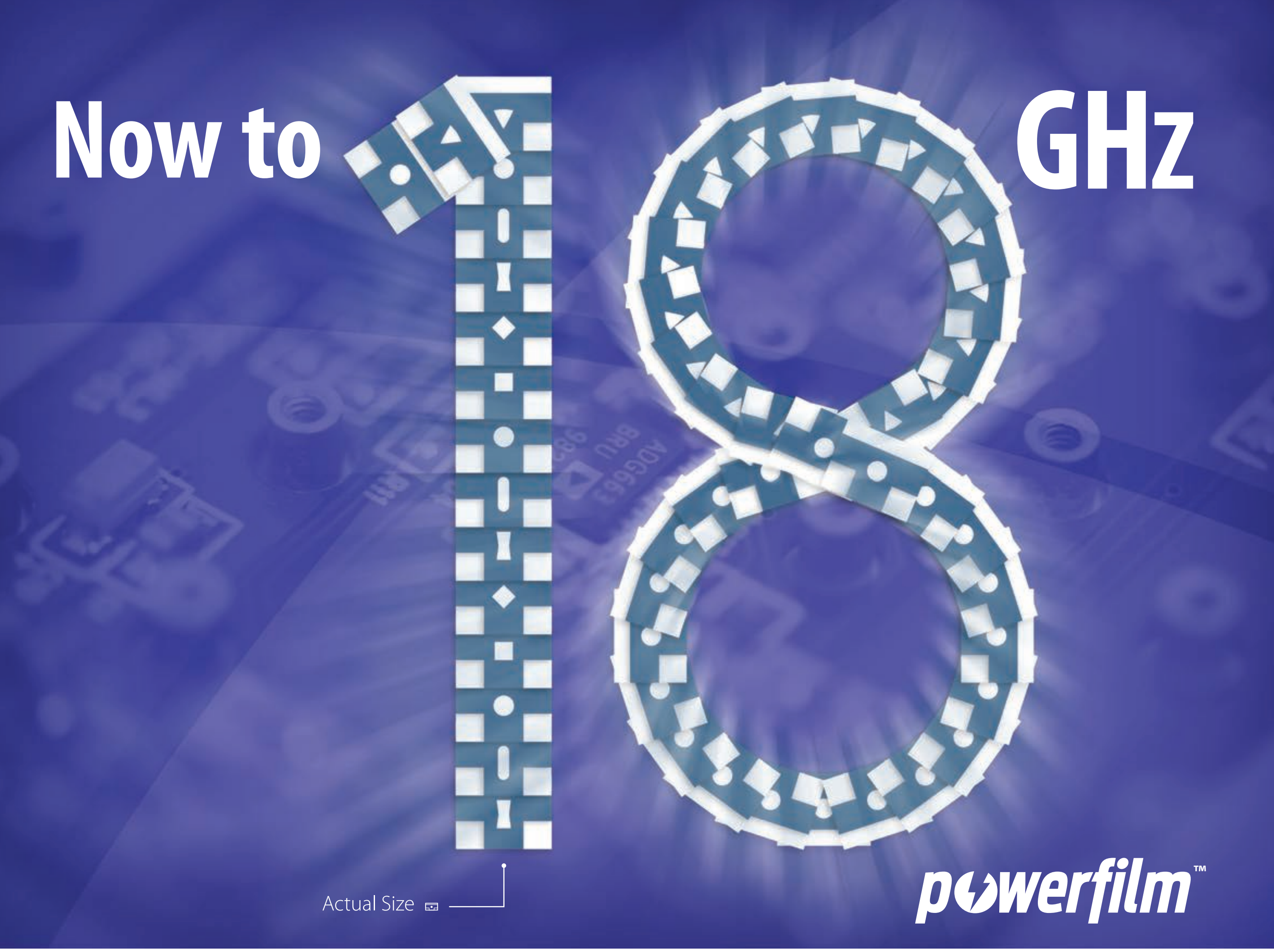
Since the summer of 1958, when Chuck Swift, founder of C.W. Swift & Associates, opened his doors for business, the company has focused on quality and customer service. For 60 years, C.W. Swift has specialized in the distribution of quality RF and microwave electronics. Currently, under the leadership of his two sons, the company continues to provide outstanding customer service along with a wide selection of products, both hard to find items as well as those available through in-stock inventory.

## DARPA—TECHNOLOGY DEVELOPMENT FOR THE US

The launch of Sputnik 1 by the Soviet Union in 1957 had a great effect on the U.S. science and technology community. On February 7, 1958, four months after the Soviet launch boosted the intensity of the Cold War, Secretary of Defense Neil McElroy established the Defense Advanced Research Projects Agency (DARPA), with the approval of President Dwight D. Eisenhower. Its creation is as much attributed to a reaction to the Sputnik launch as it was a way to advance Department of Defense (DoD) technology. Their mandate was "to provide within the DoD an agency for the direction and performance of certain advanced research and development projects." Over the years, DARPA has developed many technologies that have benefited everyday life from the invention of the Internet to miniature GPS to UAVs.

D60
BREAKTHROUGH DARPA TECHNOLOGY
PAST | PRESENT | FUTURE

DARPA has advanced RF/microwave technology with programs such as the MIMIC program that commercialized GaAs ICs, the Nitride Electronic NeXt-Generation Technology program that advanced GaN device technology, the Innovative Vacuum Electronic Science and Technology (INVEST) program to develop the technology base for new generations of more capable vacuum electron devices and the DARPA Grand Challenge, which is an annual competition for autonomous vehicles. Last year, DARPA announced their Electronics Resurgence Initiative's latest investments to keep electronics advancing along with Moore's Law, while still keeping costs and investments at a reasonable level—continuing to be very active in supporting the electronics industry.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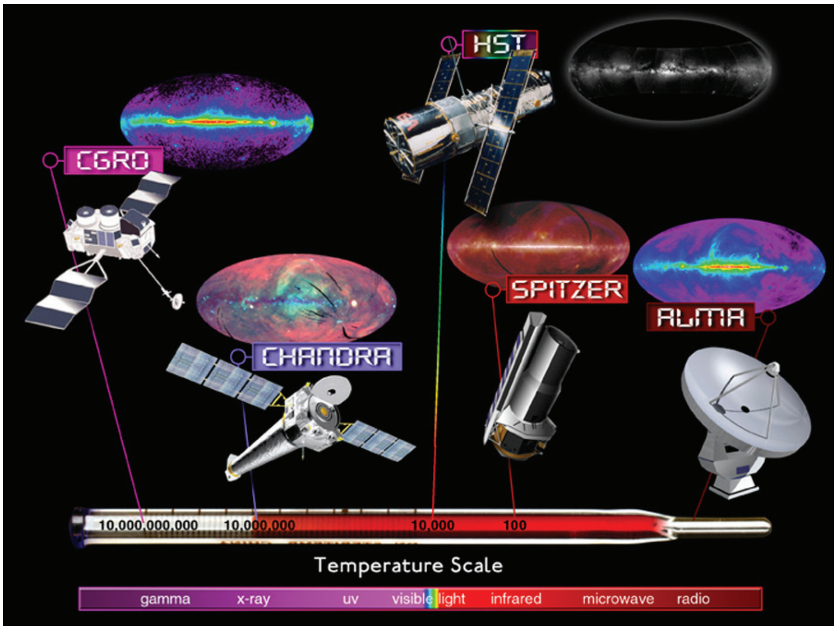
In September 2018, DARPA will highlight their achievements at a symposium called D60: Breakthrough Technology; Past, Present, Future. According to DARPA, the goals of the event are to strengthen and expand their innovation ecosystem—academia, industry and government partners—inform stakeholders about DARPA's vision and priorities and learn from the Agency's ongoing record of achievements and experience in the challenges of transforming new technology into today's technology. The event will feature plenary sessions, technical office sessions, technical breakout sessions, an exhibit, an anniversary dinner and DARPA Riser Presentations that will be presented by the next generation of innovators at the organization.

## NASA—OUT OF THIS WORLD

Sputnik's launch also led the U.S. government to focus and consolidate space exploration programs in different agencies and on January 31, 1958, the Army launched Explorer 1. The satellite measured and sent back data on temperature, micrometeorites and cosmic rays. With this success, Congress and President Eisenhower created the National Aeronautics and Space Administration (NASA) late that summer and NASA was officially launched October 1.

In 1960, NASA launched the world's first weather satellite, the Television and Infrared Observation Satel-



lite (TIROS); today, the U.S. has an extensive fleet of weather satellites operated by the National Oceanographic and Atmospheric Administration (NOAA). In 1962, NASA launched Mariner 2, the first satellite to encounter another planet, as the spacecraft flew within 21,000 miles of Venus. On July 20, 1969, NASA was the first to land a person on the moon—achieving President John F. Kennedy's end-of-decade challenge—as Neil Armstrong famously stepped off of Apollo 11's lunar module onto the moon and said: "That's one small step for man, one giant leap for mankind." NASA has since sent satellites to explore every planet in the solar system, in addition to the Sun and a number of moons, comets and asteroids, along with interstellar explorers.

During the 1990s to early 2000s, NASA launched the Great Observatories, a series of four space-borne observatories designed to conduct astronomical studies over many different wavelengths including visible, gamma rays, X-rays and infrared. The first was the Hubble Space Telescope (HST) that launched on the NASA Space Shuttle in 1990. The HST observed the universe with ultraviolet, visual and near-infrared wavelengths. The Compton Gamma Ray Observatory was the second of NASA's Great Observatories and was launched in 1991 aboard the space shuttle Atlantis. It collected data on some of the most violent physical processes in the universe observed by the high energies of gamma rays. The third Great Observatory, the Chandra X-Ray Observatory, was deployed from a space shuttle and boosted into a high-Earth orbit in 1999. This observatory imaged high energy objects such as black holes, quasars and high-temperature gases using the X-ray spectrum (I was actually part of the MIT team that designed and manufactured the High Energy Transmission Gratings for Chandra). The Spitzer Space Telescope, the fourth and final in the Great Observatories program, was launched by a Delta rocket in 2003 to detect infrared energy radiated by objects in space between wavelengths of 3 and 180 microns.

Looking towards the future, NASA plans to launch the James Webb Space Telescope next year into an orbit almost a million miles away from Earth, where it will explore a wide range of science questions to understand our place in the universe. As a successor to the Hubble Space Telescope, it will solve other mysteries of our solar system, observe distant worlds around other stars and probe the unknown structures and the origins of our universe. While the commercial space market has taken off and is working to replace some of the launch vehicle services that NASA provided, NASA is still very active in space research and will continue to be the leader in space technology.

**As we celebrate *Microwave Journal's* 60 years, our hearts are heavy as we mourn the loss of our International Editor, Richard Mumford, who passed away suddenly in early May. (See page 58 for Richard's tribute.)**

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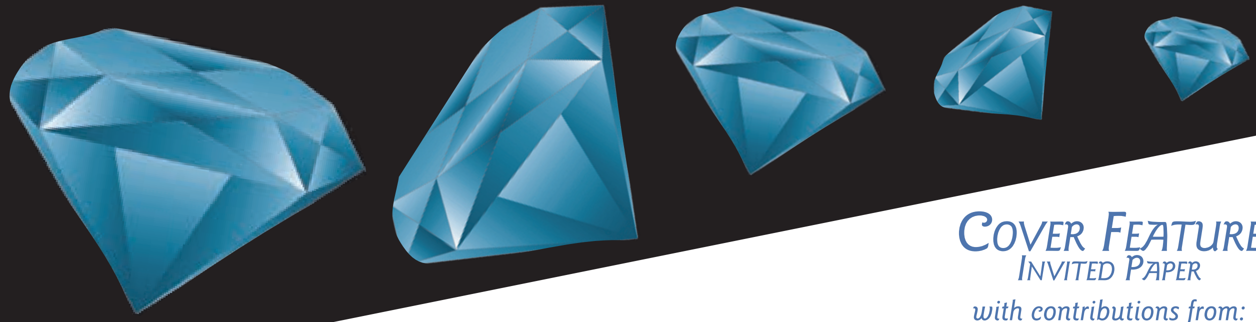

Cover Feature
Invited Paper
*with contributions from:*
*RFHIC*
*Akash Systems Inc.*
*Smiths Interconnect*
*Res-Net Microwave*
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Microwave Journal

# Diamonds are a High-Power Engineer's Best Friend

Pat Hindle, *Microwave Journal* Editor

The main factor limiting the performance of most high-power analog devices today is getting heat out more efficiently. Diamond has the best thermal conductivity of any material, so many high performance applications are trying to incorporate diamond materials into IC substrates or packaging to improve the heat dissipation. In this month's cover feature, we summarize many of the development programs and current products utilizing diamond materials, in keeping with this month's theme celebrating *Microwave Journal*'s diamond anniversary for our 60th year of publishing. Three topic areas are covered: GaN on Diamond, diamond passive components and packaging using diamond materials.

## GaN ON DIAMOND

TriQuint (now Qorvo) announced the production of the first GaN on Diamond wafers producing high electron mobility transistors (HEMT) in April 2013, in conjunction with partners at the University of Bristol, Group4 Labs and Lockheed Martin under the Defense Advanced Research Projects Agency's (DARPA) Near Junction Thermal Transport (NJTT) program. NJTT was the first initiative in DARPA's Embedded Cooling program that includes the ICECool Fundamentals and ICECool Applications research and development engagements. NJTT focused on device thermal resistance near the junction of the transistor using various cooling techniques.

The results of this effort showed a three-fold improvement in heat dissipation, while preserving RF capabilities. This improvement was attributed to a 40 percent reduction in thermal resistance for this GaN on Diamond process that simulations translate into about a 3x increase in the density of gates (or output power) in a power amplifier.[1] Today, Qorvo continues to work with DARPA and Lockheed Martin on microfluid techniques to cool GaN on SiC transistors.

Meanwhile, Raytheon has been working under the same DARPA program and developed a way to etch cooling channels in a diamond substrate and attach it to the wafer, avoiding some of the manufacturability issues with growing the GaN on the diamond substrate, and added liquid cooling. Raytheon used a glycol/water coolant to flow through the channels within 100 microns of the active HEMT area.[2] Raytheon thinned the GaN on SiC substrate and attached it to the diamond substrate with etched cooling channels. The cooling channels have a high aspect ratio, so that the tall channels maximize the surface area that can be cooled.

Raytheon demonstrated a wideband continuous-wave (CW) amplifier with 3.1x the power output and 4.8x the power density of the baseline amplifier currently designed into a next-generation electronic warfare (EW) system.[2] Raytheon plans to move the ICECool technology from the lab to production over the next few years.

In 2017, Fujitsu Ltd. and Fujitsu Laboratories Ltd. announced development of the first technology for bonding single-crystal diamond to a SiC substrate at room temperature. This overcame one of the biggest challenges to previous GaN on Diamond bonding that took place at very high temperatures causing bowing of the wafers due to mismatch of coefficient of thermal expansion (CTE).

By protecting the surface of the diamond with an extremely thin metallic film, Fujitsu succeeded in preventing the formation of the damaged layer and bonding single-crystal diamond to a SiC substrate

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- Low Passive Intermodulation
- Surface Mount Options

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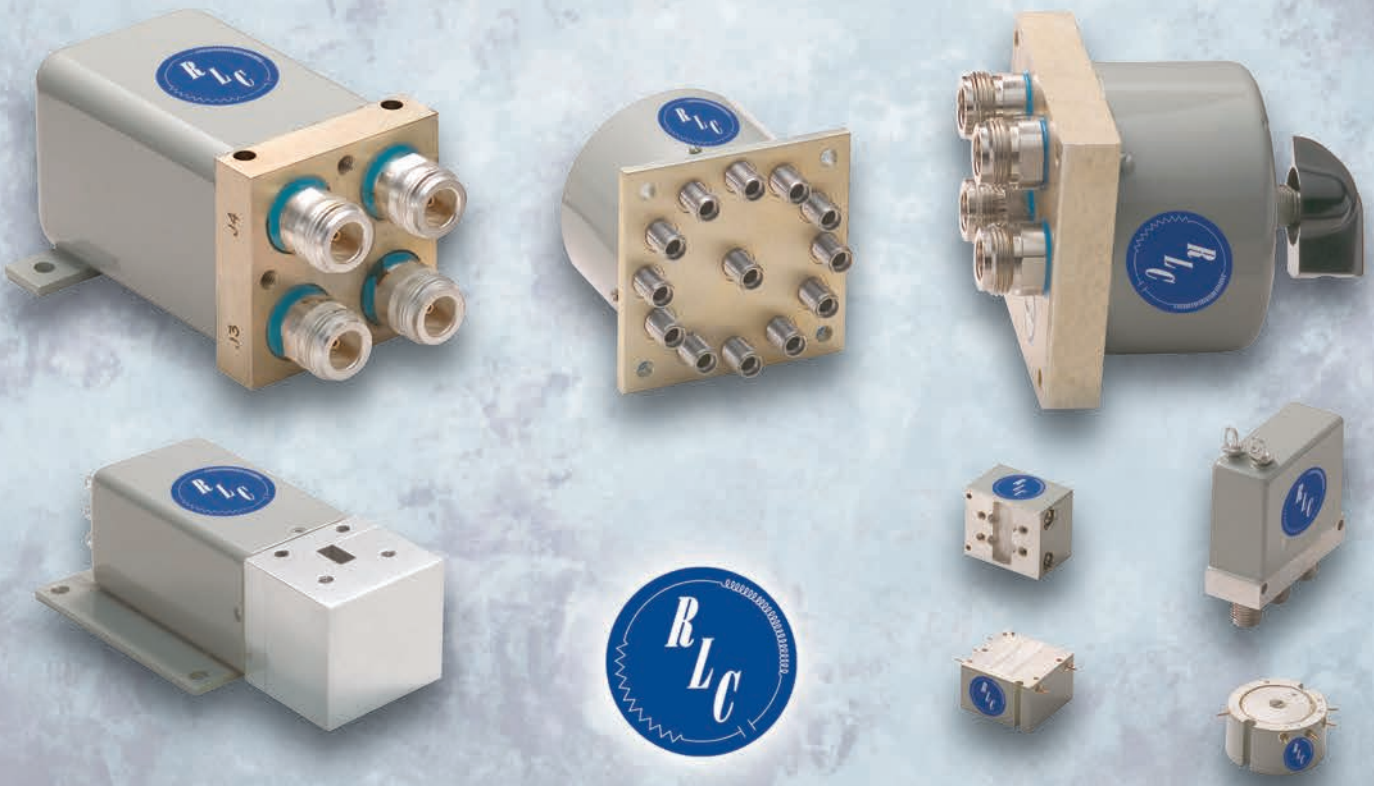

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at "room-temperature bonding." Simulations using actual measurements of thermal parameters have confirmed that devices using this technology would lower thermal resistance to 61 percent of existing ones. This technology promises GaN power amps to operate at higher power by about 1.5x when applied to systems such as weather radar.

In March 2017, RFHIC announced they had acquired the GaN on Diamond technology from Element Six and would seek to commercialize the process by the end of 2018. They have been working with GaN on Diamond technology since 2016, and in their announcement stated that "RFHIC will work closely with Element Six and foundry partners for the capability of manufacturing 10,000 6-in. GaN on Diamond wafers per year in the foreseeable future. RFHIC's technology roadmap is to introduce GaN on Diamond-based solutions covering up to 40 GHz by the end of 2018."

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## Commercialization of High Performance GaN on Diamond Amplifiers

RFHIC, South Korea

Diamond has been sought out by many researchers and companies for heat spreader application for years due to its excellent thermal conductivity (1500 W/mK). It has been shown that utilizing a diamond heat spreader can enhance RF performance by 20 percent compared to standard GaN on SiC devices.

In 2014, Element Six acquired Group 4 with the goal of improving GaN on Diamond (GoDi) epitaxial wafers, mainly the quality and thermal characteristics of the chemical vapor deposition (CVD) diamond layer. Significant improvements in

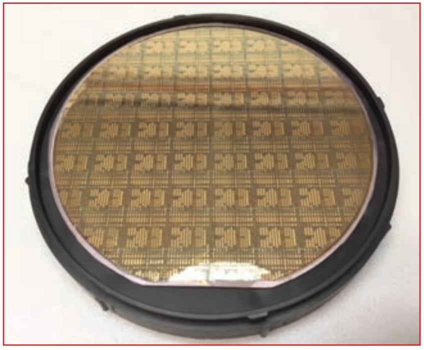

**Fig. 1** 4-in. GaN on Diamond finished wafer.

the CVD diamond deposition process lead many researchers to successfully triple the power density of GaN transistors utilizing diamond as the substrate.[1]

With ongoing demands for higher power density, smaller form factor and better RF performance throughout the market, RFHIC acquired, in a 2016 partnership with Akash Systems, intellectual property related to GoDi technology from Element Six. ***Figure 1*** shows a photo of a 4-in. GoDi epitaxial wafer. The process involves taking a GaN on Si wafer and removing the silicon substrate completely so that CVD diamond layer can be directly deposited on to the GaN surface.

Various successful demonstrations of GoDi HEMT devices show excellent thermal and RF performance has been developed in the past but most work utilized small wafers (less than 4-in.) for fabrication. With the help of RFHIC's foundry partner, fully automated 4-in. fabrication of GoDi HEMT process is now possible. For GaN HEMT process flow, standard GaN on SiC process flow is used for production with minimal process modifications. Because GoDi HEMT wafers are very thin (about 120 μm thick), special carrier bonding techniques which could withstand various processes had to be developed.[2]

Because diamond is the hardest natural element, scribing and via holes cannot be done with standard blades or etch processes. This led RFHIC to investigate laser as the source for both scribing and via hole drilling. RFHIC has managed to successfully make via holes and scribing with streets narrower than 60 μm wide with lasers. RFHIC is also looking into a newly developed plasma etching process that could significantly increase via hole process.

Currently, qualification 4-in. wafers are in the final steps of processing and measurements will be available in June 2018. A follow-up article is planned to detail the results of these development efforts.

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1. F. Ejeckam, D. Francis, F. Faili, D.J. Twitchen, B. Bolliger, J. Felbinger and D. Babic, "S2-T1: GaN on Diamond: A Brief History," *Lester Eastman Conference on High Performance Devices*, August 5-7 2014, DOI: 10.1109/LEC.2014.6951556. INSPEC Accession Number: 14775316.
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## Ultra-Cool GaN on Diamond Power Amplifiers for SATCOM

Felix Ejeckam, Ty Mitchell, Kris Kong and Paul Saunier

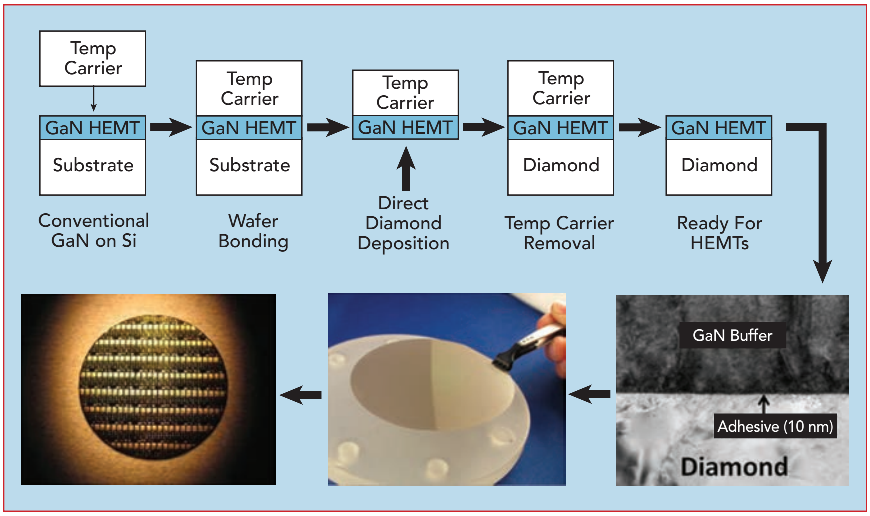
Akash Systems Inc., San Francisco, Calif.

The most advanced commercial satellites transmit data down to Earth at rates of 100 to 200 Mbps; some advanced larger single satellite concepts target 1 to 4 Gbps. These data rates are substantially limited by state-of-the-art RF power amplifiers used to make the transmitters. Akash is building, for the first time, a small satellite system (12U) that will exhibit a preliminary downlink data rate of 14 Gbps. The next demo will feature data rates of over 100 Gbps. The ultimate technical goal is to demonstrate a downlink data rate of 1 Tbps from a single, modest size satellite—using GaN on Diamond RF power amplifiers.

### GAN ON DIAMOND

Felix Ejeckam, co-founder of Akash Systems Inc., invented GaN on Diamond in 2003[1] as a way to extract heat effectively from the hottest locations in a GaN transistor. The basic concept is that a cooler GaN amplifier would make the system more energy efficient, and less wasteful. On a GaN on Diamond wafer, the GaN channel or epitaxy is

extracted from its original substrate of Si and situated on a CVD diamond substrate via a 35 nm SiN interfacial layer. This nanometer-scale proximity of a 200°C GaN channel to CVD diamond, the most thermally conductive industrial material, drastically reduces the thermal rise between the amplifier's base plate and the channel temperature. ***Figure 2*** shows the process of making GaN on Diamond wafers and devices. Many parties over the years have quantified the aforementioned thermal improvement.[2] A GaN on Si HEMT wafer is bonded to a temporary Si carrier. The original Si substrate is etched away, followed by CVD deposition of diamond via a 35 nm interfacial layer below the GaN. Finally, the temporary Si carrier is etched away. The eventual GaN on Diamond wafer is then processed into an array of HEMTs or MMICs.




▲ Fig. 2 **GaN on Diamond wafer process.**



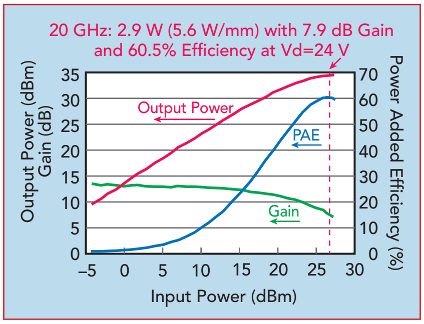
## SYSTEM IMPACT

If the thermal rise of a GaN MMIC can be shrunk by 40 to 50 percent compared to GaN on SiC, then greater power density can be squeezed into a smaller volumetric space.[3] Power is a direct parameter in a satellite's downlink data-rate budget calculation; more information can be transmitted if there is more power. Cooling requirements in a very compact space are relaxed with GaN on Diamond since the ambient temperature can be allowed to rise higher than with a typical GaN on SiC power amplifier system—without compromising performance or reliability. This reduction in cooling gear also means less weight and size, both key parameters in the cost of launching a satellite system into orbit.

## PERFORMANCE

Akash designers have recently demonstrated high performing GaN on Diamond transistors (i.e., simplified power amplifiers) at K-Band exhibiting 60 percent power added efficiency (PAE) at 20 GHz (see ***Figure 3***). In another recent work, funded by DARPA and performed by a team of researchers at Georgia Tech, Stanford, UCLA and Element Six, the GaN device's thermal rise—change in temperature from the GaN channel to the substrate bottom—was found to reduce by 80°C when compared to the same device on GaN on SiC.[2] The wafer used in the work is identical to the GaN on Diamond process used by Akash Systems.

***Figure 4*** shows the temperature distribution for the channels from




▲ Fig. 3 **Example device shows 61 percent PAE from a 2.9 W (5.6 W/mm) HEMT with 7.9 dB gain. Bias point is 24 V.**

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Model HR-Power Amplifier with optional integrated power supply in one small footprint. Air / Water cooled.

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- 2000 Watts
- 352 MHz
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- **Patent Pending**
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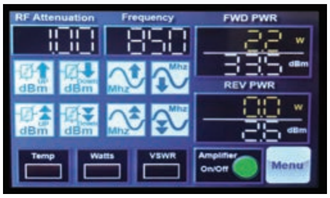
HS-Series RF Amplifier Systems use HR and HM amplifiers to provide kilo-watt power in a small footprint. These 19" rack systems are designed for high reliability and are extremely rugged. The HS-Series is designed for CW / Pulse or digital applications.

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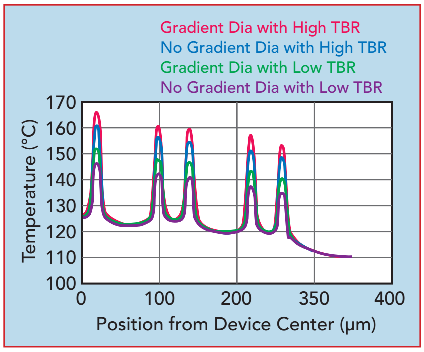


**Fig. 4** Graph showing the temperature distribution for the channels from the center to the edge of the 10 finger HEMT for various types of GaN on Diamond wafers.

the center to the edge of the 10 finger HEMT for various types of GaN on Diamond wafers. Akash Systems uses the "Gradient Diamond with Low Thermal Boundary Resistance (TBR)" process GaN on Diamond wafers (in green); this curve registers 152°C peak temperature (the first peak). GaN on SiC registers 232°C at the same point on the device.[2]

Akash Systems is planning to launch into a LEO orbit in 2019, a 24 kg 12U (36 cm x 24 cm x 23 cm) satellite system that will contain a 20 W transmitter radio built on a GaN on Diamond power amplifier. The system will exhibit a landmark 14 Gbps data rate unique for a system that size.■

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## HIGH-POWER DIAMOND PASSIVE DEVICES

### Ultra-Small, High-Power, Diamond Rf Resistives™

*Smiths Interconnect, Stuart, Fla.*

Over the past few decades beryllium oxide (BeO) and aluminum nitride (AlN) have been the preferred substrate materials for high-power RF resistors. These ceramic materials have relatively high thermal conductivities and suffice for many applications; however, as designers are facing many SWaP-C challenges today while pursuing higher frequencies, BeO and AlN substrates have very often proven to be inadequate. Seeking alternative technologies, RF designers have turned to CVD diamond-based components to address these needs.

CVD diamond is a single crystal carbon substrate material that is produced using chemical vapor deposition processing. From a structural view, Type 2 synthetic CVD diamond substrates are just like natural diamonds and can be processed similarly to commonly used RF substrate materials to form electrical circuits. New advances in thin film on CVD diamond from Smiths Interconnect have been developed by sputtering tantalum nitride (TaN) on CVD diamond substrate, leading to a growing line of ultra-small, high performance resistors, terminations and attenuators called Diamond Rf Resistives. Conductor materials have also been sputtered onto CVD diamond to create eutectic solder and wire bond pads, allowing these circuits to be easily used in many mounting configurations such as surface mount, chip and wire and flange mount.

A typical CVD diamond-based thin film resistor occupies 8x less area to dissipate the same amount of heat (see ***Figure 5***). This is due to the direct correlation between the size of the substrate and capacitance levels; capacitance issues are created between the thin film material and the ground plane under the chip. In addition, due to the relationship of capacitance levels to high-power/high frequency performance, components

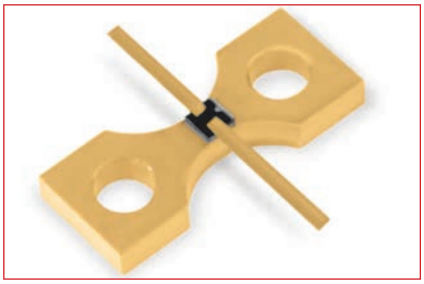


Fig. 5 Example of a diamond resistive device.

built with this material not only demonstrate high-power handling capacity at higher frequencies per square mm, they also demonstrate lower parasitic behavior, i.e., better isolation. As example, a single 0402 resistor, manufactured on a CVD diamond substrate, can dissipate 20 W of CW power and 200 W of pulsed power.

Current applications benefiting from this technology include the development of advanced Wilkinson power dividers/combiners; isolators; dual junction circulators/duplexers; and amplifier feedback networks. As the key system parameters of space systems, radar and wireless infrastructure continue to push the capabilities of the passive resistor, CVD diamond substrate-based Diamond Rf Resistives from Smiths Interconnect will continue to evolve to provide design engineers in every facet of RF and microwave system development, SWaP-C solutions for years to come.



## CVD Diamond Passive Components

**Res-Net Microwave, Clearwater, Fla.**

CVD synthetic diamond has outstanding thermal conductivity, 3 to 4x better than copper. In addition, the low dielectric constant makes CVD diamond an excellent RF dielectric material for high frequency and high-power applications. The comparison of power density between CVD diamond and standard ceramic substrates is shown in ***Figure 6***.

The mechanical and electrical characteristics of CVD diamond are excellent for making passive components, like resistors, terminations and attenuators. Using CVD material and advanced thin film processing techniques, these passive components can withstand even the most challenging space environment. Hence, these components are used in many aerospace, military and commercial applications.

The high thermal conductivity of CVD material allows for small size chips to be designed that can op-

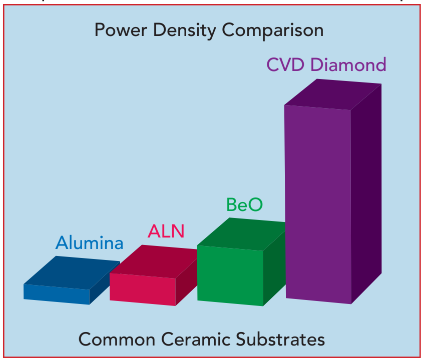



Fig. 6 Comparison of power density between CVD diamond and standard ceramic substrates.

erate above 40 GHz and still dissipate over 10 W of CW power. In addition, for CW applications, these passive components are excellent for pulsed power applications. Res-Net manufactures diamond resistors, terminations and attenuators. Example resistors range from DC to 30 GHz, 20 W to DC to 18 GHz, 150 W devices, and terminations ranging from DC to 6 GHz, 300 W to DC to 26.5 GHz, 50 W devices.

DIAMOND-BASED PACKAGING

## Aluminum-Diamond Metal-Matrix Heat Spreaders for GaN Devices

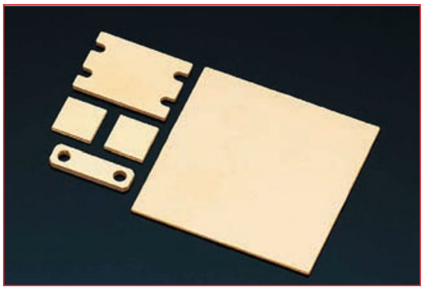
Kevin Loutfy, Nano Materials International Corp., Tucson, Ariz.

High-power RF and microwave transistors have long used various materials with high thermal conductivity as substrates and heat spreaders, including copper whose thermal conductivity is 400 W/mK, copper-tungsten (200 W/mK), copper molybdenum (250 W/mK) and copper-molybdenum-copper (350 W/mK). For GaN devices, SiC with thermal conductivity up to 400 W/mK, is the substrate material used for most high performance devices.

However, industrial-grade synthetic diamond has much higher thermal conductivity, which ranges from 1200 to 2000 W/mK, which allows heat to be removed far more effectively than with any other material. In recent years, GaN device manufacturers have become much more interested in its potential to significantly increase the performance of GaN discrete and MMIC devices both as a substrate and heat spreader. There are currently a few devices using GaN on Diamond substrates, but aluminum-diamond metal-matrix composites (MMC) fabricated by Nano Materials International Corp. (NMIC) are increasingly used as heat spreaders for GaN devices with very high RF output powers (see ***Figure 7***).

Aluminum-diamond MMCs heat spreaders are located below the die or package and can be employed regardless of the substrate material with a thermal conductivity of about 500 W/mK. Aluminum-diamond can work efficiently with die-attach processes and has yields equal to or even better than traditional heat spreader materials. NMIC's aluminum-diamond MMC's employ an aluminum alloy composition that is infiltrated into a packing of industrial-grade diamond particles.

The diamond provides exceptional thermal conductivity and the aluminum provides structure and CTE matching, as well as a very smooth



▲ Fig. 7 Aluminum-diamond MMCs in various sizes.

surface on the top and bottom that serves as the attach face. The process flow employed in producing NMIC aluminum-diamond MMCs is shown in *Figure 8*. The infiltration process produces aluminum-diamond plates called "mother plates," and multiple parts are cut from the mother plates with their size optimized to meet part dimensions. This reduces the amount of waste material produced by the cutting process. These parts are then nickel- and gold-plated to produce the final product. One of the challenges during development was related to the interface between the two materials. To solve it, NMIC developed technology to convert the surface of the diamond to SiC, a technique the company has patented.

In the last few years, the process has become very well-characterized, and aluminum-diamond MMCs are now both cost-effective and available in high volumes in sizes up to 45 mm x 45 mm—larger than other

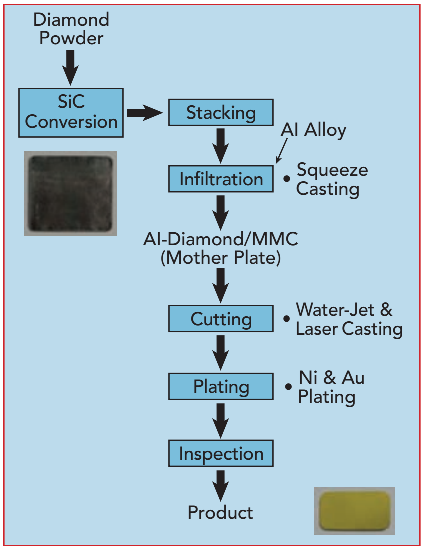



Fig. 8 The process of producing NMIC's aluminum-diamond MMCs.

diamond-based alternatives that are limited in size or thickness. Customers are using the MMCs in both hermetic and non-hermetic packages in high-reliability and space-qualified applications, both having stringent thermal cycling requirements.

In addition to high thermal conductivity, a stable CTE is essential when a material is attached to a transistor package. Aluminum-diamond's CTE has always been the equal of other engineered materials, but its stability in larger sizes sets it apart, with a CTE of 6.5 to 7.5 ppm/K, which is close to that of GaN die.

The improvements made to aluminum-diamond MMCs have in a few short years transformed this technology into one that is proving to be a viable alternative to other heat spreader materials. It exploits the inherently high thermal conductivity of diamond while also being manufacturable in large quantities and delivering better CTE performance than diamond alone.



## Diamond-Silver Composite Packaging for GaN Space Applications

**Richard Mumford, *Microwave Journal* International Editor**

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GaN packaging project, which ran from 1 October 2010 to 31 March 2012, targeted packaging for space applications to enable Europe to maintain a strong position in the highly competitive space industry. Research into the diamond-silver base plate material is highlighted in the published collaborative work between Bristol University, Plansee SE, United Monolithic Semiconductors and Thales Alenia Space.[1] It presented a new packaging solution for GaN power electronics for efficient heat extraction needed for high-power devices, illustrating for the first time the impact of using diamond-silver composite as a base plate in packages on the self-heating of GaN devices.

Diamond-silver composites consisting of diamond particles in a matrix of silver alloy feature an excellent thermal conductivity as high as 650 W/mK at room temperature and a CTE close to that of the semiconductor materials. This is significantly larger than the thermal conductivity of conventional packaging materials such as CuW.

For the study, Micro-Raman thermography measurements were performed on AlGaN/GaN multi-finger HEMTs (power bars, with 18 fingers) grown on SiC substrates to determine their device temperature at various power levels. The devices were attached to both diamond-silver composite and CuW base plates by using standard AuSn solder, in order to assess the difference between the two materials in terms of thermal management efficiency. ***Figure 9*** shows the temperature results from Raman measurements in the center finger of the devices at different power values, i.e., the peak device temperature rise with respect to the temperature at the backside of the base plate which was kept at 25°C.

Devices attached on diamond-silver composite base plates exhibit peak temperatures approximately half that of the peak temperatures exhibited by devices mounted on CuW base plates, especially at high-power levels, which are standard for device operation. The same trend was obtained for temperatures in the outer fingers. However, due to the crosstalk effect, temperatures are higher in the center finger.

Also, there was clear improvement from the point of view of heat extraction, with obvious benefits for device reliability and system requirements. A 3D finite element model of the device was built to compare to the experimental data

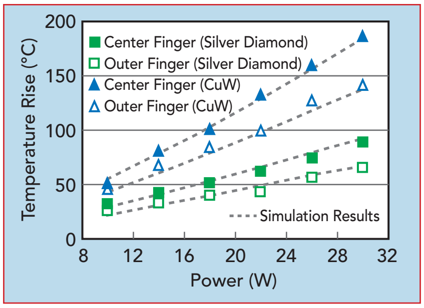


**Fig. 9** Peak temperature rise in the center finger of AlGaN/GaN HEMTs devices (18 fingers power bar) brazed to diamond-silver composite and CuW base plates as a function of the dissipated power.[1]

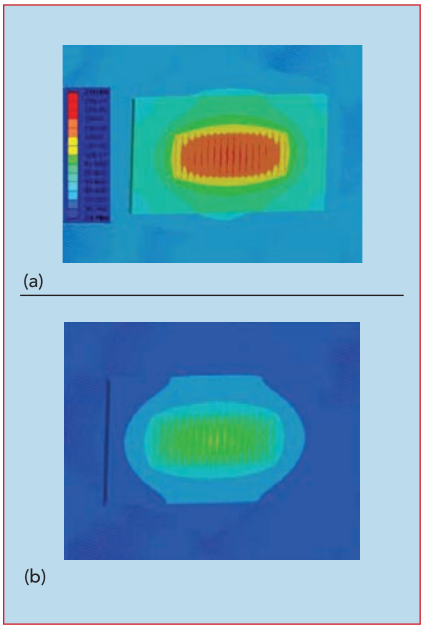


**Fig. 10** Temperature distribution in AlGaN/GaN HEMT (18 fingers power bar) for a dissipated power level of 30 W obtained from 3D finite element simulation for (a) device brazed onto CuW base plate and (b) onto diamond composite base plate.[1]

and the outcomes from the simulations were consistent and in good agreement with the ones obtained experimentally. ***Figure 10*** illustrates the temperature distribution across the whole device on diamond-silver compared to the one on the CuW base plate. Again the temperature is significantly lower in devices brazed onto the diamond-silver composite.

The final report summary for the project said: "State-of-the-art results have been obtained for L-Band HPA, putting forward the strong impact of base plate material to be used in RF power modules. Up to 65 percent PAE with up to 180 W RF power in L-Band has been obtained with no tuning on several power modules using diamond-silver base plate material. The gain in power added efficiency is about 10 points for the same design implemented into CuW standard micropackage."■

## Reference

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## Demo of Puma-Switchblade Automated S2S Capability to Counter Swarm Attacks

AeroVironment Inc. recently announced the successful maritime demonstration of a Puma™-Switchblade® automated sensor-to-shooter (S2S) capability from a U.S. Navy Coastal Riverine Craft for increased mission autonomy to counter threats.

The tightly integrated walk-on/walk-off system uses existing RQ-20B Puma Block 2-All Environment small UAS with the new Mantis i45 sensor gimbal combined with automatic coordinate transmission to the battle-proven Switchblade lethal loitering missile to quickly and accurately surveil and respond to threats on land or at sea.

"This new combination of our Puma UAS with our Switchblade loitering missile system gives commanders unprecedented ability to identify threats at long ranges, limit collateral damage and wave-off targets subsequently deemed neutral or friendly," said Rick Pedigo, VP of AeroVironment's Tactical Missile Systems business.

In a S2S mission, Puma, as a long-endurance intelligence, surveillance and reconnaissance (ISR) small UAS asset with a high-resolution day/night camera, positively identifies a target of interest and automatically passes the target location to Switchblade prior to its launch. Once Switchblade is launched, Puma continuously transmits the target location throughout the engagement sequence. When the target is in the field of view of Switchblade's optical sensors, the Switchblade mission operator confirms the target and the Switchblade vehicle operator engages the threat. Switchblade continues to offer regret (wave-off) capability if, at any time, the target is identified as neutral or friendly.

In the maritime demonstration, Puma identified a series of fast-attack craft moving toward a host platform and transmitted their target coordinates to Switchblade prior to launch. Once launched, Switchblade automatically flew to the fast-moving target and the operator defeated the threat by engaging it with an inert payload.

*Puma (U.S. Navy Photo)*

S2S combines AeroVironment's fielded Puma Block 2 (the "sensor") and Switchblade loitering munition (the "shooter") with additional equipment—a ruggedized laptop with S2S software, a Pocket DDL™ data link module and a larger gain antenna—to forward the Puma payload's center field of view (CFOV) electronically to Switchblade as its target coordinate. On the laptop, the simultaneous Puma and Switchblade video dramatically elevates operator situational awareness and reduces the chances of mis-targeting.

S2S currently is a prototype with plans for product release in Fall 2018. Currently fielded Switchblade systems can be upgraded with the S2S capability.

## DARPA Announces ERI Summit

The microelectronics community is facing an array of long foreseen obstacles to Moore's Law, the transistor scaling that has allowed for 50 years of rapid progress in electronics. Current economic, geopolitical and physics-based complications make the future of the electronics industry uniquely interesting. To jump-start innovation in the field, DARPA announced in June 2017 that it would coalesce a broad series of programs into the Electronics Resurgence Initiative (ERI). ERI calls for innovative new approaches to microsystems materials, designs and architectures.

To kick off this initiative and foster forward-looking collaborations across the U.S.-centric electronics community, DARPA is hosting the first annual ERI Summit from July 23-25, 2018 in San Francisco. The three-day event will bring together those most impacted by the coming inflection in Moore's Law, including senior representatives from the commercial sector, defense industrial base, academia and government. DARPA will begin the event by announcing the research teams selected to lead ERI's six new "Page 3" programs, which aim to complement traditional scaling and ensure continued improvements in electronics performance. During the days that follow, attendees will hear keynote presentations from industry leaders, interspersed with detailed program discussions.

Further presentations will detail ERI's six "Page 3" programs, designed to fulfill the post-scaling predictions made by Gordon Moore on the third page of his seminal 1965 paper. These programs seek to answer three key questions:

- Can we dramatically lower the barriers to modern system on a chip design and unleash a new era of circuit and system specialization and innovation?
- Can the integration of unconventional materials enhance conventional silicon circuits and continue the

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progress traditionally associated with scaling?
- Can we enjoy the benefits of specialized circuitry while still relying on general programming constructs through proper software/hardware co-design?

## Raytheon to Develop US First Drone-Testing Airspace Corridor

The Northeast UAS Airspace Integration Research Alliance selected Raytheon as a key partner in the development of the U.S.'s first and most advanced UAS-testing airspace corridor in New York State. Raytheon's Intelligence, Information and Services business will help plan, design, build and support the state's next-generation air traffic management system to safely test and manage drones.

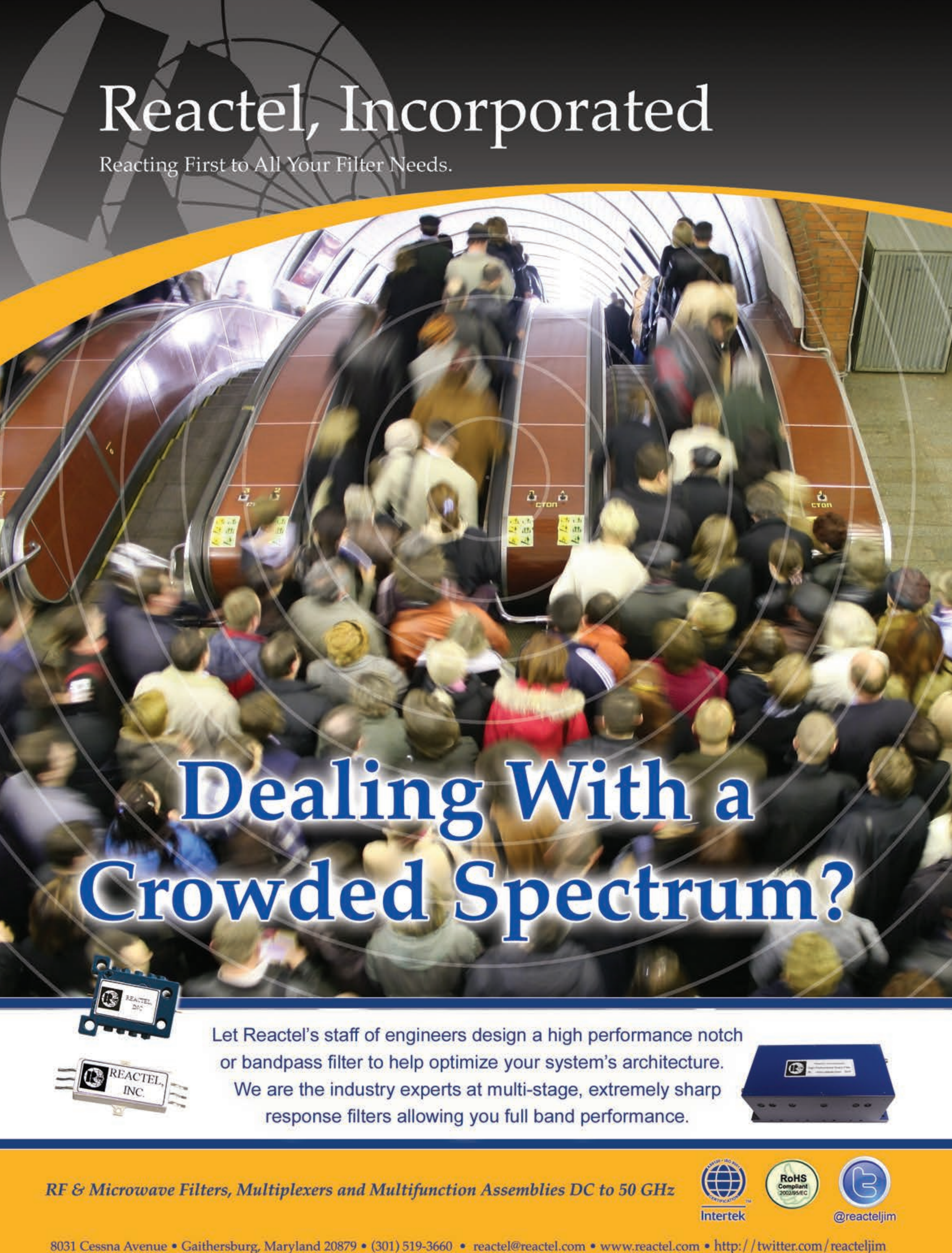
"UASs are playing an increasingly important role in our society, which means we must have low-altitude air traffic management solutions," said Matt Gilligan, VP of Raytheon's Navigation, Weather and Services mission area. "The New York airspace corridor is the first-of-its kind, but it won't be the last."

The new corridor will extend 50 miles (80 km) west from Griffiss International Airport, which is one of only seven Federal Aviation Administration-approved UAS test sites in the U.S. It will allow companies to test both drones and air traffic management technologies in real-world settings, generating valuable data that will inform industry and regulators and ultimately advance the commercial use of drones.

"We have identified the most qualified organizations to complete the New York UTM corridor and expand our UAS testing capabilities," said Maj. Gen. Marke F. Gibson, NUAIR Alliance's CEO. "With all our state economic and technical support, I think we are well positioned to accelerate the UAS industry and further establish this region as a national leader."

Raytheon's leadership in air traffic management includes the low-power radar (LPR), a small, one-meter square AESA software-defined radar unit. When numerous LPRs are networked together, the radar units can cover and control the low-altitude flights of smaller craft—a feat not possible with current large radar systems. A distributed, low-level LPR network could be created with relative ease, mounting the system atop current cell phone towers or tall buildings.

A LPR network could support safe plane and drone landings, aviation surveillance, precision weather observations (including 3D wind information and urban hydrology), small drone detection and tracking, border security and surveillance, wildfire detection and elevation and geographic gap fills.



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# The 2018 Defence, Security & Space Forum

## At European Microwave Week

EuMA Microwave Journal

**Wednesday, 26 September – IFEMA Feria de Madrid, Spain – Room N101-N102, 08:30 to 18:30**

**A one-day focused Forum addressing the integration of unmanned aerial vehicles (UAV) into defence and security scenarios.**

## Programme:

**08:30 – 10:10** **EuRAD Opening Session**

**10:10 – 10:50** **Coffee Break**

**10:50 – 12:30** **New Concepts, Technologies and Systems for UAV Integration and Their Role in Future Hybrid Scenarios.**

*Technological Demonstrator of Enhanced Situation Awareness in Naval Environment with the use of Unmanned Systems*
**Dr. Tony Arecchi, Ocean 2020 Project Coordinator, Leonardo S.p.A. Italy.**

- *UAV Integration into European Airspace: The U-Space Vision* – **Single European Sky ATM Research (SESAR) Project.**
- *Anti-UAV Defence Systems* – **Miguel Acitores, Director of Security Business Development, Indra. Spain.**

**12:40 - 13:40** **Strategy Analytics Lunch & Learn Session**

*The Implications of Expanding the UAS Mission Envelope in Military and Civilian Airspace*
**Asif Anwar, Strategy Analytics, UK**

**13:50 – 15:30** ***Microwave Journal* Industry Panel Session**

This session offers a perspective on the endeavour, innovation and investment that industry is committing to the development of Unmanned Aerial Vehicles in the defence and security sector. Speakers will offer an insight into such areas of activity as microwave sensors/sub-systems, the test and measurement challenges that are being addressed and the issue of UAV identification and detection.

**15:30 - 16:10** **Coffee Break**

**16:10 - 17:50** **Round Table: Efforts & Investment Needs to Drive UAV Technologies to Market**

High level speakers from key governmental agencies and commercial companies involved in the integration of UAV air traffic into non-segregated air spaces in the future will offer their opinions and outline the opportunities and challenges that can be expected in coming years. Speakers will also focus on the research needs and technological trends that will define the structure and technical characteristics of future unmanned systems.

**17:50 - 18:30** **Cocktail Reception**

**Registration and Programme Updates**

**Registration fee is €20 for those who registered for a conference and €60 for those not registered for a conference.**

As information is formalized, the Conference Special Events section of the EuMW website will be updated on a regular basis.

**Register online at www.eumweek.com**

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## The Race to 5G

Mobile World Live reported that three Middle Eastern operators—Etisalat in UAE, Ooredoo in Qatar and STC in Saudi Arabia—claimed to be "first" to turn on "commercial" 5G networks. Unfortunately, none of their customers have 5G handsets, so they cannot take advantage of the presumably phenomenal data rates. Etisalat and Ooredoo said their 5G services were using C-Band spectrum.

Deutsche Telekom announced the operator demonstrated Europe's "first" 5G data connection over a "live" network after deploying six antennas in Berlin covering an area 5 km wide. By the end of summer, the operator plans to install another 70 cells at more than 20 sites. The initial base stations, using equipment from Huawei, operate at 3.7 GHz and conform to the 5G NR non-standalone specification, which uses the operator's LTE network except for the 5G radio. A testing license granted by the German government allows Deutsche Telekom to use the 3.7 GHz spectrum.

Headlined as a "first in France," French mobile operator SFR completed an "over the air" 5G call in early May using 3.5 GHz spectrum and Nokia's AirScale radio, cloud RAN technology and an end-user test device, all meeting the 5G NR non-standalone standard. The laboratory demonstration was conducted at Nokia's 5G center outside Paris.

The U.K. auctioned 5G spectrum at 3.4 GHz, awarding 50 MHz to Vodafone, 40 MHz to EE, 40 MHz to O2 and 20 MHz to Three. Collectively, the operators paid £1,150 million for a place on the 5G stage.

## Holding On For 5G

Ericsson and Nokia, two of the world's top three mobile network equipment manufacturers, reported revenue for the March quarter reflecting continued softness in the infrastructure market, as LTE network deployment slows and operators await 5G.

The revenue in Ericsson's networks segment declined 10 percent from the prior year's quarter, to SEK28.6 billion, which the company attributed to lower LTE investments in China and southeast Asia. Total company revenue was SEK43.4 billion, down 9 percent from the prior year. Ericsson has been scrambling to revamp its strategy and restore profitability. It reported progress, stemming the quarter's net operating loss to SEK0.3 billion, compared to an operating loss of SEK11.3 billion in the prior year's quarter.

Nokia described the quarter as "challenging," with total revenue down 8 percent year-over-year to €4.9 billion and the mobile networks segment dropping 19 percent to €1.4 billion. Nokia's reported operating loss was €336 million, worse than the €127 million loss in the prior year's quarter. Nonetheless, Nokia's CEO Rajeev Suri expressed optimism about the company's full-year performance, seeing "further acceleration of 5G"—particularly in the U.S. —where he feels Nokia has a strong position.

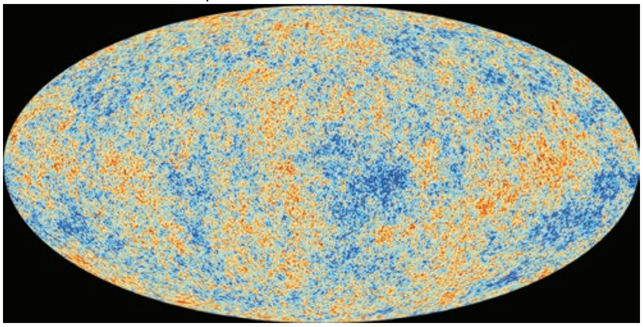
## ESA Planck Team Awarded 2018 Gruber Cosmology Prize

Billions of years after the Big Bang, the European Space Agency's (ESA) Planck team was awarded the 2018 Gruber Cosmology Prize for its mission mapping the still-observable cosmic microwave background (CMB) radiation. The Planck mission has created the most detailed map of the CMB, which was discovered by accident in 1965. Planck's data is extending humanity's understanding of the universe, including its age, the inflationary expansion following the Big Bang and the average density of ordinary matter and dark matter.

Initially called COBRAS/SAMBA (Cosmic Background Radiation Anisotropy Satellite/Satellite for Measurement of Background Anisotropies), the mission started around 1996. Renamed to honor German physicist Max Planck, the spacecraft was launched in May 2009 and operated until the satellite was deactivated in 2013. Planck carried two instruments, Low Frequency Instrument and High Frequency Instrument, which covered the frequency range from 30 to 857 GHz and detected the total intensity and polarization of detected photons. The CMB spectrum peaks at 160.2 GHz.

The Gruber Prize is awarded each year by the Gruber Foundation, based at Yale University, to recognize "individuals whose research inspires and enables fundamental shifts in knowledge and culture." The prize comprises of a gold medal and US$500,000.

ESA Director of Science Günther Hasinger said, "The ESA Planck mission has made truly fundamental contributions to our understanding of modern cosmology. It is my great pleasure to congratulate and thank the many hundreds of scientists and engineers who have made this excellent success possible."



*Planck CMB image, showing the oldest light in the universe (Source: ESA and the Planck Collaboration).*

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## In Memoriam

The microwave industry lost a friend and colleague last month with the sudden passing of Richard Mumford. Richard served as International Editor for *Microwave Journal* since 2000, working from Horizon House's London office. He kept the industry informed on all news, products and technology emanating from Europe, and helped to coordinate activities related to European Microwave Week. He represented *Microwave Journal* at the major industry events in Europe, North America and Asia each year, providing editorial coverage of conference and exhibition highlights.

Richard earned his electrical engineering degree from University of Wales Institute of Science and Technology in Cardiff. He worked initially for the Ministry of Defence, INSPEC and then as editor of several electronics publications before joining Horizon House.

Richard was a well-respected and beloved colleague to all of us at Horizon House. We will dearly miss his wit, humor, kindness and, above all, friendship.

Richard leaves his wife Sarah and son Max.

**A video tribute to Richard is available for viewing via augmented reality by scanning this page using the Layar app or visiting mwjournal.com/mumford.**

## 5G to Expand Fixed Wireless Broadband Adoption to Generate $45.2B in 2022

The worldwide fixed wireless broadband market has been growing steadily over the past several years. ABI Research forecasts that the global fixed wireless broadband market will grow 30 percent in 2018 and will generate $18 billion in service revenue. As 5G fixed wireless broadband access is set to be launched in North America in 2018, it is set to expand and provide consumers with better quality service in the years to come.

LTE is the most widely used technology to provide fixed wireless broadband service across the world. Fixed LTE is mainly deployed for residential broadband service in the areas where fixed broadband infrastructure is poor, enabling operators to provide residential broadband service more cost effectively compared to wired broadband deployment.

U.S. operator Verizon has announced plans to launch 5G fixed wireless broadband service to its residential customers in the second half of 2018, planning to first launch in California followed by additional markets later. Verizon expects initial 5G fixed wireless broadband deployment to cover around 30 million U.S. households. In addition to Verizon, other operators, including AT&T and Charter, are also carrying out 5G fixed wireless broadband tests in select markets in the U.S. However, 5G fixed wireless trials are not limited to North America. In Europe, Orange, Elisa and telecom infrastructure company Arqiva are performing 5G fixed wireless trials. In APAC, Australia's Optus is planning for 5G fixed wireless service launch in 2019.

> Early 5G fixed wireless broadband deployment is likely to focus on dense urban areas.

"5G fixed broadband access is expected to enable robust services with a reliable capacity to meet the need of residential broadband users. 5G technology can support a theoretical speed up to 20 Gbps with latency 1 ms, enabling operators to provide superior broadband access without installing fiber-optic cables to every single household," notes Khin Sandi Lynn, industry analyst at ABI Research.

Early 5G fixed wireless broadband access is likely to focus in dense urban areas and roll out in rural areas when 5G is widely launched commercially. ABI Research forecasts the worldwide fixed wireless broadband market to grow at CAGR 26 percent and to generate $45.2 billion in 2022.

## Singapore Tops in Smart City Rankings

Ranked as the top smart city, Singapore scores highest on all innovation criteria with a special focus on Mobility-as-a-Service (MaaS) and Freight-as-a-Service (FaaS). It maintains its leading role as a transportation and freight hub with driverless taxis, autonomous shuttles and platooning trials and projects, according to ABI Research. Additionally, Singapore's Smart Nation initiative addresses a wide range of urban issues linked to high-density living.

ABI Research's Smart City Ranking competitive assessment ranked 10 megacities across developed regions: New York (U.S.), Los Angeles (U.S.), Paris (France), London (U.K.), Dubai (United Arab Emirates), Beijing (China), Shanghai (China), Singapore (Singapore), Tokyo (Japan) and Seoul (South Korea). Cities were analyzed according to their innovation programs, strategies and implementation achievements measured through verifiable metrics for congestion, air quality, GDP, crime rates and cost of living. In terms of innovation, cities were assessed on the extent to which they embrace out-of-the-box thinking and planning to deploy disruptive technologies to fundamentally address the issues and challenges of megacities of the future across areas like mobility, transportation, energy, education, healthcare and public services.

> Excels in applying next generation innovation technologies and disruptive paradigms to solve hard problems.

"Singapore and second-placed Dubai emerged as smart city leaders, excelling in innovation in terms of the adoption of next-generation technologies and disruptive smart city paradigms as structural solutions for hard problems. Dubai is leading the way in the implementation of distributed ledgers with all government transactions to be processed via blockchain technology by 2030," said Dominique Bonte, VP end markets at ABI Research. "Both cities also scored high across most of the implementation criteria like congestion management, crime prevention and safety. Dubai actually has a "Happiness Index" which monitors the quality of public services and is aimed at improving overall citizen satisfaction."

London's third place is largely due to its advanced open data policies enabling a wider ecosystem of smart city application developers and startups. It forms part of a larger group of followers with New York, Paris, Tokyo, Seoul and Los Angeles engaging in multiple smart cities programs but often lacking a more ambitious vision to adopt transformative technologies and paradigms, usually linked to the legacy nature of their aging infrastructure. They also typically struggle with one or more

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implementation metrics like crime, congestion or cost of living.

Somewhat surprisingly, Shanghai and Beijing were assessed as laggers, coming in at ninth and tenth, respectively. Despite both cities' efforts to deploy technologies like smart meters and smart grids, bike sharing, vehicle electrification, smart parking and smart cards, they continue to face formidable issues related to congestion and pollution and trail the other cities on economic development in terms of GDP per capita. At the same time, both cities have huge potential to improve their ranking as they continue to evolve their smart cities solutions from basic sensor-centric technologies to more advanced approaches, while benefiting from expertise gained in trials for smaller cities.

## RF Power Semiconductors Near $1.5B for 2017 with GaN Driving the Way

Spending on RF power semiconductors (for < 4 GHz and > 3 W) was still moving forward in 2017. The wireless infrastructure segment was flat but other markets—notably the military/defense—are now moving forward, according to ABI Research. Additionally, GaN—long seen as the likely promising new "material of choice" for RF power semiconductors—is continuing its march to capture share.

> GaN shows promise to gain market share in 2018.

"GaN bridges the gap between two older technologies, exhibiting the high frequency performance of GaAs combined with the power handling capabilities of Si LDMOS," noted ABI Research Director Lance Wilson. "It is now a mainstream technology which has achieved measurable market share, and in the future will capture a significant part of the market."

Wireless infrastructure, while representing about two-thirds of total sales, has been anemic recently. Growth for other segments outside of wireless infrastructure is showing mid-single digit CAGR over the forecast period of 2018 to 2023.

The vertical market showing the strongest uptick in the RF power semiconductor adoption business, outside of defense, is commercial avionics and air traffic control. While the producers of these devices are in the major industrialized countries, this sub-segment market is now so global that end equipment buyers can be from anywhere.

# Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

## MERGERS & ACQUISITIONS

**T-Mobile US** and **Sprint Corp.** announced they have entered into a definitive agreement to merge in an all-stock transaction at a fixed exchange ratio of 0.10256 T-Mobile shares for each Sprint share or the equivalent of 9.75 Sprint shares for each T-Mobile US share. Based on closing share prices on April 27, this represents a total implied enterprise value of approximately $59 billion for Sprint and approximately $146 billion for the combined company. The new company will have a strong closing balance sheet and a fully funded business plan with a strong foundation of secured investment grade debt at close.

**TTM Technologies Inc.** announced that it has completed its acquisition of **Anaren Inc.** The combined company had pro-forma 2017 revenue of $2.9 billion. The acquisition combines TTM's strength in PCB manufacturing with Anaren's RF design capability and a product portfolio of unique and proprietary RF components and subsystems for the aerospace and defense and networking/communication end markets. The combined company will be strongly positioned to benefit from the expected increase in spending for advanced radar technology in the aerospace and defense market and 5G technology in the wireless infrastructure market.

**Silicon Labs** has completed the acquisition of **Sigma Designs' Z-Wave** business, including a team of approximately 100 employees, for $240 million in an all-cash transaction. Z-Wave is a leading mesh networking

## ANNIVERSARIES

**Exodus Advanced Communications** is celebrating its fifth aniversary as a multinational RF communication equipment and engineering service company. Exodus utilizes their global network of resources to effectively serve customer requirements. As an unique OEM of power amplifiers ranging from 500 KHz to 51 GHz with various output power levels and noise figure ranges, the company fully supports custom designs and manufacturing requirements for both small and large volume levels. Exodus brings decades of combined experience in the RF field for numerous applications, including military jamming, communications, radar, EMI/EMC and various commercial projects. Design and manufacturing of their various products are done in-house.

**Focus Microwaves** celebrates 30 years. From humble beginnings in 1988 making fundamental microwave tuners, Focus has grown into a global company that provides solutions for load pull, noise, pulsed-IV, active tuning and behavioral modeling.

**M Wave Design Corp.** was founded in 1988 in Newbury Park, California. The mission was to supply the industry with low loss, high performance ferrite and waveguide components. In 2013 M Wave Design restructured adding significant engineering and manufacturing assets and relocated into a larger facility located in Simi Valley, Calif. M Wave Design is ISO9001 certified, ITAR compliant and provides superior customer service. The company is proud to celebrate their past 30 years and the next 30. M Wave Design designs and manufactures in the U.S. and provides a broad range of custom passive microwave hardware from 100 MHz to 50 GHz.

Since 1981, **CTT** has been supplying customers worldwide with power amplifiers, frequency converters, frequency multipliers, transmitters, transceivers and receivers within the frequency spectrum of 10 MHz to 100 GHz. CTT's products are designed to provide the best price versus performance combination for each customer, whether the end use is military, industrial or commercial. Incorporation of new GaN technology into solid-state power amplifiers (SSPA) is their latest innovation and has brought dramatic results in amplifier performance. Over the past few years, CTT has been continually optimizing its proprietary designs to take advantage of the unique characteristics of the latest GaN devices.

**Teledyne Storm Microwave** was established in 1978 as a division of privately held Storm Products Company and acquired by Teledyne Technologies in 2008. For 40 years and counting, Storm Microwave's technical expertise and outstanding customer service has been put to work developing flexible and semi-rigid microwave cable assemblies—including multi-channel assemblies—for customer-specific space and military/defense programs, as well as high performance test & measurement applications, both domestic and international. The company routinely provides solutions for projects requiring assemblies with enhanced phase stability, flexure or durability; reduced diameters; and higher frequencies (up to 110 GHz) and conduct many qualification tests in house.

**Berkeley Nucleonics Corp.** was founded in 1963 as a Lawrence Berkeley National Lab spin-off. The company initially manufactured custom pulse generators used to simulate radiation for the development of nuclear electronics. With advancements in microprocessors in the 1970s and the Internet in the 1980s, innovation at BNC increased rapidly as well. The company went on to develop instrumentation for R&D in nuclear, TTL/solid-state, optical, high voltage and RF/microwave. BNC has been widely recognized for time and amplitude domain precision and stability, often presenting papers or webinars on the topic. Today, their instruments resolve time in less than a picosecond—the time it takes light to travel about 1/10 of an inch.

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technology for the smart home. More than 2,400 certified, interoperable Z-Wave devices are available from the thriving Z-Wave Alliance of more than 700 manufacturers and service providers worldwide. Combining Z-Wave's mesh technology and product interoperability focus with Silicon Labs' multiprotocol expertise gives smart home developers access to a large, varied network of ecosystems and to a full range of end-node technology options that open the door to millions of potential smart home users.

## COLLABORATIONS

**Qorvo** and **Lockheed Martin** have teamed up for the last decade to create trusted source microelectronics for the U.S. military's top systems. One example is the AN/TPQ-53, or Q-53, counterfire radar. To date, more than 100 systems have been manufactured for the U.S. Army. Developed as a replacement for the AN/TPQ-36 and AN/TPQ-37, the Q-53 Active Electronically Scanned Array (AESA) radar detects, locates and classifies incoming rockets and mortars, allowing time for shelter and counterfire opportunities. First in to the battlefield and last out, the Q-53 is highly mobile and can be set up rapidly to provide counterfire target acquisition.

## ACHIEVEMENTS

**EDI CON China 2018** enjoyed a year of record growth in both attendance and exhibition space at the China National Convention Center (CNCC) in Beijing from March 20-22. In its sixth year, EDI CON China continues to be the largest microwave and high speed digital design conference and exhibition in China. This year's event saw a 20 percent increase in exhibition space and 15 percent increase in attendance. Individual conference session attendance saw an average increase of 60 percent, with the majority of attendees returning over the course of multiple days. Space is already being booked for the 2019 event, and is on a record pace for returning exhibitors.

As part of a mission to demonstrate interlink communication on nanosatellite tandem formation flights and data retrieval, including surveillance of the Arctic area, the Danish nanosatellite specialist **GomSpace** launched two nanosatellites in February. Twelve weeks later, GomSpace for the first time showed the possibility of live data capture from the two nanosatellites in space at a press conference held in Aalborg, Denmark. At the same time, the press conference marked the official transition to the so-called demonstration phase, following the mission's test phase. The latter has thus been successfully completed, and the mission is now ready to carry out its scheduled tasks.

**Guerrilla RF Inc.**, a provider of high performance RF and microwave integrated circuits (IC) for wireless applications, announced the closing of a $3.8 million Series E funding round with participation from multiple angel investors. The $3.8 million funding is composed of a combination of equity and debt. Guerrilla RF expects to at least double 2018 revenue over 2017 revenues. The company expects to employ 25 associates by the end of 2018, with 21 employees currently.

**AR RF/Microwave Instrumentation** announced that it has been certified to International Organization for Standardization (ISO) 9001:2015 as of April 3. The company previously earned certification under ISO 9001:2008 and has been continually audited and registered annually by licensed registrars.

**NuWaves Engineering**, a veteran-owned small business providing advanced RF and microwave solutions, announced that the company has been selected for a Small Business Innovative Research (SBIR) Phase I award for the INnovative TowEd aRray Cable mOdeM (INTERCOM). The six-month Phase I project will involve research and development activities needed to set the design requirements for a miniature high bandwidth communications module that will be fully developed and delivered to the U.S. Navy during Phase II.

## CONTRACTS

**Curtiss-Wright Corp.** announced that it has been awarded a contract valued in excess of $85 million to provide main propulsion steam turbines and auxiliary equipment for the **U.S. Navy**'s Ford-class aircraft carrier Enterprise (CVN 80). The award was received from Huntington Ingalls, Newport News Shipbuilding (HII-NNS) to support planned ship construction. Curtiss-Wright is performing the work within its EMS division in the power segment. Engineering and manufacturing will commence in 2018 and will continue through at least 2022. The products will be shipped to Newport News Shipbuilding in Virginia.

**Raytheon Co.** has been awarded an $83 million contract for the design, test and deployment of the Barracuda mine neutralization system. The Barracuda mine neutralization system is an expendable, autonomous unmanned underwater vehicle intended to identify and neutralize bottom, near surface and drifting sea mines. It will field a shallow water capability and be an expendable modular neutralizer consisting of a kill mechanism, propulsion, sensors and communications buoy that enables wireless communication to the deployment platform.

**Comtech Telecommunications Corp.** announced that during its third quarter of fiscal 2018, its Orlando-based subsidiary, Comtech Systems Inc., which is part of Comtech's Government Solutions segment, received orders of approximately $6.5 million to provide tactical troposcatter equipment and to design and install ISR Video Downlink Systems for the Armed Forces of the Philippines (AFP). The Modular Transportable Transmission System (MTTS) troposcatter terminals will enable the Armed Forces to establish data links between island locations that were previously beyond the reach of high bandwidth terrestrial communications.

**L3 Technologies** announced that it has been awarded a contract for the Royal Australian Navy's (RAN) SEA

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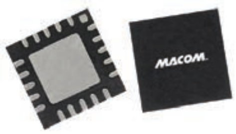


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1180 Offshore Patrol Vessels (OPV). The prime contractor, Luerssen Australia Pty Ltd., has selected L3 Communications Australia Pty Ltd. to provide the integrated communications, bridge, navigation and platform management systems for all 12 OPV platforms. Work on this program will be performed by L3 Communications Australia and supported by cross-segment collaboration from L3's Communication Systems, Sensor Systems and Electronic Systems business segments.

## PEOPLE

▲ *Jeff Shamblin*

**Taoglas**, a provider of IoT and automotive antenna and RF solutions, announced that wireless and antenna industry veteran **Jeff Shamblin** has joined Taoglas as vice president of engineering. Shamblin, who holds 77 issued patents related to antenna technology and communication systems, is tasked with driving Taoglas' continued innovation and preparing for the next generation of communications technologies in the wireless, M2M, IoT and automotive markets. Shamblin joins Taoglas from Ethertronics, where he spent 12 years in the roles of CTO and chief scientist and was responsible for R&D projects related to active antenna techniques directed towards commercial communication systems.

▲ *Meagan Sloan*

▲ *Miloš Lazic*

**Indium Corp.** has welcomed two new technical support engineers to its global support team. **Meagan Sloan** and **Miloš Lazic** are responsible for providing expert technical assistance and guidance to Indium Corp.'s customers and potential customers in the Americas to resolve soldering process related issues. Prior to joining Indium Corp., Sloan served as a laboratory technician at Anoplate, an electroplating company that serves the aerospace, computer and defense industries. Lazic previously worked at Radio-Television Nis in Serbia, where he held the position of deputy technical director. He also served as an electrical engineer for Montelektro, where he designed electrical installations for industrial, commercial and residential applications.

**NAI** announced its expansion in the Southeast Asia region with the appointment of two new executive personnel, effective immediately. NAI's sales department has appointed **Ling Chun Lim** as their business development manager in Singapore, to expand their sales operations in Malaysia. In addition, NAI's Engineering Group has appointed **ZhiQiang Lim** as their resident applications engineer in Penang. ZhiQiang Lim is a manufacturing engineer and is experienced in helping customers design new products. His recent responsibilities have included the support of new business devel-

# Around the **Circuit**

opment activities, generated by RFPs and New Product Introduction initiatives.

▲ *Wolfram Harnack*

**Mitsubishi Electric Europe** has appointed **Wolfram Harnack** as president of the Semiconductor-European Business Group. He succeeds Kenichi Makino, who will take on new responsibilities at the headquarters of Mitsubishi Electric in Tokyo. Harnack began his career at Mitsubishi Electric Europe in March 2015 as vice president and deputy division manager, Semiconductor.

**Resonant Inc.** announced **Dr. Andrew C. Guyette** was the co-recipient of the Microwave Prize, awarded by the IEEE Microwave Theory and Techniques Society (MTT-S). The annual award recognizes the most significant contribution by a published paper to the field of interest of the MTT-S. Dr. Guyette and Eric J. Naglich co-authored the winning paper, titled "Frequency-Selective Limiters Utilizing Contiguous-Channel Double Multiplexer Topology." The paper was published in *IEEE Transactions on Microwave Theory and Techniques*, Vol. 64, No. 9, pages 2871-2882, on September 2016.

## REP APPOINTMENTS

**Custom MMIC** announced the addition of sales representation in the Scandinavian region. **Bredengen AS** represents Custom MMIC in Norway. The company was established in 1926 and is based in Oslo. **Amtele Communication AB** represents Custom MMIC in Sweden, Finland, Denmark and the Baltics. The company was established in 1968, and has offices in Stockholm area, Gothenburg and Helsinki. Both companies have strong knowledge of their regions and long experience selling RF and microwave products. Custom MMIC looks forward to working with Bredengen and Amtele as a continuation of the company's global expansion.

**RFE** announced the appointment of the following regional manufacturer's sales representatives: **G Squared Technologies** covering the mid-Atlantic U.S. and **LS Engineering Inc.** covering Northern California and Nevada. RFE is an original design manufacturer (ODM) serving military, industrial and commercial markets with a product line of small profile, high performance converter and synthesizer sources.

## PLACES

**Versum Materials Inc.** announced the grand opening of its new R&D facility at its semiconductor materials manufacturing site in Hometown, Pa. The ribbon-cutting ceremony took place April 10. The state-of-the-art R&D laboratory is dedicated to new materials used in the manufacture of semiconductors. Scientists in the facility will synthesize and purify new molecules down to parts per billion impurity levels and below using the latest technologies available in the industry.

INVITED PAPER

# Designing A Broadband, Highly Efficient, GaN RF Power Amplifier

J. Brunning and R. Rayit
*SARAS Technology, Leeds, U.K.*

*A design approach for a broadband, linear, efficient output back-off mode RF power amplifier (RFPA) emphasizes the importance of minimizing design uncertainties. Using this approach, excellent agreement between modeled and measured performance is achieved with a first-pass design.*

Demand for linear RFPAs covering the frequency range from 1.5 to 2.8 GHz is driving new design methods for broadband, linear and highly efficient RFPAs operating in output back-off mode. Improving efficiency in PAs has long been a challenge for designers, in part due to poor control of harmonic load impedances. The difficulty measuring waveforms at microwave frequencies makes it hard to determine if optimum waveshaping has been achieved. Broadband design adds a challenge when a harmonic of a lower operating frequency lies in the operating band. These inherent difficulties can be compounded by imprecise design techniques, leading to multiple time-consuming and expensive iterations.

In this article, a design flow is described that uses NI AWR Design Environment platform, specifically Microwave Office circuit design software, as well as a measurement technique for determining the input and output impedances of the matching networks, prior to RFPA turn on. Several approaches to the problems inherent in PA design are presented with the aim of minimizing uncertainty and achieving first-pass success.

The effectiveness of this approach is demonstrated using a commercially available discrete 10 W GaN on SiC, packaged, high electron mobility transistor fabricated with a 0.25 μm process (Qorvo's T2G6000528) and a 20 mil RO4350B printed circuit board. The fabricated RFPA achieves a peak power greater than 40 dBm and a peak drain efficiency greater than 54 percent over its operating bandwidth. In back-off mode, the RFPA achieves an uncorrected linearity of 30 dBc and drain efficiency of 34 percent or higher when driven with a 2.5 MHz, 9.5 dB peak-to-average power ratio (PAPR) COFDM signal in the 2.0 to 2.5 GHz band.

## RFPA DESIGN FLOW

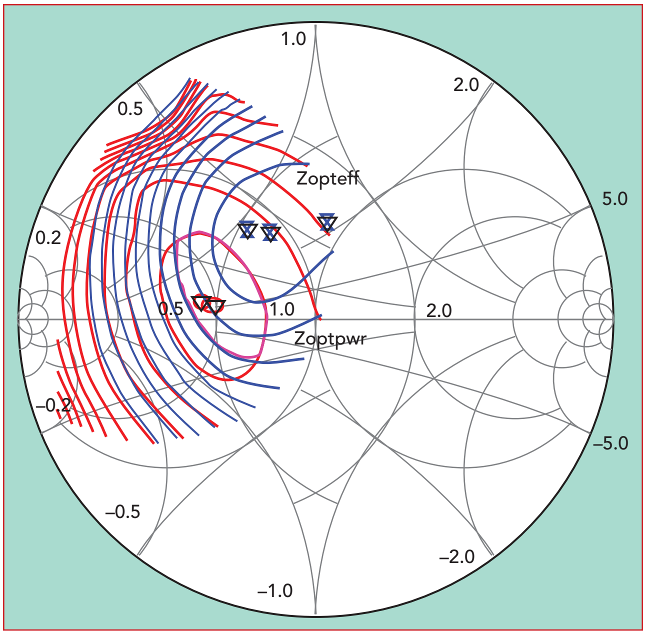
### Device Selection

The first step begins with a thorough device/technology selection process to determine the best candidate device to meet a specific set of criteria prior to the time-consuming tasks of load- and source-pull and network synthesis. Several candidates are acceptable on the basis of claimed frequency and power. In addition to the more common characteristics such as $V_{ds}$, gain, operating frequency and power rating, other parameters such as $C_{ds}$, $C_{gs}$ and transformation ratio are considered.

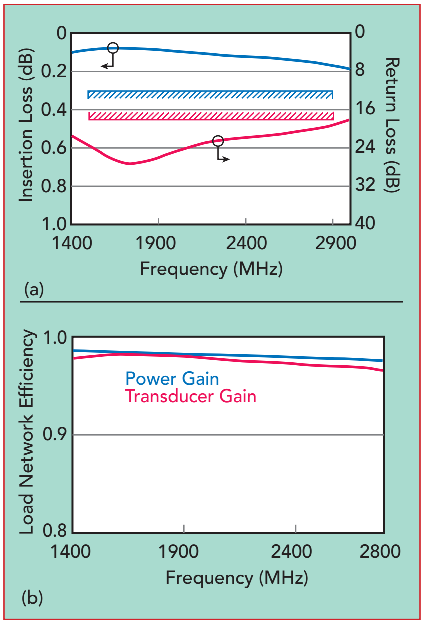
### Optimal Load Impedance Extraction

Once a device is selected and a nonlinear model obtained, optimal source and load impedances are determined. The required load impedances to achieve maximum power, efficiency and gain—or an acceptable trade-off between these performance metrics—are frequency dependent and vary substantially over the operating bandwidth of a broadband design.

To determine the correct load impedance, a combination of load-pull plotting at the fundamental and harmonic frequencies




▲ Fig. 1 **Fundamental frequency load-pull analysis showing power (red) and efficiency (blue) contours over the operating bandwidth.**




▲ Fig. 2 **Distributed load network loss and match (a) and transducer and operational power gain vs. frequency (b).**

and waveform engineering (circuit design techniques based on shaping the transistor voltage and current waveforms) are performed in Microwave Office. The use of waveform engineering relies on having access to the intrinsic device nodes across the current generator of the device plane, rather than at the package reference plane. Assuming the nonlinear device model provides these nodes, a waveform engineering approach enables the visual observation of voltage and current swing, clipping and amplifier class of operation.

For this example, a load-pull simulation is run at $V_{ds}$ = +28 V and $I_{dq}$ = 90 mA across the operating band, and the impedances for optimal power and efficiency are extracted, with the mid-band results shown in ***Figure 1***. A target load region based on the overlap between $P_{max}$ -1 dB and drain efficiency max ($eff_{max}$) -5 percent is defined. Clearly, the larger this target area is, the easier the matching problem becomes. In this case $P_{max}$ occurs on a tightly-packed clockwise rotating locus over the operating bandwidth, which is helpful in the case of a broadband amplifier. Load-pull is performed at the fundamental frequency due to the broadband nature of the RFPA and consequent difficulties in achieving optimal harmonic terminations[1] without using transmission zeros in the network.[2] Load-pull at the second harmonic is also performed, with a region of high efficiency identified[1] that can be controlled in the network synthesis.

## Network Synthesis

Narrowband RFPAs have the advantage of little variation of the optimal load impedance over their operating bandwidth, making the task of network design less complex. This is not to say that a low fractional bandwidth match is always trivial. Indeed, an investigation of source and load impedances will reveal that for very high performance, the network fundamental impedance must often be precisely controlled to a single gamma point, with significant sub-optimal performance penalties if the network locus misses its target load impedance. Precise control of harmonic termination impedances for F and $F^{-1}$ amplifier classes increases the complexity of the task beyond what is required for an average PA design.

In the case of a broadband amplifier, particularly one with high performance specifications, the network is required to control its impedance variation over a far larger fractional bandwidth. After defining optimal impedances and target areas, the load network is developed using a simplified real-frequency technique (SRFT)[3] to design the ideal lumped-element network and convert it to a distributed stepped-impedance format,[4] before performing electromagnetic (EM) simulation. In this example, EM simulation results agree closely with model predictions; however, for less conventional matching topologies, this might not be the case. In general, EM simulation is seen as an important step in reducing uncertainty in the design flow.

One design technique is to represent the conjugate of the optimal impedance as that of a two-terminal generator (port 1), after which the matching network design can be viewed as a problem of reducing the mismatch loss that exists between this complex-valued load and a 50 Ω termination over the amplifier's operating bandwidth. This mismatch can, however, be evaluated at the 50 Ω side (port 2) of the network, as shown in ***Figure 2a***. As a passive network, the output matching circuit has an operating power gain less than 1, equal to its efficiency determined only by internal dissipative loss. The necessarily smaller transducer gain is the product of this efficiency with the effect of loss due to reflection at the input. These quantities are shown as percentage efficiencies in ***Figure 2b***. The efficiency of the load network is calculated to be 96.6 percent at 2800 MHz, close to the value calculated from return loss at the same frequency. For comparison, the operational power gain, which considers purely ohmic loss in the network, is calculated to have an efficiency of 97.7 percent. Although this does not directly include reflection losses, its value does depend on the termination impedances, as these affect the distribution of current and voltage within the network, hence the

copper and dielectric losses, respectively.

Transducer gain is evaluated for a generator whose impedance is the conjugate of the target load impedance seen by the device drain. Although the output is matched for compressed power and efficiency, not for minimum reflection at the drain, the use of a conjugate match is found to agree well with the predicted reduction in compressed power due to imperfect realization of the target load impedance. Thus, the plotted transducer gain is a good measure of the overall quality of the output match.

Achieving an optimal broadband match using this transistor is relatively straightforward for several reasons. First, the transformation ratio is relatively low over the operating bandwidth (about 2:1); second, the load impedance for optimal $P_{max}$ are tightly packed; finally, the optimal impedance varies with increasing frequency in a clockwise rotating locus. The fairly low transformation ratio is a useful criterion favoring the selection of this GaN device for a broadband RFPA application.

### Source Network

Control of source impedance variation over the operating bandwidth is achieved through the use of a bandpass filter network, which also has the advantage of reducing low frequency gain, where the transistor's inherent gain is very high. This particular source impedance matching network is also responsible for improving the amplifier's low frequency stability. The impedance transformation ratio of about 15:1 requires a more elaborate network. Although not used here, matching networks with a positive slope, or equalization, can be conveniently introduced into the source matching circuit, as well.

Stability is achieved using a shunt connected series RC pair adjacent to the input port followed by a series R. Although this is a severe approach, analysis shows the transistor to be potentially unstable in the operating band, and some gain must be sacrificed to achieve unconditional stability from 1 MHz to greater than 6 GHz, where the transistor ceases to have gain ($F_{max}$).

### Waveform Engineering

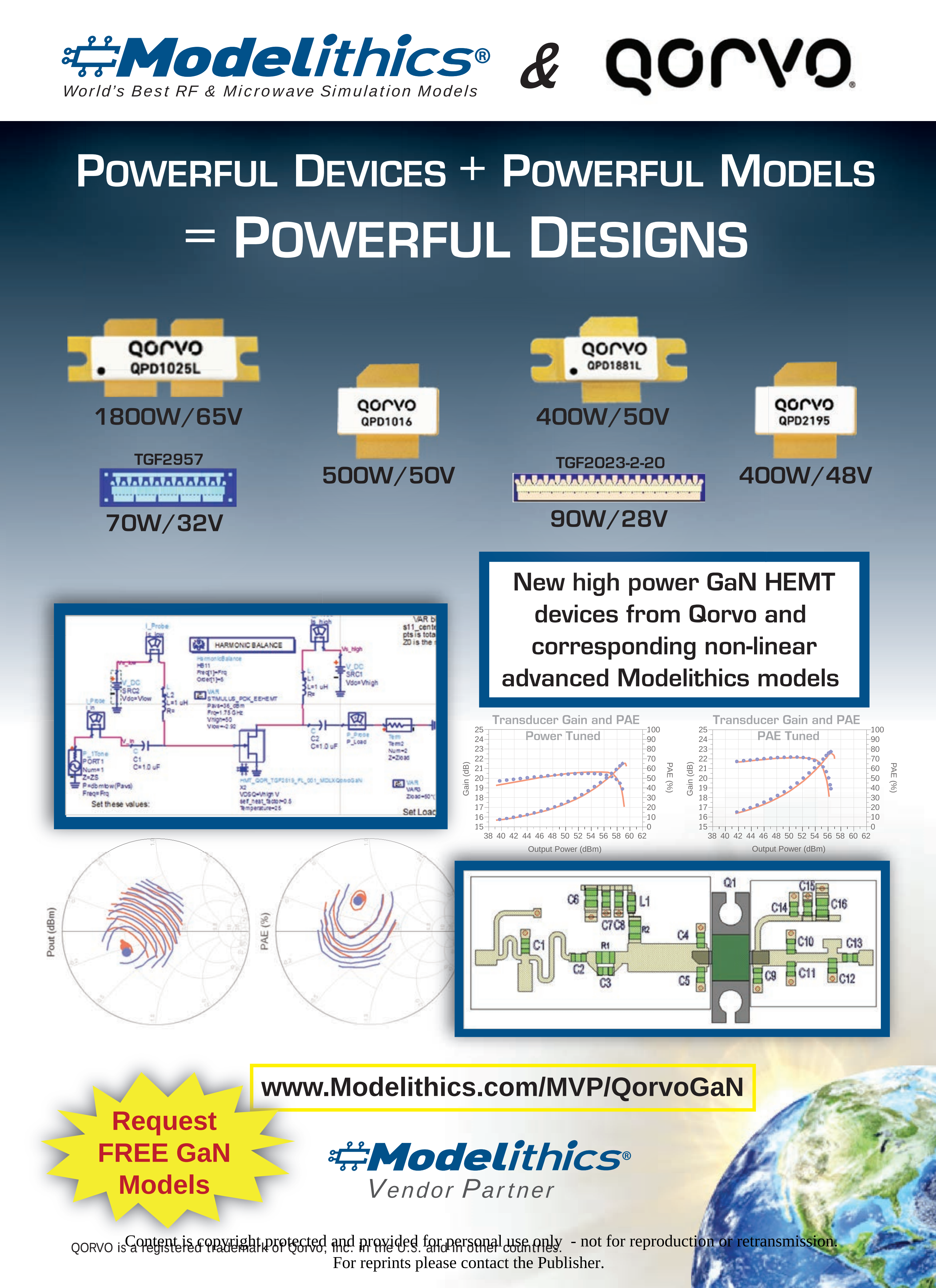
Waveform engineering[5] is also used to analyze the RFPA, using both the load-pull tuner and, more critically, the realized load network. Recent device models giving access to the voltage and current nodes at the intrinsic current generator plane allow accurate observation of both the V and I waveforms and the dynamic load line (DLL). This enables analysis of clipping and the RFPA mode of operation, as well as the peak voltages and currents generated.

Prior to these nodes being available, the only option was to monitor waveforms at the package plane, which clearly has limitations due to package parasitics. Negation of the parasitic network is feasible, but only if the topology and component values are known and their electrical impact removed through de-embedding during simulation. Although care has been taken to control the second harmonic load impedance, analysis of the waveforms (see ***Figure 3***) shows that the third harmonic impedance is favorable without further optimization.

These waveforms show a peak voltage of less than 60 V and a peak current of less than 1500 mA at 1500 MHz, which are well within device ratings. More significant, in terms of efficiency, is near-ideal class F operation, with the half-wave rectified current waveform exactly 180 degrees out of phase with the voltage waveform and very little voltage/current overlap. Using a DLL analysis, three regions are defined: region A ($V_{min}$ and $I_{max}$), region B ($V_{max}$ and $I_{min}$) and the transition region. Over one period, the waveform remains in region A or B for 63.8 percent of the time, while in the transition region for only 36.2 percent of the period.

## RFPA VALIDATION

To validate the approach, the RFPA was fabricated on Rogers 4350B 20 mil board ($\varepsilon_r$ = 3.48). The circuit



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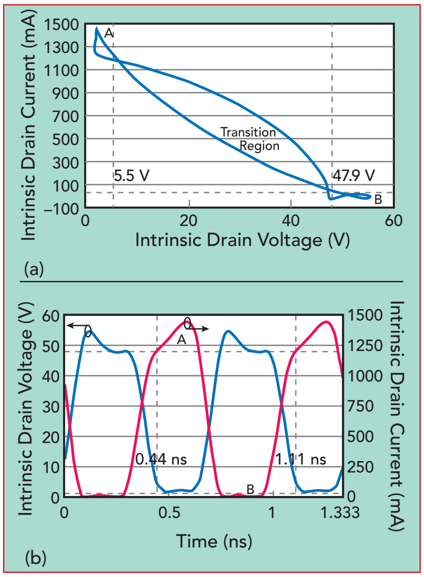


**Fig. 3** DLL (a) and IV waveforms (b) at the intrinsic device nodes, with a 1500 MHz CW signal and 10 W output power.

was mounted on a jig consisting of three pieces containing the source network (INMAT), load network (OUTMAT) and a copper center section to mount the device (see ***Figure 4***). The device source was soldered down.

## Passive Measurements

Prior to complete assembly, the impedances of the INMAT and OUTMAT circuits, as presented to the transistor tabs, were measured to correlate the modeled and measured datasets. The measured data shows excellent agreement with the modeled impedance from 1000

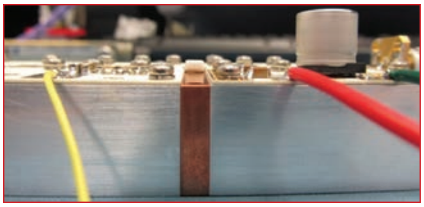

**Fig. 4** Fabricated RFPA.

to 3000 MHz with no tuning (see ***Figure 5a***). A measurement of the INMAT and OUTMAT circuits over a wider band from 20 MHz to 10 GHz still shows very good agreement between modeled and measured impedance (see ***Figures 5b*** and ***5c***). With the aid of the modular three-piece jig, impedances seen by the device can be measured directly and accurately without using mechanically awkward probes, which can introduce electrical parasitic—notably stray inductance—at the attachment point. The jig is not the production version of the amplifier but is an important step in the design flow, to eliminating uncertainties at each design stage.

## Small-Signal Measurements

Initial small-signal gain measurements used a drain bias of $V_{ds}$ = +28 V and an $I_{dq}$ = 90 mA. Measured and modeled gain and impedance match are closely correlated (see ***Figure 6***) with a small-signal gain greater than 16 dB and an input return loss greater than 7.5 dB over the operating band. The amplifier is stable when subjected to practical stability tests such as varying the drain rail voltage and using an external tuner to vary the source impedance seen by the device.

## Large-Signal Measurements

Large-signal measurements used a drain bias of $V_{ds}$ = +28 V and an $I_{dq}$ = 90 mA. A continuous wave signal source was fed to the amplifier through a driver amplifier. RF input and output power measurements were corrected for any compression in the driver. Power gain, drain efficiency and power delivered to the load were measured at 3 dB compression. The modeled results show a maximum $P_{3dB}$ of 41 dBm, maximum drain efficiency of 63.2 percent and a maximum gain of 16.4 dB. The measured results show a $P_{3dB}$ of 40.6 dBm, maximum drain efficiency of 59.1 percent and a maximum gain of 15.7 dB (see ***Figure 7***). The RFPA delivers more than 10 W down to 1300 MHz and up to 2900 MHz, extending its range to a fractional bandwidth of 76.2 percent.

To evaluate efficiency in output back-off mode and intermodulation sideband performance, a 2.5 MHz channel bandwidth COFDM signal with 9.5 dB PAPR was used over the band from 2.0 to 2.5 GHz. As a single-ended amplifier at 34.5 dBm output power, the average efficiency was 34 to 35.9 percent, with a linearity of 30 dBc measured ±1.25 MHz about the center frequency (see ***Figure 8***). Similar re-

sults were obtained in the band from 1.805 to 1.88 GHz using a WCDMA test signal with PAPR = 7.8 dB.

A balanced version of the amplifier is under construction. Including imperfect hybrids, it is predicted to achieve +37 dBm with an average efficiency of approximately 34 percent and a linearity of 30 dBc at ±1.25 MHz from the center frequency. Linearity could be improved using linearization techniques such as digital predistortion or envelope tracking. Achieving high efficiency at signal peaks enables operation at greater peak compression, so the amplifier can be operated at higher relative power over the whole dy-

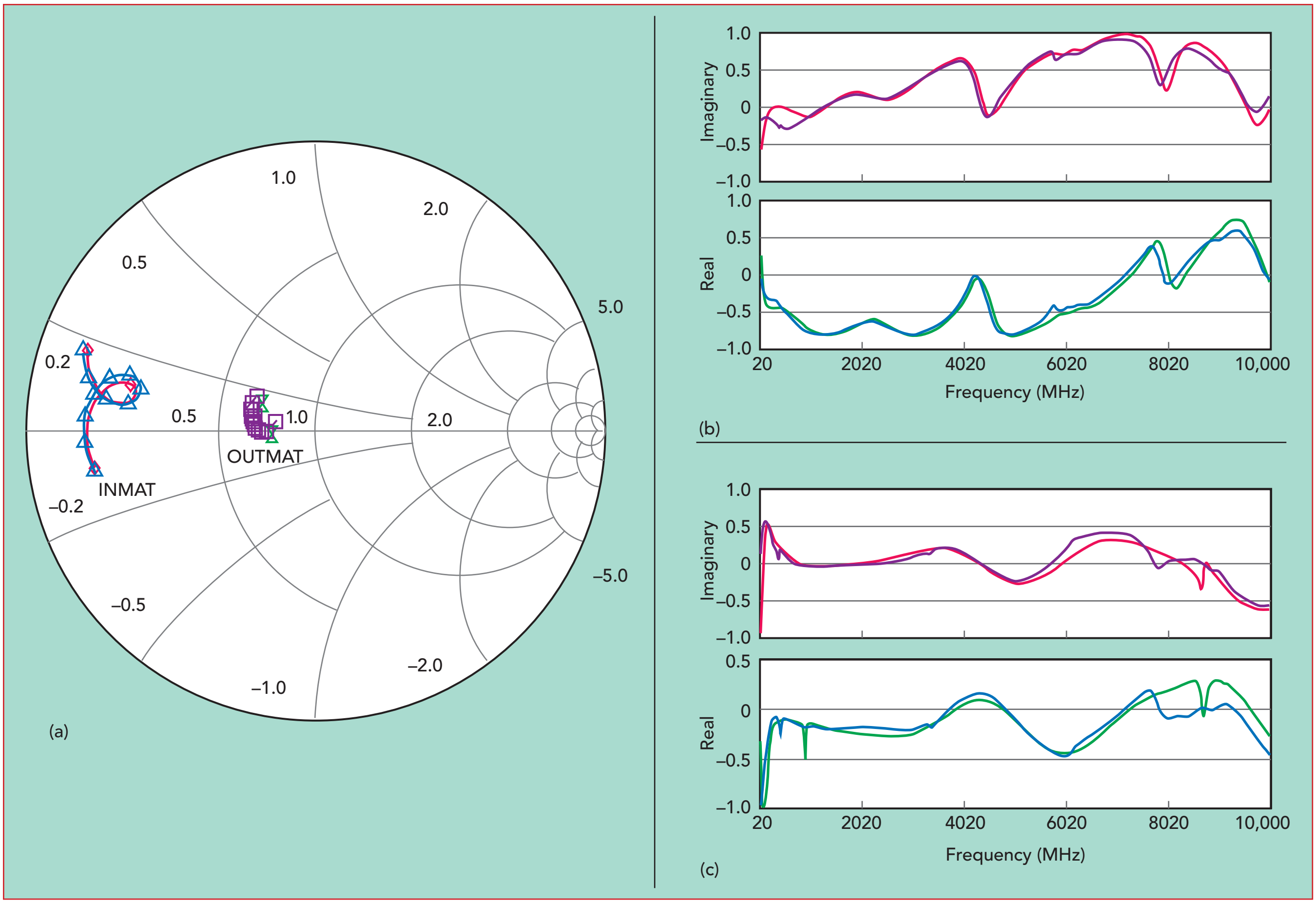


Fig. 5 Measured vs. modeled INMAT and OUTMAT impedances from 1000 to 3000 MHz (a); measured vs. modeled impedances from 20 MHz to 10 GHz for the INMAT (b) and OUTMAT (c) circuits.

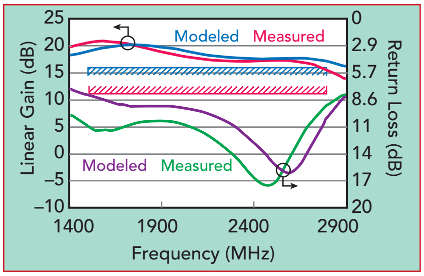


Fig. 6 **Modeled vs. measured small-signal gain and input return loss.**

namic range. Hence, efficiency and linearity are improved even on high PAPR signals.

## CONCLUSION

An approach for the design of broadband, linear and highly efficient RFPAs minimizes uncertainty to achieve first-pass success. The design methodology comprises four stages: device selection using qualitative and quantitative analysis, optimization of load and source impedance matching networks using load- and source-pull, passive network synthesis including EM verification and waveform engineering using intrinsic voltage and current nodes. Together, these techniques provide a proven systematic approach to designing the entire RFPA.

A measurement technique for fabricated source and load networks, enabling comparison of modeled and measured impedances at the transistor tabs, has also been demonstrated using a three-piece jig. Passive network synthesis, using an SRFT technique combined with analysis using mismatch loss and transducer power gain, provides a broadband match with relatively simple matching networks.■

To view the companion webinar to this design project visit: bit.ly/2lqFOqg


## ACKNOWLEDGMENTS

The authors would like to thank Andy Wallace of AWR Group, NI and Qorvo/Modelithics for the device model.


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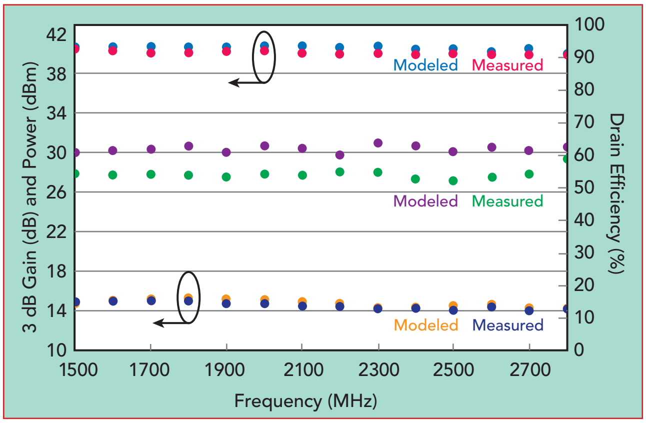



Fig. 7 **Modeled vs. measured large-signal CW power, gain and efficiency.**

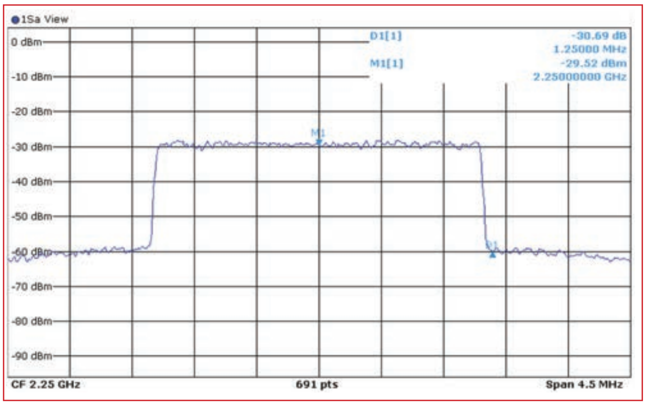
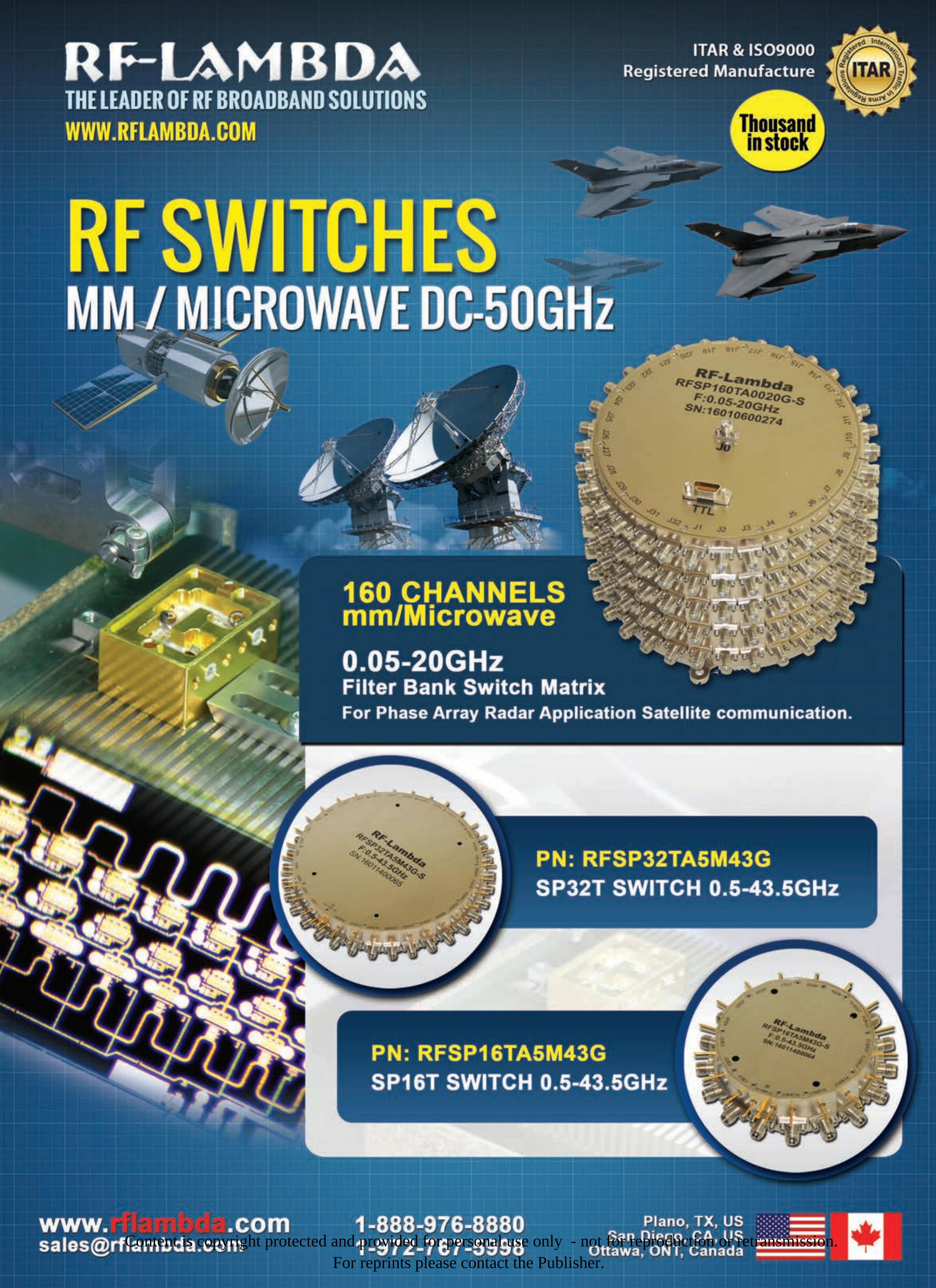



Fig. 8 **Single-ended amplifier intermodulation performance with a 2.5 MHz, 9.5 dB COFDM signal.**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INVITED PAPER

# Overcoming the Challenges of mmWave, On-Wafer Load-Pull Measurements for 5G

Richard Hilton and Steve Dudkiewicz
*Maury Microwave Corp., Ontario, Calif.*

*Hybrid-active load-pull overcomes the challenges in mmWave power amplifier design by removing the uncertainty of unclosed contours to enable designing for peak performance.*

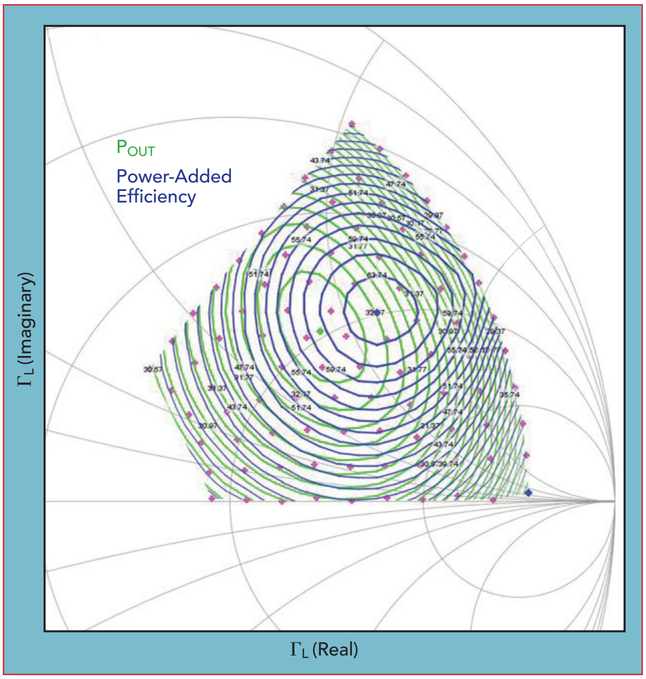


**Fig. 1** **Output power and power-added efficiency load-pull contours.**

Fifth-generation mobile represents the next evolution in wireless communications. With an emphasis on connectivity, 5G is expected to bring together data, voice, video, IoT, connected cars, smart homes, smart cities, augmented reality and industrial automation. 5G will achieve this aggressive goal by deploying technologies over multiple frequency bands, from low MHz to high GHz. Research in the 450 MHz to 6 GHz bands is targeting long-range communication and in the 28 to 30 and 37 to 39 GHz bands for high data rates. While posing unique challenges, the mmWave bands promise to bring many advantages, including larger bandwidth, greater capacity, increased security and longer battery life.

A critical enabler in the 5G infrastructure is the power amplifier (PA), which must be properly designed for optimum performance, i.e., maximizing power and efficiency while maintaining appropriate linearity. A useful design tool for maximizing performance is load-pull.

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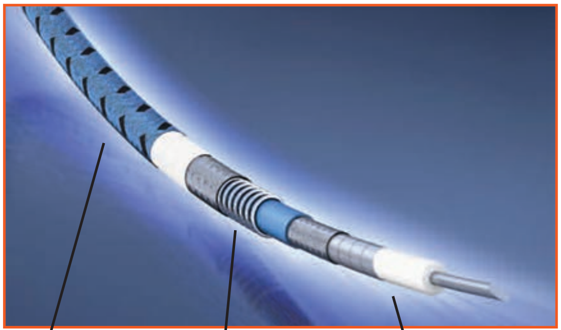


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## LOAD-PULL TECHNIQUES

Load-pull is the process of changing the load impedance presented to a device under test (DUT), commonly a transistor, to measure its performance characteristics under varying large-signal conditions. The impedance is systematically changed while parameters such as output power, gain and efficiency are measured or calculated. Contours representing fixed performance values (e.g., x dBm output power or y percent efficiency) are then plotted to visualize the point of maximum performance, the rate at which the performance changes and trade-offs between various parameters (see ***Figure 1***).

But how does load-pull work? First, consider a DUT as a two-port network (see ***Figure 2***). A signal $a_1$ is injected into port 1 of the DUT. A portion of the signal is delivered to the DUT while another portion is reflected as $b_1$, due to the mismatch between the input impedance of the DUT and the source impedance of the input network. A modified signal $b_2$ exits port 2 of the DUT and is delivered to the load, while a portion of it is reflected back as $a_2$, due to the mismatch between the output impedance of the DUT and the load impedance of the output network. The magnitude and phase of that reflection, represented as $\Gamma_L$, is

$$\Gamma_L = \frac{a_2}{b_2} \quad (1)$$

Load-pull changes the magnitude and phase of $\Gamma_L$ by changing the reflected signal $a_2$. Any load impedance, which can be calculated as

$$Z = Z_0\left(\frac{1+\Gamma_L}{1-\Gamma_L}\right) \quad (2)$$

can be presented to the DUT as long as the signal $a_2$ can be achieved. There are two common methodologies to vary the impedance presented to the DUT: passive load-pull and active load-pull.

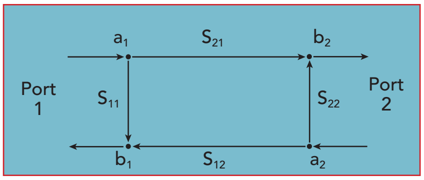


**Fig. 2** Two-port S-parameter model of a DUT.

## PASSIVE LOAD-PULL

Passive load-pull uses mechanical impedance tuners to change the magnitude and phase of the reflected signal $a_2$ and vary the impedance presented to the DUT (see ***Figure 3a***). The magnitude and phase of the load impedance are adjusted by varying the position of a probe (or slug) in both x and y axes along a 50 Ω airline (see ***Figure 3b***). The

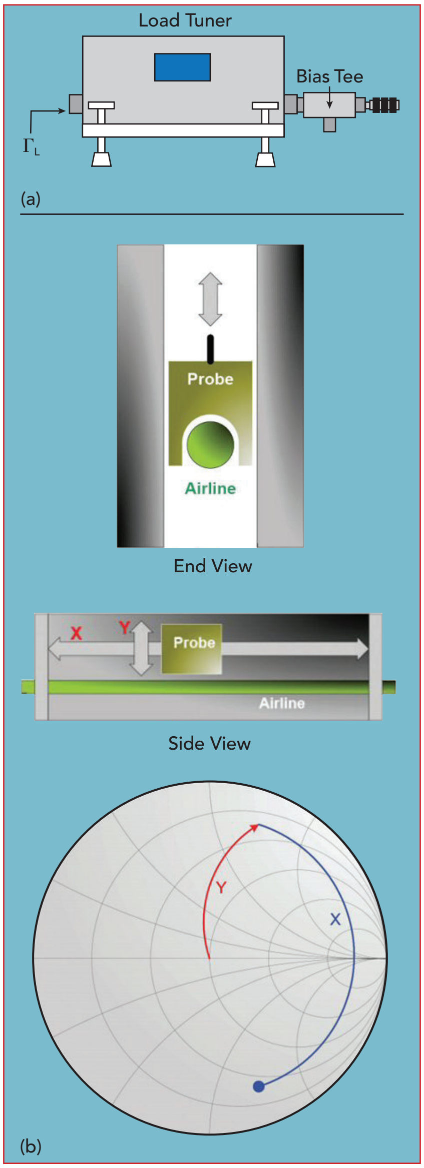


**Fig. 3** Passive tuner for performing load-pull measurements (a) comprising a passive slide screw tuner and probe (b).

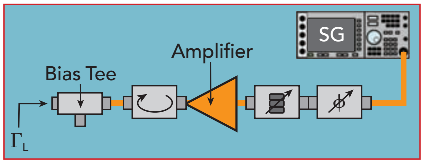


**Fig. 4** Output network of a simple active load-pull setup.

magnitude of the reflection is controlled by moving the probe vertically within the airline, while phase is controlled by moving the probe horizontally along the airline. By moving the probe up and down, left and right, it is possible to present nearly any impedance to the DUT, as long as the magnitude of $a_2$ remains sufficiently large so that the desired

$$\Gamma_L = \frac{a_2}{b_2}$$

can be achieved. It is important to note that $\Gamma_L$ is less than 1, since $a_2$ is always smaller than $b_2$ due to losses between the output of the DUT and the tuner.

## ACTIVE LOAD-PULL

Open-loop active load-pull (see ***Figure 4***) does not rely on a mechanical tuner to reflect part of $b_2$ back as $a_2$; rather, it uses a signal generator with magnitude and phase control to create a new signal $a_2$. When amplified by an external amplifier, any $a_2$ and, hence, any $\Gamma_L$ can be achieved. At first glance, active load-pull may seem superior to passive load-pull since it has no theoretical $\Gamma_L$ limitation; however, a practical limitation is the power required to achieve the signal $a_2$ actually delivered to the output of the DUT. Active tuning has several advantages over passive tuning, including speed, as there are no mechanical moving parts, and increased Smith chart coverage, as $a_2$ is directly generated, enabling

$$\Gamma_L = \frac{a_2}{b_2}$$

to be greater than 1.

The limitation is the maximum output power of the amplifier. Referring to Figure 4, the mismatch between the 50 Ω amplifier and the non-50 Ω DUT causes a portion of the signal to be reflected back toward the amplifier; the larger the mismatch, the larger the signal that is reflected. Under extremely mismatched conditions, it is possible that only 10 percent of the signal available will actually be delivered to the output of the DUT, requiring a large amplifier.

Hybrid-active load-pull overcomes this limitation by pre-matching the DUT impedance from highly mismatched to moderately mismatched, lowering the power required to deliver the same signal $a_2$ to the output of the DUT.

## mmWAVE LOAD-PULL

When performing load-pull, it is preferable to be able to close the measurement contours to ensure the DUT's maximum performance has been achieved. Without closed contours, it is possible for the optimum performance condition to be missed and the wrong conclusion formed.

With a passive load-pull system, the net magnitude of reflection achievable at the DUT reference plane can be calculated as

$$RL_{tuner} + RL_{coupler+cable+probe} = RL_{DUT} \quad (3)$$

where RL is return loss

$$RL_{tuner} = -20\mathrm{Log}\left(\frac{VSWR_{tuner} - 1}{VSWR_{tuner} + 1}\right) \quad (4)$$

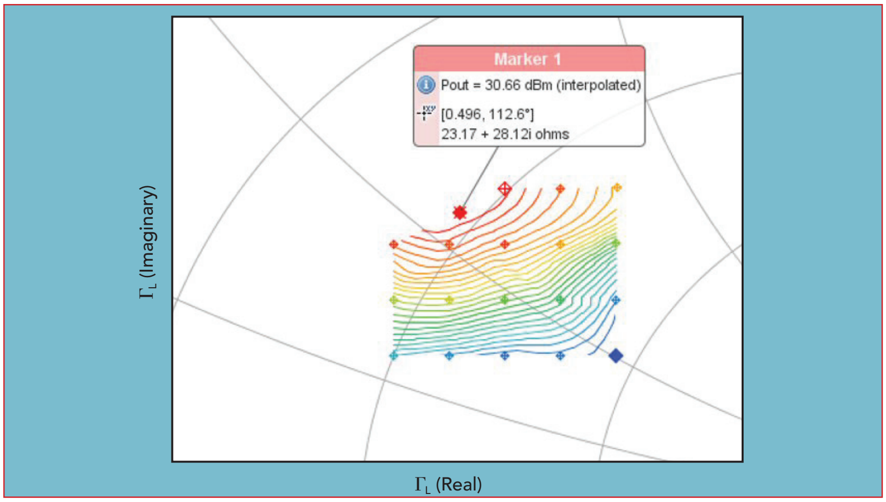


Fig. 5 Passive on-wafer load-pull measurement of a GaN transistor at 30 GHz.

$$RL_{coupler+cable+probe} = 2\left(IL_{coupler+cable+probe}\right) \quad (5)$$

and where IL is insertion loss.

$$\Gamma_{DUT} = 10^{\left(\frac{-RL_{DUT}}{20}\right)} \quad (6)$$

Assuming a typical tuner VSWR and coupler, cable and probe losses at 30 GHz, $VSWR_{tuner}$ = 20:1, $IL_{coupler+cable+probe}$ = 2.5 dB, the maximum achievable magnitude of reflection is reduced from Γ = 0.9 at the tuner reference plane to Γ = 0.5 at the DUT reference plane. Modern GaN transistors have output impedances of 1 to 2 Ω, which can be represented by Γ values from 0.96 and 0.92, respectively. ***Figure 5*** shows actual passive load-pull measurement data for a GaN transistor on-wafer at 30 GHz with a maximum output power of 30.66 dBm. Notice how the contours do not close, so it is uncertain how the transistor would perform if further tuning could be performed.

Hybrid-active load-pull overcomes this limitation in the passive load-pull's measurement range by adding an active injection signal to increase $a_2$ and, therefore, increase Γ. A com-

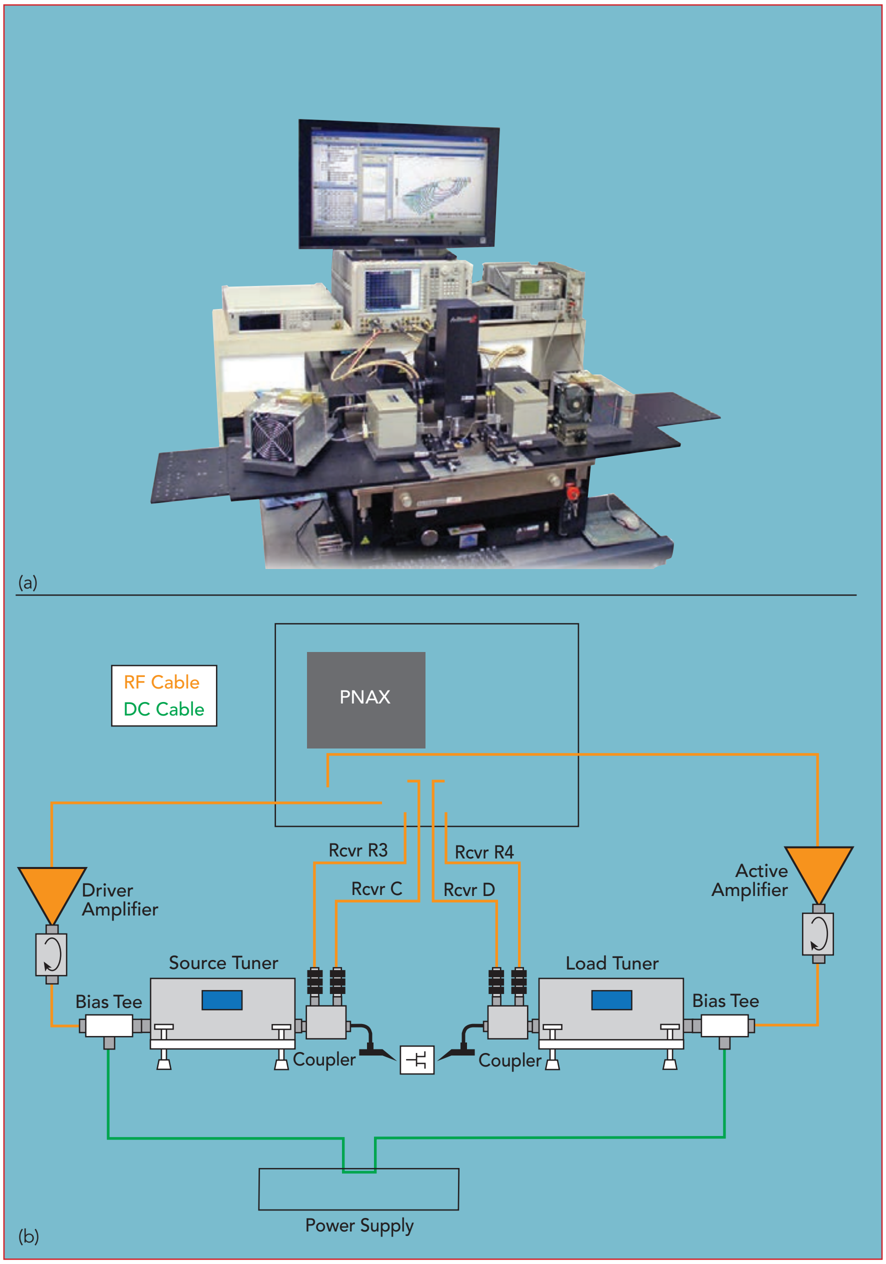


**Fig. 6** mmWave hybrid-active load-pull system (a) and setup (b).

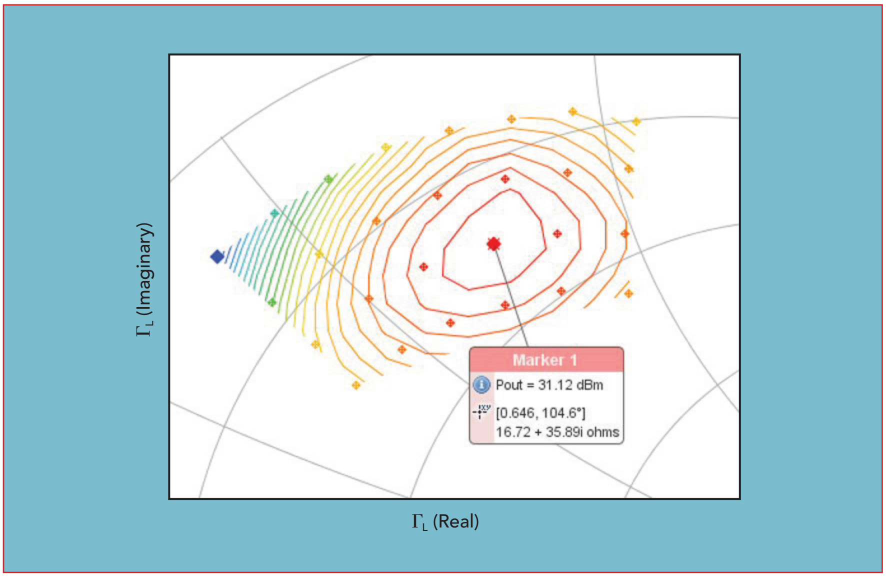


**Fig. 7** Hybrid-active on-wafer load-pull measurement of a GaN transistor at 30 GHz.

mercial hybrid-active load-pull system is shown in ***Figure 6a*** and a typical test setup in ***Figure 6b***. The relationship between the transistor, the system impedance, the injection power and the tuning range is

$$Z_L = \frac{Z_{Sys} + KZ_{DUT} - \sqrt{\left(Z_{Sys} + KZ_{Dut}\right)^2 - (1-K)\left(Z_{Sys}^2 - KZ_{DUT}\right)^2}}{1-K} \qquad (7)$$

where $Z_L$ is the impedance presented to the DUT, $Z_{Sys}$ is the system impedance and $Z_{DUT}$ is the DUT's output impedance. K is defined as

$$K = \frac{P_{a2}}{P_{b2}} \cdot \frac{1-\left|\Gamma_{Sys}\right|^2}{1-\left|\Gamma_{DUT}\right|^2} \frac{\left|Z_{Sys} + Z_0\right|^2}{\left|Z_{DUT} + Z_0\right|^2} \qquad (8)$$

where $P_{a2}$ is the active tuning power injected into the output of the DUT at the DUT reference plane, $P_{b2}$ is the DUT's output power and $Z_0$ = 50 Ω. The net reflection achievable at the DUT reference plane is

$$\Gamma_L = \frac{Z-50}{Z+50} \qquad (9)$$

With a driver amplifier output of 40 dBm and using the same passive impedance tuner to transform the system impedance from 50 Ω to 23.17 + j28.12 Ω, it is possible to achieve Γ = 0.85 and successfully close the output power contours. The contours shown in ***Figure 7*** demonstrate that a maximum output power of 31.12 dBm can be achieved by the same GaN transistor, which is 0.46 dB or approximately 11 percent more power than initially determined through passive load-pull with incomplete contours.

## CONCLUSION

As companies accelerate development of 5G technologies and compete for best-in-class solutions, the optimization of power, efficiency and linearity will become more essential. Small advantages of a few dB in power or a few percentage points in efficiency may mean the difference between best-in-class and "never was." Hybrid-active load-pull helps overcome the challenges in mmWave PA design by removing the uncertainty of unclosed contours. This enables ideal matching and gives those that adopt the methodology an edge in the marketplace.■


# 1.8 kW GaN Transistor for L-Band Avionics

Qorvo Inc.
*Greensboro, N.C.*

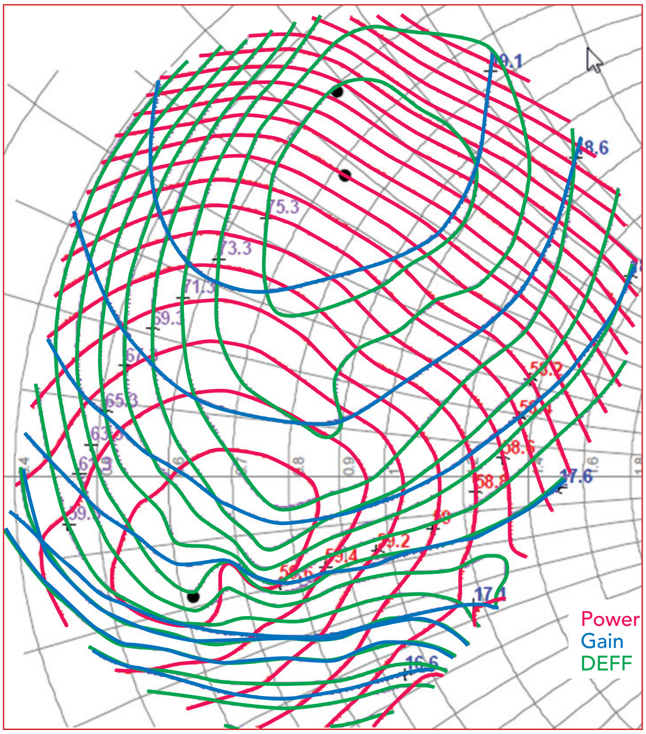


Fig. 1 Load-pull contours for a half device, measured at 1 GHz with an RF pulse 100 μs wide at a 10 percent duty cycle. The maximum power is 59.7 dBm, maximum drain efficiency is 77.2 percent and maximum gain is 19.6 dB.

In the world of high-power amplifiers, the desire to increase the amount of power from a single packaged transistor never ends. Moving from amplifiers consisting of multiple, small transistors to a single, large component simplifies assembly and external combining networks, reducing the overall footprint. Responding to this demand for power, Qorvo developed the QPD1025, a 1.8 kW GaN on SiC transistor for L-Band aeronautical radionavigation applications.

Covering 1.0 to 1.1 GHz, the QPD1025 is a dual-channel device. Biased at 65 V, each side delivers a maximum output power of 900 W at 1 GHz (see ***Figure 1***), yielding a combined power of 1.8 kW—currently the highest power GaN transistor on the market. The peak efficiency, measured with load-pull, is 77 percent. Linear gain, measured in the application board, is 21 dB (see ***Figure 2***). The QPD1025 is assembled in a 41 mm x 10 mm NI-1230 package, available in two configurations: eared (QPD1025L) and earless (QPD1025).

## BROADBAND PERFORMANCE

As transistors get larger, their impedances get lower, which often results in external matching networks difficult to realize and

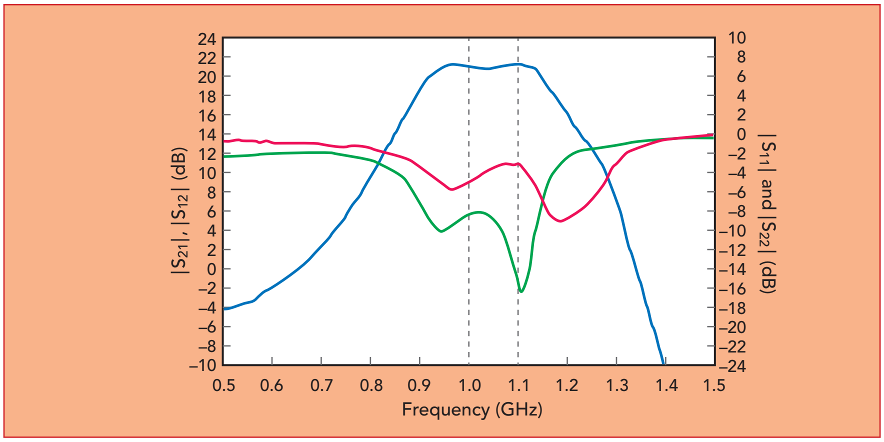


Fig. 2 Small-signal S-parameters measured in the evaluation board at 25°C, showing performance outside the 1.0 to 1.1 GHz operating band.

limited in bandwidth. The QPD1025 addresses this problem in two ways. First, using a 65 V drain voltage yields a higher device output impedance than a 50 V device of similar power and technology. The load-pull contours, shown in Figure 1, represent a very manageable output impedance of around 2 Ω per side. Second, on the input, the package contains a single stage prematch that both improves stability and provides a "friendlier" input impedance. These features allow comparatively broadband board designs without having to resort to high dielectric substrates, reflected by the broadband performance in Figure 2.

## COMBINING FLEXIBILITY

The dual-channel configuration of the QPD1025 enables multiple amplifier options. The application board, shown in ***Figure 3***, uses in-phase combining, which is compact and low loss. A balanced configuration can be designed using the appropriately-sized hybrid couplers. This architecture affords more isolation between the channels and cancellation of even-order harmonics. Since each side can be biased independently, a symmetric Doherty amplifier design is possible using the correct combining networks.

## STABILITY AND RUGGEDNESS

Ensuring the stability of all transistor products is a focus of Qorvo. This starts in the design process with even- and odd-mode simulations with linear models, using loop-gain analysis and parametric measurements. Stability is validated with small-signal measurements at -40°C, confirming the QPD1025 is unconditionally stable in the application board. High-power stability is evaluated by looking for spurs better than -60 dBc over various VSWR and drive conditions at -40°C. The QPD1025 is free of spurs at these strenuous conditions up to 2:1 VSWR. Device stability is largely the product of internal features and requires nothing exotic on the printed circuit board—only a series RC filter at the input and resistors in the gate bias line.

Ruggedness has also been thoroughly tested, demonstrating the QPD1025 survives pulsed testing at 3 dB compression with VSWR loads to 10:1 and overdrive testing to at least 6 dB compression, both measured at 25°C.

## APPLICATION BOARD PERFORMANCE

The application board offered for the QPD1025L uses a compromise match between power and efficiency, trending toward the efficiency match. At room temperature, the drain efficiency is greater than 72 percent from 1 to 1.1 GHz, while the power ranges from 1.3 to 1.5 kW (see ***Figure 4***). Peak dissipation is 460 W, which is below the 500 W CW dissipation limit. Under pulsed conditions, the dissipation limit increases and efficiency may be traded for power. The linear gain is 21 dB at room temperature.

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|---|---|---|---|---|---|---|---|
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| PSM-1G1R1G-TRSW-2500W<br>http://www.pmi-rf.com/products/switches/PSM-1G1R1G-TRSW-2500W.htm | 1.0 - 1.1 | 0.8 Typ., 1.0 Max. (J1 - J2, Tx Mode)<br>0.8 Typ., 1.0 Max. (J1 - J3, Tx Mode)<br>0.6 Typ., 0.8 Max. (J2 - J4, Tx Mode)<br>0.6 Typ., 0.8 dB Max. (J1 - J3, Tx Mode) | 25 Min. (J2 - J3)<br>60 Min. (J2 - J4)<br>60 Min. (J3 - J5) | 1.5:1 | 250 ns Typ. | 2.5 kW Peak (J1 Only) Tested @ 125.89 W CW | +50 VDC @ 60 mA Typ.<br>+5 VDC @ 400 mA Typ. |
| P2T-3G3R5G-45-R-SFF-50W-SM<br>http://www.pmi-rf.com/Products/Switches/P2T-3G3R5G-45-R-SFF-50W-SM.htm | 3.0 - 3.5 | 1.0 Typ. | 40 Typ. | 1.5:1 | 100 ns Typ. | 50 W | +5 VDC @ 100 mA |
| P2T-6G18G-40-R-570-TFF-1D6KW<br>http://www.pmi-rf.com/products/switches/P2T-6G18G-40-R-570-TFF-1D6KW.htm | 6.0 - 18.0 | 2.2 Max. At band edges for 20% bandwitdth and typically 1.75 goal. For mid-band of 80% of the bandwidth 2.0 Max., typically 1.5 goal | 40 Min. | 2.0:1 Max. | 200 ns Typ. | 1.6 kW Peak - Tested to 125.89 W CW | + 5 VDC @ 300 mA<br>-70 VDC @ 60 mA |
| PDT-8G12G-40-515-SFF<br>http://www.pmi-rf.com/products/switches/PDT-8G12G-40-515-SFF.htm | 8.0 - 12.0 | 2.0 | 40 Min | 1.8:1 | 200 ns Max. | 40 dBm CW 57 dBm, 1 µs, 1% DC | +5 VDC @ 100 mA<br>-15 VDC @ 60 mA |

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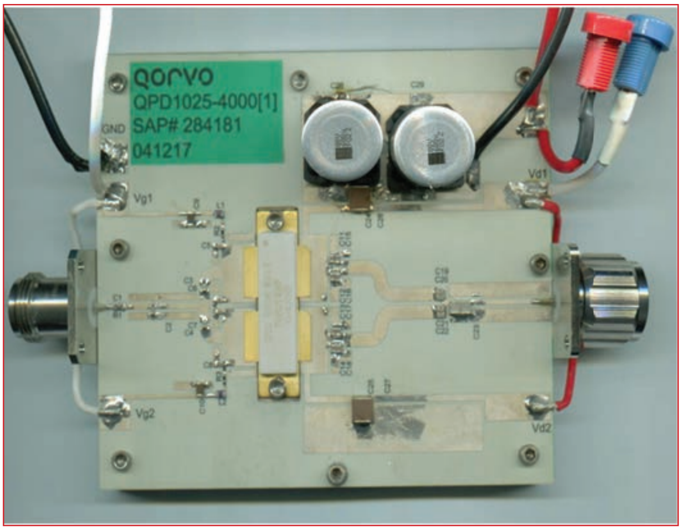


Fig. 3 **QPD1025L in the application board, which uses in-phase combining.**

The application board substrate uses the industry-standard Rogers RO4350B 20 mil organic substrate on a low-cost, nickel-plated aluminum baseplate. Although the QPD1025 supports independent drain and gate voltages for each channel, the application board ties the gates and drains together with external wires (see Figure 3). The in-phase matching network is quite compact for this power level at 9 cm x 3 cm from the input RC filter to the final output matching capacitor. The overall dimensions of the application board are 11.3 mm x 9.7 mm.

The QPD1025 provides the best combination of power, efficiency and gain available today for applications in the 1.0 to 1.1 GHz band. Its dual-channel design offers manageable impedances, flexibility in amplifier architecture and a compact footprint. Designed with stability, ruggedness and reliability as foremost considerations, the QPD1025 can handle all signal conditions so long as the dissipation limits are respected.

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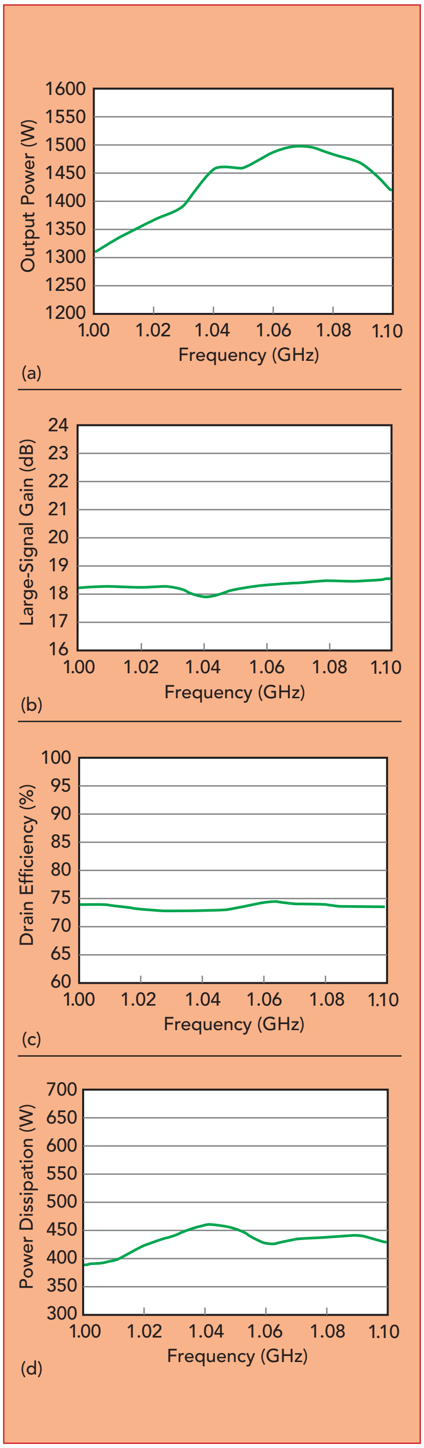



Fig. 4 **Pulsed performance of the QPD1025 at 25°C and 3 dB gain compression, with an RF pulse 100 μs wide at a 10 percent duty cycle. The application board uses in-phase combining.**

EUROPEAN MICROWAVE WEEK
IFEMA FERIA DE MADRID, SPAIN
23-28 SEPTEMBER 2018
www.eumweek.com
EuMW2018 PASSION FOR MICROWAVES

# EUROPEAN MICROWAVE WEEK 2018
# THE CONFERENCES

**Don't miss Europe's premier microwave conference event. The 2018 week consists of three conferences and associated workshops:**

- European Microwave Integrated Circuits Conference (EuMIC) 24th - 25th September 2018
- European Microwave Conference (EuMC) 25th - 27th September 2018
- European Radar Conference (EuRAD) 26th - 28th September 2018
- Plus Workshops and Short Courses (From 23rd September 2018)
- In addition, EuMW 2018 will include, for the 9th year, the Defence, Security and Space Forum on 26th September 2018

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 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..

## FAST TRACK BADGE RETRIEVAL

**Register online and print out your badge in seconds onsite at the Fast Track Check In Desk**

## CONFERENCE PRICES

**There are TWO different rates available for the EuMW conferences:**

- **ADVANCE DISCOUNTED RATE** – for all registrations up to and including 23rd August 2018
- **STANDARD RATE** – for all registrations made after 23rd August 2018

Please see the Conference Registration Rates table on the back page for complete pricing information. All payments must be in Euro – cards will be debited in Euro.

**Online registration is open now, up to and during the event until 28th September 2018**

## DELEGATES

**Registering for the Conference**

- 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 delegate badge
- Alternatively, you can register onsite at the self service terminals during the registration opening times below:

  - Saturday 22nd September (16:00 - 19:00)
  - Sunday 23rd September (08:00 - 17:00)
  - Monday 24th September (08:00 - 17.00)
  - Tuesday 25th September (08:00 - 17.00)
  - Wednesday 26th September (08:00 - 17.00)
  - Thursday 27th September (08:00 - 17.00)
  - Friday 28th September (08:00 - 10.00)

Once you have collected your badge, you can collect the conference proceedings on USB stick and delegate bag for the conferences from the specified delegate bag area by scanning your badge.

# CONFERENCE REGISTRATION INFORMATION

## EUROPEAN MICROWAVE WEEK 2018, 23rd - 28th September, Madrid, Spain

## Register Online at www.eumweek.com

**ONLINE registration is open from 28th May 2018 up to and during the event until 28th September 2018.**

**ONSITE registration is open from 16:00 on 22nd September 2018.**

**ADVANCE DISCOUNTED RATE (up to and including 23rd August) STANDARD RATE (from 24th August & Onsite).**

Reduced rates are offered if you have society membership to any of the following*: Eu*MA*, GAAS, IET or IEEE.

Eu*MA* membership fees: Professional € 25/year, Student € 15/year.

**If you register for membership through the EuMW registration system, you will automatically be entitled to discounted member rates.**

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 28th September 2018).

The fees shown below are invoiced in the name and on behalf of the European Microwave Association. Eu*MA*'s supplies of attendance fees in respect of the European Microwave Week 2018 are exempted from Spanish VAT.

### ADVANCE REGISTRATION CONFERENCE FEES (UP TO AND INCLUDING 23RD AUG.)

| CONFERENCE FEES | ADVANCE DISCOUNTED RATE | | | |
|---|---|---|---|---|
| | Society Member (*any of above) | | Non Member | |
| *1 Conference* | Standard | Student/Sr. | Standard | Student/Sr. |
| EuMC | € 470 | € 130 | € 660 | € 190 |
| EuMIC | € 360 | € 120 | € 510 | € 170 |
| EuRAD | € 320 | € 110 | € 450 | € 160 |
| *2 Conferences* | | | | |
| EuMC + EuMIC | € 670 | € 250 | € 940 | € 360 |
| EuMC + EuRAD | € 640 | € 240 | € 890 | € 350 |
| EuMIC + EuRAD | € 550 | € 230 | € 770 | € 330 |
| *3 Conferences* | | | | |
| EuMC + EuMIC + EuRAD | € 810 | € 360 | € 1140 | € 520 |

### STANDARD REGISTRATION CONFERENCE FEES (FROM 24TH AUG. AND ONSITE)

| CONFERENCE FEES | ADVANCE DISCOUNTED RATE | | | |
|---|---|---|---|---|
| | Society Member (*any of above) | | Non Member | |
| *1 Conference* | Standard | Student/Sr. | Standard | Student/Sr. |
| EuMC | € 660 | € 190 | € 930 | € 270 |
| EuMIC | € 510 | € 170 | € 720 | € 240 |
| EuRAD | € 450 | € 160 | € 630 | € 230 |
| *2 Conferences* | | | | |
| EuMC + EuMIC | € 940 | € 360 | € 1320 | € 510 |
| EuMC + EuRAD | € 890 | € 350 | € 1250 | € 500 |
| EuMIC + EuRAD | € 770 | € 330 | € 1080 | € 470 |
| *3 Conferences* | | | | |
| EuMC + EuMIC + EuRAD | € 1140 | € 520 | € 1600 | € 740 |

### WORKSHOP AND SHORT COURSE FEES (ONE STANDARD RATE THROUGHOUT)

| FEES | STANDARD RATE | | | |
|---|---|---|---|---|
| | Society Member (*any of above) | | Non Member | |
| | Standard | Student/Sr. | Standard | Student/Sr. |
| Half day WITH Conference registration | € 100 | € 80 | € 130 | € 100 |
| Half day WITHOUT Conference registration | € 130 | € 100 | € 170 | € 130 |
| Full day WITH Conference registration | € 140 | € 110 | € 180 | € 130 |
| Full day WITHOUT Conference registration | € 180 | € 140 | € 240 | € 170 |

### Other Items

#### PRIVATE VISIT TO THE THYSSEN-BORNESMIZA MUSEUM & COCKTAIL DINNER – 26TH SEPTEMBER 2018

Tickets for the private visit and cocktail dinner at the Thyssen-Bornesmiza Museum are offered at the price of **€** 45. Tickets are limited and available on a first-come, first-served basis.

#### DELEGATE LUNCHBOXES

Subsidised lunchboxes for delegates, WS/SC, doctoral and student school attendees are being offered by EuMW at the reduced cost of **€** 5 per lunchbox (one per day).

#### Proceedings on USB Stick

All papers published for presentation at each conference will be on a USB stick, given out FREE with the delegate bags to those attending conferences. The cost for an additional USB stick is **€** 50.

#### International Journal of Microwave and Wireless Technologies (8 issues per year)

International Journal combined with Eu*MA* membership:
**€** 67 for Professionals or **€** 57 for Students.

#### EUMW 2018 WORKSHOPS & SHORT COURSES

| SUNDAY 23rd September | | |
|---|---|---|
| Full Day | WS-01 | EuMC/EuMIC |
| Half Day AM | WS-02 | EuMC/EuMIC |
| Half Day PM | WS-03 | EuMC/EuMIC |
| Half Day AM | WS-04 | EuMC |
| Half Day PM | WS-05 | EuMC |
| Full Day | WS-06 | EuMC/EuMIC |
| Half Day AM | WS-07 | EuMC |
| Full Day | WS-08 | EuMC/EuMIC |
| Full Day | WS-09 | EuMC/EuMIC |
| Full Day | WS-10 | EuMC |
| Full Day | WS-11 | EuMC/EuMIC |
| Full Day | WS-12 | EuMC/EuMIC |
| Half Day PM | SS-01 | EuMC/EuMIC |
| Full Day | SS-02 | EuMC/EuMIC |
| Full Day | SS-03 | EuMC/EuMIC |

| MONDAY 24th September | | |
|---|---|---|
| Full Day | WM-01 | EuMC |
| Full Day | WM-02 | EuMC |
| Full Day | WM-03 | EuMC |
| Full Day | WM-04 | EuMC |
| Full Day | SM-01 | EuMC |
| Full Day | SM-02 | EuMC |
| Full Day | SM-03 | EuMC |
| Full Day | SM-04 | EuMC |

| TUESDAY 25th September | | |
|---|---|---|
| Half Day PM | WTu-01 | EuMC |

| WEDNESDAY 26th September | | |
|---|---|---|
| Half Day PM | WW-01 | EuMC/EuRAD |
| Full Day | WW-02 | EuRAD |

| THURSDAY 27th September | | |
|---|---|---|
| Full Day | WTh-01 | EuMC |
| Half Day AM | WTh-02 | EuMC |
| Half Day PM | WTh-03 | EuRAD |
| Half Day AM | WTh-04 | EuMC/EuRAD |
| Half Day PM | WTh-05 | EuMC |
| Half Day AM | WTh-06 | EuMC |
| Half Day PM | WTh-07 | EuRAD |

| FRIDAY 28th September | | |
|---|---|---|
| Half Day AM | WF-01 | EuRAD |
| Full Day | WF-02 | EuMC |
| Full Day | WF-03 | EuMC |
| Half Day AM | WF-04 | EuRAD |
| Full Day | WF-05 | EuMC |
| Full Day | WF-06 | EuMC |
| Full Day | WF-07 | EuMC |
| Half Day AM | SF-01 | EuMC/EuRAD |

### SPECIAL FORUMS & SESSIONS

| Date | Time | Title | Location | No. of Days | Fee | |
|---|---|---|---|---|---|---|
| Wednesday 26th September | 10:50 - 17:50 | Defence, Security & Space Forum | N101 + N102 | 1 | € 20 for delegates (those registered for EuMC, EuMIC or EuRAD) | € 60 for all others (those not registered for a conference) |
| Monday 24th - Wednesday 26th September | 08:30 - 17:50 | European Microwave Student School | N107 | One full day and two half-days | € 40 | |
| Monday 24th - Wednesday 26th September | 08:30 - 17:50 | European Microwave Doctoral School | N108 | One full day and two half-days | € 80 | |

# General Purpose Digitizers Now 50% Faster

Spectrum Instrumentation GmbH
*Grosshansdorf, Germany*

Five new models have been added to Spectrum Instrumentation's general purpose M2p.59xx series of PCIe 16-bit digitizer cards. These new versions extend the performance range by increasing the maximum sampling rate from 80 to 125 Msps. The increased sampling rate, together with higher overall bandwidth, enables the new cards to capture a wider range of electronic signals. It makes them suited for applications where signals in the DC to 50 MHz frequency range need to be acquired and analyzed with speed and accuracy. The digitizers are suitable for diverse applications such as ultrasound, laser, LiDAR, radar, power, automotive, medical science—even big physics experiments.

Based on the latest 16-bit analog-to-digital (ADC) technology, the new M2p-596x series includes models that provide one, two, four or eight input channels. Multi-channel models each have their own ADC and signal-conditioning circuitry to allow fully synchronous acquisition on all the inputs. Importantly, the high-resolution 16-bit ADCs are said to deliver 16x more resolution than digitizers using older 12-bit technology and 256x more resolution than is available from digital scopes that commonly use 8-bit ADCs. The extra resolution translates directly into improved measurement capabilities and superior dynamic performance. The series is also said to deliver a higher signal-to-noise ratio, better spurious free dynamic range and less distortion than 12- or 14-bit products.

## COMPACT AND POWERFUL

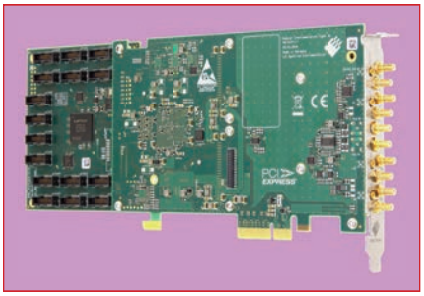
The complete product has been packed into a half-length PCIe card, yet it still offers a full set of digitizer features. Each channel has its own programmable input amplifier with ranges between ±200 mV and ±10 V, programmable input offset for unipolar measurements, programmable input termination of 50 Ω and 1 MΩ and an integrated calibration circuit. Models are available with up to eight single-ended and up to four differential channels.

To match nearly every application requirement, the units come with a variety of signal triggering techniques, an impressive on-board memory of 1 GB and a number

of intelligent acquisition modes, such as multiple recording, gated sampling or ABA (the combination of fast and slow continuous acquisitions). At 167 mm long, these multi-function digitizers fit into much smaller PC systems, making them suitable for compact original equipment manufacturer solutions.

## SIGNAL PROCESSING REVOLUTION

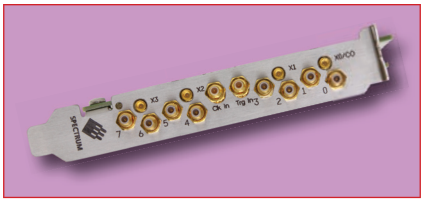
Incorporated into the digitizers is a PCIe ×4 lane interface that enables fast data streaming at rates of more than 700 Mbps—or more than 80 MSPS continuous streaming for four channels. The cards support Spectrum's new SCAPP software option—the Spectrum CUDA Access for Parallel Processing—that enables an easy-to-use, powerful way to digitize, process and analyze electronic signals. SCAPP allows a CUDA-based graphical processing unit (GPU) to be used directly between any Spectrum digitizer and the PC. The main advantage is data is passed directly from the digitizer to the GPU, where high speed parallel processing is possible using its multiple processing cores (up to 5,000). Fast data streaming and SCAPP improve overall measurement speeds and free up vital PC resources.



▲ Fig. 1 **M2p.59xx with Star-Hub module, which synchronizes up to 16 cards.**

## MULTI-CHANNEL SYSTEMS

For high density, multi-channel acquisition, up to 16 digitizer cards can be fully synchronized using the company's Star-Hub technology, which allows systems to be built with up to 128 channels, all sharing a common clock and trigger in a single chassis. ***Figure 1*** shows the M2p.59xx with Star-Hub module.



▲ Fig. 2 **Front panel connectors on the PCIe 16-bit digitizer card.**

For synchronization with other external equipment, clock and trigger inputs and outputs are also standard. Further flexibility is provided via four individually programmable, front panel connectors that offer additional trigger inputs, status outputs, synchronous digital input lines, asynchronous I/O or a reference clock input for an integrated time stamping unit. ***Figure 2*** shows the connectors.

## SOFTWARE SUPPORT

The software design of the new cards is based on Spectrum's own general driver API that was introduced in 2006; more than 400 different products now share this common driver library, allowing easy switching from slow to fast products and combining PCIe, PXIe or Ethernet/LXI products with one common software interface. A complete software development kit (SDK) based on Windows and Linux is included standard with the card.

Drivers and examples for nearly every programming language on the market are included, leaving the decision of the preferred programming interface to the customer. The current SDK includes: C, C++, C#, Delphi, VB.NET, J#, Python, Java, LabVIEW, MATLAB and LabWindows/CVI.

All units are shipped factory tested and include a base version of the SBench 6 software for first tests and simple measurement tasks. The professional license of the software adds full support for all the acquisition modes, a large number of calculations, additional displays, project control and reporting.

VENDORVIEW

**Spectrum Instrumentation GmbH**
**Grosshansdorf, Germany**
**www.spectrum-instrumentation.com/en**

# Compact, Lightweight, RF Peak Power Meter

Strengthening its reputation as a leader in RF peak power measurement, Boonton has introduced its next-generation peak power analyzer, the 4500C. Designed to capture, display, analyze and characterize RF and microwave power in both time and statistical domains, the 4500C is well-suited for design, verification and troubleshooting pulsed and noise-like signals used in commercial and military applications such as radar, electronic warfare (EW) and wireless communications.

Incorporating Boonton's unique Real-Time Power Processing™ to minimize the likelihood of missing pulses or intermittent events, the 4500C provides a wide variety of measurement functionality, including a best-in-class measurement range from −60 to +20 dBm, less than 5 ns RF channel rise time, 100 ps time resolution, 5 ns minimum pulse width, 50 MHz maximum pulse repetition frequency and 10 hour maximum viewing range. The 4500C has ultra-fast trace acquisition and refresh rates, unique trigger functionality—automatic peak-to-peak, delay-by-time and delay-by-event triggering—and powerful statistical analysis.

The 4500C is the next-generation of peak power analyzers in Boonton's 4500 series product line, and is a drop-in, code-compatible replacement to the 4500B. It has the same front panel controls and graphical user interface, eliminating the need to change any test procedures written for the 4500B. This compatibility enables Boonton customers to move to the new 4500C with virtually no down time.

With the 4500C, Boonton builds on its leadership in high performance RF and microwave test equipment for radar, avionics, EW, satellite and wireless communications and EMI/EMC applications. For more than 70 years, Boonton's products, which are designed and manufactured in the U.S., have enabled RF power measurement and signal analysis for product design, production, maintenance and system integration.

**Boonton**
**Parsippany, N.J.**
**www.boonton.com**

# Low PIM Surge Arrestors with 4.3-10 Connectors

To meet the growing demand for RF lightning and surge protection for global 4G LTE and 5G network applications, PolyPhaser's new SX™ series surge arrestors have an optimized design to meet the rigorous requirements of these high-end wireless networks. This new product line—four models with 4.3-10 connectors—covers a broad frequency range from 698 MHz to 2.7 GHz and provides market-leading, low PIM performance. The SX series has a typical PIM rating of −130 dBm (−173 dBc, 2 x 20 W), with 0.1 dB insertion loss and 28 dB return loss. Two of the models allow the pass-through of AISG signals.

The SX series uses PolyPhaser's patented spiral inductor surge protection technology, a unique spiral inductor that responds almost instantaneously to a lightning surge while maintaining optimal RF performance. PolyPhaser's technology enables these RF lightning and surge arrestors to outperform quarter-wave stub and gas tube technologies. These surge arrestors are compact; compared to bulky, quarter-wave stub RF arrestors, they occupy approximately 40 percent less space than traditional arrestors, making them well-suited for small cell networks and distributed antenna systems (DAS), as well as macro sites.

The 4.3-10 SX surge arrestors are bi-directional for ease of use and ship with a hardware kit that allows them to be bulkhead mounted. Weatherproof when installed, they are CE and RoHS compliant and meet IP67, Bellcore TA-NWT-000487 and Procedure 4.11, Wind Driven (120 MPH) standards.

PolyPhaser's surge arrestors have been field tested and are deployed by major, global cellular carriers and in critical wireless communication systems used by police, fire and emergency responders.

**PolyPhaser**
**Hayden, Idaho**
**www.polyphaser.com**

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# 20 dBm, 40 to 60 GHz Power Amplifier

The Spacek Labs SPU-20-20W is a high-power amplifier designed for operation from 40 to 60 GHz, part of a banded solution with excellent output power—greater than 20 dBm—making it well-suited for communications system transmitters. Although the amplifier typically provides 20 dB gain, it can easily be configured with 30 or 40 dB gain, if desired. The SPU-20-20W is biased with a single positive voltage between 7 and 12 V DC, applied through a solder bias pin, and draws 680 mA.

Although designed with WR19 waveguide to cover 40 to 60 GHz, the SPU-20-20W can be delivered with 1.85 mm coaxial connectors. In the coaxial configuration, the upper frequency extends to 65 GHz, with similar performance. Since this amplifier also works well down to 37.5 GHz, it can be used as an intermediate amplifier to drive passive frequency doublers for W-Band, with WR10, or to 130 GHz, with WR8 waveguide.

Spacek Labs offers both standard and custom designed amplifiers from 10 to 110 GHz. Modular construction enables a variety of configurations to meet specific requirements. Should customers need customized solutions, rather than the standard products offered on the website, Spacek Labs' engineers and in-house CNC machining facility can tailor the design.

For more than 30 years, Spacek Labs has been dedicated to providing the highest quality mmWave and microwave components and subassemblies to industry, research institutions, universities and government, from commercial to military and space applications.

**Spacek Labs**
**Santa Barbara, Calif.**
**www.spaceklabs.com**


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## New Video Series

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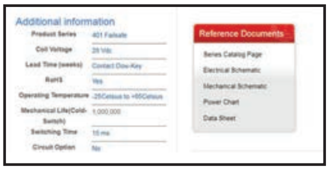
To introduce simulation solutions to engineers, CST now has a series of bite-sized videos. Each video covers one area of electrical engineering, lists some of the potential challenges that are in that field and explains how EM simulation can be used to overcome these. These videos can be found on the associated industry and market pages on the CST website.

**CST**
ow.ly/MH9n30in6xl

## Datasheets Now Available




As a process improvement to enhance Dow-Key's customer's online experience, datasheets are now available for download for the entire Standard Part List. Their datasheets provide technical RF characteristics in addition to pin out schematics. To obtain a datasheet, start your search by typing a product number into the search box from the homepage. Next, click the product number link to be re-directed to the product page. There, a reference document section will have several helpful downloads available.

**Dow-Key Microwave**
www.dowkey.com

## Online Custom Cable Creator


Fairview Microwave has introduced a new online custom cable creator tool that allows engineers and buyers to design, customize and purchase hundreds of different combinations of custom RF cable assemblies. Fairview's RF Cable Designer™ allows engineers to quickly and easily create customized RF cable assemblies from a wide selection of connectors and cable types offered by the company. The new RF Cable Designer™ can also be used to locate any of Fairview Microwave's existing cable assemblies.

**Fairview Microwave Inc.**
www.fairviewmicrowave.com

## New and Improved


K&L Microwave's website provides information and tools, such as the Filter Wizard® web application, to speed the identification of custom design solutions from a full range of company products. The latest web update features a new look, mobile device support and social media links. Research capabilities, access data sheets, submit quote requests, read the latest news and download K&L's new Product Catalog and new Space Brochure.

**K&L Microwave**
www.klmicrowave.com

## Improved Product Search

Marki Microwave continues to update their website, now with improved product search capabilities. Product Search has been expanded to include all configuration options and Marki Microwave's newest feature, the "New Products" filter, enables users to identify the latest technology for use in their designs. Marki Microwave is on the cutting edge of RF and microwave technology, and is committed to releasing new products every month, empowering customers to shatter performance barriers.

**Marki Microwave**
www.markimicrowave.com

## New Mician Website


Mician's new easy to navigate website features an overview of Mician's entire product catalog with detailed description of all available products, numerous product videos and also a new customer log-in and help desk. A download of the µWave Wizard Free Edition is available, as well as an application for a test for evaluation of the complete software package including all add-ons. The new website now also supports mobile devices.

**Mician GmbH**
www.mician.com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# Web&VideoUpdate

## RF & Microwave Filters

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Reacting first to your filter requirements, Reactel Inc. has launched its redesigned website containing links to its entire product line of RF filters, multiplexers and multifunction assemblies for aerospace, aviation, defense and wireless applications. The site includes a library of product data sheets, as well as Reactel's full line catalog, available by download. An online RFQ is also available for your custom requirements.

**Reactel Inc.**

www.reactel.com

## Case Studies Show Reliability & Quality

VENDORVIEW


The best way of understanding what a product can do is by reading about it in use. On their website, Spectrum Instrumentation has assembled a fascinating range of case studies that show how its digitizers and AWGs are used by customers to solve their problems. Most are at the cutting edge of science where precision, quality and reliability are paramount such as CERN and quantum research at several universities.

**Spectrum Instrumentation GmbH**

https://spectrum-instrumentation.com/en/case-studies

## End Launch Connectors for 40, 50 & 67 GHz


Withwave's End Launch connectors are specially designed for well-used high frequency substrates to minimize electromagnetic effects including impedance discontinuities from coaxial to GCPWG (Grounded Coplanar Waveguide) and Top Ground Microstrip structure. The types of connectors are 2.92, 2.4 and 1.85 mm. Withwave solves your performance and cost problems.

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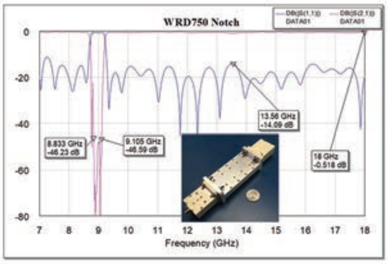
VENDORVIEW




Exceed Microwave's BSF-W-00053 is a WRD750 bandstop filter which provides a sharp and deep rejection at 9 GHz while maintaining a clean, flat passband all the way up to 18 GHz with no re-entrant rejection showing up. 9 GHz ± 100 MHz has > 45 dB rejection with 0.5 dB passband insertion loss which includes the WRD750 to SMA adapters. The low insertion loss and waveguide structure makes this an ideal bandstop filter for high-power applications.

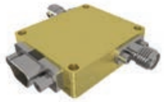
**Exceed Microwave**
**www.exceedmicrowave.com**

### E- and W-Band PIN Diode Waveguide Switches

Fairview Microwave Inc. has released a new line of E- and W-Band PIN diode waveguide switches. These single-pole single-throw (SPST) and single pole double-throw (SPDT) mmWave waveguide switches offer an ultra-broadband frequency range with fast switching performance. They are ideal for telecommunications, test instrumentation, R&D programs and radar front-ends in applications that involve general switching, receiver protection, pulse modulation and antenna beam switching.

**Fairview Microwave Inc.**
**www.fairviewmicrowave.com**

### 5G Programmable Attenuator



JFW Industries introduces their new 40 GHz Programmable Attenuator model 50P-2072 2.9MM. With a total attenuation of 0 to 31 dB in 1 dB steps and 100 MHz to 40 GHz, model 50P-2072 2.9MM is perfect for broadband testing of 5G wireless radios and networks.

**JFW Industries Inc.**
**www.jfwindustries.com**

### Tunable UHF Multicoupler

K&L Microwaves SPCL-00636 is a factory tunable UHF multicoupler designed to combine multiple UHF radios to a common antenna port. The four channels are tunable over 300 to 400 MHz and have a 2 MHz bandwidth at 15 MHz channel spacing. Insertion loss is very low at 2 dB in the band. The unit is designed to handle up to 100 W peak, 25 W CW, power. Designed for ground or airborne applications the unit will operate up to 15,000 ft. altitude.

**K&L Microwave**
**www.klmicrowave.com**

### V-Band Mixer

Marki Microwave is introducing the latest addition to their world-leading GaAs MMIC IQ Mixer family with the MMIQ-4067LU module. This V-Band mixer spans 40 to 67 GHz with an IF bandwidth of DC to 20 GHz. Due to the excellent phase and amplitude balance of its on-chip LO quadrature hybrid, the MMIQ-4067LU provides an exceptional 33 dB of LO-RF isolation and 35 dB of image rejection. It is available today in a connectorized module.

**Marki Microwave**
**www.markimicrowave.com**

### Broadband 4-Way SMA Power Dividers

VENDORVIEW

MECA Electronics' latest new product offering, 4-way compact broadband of power dividers covering 0.5 to 6 GHz (804-2-3.250) encompassing public safety through ISM bands. With typical performance of VSWRs of 1.30:1 and 1.25:1, isolation of 21 dB, insertion loss of 1.5 dB and exceptional amplitude and phase balance of 0.6 dB and 10 degrees max. This is in addition to the family of 2-, 4-, 8- and 16-way splitters in various connector styles and IP60 and 67/68 ratings. Made in the U.S. with 36 month warranty.

**MECA Electronics**
**www.e-MECA.com**

### Ultra-Wideband MMIC Frequency Doubler Die

VENDORVIEW

Mini-Circuits' CY2-44-D+ ultra-wideband MMIC frequency doubler die converts input signals from 7 to 20 GHz into output signals from 14 to 40 GHz. This new model's extremely wide output frequency range makes it suitable for applications such as 5G, Ka-Band SATCOM, instrumentation and more. It has an input power range from +12 to +18 dBm and provides low conversion loss of 13 dB (typical). The multiplier achieves excellent suppression of fundamental signal and unwanted harmonics (F1, 20 dBc or better; F3, 24 dBc or better).

**Mini-Circuits**
**www.minicircuits.com**

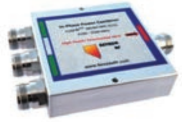
### 4-Way Splitter

VENDORVIEW

The RFSP0012 4-way splitter is a low cost design for applications that require high performance, small and highly reliable surface mount components. Applications may be found in broadband, wireless and other communications systems. These units are built lead-free and RoHS compliant. S-parameters are available on request. Available in tape and reel.

**MiniRF**
**www.minirf.com**

### High-Power In-Phase Combiners



Nevada RF announces its ColdRF™ line of in-phase combiners for equal or uncorrelated high-power inputs. Models are tailored to specific bands in the 1 to 18 GHz frequency range and offer tight amplitude and phase matching with excellent return loss and isolation. ColdRF™ combiners employ no internal resistive elements and dissipate minimal power, relying instead on a single remotely located high-power load with cable interconnection.

**Nevada RF**
**www.nevadarf.com**

# UP TO 100 Watt AMPLIFIERS

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**High-powered performance across wide frequency ranges.** Mini-Circuits' class A/AB linear amplifiers have set a standard for wideband high-power performance throughout the RF and microwave industry. Rugged and reliable, they feature over-voltage and over-temperature protections and can withstand opens and shorts at the output! Available with or without heat sinks, they're perfect for demanding test lab environments and for integrating directly into customer assemblies. With standard models covering frequencies from 100 kHz up to 26.5 GHz, chances are we have a solution for your needs in stock. Place your order on minicircuits.com today for delivery as soon as tomorrow! Need a custom model? Give us a call and talk to our engineers about your special requirements!

| Model | Frequency (MHz) | Gain (dB) | Pout @ Comp. 1 dB (W) | Pout @ Comp. 3 dB (W) | $ Price* (Qty. 1-9) |
|---|---|---|---|---|---|
| ZVM-273HP+ | 13000-26500 | 14.5 | 0.5 | 0.5 | 2195 |
| ZVE-3W-83+ | 2000-8000 | 35 | 2 | 3 | 1424.95 |
| ZVE-3W-183+ | 5900-18000 | 35 | 2 | 3 | 1424.95 |
| ZHL-5W-2G+ | 800-2000 | 45 | 5 | 5 | 995 |
| ZHL-10W-2G+ | 800-2000 | 43 | 10 | 12 | 1395 |
| ZHL-15W-422+ | 700-4200 | 46 | 8 | 15 | 2295 |
| •ZHL-16W-43+ | 1800-4000 | 45 | 12 | 16 | 1595 |
| •ZHL-20W-13+ | 20-1000 | 50 | 13 | 20 | 1470 |
| •ZHL-20W-13SW+ | 20-1000 | 50 | 13 | 20 | 1595 |
| LZY-22+ | 0.1-200 | 43 | 16 | 30 | 1595 |
| ZHL-30W-262+ | 2300-2550 | 50 | 20 | 32 | 1995 |
| ZHL-25W-63+ | 700-6000 | 53 | 25 | - | 8595 |
| ZHL-30W-252+ | 700-2500 | 50 | 25 | 40 | 2995 |
| LZY-2+ | 500-1000 | 47 | 32 | 38 | 2195 |
| LZY-1+ | 20-512 | 42 | 50 | 50 | 1995 |
| •ZHL-50W-52+ | 50-500 | 50 | 63 | 63 | 1395 |
| NEW! ZHL-50W-63+ | 700-6000 | 59 | 16 | 50 | 16995 |
| ZHL-100W-251+ | 50-250 | 46 | 63 | 100 | 1695 |
| •ZHL-100W-GAN+ | 20-500 | 42 | 79 | 100 | 2845 |
| ZHL-100W-272+ | 700-2700 | 48 | 79 | 100 | 7995 |
| ZHL-100W-13+ | 800-1000 | 50 | 79 | 100 | 2395 |
| ZHL-100W-382+ | 3250-3850 | 47 | 100 | 100 | 3595 |
| ZHL-100W-43+ | 3500-4000 | 50 | 100 | 100 | 3595 |
| NEW! ZHL-100W-63+ | 2500-6000 | 58 | 20 | 100 | 17995 |

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

*•Protected under U.S. Patent 7,348,854*

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# NewProducts

## 10 W Peak, 1 W CW Limiter

VENDORVIEW

PMI Model No. LM-100M20G-18-10W-SFF is a 10 W peak, 1 W CW limiter that operates over the 0.1 to 20 GHz frequency range. This model offers a maximum insertion loss of 2 dB and a maximum VSWR of 2.0:1. The unit is supplied with SMA female connectors in an ultra small housing measuring only 0.50 x 0.50 x 0.22 in.

**Planar Monolithics Industries Inc.**
**www.pmi-rf.com**

## 50 GHz, 2.4 mm Attenuators

A new range of attenuators equipped with 2.4 mm connectors that can reach 53 GHz is particularly suitable for equipment requiring high RF performance in a small form factor. With a VSWR of 1.65 at 50 GHz and the attenuation precision only reaching 0.7 dB at 50 GHz, this solution is ideal when performance is essential. The nominal power of the attenuator is 1 W, which is higher than existing market solutions (generally 0.5 W). The attenuator is 0.86 in. long, making it the smallest available form factor available for this frequency range.

**Radiall**
**www.radiall.com**

## Ceramic SMT Hairpin Filters

Remtec developed product family of ceramic SMT hairpin filters with insertion loss less than 1 dB across operational range (X-Band). Miniature filters with significantly reduced cross coupling are available on ceramics with dielectric constant 10-40. Ceramic filters have better reliability and repeatability and less expensive than those on organic boards.

**Remtec**
**www.remtec.com**

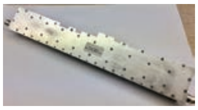
## Ultra-Broadband Coupler

Response Microwave Inc. announced the availability of its new broad band coupler for use in ATE and production applications. The new RMC013.2-50.24f covers the 1 to 50 GHz band offering typical electrical performance of 2.8 dB max insertion loss, VSWR of 1.80:1 max and min isolation of 10 dB. Power handling is 16 W and the unit is operational over the -55°C to +105°C range.

**Response Microwave Inc.**
**www.responsemicrowave.com**



## High-Power Dual Notch (Reject) Filters



RLC Electronics is now manufacturing high-power dual notch (Reject) filters. These filters are designed using interdigital finger structure on planar configuration. This interdigital finger resonator is providing us the ultra-wideband with two notches throughout the passband. This unit pictured above operates over the 500 to 2500 MHz band with two notches mid-band and handles 650 W CW. The units exhibit low loss (< 0.4 dB in the passband) and good VSWR (< 1.25:1) and are designed to operate over severe military environments.

**RLC Electronics Inc.**
**www.rlcelectronics.com**

## V-Band, 4-Way In-Line Waveguide Power Divider

VENDORVIEW

Model SWP-50375304-15-E1 is a V-Band, 4-way in-line waveguide power divider that operates across the frequency range of 50 to 75 GHz. The power divider offers a typical insertion loss of 1 dB at each output port and a typical isolation of 20 dB. The ports are well balanced and in phase for power dividing or power combining applications across the full band. This model offers an end launch design with WR-15 waveguides and UG-385/U flanges.

**SAGE Millimeter**
**www.sagemillimeter.com**

## 44 to 51 GHz Active Quadrupler

Spacek Labs' active frequency quadrupler, Model A487-4XW-19, is a frequency multiplier designed for output operation from 44 to 51 GHz. Requiring only 5 dBm input power, it is capable of generating 20 dBm typical output power across the entire frequency range with better than 35 dBc undesired harmonic rejection. This active quadrupler is ideal for use as a driver for subsequent multiplication used in very high frequency communication systems.

**Spacek Labs**
**www.spaceklabs.com**

# CABLES & CONNECTORS

## Vertical Launch Connectors

These vertical launch connectors—SMA, 2.92 mm and 2.4 mm—are specially designed for solderless vertical PCB connection on test and measurement boards. They exhibit excellent electrical transition performance up to 26.5, 40 and 50 GHz and reduce installation time by eliminating soldering. Applications include for test and measurement boards and high speed digital test boards.

**Withwave**
**www.with-wave.com**

# AMPLIFIERS

## 100 kHz to 1000 MHz U Series Amplifier

VENDORVIEW

AR's new family of "U" (Universal) Series RF solid-state Class A power amplifiers includes a 100 W amplifier that covers the 100 kHz to 1000 MHz frequency range with a 250 W model coming soon. These amplifiers are ideal for EMC, laboratory use, antenna and component testing, Watt meter calibration, medical/physics research and more. This compact, high performance and affordable amplifier joins a family of products available in 1, 2.5, 10, 25 and 50 W output levels that covers 10 kHz to 1000 MHz.

**AR RF/Microwave Instrumentation**
**www.arworld.us/html/18200.asp?id=1409**

## Multi-Mode Interoperable Power Amplifier

VENDORVIEW


Designed for optimized performance over a multitude of applications, the 2215 is a multi-mode power amplifier with built-in modes for a variety of input modulations and application scenarios that include frequency hopping, QAM-xx, OFDM, multi-carrier, pulse, AM, FM, barrage and broadband noise. For each operating mode the output power and efficiency is maximized and the protection is optimized. Empower's flexible and programmable input and output detection scheme makes multi-mode operation possible and has the added advantage of future-proofing the amplifier to changes in the ever increasing complex waveform environment.

**Empower RF Systems Inc.**
**www.EmpowerRF.com**

## High-Power Solid-State Amplifier

VENDORVIEW

New AMP4066 26.5 to 40 GHz high-power solid-state amplifier. The AMP4066 system produces 40 W of CW power with a gain of 46 dB. This is a state-of-the-art power amplifier. The amplifier features Exodus' instantaneous wideband hybrid module design with built-in protection circuits for superb reliability and ruggedness. It is packaged in a 6U (10.5 in. H) chassis and is nominally 80 lb. This system is manufactured as standard with local/remote monitoring and control circuitry interfaces. Suitable for all lab applications.

**Exodus Advanced Communications**
**www.exoduscomm.com**

## 300 W, 6 to 18 GHz Solid-State Amplifiers

RF-Lambda announces RFLUPA0618GG, a new high-power wideband solid-state power amplifier that is currently in production and will be ready in the third quarter of 2018. This amplifier is first of its class with 300 W of power and a frequency band that covers 6 to 18 GHz. The unit comes equipped with multiple protection features such as input over drive, over current and over temperature shutdown making it ideal for EMC, Vsat, test and radar applications.

**RF-Lambda**
**www.rflambda.com**

## Solid-State High-Power Amplifier


Richardson RFPD Inc. announced the availability of a new solid-state high-power amplifier from Empower RF Systems Inc. The 1205/BBM3K5OEL is suitable for broadband mobile jamming, communications, general test and band-specific applications from 500 to 2700 MHz. This compact module utilizes high-power advanced GaN devices that provide excellent power density, high efficiency, wide dynamic range and low distortion. Exceptional performance, long-term reliability and high efficiency are achieved by employing advanced broadband RF matching networks and combining techniques, EMI/RFI filters, machined housings and qualified components.

**Richardson RFPD Inc.**
**www.richardsonrfpd.com**

# SYSTEMS

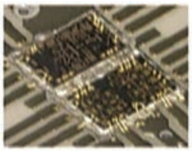
## 2 to 18 GHz Wideband Transceiver: 3U Module

Norden Millimeter introduces the NUDC2-18/1.3-2.3 wideband microwave transceiver in a low-SWaP 3U module. The NUDC2-18/1.3-2.3 is a dual conversion transceiver providing 2 to 18 GHz operation in a versatile OpenVPX platform. The NUDC2-18/1.3-2.3 includes internal LOs which provide an instantaneous IF bandwidth of 1 GHz and exceptional noise figure: down-converter NF = 6 dB max, up-converter NF = 15 dB max. Both the RF and IF paths include variable attenuation. The NUDC2-18/1.3-2.3 is digitally controlled by RS-485.

**Norden Millimeter**
**www.nordengroup.com**

# NewProducts

## 24 to 30 GHz GaN Front-End



This 24 to 30 GHz multi-purpose highly integrated power front-end is available in a 4 × 5 QFN package. The company's novel approach brings together a high linearity RF transmitter, a switch and a very low noise RF receiver, housed in a standard plastic package. The Tx provides 30 dB gain and exhibits 2 W RF output power with 20 percent efficiency by using 0.15 µm GaN technology. The Rx features 18 dB gain with a 3.5 dB noise figure.

**United Monolithic Semiconductors (UMS)**
**www.ums-gaas.com**

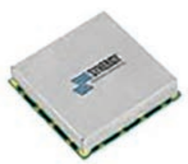
# SOURCES

## High Efficiency, Lightweight Microwave Power Module

dB Control introduced a high efficiency microwave power module (MPM). The dB-3756HE features a 9 to 10 GHz frequency range and 1 kW pulsed output power at 20 percent maximum duty cycle. It is ideal for airborne platforms requiring low power consumption and lightweight—including UAVs, high performance radar and synthetic aperture radar systems. It also features 1000 MHz of bandwidth. A technical datasheet is available by contacting dB Control's VP of Business Development Steve Walley at swalley@dbcontrol.com.

**dB Control**
**www.dbcontrol.com**

## Ultra-Low Noise VCO



The DCMO150318-5 is a small, half inch square VCO covering the greater-than-octave tuning band from 1500 to 3200 MHz with a tuning voltage of +0.5 to +20 VDC. With a bias voltage of +5 V at 30 mA, this low noise, voltage tuned oscillator will deliver a minimum buffered output power of +7 dBm. The wide tuning range gives a typical low phase noise of -93 dBc/Hz at an offset frequency of 10 kHz and -153 dBc/Hz at 10 MHz offset.

**Synergy Microwave Corp.**
**www.synergymwave.com**

## G6 USB Vector Signal Generator

This G6 USB vector signal generator is a modularized VSG that covers 10 MHz to 6 GHz, it features compact design and high performance, even complete with benchtop VSG. G6 can generate Arbitrary Wave, Pulse Modulation Signal, Digital Modulation Signal, and Standard Wireless Vector Signals including 2G, 3G, 4G, NB-IoT and LoRa. Benefits from its attractive price, G6 is suitable for manufacturing test and education purpose activities. Also Transcom Instruments provides the perfect support for system integrators: PCB version products and API library are also available for secondary development.

**Transcom Instruments**
**www.transcomwireless.com**

# TEST & MEASUREMENT

## Calibration Kits


The A-INFO CLKA1 series calibration kits are designed to provide accurate TRL (Thru-Reflect-Line), SSLT(Short-Short-Load-Thru) and offset load calibration of VNA for measurement in rectangular waveguide from WR975 to WR10 (0.75 to 110 GHz). A-INFO CLKA1 series Waveguide Calibration Kits contain all the necessary components to fully calibrate VNA configured for waveguide measurements. All kit components have both standard flange and precision flange (APF Series).

**A-INFO INC.**
**www.ainfoinc.com**

## L-Band Distributing Matrix

The $16^2$ (DEV 1985) 16 × 16 L-Band Distributing Matrix can be ordered with up to 16 input and 20 output channels and fits in a compact 2RU chassis. The DEV 1985 supports variable gain and slope and comes with a local user interface. The new $16^2$ is designed for operation via the company's web interface for multiple users. The secure lock operation mode allows users to lock a switched path so that other users cannot redirect those paths.

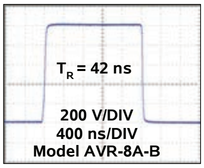
**DEV Systemtechnik**
**www.dev-systemtechnik.com**

## Miniature MS-Series Matrix

The miniature MS-series matrix is a modular and compact solution (6.29 x 3.30 x 7.05 in.) making it ideal for benchtop test & measurement applications. It is equipped with high performance Dow-Key Reliant Switches™ offering 0.03 dB insertion loss repeatability, DC to 26.5 GHz, 10 million life cycles SPDT and 5 million life cycles SP6T. A mixture of these switches can be mounted on the front and controlled with ethernet and web-based GUI.

**Dow-Key**
**www.dowkey.com**

## 100 to 1000 Volt Lab Pulsers




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

Avtech Electrosystems Ltd.
http://www.avtechpulse.com/

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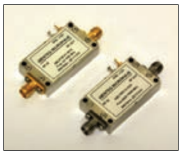

- RF isolators and circulators
- High power coaxial and waveguide terminations
- High power coaxial attenuators
- PIN diode power limiters
- Active up and down converters

**Wenteq Microwave Corporation**
138 W Pomona Ave, Monrovia, CA 91016
Phone: (626) 305-6666, Fax: (626) 602-3101
Email: sales@wenteq.com, Website: www.wenteq.com


## EMI Receiver

The new TDEMI® ULTRA EMI receiver has features such as 685 MHz real-time bandwidth, ultra-fast receiver scanning as well as multi GHz real-time scanning up to 40 GHz. It is a multi-purpose EMC tester for a wide range of applications and due to its compact design, a 12 V supply and a weight of less than 10 kg, it is suitable for field testing or on-board testing applications.
**Gauss Instruments**
**www.gauss-instruments.com**

## RF Test Solution for IoT & 5G

The HFS-856 series offers a reliable RF test solution for IoT and 5G applications. Unlike OTA measurements, the signal can be tapped directly from the PC board. The mechanical sturdiness makes it suitable for harsh production environments. The test probes have particularly good, repeatably-accurate RF features. The VSWR is at least 1.3 in specified frequency ranges, the insertion loss is maximum 0.6 dB. A SMA connector or, for smaller grid sizes, a SMPM (-T) connector is used to connect the probes to the test system. A flange makes assembly in test fixtures especially easy. Tolerances are balanced out of by the test probe's floating mount. The modular design allows the test probes to be modified for other applications.
**Ingun**
**www.ingun.com**

## Coaxial RF Probes and Probe Positioning Hardware

VENDORVIEW

Pasternack has just launched a new, innovative line of coaxial RF probes and a probe positioning hardware. These new products are well-suited for signal integrity verification, chip evaluations, coplanar waveguide, circuit debugging and test fixture applications. Pasternack's new product line consists of four coaxial RF probes and one RF PCB probe positioner with unique designs. The RF coaxial probes deliver frequency performance up to 20 GHz and return loss better than 10 dB.
**Pasternack**
**www.pasternack.com**

Buyer's Guide

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# Help! What's the Secret to Leading Engineers?

The career for a supervisor or manager in the high-tech industry typically begins with a technical path. After demonstrating proficiency in one of the technical specialties, the individual contributor is promoted into a management role—rarely with any formal training in management or leadership. The transition from technical contributor to leader is fraught with challenges, as good leadership is as much about soft skills as getting things done.

Recognizing the challenge of good leadership, Trevor Manning, himself a graduate from the engineering ranks, wrote "Help! What's the Secret to Leading Engineers?" In a short, readable book, Manning presents seven insights, each with multiple perspectives of leadership to aid the new leader and enlighten the most experienced manager. Among these insights:

Organizational goals are accomplished by people working together in teams, with each person on a team having a unique personality and multiple motivations. Hence, people are not "programmable resources." Knowledgeable workers do not want a "boss" who tells them what to do, rather a "manager" who will enable the team's diverse skills and expertise to create business value, while helping each person develop his or her skills and career. Since organizations constantly change as they pursue their goals and respond to a dynamic environment, the most effective leaders establish emotional bonds among team members and the future state the organization wants to achieve. An effective leader must approach the role with humility, and be comfortable with being wrong.

Notwithstanding thousands of books published about leadership, I recommend "Help! What's the Secret to Leading Engineers?". I'll be surprised if you do not find Manning's words inspire you to improve your own leadership skills. Listen to a conversation with Trevor Manning on my blog at www.microwavejournal.com/blogs. — Gary Lerude

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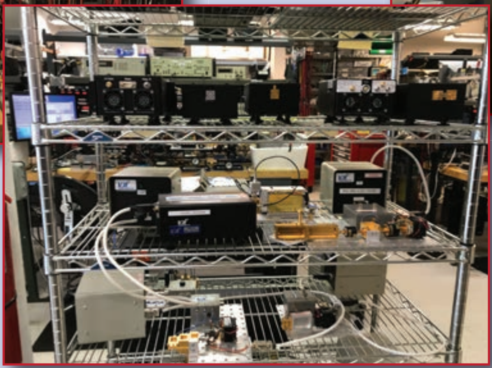


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All VDI components include in-house fabricated GaAs Schottky diodes and microelectronic filter structures so they have full control over the starting materials and production processes. Showing market leadership at high frequencies, VDI worked with Keysight to create the first system for network analysis up to 1.5 THz for Chalmers University of Technology in 2016, and is the only company supplying waveguide-based power meters over 100 GHz (using the Erickson design that they acquired years ago).

VDI was founded in 1996 by Dr. Thomas W. Crowe—still VDI's CEO and president—as a spin-off from the Terahertz Research Program at the University of Virginia (UVa). From 1996 to 2001, VDI sold only Schottky diodes for scientific applications including radio astronomy and high frequency radar. During that period, VDI operated as a UVa spin-off and utilized the facilities on-site. Around 2001, VDI expanded to include offices in downtown Charlottesville, Va. and started selling complete mixer, detector and multiplier products operating from 50 to 1000 GHz. By 2004, VDI started selling sub-systems such as THz transmitter and receiver modules. That same year, all VDI operations moved to the current location on Second Street in Charlottesville and stopped utilizing UVa facilities.

VDI has continued to grow the number of product offerings and employees needed to satisfy a broad range of THz and mmWave customers. The company employs more than 50 engineers, technicians and administrative staff working in a high tech 20,000 sq. ft. facility. Its mission is to make the THz frequency band as useful for scientific, defense and commercial applications as the microwave and infrared bands are today.

While visiting in April, *Microwave Journal* learned about a very interesting project VDI participated in under a NASA Small Business Innovative Research contract. The company developed and manufactured an 883 GHz radiometer to perform global ice cloud mapping on a NASA cubesat, appropriately called IceCube. IceCube was launched from the International Space Station in May 2017, and successfully made measurements to prove the concept of using submillimeter waves to make these measurements from space, as they had previously only been done from aircraft. NASA now plans to do future missions using COTS products from companies such as VDI due to this project's success. So if your project demands very high frequency signals or analysis, VDI is your starting point.

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INVITED PAPER

# Picking the Right Semiconductor Technology for Pulsed RF Power Amplifiers

**John Walker**
*Integra Technologies, El Segundo, Calif.*

The best solid-state, high-power amplifiers (HPA), especially those used in critical defense, aerospace and weather-radar applications, start with the right choice of discrete or integrated RF power transistors. Several active device semiconductor technologies are available today to amplify pulsed and continuous-wave (CW) signals across narrow or wide bandwidths from HF/VHF/UHF to L-, S-, C- and X-Band frequencies and beyond. Transistors for use in RF/microwave HPAs include some well-established, legacy device technologies such as silicon bipolar power transistors, as well as more recent power-transistor technologies such as Si LDMOS and GaN on SiC high-electron-mobility transistor (HEMT) power transistors.

Depending on frequency, bandwidth and other requirements, each transistor technology offers its own set of performance benefits in terms of output power, gain and efficiency. But evaluating the tradeoffs related to cost and value can be a daunting task. This article will cover the key things to look for and the advantages and disadvantages of each technology, while providing a few examples of ideal fits for certain types of applications at different frequencies and under different waveform conditions, focusing mostly on pulsed applications.

## APPLICATION CONSIDERATIONS

RF power transistors are usually characterized for the type of signals that they will handle, such as CW or pulsed signals. And when amplifying pulsed signals, the range of signal conditions are the most complex such as defined by pulse width and pulse duty cycle. Although different types of RF/microwave power transistors are capable of high-power efficiency, no power transistor is 100 percent power efficient, as some DC and RF power supplied to a transistor will inevitably be lost as heat (which also must be dissipated). Amplifying CW signals, or long-pulse length and/or high duty-cycle pulses, will result in more heat from one transistor technology than another and will vary when compared to handling short pulses


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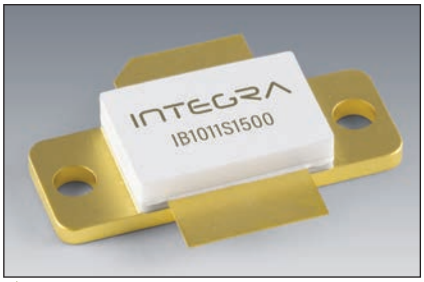
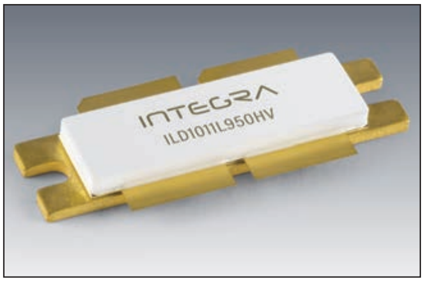



▲ Fig. 1 Silicon bipolar power transistor that is capable of 1400 W output power at 1030 or 1090 MHz with 10 µs pulse widths at 1 percent duty cycle.




▲ Fig. 2 Silicon LDMOS power transistor with 1100 W pulsed output power under Mode S ELM for IFF/SSR applications at 1030 MHz.

or low duty-cycle pulses. As a result, there is no "silver bullet" technology for all of today's high-power amplification requirements. The best solution is to match up the key characteristics of a transistor type to the most important application requirements. This becomes not only a spec-to-spec comparison exercise, it also requires recognition of other system-level tradeoffs to arrive at the best combination of performance, reliability, thermal management and total bill of materials (BOM) cost for the HPA.

## Si BIPOLAR TRANSISTORS

The Si bipolar junction transistor (BJT) is the oldest technology for pulsed applications, but it is not an obsolete technology. Si BJTs are still in regular manufacture and will continue to be manufactured for the foreseeable future due to the on-going demand and replacements. Even today, some attributes of Si BJT devices are unequalled by other technologies. For example, Si BJT amplifiers have the smallest, lowest cost circuits and only need a single positive supply voltage. Nevertheless, newer HPA designs generally do not include Si BJT devices because of their low RF gain and their need for expensive and environmentally unfriendly BeO packages. An example of a Si BJT designed for IFF/SSR applications is shown in ***Figure 1***. This device delivers typically > 1400 W output power at either 1030 or 1090 MHz with > 9.8 dB gain and 48 percent efficiency with 10 µs, 1 percent duty-cycle pulses.

## Si LDMOS

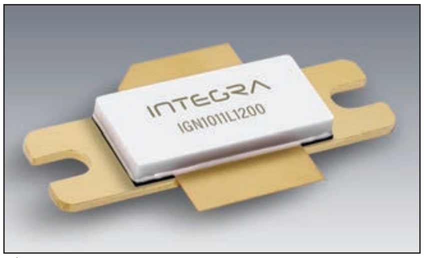
Si LDMOS is a mature technology like Si bipolar and has found widespread use in high linearity communication applications as well as in broadband CW amplifiers. It is also a great choice for pulsed applications up to L-Band. L- through S-Band LDMOS transistors are available but their performance is typically inferior to that available from GaN HEMT devices at this frequency. Si LDMOS is well-suited to long-pulse and/or high duty-cycle applications because of its very low thermal resistance per Watt that also contributes to its excellent VSWR withstanding characteristics. The limiting factor of Si LDMOS, however, is that it offers inferior power efficiency to both Si bipolar and GaN HEMT devices.

***Figure 2*** shows an example of a state-of-the-art Si LDMOS transistor for L-Band avionics applications. This transistor typically delivers 1100 W at 1030 MHz under the demanding Mode S ELM waveform (48 × {32 µs on, 18 µs off}, 6.4 percent long-term duty cycle) with 16 dB gain and 55 percent efficiency. A unique feature of this device is that it is a single-ended rather than a push-pull transistor. Consequently, it requires a smaller, less expensive and simpler circuitry since no balun is required. This type of added functionality is also something that should be considered when comparing datasheets.

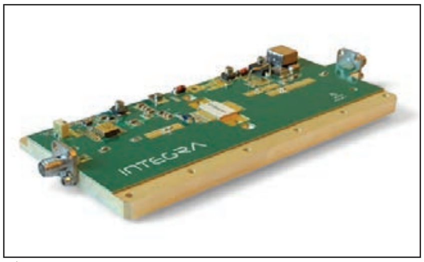
## GOING FOR GaN

GaN HEMTs are the latest in RF and microwave power transistor technology. They are quickly gaining favor for many applications because of their high gain and high-power levels at S-Band and above. GaN power transistors are most often produced on a SiC substrate which offers excellent heat extraction for enhanced long term reliability although a couple of companies are offering GaN on Si.

GaN HEMTs are ideally suited to high-power pulsed applications and their power density requirements (as compared to CW applications) as the ability to design on a SiC substrate allows for optimal cooling. Because of this superior power, the output capacitance per Watt will be much lower. This enables designers to implement harmonic tuning with output with efficiencies > 85




▲ Fig. 3 GaN on SiC power transistor capable of 1250 W pulsed output power under Mode S ELM for IFF/SSR applications at 1030 or 1090 MHz.




▲ Fig. 4 Low-profile RF Power Modules or "pallets" include RF matching, power-supply circuitry and control circuitry to ease the integration of a power transistor into a power amplifier design.

percent—even at kW power levels. The much lower capacitance per Watt is also what enables these devices to operate at much higher frequencies than possible with LDMOS. One disadvantage of GaN HEMTs, however, is that they are typically depletion-mode devices, which means not only that they require both positive and negative voltage supplies, but the gate voltage must also be applied before the drain voltage. To address this pitfall, some companies implement GPS circuitry in their pallets and test fixtures, which minimizes this issue and its impact on the BOM.

***Figure 3*** is an example of a state-of-the-art GaN HEMT device. This transistor typically delivers > 1250 W output power at both 1030 and 1090 MHz for IFF/SSR applications using the same circuit (a consequence of the low capacitance per Watt) along with 17 dB gain and a high 85 percent efficiency under Mode S ELM waveform (48 × {32 µs on, 18 µs off}, 6.4 percent long-term duty cycle).

## PICKING THE RIGHT TRANSISTOR TECHNOLOGY

The requirements of an application, such as waveform type, frequency, bandwidth and output-power level, will determine the type of performance needed by a power amplifier and its power transistors. At lower frequencies, all the transistor technologies discussed are viable candidates and the choice of which to use will depend upon what is most important in the design. At S-Band and above, GaN HEMTs on SiC are really the optimal choice. In between, the challenge is to balance cost versus performance which becomes trickier and experts advise starting with those solutions already defined by the industry as being ideally suited for either pulsed or CW designs and optimize from there. ***Table 1*** summarizes the advantages and disadvantages of the three transistor technologies considered.

Another consideration is that devices are available with and without internal impedance matching and in different package styles. In addition, many of these power transistors covered here are also available as integrated PCB assemblies, RF Power Modules or "pallets." These integrated low-profile boards include RF matching, power-supply circuitry and control circuitry (see ***Figure 4***) to ease the integration into the RF power amplification system even further. This can simplify the system designer's burden since they are drop-in blocks.

## CONCLUSION

How the specifications for the choice of RF power transistors are prioritized will depend on the performance and budget requirements of a designer's HPA. The most expensive transistors could very well be worth the investment in what they return to the total system costs. Frequency range and bandwidth, and whether the amplifier will be handling pulsed or CW signals are your first decisions, but those requirements will only help narrow down the best power transistor technology and the device for the job so much. Understanding the impacts throughout the HPA's block diagram are essential and identifying bonus features and smart design choices your transistor supplier has made can become make or break differences.

It all really comes down to deciding early on how far the radar signal must travel, at what frequency and with what level of resolution. This will determine how far a designer is willing to stretch the budget of power transistor devices in the block diagram. Get the price/performance tradeoffs right and the system will have the power needs to accomplish its goals.■

**TABLE 1**
**A COMPARISON OF TRANSISTOR TECHNOLOGIES FOR RF POWER AMPLIFIERS**

| Attributes | Si Bipolar | Si LDMOS | GaN/SiC |
|---|---|---|---|
| Power density (W/unit area) | High | Medium | Very high |
| Efficiency | High | Lowest | Very high |
| Gain | Lowest | High | Very high |
| Capacitance/W (low value needed for highest power and widest bandwidth) | Medium | Medium | Low |
| Broadband matching capability | Difficult | Difficult | Simplest |
| Bias circuitry complexity | Lowest | Medium | Highest |
| Typical bias voltage | 28 to 60 V | 28 to 50 V | 24 to 50 V |
| Maximum frequency | S-Band | C-Band | > 10 GHz |
| Transistor thermal characteristics under pulsed conditions | Fair | Good | Good |
| VSWR withstand | Poor | Best | Average |
| Technology maturity | High | High | Medium |
| Price ($/W) | Medium | Lowest | Medium |
| Green credentials | Poor (needs BeO package) | Excellent | Excellent |



# Tunable 6-Bit Digital Phase Shifter Based on Ferroelectric Material

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**Jianhua Deng**
*Sichuan Zhongce Microgrid Technology Co. Ltd. Chengdu, China*
**Yuehang Xu**
*UESTC, Chengdu, China*

*In this novel 6-bit phase shifter, a conventional switched transmission line phase shifter cell is replaced with a structure where phase is controlled by a voltage applied to a barium strontium titanate (BST) ferroelectric material for tunability, improved performance and reduced size. Performance is simulated and measured from 2.7 to 3.5 GHz.*

Phase shifters are key components in phased array radar and, increasingly, wireless communications. Well known approaches use PIN diode or FET switches to select fixed lengths of transmission line, providing adequate performance in general; however, conventional transmission line concepts lack tunability. The CRLH-TL structure has been used;[1-2] however, this approach degrades insertion loss and return loss. A substrate integrated waveguide (SIW) structure uses varactors for tunable performance; however, this increases circuit complexity.[3] The use of a ferroelectric material, which offers phase tunability and reduces circuit size, has been implemented successfully in phase shifter design.[4-7]

This article describes the design of a 6-bit digital phase shifter employing the ferroelectric material BST for tunability, improved performance and reduced size. Conventional transmission line phase shifter cells (5.6, 11.25 and 22.5 degrees) and tunable phase shifter cells (45, 90 and 180 degrees) are configured in a novel two-layer structure. It is electrically adjustable, well matched and has low insertion loss. Measured results closely agree with simulation.

## PHASE SHIFTER CELL

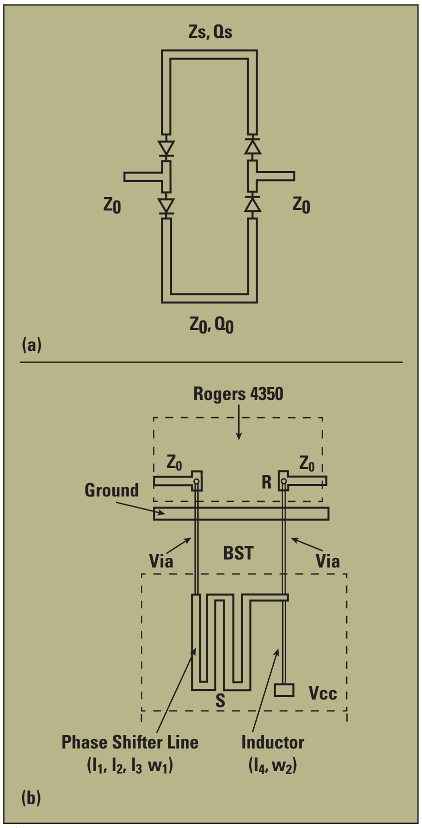
The structures of conventional and tunable phase shifter cells are shown in ***Figure 1a*** and ***b***, respectively. The conventional phase shifter cell, constructed on one microstrip layer, has phase differences given by[8]

$$\Delta\phi = \phi_2 - \phi_1 = Q_0 \times \frac{f}{f_0} - \arctan \left\{ \frac{Z_0}{2Z_s} \left[ \tan\left( Q_s \times \frac{f}{f_0} \right) - \cot\left( Q_s \times \frac{f}{f_0} \right) \right] \right\} \quad (1)$$

where $Q_s$ and $Z_s$ are the electrical length and impedance, respectively, of the phase shifter cell at the design frequency $f_0$, and $Q_0$ and $Z_0$ are the electrical length of the reference microstrip line.

The tunable phase shifter includes two layers. A conventional transmission line phase shifter cell is on the top layer and the ferroelectric phase shifter cell is on the bottom layer. Rogers 4350 substrate material is used for the upper layer cell, and BST is used for the bottom layer. The top and bottom layers are connected by via holes.

For tunability and small size, a BST thick film with a height of 2 µm is screen printed and sintered on an $Al_2O_3$ substrate with a height of 620 µm and $\varepsilon_r$ = 10.1. Using a relative permittivity of $\varepsilon_{r,BST}$ = 125, the circuit is matched with the 50 Ω transmission line of the upper layer. The phase of the structure is flexibly changed by modifying the BST voltage.




▲ Fig. 1 Phase shifter comparison: conventional cell (a) and ferroelectric cell (b).

## 6-BIT DIGITAL PHASE SHIFTER

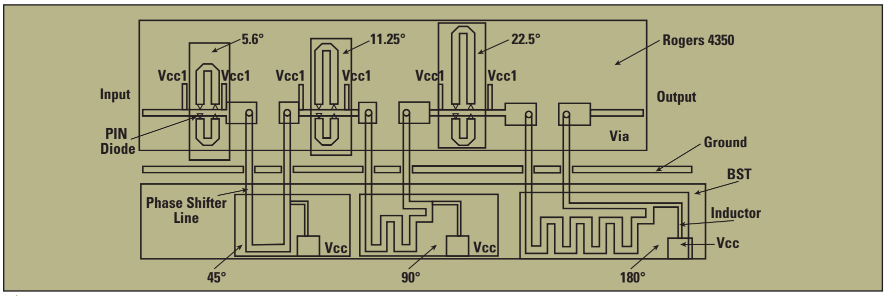
A layout of the tunable 6-bit digital phase shifter is shown in ***Figure 2***. Conventional 3-bit phase shifter cells (5.6, 11.25 and 22.5 degrees) on the Rogers 4350 material forms the upper layer, while the tunable, ferroelectric, 3-bit phase shifter cells (45, 90 and 180 degrees) reside on the BST bottom layer.

The phase shifter line lengths of the tunable cell are $l_1$, $l_2$ and $l_3$, while the width and gap are $w_1$ and S, respectively (see Figure 1). The via radius between upper and bottom layers is R. Optimized dimensions are $l_1$ = 10.2 mm, $l_2$ = 18.9 mm, $l_3$ = 27.2 mm, $w_1$ = 0.36 mm, s = 0.18 mm, $l_4$ = 6.3 mm, $w_2$ = 0.16 mm and R = 0.15 mm. With these parameters, simulated phase as a function of BST voltage is shown in ***Figure 3***. The relationship between phase and voltage is nearly linear, so phase control is simplified, especially when several phase shifters are controlled in an array. 40 V is chosen for bias.

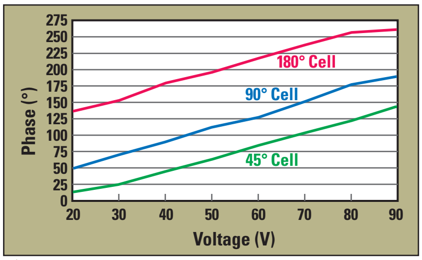
## FABRICATION AND MEASUREMENT

Photographs of the 6-bit digital phase shifter are shown in ***Figure 4***. The upper layer (Figure 4a) is manufactured on the Rogers 4350 substrate. Skyworks' SMP1321-079 PIN diodes are used as the switches in the conventional phase shifter cells. The bottom layer is fabricated using the BST-based ferroelectric material. ***Figure 5*** is a photograph comparing the size of the new structure with that of a conventional 6-bit phase shifter.

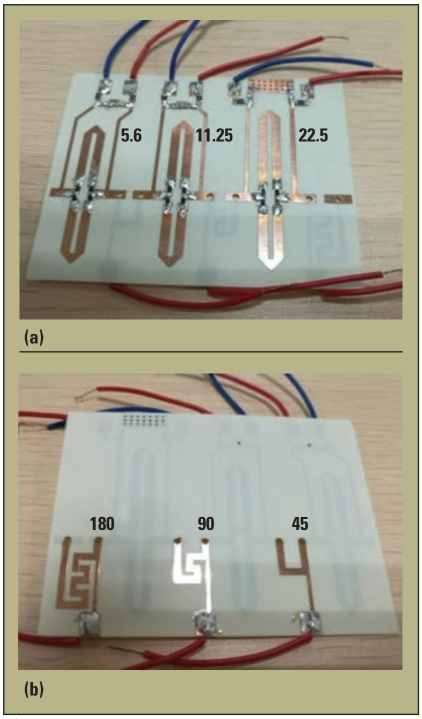
In ***Figure 6***, the simulated and measured values of $|S_{21}|$



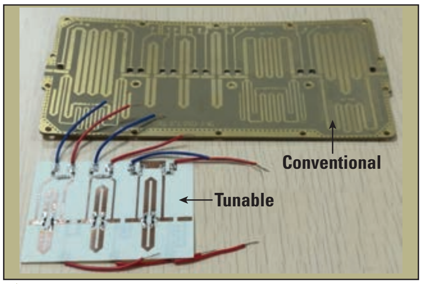

▲ Fig. 2 Layout of the 6-bit digital phase shifter.



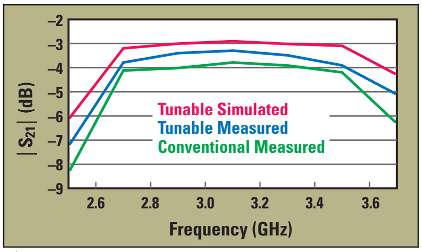

▲ Fig. 3 Simulated phase vs. BST voltage of the 45°, 90° and 180° cells.




▲ Fig. 4 Top (a) and bottom (b) layers of the tunable 6-bit phase shifter.




▲ Fig. 5 Size of the tunable 6-bit phase shifter vs. the conventional design.

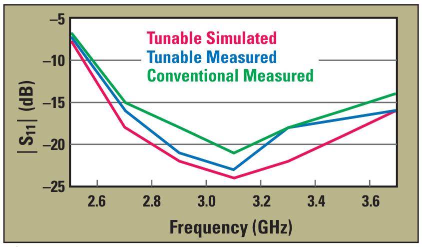



▲ Fig. 6 Measured vs. simulated $|S_{21}|$ of the tunable 6-bit phase shifter, compared to the measured $|S_{21}|$ of the conventional phase shifter.

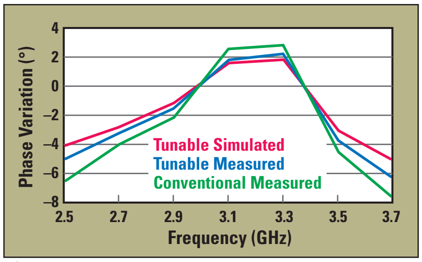
for the tunable phase shifter at 360 degrees are compared with measured values for the conventional phase shifter. Similarly, ***Figure 7*** compares the simulated and measured values of $|S_{11}|$ for the tunable phase shifter at 360 degrees with measured values for the conventional phase shifter. Comparisons of phase variation over frequency at 360 degrees are shown in ***Figure 8***.

Measured insertion loss and return loss of the tunable phase shifter are approximately 3.6 and 18 dB, respectively, in the frequency range from 2.7 to 3.5 GHz. Insertion loss is about 1 dB lower and return loss is about 5 dB higher when compared to the conventional phase shifter. Phase variation for a 360 degree phase shift indicates an improvement of about 1 degree compared with the conventional phase shifter. Total phase variation over frequency is within ±2.5 degrees.■






▲ Fig. 7 Measured vs. simulated $|S_{11}|$ of the tunable 6-bit phase shifter, compared to the measured $|S_{11}|$ of the conventional phase shifter.




▲ Fig. 8 Measured vs. simulated phase variation of the tunable 6-bit phase shifter, compared to the measured phase variation of the conventional phase shifter.

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INVITED PAPER

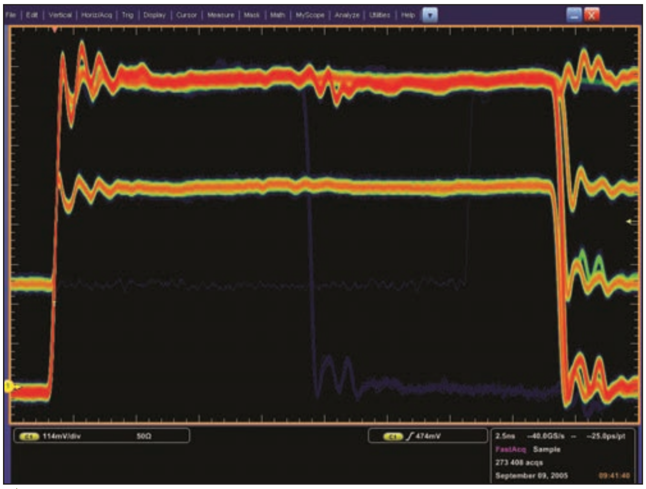
# High-Resolution, Wideband Radar Measurement Challenges

**Mark Elo**
*Tektronix, Beaverton, Ore.*

High-resolution radars have a diverse set of uses in both commercial and military applications, ranging from automotive vehicle awareness to advanced target ID, surveillance and ballistic missile defense. These applications drive the need for wide instantaneous bandwidth radar. Understanding how a radar behaves in the frequency and time domain helps determine its overall performance, especially when dealing with short-duration pulses or the performance of frequency modulation on longer pulses.

Fundamentally, radar can be characterized as a time domain phenomenon. In its simplest form, it is the time it takes a transmitted signal to illuminate a target and "reflect back" to the receiver. The signal can be continuous wave (CW) or a sequence of pulses, depending on the specific mission. Pulse rise and fall times, the type of modulation and the behavior of the transmitter amplifier can create a range of responses in the frequency domain. The radar signal needs to be tested in congested—even contested—environments, and a key task is to verify immunity to signal interference, jamming and clutter effects.

Time domain measurements are traditionally performed with oscilloscopes, while spectrum analyzers are best suited for frequency domain measurements. However, advancements in measurement instrumentation architectures have shaken this up a bit. Now, broadband frequency domain analysis can be performed with an oscilloscope, and the time domain behavior of a frequency modulated signal can be analyzed using a spectrum analyzer. This article explores the trade-offs with each instrument.



▲ Fig. 1 The fast acquisition mode can show a single, narrow pulse.

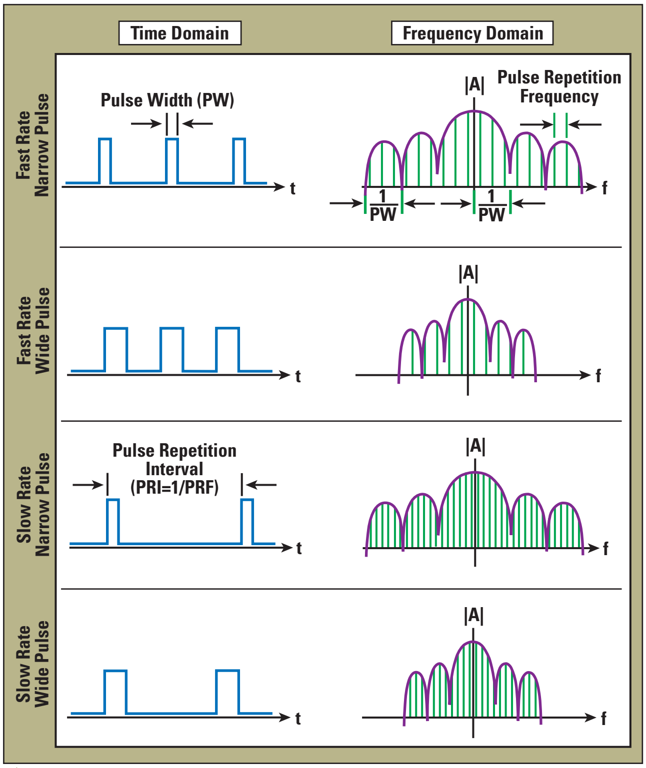
## RESOLUTION: TIME, MODULATION AND FREQUENCY

Radar resolution can be improved by using a very narrow pulse (in time); however, the amplification of short-duration pulses can be challenging, so techniques such as modulating a longer pulse with a frequency ramp, termed linear frequency modulation (LFM), are used. Frequency modulation does not necessarily have to be linear; in some cases, an exponential waveform may be better suited to a particular application.

Fast time domain events, such as radar pulses, exhibit sin(x)/x behavior in the frequency domain. If a pulse is short, the main lobe of the sin(x)/x function has a broader frequency response. If the pulse is wide, the lobe has a narrow frequency response. This affects the choice of transmission frequency: A short-duration pulse will require a large amount of spectrum,

▲ Fig. 2 Discovery of a single transient glitch in a train of pulses.

so a high carrier frequency should be used. Longer pulses require less spectrum and can be transmitted at lower frequencies. How often the pulse is repeated, termed the pulse repetition frequency (PRF), depends on the radar's mission. Low PRFs are better for detecting targets greater than 50 km range, and high PRFs are better for closer targets. As a rule, a low PRF radar uses longer pulses and transmits at lower frequencies, such as in the VHF band, and high PRF radars use narrow pulses and transmit at higher frequencies.




▲ Fig. 3 Relationship between spectrum and pulse width and PRF.


When modulation is added, further frequency and time domain interactions are observed. For example, a 4 GHz bandwidth LFM chirp gives a resolution of around 6 cm, which is ideal for imaging applications. However, adding this type of modulation to a pulse will add ±2 GHz of FM modulation to the sin(x)/x frequency response, making a logical transmission frequency in the mid 30 GHz part of the spectrum.

## TIME DOMAIN MEASUREMENTS

Traditionally, the oscilloscope has been the primary tool for examining varying voltage versus time. This is key to understanding pulse or pulse train behavior. Oscilloscopes are available with various levels of performance; a basic oscilloscope may have a bandwidth of 200 MHz, so it is a good tool for analyzing pulses with a frequency response less than 200 MHz, i.e., either unmodulated pulses or lower frequency pulses with slow modulation. However, the limited bandwidth of entry-level oscilloscopes means that degenerative effects such as intermodulation will be filtered out.

A modern, high performance oscilloscope can have bandwidths up to 70 GHz, providing the capability to capture multiple harmonics and other frequency-based distortion mechanisms. Without using a detector, oscilloscopes can capture and analyze the transmit frequency to help understand the behavior of both short-duration pulses, or impulses, and wideband signal modulation. For short-duration pulses and impulses, enhancements in architecture have improved the oscilloscope's ability to analyze these signals using a fast acquisition mode. This reduces the dead time between waveform acquisitions, enabling the capture and display of transient events. Fast acquisition combined with persistent waveform features can display phenomena at varying intensity to reflect the rate of occurrence. ***Figure 1*** shows a single pulse captured multiple times, with a persistence heat map technique used to show the rate of occurrence. Frequent occurrences are shown in red and infrequent events displayed in yellow to blue, for the most infrequent. The display identifies a number of intermittent pulses with lower amplitude and, occasionally, a pulse of shorter duration in blue. ***Figure 2*** shows a string of "good" pulses with an occasional anomaly displayed in blue.

Traditionally, oscilloscopes triggered on a simple edge or voltage level. Today, using a digital probe, the trigger can be a pattern of logic; for example, when a specific word appears on a bus, the scope can be triggered to make an analog measurement in the time domain. A mixed domain oscilloscope can add a further trigger advantage, providing the ability to simultaneously trigger and acquire signals across multiple channels. This results in time-correlated and seamless acquisitions in the analog, digital and RF domains, providing the ability to observe how the spectral and vector properties of the RF signal vary over time, along with the analog and digital signals. Complementing the advanced trigger system, a fully-automated suite of pulse timing measurements available for oscilloscopes can lead to more consistent results. Single-button selection of rise time, fall time, pulse width and other parameters simplify the measurement process and save time.

# MILLIMETER WAVE AMPLIFIERS.
# **POWERING THE FUTURE.**

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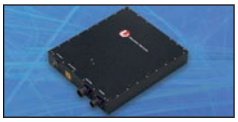

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## FREQUENCY DOMAIN MEASUREMENTS

The measurement of frequency domain characteristics of a transient, pulse-based system requires a specific type of spectrum analysis. While swept spectrum analyzers offer wide frequency and dynamic range, advances in analog-to-digital converters (ADC) and signal processing technology provide many of the same benefits while performing wide bandwidth, time domain acquisition, then post processing with a fast Fourier transform (FFT). Time domain acquisitions allow for very fast visualization of signals, referred to as real-time. Beyond speed, the advantages of real-time measurement capability are high quality persistence displays, frequency domain triggering and waveform storage, providing higher levels of measurement capability and insight.


***Figure 3*** shows the relationship between the sin(x)/x spectrum in the frequency domain and a pulsed radar signal in the time domain. Longer pulses have smaller lobes, while shorter pulses have wider lobes, as discussed earlier. Because of the inverse relationship between frequency and time, it is possible to determine basic pulse timing parameters using the spectrum analyzer frequency domain display. The pulse repetition time or pulse period is the inverse of the frequency spacing between the finely-spaced lines within the larger spectrum envelope, and the pulse width is the inverse of the frequency spacing between the nulls in the spectrum envelope. Real-time and persistence display technologies allow observation of the frequency and frequency response and improve the ability to view the PRF.

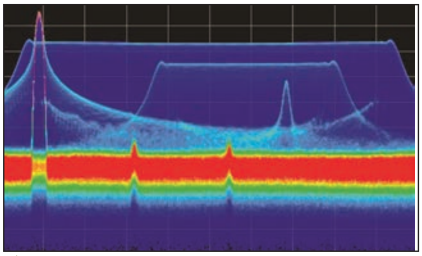
The architectures of spectrum analyzers and oscilloscopes differ. The bandwidth of an oscilloscope is usually a function of the ADC technology and sample rate of the system, while a spectrum analyzer uses some form of frequency conversion (usually super heterodyne) to create an intermediate frequency that is centered around the frequency bandwidth of a narrow ADC. As bandwidth is inversely proportional to dynamic range, the spectrum analyzer has a better dynamic range, allowing the user to view very small signals in the presence of large signals. In comparison, an oscilloscope with a bandwidth of 18 GHz will have lower dynamic range than a spectrum analyzer with a frequency range of 18 GHz. However, the 18 GHz oscilloscope captures the whole instantaneous bandwidth (DC to 18 GHz), while the spectrum analyzer captures a narrower instantaneous bandwidth—±400 MHz around a center frequency of 9 GHz, for example.

Just as an oscilloscope can translate time domain data by performing an FFT and displaying the frequency domain spectrum, a spectrum analyzer can show measurement information in the time domain. Once the spectrum analyzer is tuned to an appropriate center frequency, the required measurement data can be displayed in either the frequency or time domain. As the time domain measurement on the spectrum analyzer is limited by the bandwidth of the ADC, the maximum LFM that can be observed in the time domain will be limited; in the example of the spectrum analyzer with an instantaneous bandwidth of ±400 MHz around a center fre-

quency of 9 GHz, the maximum LFM sweep will be 800 MHz.

Another feature of the spectrum analyzer is adjustable acquisition bandwidth to make more selective measurements, by using a resolution bandwidth filter. This effectively reduces the displayed noise level. For example, a 3 kHz resolution bandwidth filter has a noise floor of 10 dB lower than a 30 kHz resolution bandwidth filter.

New is not necessarily best; many newer spectrum analyzer models emulate the displays of cathode ray tubes (CRT) used on spectrum analyzers before the advent of digital displays. A CRT uses a magnetically-controlled electron gun that fires electrons onto a phosphor-coated screen. The electrons initially illuminate the screen and the image slowly decays with time. ***Figure 4*** shows a typical display using a phosphor emulation technique. Without phosphor emulation, the screen shows just the large LFM signal, with the CW signal "popping out" the top on the left. Phosphor emulation enables a second, lower power LFM signal with several single frequency, pulsed carriers and two CW interferers to be seen.



▲ Fig. 4 Using a phosphor emulation display reveals multiple chirps in one band.

As with an oscilloscope, spectrum analyzers are available with automated pulse measurements that increase signal detail and measurement repeatability. In some cases, a spectrum analyzer will have more advanced capabilities:

- Storing up to two hours of data
- Finding the pulses within the signal
- Measuring a full set of parameters for each pulse, such as timing, frequency and phase
- Processing the results to display trends or identify the transmitter.

## PICKING THE RIGHT INSTRUMENT

High-resolution radar employs wideband techniques, either short pulses, impulses or a modulation technique such as LFM. Both oscilloscopes and spectrum analyzers are good tools for measuring performance in the time and frequency domains and can have equivalent measurement capability; however, the difference in instrument architecture makes one more optimal for some measurements than the other. An oscilloscope can have an extremely wide acquisition bandwidth in the tens of GHz, at the cost of dynamic range and sensitivity, which makes it ideal for capturing fast transient events such as narrow pulses, impulses and large frequency sweeps. A modern spectrum analyzer can tune to a specific frequency and acquire a signal in the range of a few tens of MHz up to 1 GHz, with better dynamic range and sensitivity, making it an ideal tool for broadband spectrum analysis, spurious signal searches, intermodulation and harmonic analysis.■




# High-Quality, Cost-Effective Passive Components to 50 GHz

**MECA Electronics**
*Denville, N.J.*

**TABLE 1**

**2.92 mm, 20 dB, 6 TO 40 GHz COUPLER SPECIFICATIONS**

| *Model 765-20-23.0000* | *Typical* | *Minimum* | *Maximum* |
|---|---|---|---|
| VSWR | 1.8:1 | — | 1.9:1 |
| Insertion Loss | 0.9 dB | — | 1.3 dB |
| Frequency Sensitivity | — | — | ±0.65 dB |
| Directivity | 17 dB | 13 dB | — |

**TABLE 2**

**2.92 mm, 2-WAY, 6 TO 40 GHz SPLITTER SPECIFICATIONS**

| *Model 802-3-23.0000* | *Typical* | *Minimum* | *Maximum* |
|---|---|---|---|
| VSWR | 1.30:1 | — | 1.8:1 |
| Insertion Loss | 1.4 dB | — | 1.8 dB |
| Amplitude Balance | — | — | 0.5 dB |
| Isolation | 22 dB | 14.5 dB | — |

Recognizing the growing need for higher frequency, smaller packaging and improved efficiency, MECA Electronics (Microwave Equipment & Components of America) has extended its family of high-quality components to serve mmWave applications. MECA's portfolio comprises power dividers, couplers, attenuators, terminations, bias tees, DC blocks, isolators and circulators and is available in a variety of connector styles and interfaces, including SMA, N, BNC, TNC, 7/16, 4.1/9.5, 4.3/10.0, 2.92 and 2.4 mm, offering up to 50 GHz coverage with the 2.92 and 2.4 mm connectors.

## mmWAVE EXAMPLES

Three examples of 6 to 40 GHz products for VSAT, SATCOM and 5G applications are:

- Model 765-20-23.0000 coupler, with 2.92 mm connectors, has a maximum insertion loss of 1.3 dB, frequency sensitivity of ±0.65 dB and minimum directivity of 13 dB (see ***Table 1***).

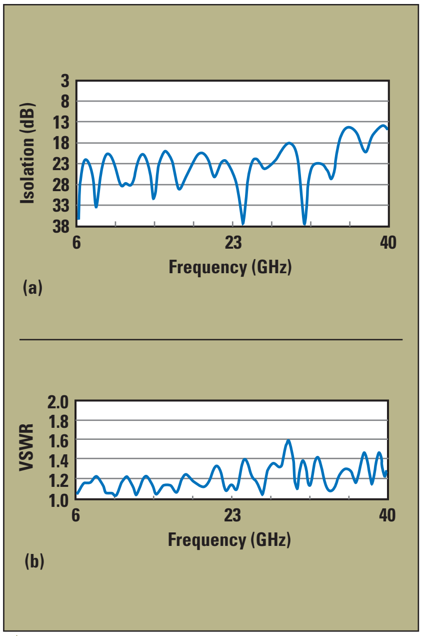

- Model 802-3-23.0000 2-way power divider, with 2.92 mm connectors, has a maximum insertion loss of 1.8 dB, amplitude balance of 0.5 dB and minimum isolation of 14.5 dB (see ***Table 2***).
- Model 804-3-23.000 4-way power divider, with 2.4 mm connectors, has a maximum insertion loss of 2.8 dB, amplitude balance of 1 dB and minimum isolation of 13 dB (see ***Figure 1***).

These products are supplemented with complementary components such as attenuators, terminations, bias tees, DC blocks and adapters.

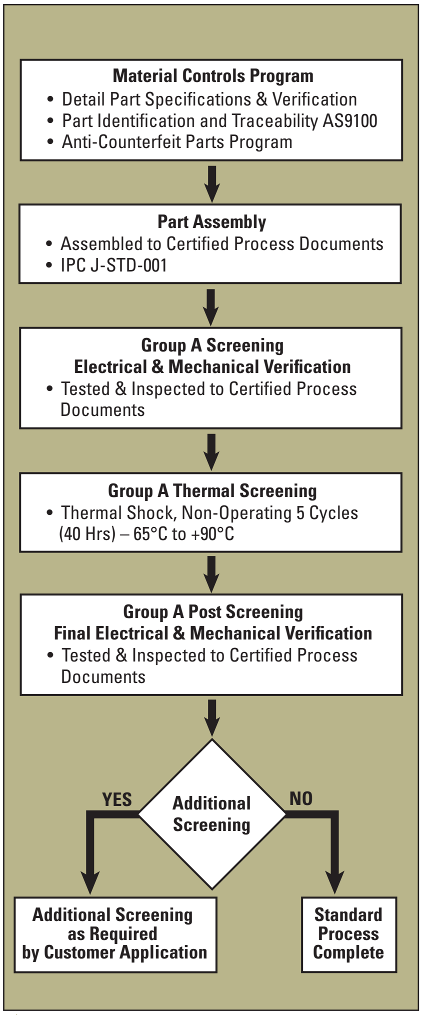
## AFFORDABLE HI-REL

MECA's ML series of components are designed for the aerospace and






▲ Fig. 1 Isolation (a) and VSWR (b) of MECA 804-3-23.000 4-way power divider.




▲ Fig. 2 ML screening flow.

defense industry. The cost-effective series, which includes power dividers, combiners, couplers and terminations, consists of commercial off-the-shelf standard products screened to predefined tests, in accordance with MIL-DTL-23971, MIL-DTL-39030E, MIL-DTL-15370 and MIL-STD-202. The models are designed for precision electrical performance, high-reliability and intended for use in harsh environments, from high altitude defense to low orbit space and satellite applications.

These models undergo MECA's ML screening process, which incorporates a level of thermal screening combined with verification of electrical and mechanical performance (see ***Figure 2***). Octave and multi-octave products with SMA connectors are built by assemblers and technicians certified to IPC J-STD-001. The ML process provides an economical level of screening for MECA's standard products, combining best practices for reliability and screening at a reasonable cost, to address the needs of the aerospace industry. To request ML screening, add the ML prefix to any 80X series power divider/combiner, 750, 765, 780 or 785 series coupler or any eligible 40X series termination. If required, enhanced screening for qualification or verification is available.

For high-reliability in harsh environments, MECA's stripline products include the option of increasing reliability by incorporating a proprietary bonding film process that renders the products impervious to (hazardous) fluids. The process also protects against high humidity and salt fog environments. The bonding film process minimizes the space needed to accomplish this level of reliability, which provides the added benefit of weight reduction. Available screened to custom requirements, these products are also subjected to MECA's standard screening process for added reliability.

While designed for the space and defense applications, the capability for extended use in harsh environments makes the ML series well-suited for outdoor public safety, commercial wireless, rail, other transportation and field VSAT installations.

A leader in RF components and manufacturing for over 56 years, MECA Electronics has served the RF/microwave industry with equipment and passive components operating to 50 GHz, featuring products manufactured in the U.S. and backed with a 36 month warranty. With expertise in both the commercial and military arenas, MECA is uniquely positioned to offer customers a cost-effective, "in between" solution to meet today's challenging and changing requirements.

VENDORVIEW

**MECA Electronics**
**Denville, N.J.**
**www.e-meca.com**



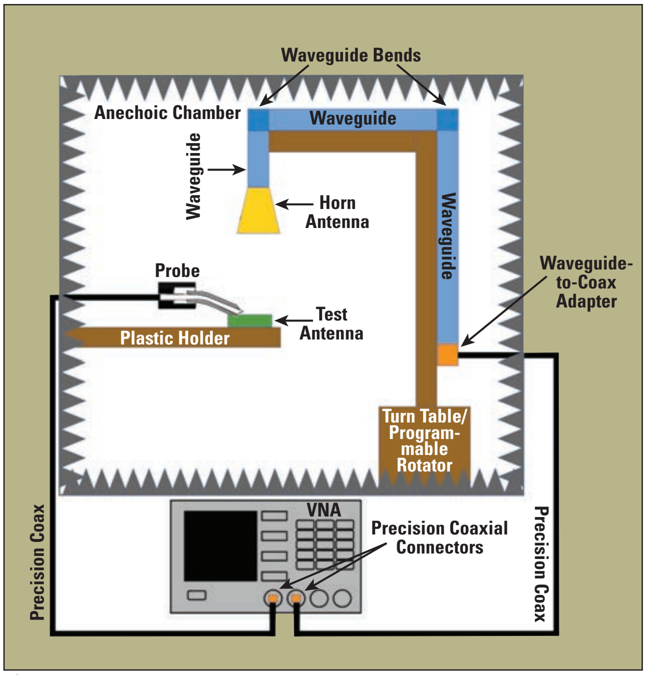
# Precision Waveguide-to-Coax Adapter Covers 75 to 110 GHz

**Fairview Microwave**
*Lewisville, Texas*

Waveguide-to-coax adapters are a necessary component in the design and development of the ever-increasing range of mmWave systems. For W-Band testing and prototyping, Fairview Microwave recently released a gold plated, male waveguide-to-coax adapter, the SMW10AC001-VM. The adapter combines a WR10 waveguide with UG-387/U-Mod round flanges and a 1 mm precision coaxial connector, creating a transition with a typical VSWR of 1.4:1. This W-Band transition is designed to serve high performance applications.

## WAVEGUIDE APPLICATIONS

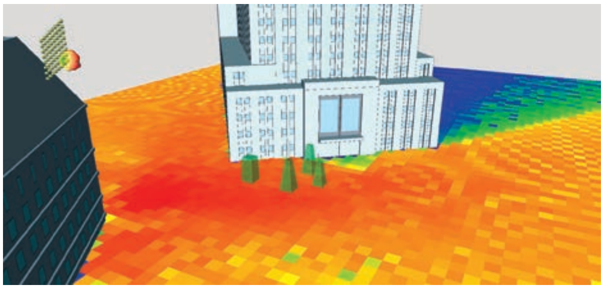
An increasing number of W-Band systems are under development and being fielded: automotive radar, point-to-point radio links, satellite services, instrument landing systems, imaging radar for security. Most require antenna and over-the-air characterization in anechoic chambers to analyze and assess performance. As shown in ***Figure 1***, connecting from the antenna or system being tested to test equipment such as vector network analyzers or spectrum analyzers requires waveguide "plumbing" with coaxial interconnects.





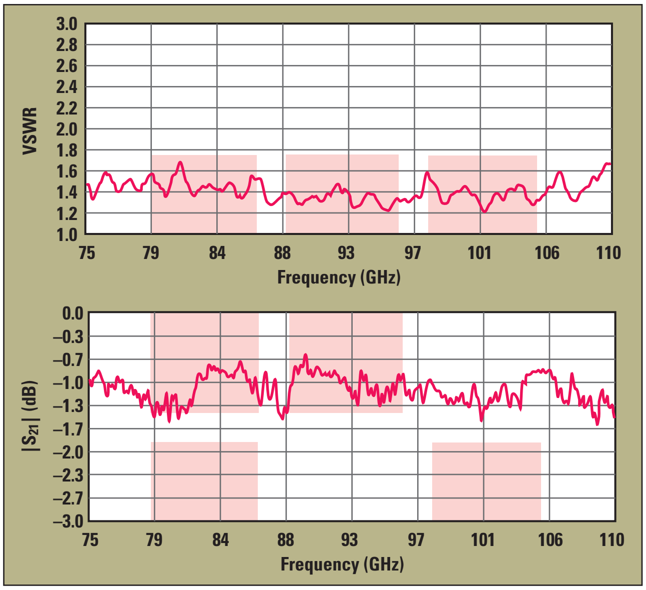
▲ Fig. 1 Test setup for mmWave antenna characterization, showing waveguide-to-coax adapters.








The advent of highly integrated MMIC modules is enabling many of these applications, which take advantage of W-Band to achieve small IC, module and aperture form factors. Many systems maximize the output power to extend range and low loss waveguide is the ideal interconnect to achieve this in the antenna feed. Waveguide is also the preferred transmission line for high-power applications, as coaxial assemblies can overheat when carrying continuous high-power levels. Coaxial cables, however, are more flexible and reduce the need for waveguide twists and bends for routing. This helps with runs through tight spaces. Also, waveguide runs introduce risks from misalignment, discontinuities and the excitation of higher-order modes, which degrade the signal. Practically, both waveguide and coaxial transmission lines are needed, requiring transitions between the two.




▲ Fig. 2 Measured VSWR and $|S_{21}|$ of the waveguide-to-coax adapter.

## ADAPTER CONSTRUCTION

The function of a waveguide-to-coax adapter is to convert the TE mode of the waveguide to the TEM mode of the coax. This is typically accomplished with a right-angled connection, where the center pin of the coaxial connector is extended into the broad wall of the waveguide. The cross-sectional view facing the iris of the waveguide reveals a probe tip entering normal to the H-plane of the waveguide. The probe is positioned so that the reflected waves from the back wall of the waveguide are in phase with the incoming fields.

An in-line waveguide-to-coax adapter typically consists of a shorting metallic elbow meeting with the coaxial probe. The short circuit forms a time-varying magnetic field that couples the signal into the waveguide. Typically, the in-line transition has a higher power handling capability but presents a higher VSWR than right-angled waveguide-to-coax adapters.

## PERFORMANCE

The SMW10AC001-VM is a right-angled design with a typical insertion loss of 1 dB, with a maximum of 2 dB, and a typical VSWR of 1.4:1, with a maximum of 1.9:1, from 75 to 110 GHz (see ***Figure 2***). The transition is a precision 1 mm male coaxial interface constructed with stainless steel. The WR10 waveguide comprises UG-387/U-Mod flanges constructed in aluminum and gold-plated for durability and repeatable performance.

The losses through waveguide depend on the conductivity of the final plating material on the inside walls. At mmWave frequencies, gold plating is often needed on the inner walls because of the skin effect, i.e., where electrons migrate to the surface of the inside walls. Materials with greater skin depth experience less loss at higher frequencies, driving the choice of aluminum for the waveguide with a gold finish.

The SMW10AC001-VM is an addition to Fairview Microwave's broad portfolio of precision coaxial and waveguide products and assemblies, including a female version of the W-Band adapter, SMW10AC001-VF. With waveguide-to-coax adapters available from K- to W-Band, Fairview Microwave offers transitions for a wide array of military, commercial and industrial platforms.

**Fairview Microwave**
**Lewisville, Texas**
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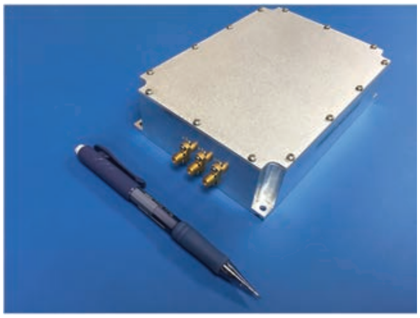
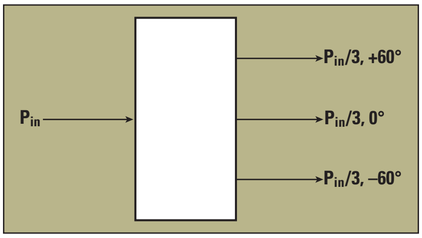


# 3-Way, 60°, 10 to 130 MHz Combiner/ Divider Improves PA Performance

**Communication Power Corp. (CPC)**
*Hauppauge, N.Y.*

Broadband quadrature (i.e., 90 degree) combiners have been the primary means to sum the outputs of multiple RF/microwave power amplifiers (PA), preferred because of their inherent interstage matching, open-loop gain flatness, load tolerant efficiency, spectral stability and third-order harmonic suppression performance. The main drawback with "quads" is they only work with pairs of amplifier modules, i.e., they combine in binary: 2, 4, 8, etc. In many applications with power density and weight restrictions—such as IED jammers, airborne EW and communications jamming—two amplifier modules do not provide enough power and four have too much power, unacceptable efficiency, cost or weight.

It is not that broadband, three-port combiners do not exist. They do. However, they have only been available in 0 degree format, and in-phase power combining lacks the benefits of the quadrature combiner. To have the advantages that quads offer, three-port combiners need to be phased with 60 degree differentials between ports. CPC has developed a new broadband technology that meets this requirement. ***Figure 1*** shows the signal flow of the CPC model CM-10-130-1E3-3P in a divider configuration. The unit covers 10 to 130 MHz and, when used as a combiner, handles a combined output power of 500 W CW, 1 kW pulsed. Insertion loss is specified at 0.5 dB typical, 0.8 dB maximum and worst-case isolation between any of the three ports is 20 dB. With all input ports terminated in 50 Ω, the typical return loss at the combined output is 20 dB, 15 dB worst-case. With the input ports open or shorted, the return loss at the output port degrades to 15 dB typical and 10 dB worst-case. The phase tolerance around the nominal 60 degree phase difference among the three ports is ±15 degrees.

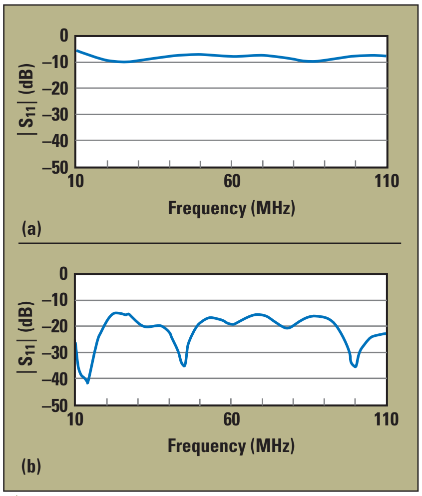



▲ Fig. 1 Signal flow of the 60 degree, 3-way divider/combiner used as a divider.

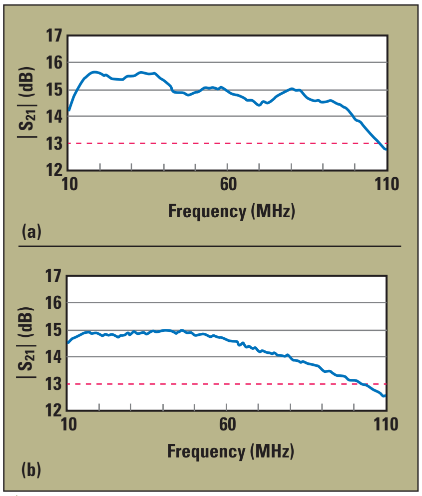
The RoHS-compliant combiner has female SMA connectors on the inputs and a type N connector on the combined output. The operating temperature range is 0°C to +40°C, and the unit will withstand 40 $G_{rms}$, six-axis random vibration.

The true test of this new 60 degree combiner/divider is how it performs in an amplifier application compared to a 0 degree combiner/divider. A thorough evaluation confirms it provides the same desirable traits as a quadrature combiner.

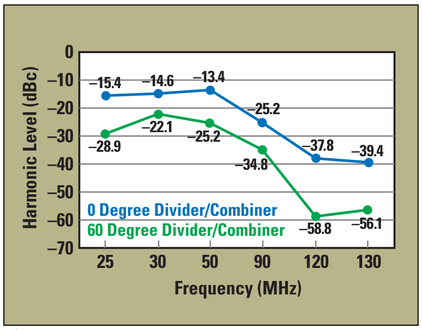
***Figure 2a*** shows the input $|S_{11}|$ of three combined amplifiers using 0 degree divider/combiners. Best case, the $|S_{11}|$ is on the order of -10 dB. Using the 60 degree divider/combiners (see ***Figure 2b***), the $|S_{11}|$ is dramatically improved to -20 dB average. This improvement in $|S_{11}|$ translates to an enhancement in gain flat-



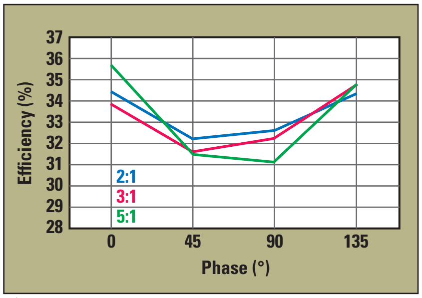

▲ Fig. 2 Amplifier $|S_{11}|$ using 3-way, 0 degree divider/combiner (a) vs. 3-way, 60 degree divider/combiner (b).




▲ Fig. 3 Amplifier gain flatness using 3-way, 0 degree divider/combiner (a) vs. 3-way, 60 degree divider/combiner (b).




▲ Fig. 4 Third-order harmonic performance comparison of an amplifier using the 0 degree divider/combiner and the 60 degree divider/combiner.



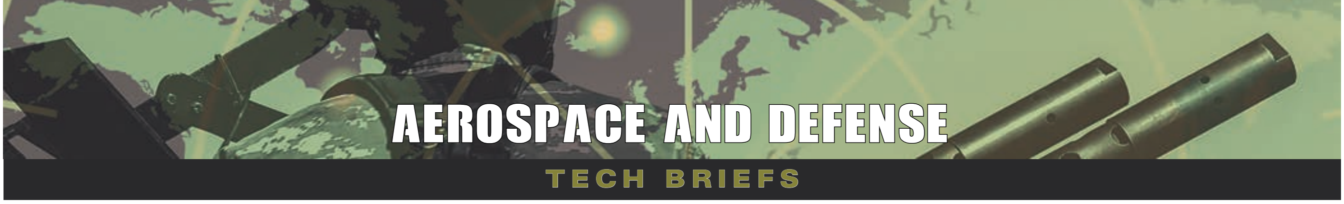

▲ Fig. 5 Efficiency vs. load for a power amplifier using the 60 degree divider/combiner. The load was varied across 45 degree phase steps around the Smith chart at VSWRs of 2:1, 3:1 and 5:1.

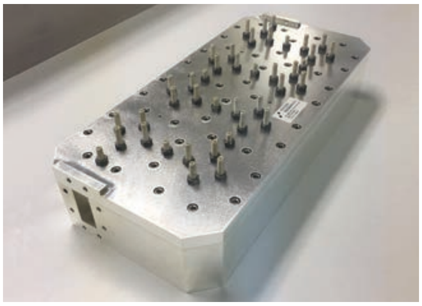
ness, shown in ***Figure 3***. The 0 degree combined amplifiers have ±1.4 dB flatness, and the 60 degree combined amplifiers show a modest improvement to ±1.2 dB. A more dramatic performance enhancement is observed with third-order harmonics, shown in ***Figure 4***. The 60 degree configuration achieves, on average, 13.4 dB lower third-order harmonics than with the 0 degree configuration.

Using the 60 degree divider and combiner helps maintain amplifier load tolerance or constant efficiency. Comparing amplifiers driven into 2:1, 3:1 and 5:1 load VSWRs with discrete 45 degree phase rotations at 100 MHz, the 60 degree power combiner maintains the efficiency within ±2.85 percent (see ***Figure 5***). Using the 0 degree combiners resulted in a ±13 percent variation in efficiency. The data indicates there are certain phase rotations where the 0 degree combiner yields higher efficiency; however, as the magnitude of the load VSWR increases, the efficiency drops below 30 percent at certain load phase angles. This is highly problematic for an RF PA designer, since the length of cable connected to the amplifier in the field cannot be controlled.

Until now, broadband RF PA engineers had to sacrifice several performance parameters to combine amplifiers with three-port networks. However, CPC's novel 60 degree divider/combiner architecture provides the means to maintain RF amplifier performance while achieving the optimum power level—not attainable with binary (2, 4, 8, etc.) combiner networks.

**Communication Power Corp. (CPC)**
**Hauppauge, N.Y.**
**www.cpcamps.com**
**info@cpcamps.com**



# Super Low Insertion Loss Waveguide Bandpass Filters

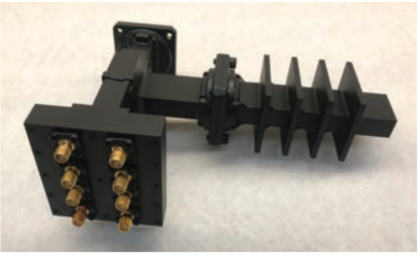
Exceed Microwave is introducing the new WZ-Series waveguide bandpass filters with super low insertion loss and very high frequency selectivity. The low insertion loss makes the filter ideal for high-power transmitters and pre-select filters, preserving low noise figure. In addition to the high average power handling capability, the WZ-Series filters have high threshold voltage to avoid voltage breakdown.

The insertion loss of any bandpass filter will increase as bandwidth decreases, so the only way to reduce insertion loss is using resonators with higher Q-factor. Typical waveguide filters at C-Band use resonators with unloaded Q-factors in the range of 9000, while Exceed Microwave's WZ-Series has unloaded Q-factors of approximately 30,000, allowing much lower insertion loss. Exceed Microwave's eight-section WZ bandpass filter has less than 0.5 dB insertion loss at 4.76 GHz, with a 22 MHz or 0.45 percent bandwidth and greater than 80 dB rejection 40 MHz away from the center frequency. At V-Band, an eight-section WZ filter with 1 GHz bandwidth has 1 dB insertion loss and 80 dB rejection 1.57 GHz from the center frequency.

Exceed Microwave designs and manufactures custom, high performance waveguide and coaxial filters for defense, space and commercial applications. Exceed Microwave's proprietary products include the WZ-Series low loss waveguide filters, WC-Series compact waveguide filters, waveguide notch filters with broad passbands and waveguide phase equalizers. Exceed supplies other filters and coaxial electro-mechanical switches. Exceed Microwave's engineers work directly with customers to provide immediate response and the optimum solution.

VENDORVIEW

**Exceed Microwave**
**Torrance, Calif.**
**www.exceedmicrowave.com**



# 2 kW, X-Band, 0 Degree, 8:1 Combiner Network

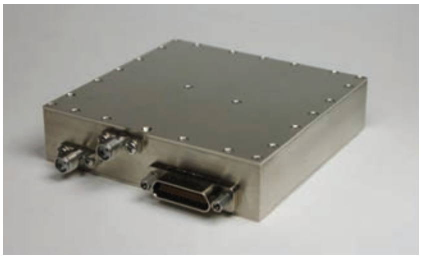
With the ever growing need to increase the output power of solid-state power amplifiers (SSPA), combiner network efficiency is even more critical. In tube replacement applications where SSPA efficiency is paramount, having a compact low loss combiner network can be a game changer.

Traditional SSPA power combiners use coaxial (Wilkinson, hybrid or radial) or waveguide (spatial and tuned cavity) structures to achieve the desired results. The choice depends primarily on the frequency of operation: At low frequencies, designers are limited primarily to microstrip or balanced stripline architectures. At higher frequencies, cavity and waveguide combiners are options. With increasing power levels, waveguide becomes a necessity, to adequately handle the dissipated heat; however, waveguide components do require a larger footprint.

To address this need, M-Wave Design developed a high-power, X-Band, 0 degree, 8:1 combiner network, the 90HPCA1201. The combiner handles 2 kW peak (more than 100 W average) at each of its eight inputs, and the rated power at the output of the combiner is 800 W CW with an integrated 50 Ω termination for phase imbalance reflection. The 90HPCA1201 weighs just under 1 lb. with SMA female connectors at the input ports and a WR90 choke flange (MIL-F-3922/59-006) at the output.

The X-Band 8:1 combiner is just one example of M-Wave Design's combiner network capabilities. M-Wave Design has 30 years of waveguide and coaxial passive design heritage developing some of the most innovative channel summing techniques available. M-Wave's history with high-power ferrite products and combiner networks of all architectures gives the company a unique set of tools to solve challenging customer problems.

**M-Wave Design Corp.**
**Simi Valley, Calif.**
**www.mwavedesign.com**



# 0.1 to 20 GHz, Fast-Tuning, Miniature Synthesizer

RFE has designed a reliable, fast-tuning, multi-octave microwave source with the smallest possible footprint and least weight. The design uses commercial, off-the-shelf, surface-mount components—VCOs, pre-scalars, amplifiers, filters and synthesizers—to shrink size, eliminate hand tuning and minimize the parts count. The result is a low-cost, lightweight, integrated module that performs in the harshest environments.

The RFE synthesizer covers the entire 0.1 to 20 GHz spectrum in 1 MHz steps, using a 10 MHz external reference. Output power is between 10 and 15 dBm, with a flatness of 1 dB. Phase noise is –65 dBc/Hz at 10 kHz offset and –100 dBc/Hz at 100 kHz offset, with spurious signals –50 dBc or better inside a ±10 MHz offset and –60 dBc elsewhere. Harmonics are no greater than –15 dBc. In 100 µsecs, the synthesizer tunes to within ±1 MHz of the final frequency. The unit has a single SMA output and a micro D-25 connector for bias and control, which allows parallel or serial control. The synthesizer is biased with +15, -5 and +5 V supplies and consumes a total DC power of 7.5 W. It can be packaged in several form factors, including low profile and hermetic.

The design uses two synthesizer ICs, one to cover 0.1 to 1.6 GHz, the other for 1.6 to 20 GHz. Signals in the 0.1 to 1.6 GHz band are produced using the Analog Devices AD4351 wideband synthesizer. Higher frequency signals are generated using a 10 to 20 GHz VCO, a divider and an Analog Devices AD4157 fractional N frequency synthesizer. The 1.6 to 10 GHz band uses a programmable pre-scalar and, to maintain harmonic performance, the band is separated into five sub-bands using a switched filter network.

VENDORVIEW

**RFE Inc.**
**Fremont, Calif.**
**www.rfe-mw.com**

# AEROSPACE AND DEFENSE

## COMPANY SHOWCASE

### PHASED ARRAY DESIGN

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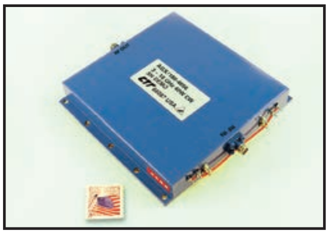

### NEW 40 W MULTI-BAND GaN POWER AMPLIFIER

CTT announces a new solid-state GaN-based power amplifier, Model AGX/180-4656, that covers a wide bandwidth of 3 to 18 GHz with 40 W of CW power output. The compact size of 5.16 in. x 4.90 in. x 0.28 in. offers RF/microwave designers an excellent choice for SWaP solutions in many applications, including EW jammers, and for transmit power in multi-band SATCOM terminals.

**CTT Inc.**
**www.cttinc.com**


### 2018 DEFENCE, SECURITY & SPACE FORUM

The Defence, Security and Space (DSS) Forum is jointly organized by Eu*M*A and *Microwave Journal*, to complement European Microwave Week's activity in the defence, security and space sector. Each year the DSS Forum focuses on a hot topic that is engaging industry, academia and organisations/agencies to develop, test and implement leading edge technology. This year's one-day focused Forum will address the integration of UAVs into defence and security scenarios. A full itinerary can be found in the conference special events section of the EuMW website.

**EuMW 2018**
**www.eumweek.com**

### SPUMA RS CABLES FOR EASY HANDLING

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HUBER+SUHNER launched a new RF cable. Thanks to the rotary swaging technology the new member of the SPUMA cable family enables a significantly easier handling while keeping the outstanding low loss values and the excellent electrical performance. The well known SPUMA product family provides flexible and halogen free cable types. With a screening effectiveness > 90 dB over the whole operating frequency range, as well as a tight bending radius, a wide application range is covered. SPUMA cables are designed for applications up to 6 GHz and are applicable in the defense, instrumentation, industrial, railway and communication markets.

**HUBER+SUHNER AG**
**www.hubersuhner.com**

### PRE-FILTERED LOW NOISE AMPLIFIERS FOR GPS

K&L Microwave offers pre-filtered low noise amplifiers for GPS and other frequency bands. The GPS offering can cover L1, L2, L5 or combinations of those frequency bands. Gains available are 16 to 40 dB with noise figures typically 1.8 dB or less. These LNA's are designed for harsh military environments with product supplied to many missile applications. Options are available with or without limiters. DC inputs can be supplied through independent pins or through the RF connector by use of a bias T.

**K&L Microwave**
**www.klmicrowave.com**

### L3 ELECTRON DEVICES' MPMS

L3 Electron Devices' MPMs are super components that combine a solid-state driver amplifier with a micro-TWT and a power supply in one package that is much smaller, lighter and more efficient than a comparable TWTA or SSPA. Their MPMs are available in bands from 2 to 95 GHz with output powers from 40 to 200 W. All L3 MPMs are optimized for demanding defense applications that require small, lightweight and environmentally rugged, high-power microwave amplifiers.

**L3 Electron Devices**
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# AEROSPACE AND DEFENSE

## COMPANY SHOWCASE


### BENCHTOP TEST SOLUTIONS PRODUCT GUIDE

VENDORVIEW

Mini-Circuits' has innovated a line of products for these functions that are smaller, faster, easier to control and much more affordable than other options typically available in the industry. Their benchtop test and measurement modules offer the ease of control via USB or Ethernet and include programmable attenuators, power sensors, frequency counters, switch modules, signal generators and control products. Depending on the application, these units may be used as standalone solutions or easily integrated as building blocks to build scalable testing platforms customized to each user's individual needs.

**Mini-Circuits**
**www.minicircuits.com**


### FILTERS, MULTIPLEXERS AND MULTI-FUNCTION ASSEMBLIES

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When being first to react makes all the difference in the world, choose Reactel for your mission-critical filter requirements. You can count on Reactel to satisfy the most demanding requirements for units used in extremely harsh environments. The full-line catalog features RF and microwave filters, multiplexers and multi-function assemblies for the military, industrial and commercial industries. To request a copy, visit the company's website or e-mail reactel@reactel.com.

**Reactel Inc.**
**www.reactel.com**


### AEROSPACE & DEFENSE SELECTOR GUIDE

Richardson RFPD is an AS9120-certified, global component distributor specializing in advanced connectivity solutions. With A&D as its largest market, the company's GaN technology portfolio and wide range of MMICs, RF transistors, PAs and diodes from leading brands like ADI, ATC, Anaren, MACOM, Microsemi, NXP, pSemi, UMS and WanTcom serve diverse A&D applications, including radar, avionics, EW and communications. Among the latest additions to Richardson RFPD's A&D line are Guerrilla RF, NewEdge Signal Solutions and Tagore Technology products and the Metelics diodes now offered by MACOM.

**Richardson RFPD**
**www.richardsonrfpd.com**


### MODULAR CONNECTOR SYSTEM

For specific test & measurement applications, Rosenberger develops and produces modular connector systems. To cover the whole frequency range from DC to 50 GHz, only one part of PCB contact for various female connector heads has to be processed. The modular connector system consists of one PCB contact which can be connected with various female connector heads—SMA, RPC-3.50, RPC-2.92, RPC-2.40. A product flyer contains information in detail and can be ordered at marketing@rosenberger.com.

**Rosenberger**
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### 16-BIT MIDRANGE DIGITIZERS NOW AS "STAND-ALONE" DEVICES

VENDORVIEW

Do you need a mid-range digitizer PCIe card with a sampling rate from 20 MS/s to 125 MS/s? Then the new 59er family from Spectrum Instrumentation is your perfect choice. Twenty product variants ensure a perfect match to the specifications you need. Now, these powerful digitizers are also available as portable "stand-alone" devices. These can be remotely controlled via Ethernet/LXI from any PC in the lab or corporate network. Nine variants with four to 16 input channels are available.

**Spectrum Instrumentation**
**www.spectrum-instrumentation.com/en/59xx-16-bit-digitizer-125-mss**

### NEW CLARITY SERIES

Times Microwave introduces its new Clarity Series of 18, 26.5 and 40 GHz coax test cables. Clarity boasts steel torque, crush and over-bend protection with abrasion resistance yet does not compromise flexibility. The cable is ultra stable through 40 GHz with exceptionally low attenuation. An industry first includes an ergonomically designed, injection molded strain relief and Times' new, SureGrip™ coupling nut to significantly improve the user's everyday experience.

**Times Microwave Systems**
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# The 2018 Defence, Security & Space Forum

## At European Microwave Week

EuMA Microwave Journal

**Wednesday, 26 September – Room N101-N102, 08:30 to 18:30**

## A one-day focused Forum addressing the integration of unmanned aerial vehicles (UAV) into defence and security scenarios.

## Programme:

**08:30 – 10:10 EuRAD Opening Session**

**10:10 – 10:50 Coffee Break**

**10:50 – 12:30 New Concepts, Technologies and Systems for UAV Integration and Their Role in Future Hybrid Scenarios.**

*Technological Demonstrator of Enhanced Situation Awareness in Naval Environment with the use of Unmanned Systems*
**Dr. Tony Arecchi, Ocean 2020 Project Coordinator, Leonardo S.p.A. Italy.**

- *UAV Integration into European Airspace: The U-Space Vision* – **Single European Sky ATM Research (SESAR) Project.**
- *Anti-UAV Defence Systems* – **Miguel Acitores, Director of Security Business Development, Indra. Spain.**

**12:40 - 13:40 Strategy Analytics Lunch & Learn Session**

*The Implications of Expanding the UAS Mission Envelope in Military and Civilian Airspace*
**Asif Anwar, Strategy Analytics, UK**

**13:50 – 15:30 *Microwave Journal* Industry Panel Session**

This session offers a perspective on the endeavour, innovation and investment that industry is committing to the development of Unmanned Aerial Vehicles in the defence and security sector. Speakers will offer an insight into such areas of activity as microwave sensors/sub-systems, the test and measurement challenges that are being addressed and the issue of UAV identification and detection.

**15:30 - 16:10 Coffee Break**

**16:10 - 17:50 Round Table: Efforts & Investment Needs to Drive UAV Technologies to Market**

High level speakers from key governmental agencies and commercial companies involved in the integration of UAV air traffic into non-segregated air spaces in the future will offer their opinions and outline the opportunities and challenges that can be expected in coming years. Speakers will also focus on the research needs and technological trends that will define the structure and technical characteristics of future unmanned systems.

**17:50 - 18:30 Cocktail Reception**

**Registration and Programme Updates**

**Registration fee is €20 for those who registered for a conference and €60 for those not registered for a conference.**

As information is formalized, the Conference Special Events section of the EuMW website will be updated on a regular basis.

**Register online at www.eumweek.com**

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