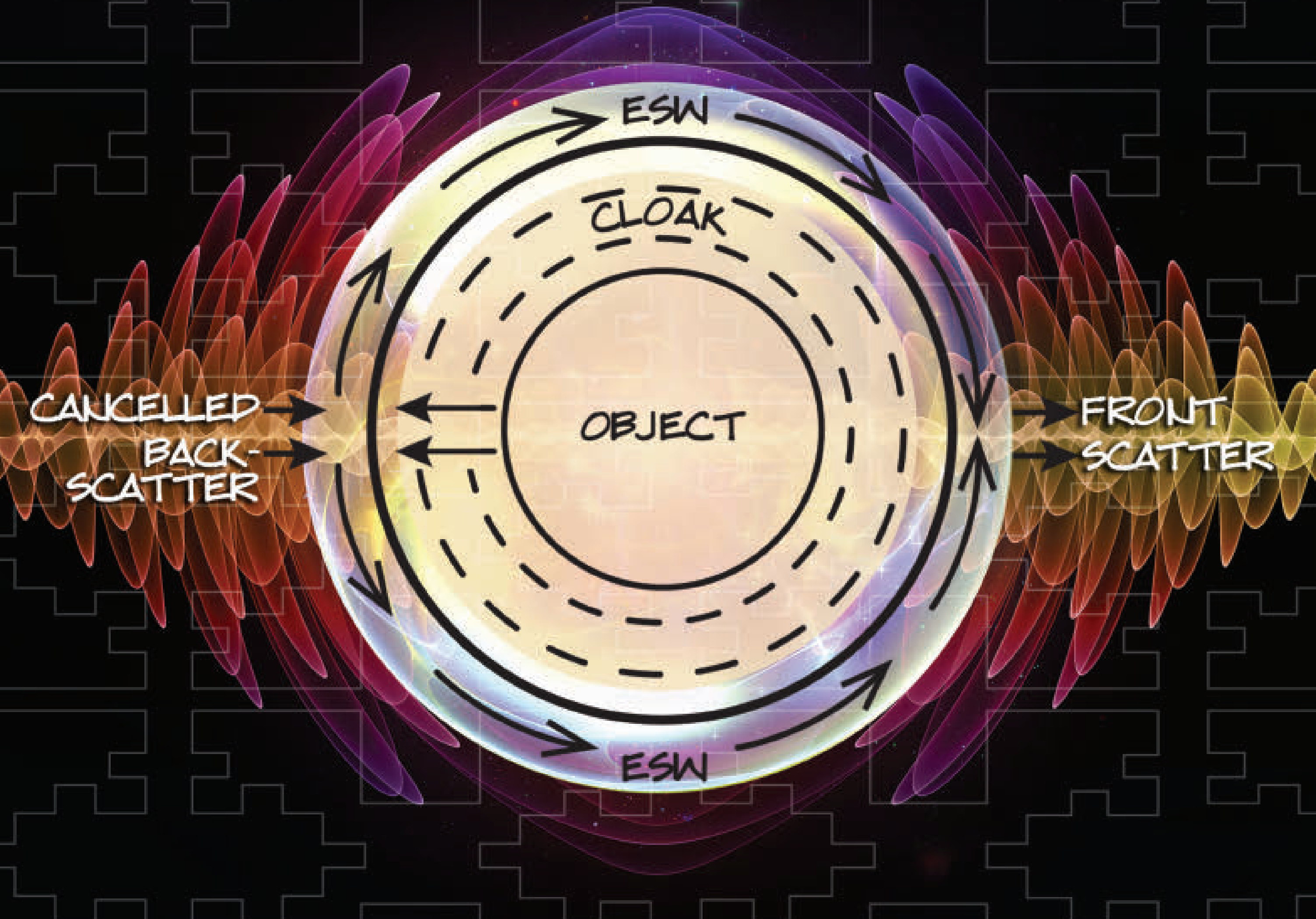
Vol. 58 • No. 1

January 2015

# Microwave Journal .com

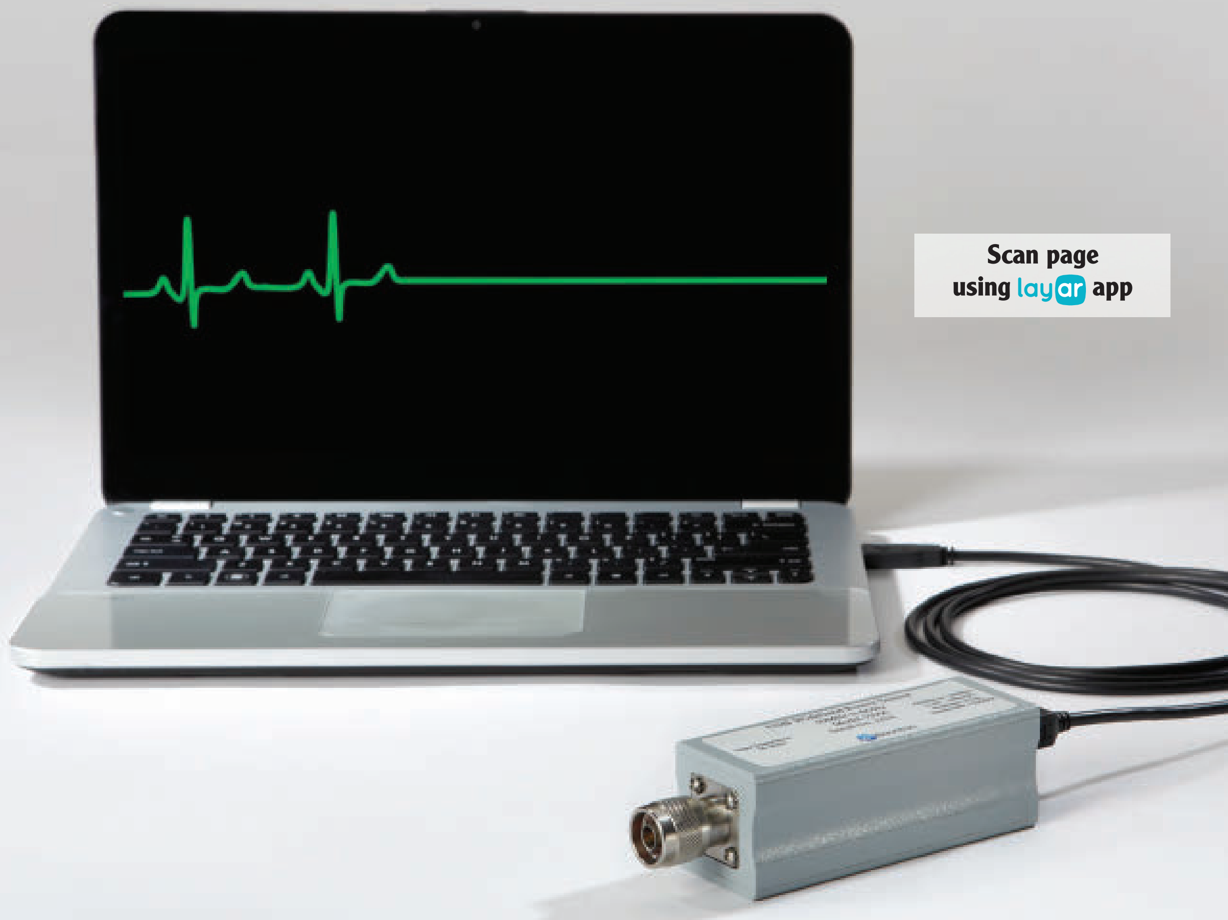



MVP
CST STUDIO SUITE

horizon house®

Founded in 1958

# *Missing a Pulse Can Be Deadly.*



Scan page using layar app

## *The Smartest, Fastest and Only Real-Time USB Peak Power Sensor.*

Capture every pulse with no missed glitches. The **55 Series** delivers unsurpassed speed and accuracy for the most demanding RF power measurements thanks to Boonton's **Real-Time Power Processing™** technology. With this revolutionary technique, all processing steps take place in parallel, guaranteeing gap-free signal acquisition and reliable capture of all transients, dropouts or interference.

***Taking Performance to a New Peak.***

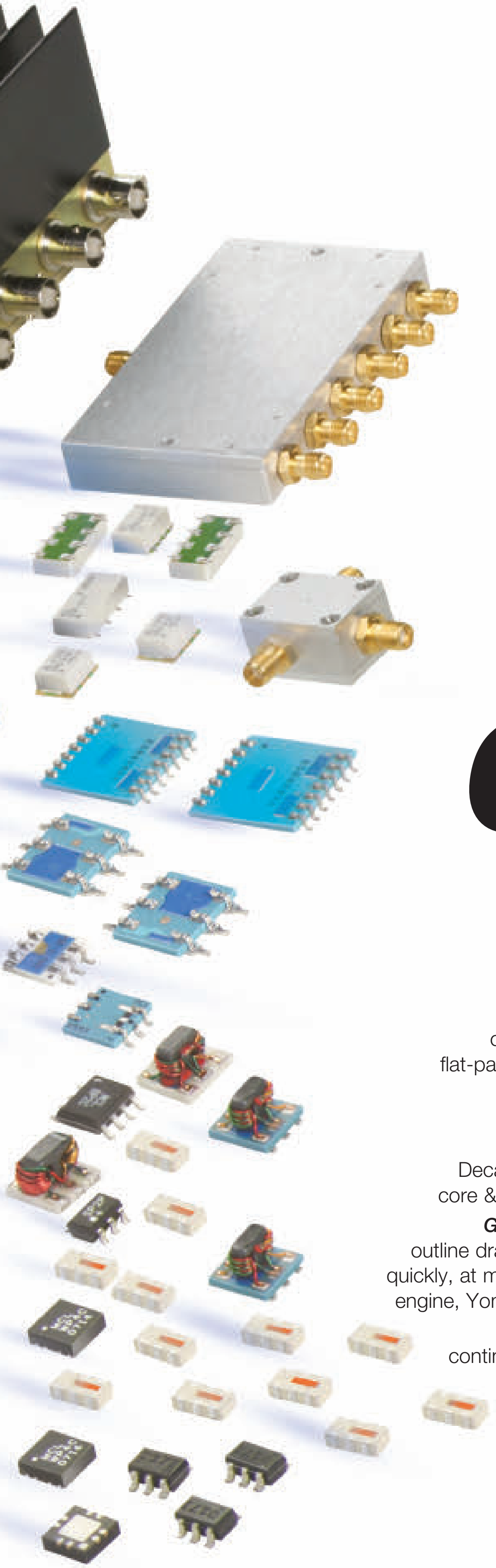
- Real-Time Power Processing™ for gap-free analysis
- 100 MSa/sec SUSTAINED sample rate is world's fastest
- 10 GSa/sec effective rate for superb waveform fidelity
- <3 ns risetime and up to 195 MHz video bandwidth
- 100 ps time resolution for enhanced trigger stability
- Triggered acquisition speeds over 100,000 sweeps/sec
- Capture and analyze data more than 100x faster than conventional power sensors

For more information visit us at boonton.com or call +1 973-386-9696.

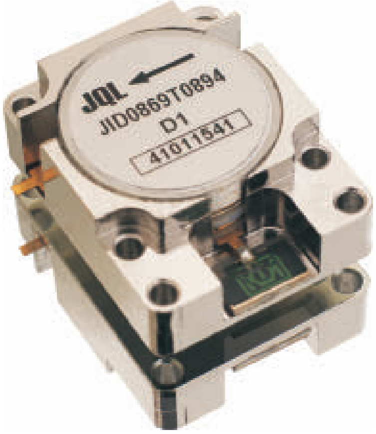
Wireless Telecom Group
Boonton Microlab Noisecom

Boonton


MCL B 744
ADP-2-10
MCL B 744
ADP-2-10
MCL B 744
ADP-2-10



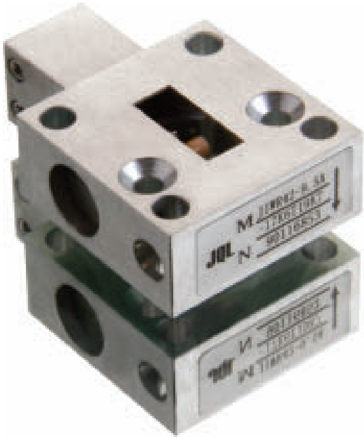
# Technology On the Move™




**Drop-in Isolators**

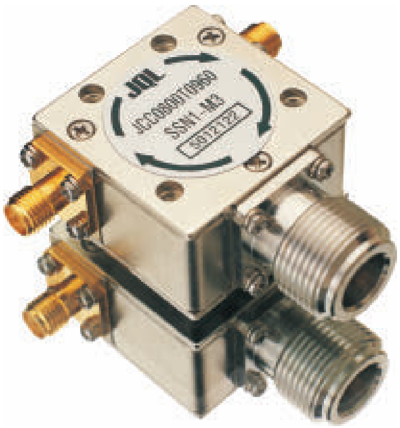
**Cavity Filters**


**Surface Mount Circulators**



**Waveguide Isolators**

**Power Combiners**

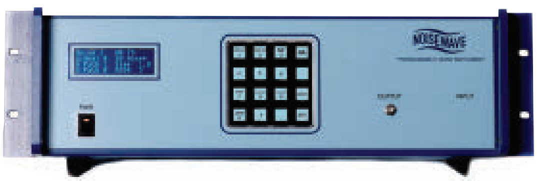



**Coaxial Circulators**

Tel:1(888)236-9828(US&Canada)
1(630)930-9917(Worldwide)
www.jqlelectronics.com sales@jqlelectronics.com


New Wave in Noise
NOISEWAVE
NW3G-D
060911
NOISEWAVE
NW3G-D-12V
072703
NOISEWAVE



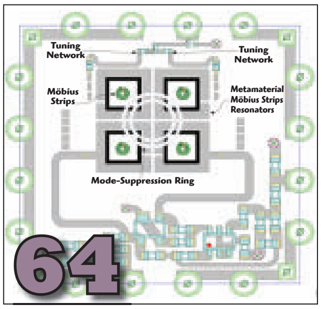


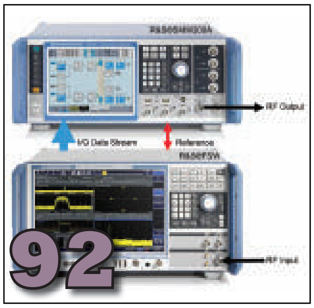
Microwave Journal

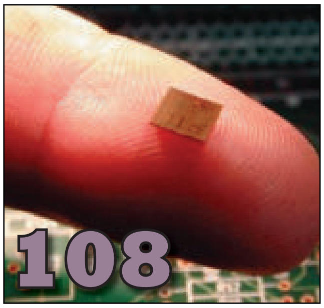
# CONTENTS

January 2015
Vol. 58 • No. 1
Radar and Antennas
mwjournal.com








**AUGMENTED REALITY: HOW IT WORKS**

**STEP 1**
Download the free Layar app from the iTunes (iOS) or Google Play (Android) store.

**STEP 2**
Launch the app to view enhanced content on any page with the layar logo.

**STEP 3**
Frame the entire page in the screen and tap to experience enhancements (tap screen again for full screen view).

**Refer to page 152 for this month's participants**

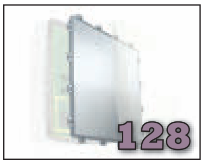
**AR pages may expire after 60 days.**

58 YEARS OF PUBLISHING EXCELLENCE

Microwave Journal

# CONTENTS

mwjournal.com




## Product Features



## Tech Briefs



## Departments



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



POSTMASTER: Send address corrections to *Microwave Journal*, PO Box 1143, Skokie, IL 60076 or e-mail mwj@halldata.com. Subscription information: (847) 763-4943. This journal is issued without charge upon written request to qualified persons working in the RF & microwave industry. Other subscriptions are: domestic, $120.00 per year, two-year subscriptions, $185.00; foreign, $200.00 per year, two-year subscriptions, $370.00; back issues (if available) and single copies, $10.00 domestic and $20.00 foreign. Claims for missing issues must be filed within 90 days of date of issue for complimentary replacement.



## STAFF

**Publisher:** Carl Sheffres
**Editor:** Patrick Hindle
**Technical Editor:** Gary Lerude
**Managing Editor:** Jennifer DiMarco
**Associate Technical Editor:** Cliff Drubin
**Multimedia Staff Editors:** Barbara Walsh and Leslie Nikou
**Consulting Editor:** Harlan Howe, Jr.
**Consulting Editor:** Frank Bashore
**Consulting Editor:** David Vye
**Consulting Editor:** Raymond Pengelly
**Web Editor:** Chris Stanfa
**Client Services Manager:** Kristen Anderson
**Audience Development Manager:** Carol Spach
**Traffic Manager:** Edward Kiessling
**Director of Production & Distribution:** Robert Bass
**Art Director:** Janice Levenson
**Graphic Designer:** Sachiko Stiglitz

**EUROPE**

**International Editor:** Richard Mumford
**Office Manager:** Nina Plesu

**CORPORATE STAFF**

**CEO:** William M. Bazzy
**President:** Ivar Bazzy
**Vice President:** Jared Bazzy



**Executive Editorial Office**
685 Canton Street, Norwood, MA 02062
Tel: (781) 769-9750
FAX: (781) 769-5037
e-mail: mwj@mwjournal.com

**European Editorial Office**
16 Sussex Street, London SW1V 4RW, England
Tel: Editorial: +44 207 596 8730 Sales: +44 207 596 8740
FAX: +44 207 596 8749

**Subscription Services**
Send subscription inquiries and address changes to:
Tel: (847) 763-4943
e-mail: mwj@halldata.com

BPA WORLDWIDE

www.mwjournal.com

Printed in the USA

# Microwave Journal Online

Scan page using layar app

Visit us @ mwjournal.com

## eLEARNING free webinars

**LTE-Advanced: 3GPP Release 12 and 13**
*Presented by: Keysight Technologies* 1/27

**Laser Test of RIN, Linewidth and Optical Noise Parameters**
*Presented by: Keysight Technologies* 1/29

## WHITE PAPERS

Anritsu envision : ensure

Modern Vector Network Analyzer Test Solutions Improve On-Wafer Measurement Efficiency

METRIGRAPHICS

A Foundation in Thin Film Circuit Manufacturing

## Web Survey

What is your favorite cover from 2014?

Look for our multiple choice survey online at mwjournal.com

**November Survey**

What filter technology will win the most duplexer sockets in small-cell base stations?

Metal cavity. I'll tolerate the size and weight to get the performance. [14 votes] (26%)

Ceramic. I'm willing to give some performance for smaller size and lower weight. [22 votes] (41%)

Acoustic (BAW, FBAR, SAW). The smaller the better, and my output power won't burn them up. [18 votes] (33%)

## Executive Interview

**Ross Q. Smith**, CEO of **RADX Technologies**, and **Wade Lowdermilk**, CTO of **RADX Technologies**, discuss the company's unique approach to test instrumentation called Software Defined Synthetic Instruments and how they produce configurable, high speed test equipment.


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

COM

# FEBRUARY

## MARK YOUR CALENDAR

## 5

WEBINAR

**Understanding 5G and How to Navigate Multiple Physical Layer Proposals**

*Sponsored by:*

KEYSIGHT TECHNOLOGIES

## 9

**Call for Papers Deadline**

EUROPEAN MICROWAVE WEEK
EuMW 2015 FREEDOM THROUGH MICROWAVES
PALAIS DES CONGRÈS DE PARIS, FRANCE
6 - 11 SEPTEMBER 2015
www.eumweek.com

Bringing industry, academia and commerce together, European Microwave Week 2015 is a SIX day event, including THREE cutting edge conferences and ONE exciting trade and technology exhibition with leading players from across the globe. EuMW 2015 will see an estimated 1700 to 2000 conference delegates, over 5,000 visitors and more than 250 exhibitors. **www.eumweek.com/conferences/callforpapers.html**

## 11

WEBINAR

**Transmission-Line Theory and Advanced Measurements in the Field**

*Sponsored by:*

KEYSIGHT TECHNOLOGIES

## 18

WEBINAR

**Tips and Techniques for Making Microwave Vector Network Analysis Measurements in the Field**

*Sponsored by:*

Anritsu envision : ensure

## 22-26

**International Solid-State Circuits Conference**
San Francisco, Calif.

Big data generated by IoT, healthcare and www are changing our lifestyles and our society. Small silicon chips are enabling this through data sensing, gathering, processing, storing and networking, using wireless and wireline connections. ISSCC 2015 is looking for novel system and circuit solutions which will open new vistas for society, with opportunities for new lifestyles, all driven by big data technology. **www.isscc.org**

## 23-25

**8th Annual Military Radar Summit**
Washington, DC

Military Radar Summit returns for its 8th consecutive year as the only radar event to exclusively focus on the greatest challenges in radar that are impacting OEMs and military forces. Join hundreds of radar professionals to preview the future of radar strategies, funding, and technology from those leading the efforts critical to the safety and future of the nation.
**www.militaryradarsummit.com**

## 24-26

**Scalable Active Sensor Architectures**
Ulm, Germany

Active safety in vehicles is increasingly important for automakers. This workshop will assess and compare perception technologies, sensor architectures and fusion approaches for applications ranging from driver assistance to automated or autonomous driving.
**www.iwpc.org**

## 22

**February 1857- January 1894**

The great German physicist, **Heinrich Hertz** made the development of radio, television and radar possible by proving that electricity can be transmitted in electromagnetic waves. He explained and expanded the electromagnetic theory of light that had been put forth by Maxwell. He was the first person who successfully demonstrated the presence of electromagnetic waves, by building an apparatus that produced and detected VHF/UHF radio waves. His undertakings earned him the honor of having his surname assigned to the international unit of frequency (one cycle per second).

FOR DETAILS, GO TO MWJOURNAL.COM/EVENTS

# Coming**Events**

**CALL FOR PAPERS**

**WAMICON 2015**
January 19, 2015

**EuMW 2015**
February 9, 2015

**mwjournal.com**

## JANUARY

**RWW 2015**
**Radio and Wireless Week**
*January 25–28, 2015 • San Diego, Calif.*
www.radiowirelessweek.org

**DesignCon**
*January 27–30, 2015 • Santa Clara, Calif.*
www.designcon.com

## FEBRUARY

**IDGA 2015**
**Military Radar Summit**
*February 23–25, 2015 • Washington, DC*
www.militaryradarsummit.com

**ISSCC 2015**
**International Solid-State Circuits Conference**
*February 22–26, 2015 • San Francisco, Calif.*
www.isscc.org

**Scalable Active Sensor Architectures**
*February 24–26, 2015 • Ulm, Germany*
www.iwpc.org

## MARCH

**Mobile World Congress**
*March 2–5, 2015 • Barcelona, Spain*
www.mobileworldcongress.com

**CS International Conference 2015**
*March 11–12, 2015 • Frankfurt, Germany*
www.cs-international.net

**IEEE EMC & SI 2015**
*March 15–21, 2015 • Santa Clara, Calif.*
www.emc2015usa.emcss.org

**Satellite 2015**
*March 16–19, 2015 • Washington, DC*
www.satshow.com

**GOMACTech 2015**
*March 23–26, 2015 • St. Louis, Mo.*
www.gomactech.net

## APRIL

**Microwave & RF 2015**
*April 1–2, 2015 • Paris, France*
www.microwave-rf.com

**WAMICON 2015**
**IEEE Wireless and Microwave Technology Conference**
*April 13–15, 2015 • Cocoa Beach, Fla.*
www.wamicon.org

**EDI CON 2015**
**Electronic Design Innovation Conference**
*April 14–16, 2015 • Beijing, China*
www.ediconchina.com

**SPACOMM 2015**
**7th International Conference on Advances in Satellite and Space Communications**
*April 19–24, 2015 • Barcelona, Spain*
www.iaria.org

## MAY

**AUVSI's Unmanned Systems 2015**
*May 4–7, 2015 • Atlanta, Ga.*
www.auvsi.org

**RFIC 2015**
**IEEE Radio Frequency Circuits Symposium**
*May 17–19, 2015 • Phoenix, Ariz.*
www.rfic-ieee.org

**IMS 2015**
**IEEE MTT-S International Microwave Symposium**
*May 17–22, 2015 • Phoenix, Ariz.*
www.ims2015.org

**CS Mantech 2015**
*May 18–21, 2015 • Scottsdale, Ariz.*
www.csmantech.org

**Space Tech Expo 2015**
*May 19–21, 2015 • Long Beach, Calif.*
www.spacetechexpo.com

**Aerospace Electrical Systems Expo 2015**
*May 19–21, 2015 • Long Beach, Calif.*
www.aesexpo.com

**85th ARFTG Microwave Measurement Symposium**
*May 22, 2015 • Phoenix, Ariz.*
www.arftg.org

**EW Europe 2015**
*May 26–28, 2015 • Stockholm, Sweden*
www.eweurope.com

## JUNE

**Sensors Expo & Conference 2015**
*June 9–11, 2015 • Long Beach, Calif.*
www.sensorsexpo.com

# 2015 and Beyond...

**Carl Sheffres**
Microwave Journal *Publisher*

Every year, we make a few design changes to the magazine, add new features to our online products and expand our event presence. This year is no exception. You'll find a new look on several of our pages, including the "Mark Your Calendar" page and the inside back page, which features a new "Fabs and Labs" series that highlights companies with interesting design, fabrication, assembly and test facilities that our editors visit during their travels around the industry. This series will run intermittently during the year, rotating with the "STEM Works" feature that debuted in 2014. We have also added a fourth special supplement, focused on "Aerospace & Defense Electronics," which will be mailed with our May issue. If you have not renewed your subscription lately, I hope you'll do so soon. It's free; all we ask is two minutes of your time to update your profile.

On our website, you'll soon find a new, state-of-the-art video platform. This platform allows us to aggregate relevant RF/microwave videos into a well organized and easy to navigate format. As far as I know, this is the only video site that caters only to our industry. You'll also find a slate of new and informative webinars scheduled for 2015, including the popular Besser Associates and Strategy Analytics series and presentations from industry leaders like Keysight Technologies, CST, Rohde & Schwarz and National Instruments. We've redesigned our weekly newsletters, Microwave FLASH and Microwave ADVISOR with a fresh look and easier read. I encourage you to sign up for your choice of newsletters on our website.

It's an exciting year for events. In the first quarter alone, you'll find MWJ editors at DesignCon (Santa Clara, Calif.), Mobile World Congress (Barcelona) and Satellite (Washington, DC). April brings us to Microwave & RF (Paris), WAMICON (Cocoa Beach, Fla.) and EDI CON China (Beijing). The IEEE MTT-S IMS takes place in May in Phoenix this year, so our show issue will be in April and not the usual May. The European Microwave Week event is also earlier this year, taking place in September in Paris. Our August issue will serve as the preview for EuMW. Paris is always a good venue for this annual event, so I expect an excellent turnout this year. I'm also looking forward to the return of the IEEE COMCAS event in Tel Aviv in November. *Microwave Journal* will be coordinating the Publicity for COMCAS, so look for updates as the year progresses.

EDI CON China has moved to the new China National Convention Center in Beijing this year. The event will take place on April 14–16 and features a larger exhibition and expanded conference, with a 5G track added to the schedule. Many of the leading test and measurement, semiconductor and component manufacturers will be showcasing their products and technologies on the show floor and in the conference through submitted papers and workshops. This event is unique in that it is industry-driven, with practical information for working engineers. The conference and exhibition are synergistic and focused on the needs of the audience.

Looking further ahead, I'm pleased to announce that the EDI CON event will make its debut in the U.S. next year. We're taking the model that has proven so successful in China to Boston in September, 2016. We have the perfect venue, in the heart of the city, during the nicest time of the year in New England. That's right – you can come to Boston, learn the latest design techniques and technologies while enjoying the local attractions of Boston and the spectacular fall foliage. Stay tuned for more details during the year.

This issue of *Microwave Journal* has an editorial focus on "Radar and Antennas," featuring a very interesting cover story on "Wideband Omnidirectional Microwave Cloaking." The Romulans would be proud of the work of author Nathan Cohen of Fractal Antenna Systems. Also featured is the third and last in the special report series from distinguished authors Ulrich Rohde and Ajay Poddar on their research on Möbius Metamaterial and Strip Resonators. This series of articles has generated a lot of attention and positive feedback from our readers. In the MVP, CST unveils its "STUDIO SUITE 2015" and the lineup of technical features includes several theme-related topics. There's something for everyone, including a recap of our recent visit to the "new" Keysight Technologies headquarters.

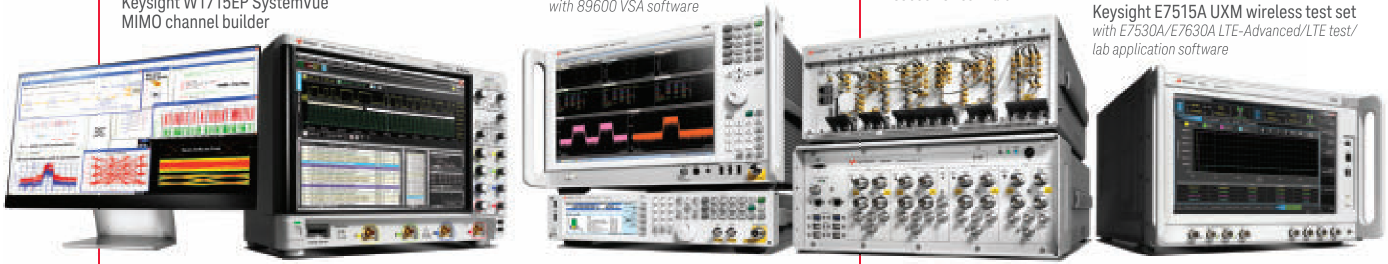
Thanks for reading and wishing all of you a successful year ahead! ■

Keysight W1715EP SystemVue MIMO channel builder

Keysight N9040B UXA signal analyzer
*with 89600 VSA software*

Keysight MIMO PXI test solution
*with N7624/25B Signal Studio software for LTE-Advanced/LTE FDD/TDD and 89600 VSA software*

Keysight E7515A UXM wireless test set
*with E7530A/E7630A LTE-Advanced/LTE test/lab application software*



Keysight Infiniium S-Series high-definition oscilloscope
*with N8807A MIPI DigRF v4 (M-PHY) protocol decode software*

Keysight N5182B MXG X-Series RF vector signal generator
*with N7624/25B Signal Studio software for LTE-Advanced/LTE FDD/TDD*

Keysight E6640B EXM wireless test set
*with V9080/82B LTE FDD/TDD measurement applications and N7624/25B Signal Studio software for LTE-Advanced/LTE FDD/TDD*

## HARDWARE + SOFTWARE

The more complex your LTE-A design, the more you need help from test and measurement experts. Keysight is the only company that offers benchtop, modular and software solutions for every step of the LTE-A design process. From R&D to manufacturing, we can give you the expertise, instruments and applications you need to succeed.

- *Complete LTE-Advanced design and test lifecycle*
- *Identical software algorithms across platforms*
- *300+ software applications for the entire wireless lifecycle*

## PEOPLE

We know what it takes for your designs to meet LTE-A standards. After all, Keysight engineers have played major roles in LTE-A and other wireless standards bodies, including 3GPP. Our engineers even co-authored the first book about LTE-A design and test. We also have hundreds of applications engineers. You'll find them all over the world, and their expertise is yours for the asking.

- *Representation on every key wireless standards organization globally*
- *Hundreds of applications engineers in 100 countries around the world*
- *Thousands of patents issued in Keysight's history*

KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights


COVER FEATURE
INVITED PAPER

# Wideband Omnidirectional Microwave Cloaking

Nathan Cohen
*Fractal Antenna Systems, Bedford, Mass.*

***Scattering from electrically large objects invites discussions of Mie versus Rayleigh, shadows and diffraction, side scatter and backscatter. But one attribute remains infrequently discussed: forward or "front" scatter. Antipodal transmission, the continuation of the transmitted wave with fidelity to the other side, is a puzzle posed by blockage and failure to find a way to fully propagate waves around it. If robust front scatter is possible, and the surface orientation is not prescriptive, the object itself becomes hidden, cloaked by the mirage of the environment on the other side. The object is invisible. Such a phenomenon is not a natural occurrence and requires new technology to approximate and achieve realization.***

While invisibility has always been a fantasy of fiction for many,[1] engineering has developed limited alternatives with camouflage or stealth methods that absorb, reflect or directionally side-scatter waves to block the appearance of objects and render them less visible.[2,3] Although many of these methods are ambiguously described as cloaking, they do not uniformly propagate front scatter without a preferential orientation, nor do they employ front scatter as a dominant mechanism. This article summarizes the results of the first true cloaking,[4-6] demonstrating microwave cloaking with wideband performance, a dramatic decrease of side and backscatter, no preferred angular orientation in azimuth and robust front scatter.

## EVANESCENT SURFACE WAVES

Applications of the near field still render some surprising advantages, the most recent being associated with evanescent surface waves (ESW), also called plasmonics.[7,8] ESWs are produced by impinging radiative traveling waves upon resonators and dielectrics in close electrical proximity to conductors, including other resonators. By their nature, ESWs dominate electromagnetic transmission with close resonators, usually with less than $\lambda/10$ separation. Electromagnetic waves jump from one resonator to the next and remain on the surface. When such circuits are closely packed, they are also called metamaterials, whereas when they are more widely spaced, they have limited ESW transmission and are often called frequency selective surfaces.[9] Metamaterial performance has previously been limited by the footprints and passband responses of the resonant structures used, which are typically split ring resonators. Such resonators are high Q but moderate in size, thus constraining their packing ability and limiting the efficiency of ESW transmission.

Fractals offer a unique opportunity as antennas and resonators, based on their multiband or broadband performance, small size, absence of LC components and efficiency.[10-12] A good example with an excellent tradeoff of

# CoverFeature

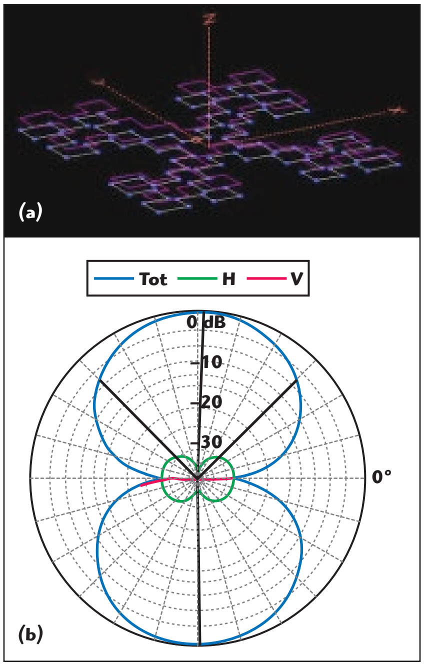



*Fig. 1 Minkowski loop fractal antenna model with amplitude of the two current maxima (a) and power pattern at lowest resonant frequency (b). Gain is within 0.2 dB of a dipole (copper losses included).*

characteristics is a Minkowski fractal antenna,[10] shown in ***Figure 1***. The small footprint, about λ/8 on a side at the lowest resonant frequency, yields a highly efficient figure-eight dipole pattern with excellent polarization integrity. It also has multiple non-harmonic resonances that make a "passband meld" for broader bandwidth at the lower frequencies and a continuous broadband characteristic at higher frequencies.[13-15] Thus, it has been used in close packed arrays, where ESWs are expected to be important.

ESWs on a fractal array were first demonstrated in 2001.[16] This is reproduced in ***Figure 2a***, showing a 3 × 3 array of Minkowski fractal elements[10] shaped as loops that is corporate fed with an element spacing of about λ/14. Each element falls within a footprint of approximately λ/8 at the lowest resonant frequency, and the array is offset slightly in azimuth to facilitate measurements on the plane. A metal backplane with roughly λ/8 air dielectric separation is behind the array, acting as the boundary condition required in plasmonics to give rise to ESWs.

The azimuthal power pattern (see ***Figure 2b***) is notable as showing super gain, but the interest here is focused on the 90 degree lobes. These

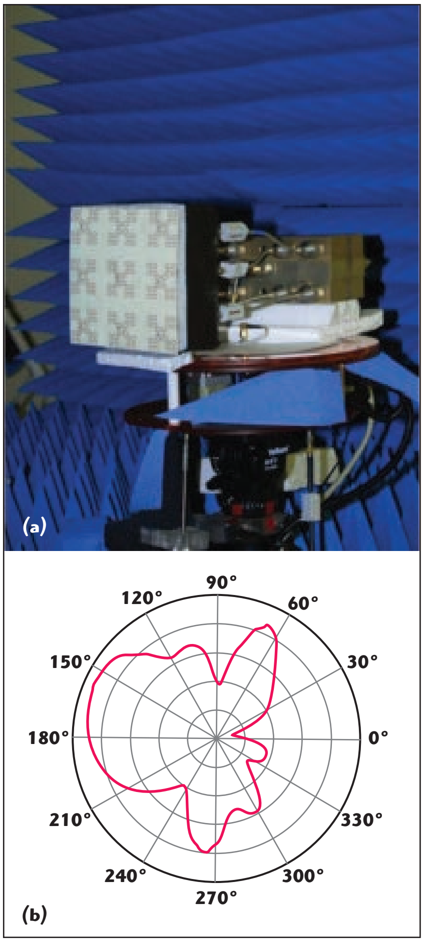


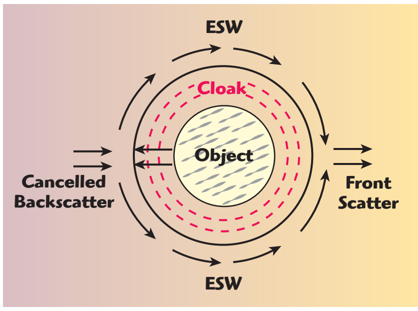

*Fig. 2 Fractal array (a) and power pattern with ESW lobes (b).*

lobes are caused by ESWs with intensities that rival those of the main lobe. The ESWs terminate at the array edge and become propagated radiated waves.

This demonstrates that for close packing, less than λ/10, ESW effects become appreciable in fractal metamaterial arrangements. It also shows that fractal structures, being far smaller than conventional designs and with no additional components attached, are natural to use if these effects are desired. The strong ESWs from these fractal metamaterials poses an opportunity to explore applications where ESWs may be needed, including cloaking.

## RECIPE FOR A CLOAK

A cloaking mechanism must have the ability to passively guide far field traveling waves around an object or utilize ESWs to do so. Mirrors and lenses can be used to satisfy the former, but like the magicians' invisibility illusion, they require very specific




▲ *Fig. 3 Cloak concept showing front and back scatter.*

orientations or cannot entirely hide the blocked object. A cloak exploiting ESWs does not suffer from these hindrances.

Far field traveling waves impinge on a metal-backed metamaterial, producing ESWs. Care should be taken so that the resonators are wideband and closely packed (that is, a fractal metamaterial). The metamaterial array, which can be constructed in closed-surface layers, cloaks the object housed within the metal backing, for example, a metal cylinder. Any object of any composition may be considered cloaked inside that region. In addition, when properly spaced, the far field traveling wave reflects in backscatter and combines out of phase with its own impinging wave, yielding phase cancellation. There is also an attenuation of side scatter, as the ESW propagate on the surface, with little, if any, radiating wave in the far field.

If the cloak's surface is closed, then at the antipodes of the impinging wave, the ESWs combine and produce a radiating traveling wave emerging from the plane of the surface in a reversal of their production. With no impinging radiating traveling wave on the "front" side, the produced radiating traveling wave does not have a second wave with which to combine and phase cancel. It constitutes front scatter of the wave which impinged from the opposite side, as shown in ***Figure 3***.

From a construction standpoint, a cloak is thus a closed surface structure composed of an array of fractal metamaterials, dielectric and a metal inner sheet. ***Figure 4*** shows the outer layer of a simple two-layer cloak. Note the closely packed Minkowski fractal resonators, with a slight modification to the design for better packing. Material and structural information is given in ***Table 1***.

▲ *Fig. 4 Outer layer of a simple two-layer cloak for microwaves.*

**TABLE 1**

**CLOAKING LAYER MATERIAL AND STRUCTURAL INFORMATION**

| | |
|---|---|
| Material | RF35 PCB with Minkowski fractal traces |
| Separation of layers | 1 inch |
| Height | 15.3 inches |
| Outer diameter | 11 inches |
| Spacer dielectric | Air foam |
| Object diameter (max) | 6 inches |
| Fractal loop | Modified Minkowski[5] |

Other phenomena support this cloaking approach. For example, Chandran, et al.,[17] reported highly reduced backscatter in metal-backed fractal surfaces, evidence for reflected and impinging radiated wave cancellation during backscatter. This reflection approach is an extrapolation of Jaumann absorbers, but the ease of realization with fractal structures was not anticipated.

A cloak attempt by Schurig, et al.,[18] demonstrating a lossy, high Q device with moderate shadowing, is believed to result from transformational optics. Transformational optics must be considered a generic term without invoking a specific radiative transport mechanism, and ESW transport falls within that category. Yet the failure of that device to exclude diffraction as a mechanism for the attenuated, narrowband front scatter leaves the success of that as a bona fide cloak ambiguous.[19]

## SIMPLE CLOAK

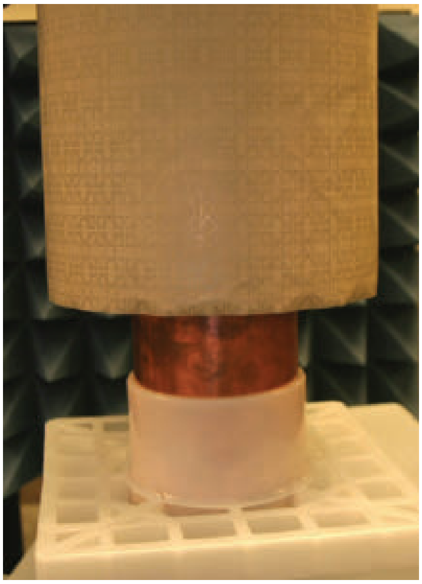
Before advanced cloaks with precise imaging properties and visual light abilities (the fantasy of science fiction) are realized, it is necessary to demonstrate the ability to produce even the simple cloak illustrated in Figure 3. The approach is to use the microwave spectrum for construction simplicity of electrically thin cloak layers and a simple closed-surface geometry. First accomplished in 2008,[4,5] this version of the simple cloak is sufficiently large to cloak 3D objects and to accomplish measurements with L-Band equipment.

Structural symmetry is not a restriction for cloaking: only a closed surface is needed to assure antipodal transmission of front scatter. However, for illustration, cylindrical symmetry limits the number of variables which might otherwise obscure understanding the ESW effects. Thus the results will be independent of the azimuthal rotation of the cloak itself: there is no specific requirement of preferred azimuthal alignment.

Measurement employs two log periodic antennas at sufficient separation so that the cloak fills the beam vertically.[6] Since the horizontal portion of the beam is far wider, the cloak cannot fully fill the beam in that direction, so some coverage extends beyond the cloak, limiting the degree of blockage by an object to be cloaked and the dynamic range to roughly 25 dB or less. Polarization is taken as linear vertical, with the cloak oriented as a vertical cylinder. The cloak is electrically large, and the lower cutoff is limited to 700 MHz, where the height is approximately one wavelength.

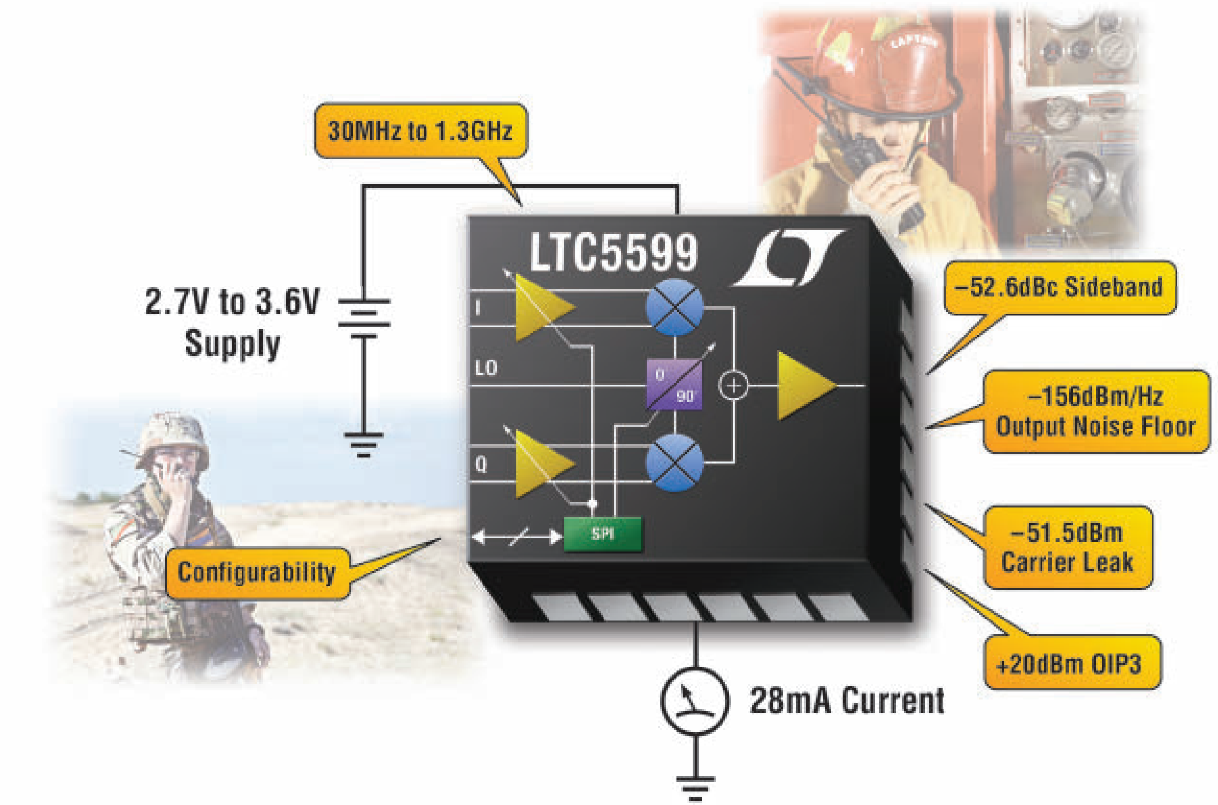
A vector network analyzer made the S12 measurements. All gain data is normalized to the direct path, that is, two antennas on opposite sides of the cloak's center position (zero degrees in azimuth) with no blockage or cloak present. While these measurements are with the vertical polarization along the major axis of the cloak, the loop configuration of the fractal metamaterial resonators is agnostic to polarization orientation.

With no cloak or other objects present, this yields a 0 dB reference line at all frequencies. Then the cloak is introduced, using an internal metal pipe to be cloaked, as an example. This is shown in ***Figure 5*** (see video at www.



▲ *Fig. 5 Placing the cloak over a metal cylinder (pipe) to be cloaked.*

# 90mW I/Q Modulator



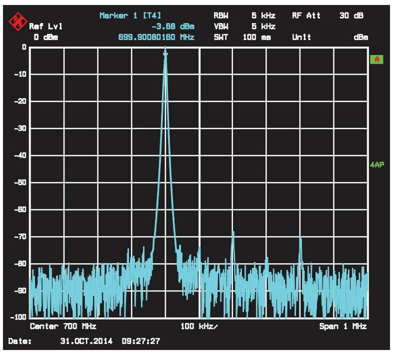

Powered from a single supply from 2.7V to 3.6V, the LTC®5599's 28mA supply current extends battery run time. The modulator offers superb –52.6dBc sideband and –51.5dBm carrier suppression—without the need of calibration. Its low noise floor of –156dBm/Hz and 20dBm OIP3 capability ensure outstanding transmitter performance. The LTC5599's built-in configurability allows users to optimize performance from 30MHz to 1.3GHz, minimizing external components and saving costs.

## Features

Built-in Configurability Features:

- Gain Adjustable from 0dB to –19dB, with Supply Current Change from 35mA to 8mA
- Improves Sideband Suppression from –52.6dBc to –60dBc
- Reduces Carrier Leakage from –51.5dBm to –60dBm

**Output Spectra (Optimized)**




## Info & Free Samples

www.linear.com/product/LTC5599

1-800-4-LINEAR

www.linear.com/solutions/5429

**SIDEBAR**

### First Person Cloaked

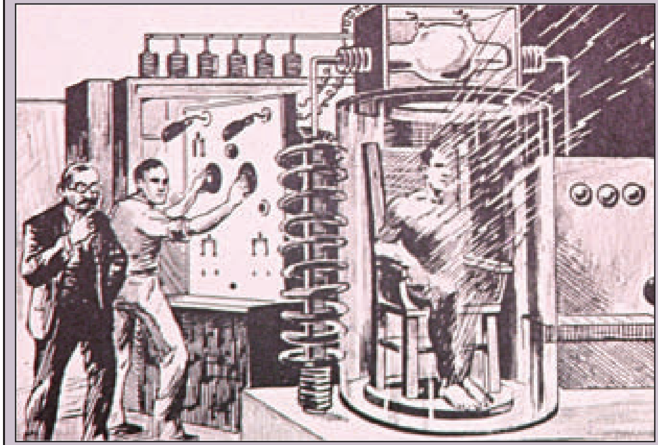
To the general public, rendering a person invisible is the stuff of Star Trek, Harry Potter and H.G. Wells (see ***Sidebar 1***). But beyond the dreams and fantasy, the quest for human invisibility poses technical challenges and compelling examples of electromagnetics. Furthermore, it sets the bar for future cloaking efforts.

In August 2012, to commemorate the issuance of the world's first true invisibility cloak patent and serve as a symbol that the path of this new field rests on the shoulders of those who grew up during the wireless revolution, the team at Fractal Antenna Systems scaled up a two-layer microwave cloak to make an engineering intern disappear (see ***Sidebar 2***).

The human cloak, illustrated in ***Sidebar 3***, is electrically larger in size, has a larger cloaking volume, a greater signal to noise ratio and higher fidelity, compared with the smaller cloaks previously built. It simply consists of a thin copper cylinder, two fractal metamaterial layers, air foam spacers and an RF transparent support structure.

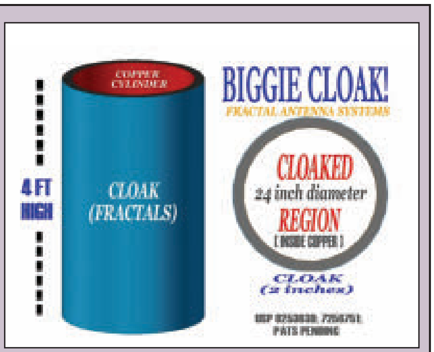
***Sidebar 4a*** shows the direct path with no obstruction (dotted line) compared with the intern crouched and blocking the path of radiation (solid line). ***Sidebar 4b*** compares the same direct path to the path with the cloak placed over the crouching intern. Note the transmission "through" the intern (solid line), demonstrating ESW-enabled front scatter with the cloak on. The intern has "disappeared" over a broad frequency range centered at 1 GHz.

**Visit www.mwjournal.com/cloaking for more demos.**

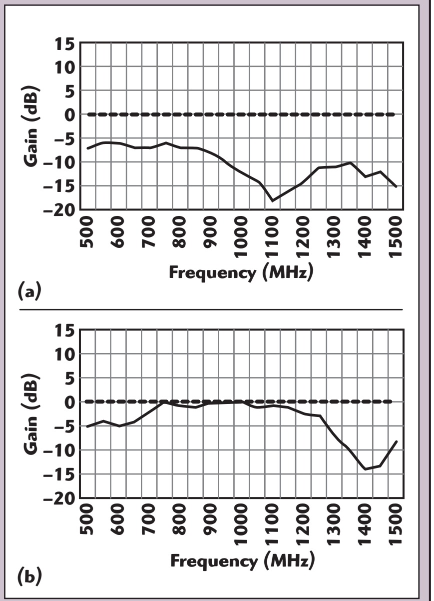


▲ *Sidebar 1  1930s pulp sci-fi illustration shows a man in a cylinder dematerializing and becoming invisible.*

▲ *Sidebar 2  Cloaking of an engineering intern.*




▲ *Sidebar 3  Design of a large cloak.*




▲ *Sidebar 4  Scattering responses of the uncloaked intern compared with the direct path (a) and the cloaked intern compared with the direct path(b).*

mwjournal.com/cloakingvideo1). The pipe alone blocks the signal by more than 10 dB at some frequencies. With the cloak covering it, however, front scatter gain is returned to 0 dB over a broad frequency range from about 700 to 1400 MHz. The cloak diverts transmission around the pipe and produces front scatter.

The cloak performs the same under rotation, with both antennas fixed on opposite sides. The rotation of the cloak in azimuth, with the antennas held stationary, produces virtually no change to the front scatter gain, as expected. There is no preferred orientation in azimuth. This, along with dramatic enhancement of front scatter and reduction of side and backscatter are the key characteristics of true cloaking.

As in all experimental measurements, a control is essential. Here, it is the replacement of the entire cloak by a metallic 'copper' cylinder of the same size. In the video, this is done by covering the outer cloak layer with aluminum foil. For multiple measurements at different azimuthal angles of the two antennas, a copper-clad cylinder control is placed next to the cloak itself (see ***Figure 6***).

The data shows the effects of the cloak on front scatter and backscatter. Starting with the control 'copper' cylinder directly blocking the direct path between the two antennas, we expect the front scatter to be greatly reduced, and the backscatter to be greatly enhanced from specular reflection. In such measurements the antennas are on opposite sides of the

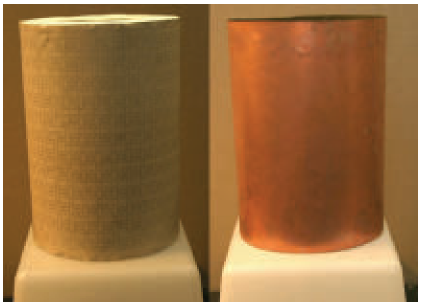


Fig. 6 Cloak (left) and copper cylinder used as a control (right).

cloak or copper for front scatter, and next to each other, on the same side, for backscatter. Again, using the direct path normalized at 0 dB, the response of the control for front and backscatter is shown in ***Figure 7***. As expected, backscatter is present, approaching a gain nearly that of the direct path, while the front scatter is significantly lower.

Placing a cloak with the pipe as an object in place of the control cylinder yields the exact opposite; backscatter is reduced and front scatter is enhanced (see ***Figure 8***). Front scatter now closely tracks the direct path intensity over a frequency range of approximately 700 to 1400 MHz, a 2:1 bandwidth. In other words, we are are "seeing through to the other side" with excellent amplitude fidelity. Note that the backscatter is dramatically reduced from about 700 to 950 MHz, with a minimum at about 825 MHz. The Q is higher (about 30 percent bandwidth) for the backscatter because the reflected traveling wave has only one main layer to reflect from; additional fractal metamaterial layers would substantially increase the bandwidth to minimize back scatter.

With the minimum backscatter at 825 MHz, a full azimuthal scan of the antenna at that frequency is useful to compare the overall scattering behavior of the cloak versus the control. Because the log periodic antennas have wide beams, baffles were used to suppress off-angle coupling and measurements were done by moving one antenna in 30 degree steps, starting with the direct path at zero degrees. The cloak and control, when measured, do not change their positions; only the antenna angles relative to the center point of the cloak's placement change.

To understand how these measurements relate to scattering, side scatter is sampled at angles near 90° and 270°, while backscatter is near 180°;

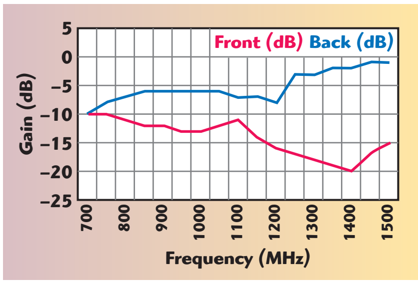



Fig. 7 Front and back scatter measurements of the copper cylinder used as the control.

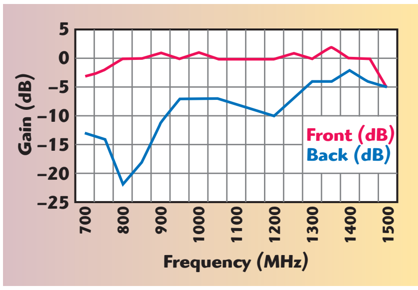



Fig. 8 Front and back scatter measurements of the cloak with internal pipe.

and front scatter is near 0° in azimuth. The values at 180° are approximated to be 183° and 177°, respectively, as the baffle prevents the two antennas from being placed at the same position simultaneously.

The two antennas without any cloak or obstruction are measured over the full azimuthal range of their differential angular placement (direct). This represents the response of the antenna system, with the baffles and other (minor) reflections present, without a blocking object, cloak or control. Next, at each differential azimuth angle, the cylinder (copper) and then cloak-on-pipe (cloak) are measured, yielding a total of three measurements per azimuth sample. This allows an unbiased comparison of the cloak and copper. A polar plot of the data is shown in ***Figure 9***.

The cloak scattering response closely matches that of the azimuthal response of the antennas alone, without any cloak or obstructions. The front, back and side scatter all act as if there is nothing there. In contrast, the copper control shows very little front scatter (as in Figure 6), and substantial side and back scatter. The lobe-like pattern is produced by the variation in response from baffle placement with changing azimuth. A marked difference between the control and the cloak, with a close match of the cloak to the direct measurement, is compelling evidence for cloaking by the enhancement of front scatter and the reduction of side and backscatter.



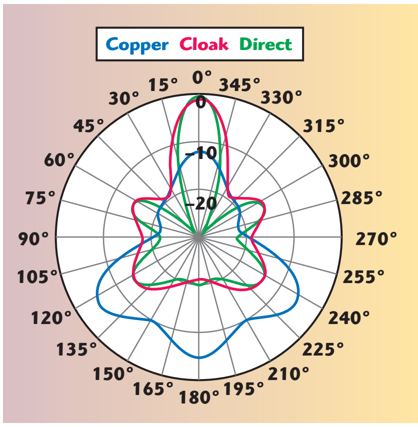
## NEXT STEPS

This simple cloak establishes the value of using ESWs for cloaking with fractal arrays as the enablers. With cloaking realized, questions and issues become varied and numerous. In fact many have already been addressed by the author and will be discussed in future publications. It is helpful to enumerate these issues as next steps.

**Large object, thin cloak:** Much larger microwave cloaks have been built and function successfully. The largest cloak yet devised successfully cloaked a person, realizing H.G. Well's historic fantasy.[6] The sidebar (see page 32) describes that effort. The cloak is a thin skin on a large cloak because the cloaking layers depend on wavelength separation, not scaled-size ratios.

**Tunneling and object-view non reciprocity:** Seeing out of a cloak from inside is not the reciprocal action of external cloaking. However, having a copper or metal barrier certainly stops the action. This has been overcome with a fractal screen as the inside barrier rather than a solid metal sheet.[20]

**Reduced backscatter and op-**




▲ *Fig. 9 Azimuthal scattering from the control and the cloak.*

**timization:** Cloaking may achieve wideband and significant backscatter reduction by optimizing the cloak parameters and by adding layers. This awaits a defined need.

**Diverted imaging:** Antipodal transmission implies origin symmetry of the image. Whether this will limit cloaking, ultimately, as an optical camouflage method will depend on the understanding of cloaking as an imaging system, rather than the radiometric one discussed here.

**Non-symmetric surface cloaking:** Surface symmetry (as in cylinders or spheres) is not a requirement for cloaking and cloaking with asymmetric surfaces has been demonstrated.[20]

**Visual light and infrared cloaking:** The patterning of resonators is easily achieved at infrared wavelengths but this may prove challenging at optical wavelengths for any large surface. Additional manufacturing developments may warrant interest in the "Harry Potter" effect when this is achieved.



## CONCLUSION

The first true cloaking system uses ESWs to produce substantial front scatter over a wide bandwidth and reduced backscatter and side scatter, with no preferential angular orientation of the cloak's surface. Far from science fiction, the world of invisibility looms ahead, neither blocked by an absence of mechanism nor totally transparent in its use and implications.■

### References


1. H. G. Wells, "The Invisible Man," Pearson, London, 1897.
2. K. Vinoy and R. Jha, "Radar Absorbing Materials," Kluwer, Boston, 1996.
3. G. Ruck, D. Barrick, W. Stuart and C. Krichbaum, "*Radar Cross Section Handbook*," Plenum, New York, 1970.
4. N. Cohen, "Fractal Antennas and Fractal Resonators," U.S. Patent 7,256,751, 2007.
5. N. Cohen, "Wideband Electromagnetic Invisibility Cloak," U.S. Patent 8,253,639, 2012.
6. N. Cohen, "Body-Sized Wideband High Fidelity Invisibility Cloak," *Fractals*, Vol. 20, November 2012, pp. 227–232.
7. R Maier, *Plasmonics*, Springer, New York, 2007.
8. S. Zoughi, A. Sihvola and A. Vinogradov, "Metamaterials and Plasmonics: Fundamentals, Modelling, Applications," Springer, Dordtrecht, 2008.
9. B. Munk, "Metamaterials: Critique and Alternatives," Springer, Dordtrecht, 2008.
10. N. Cohen, "Fractal Antennas Part 1", *Communications Quarterly*, Vol. 5, No. 3, Summer 1995, pp. 7–22.
11. N. Cohen, "Fractal Antennas and Fractal Resonators," U.S. Patent 6,452,553, 2002.
12. A. R. Harish, A. Agarwal, N. Kuchhal and V. Jain, "Compact Loop Antennas and Arrays," *Proceedings of the International Conference on Antenna Technologies*, 2005, pp. 531-535.
13. N. Cohen, "Fractal Antennas Part 2," *Communications Quarterly*, Vol. 6, No. 3, Summer 1996, pp. 53–66.
14. N. Cohen, "Practical Introduction to Fractals: Antennas and Beyond Part 1," *Proceedings of the Radio Club of America*, Spring 2014, pp. 12–18.
15. A. Raveendran, "A Study on Minkowski Fractal Wideband and Multiband Antenna," M.S. thesis, Texas A&M University, 2012.
16. N. Cohen and R. Hohlfeld, "Close-Packed Fractal Antenna Array," AFRL/SNRT Contracts F30602-02-M-V042V-034, 2002.
17. A. R. Chandran, T. Matthew, C. K. Aanandan, P. Monahan and K. Vasudevan, "Low Backscattered Dual-Polarized Metallo-Dielectric Structure Based on Sierpinski Carpet," *Microwave and Optical Technology Letters*, Vol. 40, No. 3, February 2004, pp. 246–248.
18. D. Schurig, J.J. Mock, B.J. Justice, S. A. Cummer, J.B. Pendry, A.F. Starr and D.R. Smith, "Metamaterial Electromagnetic Cloak at Microwave Frequencies," *Science*, Vol. 314, No. 5801, November 2006, pp. 977–980.
19. J. B. Pendry, D. R. Smith and D. Schurig, "Electromagnetic Cloaking System." U.S. patent application 20080024792 (examiner's comments in rejection), 2008.
20. N. Cohen, "Additional Advances in Cloaking Using Fractal Resonators," in preparation, 2015.

# Synthesis and Simulation Converge in CST STUDIO SUITE 2015

CST – Computer Simulation Technology

Simulation helps engineers analyze and optimize products, while synthesis software helps them select and create designs. Alone, these are powerful tools for the development of any electromagnetic device. Combined, they complement and strengthen each other. With the release of the CST STUDIO SUITE® 2015, synthesis, design and optimization are now more tightly integrated into the simulation workflow.

New design tools for filter synthesis, phased array creation and decoupling capacitor optimization supplement the tight integration with the antenna synthesis tool, Antenna Magus, and the matching circuit synthesis tool, Optenni Lab. New, fully parametric import options from leading computer-aided design (CAD) software allows CST STUDIO SUITE to be integrated into a wide range of external workflows.

## PHASED ARRAY WIZARD

Although complex to design, phased arrays offer excellent performance and beam steering. For engineers working on array design, CST STUDIO SUITE 2015 introduces the Phased Array Wizard. This tool helps design both the individual element and the full array layout, in a single smooth workflow.

First, a unit cell simulation calculates the performance of the individual elements, including the active element impedance and pattern. These are used to optimize the element across all scan angles and frequencies, and array performance is estimated from the array factor.

Once the element is designed, the full array is created. The user defines the excitation and layout, including passive elements, and the Phased Array Wizard automatically creates a full 3D model of the array, including the feed, mounting brackets and radome. The simulation also produces a field source for analysis of installed performance.

## FILTER DESIGNER 2D

The recent addition of Filter Designer 2D (FD2D) to CST STUDIO SUITE significantly improves planar filter design. FD2D is based on trusted, mature filter synthesis technology from Nuhertz and is directly integrated into CST STUDIO SUITE. The user specifies the filter requirements, and FD2D recommends suitable topologies. Users compare these suggestions to find the filter type that best suits their needs.

Once the filter is selected, FD2D automatically exports the filter schematic directly into the simulation project. Filters can be integrated into larger devices and simulated with the circuit simulation tools included in CST STUDIO SUITE. Planar filters can be automatically assembled in full 3D, allowing users to fine tune the design, investigate installed performance and calculate thermal detuning.

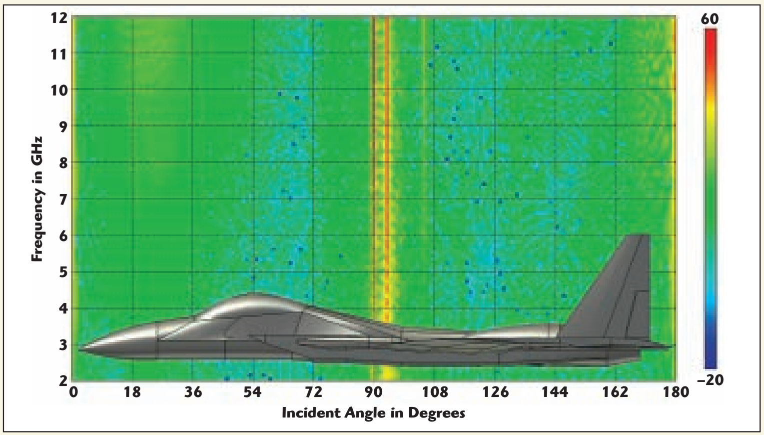
## PARAMETRIC IMPORT TOOLS

Increasingly, CAD tools are becoming full project managers, capable of storing vast amounts of information about the design project. To improve integration with these powerful tools, CST STUDIO SUITE 2015 supports fully parametric import from SOLIDWORKS 2013 and PTC Creo™ Elements™ 5.0. Models that are imported include the design parameters that have been defined, making it easier to incorporate simulation into the design process.

## COMPLETE NEAR FIELD SOURCE COUPLING

Excitation using near field sources to the frequency domain solver and the asymptotic

CEL
INTRODUCING
TOKYO KEIKI
CUSTOM RF PRODUCTS
Delivering High Quality & Performance
5 CLEANROOMS
JIS-Q9100 CERTIFIED FACTORY
AS9100 U.S. EQUIVALENT
X-Band
100 W
GaN Power AMP
Best in Class
Bring us your challenging specs
Lumped Element Filter
High Power Amplifier
Directional Coupler
Monitor
Broadband Amplifier
PIN Diode Switch
VCO/Synthesizer
Power Divider
Cavity Filter/Duplexer
Low Noise Amplifier
Balanced Mixer
Filter
Amp
Mixer
HPA
Divider
CEL
TOKYO KEIKI
Scan code to learn more or visit:
www.cel.com/TK-MJ




▲ *Fig. 1 RCS map for an aircraft.*

solver is included. This means all of the general-purpose high frequency solvers in CST STUDIO SUITE are fully compatible, enabling hybridized simulation for a wide range of applications.

For example, it is now possible to use inward-facing near field sources from a complex device to irradiate a single component in the frequency domain solver or to use the near field of an antenna as the excitation for an installed performance simulation using the asymptotic solver. Measured near field sources can be used with these solvers, allowing physical components to be incorporated into virtual prototypes.

## RADAR CROSS SECTION

Radar cross section (RCS) has long been a major application for CST STUDIO SUITE, and the 2015 release introduces several new features that further increase RCS capabilities. The asymptotic solver now supports frequency, angle and polarization dependent radar absorbing material (RAM), allowing these coatings to be simulated more accurately.

The solvers now automatically produce RCS maps – plots of RCS versus incident angle and frequency, as shown in ***Figure 1*** – that help identify the causes of scattering.

## PCB SIMULATION

When designing PCBs and packages, a full 3D simulation is often necessary to understand the behavior of the board, components and housing. Discretizing a complex multilayer board accurately is time consuming, so a new tetrahedral meshing technique optimized specifically for printed structures has been developed. This algorithm intelligently identifies and meshes standard structures such as signal lines, reference planes and vias. For complex packages, it can reduce meshing time by more than 85 percent.

Also, the placement of decoupling capacitors can now be optimized automatically with the Pareto frontier optimizer (see ***Figure 2***). This balances cost with performance and helps find the most cost-effective solution to power integrity issues.

## QUAD MESHING

The integral equation solver and the multilayer solver, respectively used to simulate electrically large and planar structures, have improved performance due to the new quad-based surface mesh. Using quadrilaterals instead of triangles, the new mesh reduces the number of unknowns and reduces simulation time.

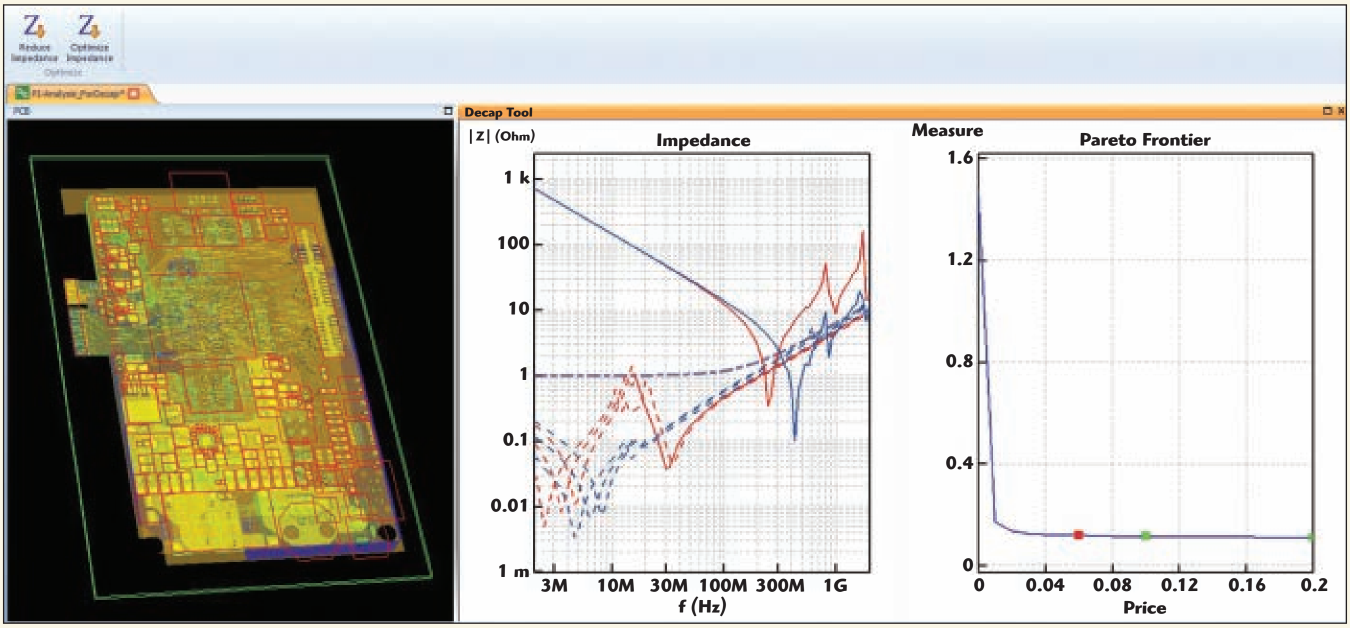
## HIGH PERFORMANCE COMPUTING

Support for the Intel® Xeon Phi™ hardware acceleration family and for high-performance cluster storage increases the high performance computing capabilities of the 2015 release.

CST STUDIO SUITE 2015 introduces a range of new features that make synthesis, simulation and optimization of designs more efficient. All of these are built into CST STUDIO SUITE, broadening its capabilities while maintaining the familiar user interface.

**VENDORVIEW**

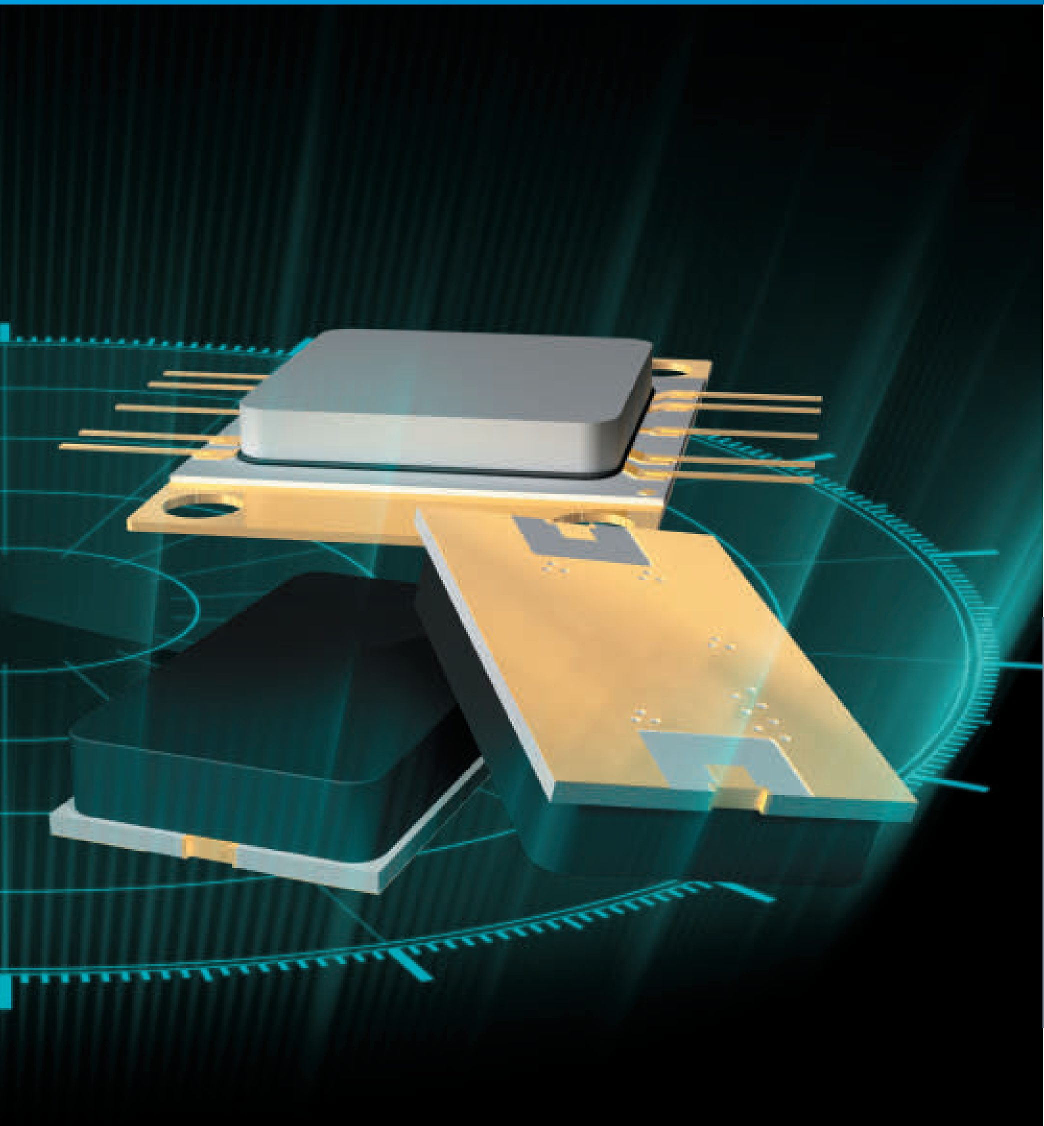
**CST**
**Computer Simulation Technology**
**www.cst.com**




▲ *Fig. 2 The decap optimization tool, showing the circuit board (left), impedance curves for several decoupling capacitor configurations (center) and the Pareto frontier (right).*

# Protecting your radar system just got a whole lot easier.

The most important thing we build is trust



New high power surface mount limiters from Cobham Metelics are making your receiver/ protector sections a whole lot easier to design. These drop-in devices include 11 completely integrated components that have been optimized for L, S, and C band radar systems. In comparison to silicon and GaAs MMICs, which lack thermal capacity and thermal conductivity, these devices offer stable peak power handling through 8 GHz.

- **Frequency bands from 20 to 8000 MHz**
- **100 W CW and 1 kW (SMT) Peak Power**
- **200 W CW and 2 kW (Hermetic) Peak Power**
- **Flat Leakage Power of 20 dBm**
- **8 x 5 x 2.5 mm SMT Packaging**

We've put our semiconductor experience to work in developing a variety of broadband and octave band models. Call or visit our website for details.

**Cobham Metelics**
888-641-7364
www.cobham.com/Metelics

**High Power Surface Mount Limiters**

| Part Number | Type | Frequency (MHz) | Loss (dB) | CW Power (W) |
|---|---|---|---|---|
| LM200802-M-A-300 | Medium Power Broadband | 20-8000 | 1.4 | 20 |
| LM501202-L-C-300 | Octave Band, Low Power | 500-2000 | 0.4 | 4 |
| LM501202-M-C-300 | Octave Band, Med Power | 500-2000 | 0.6 | 30 |
| LM202802-L-C-300 | Octave Band, Low Power | 2000-8000 | 1.0 | 4 |
| LM202802-M-C-300 | Octave Band, Med Power | 2000-8000 | 1.2 | 30 |
| LM401102-Q-C-301 | Octave Band, High Power, "Quasi-Active" | 400-1000 | 0.3 | 100 |
| LM102202-Q-C-301 | Octave Band, High Power, "Quasi-Active" | 1000-2000 | 0.5 | 100 |
| LM202802-Q-C-301 | Octave Band, High Power, "Quasi-Active" | 2000-8000 | 1.4 | 100 |
| LM401402-Q-D-301 | Decade Bandwidth, High Power | 400-4000 | 0.75 | 50 |

*Cobham Metelics formerly Aeroflex / Metelics*

TRUST • TALENT • TECHNOLOGY
80 YEARS
COBHAM 1934 - 2014

**DefenseNews**
Cliff Drubin, Associate Technical Editor

## Global Military Radar Market Continues Growth Trajectory

Early warning and surveillance along with fire control radars will account for about 76 percent of the global military radar market between 2013 and 2023, with the total market growing to over $18.5 billion, according to Strategy Analytics Advanced Defense Systems (ADS) forecasts covering the global military radar market. The forecast includes expenditure and system shipments across land, air, sea and space domains.

North America will continue to represent the largest regional end market, but the fastest growth will be exhibited by demand from the Asia-Pacific region. Airborne radar will represent the largest market, both in dollars and total shipments. L, S and C-Bands will represent the largest market followed by radars operating at X-Band, reflecting the primary frequencies used by surveillance/early warning and fire control radars.

> "The associated market for semiconductors and other components will grow from $1.2 to $2.1 billion with GaN becoming an established technology..."

"The total number of radar shipments is forecast to grow at a CAGR of 4.1 percent through 2023, reaching 1393 units," notes Eric Higham, North American director for ADS. "Fire control radar shipments will continue to dominate the traditional mix, but the fastest growth in shipments will come from emerging platforms such as unmanned systems as well as new radar system types".

"The associated market for semiconductors and other components will grow from $1.2 to $2.1 billion, with GaN (gallium nitride) becoming an established technology as it grows at a CAGR of 26.4 percent and finds use across all radar systems," added Asif Anwar, ADS director at Strategy Analytics.

## Need for High Throughput Connectivity in Defense Drives Global Satcom Applications

The demand for high throughput military satcom (MilSatCom) applications is growing as the use of unmanned aerial systems and implementation of command, control, communications, computers, intelligence, surveillance and reconnaissance of C4ISR systems increase. High throughput satcom applications can support imagery streaming and seamless connectivity across tactical and strategic networks – capabilities which have become vital in the military space.

New analysis from Frost & Sullivan, "Analysis of the Global Military Satcom Applications Market," finds that the market earned revenues of $3.05 billion in 2013 and estimates this to reach $3.82 billion in 2022. The study covers manpack/handheld, ground vehicle, air platform, naval platform mounted and fixed MilSatCom applications.

"To support MilSatCom suppliers and service providers, governments and commercial operators are launching high throughput satellite systems which are driving Ka-Band capacity," said research analyst Arun Kumar Sampathkumar. "Currently, unused satellite spectrum capacity is delaying the migration to high throughput frequencies, hence lowering MilSatCom hardware expenditures. As military users migrate to Ka bandwidth and Internet protocol (IP)-based strategic military communication networks, spending on MilSatCom will rise."

Globally, spending is focused on upstream spectrum procurement. As a result, spending on hardware upgrades will go up in the coming decade and stimulate the use of MilSatCom applications.

With the recent amendment to the United States Defense Authorization Act, which necessitates the adoption of a long-term strategy for commercial spectrum procurement, the market will continue expanding. Hardware manufacturers are planning to offer multi-band satcom terminals to meet the upgrade trend, while allowing users to operate across existing and upcoming capacities.

> "Strong opportunities for MilSatCom suppliers will come from the Middle East and Asia-Pacific markets, where defense spending and cross-border security concerns are increasing..."

However, reducing military budgets and force downsizing, especially among western defense forces – the big spenders in the MilSatCom domain – are dampening the prospects of hardware providers. The withdrawal of troops from Afghanistan, budget sequestration in the U.S. and reduced deployment of special forces have especially restricted MilSatcom spending.

To win contracts globally, MilSatCom suppliers should offer cost-effective solutions that enable defense forces to reduce their overall upstream and downstream expenditure. This will help hardware suppliers secure satellite capacities and promote their new age MilSatCom capabilities as solutions rather than stand-alone hardware offerings.

"Strong opportunities for MilSatCom suppliers will come from the Middle East and Asia-Pacific markets, where defense spending and cross-border security concerns are increasing," pointed out Sampathkumar. "Suppliers must target these markets that have evolving MilSatCom needs not entirely met by proprietary systems."

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

## TRS-3D Naval Radar Provides Information Superiority in Maritime Security

Airbus Defense and Space Inc. has installed and put into operation the third TRS-3D naval radar for the U.S. Navy's Littoral Combat Ship (LCS) program through its agreement with the LCS prime contractor Lockheed Martin. The radar has been integrated on the third "Freedom" variant of the new Littoral Combat Ship, "Milwaukee" (LCS 5). In total, eight TRS-3D radars, designated AN/SPS-75 by the U.S. Navy, have passed their equipment acceptance tests, each now in varying stages of installation within the USS Freedom variant ships.

> "The TRS-3D is a three-dimensional, multimode naval radar for surveillance, self-defense, gunfire support and helicopter control. It is used to automatically locate and track all types of air and sea targets."

The TRS-3D is a three-dimensional, multimode naval radar for surveillance, self-defense, gunfire support and helicopter control. It is used to automatically locate and track all types of air and sea targets. Among the ships equipped with TRS-3D are the National Security Cutters of the U.S. Coast Guard, and outside the U.S., the K130 corvettes of the German Navy, the "Squadron 2000" patrol boats of the Finnish Navy and the Norwegian Coast Guard "Nordkapp" and "Svalbard" icebreakers.

Littoral combat ships are fast, agile surface combatants optimized for operating in the highly trafficked near-shore regions of the world against asymmetric "anti-access" threats. Through its innovative design, LCS can be reconfigured for surface warfare, anti-submarine warfare and mine countermeasures.

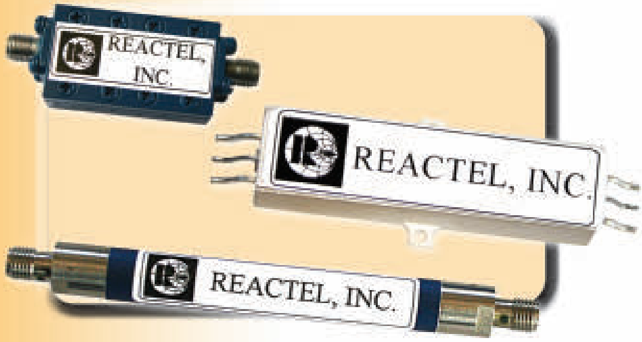
*USS Freedom (U.S. Navy photo)*

# Reactel, Incorporated

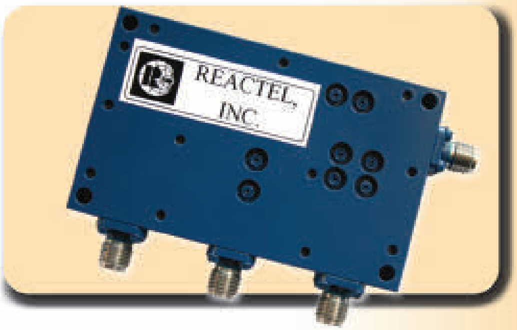
Reacting First to All Your Filter Needs.

## *When Being the First to React Makes all the Difference in the World*

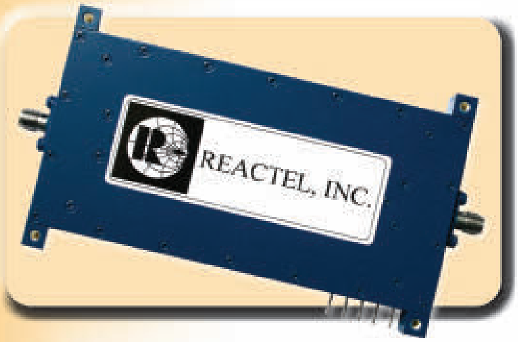
- **RF & Microwave Filters**




- **Diplexers & Multiplexers**




- **Multifunction Assemblies**



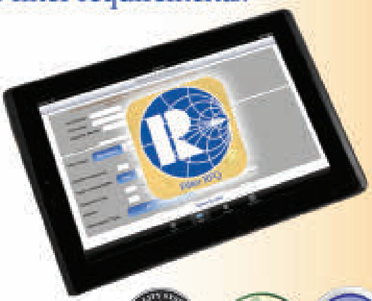

- **Ceramic Filters**


Reactel, Incorporated is your source for RF & Microwave Filters, Multiplexers and Multifunction Assemblies covering DC - 50 GHz.
Trust in Reactel's highly skilled engineers and technicians to quickly develop and produce the most reliable products for your filter requirements.

- Submitting a request for immediate attention will never be easier.
- Full featured App contains expanded RFQ capability, catalog, data sheets and more.
- Available for iPad, iPod and Android devices via the App Store and Google Play.

Available on the App Store

Google play



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

ISO 9001:2000 Registered

RoHS Compliant

@reacteljim

## Thales and AGH University, Poland Sign Innovation Agreement

Under a new cooperation agreement Thales and one of the leading Polish technical universities – the AGH University of Science and Technology (AGH UST) – will conduct joint scientific research projects for the development and implementation of new technologies. The cooperation will primarily focus on capabilities for space, defence, security and smart transportation.

The main beneficiaries of the agreement are students and graduates of the university as the cooperation will allow practices, internships and assistance in the funding of research projects for students, graduates and university staff.

At the signing ceremony, Pawel Piotrowski, managing director of Thales in Poland, commented, "Thales is investing annually 20 percent of its income in research and development. Thanks to this policy, we are enjoying direct applications of Thales innovations, for example, in the fields of train control solutions. The cooperation between Thales and AGH UST will further boost the capabilities for Polish innovations."

Marko Erman, SVP and chief technical officer of Thales, emphasized, "Over the past years Thales has created an environment that promotes innovation thanks to numerous investments and cooperation with our partners. We are developing common projects with over 50 prestigious universities and research laboratories in Europe, the United States, the Middle East and throughout Asia. Our Polish partners are joining a group of international experts thanks to AGH, their scientists and promising talents."

"...both parties will gain a lot from this collaboration."

"We often emphasize the strong links AGH has with industry and business – we have almost 300 agreements concerning close cooperation with the largest companies in many industries. But cooperation with Thales, due to its huge potential, has a special meaning for us. I am sure that both parties will gain a lot from this collaboration," said AGH UST vice-rector for cooperation, Prof. Tomasz Szmuc.

## RFEL Awarded Follow-On R&D Contract by ESA

RFEL has been awarded a follow-on research and development contract by the European Space Agency (ESA), in collaboration with other European partners. The initial contract covered the research phase into a flexible, wideband receiver front-end architecture for next generation broadband and broadcast satellite services. This requirement needed a software-defined, front-end design that could be configured on the fly to meet whatever the service demands required.

One element that RFEL introduced to the research was the use of a flexible and dynamically reconfigurable, digital filter bank based on its ChannelCore Flex (CCF) design. The CCF design can extract up to 32 independent channels from an instantaneous bandwidth of 2 GHz, which is supplied from a high-speed analogue to digital converter (ADC) running at 5 Gsps. Each output channel can be independently configured at run-time for a bandwidth up to 500 MHz, sample rate of either 2× or 4× bandwidth, centre frequency and output filtering type. The only constraint is that the total bandwidth of all output channels must be no more than 500 MHz. RFEL believes the channeliser to be one of the most efficient digital architectures available (in terms of silicon resources).

"The research element of the project was a great success..."

"The research element of the project was a great success," said Alex Kuhrt, RFEL's CEO, "so this second, follow-on contract has now been placed by ESA to build a prototype demonstrator that includes the full, front-end receiver chain with all the digital processing demonstrated in FPGA technology."

The funding provided by ESA for this project has resulted in the creation of technology that will be taken forward to assist in the development of the next generation of receiver technology for flexible, wideband satellite receivers.

## ETSI and NGMN Cooperate on Future Mobile Broadband Solutions

After many years of successful collaboration in the areas of LTE, Open Radio equipment Interface (ORI), the Multi-SDO initiative on network management and others, the European Telecommunications Standards Institute (ETSI) and the Next Generation Mobile Networks (NGMN) Alliance have agreed to intensify the joint cooperation beyond the existing Memorandum of Understanding framework.

The new cooperation agreement will provide a thorough framework for future cooperation between ETSI and NGMN. It will improve the dialogue and exchange of information between the two organizations and also provide a mechanism for exchanging draft documents and referencing each organization's specifications. Going forward, ETSI and NGMN plan to work closely on the next generation of mobile networks, in particular to support standardization with a view to upcoming 5G technologies.

Peter Meissner, CEO of NGMN, stated, "The new agreement honours the good and long-standing relationship between ETSI and NGMN and recognizes the importance of both organizations in shaping future mobile broadband solutions."

**For More Information** Visit mwjournal.com for more international news

Luis Jorge Romero, ETSI director general welcomed the new cooperation agreement, "Cooperation between standards development organizations is required, in particular when dealing with subjects of common interest for the mobile industry, like the development of 5G, in order to avoid conflicting standards and increased cost to the industry. We welcome the strong relationship with NGMN and the extension of our cooperation into new fields."

## EU Companies Must Boost R&D Investment to Stay Globally Competitive

Investment in research and development by companies based in the EU grew by 2.6 percent in 2013, despite the unfavourable economic environment, according to the European Commission's 2014 EU Industrial R&D Investment Scoreboard. However, this growth has slowed in comparison to the previous year's 6.8 percent. It is also below the 2013 world average (4.9 percent) and lags behind companies based in the U.S. (5 percent) and Japan (5.5 percent).

Data collected for the Scoreboard showed that EU-based companies surveyed invested €162.4 billion in 2013, whereas the U.S.-based companies surveyed invested €193.7 billion and the 387 Japanese companies invested €85.6 billion.

> "Horizon 2020 is already engaging more businesses than ever before..."

Carlos Moedas, commissioner for research, science and innovation said, "Despite the harsh economic climate, EU companies continue to invest in R&D. That is good news, but more is needed to keep up with our competitors. With public resources limited, attracting private R&D investment is even more essential. Horizon 2020 is already engaging more businesses than ever before, but now we're ready to step up our game. The €315 billion investment plan presented by the commission and European Investment Bank will help to raise more private investment for riskier projects, benefiting R&D across Europe."

Tibor Navracsics, commissioner for education, culture, youth and sport highlighted, "Thanks to the presence of excellent researchers and good knowledge-sharing opportunities, Europe is an attractive destination for R&D investment. But to keep up with global competitors we need to boost investments – and these should benefit a range of research disciplines and sectors. Building a knowledgeable economy requires strong foundations and we count on our industry partners to help us in these efforts."

## Antenna Tuners from RFMD, Skyworks and Qualcomm Surge in Flagship Smartphones

Shipments of LTE smartphones supporting more cellular bands will drive antenna tuner shipments to billions of units per year, according to Strategy Analytics:

- More than one billion phones will ship with antenna tuners in 2019, each using two or more antenna tuners on average.
- Benefits will go to top RF front-end subsystem and antenna tuning component suppliers RFMD (Qorvo), Qualcomm, Skyworks and Peregrine (Murata).
- Antenna specialists and smaller suppliers promoting new technologies such as RF MEMS tuners will also win some share.
- OEMs, wireless operators and consumers will benefit with better-performing smartphones.

Antenna tuners have emerged quite recently as an important means of improving call quality mainly in LTE phones, which have less space available for antennas tasked with supporting an ever-increasing number of cellular bands.

According to Christopher Taylor, director of the RF & Wireless Components (RFWC) strategic advisory service and author of the report, "CMOS silicon on insulator (SOI) switches for configuring the antenna lead the market, supplied primarily by RFMD, Qualcomm and Skyworks, with a host of other suppliers not far behind. What sets the leading suppliers apart is expertise in RF switch technology and a breadth of RF front-end products and subsystem solutions."

> "CMOS SOI switches for configuring the antenna lead the market..."

Steven Entwistle, VP of Strategic Technologies, added, "RF MEMS look very promising as a technology for tunable antennas, adjustable PA impedance and potentially even tunable RF filters. We expect to see antenna tuning design wins for MEMS-based devices from Cavendish Kinetics and WiSpry in phones in 2015 and could see MEMS take a significant share of the market by 2019."

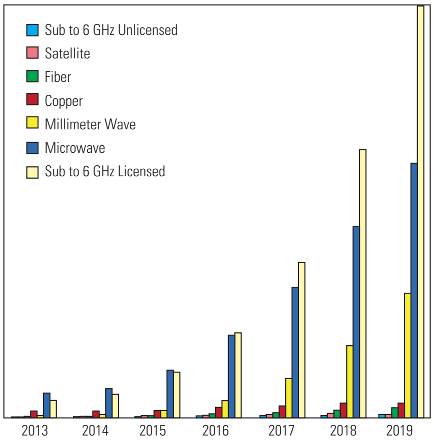
## Small Cell Backhaul Market to $5 Billion by 2019 as mmWave Technologies Advance

ABI Research expects the small cell backhaul equipment market to exceed $5 billion in 2019, which aligns with operators' deliberate approach to small cell deployments. Millimeter wave technology – thanks to its large bandwidth and NLOS capability – is the fastest growing technology in the forecast, outpacing the overall market with over 100 percent CAGR between 2014 and 2019. Sub 6 GHz technology will capture the largest share of small cell backhaul "last mile" links, also outperforming the total market by 2019. Traditional microwave equipment remains a top technology for small cell backhaul applications, with a leading share of revenue and one-fourth the share of links in 2019.

"We believe that 4G/LTE small cell solutions will again drive most of the microwave, millimeter wave and sub 6 GHz backhaul growth in metropolitan, urban and suburban areas; and backhaul for 4G/LTE small cells will grow at 2× the rate for 3G, surpassing both 2G and 3G in 2016," says Nick Marshall, research director at ABI Research.

"While the North American and Asia-Pacific regions today are equivalent in market share, we forecast that the Asia-Pacific region will outperform the market with 2 to 3× the size of any other region, though North America and Europe will also outperform the market," continues Marshall. Leading vendors such as Alcatel-Lucent, NEC, Ericsson, DragonWave, Ceragon, Aviat, CCS and Siklu are among the vendors which stand to benefit from this growth.

**Backhaul Equipment Revenue by Technology**
World Market Forecast: 2013 to 2019




*Source: ABI Research*

## Device-to-Device Communications, Machine Learning and Cellular RAN Virtualization Top Technology Disruptors

Technology can either be a differentiating factor that helps businesses be successful, or it can be something that contributes to a company's downfall. Technology adoption and usage can help to increase efficiency, increase stickiness, reduce wastage, improve product development, improve service and improve time to market. Technology is at the heart of many business success stories. The role of the CIO is a recent development and becoming one of the key positions within a company, also one of the most challenging.

ABI Research has collected inputs from the ABI analyst community as to what technologies should be on any CIO's or product manager's radar and should be considered when looking at the future roadmap of either products or internal solutions. The top technologies were grouped into the following categories:

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

**Top 5 Overall:**
1. Device-to-Device Communications (D2D)
2. Machine Learning
3. Cellular RAN Virtualization
4. Bluetooth Low Energy/Bluetooth Smart
5. LTE-Advanced

**Most Potential Impact:**
1. Device-to-Device Communications (D2D)
2. WiGig
3. Energy Storage for Portable Devices
4. Graphene
5. Machine Learning

**Time to Disruption:**
1. Cellular RAN Virtualization
2. ISW and Unified SON
3. Bluetooth Low Energy/Bluetooth Smart
4. In-Vehicle Smartphone Standards
5. Machine Learning

**Highest Probability:**
1. Cellular RAN Virtualization
2. Bluetooth Low Energy/Bluetooth Smart
3. Machine Learning
4. LTE-Advanced
5. Device-to-Device Communications (D2D)

## LTE Handset Shipments Expected to Soar to Nearly 680 Million in 2015

ABI Research estimates that 676 million 4G LTE handsets will be shipped in 2015, growing 204 million from 2014. The total number of LTE connected devices shipped worldwide will exceed 1.89 billion units by end 2019, demonstrating the need for infrastructure and spectrum to support the stellar growth in the industry.

"With the proliferation of larger screen smart devices driving up the insatiable appetites for content and faster speeds, ABI Research estimates that there will be 350 commercial LTE networks by 4Q 2014," comments Cheri Wong, research analysis. LTE-Advanced is now commercial on 20 networks in 14 countries. To cope with the demand for higher data rates, FDD/TDD LTE carrier aggregation trials are starting to take place. Ericsson, Sing-Tel and Qualcomm demonstrated a downlink speed of 260 Mbps in their trial. The first ever TDD-FDD LTE trial took place in February 2014 between Korea Telecom and SK Telecom, with assistance from Nokia Networks. The growing demand for data also emphasizes the need for additional bandwidth to support the massive strain on operator networks which can be alleviated through the re-farming of unused spectrum.

# Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

## MERGERS & ACQUISITIONS

**M/A-COM Technology Solutions Holdings Inc.**, a supplier of high performance RF, microwave and millimeter wave products, announced it has successfully completed its previously announced acquistion of **BinOptics Corp.**, a merchant provider of indium phosphide lasers for data centers, mobile backhaul, silicon photonics and access networks, in an all-cash transaction valued at $230 million.

**Murata Electronics North America Inc.**, a wholly owned subsidiary of **Murata Manufacturing Co. Ltd.**, and **Peregrine Semiconductor Corp.**, founder of RF silicon on insulator (SOI) and pioneer of advanced RF solutions, announced that Murata has acquired all outstanding shares of Peregrine. The cash transaction paid the holders of Peregrine common shares $12.50 per share.

**Crane Aerospace & Electronics**, **Power Solutions** will be supplying ELDEC Power Conditioning Modules (PCM) to provide flight critical and reliable power management and conversion for the **Honeywell Flight Control Electronics** (FCE) supplied to COMAC. The FCE is part of the flight control fly-by-wire system that will be utilized on the COMAC C919 family of narrow body aircraft. Fly-by-wire systems enable an electronic interface between the cockpit and the aircraft flight control surfaces. Crane's PCM selects the proper source, conditions and supplies uninterruptable power to the FCE.

**American Certification Body** (ACB) announced a coordinated agreement with **ART-FI** and **EMTREK** to market and service the ART-MAN SAR test bench to Chinese mobile and laptop manufacturers. ART-MAN is a new Specific Absorption Rate (SAR) testing solution that uses cutting-edge technologies to make SAR testing more accurate, faster and easier to carry-out for the testing engineers and antenna designers. Mobile manufacturers who have an ART-MAN can launch their products faster, because the SAR testing is completed faster. EMTREK is the third largest testing laboratory in China.

## NEW STARTS

**TE Connectivity** announced the official opening of its TE Wearables Lab in Menlo Park, Calif. Exclusively focused on wearable technologies across consumer, medical, industrial and defense businesses, the lab serves as a collaboration center for TE's team of engineers, scientists and its customers throughout the design process. The lab is currently being used by a number of start-up and middle stage companies from design, manufacturing and integration industries.

## ACHIEVEMENTS

**Skyworks Solutions Inc.** announced that its Board of Directors has authorized the repurchase of up to $300 million of the company's common stock from time to time prior to November 11, 2016, on the open market or in privately negotiated transactions, in compliance with applicable securities laws and other legal requirements. This newly authorized stock repurchase program replaces in its entirety the $250 million stock repurchase program which was approved by the Board of Directors on July 16, 2013, and had $63.9 million of repurchase authority remaining.

**Anritsu Co.** announced that it is the market leader in approved test cases for TD-LTE Carrier Aggregation and is the only test company with Global Certification Forum (GCF)-approved TD-LTE test cases in the IMS Voice over LTE (VoLTE)-related technology of aSRVCC. Anritsu's leading position in these work items, as well as the FDD variant of aSRVCC, was confirmed by GCF at the CAG meeting held October 14-15 in Los Angeles. The approved test cases are for Anritsu's ME7834L Protocol Conformance Test (PCT) Platform.

Scientists at **Tech-X Corp.** modeled a complex power-loss mechanism that contributes to inefficiencies in the microwave heating of fusion plasmas. This research helped identify when parasitic slow-wave losses near the reactor edge are likely to occur. Detailed simulations of microwave antenna operation in MIT's Alcator C-Mod fusion experiment were carried out using the VSim software. Such modeling, in addition to augmenting scientific understanding of existing experiments, can be used to explore operation scenarios in future devices. The ITER fusion reactor facility, currently under construction in France, is a multibillion-dollar international project with first experiments scheduled in the 2020s.

**RF Techniques** celebrated its 25th year anniversary in November. They attribute 25 years of success to a meticulous commitment to core values: a commitment to provide superior quality products and a service commitment to their customers.

**Raytheon** is awarding 36 Engineering is Elementary® (EiE) scholarships to teachers in disadvantaged, rural or inner city schools across the country. Each teacher will receive $2,500 towards implementing the innovative EiE curriculum developed by the Museum of Science, Boston. EiE was designed by the Museum's National Center for Technological Literacy® (NCTL) to help elementary school educators and students better understand engineering and technology concepts. The award-winning curriculum has already reached an estimated 71,000 teachers and 6.2 million students.

## CONTRACTS

**API Technologies Corp.** announced that it has received a follow-on order for $1.3 million to provide microwave modules for the latest generation radar. The customer program, anticipated to continue through 2025, is expected to add an additional $20 million in revenue. The product features the use of a proprietary Glass Microwave Integrated Circuit (GMIC) fabrication process that offers shorter cycle time

**For More Information**

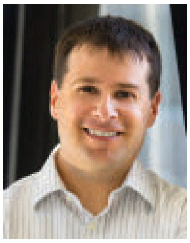
**For up-to-date news briefs, visit mwjournal.com**

## Around the **Circuit**

and affordability compared to traditional MMIC-based solutions. GMIC is a medium-volume substrate process where passive components and wire bonds or airbridges are fabricated at wafer level.

**Mercury Systems Inc.**, a provider of affordable, commercially developed, open sensor processing systems and services for critical commercial, defense and intelligence applications, announced that its **Mercury Defense Systems** subsidiary recently received a $1.2 million order from a leading international aerospace and defense company for radar environment simulation equipment to support European Fighter Aircraft (EFA). The order was booked in the company's fiscal 2015 second quarter and is expected to be shipped by its fiscal 2016 third quarter.

### PEOPLE



▲ *Robert Furtaw*

**Texas Instruments Inc.** announced the election of **Robert Furtaw** to vice president of Worldwide Semiconductor (SC) Quality, an organization within TI's Technology and Manufacturing Group (TMG). As vice president, Furtaw will oversee a global team responsible for ensuring TI meets applicable quality requirements and customer expectations, from product and process technology development through manufacturing and delivery. His team is also accountable for developing and driving the use of methodologies, tools and statistical processes across the company to deliver global, robust products, processes and services.

**TriQuint's Glen Riley**, vice president of business development, received the prestigious Edward T. Bryand Distinguished Engineering Award from the University of Maine's College of Engineering. This award is the college's highest honor for career excellence and accomplishment. Riley received the award on November 7, 2014, at the university's annual recognition banquet. Riley joined TriQuint in 2003 and most recently completed a two-year assignment in Singapore as managing director of TriQuint International Pte Ltd. Prior roles at TriQuint include vice president and general manager of foundry services and vice president and general manager of TriQuint Optoelectronics.

▲ *Glen Riley*

▲ *Brian O'Leary*

**Indium Corp.** announced that **Brian O'Leary** has joined the company as a global accounts manager. Based in Phoenix, Ariz., O'Leary will be responsible for the management and development of key global accounts. He will work closely with product managers, regional sales managers and technical engineers to develop and execute strate-

# Around the **Circuit**

gies to maintain existing accounts and grow new business. O'Leary has more than 15 years of experience in global sales across a variety of industries, including electronics assembly and medical device manufacturing.

## REP APPOINTMENTS

**Modelithics** announced an expansion of the partnership with **TACTRON ELEKTRONIK GmbH** in Martinsried, Germany as a reseller for Modelithics library sales and services. TACTRON, currently a reseller for Modelithics in Germany, Switzerland and Austria, will now offer the same excellent reseller representation in Italy and France. For more information, contact Modelithics at sales@modelithics.com or TACTRON at info@tactron.de.

**Analog Devices Inc.** announced that its complete RF and microwave portfolio, including the **Hittite Microwave Products** from Analog Devices, is now available for sale through the company's extensive distribution network. ADI's distribution network includes a variety of channel partners worldwide consisting of: global distribution partners; a vast range of regional partners located throughout the Americas, Europe, China and Asia Pacific; and catalog distributors. These partners have been fully trained and received RF and microwave accreditation to ADI standards on the Hittite Microwave products. A complete list of ADI's partners can be found at www.analog.com/salesdir/continent.asp.

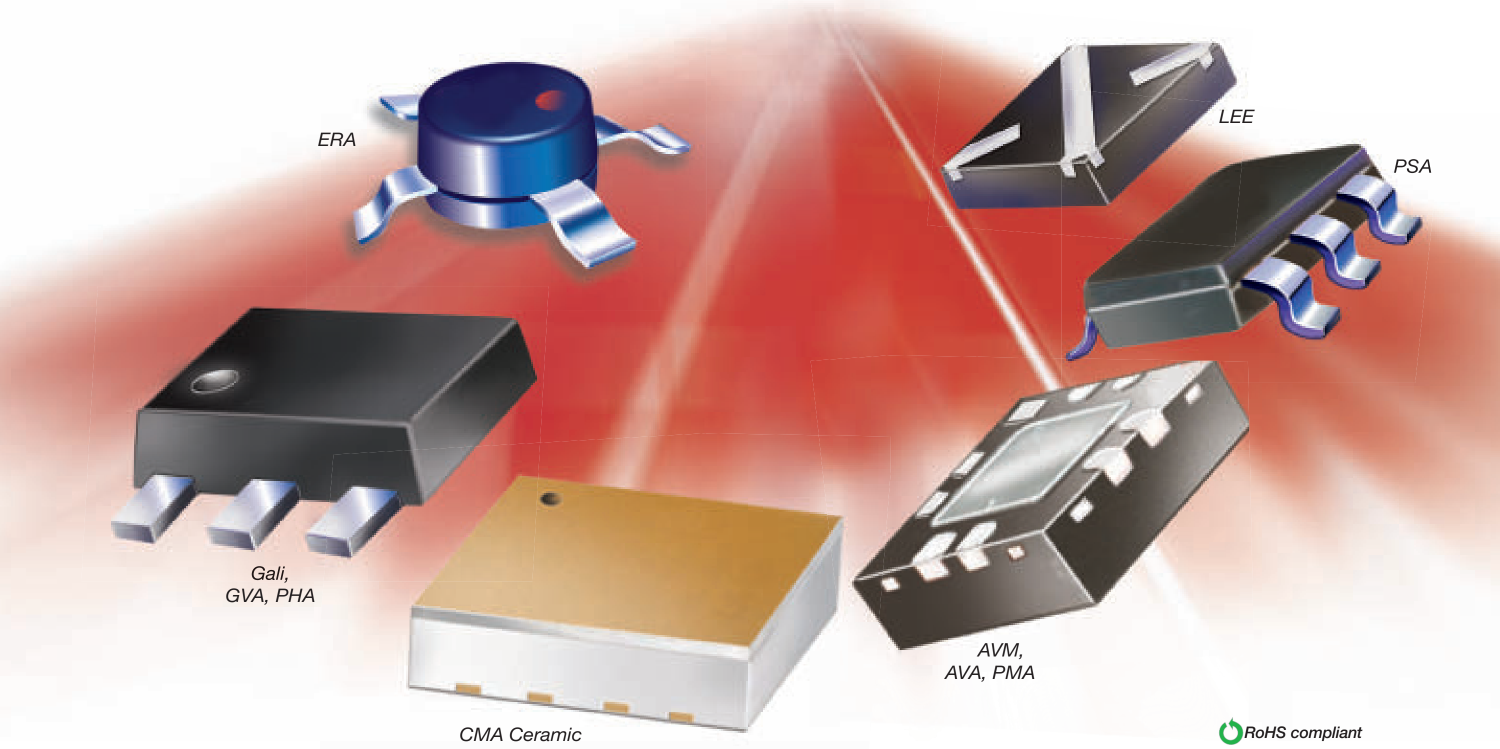
## PLACES

**Richardson RFPD Inc.** announced that it has moved to a larger and newly-renovated office space. The new 24,000-square-foot corporate headquarters is sized to accommodate the company's continued growth as a global leader in the RF and wireless communications, power conversion and renewable energy markets. Richardson RFPD's new offices are conveniently located in historic Geneva, Ill., 40 miles west of Chicago and within 30 minutes of Chicago O'Hare International Airport. The new corporate headquarters is located at 1950 S. Batavia Avenue, Suite 100, Geneva, Ill. 60134. The new main telephone number is 630-262-6800.

**Tecdia Inc.**, a manufacturer of leading edge components and equipment to microwave and lightwave industries has opened a new office branch based in the UK servicing distributors and customers throughout Europe. The office will be managed by their newest addition to the Tecdia Inc. family, Hazel Doughty (former sales manager, Castle Microwave Ltd., UK). Doughty will serve as Tecdia's European sales and distribution manager. Her background covers sales/distribution management and hands-on engineering roles across RF/microwave, smart energy, semiconductors, manufacturing, telecoms and defence related sectors.

# MMIC AMPLIFIERS

NOW! DC to 26.5 GHz from 73¢ qty.1000




**NF from 0.5 dB, IP3 to +48 dBm, Gain from 8 to 39 dB, Pout to +30 dBm**

Now with over ~~145~~ 170 MMIC amplifier models covering frequencies from DC to 26.5 GHz*, chances are, Mini-Circuits has your application covered. Our ultra-broadband InGaP HBT and PHEMT amplifiers offer one of the industry's broadest selections of gain, output power, IP3, and noise figure to optimize your commercial, industrial, or military system performance. They can even meet your most critical size and power requirements with supply voltages as low as 2.8V, current consumption as low as 16mA, and packages as small as SOT-363 (1.35 x 2.25mm). Our tight process control guarantees consistent performance across multiple production runs, so you can have confidence in every unit.

Visit minicircuits.com and use our Yoni2™ search engine to search our entire model database by performance criteria for the model that meets your needs. You'll find pricing, full model specs, characterization data, S-parameters, and even free samples of select models! So why wait? Place your order today, and have units in your hands as soon as tomorrow!

*Low-end frequency cut-off determined by external coupling capacitors and external bias choke.

Yoni2™ Searching millions of actual data points to meet your specific requirements.
U.S. Patents 7739260
7761442

EZ To Get SAMPLES
**FREE** Samples On Demand!
www.minicircuits.com/products/ez_samples.shtml

**Mini-Circuits®**

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

# Metamaterial Möbius Strip Resonators for Tunable Oscillators

Ulrich L. Rohde
*Brandenburgische Technische Universitat, Cottbus, Germany*
Ajay K. Poddar
*Synergy Microwave Corp., Paterson, N.J.*

*This third article in the series on metamaterial Möbius strip resonators addresses their use in signal sources for test and measurement equipment and wireless communications systems. The resonators enable tunable, multi-band oscillators with smaller size and lower power consumption compared to separate oscillators for each band. The signal sources described in this article demonstrate significant improvements in figure-of-merit (FOM) for a given phase noise, tuning range, power consumption, size and cost. With MMIC fabrication techniques and the broad application of this artificial material, metamaterial technology offers promising planar voltage-controlled oscillator (VCO) solutions for microwave frequencies.*

Modern communications systems require compact signal sources with low phase noise. For decades, design engineers have been improving phase noise and broadband tuning to satisfy the evolving performance requirements that modern communication systems are demanding. This development has followed two distinct paths: reducing the size of the printed resonator without degrading the quality factor and improving oscillator circuit topologies to improve FOM.

A spot phase noise (PN) number is misleading when comparing oscillators, unless they are at the same frequency offset from the carrier for a given tuning range and output power. To compare oscillators operating at different frequencies, tuning ranges and output power levels, a single number FOM has long been desired. Two metrics being used are a FOM, in dBc/Hz, and power frequency tuning normalized (PFTN), in dB, defined as[1,28]

$$\mathrm{FOM}\big|_{f_{offset}} = \left[\pounds(f_{offset}) - 20\log_{10}\left(\frac{f_0}{f_{offset}}\right) + 10\log_{10}\left(\frac{P_{DC}}{1\,\mathrm{mW}}\right)\right]\left(\frac{\mathrm{dBc}}{\mathrm{Hz}}\right) \quad (1)$$

$$\mathrm{PFTN} = \left[\pounds(f_{offset}) - 20\log_{10}\left(\frac{\Delta f}{f_{offset}}\right) - 10\log_{10}\left(\frac{P_{DC}}{kT}\right)\right](\mathrm{dB}) \quad (2)$$

where $f_0$ is the oscillation frequency, $\pounds(f_{offset})$ is the phase noise at the offset frequency $f_{offset}$, k is the Boltzmann constant, $\Delta f = f_{max} - f_{min}$ or the tuning range, T is temperature in Kelvin, and $P_{DC}$ is the total consumed DC power in mW. The larger the |FOM| and PFTN values, the better the oscillator.

PFTN is a critical requirement for multi-band tunable oscillators. The other important requirement is DC to RF conversion efficiency. From equations 1 and 2, the FOM for integrated phase noise, in dBc, from 1 kHz to 1 MHz is given by

$$\mathrm{FOM}\big|_{\mathrm{Integrated(1\,kHz-1\,MHz)}} = 10\log\left(P^2(\phi)\right) + 10\log\left(\frac{P_{RF}}{P_{DC}}\right) - 20\log\left(\frac{2\Delta f}{f_{max}+f_{min}}\right) \quad (3)$$

where: $\Delta f = f_{max} - f_{min}$; $f_{max}$ = maximum oscillation frequency; $f_{min}$ = minimum oscillation frequency; $P^2(\phi)$ = integrated phase noise from 1 kHz to 1 MHz; $P_{RF}$ = signal output power averaged over frequency; $P_{DC}$ = DC power consumption of the oscillator.

A compact, high Q-factor resonator is key to obtaining the best FOMs. Toward this goal, substrate integrated waveguides (SIW) are attractive because of their waveguide-like performance and compatibility with planar printed circuit board (PCB) technology.[2] Cavities


Making the Connection to
Millimeter Wave Solutions
From 50 to 500 GHz
Source Modules
VNA
Harmonic Mixers
Patented "Boss & Jack"
Precision Waveguide Interface
Intermodulation Distortion (IMD)
Innovation in Millimeter Wave Solutions
www.omlinc.com
(408) 779-2698
OML

**TABLE 1**

**COMPARISON OF PUBLISHED OSCILLATOR PERFORMANCE**

| Ref. | $f_0$ GHz | $P_{DC}$ mW | $P_0$ dBm | Tuning GHz | $£(f)$ dBc/Hz | FOM dBc/Hz | PFTN dB |
|---|---|---|---|---|---|---|---|
| [6] | 25.1 | 11 | -4.2 | 12% | -99.9 | -177 | -14.7 |
| [7] | 20.9 | 40 | -6.8 | 10.4% | -111 | -181 | -11.5 |
| [8] | 19.9 | 39 | -3 | 2.6% | -111 | -181 | -24.6 |
| [9] | 20.7 | 10.8 | -21 | 8.7% | -108 | -181 | -24.6 |
| [10] | 40 | 6 | | 2.8% | -109 | -193 | -14.4 |
| [11] | 28 | 12 | | 6.7% | -113 | -191 | -6.3 |
| [12] | 20.9 | 6.3 | | 3.1% | -117 | -195 | -8.5 |
| [13] | 18.9 | 3.3 | | 3.58% | -110 | -191 | -11.7 |
| [14] | 21.3 | 3.5 | | 5.1% | -109 | -190 | -8.8 |
| [15] | 44 | 7.5 | | 9.8% | -101 | -185 | -9 |
| [16] | 38.4 | 80 | | 17.9% | -97.5 | -170 | -18.3 |
| [17] | 17.6 | 1.4 | -9 | 2.1% | -112 | -195 | -12.1 |
| [18] | 41 | 280 | | 26.3% | -110 | -177 | -7.8 |
| [19] | 22.1 | 11.1 | -11 | 20.6% | -109 | -181 | -2.26 |
| [20] | 9.5 | 37 | 7.5 | 4.8% | -117 | -180.9 | |
| [21] | 11.16 | 20 | 2.9 | 4.1% | -125 | -193 | |
| [22] | 10 | 10.5 | -2 | 1.8 | -105 | -174.8 | |
| [23] | 12.4 | 30 | 7 | 2.5 | -122 | -189.1 | |
| Fig. 7 | 3.85 | 300 | 5 | 0% | -168 | -215 | |
| Fig. 20 | 10.2 | 300 | 10 | 0.01% | -160 | -215 | -14.1 |
| Fig. 23 | 3 | 100 | 3.3 | 66.7% | -130 | -179 | 2.04 |

based on SIWs are an excellent choice for oscillator resonators, since they have high Qs and low loss. Several tunable or switchable SIW resonators have recently been reported.[3-5] Tuning or switching is achieved by connecting a varactor or PIN diode to a floating metal pad on the top of the SIW cavity, using bond wires. However, this creates unwanted radiation loss and reduces the Q, because of the closed-loop slots surrounding the floating metal. Also, the bond wires used for DC bias increase the fabrication complexity and may introduce parasitics.

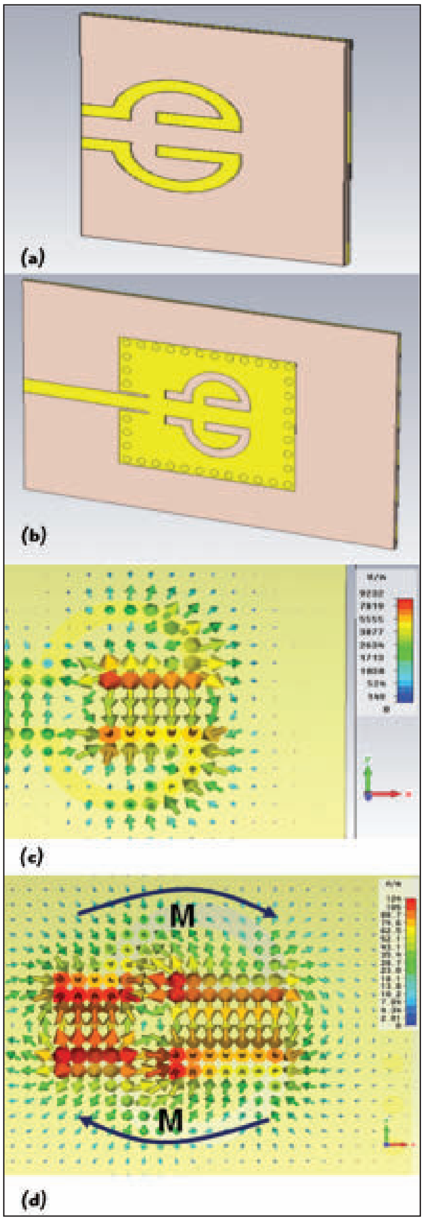
The novel evanescent-mode metamaterial resonator enables the design of oscillators with improved phase noise and FOM compared to other published results. ***Table 1*** shows the performance of state-of-the-art VCOs that use various fabrication technologies. The metamaterial designs described in this article achieve superior FOM and PFTN for a given class, topology and bill of materials (BOM).

## NEGATIVE INDEX PRINTED RESONATOR

The negative index printed resonator is a key component for the design of oscillator circuits at microwave and millimeter wave frequencies. Originally proposed by John Pendry, a typical printed split ring resonator (SRR) is a sub-wavelength resonator that inhibits signal propagation in a narrow band in the vicinity of its resonant frequency, provided the magnetic field is polarized along the axis of the ring.[24-26]

Recently, a new type of tunable resonator was reported based on complementary coupled resonators (CCR) using SIW technologies.[27-33] The proposed CCR is essentially a complementary version of a conventional microstrip coupled-line resonator. ***Figure 1a*** shows the typical geometry of the conventional coupled-line resonator, ***Figure 1b*** the equivalent complementary structure. The electric field and current flow of the coupled-line resonator with differential excitation is shown in ***Figure 1c***. Using the principle of duality, the coupling mechanism for the complementary coupled resonator is through the magnetic field, shown in ***Figure 1d***, which has a distribution similar to the electric field in the conventional coupled-line resonator.

In the conventional coupled resonator, the differential mode needs to be excited by a pair of inputs with opposite polarity. However the com-




▲ *Fig. 1 The microstrip coupled-line resonator (a) and complementary coupled resonator (b). The coupled-line resonator's electric field distribution and electric current flow with differential excitation (c). The magnetic field distribution and equivalent magnetic current flow of the complementary coupled resonator (d). Results from a collaboration between Synergy Microwave and Prof. Tatsuo Itoh of UCLA.*[33]

plementary coupled resonator is normally excited in a differential mode due to the nature of the fundamental mode in the waveguide. The equivalent magnetic currents on the slots of the complementary coupled resonator flow in opposite directions at the symmetrically opposite edges on the SIW resonator, minimizing radiation and yielding a high Q-factor.

The Q-factors of one and two-port resonators are given by[33]

$$\left[Q_{unloaded}\right]_{1-Port} = \frac{\omega_0}{2}\left|\frac{Z_{21}(\omega_0)'}{Z_{21}(\omega_0)}\right| \quad (4)$$

$$\left[Q_{loaded}\right]_{2-Port} = \frac{\omega_0}{2}\left|\frac{Z_{21}(\omega_0)'}{Z_{21}(\omega_0)}\right| \quad (5)$$

where $Z_{21}(\omega_0)$ and $Z_{21}(\omega_0)'$ signify the impedance and its derivative, respectively, of the SIW resonator structure at frequency $\omega_0$.

The drawback of the CCR structure is its limited tuning range. A possible way for improving the tuning of the CRR topology is to use negative index material in conjunction with evanescent-mode coupling. Negative index material, broadly known as left-handed (LH), has a negative refractive index.[30]

$$n = \sqrt{(-\varepsilon)(-\mu)} = -\sqrt{\mu_0\mu_r\varepsilon_0\varepsilon_r} \quad (6)$$

where n is the refractive index of the medium, $\varepsilon_o = 8.85 \times 10^{-12}$ and $\mu_0 = 4\pi \times 10^{-7}$.

The sign of permittivity and permeability in equation 6 is not restricted by any physical law and can be positive or negative. Negative refractive index material has anti-parallel phase and group velocities, which allows an electromagnetic wave to convey energy and group velocity in the opposite direction to its phase velocity. This causes strong localization and enhancement of the fields, significantly enhancing the quality factor of resonators.

In the remainder of this article, several examples of oscillator circuits using Möbius metamaterials are shown. The designs are targeted to replace competing high Q technologies such as surface acoustic wave (SAW), bulk acoustic wave (BAW), surface transverse wave (STW), whisper gallery mode (WGM), ceramic and dielectric resonators.

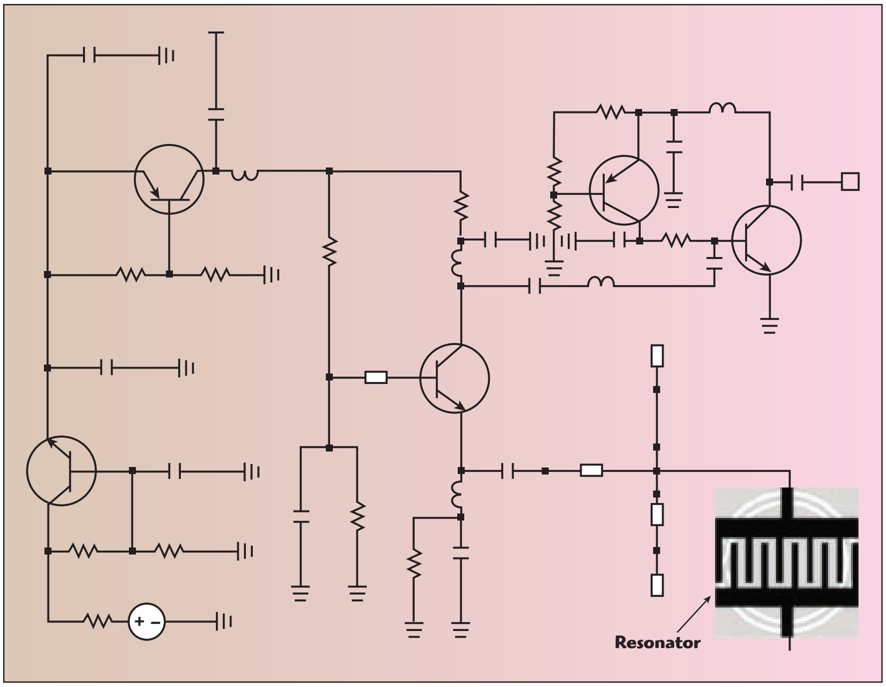
As discussed in the prior two articles (November and December, 2014), the manipulation of evanescent mode coupling enables the Q of the resonator to be multiplied and used for high performance tunable oscillators. The Q multiplier effect does not violate energy conservation because the evanescent mode only stores and does not transport the energy.

Metamaterial Möbius strip resonators have several advantages compared with conventional planar resonators:[30]

- High Q-factor and improved selectivity
- Easy integration in MIC/MMIC technologies
- Small dimensions and weight
- Multi-band characteristics
- Relative insensitivity to electromagnetic interference

## 3.85 GHz EVANESCENT-MODE METAMATERIAL MÖBIUS RESONATOR OSCILLATOR

The schematic of a fixed 3.85 GHz oscillator is shown in ***Figure 2*** and

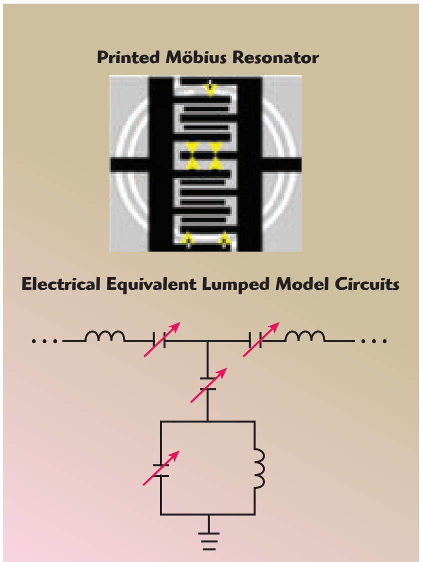



▲ *Fig. 2 Schematic of a 3.85 GHz oscillator using an evanescent-mode coupled metamaterial resonator (patent pending).*[30]

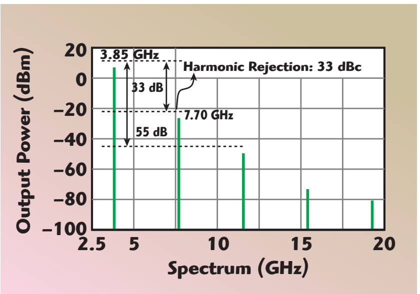
▲ *Fig. 3 Layout of the oscillator (patent pending).*

the board layout in ***Figure 3***. The design uses a SiGe transistor as the active device and a 20 mil thick substrate, with a dielectric constant of 2.2, for the microstrip and stripline matching circuits and interconnects. ***Figure 4*** provides a close-up view of the metamaterial Möbius strip resonator with varactor diodes that are used for tuning (top); the equivalent circuit of the resonator structure is shown on the bottom.[32]

The oscillator is biased at 5 V DC and consumes 60 mA; the measured output power exceeds 5 dBm. ***Figure 5*** is a plot of the simulated output spectrum, showing that evanescent mode coupling improves the second and third harmonic rejection by more than 33 and 55 dB, respectively. The

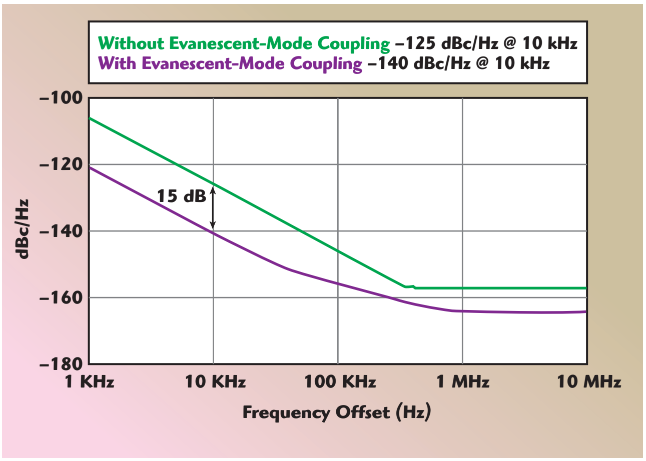



▲ *Fig. 4 Layout of the metamaterial Möbius resonator with varactor diodes used for tuning (top) with lumped-circuit model (bottom).*[30]

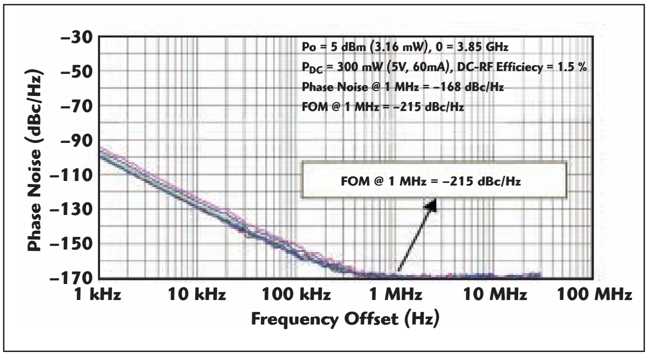



▲ *Fig. 5 Simulated spectrum showing the harmonic rejection achieved with evanescent-mode coupling.*

simulated phase noise (see ***Figure 6***) also shows the effect of evanescent-mode coupling, which improves the noise performance by 15 dB. The measured phase noise (see ***Figure 7***) indicates that 5 to 8 dB of the 15 dB predicted improvement is realized, depending upon of the level of evanescent-mode coupling. The FOM for the oscillator is -215 dBc/Hz.




▲ *Fig. 6 Simulated phase noise plots showing 15 dB improvement from evanescent-mode coupling.*




▲ *Fig. 7 Measured phase noise of the 3.85 GHz oscillator.*

The varactor diodes incorporated in the Möbius resonator improve the tuning, but the oscillator is susceptible to mode jumping, since the resonator structure exhibits both series and parallel resonance. To ensure reliable and stable operation, the higher order modes are suppressed using a phase-injection locking mechanism.

## 7 GHz EMPIMC RESONATOR BASED OSCILLATOR

The evanescent-mode phase-injection mode-coupled (EMPIMC) oscillator significantly improves phase noise performance, as shown by the simulation in ***Figure 8***. The basic oscillator without phase-injection consists of an analog mixer feeding an LC tank with finite Q-factor and a feedback loop from the output to the mixer, as shown in the block diagram of ***Figure 9a***. To maintain stable oscillation, the loop gain should be greater than unity, and the total phase shift must be zero. The loop gain condition is easily satisfied, but the phase shift condition limits the locking range.[24] Considering the phase shift introduced by the LC tank at frequency ω is β, the mixer is required to introduce another phase shift α so that α + β = 0. By incorporating additional phase shift, γ, after the mixer, the locking range can be increased (see ***Figure 9b***).

The locking condition is described by

$$\frac{2(f-f_0)}{f}=\frac{\eta\sin(\phi)}{2+\cos(\phi)} \qquad (7)$$

From equation 7, the locking range is restricted by the maximum phase shift that the mixer can provide and is described by

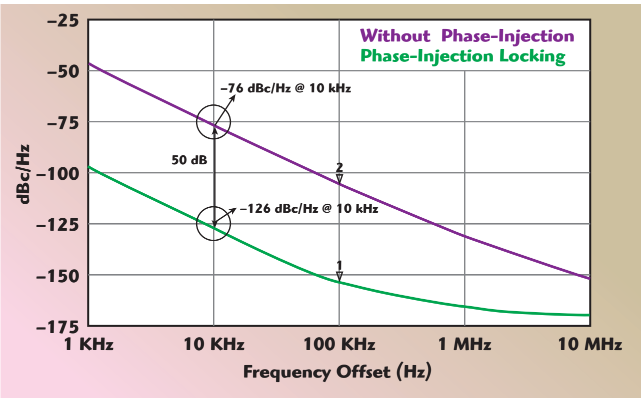
$$\Delta f=\frac{f_0}{2Q}\tan\left(\sin^{-1}\left(\frac{\eta}{2}\right)\right) \qquad (8)$$

where $f_0$ is the resonant frequency, Q is the quality factor of the LC tank and η is the injection ratio ($i_{inj}$/IDC). The Q-factor is given by[34]

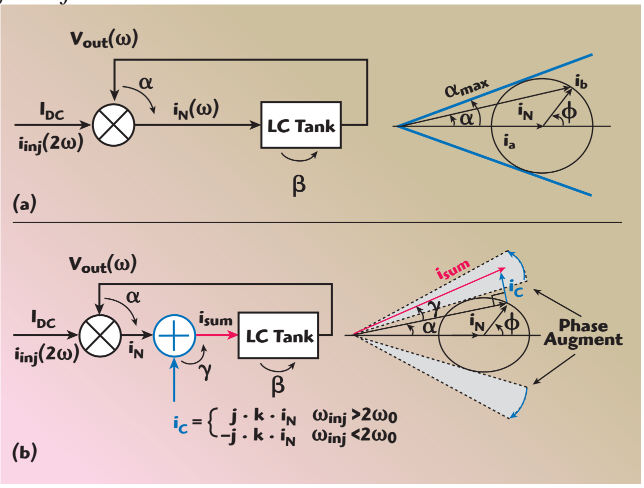
$$Q_L=\frac{\omega_0}{2}\left|\frac{d\varphi(\omega)}{d\omega}\right|_{\omega=\omega_0}=\frac{\omega_0}{2}\tau_d;\ \tau_d=\left|\frac{d\varphi(\omega)}{d\omega}\right|_{\omega=\omega_0} \qquad (9)$$

$$\tau_d=\left|\frac{d\varphi(\omega)}{d\omega}\right|_{\omega=\omega_0}=\frac{\varphi(\omega_0+\Delta\omega)-\varphi(\omega_0-\Delta\omega)}{2\Delta\omega} \qquad (10)$$

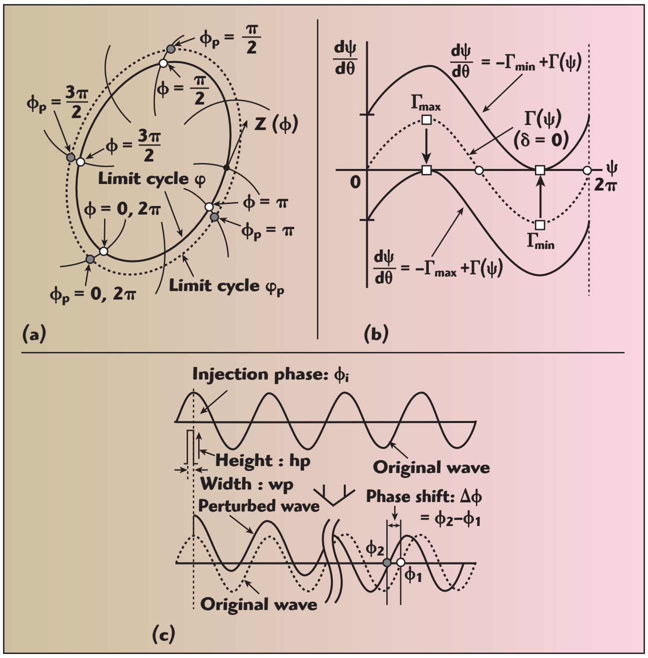
where φ(ω) is the phase of the oscillator's open loop transfer function at




▲ *Fig. 8 Simulated phase noise of the evanescent-mode phase-injection locked oscillator. Phase injection locking improves the noise floor by 50 dB.*




▲ *Fig. 9 Oscillator block diagram and phasor diagram for an oscillator without phase-injection (a) and with phase-injection (b).*[24]




▲ *Fig. 10 Oscillator circuit dynamics, showing the limit cycle (a) dψ/dt versus ψ (b) and phase shift due to impulse perturbation at $\phi_i$.*[24]

steady state, and $\tau_d$ is the group delay of the resonator. From equation 9, $Q_L$ is proportional to the group delay; therefore, for low phase noise, the design goal is to maximize the group delay of the Möbius strip resonator by incorporating phase-injection techniques. The unique characteristic of the Möbius strip is self phase-injection along the mutually-coupled surface of the strips, which enables higher Q-factor for a given size of the printed transmission line resonator.[30]

By incorporating additional phase shift $\gamma = \tan^{-1}(|i_C|/|i_N|)$ after the mixer module, as shown in Figure 9b, the locking range can be increased and is described by[24]

$$\Delta f_{max} = \frac{f_0}{2Q}\tan\left(\sin^{-1}\left(\frac{\eta}{2}\right) + \tan^{-1}(m)\right),$$
$$k = \frac{|i_c|}{|i_N|} \qquad (11)$$

where m is the coupling strength. ***Figure 10*** shows the typical oscillator

# Our RF & Microwave Products Give You An Unfair Advantage

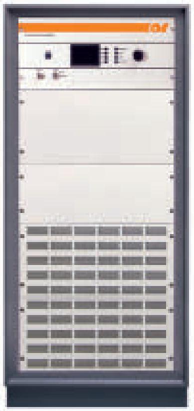
## Hybrid Power Solid State Modules & Benchtop Amplifiers

*700 MHz to 6 GHz and 4-18 GHz Single Band Units*

Now you can have Class A designs when linearity is the driving force, as in EMC and wireless applications OR Class AB designs when increased power and efficiency is paramount for EW applications. Standard 6 GHz modular designs provide up to 50 watts P out while benchtops are capable of over 200 watts. 18 GHz products deliver up to 10 watts in a modular package and 40 watts in a benchtop.

## Dual Band Amplifiers

AR now offers the widest Class A solid state frequency range coverage in a single amplifier housing. Our widest bandwidth designs now cover 0.7 to 18 GHz in a dual band configuration. These amplifiers come in two different band split configurations from 0.7 to 4.2 GHz and 4 to 18 GHz, or from 0.7 to 6 GHz and 6 to 18 GHz. Output powers provide up to 80 watts for the lower band split while the higher band provides up to 40 watts.



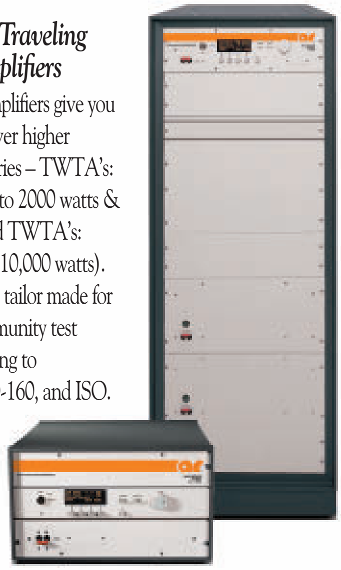
## "S" Series Solid State

Numerous models from 0.7 to 18 GHz, 1 to 1200 Watts. For Immunity, Wireless Testing and TWTA replacements. Our "S" Series amplifiers are Mismatch Tolerant providing 100% of rated power without foldback. These amplifiers will reproduce input signals and remain stable with any magnitude and phase load impedance, without damage.

*1000S1G2z5 (1000 watts, from 1 to 2.5 GHz)*

## "T" and "TP" Traveling Wave Tube Amplifiers

AR's microwave amplifiers give you more power and cover higher frequencies ("T" Series – TWTA's: 1- 45 GHz; CW 15 to 2000 watts & "TP" Series – Pulsed TWTA's: 1- 18 GHz; 1000 to 10,000 watts). These amplifiers are tailor made for various radiated immunity test applications according to MIL-STD-461, DO-160, and ISO.



## "A" Series Solid State

RF Solid State Amplifiers up to 400 MHz, and 50,000 watts. All of our RF Solid State Amplifiers have modulation capability that will faithfully reproduce AM, FM or pulse modulation for demanding EMC Radiated Immunity testing applications.

**www.arworld.us/advantage**

**In China, call Corad at 400-007-3336**

ISO 9001:2008 Certified

**rf/microwave instrumentation**

Other ar divisions: modular rf • receiver systems • ar europe

USA 215-723-8181. For an applications engineer, call 800-933-8181.

www.arworld.us

circuit dynamics for enabling phase-injection and improving the locking range.

An objective of this design was to improve the Q of the metamaterial resonator by cascading a progressive-wave evanescent mode-coupled resonating network (shown in the schematic of ***Figure 11***) to lower the phase noise without

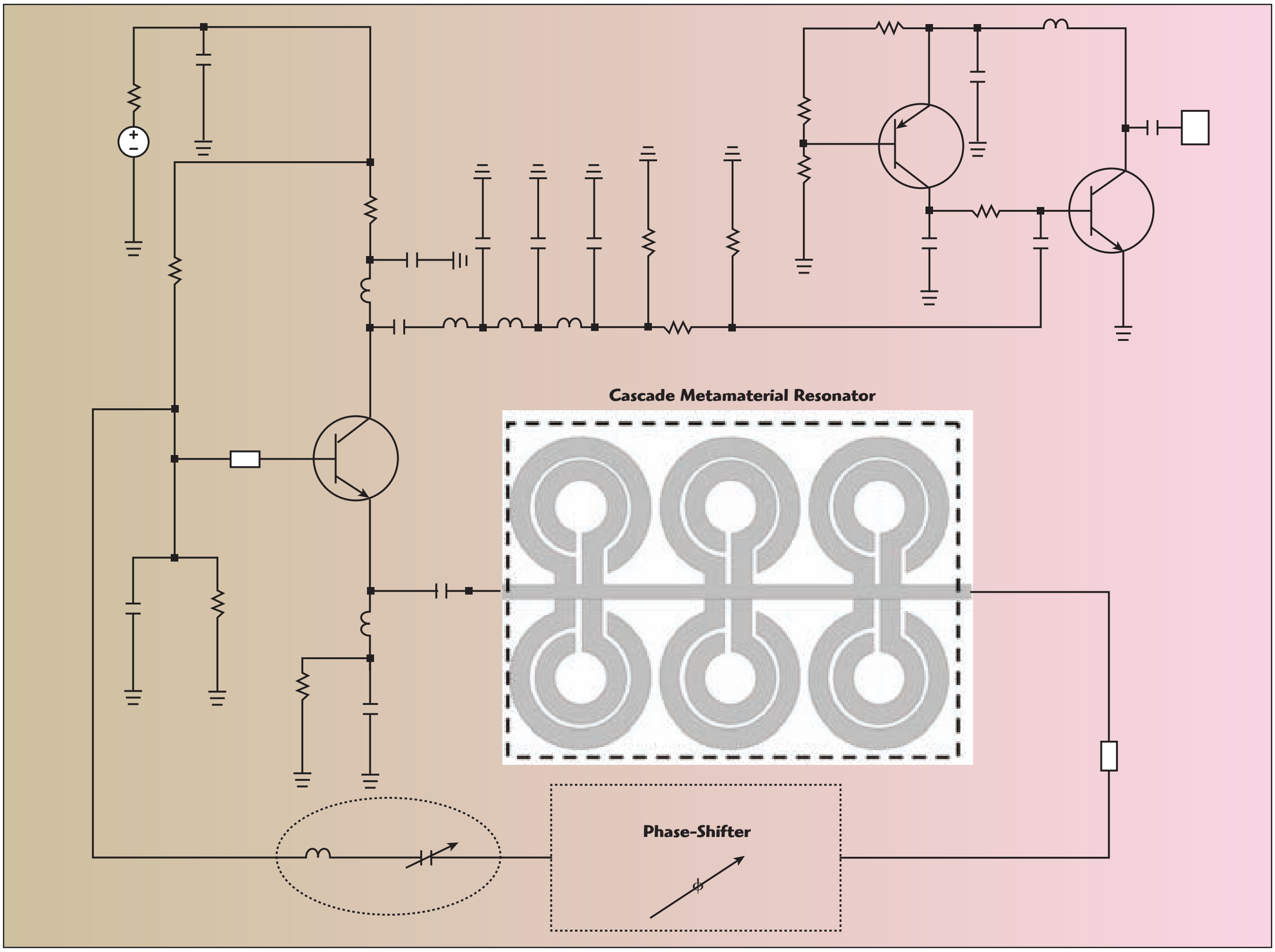
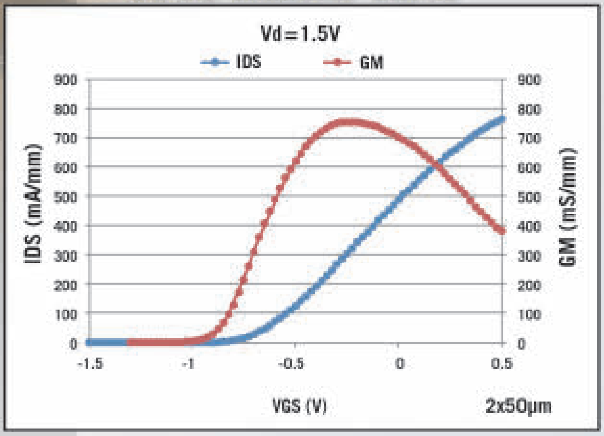



*Fig. 11 Oscillator schematic, showing the cascaded metamaterial resonator (patent pending).*

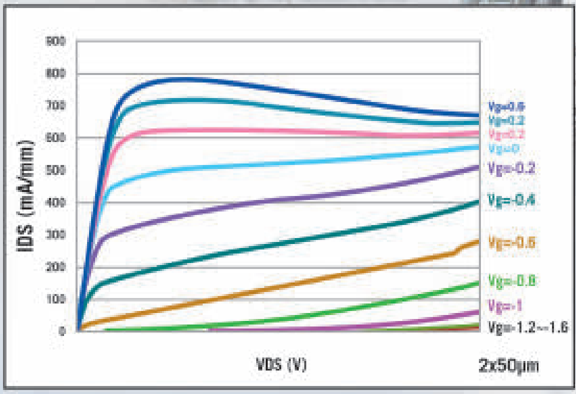
# PP10-10/-11 0.1µm Power pHEMT

- 0.1µm high performance power / low noise process
- 50µm and 100µm thickness are standard
- Useable gain to 110GHz
- 4V operation - Psat > 800mW/mm, > 50% PAE, and 13dB Gain at 29GHz

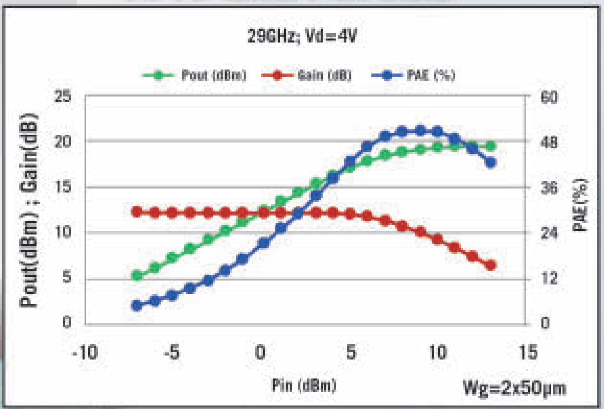
## PP10 Transfer Curve



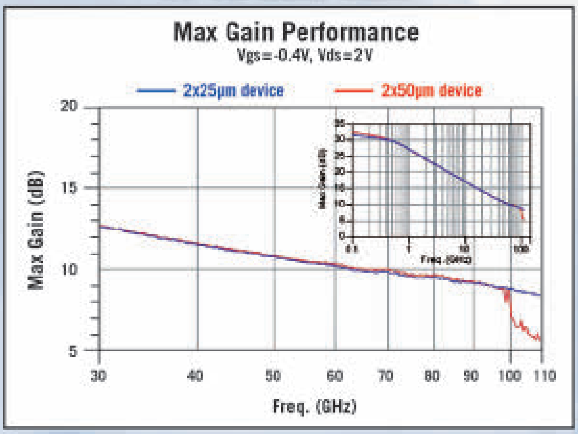

## PP10 I-V Curves



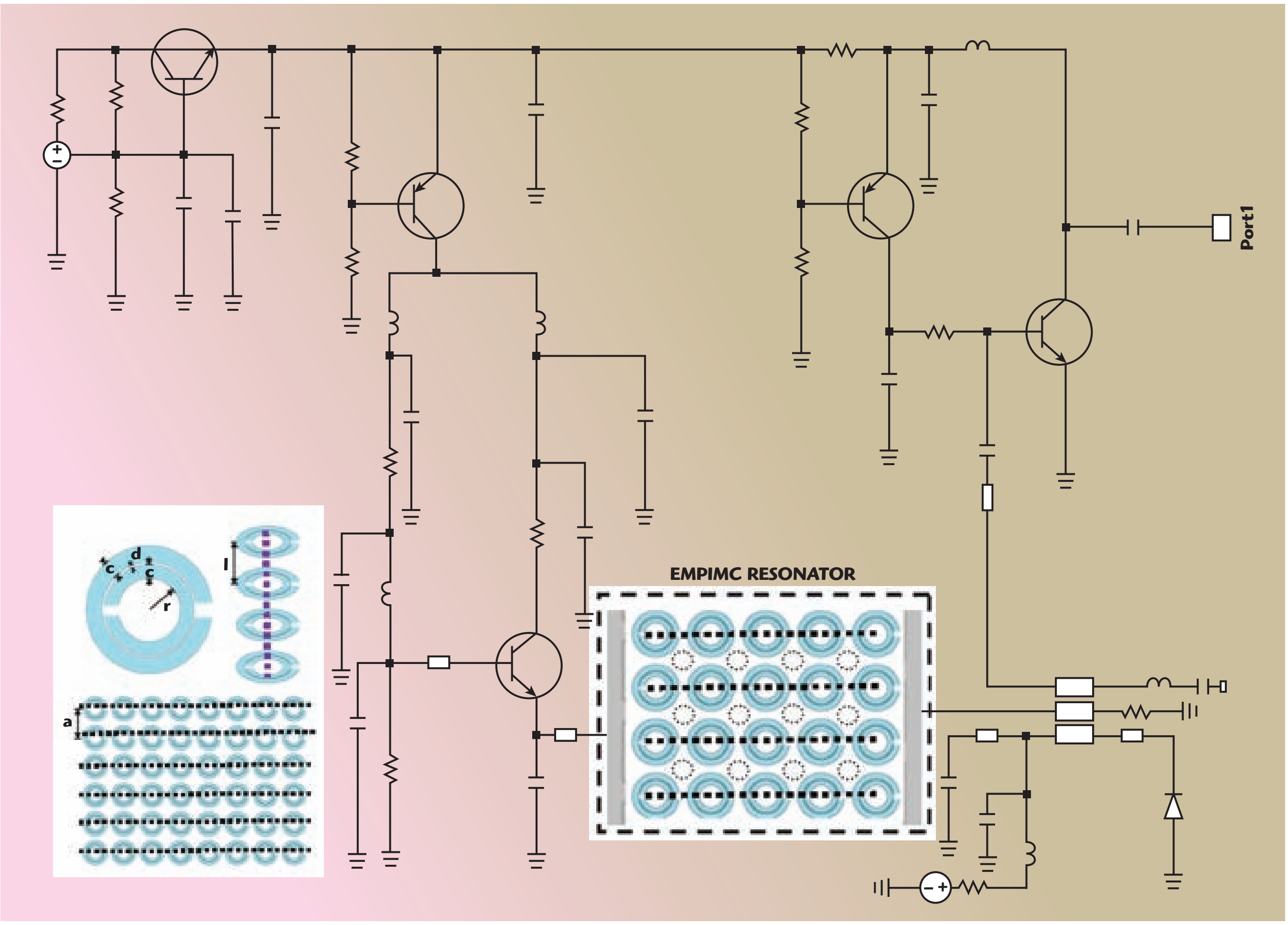

## PP10 Load Pull Data




## PP10 Max Gain




WIN SEMICONDUCTORS CORP. Tel:+886-3-397-5999 Fax:+886-3-397-5069 http://www.winfoundry.com




▲ *Fig. 12 Schematic of a tunable oscillator using a two-dimensional cascaded injection-locked metamaterial resonator network (patent pending).*

compromising the tuning range. Phase-injection locking improves the oscillator's phase noise by 50 dB (see Figure 8). Cascading resonators improves the Q of the overall resonator, because the sharp change in permittivity and permeability at resonance causes a significant increase in the group delay, multiplying the Q. However, one must be careful to avoid or suppress the degeneration modes, which limits the application to below 20 GHz.

The Q-factor of a conventional LC or printed resonator at a given frequency is independent of the current through the resonator, described by

$$Q(\omega) = \frac{\omega_0}{2}\left[\frac{\partial\phi(\omega)}{\partial\omega}\right]_{\omega\to\omega_0} \tag{12}$$

where $\phi(\omega)$ is the phase of the resonator impedance.

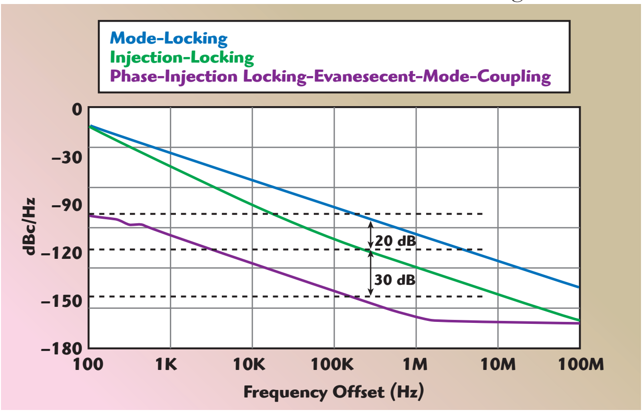
Unlike passive LC resonators, the effective inductance of the metamaterial resonator varies with current and voltage, so this definition of Q is not valid. Accounting for the variation in permittivity and permeability of a metamaterial resonator, the Q is given by[30]

$$\overline{Q_a(\omega)}_{\omega\to\omega_0} = \left[\frac{\omega}{2(I_{max}-I_{min})}\int_{I\,min}^{I\,max} Q_a(\omega,i)\,di\right]_{\omega\to\omega_0} \tag{13}$$

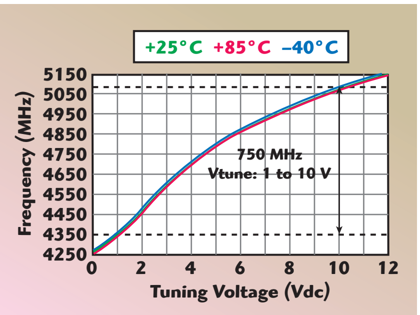
where $I_{min}$ and $I_{max}$ are the minimum and maximum currents, and $Q_a(\omega,i)$ is the instantaneous quality factor at frequency $\omega$ and current i. This equation enables the calculation of the Q-factor of a metamaterial resonator when the resonator operates in negative permeability ($\mu < 0$) or negative permittivity ($\varepsilon < 0$) conditions.

## TUNABLE EMPIMC RESONATOR BASED OSCILLATORS

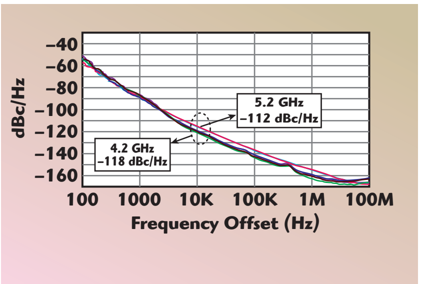
The schematic of a tunable oscillator using evanescent-mode phase-injection mode coupling is shown in ***Figure 12***. The simulated phase noise is plotted in ***Figure 13***. The oscillator covers 4.25 to 5.1 GHz with a tuning voltage from 0 to 12 V (see ***Figure 14***) and delivers a typical output power of 3 dBm. The design is biased at 5V and consumes 80 mA. As simulated,



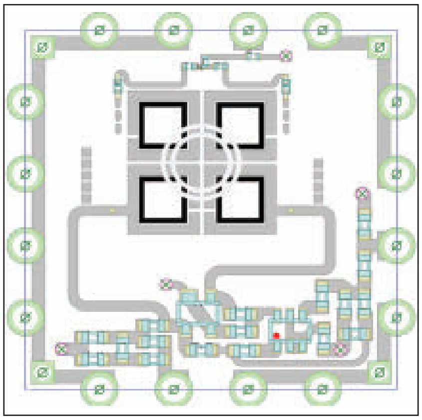

▲ *Fig. 13 Simulated phase noise of the tuned metamaterial oscillator. Phase-injection locking improves the phase noise by 30 dB.*




▲ *Fig. 14 Tuning characteristics of the oscillator.*




▲ *Fig. 15 Measured phase noise of the evanescent-mode phase-injection locking oscillator.*



▲ *Fig. 16 Board layout of the X-Band oscillator (patent pending).*

evanescent-mode phase-injection locking improves oscillator phase noise by 30 dB compared with injection-locking. The measured phase noise is plotted in ***Figure 15***. At 10 kHz offset, the phase noise ranges from -118 dBc/Hz at 4.2 GHz to -112 dBc/Hz at 5.2 GHz.

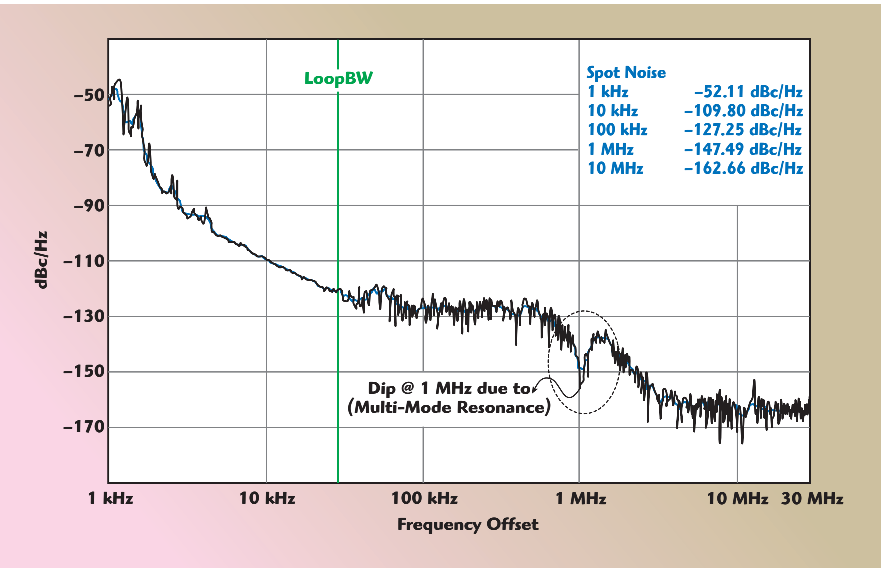
## X-BAND TUNABLE EMPIMC RESONATOR OSCILLATOR

An oscillator using a novel mode-locked evanescent-mode metamaterial resonator was developed to provide a tunable signal source for X-Band radar applications. The design uses SiGe HBTs as the active stages and provides 5 dBm output power, drawing 30 mA at 10 V bias. The oscillator is assembled on a 20 mil board with a dielectric constant of 2.2 (see ***Figure 16***).

The phase noise of the design, shown in ***Figure 17***, exhibits a hump and dip at around 1 MHz offset. This reflects the resonator mode jumping phenomena or, possibly, phase-injection from the measurement equipment. To overcome mode-jumping and tuning problems, mode stabilization is incorporated into the design by introducing a mode-suppression ring that allows multi-mode self-injection into the Möbius strip cavity. A block diagram of the design is shown in ***Figure 18***, with the board layout in ***Figure 19***. ***Figure 20*** plots the measured phase noise of the new design, which has significantly lower phase noise and no hump or dip at 1 MHz offset.

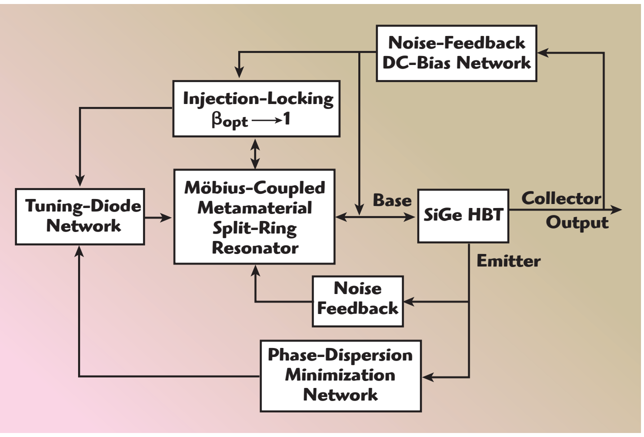
## TUNABLE MULTI-BAND OSCILLATORS

The concept of evanescent-mode Möbius metamaterial resonator oscillators can be utilized to make com-



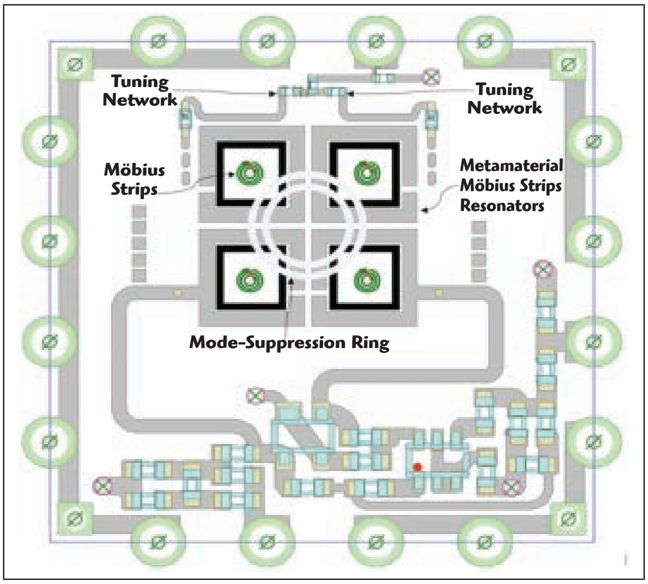

▲ *Fig. 17 Measured phase noise of the X-Band oscillator showing jumping phenomenon at 1 MHz offset.*

pact, tunable, multi-band oscillators that cannot be achieved with conventional printed transmission line resonators. As an example, a tunable oscillator was developed covering four bands: 2 to 2.5, 2.5 to 3, 3 to 3.5 and 3.5 to 4 GHz. It provides a cost-effective alternative to traditional VCOs for wireless applications.




▲ *Fig. 18 Block diagram of the mode-stabilized oscillator design.*

A simplified circuit schematic is shown in ***Figure 21***. Fourth-order, evanescent-mode metamaterial resonators are used to generate the four multi-band frequencies without multipliers or switching among resonators and oscillators. This approach reduces the complexity, size and power consumption of the oscillator, compared with other methods, and achieves excellent phase-noise performance. The multiple-band oscillator requires only 20 mA at 5 V bias and delivers 3 dBm typical output power. The simulated



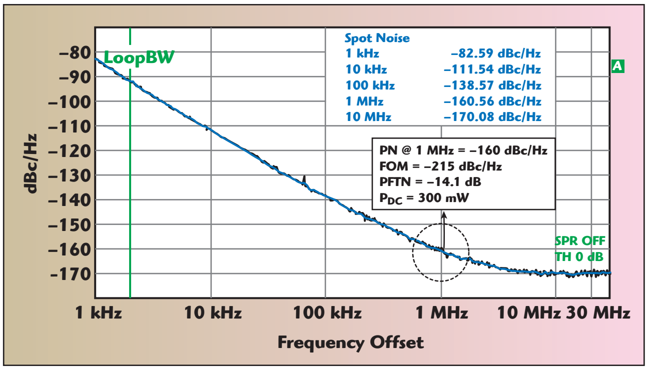

▲ *Fig. 19 Board layout of the mode-stabilized VCO showing the Möbius strips and mode suppression ring.*

phase noise is better than -130 dBc/Hz at 1 MHz offset for any of the four bands, as shown in ***Figure 22***. The measured phase noise (see ***Figure 23***) agrees with the simulations within 3 to 5 dB.

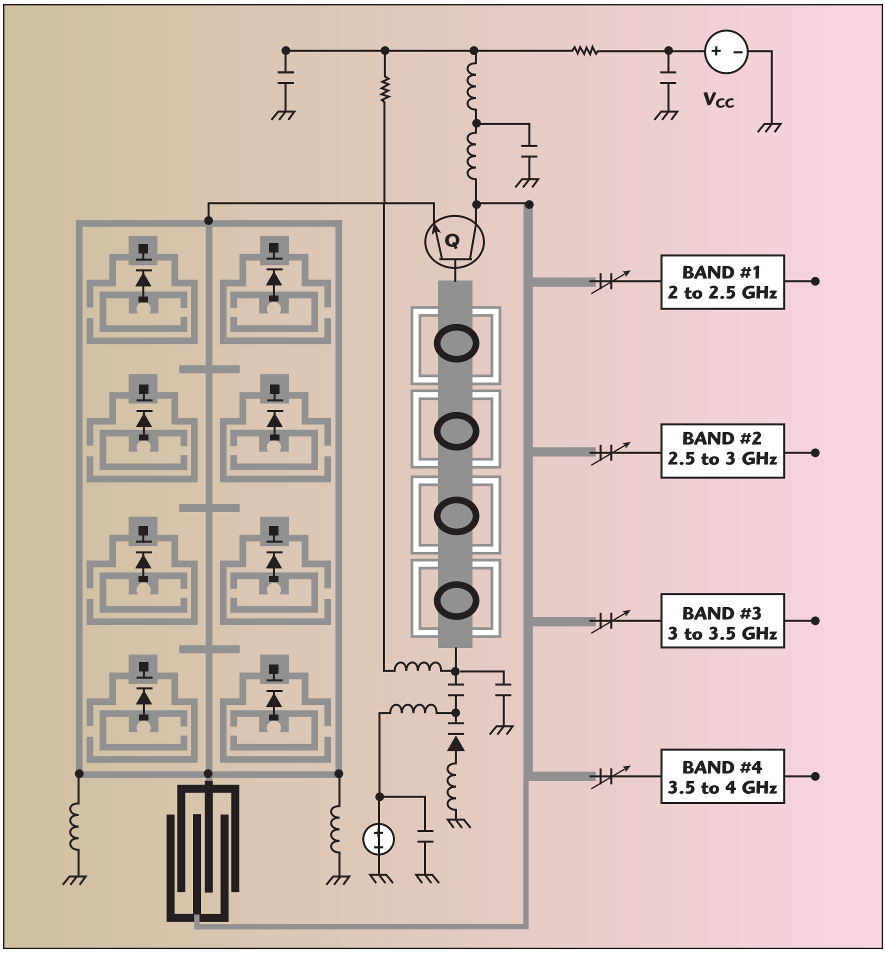
## CONCLUSION

Möbius metamaterial technology is a promising alternative to high frequency planar VCO solutions for radio communication systems, enabled by the development of MMIC fabrication techniques and the broad application of this artificial material. As shown in Table 1, the VCO designs presented in this article show superior FOM and PFTN performance for a given class, topology and BOM.

As stated throughout this series, the Möbius strip has captured the imaginations of mathematicians and engineers since it was discovered. Its non-orientability and one-sidedness continue to intrigue. Even as applications like conveyor belts with twice the lifespan of non-twisted belts fade out of use, new applications of the Möbius strip, such as the Möbius resistor, are discovered. The Möbius strip will continue to appear, both as a novelty mathematical figure and an

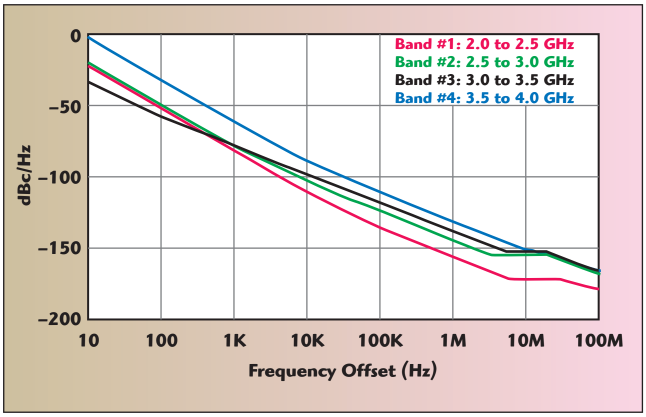



▲ *Fig. 20 Measured phase noise of the X-Band oscillator after mode stabilizing the design. The noise floor has been significantly improved, with no jumping at 1 MHz offset.*

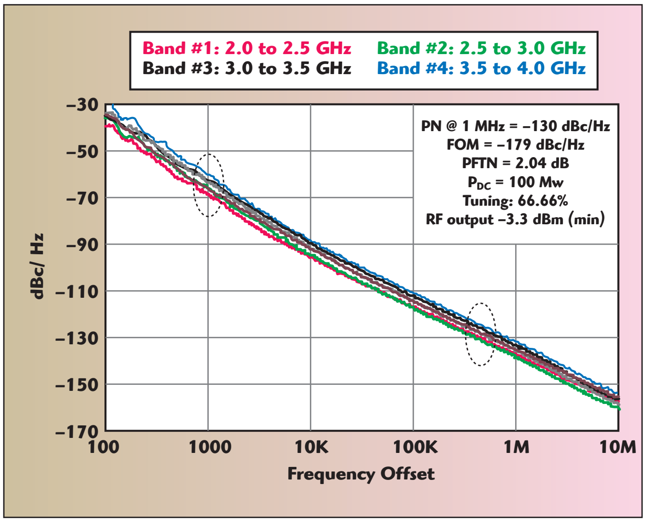



▲ *Fig. 21 Simplified schematic of a tunable multi-band oscillator design using an evanescent-mode metamaterial resonator network (patent pending).*

essential component in inventions, recurring in an endless – one could even say Möbius – loop. ■




▲ *Fig. 22 Simulated phase noise of the multi-band VCO design, designed to cover 2 to 4 GHz.*




▲ *Fig. 23 Measured phase noise of the multi-band VCO design covering 2 to 4 GHz.*

## References

1. D. Hamand and A. Hajimiri, "Concepts and Methods in Optimization of Integrated LC VCOs," *IEEE Journal of Solid-State Circuits*, Vol. 36, No. 6, pp. 896–909, June 2001.
2. F. Xu and K. Wu, "Guided-Wave and Leakage Characteristics of Substrate Integrated Waveguide," *IEEE Transactions Microwave Theory & Techniques*, Vol. 53, No. 1, pp. 66–73, January 2005.
3. Y. Dong and T. Itoh, "A Dual-Band Oscillator with Reconfigurable Cavity-Backed Complementary Split-Ring Resonator," *IEEE MTT-S International Digest*, June 17–22, 2012, pp. 1–3.
4. F. F. He, K. Wu, W. Hong, L. Ha and X. Chen, "A Low Phase-Noise VCO Using an Electronically Tunable Substrate Integrated Waveguide Resonator," *IEEE Transactions Microwave Theory & Techniques*, Vol. 58, No. 12, pp. 3452–3458, December 2010.
5. S. Sirci, J. D. Martinez, M. Taroncher and V. E. Boria, "Varactor Loaded Continuously Tunable SIW Resonator for Reconfigurable Filter Design," *Proceedings 41st European Microwave Conference*, 2011, pp. 436–439.
6. D. Ozis, N. M. Neihart and D. J. Allstot, "Differential VCO and Passive Frequency Doubler in 0.18 mm CMOS for 24 GHz Applications," *IEEE RF IC Symposium Digest*, 2006.
7. S. Ko, J. G. Kim, T. Song, E. Yoom and S. Hong, "20 GHz Integrated CMOS Frequency Sources with a Quadrature VCO Using Transformers," *IEEE RF IC Symposium Digest*, 2004.
8. H.H. Hsieh and L.H. Lu, "A Low-Phase-Noise K-Band CMOS VCO," *IEEE MWCL*, Vol. 16, No. 10, pp. 552–554, October 2006.
9. C. M. Yang, H. L. Kao, Y. C. Chang and M. T. Chen, "A Low Phase Noise 20 GHz Voltage Control Oscillator Using 0.18 µm CMOS Technology," *IEEE DDECS*, pp. 185–188, 2010.
10. Chien et. al., "40 GHz Wide-Locking-Range Regenerative Frequency Divider and Low-Phase-Noise Balanced VCO in 0.18 µm CMOS," *IEEE International SSC Conference Technical Digest*, February 2007, pp. 544–545.
11. Y. Wachi, T. Nagasaku and H. Kondoh, "A 28 GHz Low-Phase-Noise CMOS VCO Using an Amplitude Redistribution Technique," *IEEE International SSCF Tech. Digest*, February 2008, pp. 482–483.
12. H.Y. Chang and Y.T. Chiu, "K-Band CMOS Differential and Quadrature Voltage-Controlled Oscillators for Low-Phase-Noise and Low-Power Applications," *IEEE Transactions Microwave Theory Techniques*, Vol. 60, No. 1, pp. 46–59, January 2012.
13. T.P. Wang, "A K-Band Low-Power Colpitts VCO with Voltage-to-Current Positive-Feedback Network in 0.18 µm CMOS," *IEEE MWCL*, Vol. 21, No. 4, pp. 218–220, April 2011.
14. Liu et al., "A Low-Power-Band CMOS VCO with Four-Coil Transformer Feedback," *IEEE MWC*, Vol. 20, pp. 459–461, 2010.
15. J. Kim et al., "A 44 GHz Differentially Tuned VCO With 4 GHz Tuning Range in 0.12 m SOI CMOS," *IEEE International Solid-State Circuits Conference Digest*, February 2005, pp. 416–417.

16. O. Richard et al., "A 17.5 to 20.94 GHz and 35 to 41.88 GHz PLL in 65 nm CMOS for Wireless HD Applications," *IEEE International SSC Conference Digest*, February 2010, pp. 252–253.
17. S. Choi, Y. Jeong and K. Yang, "Low DC-Power Ku-Band Differential VCO Based on an RTD/HBT MMIC Technology," *IEEE MWCL*, Vol. 15, No. 11, pp. 742–744, November 2005.
18. H. Li et al., "47 GHz VCO with Low Phase Noise Fabricated in a SiGe Bipolar Production Technology," *IEEE MWCL*, Vol. 12, No. 3, pp. 79–81, March 2002.
19. T. Nakamura et al., "A 11.1-V Regulator-Stabilized 21.4-GHz VCO and a 11.5% Frequency-Range Dynamic Divider for K-Band Wireless Communication," *IEEE Transactions on MTT*, Vol. 60, No. 9, pp. 2823–2832, September 2012.
20. F. F. He, K. Wu, W. Hong, L. Han and X. Chen, "A Low Phase-Noise VCO Using an Electronically Tunable Substrate Integrated Waveguide Resonator," *IEEE Transactions Microwave Theory Techniques*, Vol. 58, No. 12, pp. 3452–3458, December 2010.
21. Z. Chen, W. Hong, J. Chen and J. Zhou, "Design of High-Q Tunable SIW Resonator and its Application to Low Phase Noise VCO," *IEEE Microwave Wireless Components Letter*, Vol. 23, No. 1, pp. 43–45, January 2013.
22. F. Giuppi, A. Georgiadis, A. Collado, M. Bozzi and L. Perregrini, "Tunable SIW Cavity Backed Active Antenna Oscillator," *Electronic Letter*, Vol. 46, No. 15, pp. 1053–1055, July 22, 2010.
23. A. Collado, F. Mira and A. Georgiadis, "Mechanically Tunable Substrate Integrated Waveguide (SIW) Cavity Based Oscillator," *IEEE Microwave Wireless Component Letter*, Vol. 23, No. 9, pp. 489–491, September 2013.
24. H. Wang et. al., "A 60 GHz Wideband Injection-Locked Frequency Divider with Adaptive-Phase-Enhancing Technique," *2011 RFICS*, pp. 75–78.
25. Li Zhang, U. L. Rohde, A. K. Poddar and A. S. Daryoush, "Evanescent-Mode Self-Injection Phase-Locked (EMSIPL) OEO," *IEEE IMaRC Delhi*, December 14–16, 2013.
26. U. L. Rohde and A. K. Poddar, "A Novel Evanescent-Mode Mobius-Coupled Resonator Oscillators," *IEEE Joint UFFC Symposia with European Frequency and Time Forum (EFTF) and Piezo Response Force Microscopy*, July 21–25, 2013.
27. U. L. Rohde, A. K. Poddar and D. Sundararjan "Printed Resonators: Möbius Strips Theory and Applications," *Microwave Journal*, November 2013.
28. A. K. Poddar and U. L. Rohde, "Latest Technology, Technological Challenges, and Market Trends for Frequency Generating and Timing Devices," *IEEE Microwave Magazine*, pp.120–134, October 2012.
29. A. K. Poddar, U. L. Rohde and Anisha Apte, "How Low Can They Go, Oscillator Phase Noise Model, Theoretical, Experimental Validation and Phase Noise Measurements," *IEEE Microwave Magazine*, Vol. 14, No. 6, pp. 50–72, September/October 2013.
30. A. K. Poddar, "Slow Wave Resonator Based Tunable Multi-Band Multi-Mode Injection-Locked Oscillators," Dr.-Inh.-habil Thesis, *BTU Cottbus*, Germany, 2014.
31. A. K. Poddar and U. L. Rohde, "Slow-Wave Evanescent-Mode Coupled Resonator Oscillator," *2012 IEEE FCS*, pp. 1–7, May 2012.
32. A. K. Poddar. U. L. Rohde, "Evanescent-Mode Phase-Injection Mode-Coupled (EMPIMC) Metamaterial Resonator Based Tunable Signal Sources," *IEEE Wamicon*, June 6, 2014.
33. C. T. M. Wu, A. K. Poddar, U. L. Rohde and T. Itoh, "A C-Band Tunable Oscillator Based on Complementary Coupled Resonator Using Substrate Integrated Waveguide Cavity," submitted to European Microwave Symposium 2014.
34. A. K. Poddar, "Slow Wave Resonator Based Tunable Multi-Band Multi-Mode Injection-Locked Oscillators," research report submitted to the faculty of mechanical, electrical and industrial engineering of the Brandenburgische Technische Universität, Cottbus-Senftenberg, Germany, January 2013, https://www-docs.tu-cottbus.de/mikrowellentechnik/public/ajay/poddar_report_long_ebook.pdf.


Think RFHIC
GaN
1W~90W peak SMT type
Hybrid Amplifiers
Applications
Small Cell Systems
Point-to-Point Radio
Multifunction Phased Array Radar
Marine Radar
VSAT
Plasma Etching / Cleaning/ Coating
Ion Sources
Plasma Light
UV Lamps
10W~1kW(peak)
GaN Pallet & Module
Applications
Telecom, BTS & RRU
Satellite Power Amplifier
Marine Radar
Phase Array Radar
Laser & X-ray Drive
Microwave Heating
Microwave Cancer Treatment
Thin Film & Diamond Deposition
Plasma Source
RFHIC
www.rfhic.com

INVITED PAPER

Scan page using layar app

# Real Time Radar Target Generation

Steffen Heuel and Darren McCarthy
*Rohde & Schwarz, Munich, Germany*

Radar systems are used across many industries and in a variety of commercial, industrial and defense applications. Uses range from commercial applications such as automotive collision avoidance, weather and air traffic control (ATC) to defense systems such as early warning and missile tracking. The radar's application dictates its physical size, operating frequency, waveform, transmit power, antenna aperture and many other parameters. Every parameter and component must be tested to ensure proper operation.

Radar system operators are interested in functionality testing, namely target detection and tracking. To ensure the accuracy and resolution, detection and false alarm rate of the radar, targets must be generated over the entire unambiguous range, the unambiguous radial velocity interval, azimuth and elevation angles and different radar cross sections (RCS). Testing in the field can be extremely time-consuming, complex and expensive. Repeatable conditions are difficult to configure. For example, consider a radar on a fighter jet that is tested at a test range, where artificial targets are deployed, detected and tracked. The global positioning system (GPS) coordinates of the targets are compared with the collected radar data to verify radar performance.

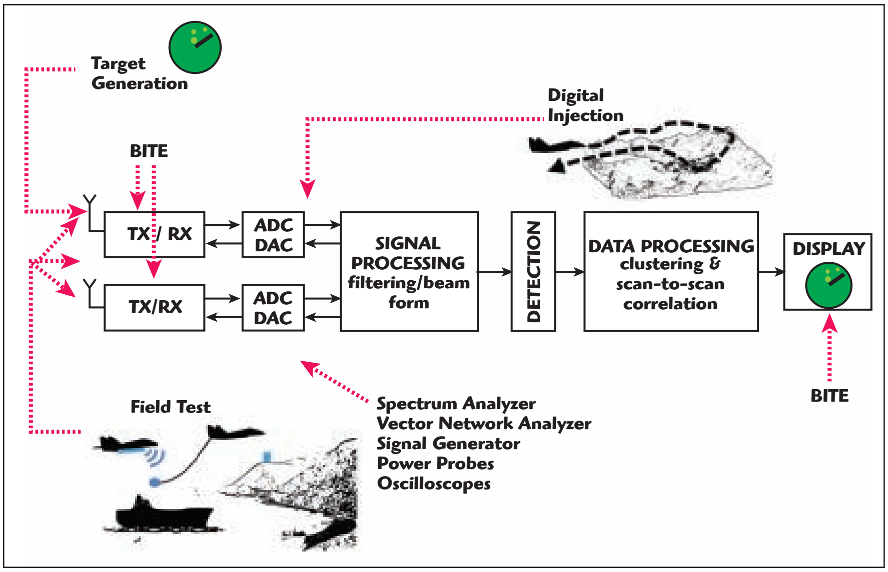
Since the cost of field-testing can be prohibitive if done on a regular basis, an alternative is to set up "real-life" radar simulations that include many different types of targets and scenarios. Generating radar targets makes it possible to test the functionality of the radar, including RF, without the expense of field testing. Radar target generators can introduce targets with time delay, Doppler frequency shift and attenuation. Several implementations of target generators have been used, including coaxial delay lines (CDL), fiber optical delay lines (FODL) and digital radio frequency memory (DRFM). Commercial off-the-shelf (COTS) measuring equipment is increasingly used.

The performance and capability of radar target generators to test a radar system depend on several technical parameters. This article explains the different target generator architectures, clarifies the performance needs and design criteria that favor one approach over another and shows examples of measurement results with a COTS system.

## RADAR TESTS – LAB OR FIELD?

Many measurements must be performed before a radar system is put into service. During research and development (R&D), mainly hardware component tests are performed. Most of these focus on the transmitter and receiver, with less emphasis on the signal processing and system functionality. As a result, the radar is only partially tested during R&D and important functionality, such as signal detection, is never completely tested in closed-loop operation. To evaluate the complete system (RF and baseband) and ensure that all elements meet specifications and customer requirements, many additional tests are required, as shown in ***Figure 1***.

Parametric measurements must be supplemented by tests to evaluate the functionality of the system. Built-in test equipment (BITE) monitors some hardware components and functionalities. While BITE is able to provide a pass-fail assessment, it is not necessarily designed to give information on the radar's per-




▲ *Fig. 1 Extensive tests are performed on a multipurpose radar system.*

formance. If a radar does not detect a target, for example, how does the operator know that the radar is not functioning properly?

To address this, field tests with towed spheres may be conducted to baseline radar capabilities and evaluate the entire radar processing chain. However, field tests won't specifically test the processing capabilities. So some radars have a digital injection capability, where scenarios can be loaded into the radar processor to test the processor.

As previously mentioned, field tests are expensive and barely reproducible, and the availability of certain targets is limited. For these reasons, radar target generators are used to replace some field tests and make tests reproducible; they save time and reduce cost and can test the entire processing chain by injecting targets. The technical demands placed on radar target generators represent a challenge to the fundamental architecture of the target generation system. While economic advantages tend to favor a laboratory test system instead of field testing, the functional performance of the radar system must be verified through a balance of laboratory and field test environments. Furthermore, as radar systems add electronic protection functionality, these new system capabilities may require new test methods.

The test and measurement (T&M) industry offers various types of radar test equipment that can be used during development and production. These focus on the parametric performance of the radar and can measure spectral purity, transmit power and sensitivity.

## RADAR TARGET GENERATORS

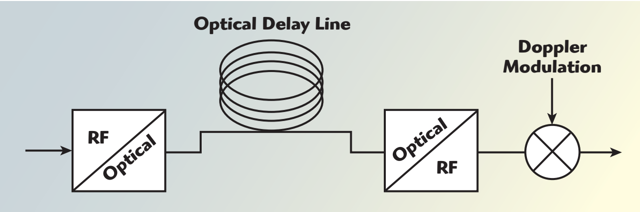
Radar target generators apply time delay (range), Doppler frequency shift (radial velocity) and attenuation to a radar signal. The actual radar signal is received, manipulated and retransmitted. Other systems have the radar waveform stored and trigger waveform replay. The architecture of radar target generators determines the performance and capability to test different levels of functionality. Some are able to generate a single target in a dedicated frequency band, for very specific radar systems, while others cover a wide frequency spectrum and offer complex target scenario simulation. There are also specific radar target generators for dedicated frequency bands, such as for testing automotive radar sensors.[1]

The performance and capability of radar target generators and their ability to test a radar system depend on several economic and technical parameters. Aside from efficiency and cost, the following technical parameters are important:

- System architecture
- Frequency coverage and bandwidth

- Phase noise performance, signal distortion, spurious emissions and overall echo signal quality
- Digitization performance, sampling frequency and number of effective quantization bits
- Maximum Doppler frequency shift and Doppler steps
- Maximum range, minimum range and range steps
- Trigger and/or continuous operation
- Flexibility to reproduce authentic environmental scenarios and possible tests of interest.

Operating frequencies of radar systems vary over a wide range of bands: Long range surveillance radars operate in high frequency (HF) or L-Band, ATC radars in S-Band, naval surveillance radars in X-Band and automotive radar sensors in K- and W-Band. Therefore, the radar target generator should cover a broad spectrum. The bandwidth of the target generator must faithfully reproduce the radar waveform, as bandwidth determines the range resolution and the span of frequency agile radars.




▲ *Fig. 2 Simplified block diagram of a fiber optical delay line (FODL).*

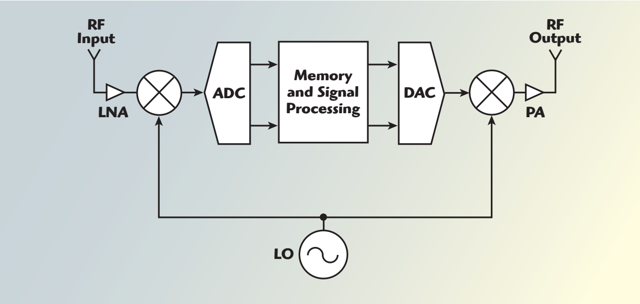
Signal fidelity and phase noise are also important. Poor signal fidelity distorts the retransmitted signal. The radar can only detect slow moving targets if it has low phase noise performance; if the target generator has high additive phase noise, it may limit the ability to assess the actual performance of the radar.

To simulate delay and Doppler, digitization is used in most modern radar target generators. The radar signal is captured, digitized, manipulated, converted to analog and retransmitted with attenuation. The effective number of bits (ENOB) and spurious-free dynamic range (SFDR) quantify the quality of an analog-to-digital converter (ADC) and are important parameters for accurately representing the incoming radar signal and reproducing the radar echo. Other parameters, such as the minimum and maximum range, the number of targets or test scenarios, mainly depend on the signal processing performance, architecture and baseband processing capabilities of the radar target generator.

Today, radar engineers use the following types of radar target generators:

### Fiber Optic Delay Lines (FODL)

FODLs have been used for several decades to test radar systems, measuring phase noise and simulating reproducible signals for outdoor range testing. These small, relatively flexible, and phase-coherent systems convert the RF signal to optical, delay it with a fiber optic line of a defined length, reconvert it to RF and retransmit it to the radar (see ***Figure 2***). Some systems are able to introduce Doppler frequency shift.




▲ *Fig. 3 Simplified block diagram of a DRFM system.*

The phase velocity of an optical signal in fiber is approximately 5 µs/km, and the loss is on the order of 0.5 dB/km. Hence, the FODL achieve very good range spacings, i.e., in the domain of picoseconds, when cut properly. The bandwidth of a FODL is very high. With multimode fibers, bandwidth is mainly limited by the modal dispersion, which is in the range of GHz/km. In single-mode fibers, modulation bandwidth is limited by material dispersion and can be 100 GHz/km for a wavelength with very low dispersion.[2] Dynamic range is limited by quantum noise at low RF and by nonlinear processes at high RF,[3] decreasing linearly with increasing signal bandwidth.[2] With a Doppler shift added, the spurious-free dynamic range depends on additional factors and is often reduced by dozens of dB. Although the Doppler frequency shift can modulate the RF signal, the length of the fiber delay (i.e., the range) is constant, and a realistic moving target cannot be generated.

FODLs have several advantages. They have constant delay versus frequency, are immune to vibration and largely resistant to electromagnetic interference, and fiber does not radiate energy. Repeatability of simulation, low system cost and time-savings are also advantages. Where excellent close-in carrier phase noise performance is necessary, such as the fixed target suppression test, FODLs perform very well. However, they cannot generate time-variant range-Doppler targets, nor do they offer continuous range settings or arbitrary signal attenuation and gain.

## Digital Radio Frequency Memory (DRFM)

DRFMs manipulate the radar signal digitally, as shown in ***Figure 3***. A DRFM down converts, filters and digitizes the received RF signal. The digital data is stored and/or modified, then reconverted to analog and upconverted to RF using the same local oscillator (LO) used for down conversion. Amplification and retransmission of the RF finalizes the processing chain.

The ALQ-165 airborne self-protection jammer (ASPJ) was one of the first DRFMs designed, with development beginning in 1979.[4] ASPJ initially covered 0.7 to 18 GHz and later, from 1 to 35 GHz. The average cost was $1.27 million.[5]

Technical performance specifications and the cost of a DRFM are rarely available publicly. From what information is available, the cost of a

# Planar Monolithics Industries, Inc.

*Offering State-Of-The-Art RF and Microwave Components & Integrated Assemblies From DC to 40GHz*

- Amplifiers
- Attenuators - Variable
- DLVA & ERDLVA & SDLVA's
- DTO's & Frequency Synthesizers
- Filters
- Form, Fit & Function Products
- IFM's & Frequency Discriminators
- Integrated MIC/MMIC Modules
- I/Q Vector Modulators
- Limiters & Detectors
- Log Amplifiers
- Pulse & Bi-Phase Modulators
- Phase Shifters
- Rack & Chassis Mount Products
- Receiver Front Ends & Transceivers
- Single Sideband Modulators
- SMT & QFN Products
- Solid-State Switches
- Switch Matrices
- Switch Filter Banks
- Threshold Detectors
- USB Products

## ANOTHER PMI BREAKTHROUGH IN HYBRID MIC/MMIC UP & DOWN CONVERTERS

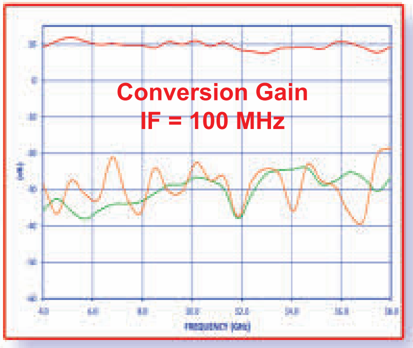
## PMI Model No. PUC-4G18G-CD-1

### KEY FEATURES:

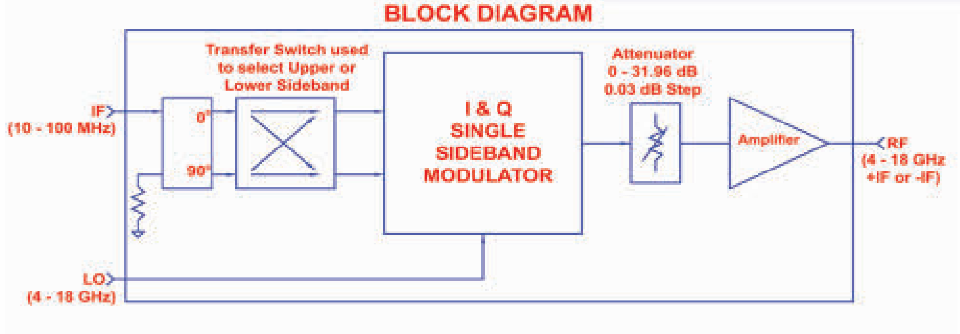
- 4.0 to 18.0 GHz RF Range
- Selectable Side Bands
- 10 to 100 MHz IF Range
- 10dB Conversion Gain
- 25dBc Typical Suppression

| | |
|---|---|
| Frequency Range | 4.0 to 18.0GHz |
| Conversion Gain | 10dB, ±3dB max<br>(RF+ 0dBm, IF Modulation = +14dBm) |
| Max Input Power | 20dBm max |
| VSWR | 2.0:1 max<br>(RF - 0dBm, IF Modulation - +14dBm) |
| Carrier Suppression | 20dBc min, 25dBc typ |
| Side Band Suppression | 15dBc min, 20dBc typ |
| IF Frequency Range | 10MHz to 100MHz |
| Power Supply | +15V @ 400mA max<br>-15V @ 100mA max |
| RF Output 1dB Compression | 12dBm typ<br>(RF = 2dBm, IF Modulation = +14dBm) |
| RF Input 1dB Compression | 5dBm typ<br>(IF Modulation - +14dBm, >5dB Attenuation) |
| Sideband Switching Speed | 150ns max |
| RF Connectors | SMA(F) Inputs and Outputs |
| Data Control Input | True Binary |
| Logic Levels | TTL & LVTTL Compatible |
| Latch | Logic "1" = Data Transparent<br>Logic "0" = Data Locked |
| Size | 6.5" x 2.5" x 0.5" |
| Finish | Painted Blue |
| **Attenuator** | |
| Attenuation Range | 0 to 31.96dB |
| Number of Attenuation Bits | 10-Bits (1024 Steps) |
| Max Attenuation Step Size | 0.03dB |
| Switching Speed | 500ns max |


Sideband Switching Speed
45ns Measured




### BLOCK DIAGRAM





*West Coast Operation:*
4921 Robert J. Mathews Pkwy, Suite 1
El Dorado Hills, CA 95762 USA
Tel: 916-542-1401 Fax: 916-265-2597
ISO9001:2008 REGISTERED

*East Coast Operation:*
7311-F Grove Road
Frederick, MD 21704 USA
Tel: 301-662-5019 Fax: 301-662-1731
ISO9001:2008 REGISTERED

Email: sales@pmi-rf.com
Website: www.pmi-rf.com


Hermetic Sealing, High Reliability to Mil-Std-883, Small Quantity Requirements accepted & we offer Custom Designs too single DRFM module ranges from $150 to $700 thousand, depending on capabilities.[6] DRFMs can cover up to 40 GHz, offer 12-bit digitization with 1.4 GHz instantaneous bandwidth, -65 dBc SFDR and a minimum delay of 90 ns. Due to technical restrictions, however, these figures cannot be combined into a single DRFM. For example, most of the wideband DRFMs have lower signal fidelity and use less than 12 bits.

The minimum delay is primarily limited by the ADC and DAC, which take several cycles to convert the analog data to digital and vice versa. The delay also depends on the bandwidth and number of bits. Signal processing adds a number of processing cycles to the radar echo signal. Typical minimum delays now range from below 100 ns to below 1 µs.

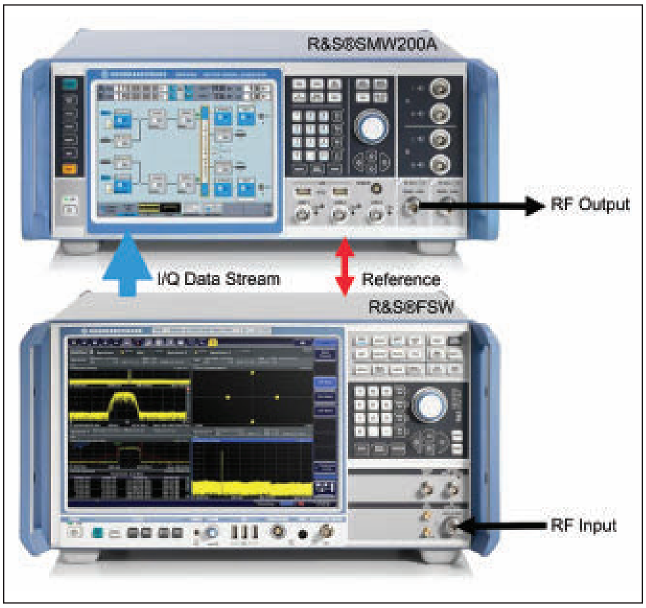
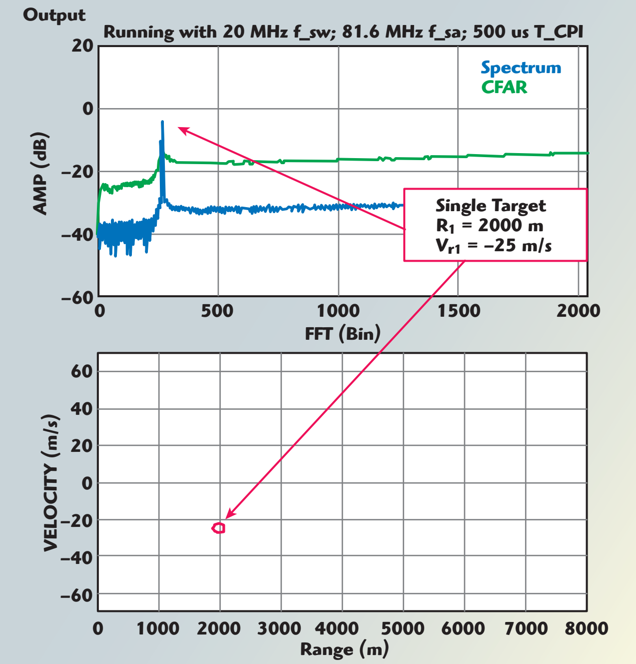



Fig. 4 Example of a COTS radar target generator using the R&S®SMW200A vector signal generator and R&S®FSW signal and spectrum analyzer.

With DRFMs it is important to know how the analog RF signal is represented in the digital domain: the number of bits, amplitude and phase. These determine the signal fidelity. Another key parameter is the SFDR, because the radar may try to discriminate between targets and electronic countermeasure (ECM) signals. The SFDR will be limited depending on the ENOB, nonlinearity of components and the noise.



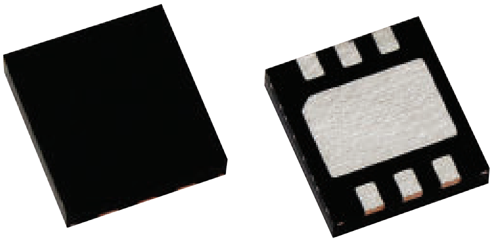

Target Detected

| | Target | R | vr | Ghost Targets |
|---|---|---|---|---|
| 1 | 1 | 2000.13 | –25.0037 | 1 |
| 2 | 0 | 0.00 | 0.00 | 0 |
| 3 | 0 | 0.00 | 0.00 | 0 |
| 4 | 0 | 0.00 | 0.00 | 0 |

Fig. 5 MATLAB® display of a SDR detecting a single target at a range of 2000 m and moving at –25 m/s.


## High-Performance Wideband Amplifiers – Now in Cost-Effective Plastic Packages

- DC to 3 GHz
- 2 Stage Device
- 2 Voltages: 28V and 50V
  - 10W @ 28V
  - 20W @ 50V
- Power Gain: 24dB
- 6.5 x 7.0mm SMT Package



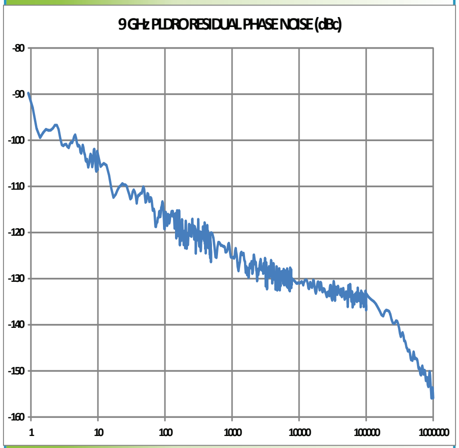
FOR SAMPLES AND EVALUATION BOARDS

COMPONENT DISTRIBUTORS, INC.
rf.cdiweb.com

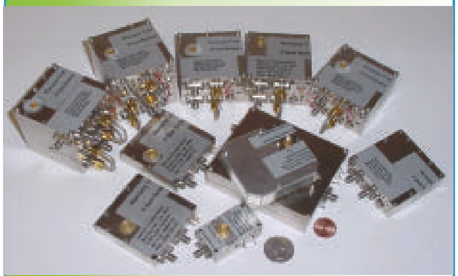
**800-777-7334**
**rf.cdiweb.com/sedi**

www.sei-device.com

SUMITOMO ELECTRIC
Device Innovations USA







While high signal fidelity DRFMs with coherent target echo returns may be suitable for radar tests, the use of a DRFM with a user interface to test a broad variety of signal conditions and scene effects may be limited. This very dedicated equipment comes at a price and perhaps, with limited flexibility to thoroughly test the functional parameters of the radar.

## Commercial Off-the-Shelf (COTS) Test and Measurement Equipment

COTS test and measurement equipment is also able to generate radar targets, in a similar fashion as DRFMs, by RF down conversion, baseband digital signal processing and RF up conversion.

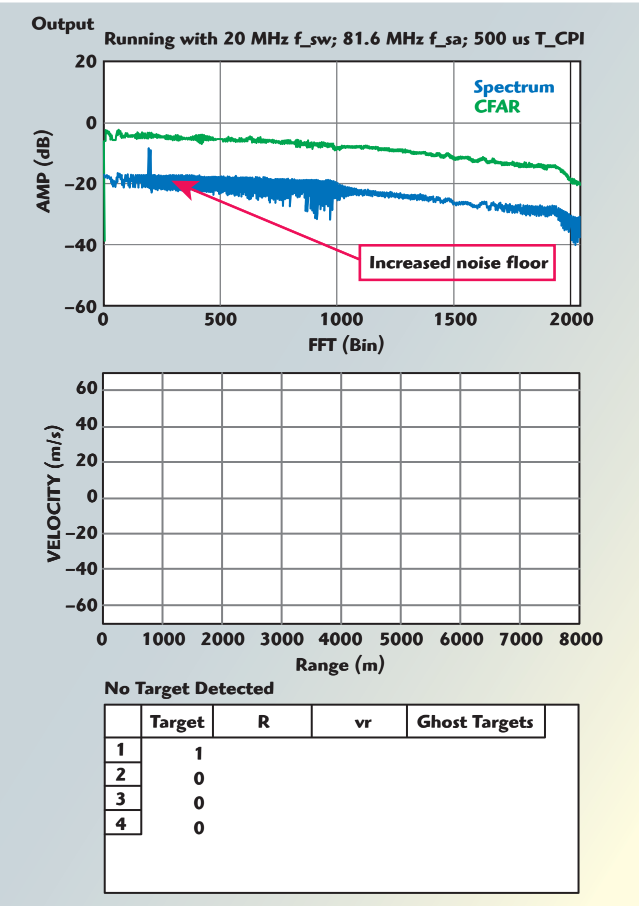
While an RF signal analyzer and RF signal generator are normally used stand-alone, the two instruments can operate as a radar target generator when used together. The radar target generator uses the signal analyzer as the receiver and the signal generator as the transmitter.

A COTS system, as shown in ***Figure 4***, operates from 100 kHz to 40 GHz and will process any type of RF radar signal in this frequency range with up to 160 MHz bandwidth. The signal analyzer converts the incoming radar signal to in-phase and quadrature-phase (I/Q) data. The I/Q data is transferred to the baseband input of the signal generator, where time delay, Doppler frequency shift and attenuation are applied as defined by the user. The radar echo signal is then retransmitted to the radar by the signal generator.

One advantage of using COTS measuring equipment is its exceptional RF performance, which is suitable for additional parametric radar tests during research and development or production. The flexible and modular approach allows the vector signal generator and signal and spectrum analyzer to be used in other setups or in a dedicated field installation.

## COTS RADAR TARGET GENERATOR DEMO

A software defined radar (SDR) using MATLAB® signal processing can demonstrate the capability of a COTS radar target generator. A single target with a range of 2000 m and velocity of -25 m/sec is created by the radar target generator and "detected" by the SDR. The MATLAB® graphical user interface (GUI) of the radar (see ***Figure 5***) shows the spectrum (top), range-Doppler map (middle) and target list (bottom). The spectrum plot shows a single local maxima whose power is higher than the constant false alarm rate (CFAR) threshold. By measuring the beat frequency, the range and radial velocity are calculated, which match the target created by the radar target generator.




▲ *Fig. 6 Display of the SDR detecting the same target in the presence of a CW frequency-modulated interfering signal.*

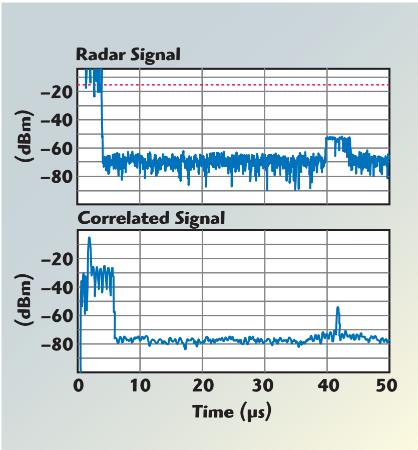
The COTS radar target generator can generate up to 20 targets in different range-Doppler cells. The signal generator also has multiple RF sources, making it possible to test the radar in the presence of interference, such as cellular or other services.[7] ***Figure 6*** shows the same radar target with a second, frequency-modulated continuous-wave signal. The noise floor is significantly higher. While the radar echo signal can still be observed visually, the CFAR threshold is too high for an automatic detection.

In addition to testing the functional performance of the radar, the COTS target generator can help assess modern electronic protection measures in the radar, such as detecting the presence of a DRFM used as a jammer. An example of the importance of this occurred in mid-2014, when several aircraft vanished from ATC radar screens in Europe, which occurred coincidentally with military exercises.[8]

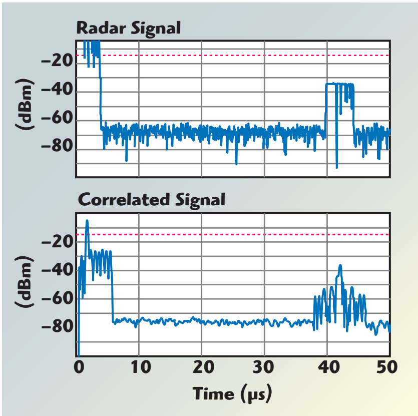
A phase-modulated radar waveform, such as a Barker code, can be used to test the performance of the radar's signal processing. The Barker code is transmitted and delayed in the radar target simulator. The radar has a very specific baseband waveform, and the radar receiver can detect the fidelity of the echo and, using correlation filters, whether the echo is virtual or real. An uncorrelated signal might result from an ECM system, due to resampling at a different rate, a small number of effective bits in the ADC, phase noise or amplifier distortions in the target simulator. Depending on the DRFM, the generated echo signal fidelity will likely be different than one from a real target.

The radar processes focused on electronic protection can detect differences in fidelity in the returned echo. ***Figure 7*** shows a Barker-coded






▲ *Fig. 7 Barker-coded radar signal (top), showing the echo after 40 μs, correlated echo signal (bottom).*




▲ *Fig. 8 Barker-coded radar signal (top) with an uncorrelated echo, representing a DRFM return signal created at a different sampling rate (bottom).*

EWT
Where Performance Counts
Bandpass • Bandreject • Highpass • Lowpass • Transmit • Receive • Duplexers • Multiplexers
Military • Commercial
Wireless • Space
Eastern Wireless TeleComm understands just how much is on the line with each and every product we make. We continually provide the highest quality filter products, design support, and service to our customers each and every time. Where Performance Counts, Count on EWT.
Specializing in custom design and manufacturing of RF and Microwave filters and filter based products to 50 GHz.
www.ewtfilters.com
Eastern Wireless TeleComm, Inc.
Tel: 410.749.3800 Fax: 410.749.4852
sales@ewtfilters.com

radar signal at the beginning of the measurement and the corresponding radar echo signal attenuated about 50 dB and delayed by 40 µs. The lower plot shows the return signal processed with the correlation filter. ***Figure 8*** shows the echo signal processed with a different sampling rate, as might occur in a DRFM. The different signal fidelity causes the correlation of the echo signal to change fairly dramatically.

## CONCLUSION

The reliability expected of radar systems is extremely high, which is why test and measurement is very important. This article presented several different approaches to using radar target generators to test the entire radar system, including the antenna, transmitter, receiver and signal processing. Comparing the technical performance and economic factors, a perfect balance would bring many field tests into the lab and reduce the cost of software and hardware testing.

The target generator's RF performance must be better than the performance of the radar and offer a variety of test scenarios. FODLs are still used but lack flexibility, for example in generating range-Doppler-dependent targets. A DRFM overcomes this drawback and offers additional options for generating radar echo signals. However, DRFMs are dedicated solutions, can be costly and are not designed to be as flexible as test equipment. COTS test and measurement equipment offers a wide range of test solutions, from signal and component test and analysis to radar target generation. Such equipment is modular, multi-purpose and flexible; it can be used both as a radar target generator and serve other functions in a laboratory.

These different radar target generator approaches each have their own advantages, yet all bring parts of the field test into the laboratory, reducing test complexity and lowering costs. They provide repeatability and automated test capabilities.■

## References


1. "Rohde & Schwarz Enables Comprehensive Automotive Radar Tests with Target Simulator and FM CW Signal Analysis," press release, www.rohde-schwarz.com/ad/press/automotive, October 2014.
2. K.P. Jackson et. al., "Optical Fiber Delay-Line Signal Processing," *IEEE Transactions on Microwave Theory and Techniques*, Vol. MTT-33, No. 3, pp. 193–210, March 1985.
3. K. Ogawa, "Considerations for Single Mode Fiber Systems," *Bell Syst. Tech. Journal*, Vol. 61, pp. 1919–1931, 1982.
4. N. Friedman, "The Naval Institute Guide to World Naval Weapons Systems," 1997–1998.
5. "AN/ALQ-165 Airborne Self-Protection Jammer (ASPJ)," www.dote.osd.mil, October 2014.
6. Small Business Innovation Research (SBIR), Navy, Topic N131-006, *Acquisition Program*, "Direct Digital Radio Frequency (RF) Conversion Digital Radio Frequency Memory (DRFM)," 2013.
7. S. Heuel and A. Roessler, "Co-existence Tests for S-Band Radar and LTE Networks," *Microwave Journal - Military Microwaves*, August 2014.
8. Reuters, "Jets Vanishing from Europe Radar Linked to War Games," www.reuters.com/article/2014/06/13/us-europe-airplanes-safety-idUSKBN0EO1CW20140613, November 2014.


FLORIDA RF Labs
Lab-Flex® Q
&
Lab-Flex® AF
The COMPLETE cable assembly solution
for Ground, Airborne and Satellite communications.
• Space applications qualified to NASA/ESA requirements with over 30 years in flight.
• Rugged Aircraft assemblies per MIL-T-81490, MIL-STD-810 for both static applications and dynamic antenna applications.
• Ground based SatCom, Fixed Stations or Mobile Vehicles, specific hermetic designs for all types of harsh environments.
Challenged with a
High Rel cable design?
Transmit no further than Florida RF Labs
and Receive a complete solution.
smiths microwave
www.emc-rflabs.com

INVITED PAPER

Scan page using layar app

# Single-Chip Millimeter Wave Radar

G. Klaric Felic, R. J. Evans, Hoa Thai Duong, Hoang Viet Le, J. Li and E. Skafidas
*University of Melbourne, Parkville, Australia*

*In this article we explore the coming consumer radar era, where tiny single-chip radar systems will be available for just a few dollars. These systems will use sophisticated waveform diversity and adaptive signal processing to optimize performance. Automotive radar concepts developed at the University of Melbourne are discussed, including CMOS RF transceivers, waveform and signal processing, and antennas.*

The idea of radar is more than 100 years old. In 1900, Nikola Tesla foreshadowed the idea of remotely detecting and locating objects using radio waves. His idea was first demonstrated in Germany in 1904 when Christian Hulsmeyer detected ships using echoes of radio signals.

While the essential idea of radar is simple, the evolution to improve performance and capabilities has been an ongoing technology driver. We believe this trend will accelerate with the emerging capabilities in single-chip millimeter wave radar that are enabled by CMOS scaling (Moore's law) and recent advances in adaptive waveform design.

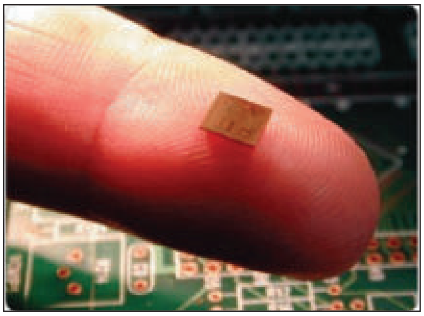
Interest in consumer applications for radar is not new, of course. In 1993, the IEE held a symposium on this very topic,[1] and low cost, handheld Doppler radar systems are already on the market (e.g., pocket radar). Today, the automotive market is arguably the main opportunity driving innovation in small, low cost millimeter wave radar. Radar systems are installed in many transportation vehicles to assist safety and comfort, providing drivers with information about the distance between vehicles and obstacles on the road. Radar systems can take another step functionally, by automatically controlling acceleration and braking to avoid collisions.

Sensing systems for "micro" unmanned aerial vehicles (UAV) is another application for small, lightweight, yet high performance radar technology. The availability of tiny and cheap radar systems is likely to open up many new applications, mimicking the transformation following the availability of small, inexpensive GPS systems.

The relentless scaling of semiconductor technology is enabling the move to higher and higher RF frequencies and integrating complete radar systems, with both RF and digital processing, on a single IC. Clever new waveform diversity techniques[2] with innovations in small antenna technology will lead to highly sophisticated consumer radar systems over the next few years.

## SINGLE CHIP RF SYSTEM

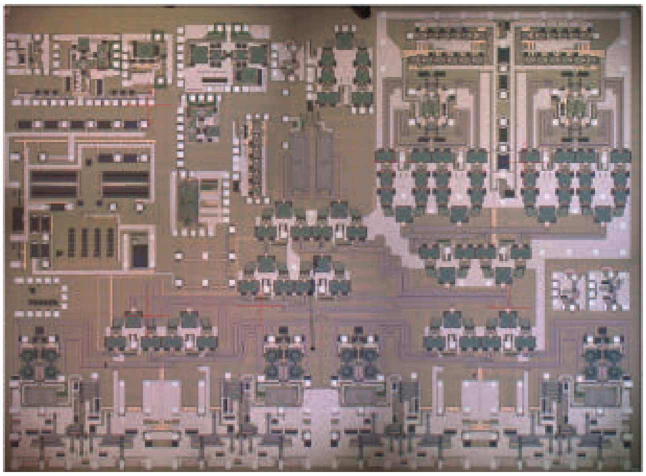
The advancement of key techniques and technologies in low cost millimeter wave radio systems has aided the development of automo-



▲ *Fig. 1 The single-chip radar transceiver developed by the University of Melbourne.*

tive radar sensors in the frequency bands from 60 to 95 GHz. Today, with the rapid evolution of SiGe bipolar and CMOS processes, a 77 GHz automotive radar transceiver can be realized in a single IC (see ***Figure 1***). The low cost and compact size of the chip are enabling the adoption by low and medium priced cars.[3–7]

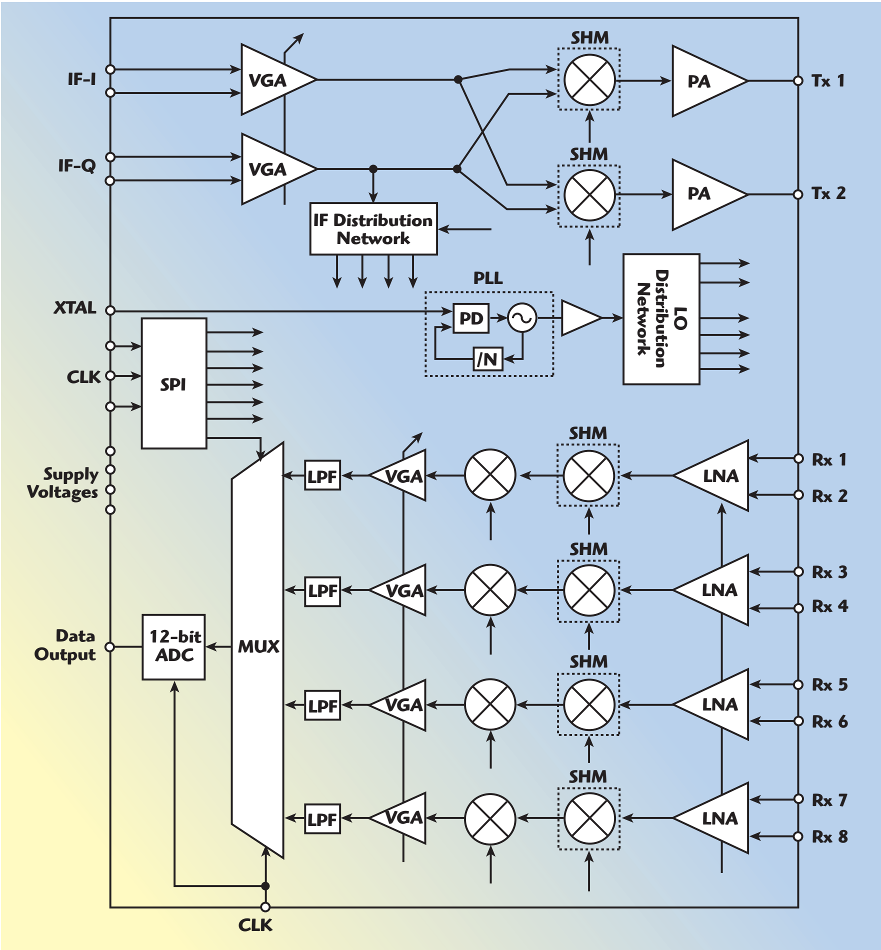
Compared with a SiGe bipolar process, CMOS is lower cost, better integrates digital circuitry and benefits from technology scaling. However, the maximum available gain (MAG) at millimeter wave frequencies is lower for CMOS, and its low supply voltage limits output power. Therefore, developing a millimeter wave CMOS transceiver is still a challenging task for many researchers.[8–13]



▲ *Fig. 2 Photograph of the single-chip CMOS transceiver die, which contains two transmit and four receive channels and the local oscillator.*

The radar sensor on a chip developed by the University of Melbourne is a CMOS transceiver (see ***Figure 2***) suitable for both short and long range sensing and operating in the globally harmonized 76 to 77 GHz band.[14-15] Design objectives were low cost, low power dissipation, compact size, flexibility and ease of use. As shown in the schematic (see ***Figure 3***), the transmitter comprises two variable gain amplifiers (VGA), sub-harmonic mixers (SHM) and power amplifiers (PA). Four receive channels, supporting eight separate receive antennas, each contain a chain of switched low noise amplifiers (LNA), SHMs, VGAs, and lowpass filters (LPF). The IF outputs from the four receive channels are multiplexed into a single 12-bit, 100 MSPS analog-to-digital converter (ADC). All the RF components – passives, amplifiers, mixers, oscillators – are fabricated on the 7.2 × 5.5 mm chip.

In the 76 to 77 GHz band, the transceiver has demonstrated 10 dBm single sideband output power[14] with LO-RF leakage power of -35 dBm. Receiver sensitivity is better than -100 dBm.[15] The gain of each receive channel is adjustable in 5 dB steps from 0 to 80 dB.




▲ *Fig. 3 Schematic showing the functional complexity of the single-chip radar transceiver.*

## WAVEFORMS AND SIGNAL PROCESSING

Radar design was put on a sound theoretical footing in 1953 when Philip Woodward developed the radar ambiguity function at TRE in England.[16] His work was based on the matched filter developed by Dwight North in 1943 at RCA Labs in Princeton, N.J. Woodward's ambiguity function characterizes the performance of a matched filter radar for any particular transmitted waveform. Unfortunately, it is not possible to precisely synthesize a transmit waveform based on the desired ambiguity function. Significant research has been devoted to the synthesis problem, including the work of Wilcox[17] on the group theoretic foundations of ambiguity theory, which enabled synthesis of a certain restricted class of waveforms. Suss-

# ATC Ultra-Broadband SMT Capacitor Solutions

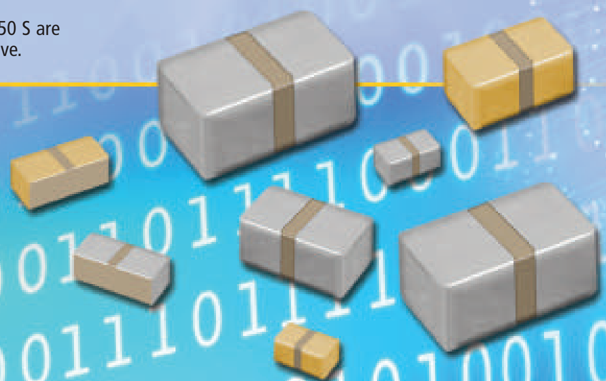
## *Reliable and Repeatable Ultra-Broadband Performance for Signal Integrity Applications*

ATC's 550 Series family of Ultra-Broadband Capacitors exhibit ultra-low insertion loss and flat frequency response from 16 KHz through 40+ GHz with excellent return loss and voltage ratings to 50 WVDC. They are ideal for use in ultra-broadband DC blocking, coupling, and bypassing for optoelectronics / high speed data, SONET, broadband test equipment and broadband microwave / millimeter-wave based applications. The 550 Series is orientation insensitive* for ease of high speed automated placement.

### Attributes

- Surface Mount EIA Case Sizes
- 16 KHz to 40+ GHz Coverage
- Ultra-Low Insertion Loss
- Voltage Ratings to 50 WVDC
- Orientation Insensitive*
- One-Piece Ceramic Construction
- Unit-to-Unit Performance Repeatablity

*550 Z, 550 L, and 550 S are orientation insensitive.



| ATC Series | EIA Size | Capacitance | Frequency Range | Insertion Loss | Voltage Rating | Orientation Insensitive |
|---|---|---|---|---|---|---|
| **550 Z** | 0201 | 10 nF | 160 KHz to 40+ GHz | <0.4 dB typ. | 10 WVDC | Yes |
| **550 U** | 0301 | 100 nF | 16 KHz to 40+ GHz | <0.4 dB typ. | 6.3 WVDC | No |
| **550 L** | 0402 | 100 nF | 16 KHz to 40+ GHz | <0.5 dB typ. | 16 WVDC | Yes |
| **550 S** | 0603 | 100 nF | 16 KHz to 40+ GHz | <1 dB typ. | 50 WVDC | Yes |

AMERICAN TECHNICAL CERAMICS

ATC North America
sales@atceramics.com

ATC Europe
saleseur@atceramics.com

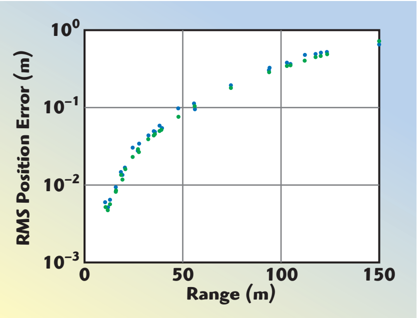
ATC Asia
sales@atceramics-asia.com

THE ENGINEERS' CHOICE™ www.atceramics.com

THE ENGINEERS' CHOICE®
ISO 9001 REGISTERED COMPANY

RoHS Compliant

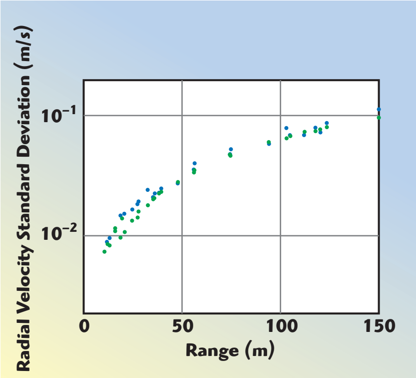
man[18] and Vakman[19] subsequently proposed Hilbert-Schmidt operator approximation techniques to approximately synthesize waveforms with specified ambiguity properties. Work in this direction is continuing.[20] Progress on this difficult yet deeply important problem has taken on a new flavor in recent years under names such as waveform diversity, adaptive waveforms and waveform scheduling.[2] Digital waveform generation and fast adaptable digital matched filter implementation allow waveform diversity techniques to be implemented even in low cost, single-chip radar systems.




▲ *Fig. 4 Position error as a function of range.*

The radar-on-a-chip developed at the University of Melbourne employs adaptive digital matched filtering and scheduling of advanced multi-frequency coded waveforms to reduce clutter, mitigate against interference and reduce the computational load in the digital signal processing. Waveforms employed include sections of fast ramping linear FM (LFM), long random stepped frequency waveforms and bursts of CW.

Typical radar performance is demonstrated with an automotive scenario consisting of 25 oncoming point scatterers, centered on, and five targets, centered around the field of view. All scatterers and targets have unity radar cross section (RCS), and the speed of each target and scatterer is chosen randomly within the range of typical automobile speeds. The performance of the radar is shown in ***Figure 4***, the range estimation error as a function of target range, and ***Figure 5***, the Doppler estimation accuracy.




▲ *Fig. 5 Doppler estimation error as a function of range.*



As radar sensing becomes ubiquitous in consumer applications, the spatial density of users utilizing a common frequency band will increase vastly. While it is fortunate that a range of techniques for mitigating interference has been developed for use in wireless communications, the requirements for radar pose distinct new challenges.

## ANTENNA SYSTEM

The antenna is a critical element in all radar systems. For automotive applications, the requirements are especially challenging: high gain and low loss for best performance traded off with small size, low cost and aesthetically pleasing for vehicles. The additional need for the radar to have wide angle visibility requires the use of multi-beam or scanning antennas and solutions based on digital beam forming with multiple antenna elements.

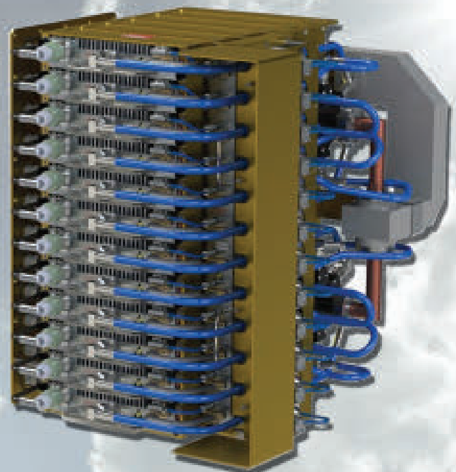
The design of the radar antenna depends on the specifications for directivity/gain, angular resolution and accuracy. These parameters determine the ability of a radar sensor to detect a target at the required distance, resolution and accuracy. The radar equation defines the required antenna directivity/gain necessary to detect an object at distance R

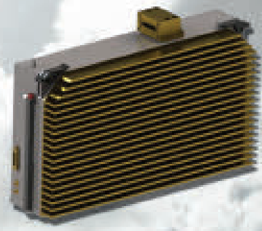
$$G_T G_R = \frac{R^4 P_R (4\pi)^3}{P_0 \lambda^2 \sigma} \tag{1}$$

where $P_0$ is the feeding power of the antenna, $\sigma$ is the radar cross section of the object, $\lambda$ is the wavelength and the receiving power $P_R$ is determined by the minimum signal-to-noise ratio. The ability of a radar system to determine the exact position of an object is based on the half power (3 dB) antenna beamwidth. For a linear array, this can be estimated by

# Solid State Power Amplifiers

S-Band



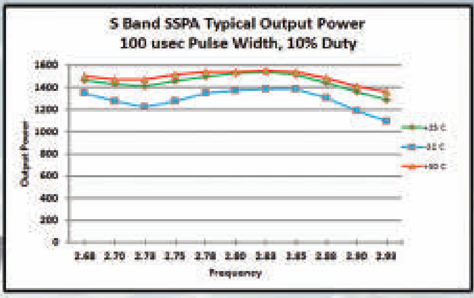


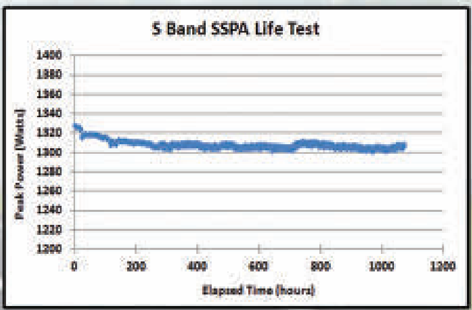
X-Band

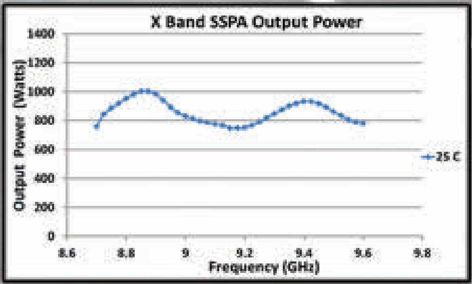
## GaN Solid State Amplifiers

### FEATURES

- High Efficiency Pulsed Modules (10% duty)
- BIT & Controls via - EIA 422
- Compact Light Weight
- High Reliability
- Field Replaceable Modules
- 9.0 - 9.2 GHz X-Band: 1 kW Modules
- 2.7 - 2.9 GHz S-Band: 1.3 kW Modules
- 1.2 - 1.4 GHz L-Band: 700 W Modules
- Power Combine Modules up to 25KW



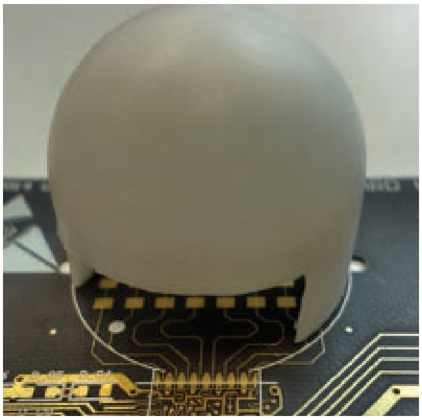




### For more information contact

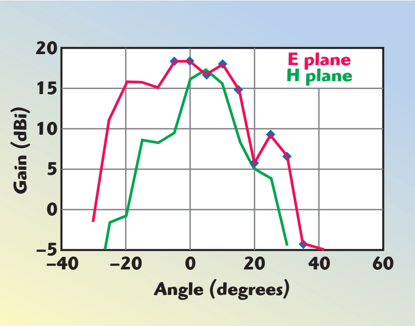
Communications & Power Industries
Beverly Microwave Division
150 Sohier Road Beverly, MA 01915
Phone:(978) 922-6000 Fax: (978) 922-2736
Email: bmdmarketing@cpii.com

CPI Communications & Power Industries

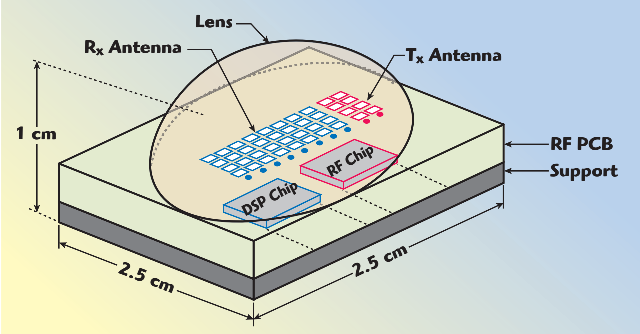
www.cpii.com/bmd
Beverly Microwave Division



▲ *Fig. 6 Photograph of the microstrip series-fed patch array and lens.*




▲ *Fig. 7 Measured antenna gain of one channel at 77 GHz.*




▲ *Fig. 8 Concept design of the integrated radar system. The single-chip RF transceiver, DSP, patch antenna array and lens are integrated on a PCB to minimize cost.*

$$\Delta\theta_{3dB} = \frac{\lambda}{d\cos(\theta)\sqrt{M^2-1}} \quad (2)$$

where M is the number of antenna elements, d is distance between the antennas and θ is the beam angle towards the normal of the air-dielectric interface. The angular accuracy can be determined with the signal-to-noise ratio of the system as

$$\delta\theta_{3dB} = \frac{\Delta\theta_{3dB}}{\sqrt{2S/N}} \quad (3)$$



Mid and long-range radar systems have smaller beam-width than short-range antennas. For 77 GHz long-range radar, 3 to 4 degree beamwidths are typically required. This results in very large arrays and gains around 30 dB, which led the first automotive radar systems for long-range detection to adopt parabolic reflector or lens antennas.[21] The advantage of lens over reflector antennas is that the feed is not in the path of the secondary rays; however lens antennas are typically thicker, heavier and more difficult to construct. The need for small sensor depth in vehicles limits their use.

The University of Melbourne radar sensor uses a dielectric lens antenna illuminated by series-fed patches, achieving both low cost and high gain for mid and long-range applications. ***Figure 6*** shows the lens antenna with cascaded microstrip patch elements interconnected by half-wavelength high impedance transmission lines. The patch element design is based on the transmission line model and the equivalent circuit concept.[22–23] The lens is hemispherical (plano-convex) and made of a low dielectric constant material such as Teflon ($\varepsilon_r$ = 2.2), which is low loss and easy to manufacture. The lens provides a support structure for the substrate containing the patch antenna elements.

The antenna gain and the 3 dB beamwidth of the dielectric lens depend on its size. The correlation between the radius, r, of the lens and the 3 dB beamwidth (in the elevation plane) for a uniform illuminated circular lens is given by [24]

$$\theta_{3dB} = 57\frac{\lambda}{2r} \quad (4)$$

where λ is the operating wavelength.

The measured elevation (H plane) and azimuth (E plane) radiation patterns of the antenna are shown in ***Figure 7***. The maximum gain at 77 GHz is 18 dB, and the 3 dB beamwidth is 10 degrees in elevation and 18 degrees in azimuth.

## INTEGRATED RADAR

Our vision of the integrated radar system is shown in ***Figure 8***. An RF printed circuit board (PCB) contains the RF transceiver IC, digital signal processor (DSP) and printed antenna array. The lens extends above the PCB, attached to the board and providing a protective cover for the complete assembly. The ICs are flip-chip attached to the RF PCB.

Antenna scanning is achieved with phased arrays and digital beam forming. The phase shifting method connects antenna elements or sub-arrays to phase shifters, enabling beam scanning. At millimeter wave frequencies, this approach can be complex, lossy and costly. With digital beam forming, several antenna elements or sub-arrays are successively switched to a receiver or transmitter or, alternatively, connected to multiple transmit–receive circuits.

## CONCLUSION

This article describes the concept and development of a low cost, 77 GHz automotive radar system, including a single-chip CMOS millimeter wave transceiver. The architecture shown in Figure 8 will enable a consumer radar revolution as a result of advances in CMOS semiconductor processes and radar algorithms.

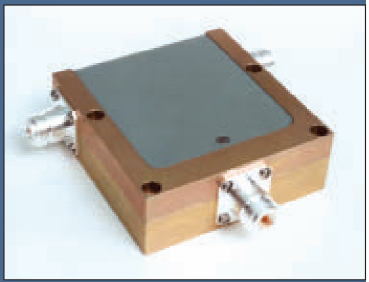
The performance achieved from this radar matches standard radar theory, with the potential for further improvement in the information that can be extracted from a radar system. Our approach to this [25] builds on Lebedev's work [26] on the information carrying capacity of a bosonic field. ■

## References


1. IEEE Symposium on Consumer Applications of Radar and Sonar, London, UK, May 1993.
2. M. C. Wicks, E. L. Mokole and S. D. Blunt, "Principles of Waveform Diversity and Design," *SciTech*, 2010.
3. M. Hartmann, C. Wagner, K. Seemann, J. Platz, H. Jager and R. Weigel, *"A Low-Power Low-Noise Single-Chip Receiver Front-End for Automotive Radar at 77 GHz in Silicon-Germanium Bipolar Technology,"* pp. 149–152.
4. J. Lee, Y.A. Li, M.H. Hung and S.J. Huang, *"A Fully-Integrated 77 GHz FMCW Radar Transceiver in 65-nm CMOS Technology,"* Vol. 45, No. 12, pp. 2746–2756, 2010.
5. H. T. Duong, H. V. Le, A. T. Huynh, R. J. Evans and E. Skafidas, "Design of a High Gain Power Amplifier for 77 GHz Radar Automotive Applications in 65-nm CMOS," EuMIC, 2013.
6. H. V. Le, H. T. Duong, A. T. Huynh, R. J. Evans and E. Skafidas, "A CMOS 77 GHz Radar Receiver Front-End," EuMIC, 2013.
7. A. Natarajan, A. Komijani, X. Guan, A. Babakhani and A. Hajimiri, "A 77 GHz Phase-Array Transceiver with On-chip Antennas in Silicon: Transmitter and Local LO-path Phase Shifting," *IEEE J. Solid-State Circuits*, Vol. 41, No. 12, pp. 2807–2819, December 2006.
8. U. R. Pfeiffer, S. K. Reynolds and B. A. Floyd, "A 77 GHz SiGe Power Amplifier for Potential Applications in Automotive Radar Systems," *IEEE RFIC Symp.*, pp. 91–94, June 2004.
9. A. Komijani and A. Hajimiri, "A Wideband 77 GHz, 17.5 dBm Power Amplifier in Silicon," *IEEE Journal of Solid-State Circuits*, Vol. 41, No. 8, pp. 1749–1756, August 2006.
10. T. Suzuki, Y. Kawano, M. Sato, T. Hirose and K. Joshin, "60 and 77 GHz Power Amplifier in Standard 90 nm CMOS," *ISSCC Digest Technical Papers*, pp. 562–563. February 2008.
11. B. Wicks, E. Skafidas and R. Evans, "A 77-95 GHz Wideband CMOS Power Amplifier," *Microwave Integrated Circuit Conference*, pp. 555–559. February 2008.
12. J. Lee, C. C. Chen, J. H. Tsai, K. Y. Lin and H. Wang, "A 68-83 GHz Power Amplifier in 90 nm CMOS," *IEEE MTT-S International Microwave Symposium Digest*, pp. 437–440, June 2009.
13. Y. A. Li, M. H. Hung, S. J. Huang and J. Lee, "A Fully-Integrated 77 GHz FMCW Radar System in 65 nm CMOS," *ISSCC Digest Technical Papers*, pp. 216–217, February 2010.
14. Viet Hoang Le et al., "A CMOS 77-GHz Receiver Front-End for Automotive Radar," *IEEE Transactions Microwave Theory and Techniques*, Vol. 61, No. 10, pp. 3783–3793.
15. Hoang Viet Le et al., "A CMOS 77 GHz Radar Receiver Front-End, 8th EuMIC, Nuremberg, Germany, October 2013.
16. P. M. Woodward, "Probability and Information Theory with Applications to Radar," Pergamon Press, 1953.
17. C. H. Wilcox, "The Synthesis Problem for Radar Ambiguity Functions," *MRC Technical Report 157*, Mathematics Research Centre, U.S. Army, University of Wisconsin, Madison, 1960.
18. S. M. Sussman, "Least-Square Synthesis of Radar Ambiguity Function," *IRE Transactions on Information Theory*, Vol. IT-8, No. 3, 1962.
19. D. E. Vakman, "Sophisticated Signals and the Uncertainty Principle in Radar," Springer-Verlag, 1968.
20. S. Lloyd, "Enhanced Sensitivity of Photo-Detection via Quantum Illumination," *Science*, Vol. 321, September 2008, pp. 1463–1465.
21. Bradley G. Porter, Leonard L. Rauth, John R. Mura and Steven S. Gearhart, "Dual-Polarized Slot-Coupled Patch Antennas on Duroid with Teflon Lenses for 76.5 GHz Automotive Radar Systems," *IEEE Transactions on Antennas and Propagation*, Vol. 47, No. 12, December 1999.
22. J. Freese and R. Jakoby, "Synthesis of Microstrip Series-Fed Patch Arrays for 77 GHz Sensor Applications," Microwave Conference, 2000 Asia-Pacific, 2000, pp. 29–33.
23. B. B. Jones, F. Y. M. Chow and A. W. Seeto, "The Synthesis of Shaped Patterns with Series-Fed Microstrip Patch Arrays," *IEEE Transactions on Antennas and Propagation*, Vol. AP-30, No. 6, November 1982.
24. T. Binzer, M. Klar and V. Gross, "Development of 77 GHz Radar Lens Antennas for Automotive Applications Based on Given Requirements," *INICA, 2nd International ITG Conference on Antennas*, 2007, pp. 205–209.
25. R. J. Evans et al., "Consumer Radar: Technology and Limitations," *International Radar Conference*, Adelaide, September, 2013, pp. 21–26.
26. D. Lebedev and L. Levitin, "Information Transmission by Electromagnetic Field," *Information and Control*, Vol. 9, No. 1, pp. 1–22, 1966.

# HIGH POWER

100 MHz to 20 GHz



## For Military / Radar Applications.

# Isolators/Circulators

As one of the leading suppliers of ferrite components in the industry, UTE Microwave has pioneered innovative designs, quality craftsmanship and exceptionally high quality products. Custom designs, standards...many of them off-the-shelf, are the result of over 35 years of experience in the industry. UTE Microwave continues this tradition with new products for ever changing applications. Our broad line of HIGH POWER, low loss circulators and isolators spans the spectrum from below 100 MHz in coax/stripline units to waveguide devices at 18 GHz for both peak and average powers.

## **100 MHz HIGH POWER** Circulator for Medical, Scientific and Industrial applications

A new HIGH POWER Circulator suitable for FM Broadcast, Scientific and Medical applications is now available. The unit provides 10 MHz bandwidth in the 85–110 MHz spectrum.

Specifications are 20 dB min. isolation, 0.3 dB max. loss and 1.25 max. VSWR. Operating power is 1 kW average and 25 kW peak. The 8-1/2" hex x 2" thick unit operates over a 15°–50° C temperature range. DIN 7/16 connectors are standard. Other units are available at higher frequencies.

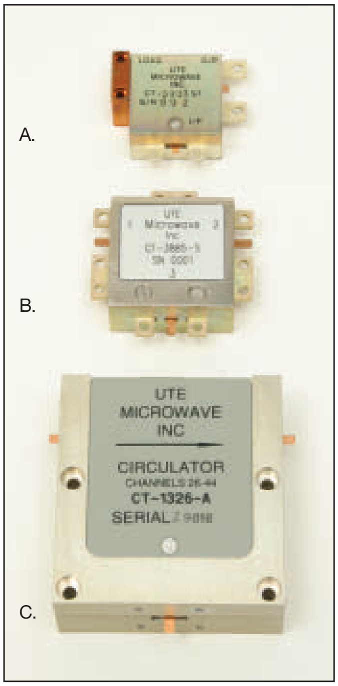
## HIGH POWER Drop-in Series

A broad line of low loss HIGH POWER Drop-in circulators are available from VHF to Ku band including Kilowatt average power levels at VHF thru S band. L and S band radar are a specialty. A few of these are shown here.

A) 2.7–3.1 GHZ 1 kW pk, 100 W av

B) 1.2–1.4 GHZ 3 kW pk, 300 W av

C) UHF TV Band 5 kW pk, 500 W av




### Our "POWER-LINE" serves the COMMUNICATIONS, TELECOM, MEDICAL, SCIENTIFIC, TV, PCS and INDUSTRIAL markets.

**The following models are examples of our High Power units**

| Model No. | Power | Connectors | Freq. Range |
|---|---|---|---|
| CT-1542-D | 10 Kw Pk 1 Kw Av | DIN 7/16 | 420–470 MHz |
| CT-2608-S | 3 Kw Pk 300 W Av | "Drop-in" | 1.2–1.4 GHz |
| CT-3877-S | 2.5 Kw Pk 250 W Av | "Drop-in" | 2.7–3.1 GHz |
| CT-3838-N | 5 Kw Pk 500 W Av | N Conn. | 2.7–3.1 GHz |
| CT-1645-N | 250 W Satcom | N Conn. | 240–320 MHz |
| CT-1739-D | 20 Kw Pk 1 Kw Av | DIN 7/16 | 128 MHz Medical |

### FEATURES:

- Power levels to 5 KW CW, 75 KW Pk.
- Low Intermod Units
- Low Loss Options
- Extended Octave Bandwidths
- Power Monitors and DC Blocks
- Iso Filter-Monitor Assemblies

Broadband Units • Common Band Devices • High Isolation Units • Multiport Devices • Drop-In Devices • Wireless/PCN Devices • High-Power Industrial/Medical Iso Adaptors Waveguide Junctions • High-Power TV Units • VHF and UHF Devices

sales@utemicrowave.com

UTE MICROWAVE INC.

3500 Sunset Ave., Asbury Park, NJ 07712
Tel: 732-922-1009 Fax: 732-922-1848
E-mail: info@utemicrowave.com

Contact us for more information on our extensive product line and current catalog. We accept Visa, MC, Amex

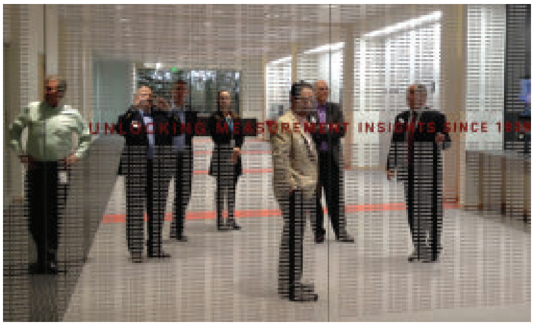
# Keysight Technologies: Reborn

Patrick Hindle and Gary Lerude
**Microwave Journal**, ***Norwood, Mass.***

*After serving as something of a cash cow for HP and then Agilent Technologies, the electronic measurement business is now charting its own course as an independent company – Keysight Technologies.* Microwave Journal *was honored to be the first of the industry trade media to visit and tour Keysight's new Santa Rosa headquarters. This special report summarizes what we saw and learned.*

Reborn. As they rang the bell at the New York Stock exchange on November 3, Keysight Technologies returned to its roots in electronic measurement, the last step in splitting off from Agilent Technologies to become a separate company. Grown out of Bill Hewlett's and Dave Packard's audio oscillator, invented in the famous garage in Palo Alto in 1939, HP became so large that it split in 1999, with the electronics group becoming Agilent Technologies. Agilent grew its two businesses in electronic measurement and life sciences into dominant segments in their respective markets. Yet each was different. With time, it made sense to split the two, so each could best serve its own market and needs.

Keysight is based at the Santa Rosa campus that Hewlett Packard established in 1972. They are among the largest employers in the city, with 1250 employees and 400 contractors occupying four buildings. Since 2008, the company has invested $100 million in the site, blending funding with values that make Keysight a model of corporate citizenship: an onsite school for employees' children, offering classes from kindergarten through second grade; 3 acres of solar panels generating 1.8 million kWh per year; onsite recycling that reuses about 70 percent of their water; employee gardens that provide fresh food for the on-site chefs to feature in the dining areas; and workout facilities that include a gym, baseball and soccer fields.

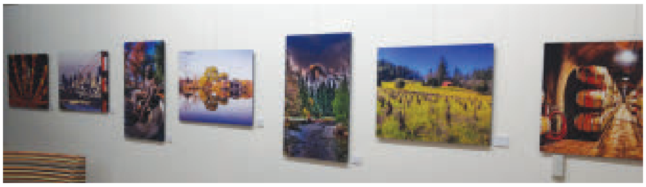



▲ *Fig. 1 Wall listing all Hewlett Packard – Agilent – Keysight Technologies' patents since 1939.*

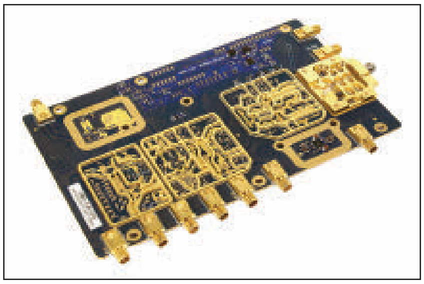
Keysight carries on the legacy of "the HP way," management practices such as the open door policy (none of the offices have doors, including the CEO's), collaborative workspaces (most of the cubical walls are low to facilitate interaction) and flexible work schedules. Employees are encouraged to start clubs and interest groups and can apply for company funding to hold events and meetings, requests which the CEO personally approves. Employees generously support charitable and community needs, volunteering more than 50,000 hours a year. The company supports their efforts with paid time off. In 2013, Santa Rosa employees donated some $320 thousand to charitable causes, funds that were matched by the company. Keysight and its foundations strongly support science, technology, education and math (STEM), contributing more than $10 million to STEM programs, universities and non-profits in 2013.

Building 1 on the sprawling campus includes an area commemorating the firm's 75-year history, including a large wall listing each of the patents in their portfolio (see ***Figure 1***) as well as displays of the test equipment that is their raison d'être. An HP200A audio oscillator – the product that launched HP – is fully functional, with glowing tubes and a red power light on the front panel (see ***Figure 2***). It is joined by a progression of test systems produced over the years, with a large timeline that spans the hallway and commemorates the key events in the company's history. Adjacent walls are deco-

▲ *Fig. 2 Fully functional HP200A audio oscillator, the first product offered by HP.*



▲ *Fig. 3 Photos taken by employees hang on the walls at Keysight Technologies' headquarters in Santa Rosa.*



▲ *Fig. 4 Integrated RF subassembly showing Keysight's chip-on-board technology. Connectorized thin-film modules, such as the one on the right side of the board, are used for circuits operating well into millimeter wave frequencies.*

rated with stunning photos taken by employees, the winners of a monthly contest (see ***Figure 3***).

## STRATEGY

Keysight is focusing on three broad markets: 1) communications 2) aerospace and defense, and 3) industrial, computers and semiconductors. Each segment offers growth, from such drivers as mobile data, more connections, higher data rates and defense modernization. To broaden its product portfolio from the long-standing test and measurement "boxes," Keysight is expanding its offerings in modular, software and complete system solutions.

One recent example of the latter is the collaboration between Keysight and Cascade Microtech to offer a wafer-level measurement system. This comprises all hardware and software as well as initial setup, calibration, training and service. Cascade provides a single point-of-contact for all technical support. This complete system solution was prompted when both companies noticed that many customers let these large capital items sit for months awaiting setup and qualification, simply because of a lack of manpower or missing accessories. So Keysight and Cascade Microtech teamed up to solve the problem and provide more value to their customers. They also developed a software platform, WaferPro Express, to automate on-wafer measurements and manage a device modeling database for data analysis, model extraction and verification.

To serve the rollout of 4G and adoption of heterogeneous networks, Keysight is developing products such as one-box testers like the UXM, for R&D, and EXM for manufacturing. With the Internet of Things (IoT) and 5G on the horizon, the company is engaged in industry research and standards development, which will define future test and measurement needs.

## VERTICAL INTEGRATION

Keysight is known for high quality and high performance test equipment, which is a result of attention to detail at every step of design, manufacturing and test. Almost all of their microwave devices are produced in Santa Rosa, including GaAs and InP MMICs and YIG spheres. Their III-V wafer fab focuses on performance, reliability and long lifetimes, not volume. The fab runs about 2500 three-inch wafers per year across 13 processes that include MESFET, PHEMT and HBT devices. Keysight operates several MBE systems to tailor device epitaxy and optimize performance.

To support the unique needs of test and measurement equipment, they develop custom packaging solutions that include thin-film deposition, machining and sealing. Internal semi-automated and fully automated die-attach and wire bonding manufacturing lines serve both development and production.

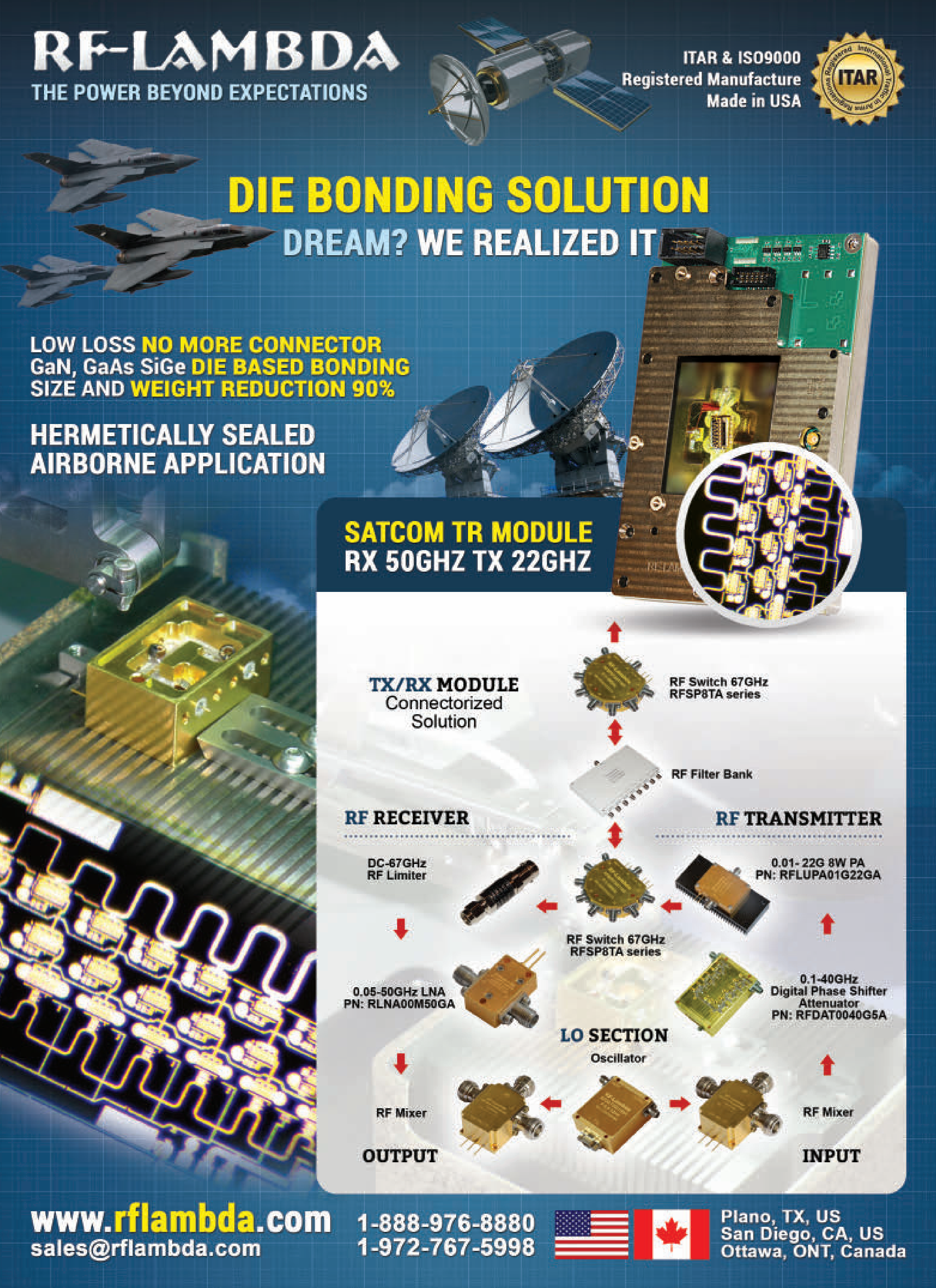
A good example of Keysight's RF expertise is the development of RF assemblies using a high performance, chip-on-board technology that can integrate an RF front end onto a single laminate board (see ***Figure 4***). This packaging technology includes the capability to incorporate walls to shield sensitive RF circuits. A typical board is highly integrated, containing 35 to 40 RF devices and hundreds of other components. Compared with the traditional approach of thin-film circuit assemblies in machined and plated housings, the chip-on-board laminate reduces size, weight and cost while maintaining – even improving – performance.

The laminate board works to frequencies well beyond 26.5 GHz and traditional hybrid modules can be used in concert with the laminate to deliver performance far into the millimeter wave range. Modules can be mounted onto the laminate board, with the module RF signal connected to the laminate before or after frequency conversion. Figure 4 shows a high frequency module with a precision, ruggedized connector on the right side of the laminate board.

To automate the final testing of Keysight's test and measurement equipment, five company engineers developed a robotic line that moves each instrument into and out of various test stations, tracking the test flow, measured data and pass/fail results. DC and RF connections to the unit under test are made automatically, and electrical tests can be performed at hot and cold temperatures. When a test is complete, the robotic cart returns to the station and moves the unit to the next test. Status and data are available online, allowing employees to monitor the results from anywhere. Two robotic lines run in Santa Rosa, and the company's production facility in Malaysia has eight.

## CULTURE AND STRATEGY

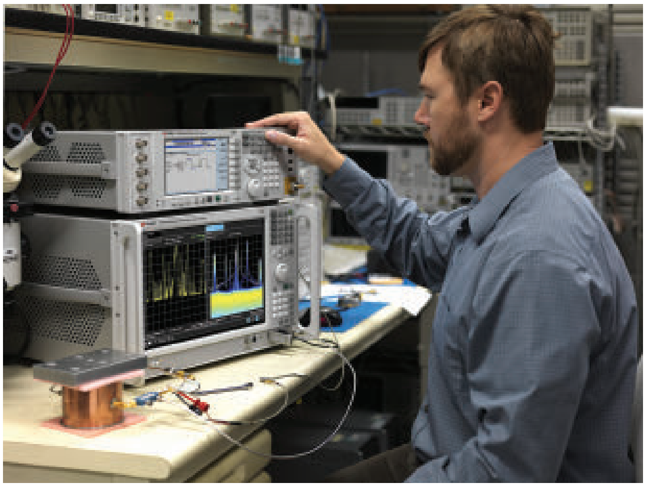
Management guru Peter Drucker is credited with coining the maxim "culture eats strategy for breakfast," meaning a misaligned culture can undermine the best strategy. After a day walking the halls and speaking with numerous Keysight employees, we left Santa Rosa feeling that the people are proud, energetic and enthusiastic about the future – which makes the culture a strong and secure foundation for Keysight's strategy. The energy and enthusiasm felt like a startup, yet one with a proud, 75-year history. A unique $3 billion startup has indeed been reborn. ■


RF-LAMBDA
THE POWER BEYOND EXPECTATIONS
ITAR & ISO9000
Registered Manufacture
Made in USA
ITAR
DIE BONDING SOLUTION
DREAM? WE REALIZED IT
LOW LOSS NO MORE CONNECTOR
GaN, GaAs SiGe DIE BASED BONDING
SIZE AND WEIGHT REDUCTION 90%
HERMETICALLY SEALED
AIRBORNE APPLICATION
SATCOM TR MODULE
RX 50GHZ TX 22GHZ
TX/RX MODULE
Connectorized
Solution
RF Switch 67GHz
RFSP8TA series
RF Filter Bank
RF RECEIVER
RF TRANSMITTER
DC-67GHz
RF Limiter
0.01- 22G 8W PA
PN: RFLUPA01G22GA
RF Switch 67GHz
RFSP8TA series
0.05-50GHz LNA
PN: RLNA00M50GA
0.1-40GHz
Digital Phase Shifter
Attenuator
PN: RFDAT0040G5A
LO SECTION
Oscillator
RF Mixer
RF Mixer
OUTPUT
INPUT
www.rflambda.com
sales@rflambda.com
1-888-976-8880
1-972-767-5998
Plano, TX, US
San Diego, CA, US
Ottawa, ONT, Canada

# New Signal Generation Techniques Enhance EW Environment Simulation

Keysight Technologies
formerly Agilent Technologies electronic measurement business
*Santa Rosa, Calif.*

In recent years, various architectures have been used to develop the agile, wideband signal sources needed for threat simulation in electronic warfare (EW) applications. Similar approaches have been used to create local oscillators (LO) and RF pulse generators that can quickly switch over wide frequency and amplitude ranges.

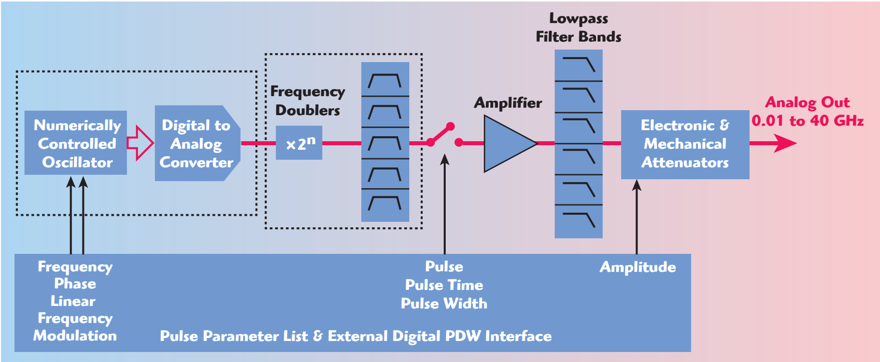


▲ *Fig. 1 The Keysight UXG agile signal generator (top) is a powerful building block as either a dependable LO or a scalable threat simulator.*

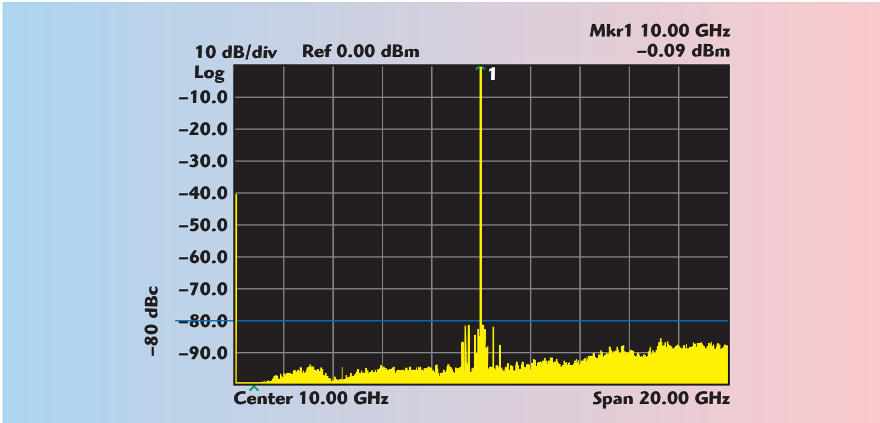
These ideas were central to the creation of the new Keysight UXG agile signal generator shown in ***Figure 1***. The UXG architecture uses a direct digital synthesizer (DDS) and new switching technology to create a signal generator ideally suited to applications that need an agile LO or require highly realistic simulation of EW environments. The DDS is built around a digital-to-analog converter (DAC) that was developed by Keysight to achieve dramatic improvements in dynamic range and phase noise.

## DESIGNING FOR PURITY, AGILITY AND SPEED

The performance and capabilities of the UXG are based on three innovative technologies: DDS-based signal generation with an exceptional combination of purity and bandwidth, from 10 MHz to either 20 or 40 GHz; solid-state switches that change output levels in as little as 180 ns over large amplitude rang-




▲ *Fig. 2 The architecture of the UXG enables accurate simulation of complex signal scenarios through fast switching, phase repeatability and extensive pulse-modulation capabilities.*




▲ *Fig. 3 In this 20 GHz spectrum measurement, a 10 GHz CW signal from the UXG signal generator exhibits high dynamic range, with a low noise floor and minimal spurious signals.*

es and with accurate time alignment; and direct support for pulse descriptor words (PDW), the natural language of EW engineers, that enables efficient creation of complex and precise outputs.

The block diagram shown in ***Figure 2*** illustrates the DDS-based architecture of the UXG. A high speed DAC is the heart of the DDS. An array of doublers and filters is used to multiply the signal up to a maximum frequency of 40 GHz. The DAC covers an octave centered at 1 GHz and provides dramatic improvements in dynamic range and phase noise. This results in very high purity signals, as shown in ***Figure 3***.

This performance is available with industry-leading switching speed and very low latency for changing frequency. Frequency can be updated in as little as 180 ns. Depending on the selected instrument mode, the delay between an external command and frequency change (i.e., latency) is as little as 370 ns. The UXG can also generate wide chirps 10 to 25 percent of the carrier frequency.

Comprehensive EW threat simulation needs amplitude agility that matches the source's frequency agility. This requires coordinated switching from solid-state attenuators, which the UXG does using "nanoFET" MMICs invented and manufactured by Keysight. These new switches are designed for microwave and millimeter wave frequencies, with fast settling to minimize distortion of the pulse shape. The resulting 90 dB agile amplitude range can be used between output levels from 0 to -130 dBm, which handles a wide range of threat scenarios.

To optimize cost and capability for different applications, the solid-state agile attenuator is optional.

For some threat environment scenarios, it is essential to maintain specific phase and frequency rela-

tionships while signals are pulsed, frequency-hopped or interleaved in a sequence. The UXG produces any phase or frequency trajectory without limiting frequency or amplitude agility. It also maintains any desired relationships as frequency, amplitude and pulse characteristics are changed or as signals are pulsed on and off.

Multiple UXGs can be linked through clocks and triggers to provide phase coherence across the sources, making it possible to simulate steerable beam antennas or produce angle-of-arrival trajectories to evaluate direction-finding receivers.

## AVOIDING SURPRISES LATE IN THE DEVELOPMENT PROCESS

The EW environment is an ongoing contest between the development and implementation of improved systems and the analysis and countermeasures needed to defeat those systems.

As implemented in the UXG, the DAC-based DDS architecture offers compelling advantages for EW applications, whether the need is for agile LO generation or PDW-based EW environment simulation:

**Signal quality** – The UXG generates signals with low spurious and without the phase noise pedestal that is characteristic of systems that use phase-locked loops (PLL) instead of DDS.

**Very high agility in frequency, amplitude and phase** – All three aspects of the signal output can be updated in as little as 180 ns.

**Support of multiple signals and complex scenarios** – Sample sequences can represent multiple emitters from a single source.

**Phase repeatability** – Signal-generation calculations include phase accumulators programmed with any desired phase relationship.

**Good match to evolving threats** – The agility and flexibility of the UXG allows it to accurately simulate the equivalent characteristics of the modern threat environment and adapt as these threats change.

**Simpler path from pulse requirements to actual signal output** – The UXG can directly reproduce complex dynamic and pulsed signals by creating them mathematically from the desired pulse characteristics.

This last point is important: the UXG directly understands PDWs. Each word describes all the parameters of an individual pulse: frequency, duration, amplitude, chirp rate and more. Tables of PDWs can be transferred to UXG memory and complex sequences produced at high speed. Individual pulses can be as narrow as 10 ns, with 3 ns rise and fall times and an 90 dB on/off ratio. Marker outputs are available to coordinate execution of PDWs with other devices, and sequences of PDWs can be triggered and regulated by sending external triggers to the UXG.

With these capabilities, the UXG brings extensive and realistic testing to earlier stages of the design process, allowing engineers to optimize and verify system performance before the expense, potential delay and poor repeatability of field testing. It also significantly reduces the time from gathering new signal intelligence to creating realistic simulated threats.

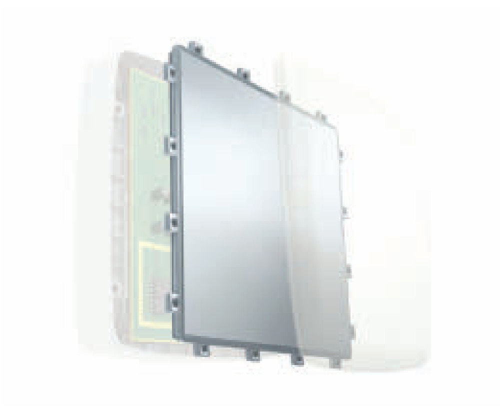
## GETTING CLOSER TO REALITY

In development and mission data reprogramming, better testing performed sooner enables deeper confidence in the performance of EW systems. The Keysight UXG agile signal generator lets EW engineers create complex scenarios when they need them.

Off the shelf, the UXG is a powerful building block, whether the need is for a dependable LO or a scalable threat simulator. Because the UXG is fluent in the language of EW systems, it accelerates the conversion of new intelligence into up-to-date signal scenarios. With unmatched performance in switching speed and phase noise, the UXG makes it possible to generate increasingly complex simulations and get closer to reality.

VENDORVIEW

**Keysight Technologies Inc.**
**Santa Rosa, Calif.**
**www.keysight.com/find/UXG.**



# Low Profile, Lightweight E/V-Band Flat Antennas

HUBER+SUHNER
*Herisau, Switzerland*

The increasing volume of wireless data year after year poses the challenge of providing enormous data capacity while meeting customer expectations for service quality and operator requirements for cost-effective service delivery. As mobile data traffic continues to grow, small cells in heterogeneous networks are increasingly seen as vital to meeting the challenge. Since copper or fiber is rarely available to connect these cells with the network, unobtrusive and cost-efficient wireless backhaul is essential.

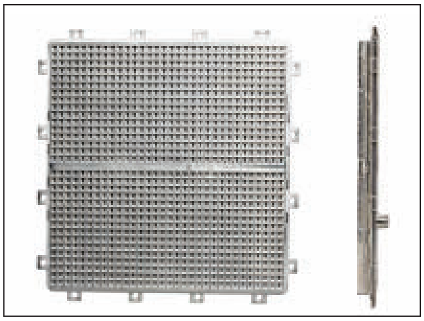
SENCITY®Matrix flat antennas address these issues and offer solutions. The latest additions to the series are highly directional V- and E-Band antennas for 60 and 70/80 GHz. The V-Band antenna covers 57 to 66 GHz, while the E-Band antenna addresses 71 to 76 and 81 to 86 GHz. Smaller than conventional antennas, the SENCITY®Matrix antennas are low profile, light weight and easily aligned.

## COMMUNITY FRIENDLY

The small size of the antennas allows operators to access rooftop, wall and street-level sites that are often not viable for traditional parabolic antenna systems because of technical, environmental or planning restrictions. The "community friendly" design of the SENCITY®Matrix avoids aesthetic concerns for street-level installations on lamp posts, street signs and kiosks, which are the primary choices for small cell sites. The antenna's flat shape and compact design significantly reduces the visual impact and total cost of ownership while providing excellent electrical performance.

In order to meet the high gain requirement for millimeter wave backhaul systems, the flat antennas include an ad-hoc distribution network that feeds the array elements. This network combines innovative elements to achieve a relative bandwidth as large as 20 percent. SENCITY®Matrix antennas substitute the lossy planar dielectric lines and elements with hollow waveguide structures that drastically reduce signal attenuation while maintaining an elegant low profile (5 to 10 mm).

The boresight gain of the antennas inherently coincides with the normal axis of the radiator. This enables the use of optical techniques (e.g., camera or laser) for quick and easy radio alignment. The design of the flat antenna also ensures 0° beam squint electromagnetic radiation over all working frequencies. This means



▲ *Fig. 1 A 60 GHz flat antenna without a housing, which can easily be integrated into a customer's radio housing.*

▲ *Fig. 2 The "lotus effect" cover is water repellent, providing super hydrophobic characteristics.*



no compromise among different frequency bands, and all channels simultaneously benefit from the optical alignment.

The intrinsic isotropic thermal expanding behavior of the SENCITY®Matrix material guarantees a very stable radiation characteristic. Changes in temperature produce only a minimal frequency shift: ±150 MHz from -45° to +75°C. This is well within the extremely wide bandwidth of the antennas.

## ENVIRONMENTAL FACTORS

The small size, mechanical robustness and flatness of the antennas facilitate integration into radios and provide maximum possible freedom for the mechanical design team (see ***Figure 1***). The integration of the antenna into the radio protects it from exposure to environmental conditions such as dust, water and ice, which can cause issues at the interface between radio and antenna in traditional split-mount setups. An ingenious attachment of the antenna to the power amplifier enables direct heat transfer between the radio and antenna, preventing surface icing and the creation of water droplets.

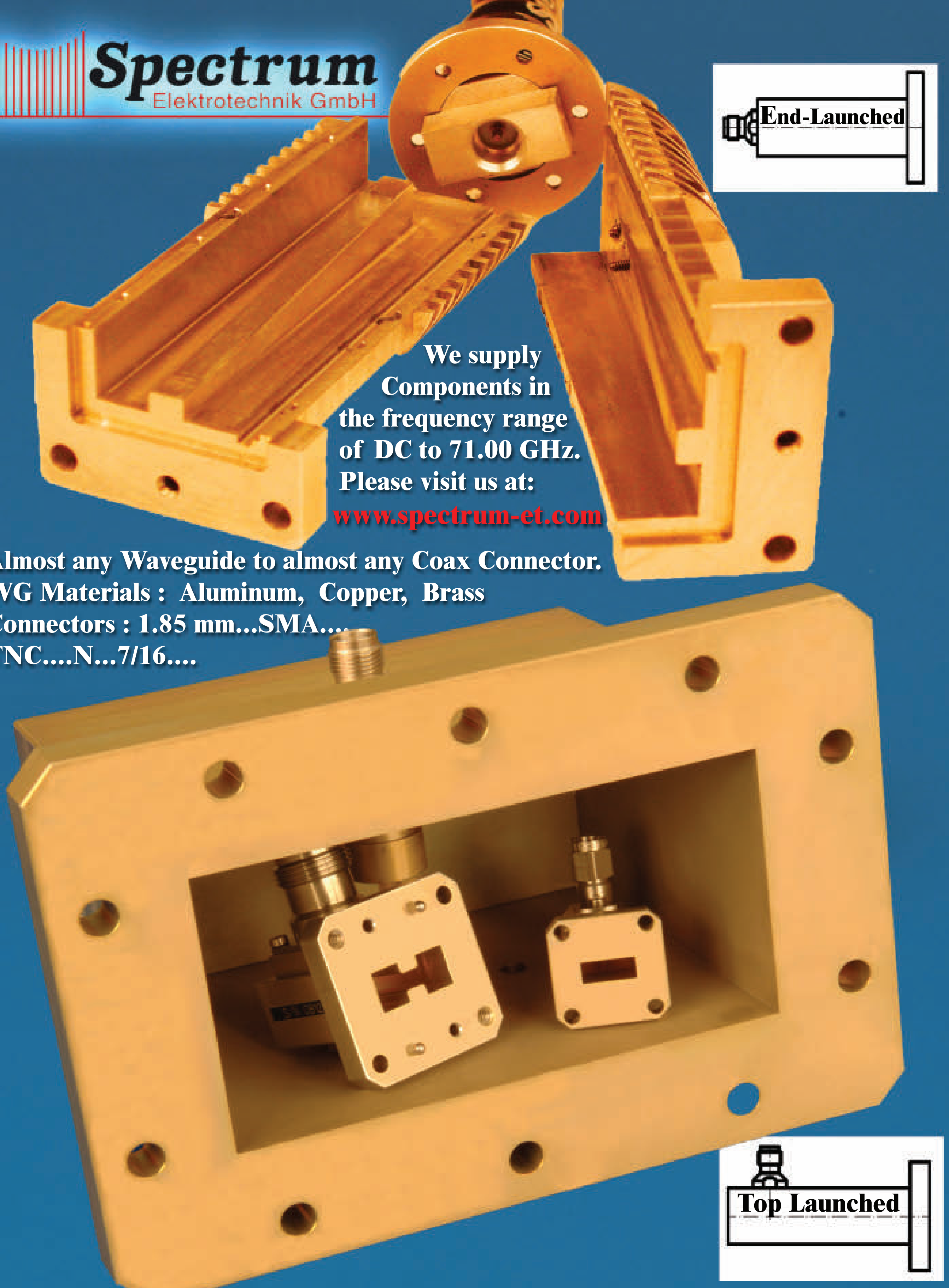
A "lotus effect" water repellent cover (shown in ***Figure 2***) provides super hydrophobic characteristics to SENCITY®Matrix antennas. Its contact angle of ~155° is far greater than the 80° to meet the HC Class 1 standard in STRI Guide 92/1 and the 90° in ASTM-D7334, 2013. This cover minimizes the impact of water and maximizes the radio link performance.

The antennas are manufactured out of metallized plastic parts produced by high precision injection molding.

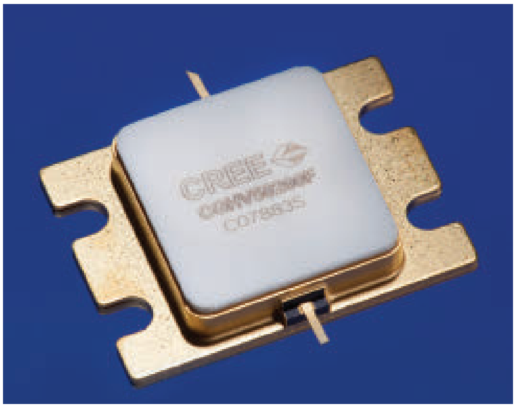
The highly directional E/V-Band flat antennas are very low profile, lightweight and easily aligned. SENCITY®Matrix antennas provide key distinguishing benefits in mobile backhaul applications. The biggest contributor to reduced operating expense is the unobtrusive appearance of these planar antennas, which facilitates site acquisition and reduces tower rental cost.

VENDORVIEW

**HUBER+SUHNER**
**Herisau, Switzerland**
**+41 71 353 4111**
**www.hubersuhner.com**



End-Launched
Top Launched

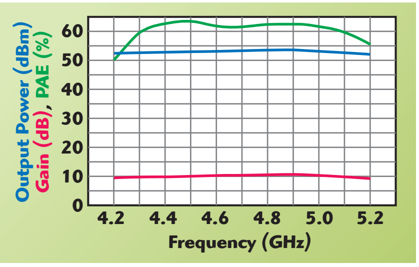



# C-Band GaN HEMT Delivers 200 W CW

Cree Inc.
*Research Triangle Park, N.C.*

Troposcatter, satellite ground stations, and beyond-line-of-sight communication require high power — hundreds of watts to kilowatts — to overcome the high loss and variable propagation inherent in long-range microwave links. These C-Band applications have historically used traveling wave tube amplifiers (TWTA) or klystron power amplifiers to achieve the required power.

With the introduction of Cree's new 200 W GaN HEMT, solid-state power amplifiers (SSPA) can replace TWTAs and klystrons for such applications while offering greatly improved performance. Previously, SSPAs combined a large number of lower power devices. Now, with a 200 W device, the SSPAs can be smaller and lighter, reduce hardware and operating costs and improve system reliability.




▲ *Fig. 1 Pulsed performance of the GaN PA with a 43 dBm, 100 μs, 10 percent duty cycle input drive.*

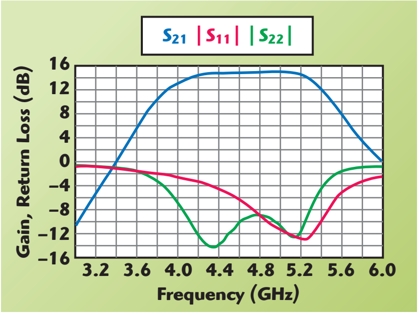
## PRODUCT DESCRIPTION AND PERFORMANCE

The CGHV50200F is a 50 ohm GaN HEMT, internally matched at both input and output. The device was designed for high output power, efficiency and gain across a wide bandwidth. From 4.4 to 5 GHz, it provides over 200 W output at 48 percent power-added efficiency (PAE) and 15 dB small-signal gain. At 180 W output, the device can drive a load VSWR of 3:1 at all phase angles without damage.

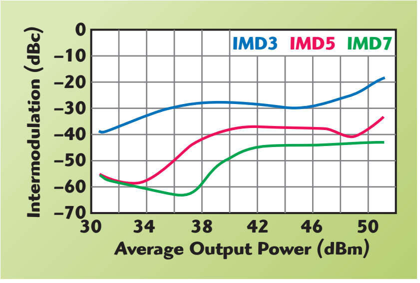
The transistor is supplied in a ceramic metal-flange package (type 440215) with a flange size of 17.4 × 24 mm, not including the gate and drain leads. The surface area can dissipate 166 W at a maximum case temperature of 85°C. With 48 percent PAE, power consumption and heat dissipation are reduced, simplifying the electrical and mechanical design of high power SSPAs.

In a demonstration amplifier circuit, the device delivers 198 to 218 W (53 to 53.4 dBm) CW output power from 4.4 to 5 GHz, with 47 to 49 percent PAE and 11.4 to 11.8 dB power gain. Small-signal gain is 14.9 to 15.1 dB. ***Figure 1*** shows the pulsed performance of the device.

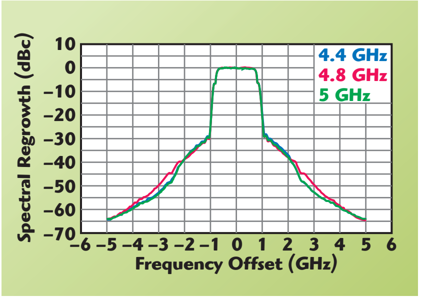
***Figure 2*** demonstrates the effectiveness of the input and output matching, with $|S_{11}|$ ranging from -4 to -12 dB and $|S_{22}|$ from -9 to -14 dB. ***Figure 3*** shows the two-tone linearity versus output power with 1 MHz spacing of the test carriers. Third-order intermodulation distortion (IMD) is less than 22 dBc up to




▲ *Fig. 2 Input and output return loss, showing the quality of the internal matching.*




▲ *Fig. 3 Two-tone intermodulation distortion with 1 MHz test signal spacing at 4.4 GHz.*




▲ *Fig. 4 OQPSK spectral mask at 4.4, 4.8 and 5 GHz with the PA backed off to 48 dBm output power.*

100 W output, with fifth- and seventh-order IMD at progressively lower levels, which is expected for a transistor amplifier. With OQPSK modulation, linearity at 48 dBm output power is specified as -34 dBc at the middle of the frequency band. ***Figure 4*** shows the OQPSK spectral mask at several frequencies.

The amplifier's typical drain bias is +40 V. The 125 V maximum drain-source voltage provides ample margin for peak voltages resulting from operating class, matching and modulation. The gate threshold voltage is typically -3 V, with the gate bias ranging from -2 to -3.5 V, depending on the desired class of operation.

A demonstration board (CGHV50200F-TB) is available and enables easy evaluation of the device in a proven circuit. The board includes input and output connectors and transmission lines, DC blocking capacitors, decoupling stubs for drain and gate bias, bypass capacitors and a power connector. The printed circuit board is layered with a heat spreader that can be mounted on a cold plate or attached to a heat sink.

## TARGETED APPLICATIONS

The main application for the CGHV50200F is tropospheric scattering or troposcatter. At C-Band, radio propagation is normally limited to line-of-sight. Ionized layers of the atmosphere do not efficiently reflect microwaves, and the short wavelengths are not refracted by the topographic features that allow lower frequency signals to reach beyond the horizon. Despite these limitations and depending upon weather phenomena, a small amount of C-Band energy will bend and scatter and pass beyond the horizon. Using the brute force of hundreds or thousands of watts, reliable communication can be achieved at distances much greater than a typical microwave path.

Satellite communication is the other major C-Band application that requires significant transmitter power. Higher power amplifiers enable smaller antennas at the earth station and increase the reliability of the link.

A high power transistor such as the CGHV50200F allows designers to build SSPAs with fewer devices, which greatly simplifies power combining, device gain matching and DC power distribution. The device also has the linearity for OQPSK modulation when operated "backed off" at 100 W average output power.

**Cree Inc.**
**Research Triangle Park, N.C.**
**(919) 407-5302**
**www.cree.com/RF**

# 16 kHz to > 67 GHz Ultra-Broadband Ceramic Capacitors

Passive Plus Inc. (PPI) has introduced the 01005BB104 and 0201BB104 ultra-broadband 100 nF multilayer ceramic capacitors. With a case measuring 16 × 8 × 8 mils, the 01005BB104 is the industry's smallest 100 nF broadband part characterized for RF performance, according to Passive Plus. The capacitor has resonant-free DC blocking and RF coupling from 16 kHz, at the lower 3 dB frequency, to beyond 67 GHz. On suitable substrates, insertion loss is less than 1 dB, and return loss is better than -15 dB. The 01005BB104 is rated at a DC working voltage (WVDC) of 4 V and is available in a nickel-tin termination.

The 0201BB104 also provides resonant-free DC blocking and RF coupling from 16 kHz to beyond 65 GHz, with less than 1.3 dB insertion loss and better than -15 dB return loss on suitable substrates. Up to 40 GHz, the insertion loss is typically under 0.6 dB and return loss better than -20 dB. The 0201BB104 is rated at a WVDC of 16 V and measures 24 × 12 × 12 mils. It is available in nickel-tin and gold terminations.

All lots of the 01005BB104 and 0201BB104 are tested at RF frequencies to insure performance consistency. Modelithics offers RF models for both types, enabling accurate design simulation on various substrates and with a range of mounting pad dimensions. Modelithics models are offered with free 30-day trials.

Passive Plus offers a wide variety of ultra-high-Q, broadband, and general-purpose multi-layer ceramic capacitors for commercial and military applications.

VENDORVIEW

**Passive Plus Inc.**
**Huntington, N.Y.**
**www.passiveplus.com**


# Integrated RF Switching and Microprocessor in One Device

The EtherChip™ EC459™ is the world's first device integrating RF switching and a full-featured microprocessor on a single device, according to Ethertronics.

Embedded in the EC459 are Ethertronics' proprietary algorithm, and communication and control conduits that enable Active Steering.™ The EC459 samples and switches among various antenna radiation patterns, adaptively choosing the best one. Combining the device with an advanced Ethertronics antenna architecture, Ethertronics provides OEMs with an easy-to-integrate, plug-and-play solution. This frees an OEM's existing operating system or apps processor, since the EC459 handles this for them. No baseband software or hardware modifications are required for product integration.

Active Steering maximizes throughput and reliability in 3G and 4G (LTE and LTE-Advanced), reduces interference, enables seamless hand-off between cell towers, and provides connection reliability and spectral efficiency. Active Steering demonstrated a 30 percent improvement in spectral efficiency during recent trials on two Tier One LTE carrier networks in the United States and Europe.

The EC459 operates from 100 to 6000 MHz, supporting the GSM/W-CDMA/LTE, Wi-Fi, Bluetooth, RFID and GPS bands. The device features a flexible control interface that is customizable among SPI, I2C, UART and USART protocols, providing flexibility and speeding integration and testing. The EC459 is packaged in a 4 × 4 × 0.65 mm$^3$ QFN.

Worldwide application support and user development tools are available, including an evaluation board, antenna reference design, host firmware driver and PC control software with driver.

**Ethertronics Inc.**
**San Diego, Calif.**
**www.ethertronics.com**

International Microwave Symposium

IEEE 17-22 May 2015 · Phoenix, Arizona, USA MTT-S

IMS

# 2015 PLENARY SPEAKER

## SOFT ASSEMBLIES OF RADIOS, SENSORS AND CIRCUITS FOR THE SKIN

**- Dr. John Rogers**

*Swanlund Chair, Professor of Materials Science and Engineering, Professor of Chemistry*

*University of Illinois, Urbana-Champaign*

Professor John A. Rogers obtained BA and BS degrees in chemistry and in physics from the University of Texas, Austin, in 1989. From MIT, he received SM degrees in physics and in chemistry in 1992 and the PhD degree in physical chemistry in 1995. From 1995 to 1997, Rogers was a Junior Fellow in the Harvard University Society of Fellows. He joined Bell Laboratories as a Member of Technical Staff in the Condensed Matter Physics Research Department in 1997, and served as Director of this department from the end of 2000 to 2002.

He is currently Swanlund Chair Professor at the University of Illinois at Urbana/Champaign, with a primary appointment in the Department of Materials Science and Engineering, and joint appointments in several other departments, including Chemistry. He is Director of the Seitz Materials Research Laboratory.

Rogers' research includes fundamental and applied aspects of materials for unusual electronic and photonic devices, with an emphasis on bio-integrated and bio-inspired systems. He has published more than 450 papers and is inventor on over 80 patents, more than 50 of which are licensed or in active use. Rogers is a Fellow of the IEEE, APS, MRS and the AAAS, and he is a member of the National Academy of Engineering and the American Academy of Arts and Sciences. His research has been recognized with many awards, including a MacArthur Fellowship in 2009, the Lemelson-MIT Prize in 2011, the MRS Mid-Career Researcher Award and the Robert Henry Thurston Award (American Society of Mechanical Engineers) in 2013, and the 2013 Smithsonian Award for Ingenuity in the Physical Sciences.

# 600 W, X-Band Solid-State Power Amplifier

Comtech PST's solid-state power amplifier (PA) module delivers 600 W peak output from 8.5 to 10 GHz with 58 dB nominal power gain. Designed for radar applications, the BMC858109-600 PA handles pulse widths from 300 ns to 100 µs at duty cycles up to 10 percent and less than 1 dB pulse droop. Typical rise and fall times are under 60 ns. Input VSWR is better than 1.5:1 and output VSWR is less than 2:1.

The amplifier design uses GaN devices in an AB configuration to achieve high efficiency and low harmonics. DC to RF efficiency is 20 percent and harmonic levels are better than -40 dBc for the second, and -50 dBc for the third. The PA operates from a single 40 V supply and nominally draws 7.5 A with a 10 percent duty cycle signal. The operating temperature range is 0° to 55°C, measured at the base plate of the unit.

The design incorporates detectors that sample forward output and reflected output signals. The output samples are 50 dB below the forward and reflected signals. The PA has built-in protection that prevents exceeding the maximum pulse width, duty factor, temperature and load VSWR. The RF input connector is SMA, while the output features a Type TNC. The unit weighs 4 lbs. and measures 8.8" × 8.0" × 0.5".

The amplifier features a digital interface for monitoring status. It also provides an option for controlling gain and phase, which enables the PA to be integrated into higher power radar systems using conventional binary or phased array combining. This capability supports power levels up to 16 kW.

**Comtech PST Corp.**
**Melville, N.Y.**
**(631) 777-8900**
**www.comtechpst.com**

# 0.5 to 40 GHz High-Speed Tuner Captures 500 MHz Bandwidth

The P540B500 wideband tuner from diminuSys spans 500 MHz to 40 GHz with 500 MHz instantaneous bandwidth, fast tuning, low phase noise, control flexibility, output versatility and surprising affordability. Overall tuner gain is adjustable from -20 to +40 dB.

The P540B500 design enables input preselection with bypass, and input preamplification, bypass, or attenuation. The tuner's wideband output is centered at either 1000 or 1200 MHz, with auxiliary outputs at 900, 120/160 and 21.4 MHz included. All four ports are synchronous and without frequency inversion. Control is by a simple command set via the included Ethernet, serial or USB interfaces.

With its enhanced performance option, the system tunes in 1 Hz increments and can switch between any two frequencies in less than 100 µs. Phase noise at 10 kHz offset is below -105 dBc/Hz when tuned to 40 GHz and well below that for lower frequencies. The P540B500 includes an external frequency synthesizer input to accommodate a user-provided local oscillator. The tuner can change bands, preselection, gain and attenuation in less than 100 ns in this mode, which is tailored to ELINT, SIGINT and COMINT applications.

The P540B500 resides in a low profile 1U rack-mount chassis with custom configurations available. A field replaceable 2.92 mm input connector is standard. Air cooling input and output ports are both on the rear panel. The system operates from 85 to 264 V AC and 47 to 63 Hz. Availability is 30 to 60 days; price for the standard system is $42,500.

**diminuSys**
**Irvine, Calif.**
**www.diminusys.com**

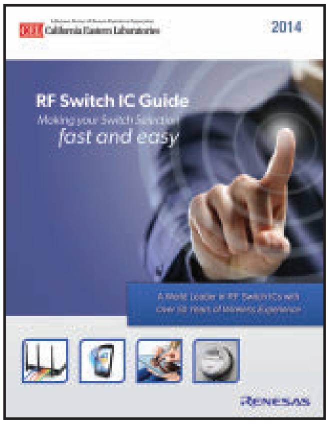
## EMC & RF Testing Catalog

VENDORVIEW


AR has completed another version of their full line product catalog. Many new products have been added and various sections have been updated to help make your equipment research more efficient. The new "find it fast" charts and color coding provide more in-depth product information, guiding you to the specific RF & EMC testing products you need faster. Please contact your local AR sales associate for a hard copy or visit the company's website at www.arworld.us for a free download, either in full or by section.

**AR RF/Microwave Instrumentation**
**www.arworld.us**

## RF Switch IC Guide

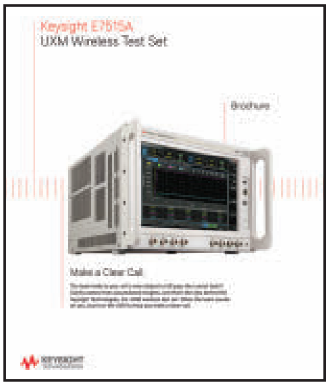



California Eastern Laboratories (CEL) product selector guide for Renesas RF Switch ICs helps make your switch selection fast and easy. CEL offers a broad selection of RF switch ICs with many configurations, package styles, performance and price points. This selector guide is a great aid in helping to simplify your selection of the best and most economical RF switch ICs for your application.

**California Eastern Laboratories (CEL)**
**www.cel.com/rf**

## 4G Functional and RF Design Validation

VENDORVIEW




The new brochure for Keysight's E7515A UXM wireless test set presents a highly integrated signaling test set created for functional and RF design validation in the 4G era and beyond. The UXM provides the capabilities you need to test the newest UE and chipset designs, delivering LTE-Advanced (LTE-A) category 4/6/7 now and handling more complex requirements later. Its powerful and extensible architecture supports multiple cells, carrier aggregation, MIMO, internal fading and a built-in application server, allowing you to assess design readiness with greater confidence.

**Keysight Technologies Inc.**
**www.keysight.com**

## Rapid PCB Prototyping Catalog


The LPKF Laser & Electronics In-House Rapid PCB Prototyping Catalog features not only the milling and laser systems the manufacturer has become known for, but also its complete line of through-hole, multilayer and SMT/finishing equipment. LPKF is the only company to provide the full line of equipment necessary to complete in-house PCB prototypes up to eight layers in-house. To learn more about LPKF's in-house PCB prototyping technology, visit the company's website.

**LPKF Laser & Electronics**
**www.lpkfusa.com**

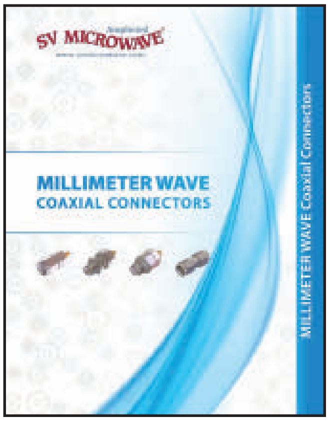
## RF Product Guide

VENDORVIEW


Pasternack's latest 264 page catalog contains thousands of in-stock products such as RF cable assemblies, an expanded portfolio of RF amplifiers, 60 GHz systems and modules, and hundreds of other passive and active RF components, all available for same-day shipping worldwide. Pasternack also introduced 24/7 support to assist customers all over the world to place orders, request quotes and answer questions. Other improved features include an updated adapter and cable assembly matrix that allows users to easily identify all available in-series and between-series configurations. Visit the company's website to request a free print copy or to download a PDF version.

**Pasternack Enterprises**
**www.pasternack.com**

## Millimeter Wave Connector Series




SV Microwave recently released a new catalog for their Millimeter Wave connector series. SV's product line offers the precision, quality and performance needed for the millimeter wave spectrum through 67 GHz. Products include 2.92, 2.4 and 1.85 mm and are available as connectors, terminations, attenuators, cable assemblies and customized solutions. Visit www.svmicrowave.com/productliterature or email marketing@svmicro.com for your copy.

**SV Microwave**
**www.svmicrowave.com**

# New Products

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

FEATURING VENDORVIEW STOREFRONTS

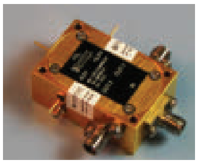
## Components

### Ultra Wideband Cavity Notch Filter

3H Communication Systems announced the LTE/WiMAX, an ultra wideband cavity notch filter. This 2600 MHz notch filter provides >50 dB rejection across the notch bandwidth of 190 MHz, while maintaining low insertion loss of < 0.5 dB from DC to 2210 and 2900 to 3500 MHz. Contact sales@3hcomm.com for additional information.

***3H Communication Systems***
***www.3hcomm.com***

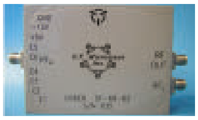
### Ultra Broadband PIN Diode Switches



Ducommun RF Product Group released a new line of ultra-broadband PIN diode switches. These ultra-broadband PIN diode switches cover 0.05 to 110 GHz. These unique, ultra wideband and high frequency switches are ideally suited for R&D laboratories, test environments and high frequency applications. Ducommun's ultra-broadband PIN diode switches are available both as reflective or absorptive, from SPST to SP8T configuration.

***Ducommun***
***www.ducommun.com***

### PIN Diode Switched Filter Assembly

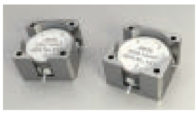


Model SF-69-BZ is a four-band with two through paths PIN diode switched filter assembly. It is capable of isolations of 60 dB minimum in RFH-RFOUT and a 30 dB minimum in RFL-RFOUT. The amplitude flatness is 2 dB peak-to-peak. This device operates with a handling power of +23 dBm CW RFH, +18 dBm RFL, 1 W max via 6 bits of TTL compatible logic and a switching speed less than 300 nsec max. The package size is 3" × 2.25" × 0.70".

***G.T. Microwave***
***www.gtmicrowave.com***

### S-Band Circulator

The SZM 10497 is a small form factor, high power S-Band package drop-in circulator for commercial markets.



Derived from a military part capable of handling up to 4 kW peak power, the circulator is suited to GaN power amplifiers for microwave heating, lighting and ATC radar applications. Operating from 2.4 to 2.5 GHz, the SZM 10497 offers an average power of 250 W max, peak power of 1000 W, return loss of 18 dB min and operating temperature of -20° to +80°C.

***MESL Microwave***
***www.meslmicrowave.com***

### Four-Way, 0° Splitter/Combiner

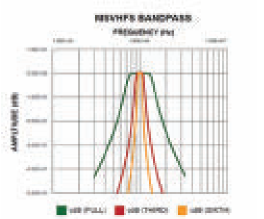
VENDORVIEW

Mini-Circuits' ZB4PD-282-50W+ high power, four-way, 0° splitter/combiner covers 500 to 2750 MHz, supporting applications such as

high band PCS, UNII, WiMAX and more. This model can handle up to 100 W RF input power as a splitter and is capable of passing up to 0.5 amps DC current from input to output. It provides 1.5 dB insertion loss, 21 dB isolation between ports, 5° phase unbalance and 0.3 dB amplitude unbalance.

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

### Switched-Capacitor Filter ICs



Mixed Signal Integration (MSI) announced switched-capacitor filter ICs with frequencies of 5 MHz and beyond. The selectable very high frequency filter ICs (MSVHFS1-6) have six pole Butterworth, Elliptic or Bessel lowpass responses or six pole full octave, one third octave or one sixth octave bandpass responses. These filter ICs have better roll-off and stopband rejection than passive component or low order op-amp solutions.

***Mixed Signal Integration***
***www.mix-sig.com***

### PIN Diode Digital Step Attenuators

VENDORVIEW

Pasternack Enterprises Inc. released their new 5, 8 and 10 bit broadband PIN diode digital step attenuators with performance up to 40 GHz, depending on the configuration. These programmable, variable step attenuators are commonly used in electronic warfare, military and space communication systems, radar, and test and measurement applications. Pasternack's new digital step attenuators come in 30 and 60 dB values and have attenuation step resolution of 0.25 to 1 dB depending on the model.

***Pasternack Enterprises Inc.***
***www.pasternack.com***

### 8-Bit Digital Phase Shifter

VENDORVIEW

PMI model no. PS-2G6G-8B-SFF is an 8-Bit digital phase shifter that operates from 2 to 6 GHz. This model offers 360 degrees of phase shift having a LSB of 1.4 degrees. The insertion loss is 10.5 dB typical with a typical phase accuracy of ±0.5 degrees. It is supplied in a housing measuring 3.25" × 3.25" × 0.94".

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

### Converters

VENDORVIEW

Richardson RFPD Inc. announced the availability and full design support capabilities for three new converters from Analog Devices Inc. The new devices include a digital-to-analog converter, an analog-to-digital converter and a dual analog-to-digital converter. All of the devices are suitable for a range of applications, including 3G/4G cellular infrastructure, aerospace, and defense and instrumentation.

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

### PIN Diode Switches

S2D Microwave Inc. offers broadband, high performance RF microwave PIN diode switches. S13-16A5811 is high performance 8.4 to 10.2 GHz absorptive design with low insertion loss of 3 dB max. The switch is phase and amplitude matched.

***S2D Microwave Inc.***
***www.s2dmicrowave.com***

### Power Circulator

Model CT-1872-S is rated at 60 kW peak and 600 W average power at 325 MHz. The unit

provides 20 dB min. Isolation at 0.2 dB insertion loss and 1.20:1 max VSWR. The extremely compact design has flange to flange insertion length of only 6¾" and a height of 5¼". For use in radar applications, it has 1⁵/₈" EIA connectors. It is also available at other UHF frequencies and connector types.

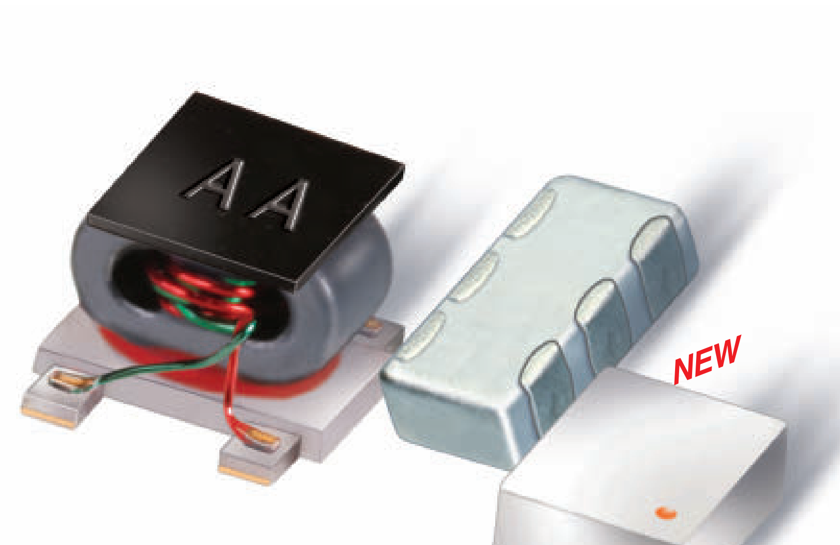
***UTE Microwave***
***www.utemicrowave.com***

## Cables and Connectors

### Low PIM Terminations

VENDORVIEW

MECA Electronics announced its latest low PIM terminations with -165 dBc (typical) passive intermodulation. All of MECA's low PIM terminations cover 698 to 2700 MHz. These terminations are ideal for IDAS/ODAS, in-building, base station, wireless infrastructure, 4G and AWS applications. VSWR is 1.10:1 (typ-




TINY

# Wideband Transformers & Baluns!

NOW!
**4 kHz - 18 GHz** From 99¢ ea.(qty.20)

**To support an even wider range of applications,** Mini-Circuits tiny surface-mount transformers and baluns now cover frequencies up to 18 GHz! Our latest designs achieve consistent performance across very wide frequency bands, and our baluns have demonstrated great utility for chipsets. With over 250 trusted models in stock representing a wide selection of circuit topologies and impedance ratios, chances are, we have a solution for your needs!

Our Low Temperature Co-Fired Ceramic (LTCC) models provide reliable performance in tough operating conditions, tiny size – as small as 0805 – and very low cost. All core-and-wire models are available with our exclusive Top Hat™ feature, improving pick-and-place accuracy and throughput. We even manufacture our own transmission wire under rigorous control and use all-welded connections to ensure reliability and repeatability you can count on.

Visit minicircuits.com and use **Yoni2**™, our patented search engine to search our entire model database by performance criteria and find the models that meet your requirements. Order today and have them in hand as soon as tomorrow! Cost-effective custom designs and simulations with fast turnarounds are just a phone call away!


*TC* 0.15" x 0.15"


*NC* 0.08 x 0.05" Ceramic


*NCR2* 0.08 x 0.10" Ceramic

***RoHS compliant.***

**Mini-Circuits®**

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

528 rev org

# New**Products**

ical). These products are made in the U.S. and have a 36-month warranty.
***MECA Electronics Inc.***
***www.e-MECA.com***

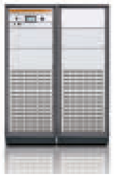
### SMP/SMPM Style Line of Connectors

SV Microwave released a new SMP/SMPM style line of connectors-QuarterBack® series. The line utilizes a quarter turn bayonet style coupling nut with a locking feature for standard SMP/SMPM interfaces. The QuarterBack® connectors are ideal for high vibration and test applications that require a large number of mating cycles. Email marketing@svmicrowave.com for more information.
***SV Microwave***
***www.svmicrowave.com***

## *Amplifiers*

### Solid State Amplifier

VENDORVIEW



AR's new 3000S1G2z5 solid-state amplifier provides 3000 W of output power from 1 to 2.5 GHz. It offers superior gain flatness, exceptional noise figure, better efficiency and harmonics than current TWTA models and the reliability of solid state. Typical applications include radiated immunity testing and TWT replacements.
***AR RF/Microwave Instrumentation***
***www.arworld.us***

### Traveling Wave Tube Amplifiers

dB Control introduced new Ka-Band high power traveling wave tube amplifiers. Model number dB-3860 offers 700 W peak, 34.5 to 35.5 GHz and indoor rack-mount. Ka-Band applications include radars, test and measurement, antenna pattern, radar cross-section measurements and EW simulation.
***dB Control***
***www.dbcontrol.com***

### RF Amplifiers

Fairview Microwave debuted new off-the-shelf RF amplifiers which operate to 26.5 GHz. This release includes power amplifiers, broadband amplifiers, gain blocks, limiting amplifiers and low noise amplifiers designed for use across the spectrum of commercial and defense applications. Gain levels reach 50 dB, P1dB from 10 mW to 20 W, noise figure from 0.8 to 2 dB and gain flatness of ±0.5 dB. All amplifiers are in-stock and ship same-day.
***Fairview Microwave***
***www.fairviewmicrowave.com***

### Amplifier and Lensed Horn

The AS0104-700/300 dual band solid state amplifier, used in automotive EMC testing, complements the company's existing 1 to 4 GHz amplifiers. It is designed to exceed the

requirements of the automotive radar pulse test standards when used in conjunction with the new MILMEGA lensed horn, enabling ease of calibration using CW power. Each band covers only one octave (1 to 2 and 2 to 4 GHz), and the lowest test frequencies are 1.2 and 2.7 GHz in each band.
***MILMEGA Ltd.***
***www.milmega.co.uk***

### Low Noise Amplifier

VENDORVIEW

Model SBL-0524034260-KFKF-SB is a bench-top broadband low noise amplifier operating from 0.5 to 40 GHz. The amplifier exhibits 42 dB small-signal gain and averages 6 dB noise figure over the entire frequency range.

The minimum P-1 dB is +10 dBm. The bench-top amplifier is designed to use 100 to 240 V AC power directly from a lab outlet. The bench top amplifier measures 3.75" (W) × 4.15" (L) and 1.75" (H). It is equipped with K female connectors for RF input and output.
***SAGE Millimeter Inc.***
***www.sagemillimeter.com***

### 100 W, Solid State GaN Power Amplifier

The TA79ZSD6 is a new X-Band, 100 W solid-state GaN power amplifier. It uses a compact and lightweight 17.4 × 24 × 4.1 mm package. It has greater than 36 percent drain efficiency and 11 dB of gain. It requires a +30 V supply voltage. All bias, input and output matching circuitry are included.

***Tokyo Keiki***
***www.tokyokeiki-usa.com***

### Microwave Power Amplifier

The AHP2225-38-3330 is a three-stage PHEMT MMIC based power amplifier module offering 33 dB of linear gain and 30 dBm minimum output power at 1 dB gain compression over 18 to 26.5 GHz, with excellent gain flatness and VSWR. The amplifier has built-in DC voltage regulators and voltage inverters and requires only a single +9 to 12 V DC power supply.

***Wenteq Microwave Corp.***
***www.wenteq.com***

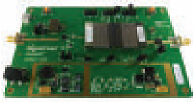
## Sources

### Surface Mount OCXO

Morion announced its new high precision, surface mount OCXO for SatCom, GPS, network-synchronization and test & measurement applications. The MV272M is presently available at a fixed frequency of 10 MHz. The MV272M has phase noise of -115 dBc/Hz at 1 Hz offset, with short-term stability (ADEV) better than 5 × $10^{-13}$ per second. The surface mount (SMD) package measures 30 × 41 × 17 mm and is RoHs compliant.

***Morion US LLC***
***www.morion-us.com***

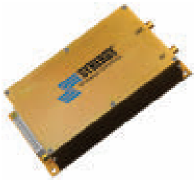
### Signal Synthesizers



The SC800 nanoSynth™ is a fully integrated broadband CW signal synthesizer designed with a proprietary architecture in a rugged and miniature 2" × 1" surface mountable package. The output frequency range is 25 MHz to 6 GHz with average output power of +10 dBm. Tuning at 1 Hz resolution, the multiple PLL design eliminates close-in phase spurs associated with fractional-N PLLs. The SC800 has low phase noise of -118 dBc/Hz at 10 kHz offset from a 1 GHz carrier.

***SignalCore Inc.***
***www.signalcore.com***

### Miniature Footprint 12S PLL Synthesizer



The KFXLNS-1000 is an ultra-low noise frequency source operating at a fundamental output frequency of 1000 MHz from a 100 MHz external reference signal. This product operates with a 12 V supply and offers significant phase noise and spectral quality over competing and more complicated multiplied-up legacy solutions. It is the perfect clean signal source for minimizing overall system noise and reduced power consumption. The typical phase noise is -120 dBc/Hz at 100 Hz offset, -140 dBc/Hz at 10 KHz and -174 dBc/Hz at 1 MHz offset.

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

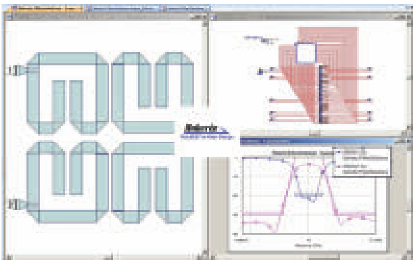
## Software

### Filter Circuit Synthesis Software

FilterSolutions®, the filter circuit synthesis software from Nuhertz, has added the capability of exceptionally rapid and accurate electromagnetic (EM) optimization utilizing Axiem® tuning port capability, the electromagnetic analysis tool from AWR® (division of National Instruments Corp.). By automated insertion of strategically placed tuning ports into FilterSolutions planar geometry and exporting to the

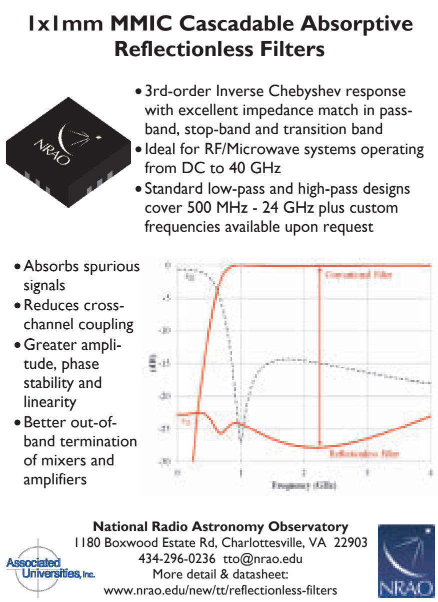
# MICRO-ADS





Axiem software, planar filters can be EM optimized across a frequency range with only a few mouse clicks.

***Nuhertz Technologies LLC***
***www.nuhertz.com***


# Test Equipment

## RF Analyzers

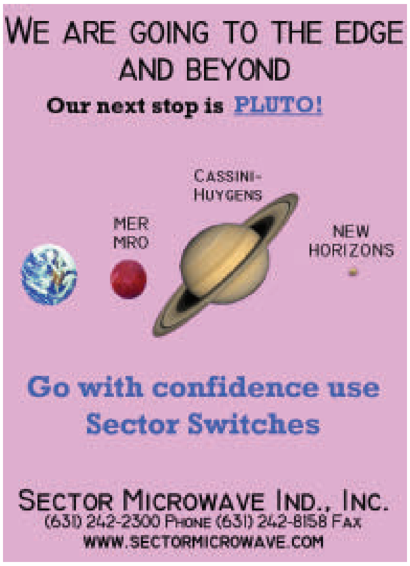
The 19" rack mount NRA-3000 RX (9 kHz to 3 GHz) and NRA-6000 RX (9 kHz to 6 GHz) RF analyzers are equipped with an RF module that has been developed for low phase noise and low intrinsic interference. The analyzers can yield spectrums of up to 600,000 frequency points with time resolutions as fine as 30 nanoseconds. High channel bandwidths can be captured with intermediate frequency bandwidths of up to 32 MHz. The devices are primarily designed for use in automated and remote controlled measuring systems.

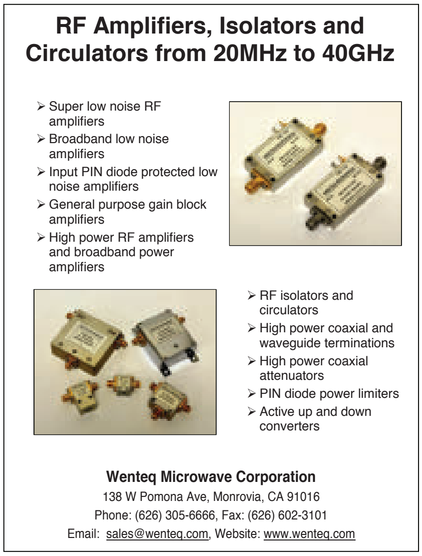
***Narda Safety Test Solutions***
***www.narda-sts.com***

## Expanded Source Module

OML introduced a new option for its signal generator frequency extension module, SxxMS. Already available with options for manual adjustable attenuation and DC power connection to Keysight's PSG, the source module now includes an option for electronic attenuation. The SxxMS series will expand your existing microwave signal generator capabilities to conduct measurements from 50 to 500 GHz. Easily connected to the output of a signal generator, this module enables high performance sources for your DUT.

***OML Inc.***
***www.omlinc.com***

## Highly Integrated Low Power Radars

**Sergio Saponara, Maria Greco, Egidio Ragonese, Giuseppe Palmisano and Bruno Neri**

Continuing advances in semiconductor technology, from RF to signal processing, are enabling radar to migrate from defense to civilian applications. Automotive is probably the most obvious example, with radar being used to assist drivers and increase safety through applications such as autonomous cruise control, blind spot detection and parking aids. Not as well known, perhaps, are harbor traffic control and contactless vital sign monitoring (heart and breath rate, for example).

The authors claim that radar is superior to competing sensor technologies, such as laser, lidar, ultrasound, and visible and infrared cameras. Radar operates in all weather conditions and provides detailed information about the target: whether a target exists, its distance, speed, and direction of arrival. Since the radiation is non-ionizing, radar is safe for biomedical applications.

Seeing the market opportunities and the underlying technology enablers, the premise of "Highly Integrated Low Power Radars" is that a radar sensor designed to minimize size, power consumption and cost will become a ubiquitous, contactless sensor for a myriad of applications. The book aims to walk through the design trade-offs and technology options to show the reader how to achieve this goal.

The book covers both theory and practical applications, beginning with scenarios and requirements for highly integrated, low power radars. To gain wide commercial adoption, the radar design should trade performance to reduce cost, size and power consumption. Integrating all functions using system-on-a-chip (SoC) or system-in-a-package (SiP) approaches is the strategy to achieve this. Technology and integration options for the transceiver and antenna are discussed, including comparisons of GaAs, CMOS and SiGe technologies.

Chapter 3 addresses the hardware and software platforms for the digital signal processing of the radar waveform. The authors compare the computational capabilities of various graphics processors, field programmable gate arrays (FPGA) and digital signal processors (DSP).

The remainder of the book addresses applications, with one chapter devoted to health-care signal processing and one to automotive. Two case studies are presented, covering front ends developed for healthcare and harbor surveillance. The final chapter on applications describes IC designs for 24 GHz short-range and 77 GHz long-range automotive radar systems.

"Highly Integrated Low Power Radars" offers a topical view of the emerging commercial applications for radar. It should be interesting and informative for anyone interested in the applications or enabling technologies.

*To order this book, contact:*

Artech House
685 Canton Street
Norwood, Mass.
www.artechhouse.com

232 pages, $149 for print or eBook
ISBN: 978-1-60807-665-9

# eLEARNING center

Presented by: Microwave Journal

## January Short Course Webinars

**Keysight in LTE/Wireless**
**LTE-Advanced: 3GPP Release 12 and 13**
Live webcast: 1/27/15

**Technical Education Training**
**Laser Test of RIN, Linewidth and Optical Noise Parameters**
*Presented by: Keysight Technologies*
Live webcast: 1/29/15

## Past Webinars On Demand

**RF/Microwave Training Series**
*Presented by: Besser Associates*
- Passive Components: Dividers, Couplers, Combiners
- MMIC Design Overview
- Introduction to Radar
- RF Components for Aerospace/Defense

**Technical Education Training Series**
- Marchand Balun and Its Evolution into Modern Microwave Systems
- Non-Destructive Testing of Powders, Ceramic, Oils and Other Composite Materials
- Design Challenges for Handset Power Amplifiers Due to LTE-Advanced
- RF PCB Design, Inclusive of EM Analysis
- Essential Thermal Mechanical Concepts Needed in Today's Microwave Circuit Designs
- VCO Fundamentals
- Single Sweep 70 kHz to 145 GHz Broadband System and On-Wafer Measurements
- High Frequency Materials and Characterization up to Millimeter Wave Frequencies
- Simulations of Gyrotrons with VSim
- Practical Simulation and Design of Broadband GaN RF Power Amplifiers – How Close are We to Right First Time Now?
- Peregrine's UltraCMOS® Technology: Delivering Intelligent Integration
- Accelerating Custom Test Solutions
- Switching Solution Webcast

**CST Webinar Series**
- Simulation-Enabled 5G Antenna Design
- Antennas for Automobile Applications
- Modeling Material Properties
- Modeling a DDR4 Memory Channel
- Efficient Simulation of Optical Devices
- EMC Simulation in Modern Electronics
- Lightning and EMP Protection in Buildings
- Simulation of Accelerator Components
- Designing Clean Mobile Devices – Mobile Phones & Automobile Systems
- Power Delivery Network (PDN) Analysis
- Multiphysics Simulation for Medical Applications

**Innovations in EDA**
*Presented by: Keysight Technologies*
- RF System Design, Prototype & Production with X-Parameters in One Pass
- DynaFET: Advanced Model for GaN/GaAs HEMTs from NVNA Measurements and ANNs

**Keysight in LTE/Wireless Series**
- Characterization and Test Challenges for MMPAs with ET & DPD

**FieldFox Handheld Analyzers Series**
*Presented by: Keysight Technologies*
- Precision Validation, Maintenance and Repair of Satellite Earth Stations

**RF and Microwave Education Series**
*Presented by: Keysight Technologies*
- Techniques for Characterizing Spurious Signals

**Register to attend at mwjournal.com/webinars**

Scan page using layar app

# Advertising**Index**

Advertisers in blue are enabled with the layar app



# Sales Representatives

Microwave Journal
Frequency Matters.


**Eastern and Central Time Zones**
Chuck Boyd
*Northeast Reg. Sales Mgr.*
(New England, New York, Eastern Canada)
685 Canton Street
Norwood, MA 02062
Tel: (781) 619-1942
FAX: (781) 769-5037
cboyd@mwjournal.com

Michael Hallman
*Eastern Reg. Sales Mgr.*
(Mid-Atlantic, Southeast, Midwest)
4 Valley View Court
Middletown, MD 21769
Tel: (301) 371-8830
FAX: (301) 371-8832
mhallman@mwjournal.com

**Pacific and Mountain Time Zones**
Brian Landy
*Western Reg. Sales Mgr.*
(CA, AZ, OR, WA, ID, NV, UT, NM, CO, WY, MT, ND, SD, NE & Western Canada)
144 Segre Place
Santa Cruz, CA 95060
Tel: (831) 426-4143
FAX: (831) 515-5444
blandy@mwjournal.com

**International Sales**
Richard Vaughan
*International Sales Manager*
16 Sussex Street
London SW1V 4RW, England
Tel: +44 207 596 8742
FAX: +44 207 596 8749
rvaughan@horizonhouse.co.uk

**Germany, Austria, and Switzerland (German-speaking)**
WMS.Werbe- und Media Service
Brigitte Beranek
Gerhart-Hauptmann-Street 33, D-72574 Bad Urach
Germany
Tel: +49 7125 407 31 18
FAX: +49 7125 407 31 08
bberanek@horizonhouse.com

**Israel**
Liat Heiblum
Oreet International Media
15 Kineret Street
51201 Bene-Berak, Israel
Tel: +972 3 570 6527
FAX: +972 3 570 6526
liat@oreet-marcom.com

**Korea**
Young-Seoh Chinn
JES Media International
2nd Floor, ANA Bldg.
257-1, Myungil-Dong
Kangdong-Gu
Seoul, 134-070 Korea
Tel: +82 2 481-3411
FAX: +82 2 481-3414
yschinn@horizonhouse.com

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

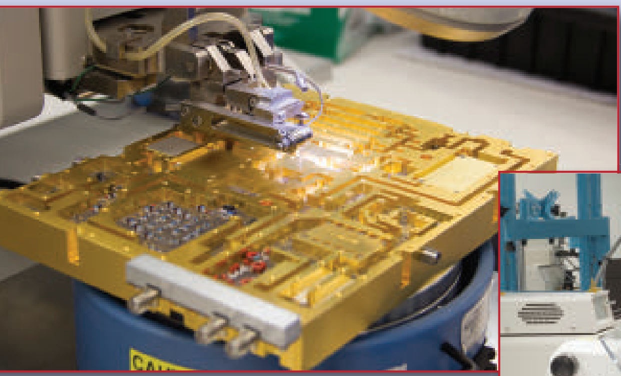
**China**
Michael Tsui
ACT International
Tel: 86-755-25988571
Tel: 86-21-62511200
FAX: 86-10-58607751
michaelT@actintl.com.hk

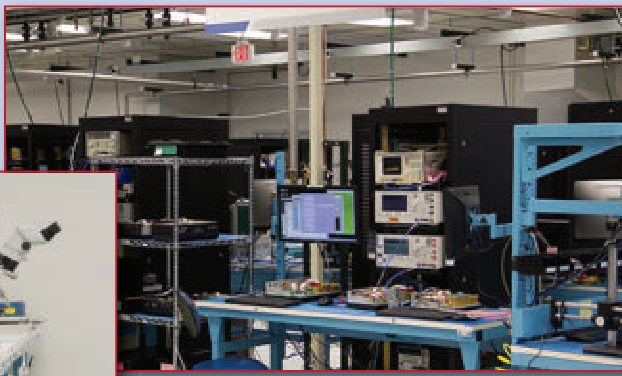
**Hong Kong**
Mark Mak
ACT International
Tel: 852-28386298
markm@actintl.com.hk

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

# FABS and LABS

*This is the first article in our new "Fabs and Labs" series featuring companies with interesting design, fabrication, assembly and test facilities that we visit in our travels around the industry.*







Mercury Systems has hit the sweet spot for producing commercial and defense sensor systems in their Advanced Microelectronics Centers. Mercury is a provider of commercially developed, open sensor and Big Data processing systems, software and services for critical commercial, defense and intelligence applications. They are able to deliver innovative solutions, rapid time-to-value and world-class service and support to prime contractor customers due to their intelligent setup of design and manufacturing facilities and industry expertise.

About six years ago, Mercury targeted additions in the RF and microwave sector that would enable them to provide the entire sensor chain from end-to-end: acquire, digitize, process, store, exploit and disseminate/electronic countermeasures. They acquired several microwave companies including LNX, KOR Electronics, Micronetics and Echotek Corp. These acquisitions gave them a wide array of microwave component and sub-assembly capabilities to fill out their portfolio of sensor capabilities.

After these acquisitions, Mercury developed their Advanced Microelectronics Centers in Hudson, N.H. and West Caldwell, N.J. to design and build high quality sensor assemblies. These centers provide the right flexibility and volume needed for the high performance sensor market. While many larger companies provide high volume production, they typically lack the flexibility needed by customers. There are also many smaller companies that provide flexibility but lack the scale to provide LRIP and production quantities. With their Advanced Microelectronics Centers, Mercury has filled the missing gap with facilities that can be flexible and still meet the production volumes needed for this market.

The Hudson facility has 72,000 square feet with 12,000 square feet of clean room space and the West Caldwell facility has 23,000 square feet with 8,000 square feet of clean room space. The clean rooms provide full manual and automated microelectronics assembly plus digital and high frequency testing. The facilities also have machine shops and environmental testing facilities so that everything can be done on-site to build prototype and production products. Design and manufacturing engineers are co-located in the facilities for a smooth handoff from development to production. The clean rooms are also laid out to maximize cleanliness and optimize workflow. Both facilities have the same equipment and processes so that there is capacity flexibility and redundancy. For critical military programs, these attributes can be a strategic advantage. The New England locations are also in close vicinity to many of their customers.

Mercury Systems has built a "right-sized" company that is flexible like a small company but also has the scale to provide production quantities of high-performance sensor systems, including microwave components and sub-assemblies. They are leveraging their microwave company acquisitions and combined design power to introduce custom products to the commercial and defense industries. View their Advanced Microelectronics Center overview video at

**www.microwavejournal.com/AMC**

# WERLATONE

Decades Ahead 50th Since 1965

Celebrating 50 Years of High Power Passive Components

Celebration 50th Anniversary

Scan page using layar app

# 20 to 1000 MHz

## 0° Combiners / Dividers | Directional Couplers

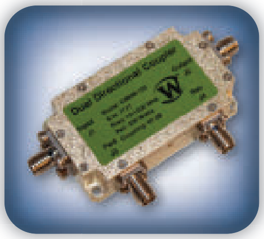
*3:1 Load VSWR*
Model C9107

*Non-Coherent*
Model D8300

*100 W CW*
Model D7365

*Watertight*
Model D8544W

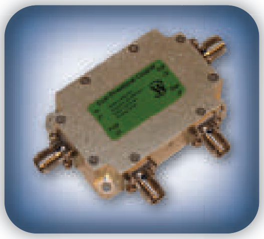
*10 to 1000 MHz*
Model C8858



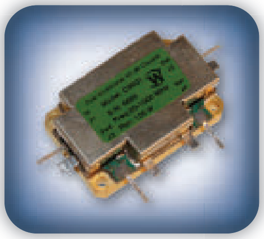
*1000 W CW*
Model D9264

*Fully Isolated*
Model D8682

*Mismatch Tolerant®*
Model C8696



*Tab Interface*
Model C8631



*Low Insertion Loss*
Model D9048

☑ *Directional Couplers Operate, at Rated Power, into High Load VSWR Conditions.*

☑ *Combiners are Fully Isolated and Designed to Handle Severe Input Unbalances.*

### High Power Combiners/Dividers

| Model | Type | Frequency (MHz) | Power (W CW) | Insertion Loss (dB) | VSWR | Phase Balance (°) | Isolation (dB) | Size (L x W x H) (Inches) |
|---|---|---|---|---|---|---|---|---|
| D6233 | 2-Way | 10-1000 | 25 | 0.75 | 1.35 | 5 | 20 | 3.25 x 2 x 1.1 |
| D8632 | 2-Way | 20-1000 | 50 | 0.7 | 1.40 | 5 | 20 | 2.2 x 1.5 x 0.9 |
| D8300* | 2-Way | 20-1000 | 100 | 0.5 | 1.35 | 5 | 20 | 2.45 x 2 x 0.91 |
| D8544W | 2-Way | 20-1000 | 100 | 0.5 | 1.35 | 3 | 18 | 2.85 x 2.5 x 1 |
| D8682 | 2-Way | 20-1000 | 500 | 0.7 | 1.35 | 5 | 15 | 5.2 x 2.65 x 1.8 |
| D9264 | 2-Way | 20-1000 | 1000 | 0.8 | 1.40 | 5 | 18 | 6.5 x 6.25 x 2.25 |
| D7365 | 4-Way | 20-1000 | 100 | 0.75 | 1.35 | 5 | 20 | 5.09 x 2.3 x 1 |
| D7439 | 4-Way | 20-1000 | 250 | 0.75 | 1.35 | 5 | 18 | 5.1 x 5 x 1.5 |
| D9048 | 4-Way | 20-1000 | 500 | 0.6 | 1.35 | 5 | 17 | 5 x 4.7 x 1.4 |
| D9075 | 4-Way | 20-1000 | 1000 | 0.65 | 1.35 | 5 | 15 | 5.7 x 4.7 x 1.75 |

* Designed for 10 W / Input Non-Coherent. All designs provide full port-to-port Isolation.

### High Power Directional Couplers

| Model | Coupling (dB) | Type | Frequency (MHz) | Power (W CW) | Insertion Loss (dB) | VSWR (ML) | Directivity (dB) | Size (L x W x H) (Inches) |
|---|---|---|---|---|---|---|---|---|
| C9770 | 30 | Dual | 20-1000 | 50 | 0.7 | 1.10 | 20 | 3 x 2 x 1 |
| C9191 | 30 | Dual | 20-1000 | 100 | 0.7 | 1.25 | 20 | 1.76 x 1.16 x 0.57 |
| C9552 | 30 | Dual | 20-1000 | 150 | 0.8 | 1.30 | 20 | 3 x 2 x 1 |
| C8696 | 40 | Dual | 20-1000 | 150 | 0.35 | 1.25 | 20 | 1.76 x 1.16 x 0.57 |
| C8858 | 40 | Dual | 10-1000 | 250 | 0.4 | 1.30 | 20 | 2.01 x 1.16 x 0.57 |
| C9446 | 40 | Dual | 20-1000 | 250 | 0.5 | 1.30 | 20 | 3 x 2 x 1 |
| C8686 | 50 | Dual | 20-1000 | 500 | 0.35 | 1.25 | 20 | 5.2 x 2.68 x 1.69 |
| C9107 | 53 | Dual | 20-1000 | 1000 | 0.4 | 1.30 | 20 | 4.45 x 2.4 x 1.59 |

Werlatone®, Inc.
17 Jon Barrett Road
Patterson, NY 12563
T 845.278.2220
F 845.278.3440
www.werlatone.com